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Austro Control GmbH

17th
International Flight Inspection Symposium
Braunschweig, Germany, 4 - 8 June 2012

IFIS 2012

Proceedings

17th International Flight Inspection Symposium
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DFS Deutsche Flugsicherung GmbH, the German air navigation service provider, is a State-owned company under private law and has 6,000 employees. DFS ensures the safe and punctual flow of air traffic over Germany. Staff coordinate up to 10,000 aircraft movements in German airspace every day, and about three million movements every year. This makes Germany the country with the highest traffic volume in Europe. DFS operates control centres in Langen, Bremen, Karlsruhe and Munich. In addition, DFS is represented in the Eurocontrol Centre in Maastricht, the Netherlands, and in the control towers of the 16 international German airports. DFS provides training and consultancy services around the world and develops and sells air traffic management systems. The company's portfolio also comprises flight-relevant data, aeronautical publications and aeronautical information services. DFS has the following business units: Control Centre, Tower, Aeronautical Solutions and Aeronautical Information Management.

Skyguide is responsible for providing air navigation services within Swiss airspace and in the airspace of certain adjoining regions in neighbouring countries. The company guides the civil and military aircraft entrusted to its care – around 3,270 flights a day or 1.2 million a year – through the busiest and most complex airspace in Europe.

Skyguide is a non-profit limited company which has its head office in Geneva. The majority of its shares are held by the Swiss Confederation. The company generated total operating revenue of over CHF 427 million in 2011, and employs some 1,400 people at 14 locations in Switzerland. Skyguide is a member, together with its partner organizations in Belgium, France, Germany, Luxembourg and the Netherlands, of the FABEC initiative to create a common functional airspace block that will bring greater efficiency to Central Europe’s air traffic management services and activities.

Austro Control’s key task is maintaining safe, punctual and environmentally friendly air traffic in Austrian airspace round the clock, 365 days a year. Austro Control coordinates more than 1 million flights per year and there are as many as 4,000 controlled flights in Austrian airspace on some days. Air traffic controllers at the area control centre in Vienna and at the air navigation service units at all Austrian international airports guide aircraft safely and efficiently through the airspace. With a workforce of about 1,000, Austro Control is responsible not only for air navigation services, but also for the set-up and operation of technical air traffic control facilities, the aeronautical meteorological service, the certification and airworthiness of aircraft, the issuance of pilot licences, the search and rescue service and the supervision of flight training centres.

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Welcome

On behalf of the hosts – the air navigation service providers of Germany (DFS), Switzerland (skyguide) and Austria (Austro Control) and the International Committee for Airspace Standards and Calibration (ICASC) – I am honoured to welcome you to the 17th International Flight Inspection Symposium 2012 (IFIS 2012) in Braunschweig, Germany. Braunschweig will be the setting for the IFIS for the second time since first hosting it in 1996.

The theme for the 17th IFIS is **"Waypoints to New Horizons"**. The joint organisation of the symposium by several air navigation service providers may be seen as one of these waypoints. Our industry is evolving rapidly and the future is taking shape on the horizon. Nevertheless, choosing and implementing the exact route to be taken presents its own challenges; many of which are already well known from earlier symposia: isolating radio frequency interference, ensuring navigation database integrity, developing meaningful flight inspection criteria and ensuring appropriate regulatory oversight of emerging technologies.

Relating to the theme, interesting presentations about flight inspection methods (e.g. GNSS, ADS-B), validation of flight procedures, new flight calibration methods for ground and flight inspection, data management and regulatory aspects will allow a fruitful exchange of views between the various national representatives, service providers, air traffic management and flight inspection experts, research bodies and industry. Additionally, a static display will allow visitors to see calibration aircraft from around the world first-hand at Braunschweig Airport.

I would like to thank the organisers, exhibitors and delegates for their invaluable efforts in making this symposium a success. A special thanks goes to our generous sponsors, who are acknowledged in this document. Their sponsorship contributions have allowed us to offer you an engaging and entertaining experience with a full and content-rich agenda.

May I wish to all a productive and enjoyable symposium both on a professional and personal level.

Egon Koopmann

ICASC Member and 17th IFIS 2012 Chairman

Welcome address by the Prime Minister of Lower Saxony, Mr David McAllister at the 17th International Flight Inspection Symposium (IFIS) in Braunschweig, Germany, from 4 to 8 June 2012

The international flight inspection symposium is taking place in the city of Braunschweig for the second time since it was last here in 1996.

We are glad that Beijing passed on the role of host to us and that Lower Saxony as an important location in aviation and the Braunschweig research airport are able to provide a fitting venue for this year's event.

The motto "Waypoints to New Horizons" of this year's symposium is meant to tie in all the various topics and areas of air navigation services which are now relevant for experts from companies and government agencies around the globe. These topics include flight inspection methods with new technologies, validation of flight procedures, new calibration methods for ground and flight inspections, data management and regulatory aspects.

Challenges arising from continued growth in the volume of air traffic require specialists around the world to find solutions. Around 300 expert participants from around the world are gathered here in Braunschweig to discuss new developments.

As the sponsor of the event, I would like to wish you all lots of new ideas and engaging discussions. I would also like to thank the event organisers Austro Control, Skyguide and DFS Deutsche Flugsicherung for putting together such a wonderful conference.

Hannover, June 2012

David McAllister

Prime Minister of Lower Saxony

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The selection of abstracts was supported by members of the International Committee for Airspace Standards and Calibration (http://www.icasc.co).

Acknowledgement

We would like to thank the International Committee for Airspace Standards and Calibration, the team of DFS Language Service and many other people who helped to organise the 17th International Flight Inspection Symposium.

Content

Content

Flight Inspection Intervals

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Chairman of the ICASC Technical Working Group

ABSTRACT

After investigations by the Japanese Civil Aviation Bureau (JCAB) to reduce the impact of Flight Inspection at Tokyo International airport, it was decided to analyse with the International Committee for Airspace Standards and Calibration (ICASC) Technical Working Group, whether a case could be made to extend the flight inspection interval. The group identified that the International Civil Aviation Organisation (ICAO) Document 8071 Manual on Testing of Radio Navigation Aids Volume 1 Testing of Ground-Based Radio Navigation Systems, Fourth Edition issued in 2000 [1] provided guidance to allow an extension to be made, but felt further guidance could assist a state in its decision making process.

This paper will:

- Summarise the history of the development of the flight inspection intervals detailed in the schedule of Doc 8071 [1]
- Summarise the inspection intervals and inspection interval tolerance (referred to as due date windows in this paper) for a number of states.
- Review and provide further guidance on the criteria for determining and extending the inspection interval in Doc 8071 [1], including:
    - Reliability and stability of operation of the equipment.
    - Extent of ground monitoring
    - Degree of correlation between ground and flight measurements
    - Changes in the operating environment
    - Manufacturers recommendations
    - Quality of maintenance

In addition the paper will include:

- Use of engineering judgement
- Use of a “Due date window”
- Actions that can be taken if an inspection is not conducted at the appropriate time

INTRODUCTION

The ICASC Technical Working Group identified that Doc 8071 [1] provides nominal schedules for flight inspection intervals. It also provides guidance on the factors to consider when determining a different inspection interval. Doc 8071 [1] states that the schedules should be used as a basis for determining the appropriate inspection interval. It is further stated that this may be more or less frequent than the inspection interval described in the schedules.

For the purposes of this paper, only Instrument Landing System (ILS) flight inspection intervals have been considered. The same methodologies identified in this paper can be applied for other Navigational Aids.

Purpose of Flight Inspection

Before starting to investigate changes to inspection intervals it makes sense to remind ourselves what the flight inspection is intended to achieve and what types of thing would influence the results of an inspection.

Doc 8071 [1] §4.3.1 to 4.3.2 describes the purpose of flight Inspection as:

> “*4.3.1 The purpose of flight testing is to confirm the correctness of the setting of essential signal-in-space parameters, determine the operational safety and acceptability of the ILS installation, and periodically correlate signal patterns observed in flight and from the ground. Since flight testing instrumentation varies greatly, only a general description of the test methodology is given below.*
>
> *4.3.2 Flight tests constitute in-flight evaluation and sampling of the radiated signals in the static operating environment. The signals-in-space are evaluated under the same conditions as they are presented to an aircraft, receiving system and after being influenced by factors external to the*

> *installation, e.g. site conditions, ground conductivity, terrain irregularities, metallic structures, propagation effects, etc. Because dynamic conditions, such as multipath due to taxiing or overflying aircraft or moving ground vehicles, are continually changing, they cannot be realistically flight-tested. Instead, these effects on the signal-in-space are controlled by the establishment of critical and sensitive areas and by operational controls".*

So in summary flight inspection ensures that the Navigational Aid Signals in Space remain within the ICAO stated tolerances. There are two main contributions that can affect the signals in space, namely:

- Stability of the equipment
- Changes in the operating environment

Financial Constraints

Financial factors are often considered as part of the flight inspection extension process, it is essential that the final decision is made on a technical basis and that the safety of the service is not impacted. It should be recognised that over time a facility may become less stable and need to revert to a more frequent flight inspection interval.

History of Changes in Doc 8071

ICAO Doc 8071 Volume II ILS (Instrument Landing System) 3rd edition issued in 1972 [2] stated the periodic interval for ILS as 90 days extending to 120 days for those facilities which have a history of good performance. No guidance was provided in the 3rd Edition to judge what constitutes good performance. A tolerance of +/- 15 days was allowed for routine inspections and +/- 60 days for the annual inspection.

The 4th edition [1] included some significant changes:

1. Increase in the nominal flight inspection interval to 180 days.
2. Guidance on the factors to consider when extending the inspection interval.
3. Removal of the due date window for the inspection interval.

According to one member of the Testing of Radio Navigation Study Group (TRNSG) present during the drafting stages of the 4th Edition, the group had to consider the interval standard under a consensus-setting environment. There were several constraints that had to be considered for example:

- Doc 8071 is used by some states as a contractual Statement -
  Many States were concerned that they should not make substantial changes; otherwise their contracts may need to be renegotiated, perhaps at higher costs.
- Technology advances -

  Solid state equipment and microprocessors where in common use, however, some States still had a significant proportion of thermionic tube equipment.
- Necessity of flight inspection -

  Flight inspection is necessary at least partly to ensure that the ground maintenance adjustments were performed well.
- Equipment stability –
  Newer ground equipments and flight inspection systems drifted very little. Similarly test equipment was much more advanced.
- Financial constraints –
  Flight inspection organizations began seeing pressures to reduce flight hours.

Considering the above constraints, their conclusion was a compromise amongst the members. As a result, the periodic interval for ILS was extended from 90 to 180 days.

SUMMARY OF INSPECTION INTERVALS

To understand how the guidance of Doc 8071 [1] has been implemented a survey was conducted of the ILS periodic flight inspection interval in the states represented by the ICASC members. This identified a contrast of different flight inspection intervals from 90 days to 360 days. A similar range of due date windows is also in use, ranging from 0 to 4 months. This paper has not attempted to analyse the differences, it is more of a demonstration that different policies can exist all of which provide safe operating systems.

Table 1 shows the result of the survey.

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State	Flight Inspection Interval (Days)	Due Date window(Days)
Doc 8071 3rd Edition [2]	90 to 120 Depending upon performance	+/-15
Doc 8071 4th Edition [1]	180	Not included
Australia	180	30
Canada	180	60
China	120 (CAT II/III) 270 (CAT I)	0
France	360	120
Germany	180	30
Italy	180	0
Japan	180	60 Further 60 days with agreement of ground and flight inspection personnel
New Zealand	180	30
Nigeria	180	0
Norway	90 (CAT II/III) 180 (CAT I)	21
South Africa	120	30
United Kingdom	180	20 Further 25 days if a partial check is conducted.
United States of America	270	+/- 15 days

Note: Some states conduct an initial inspection at 90 days after commissioning and extend to the nominal interval based upon acceptable performance.

Table 1. Survey of Periodic Flight Inspection Intervals.

ENGINEERING JUDGEMENT

Doc 8071 [1] provides the factors that influence the flight inspection interval decision making process and goes on to provide further guidance on each of the factors, however there is no guidance on how to determine an acceptable inspection interval.

The probability of any navigation aid presenting a Signal in Space that is out of tolerance would increase with time. An inspection interval (including any due date window allowance) needs to be determined such that there is a high confidence that the signal in space will not be outside of tolerance before the flight inspection is conducted. This would normally mean that the inspection is conducted at a time when the signals are still well within tolerance.

It is clear that there is not a formula for defining the correct flight inspection interval, so some degree of subjective evaluation is necessary. This evaluation needs to be based on Engineering Judgement. Engineering judgement requires coming to an informed decision based upon understanding of all of the relevant information that is available. In particular this may require sound knowledge of the equipment, site, maintenance philosophy and any other criteria that may be used to set the inspection interval.

Once an inspection interval has been set evidence to support its suitability would be gained from the results of each subsequent flight inspection. This evidence may identify that the system is sufficiently stable to allow the interval to be extended.

There is no exact number of days that can be used when deciding a change in the flight inspection interval; several smaller increases over time may be easier to justify than a large increase. Changes in the region of 10 - 20 % of the current interval may be considered appropriate.

It is recommended that the organisation setting the flight inspection interval has a clear documented policy and process for determining and recording the flight inspection interval.

CRITERIA FOR DETERMINATION OF INSPECTION INTERVALS

Doc 8071 [1] §4.3.1 to 4.3.2 describes the purpose of flight Inspection; §1.15.4 “Determination of test /inspection interval” provides guidance on the factors that influence the choice of flight inspection interval. These factors are discussed in the following paragraphs.

An excerpt from Doc 8071 [1] covering inspection intervals is provided in Appendix 1 for reference.

Reliability and Stability of Operation of the Equipment [1] §1.15.5

Stability of the navigation aid can best be established by reviewing the ground and flight inspection results. [1] §1.15.8 suggests that 4 consecutive inspections should be used in the evaluation. This is considered to be reasonable guidance and will give confidence that the system is stable.

Technological advances have been made to make the equipment more stable, however stability still needs to be demonstrated practically. Using modern equipment utilising the technological advance listed below should give an assessor more confidence that the system will remain stable over time.

The development of Instrument Landing Systems (ILS) started in the 1940’s. Over this long operational lifetime there have been many advances in technology which have contributed to the long-term stability and accuracy.

Some of the major technological advances that can be considered when evaluating a possible extension have been included below:

- Improved antenna array designs for both localiser and glide path.
- Evolution from thermionic tube to solid state hardware
- Introduction of electronic versus mechanical modulators
- Progression from analogue to digital circuitry for both transmitters and monitors
- Introduction of microprocessor controlled transmitters and monitors
- Remote maintenance monitoring via modern telecommunications capabilities
- Digital Signal Processing (DSP) methods for very accurate DDM and SDM monitoring
- Increased accuracy of ground test instruments (portable ILS receivers, also using DSP methods)
- Stripline and microstrip circuit technology for antenna distribution and monitoring rather than discrete components connected by coaxial cables
- Improved coaxial cables for both transmit and monitor antenna feed cables (with air/gas and foam core dielectric materials which provide much better performance over temperature than Teflon and plastic dielectric cables)

Extent of Ground Monitoring [1] §1.15.6

The term ground monitoring referred to in [1] §1.15.4 is considered to mean ground maintenance activities as described in [1] §1.15.6. It is not associated with Navigation Aids internal monitoring systems.

Doc 8071 [1] recognises that the overall inspection regime for a navigation aid consists of both ground and flight Inspection. There is a balance between ground and flight inspection to ensure the Signals in Space remain within the ICAO tolerances.

There is an obvious limit to the extent that ground maintenance can be used to confirm that the Signals in Space as presented to an aircraft are acceptable.

Some states restrict the adjustment of the safety critical parameters without a flight inspection or establish ground maintenance methods to verify that the equipment is operating within clearly defined specifications.

Ground measurements of the transmitting equipment can help ensure that the radiating signal generation had not changed since the last inspection. Measurement of the following parameters should be considered as part of an overall maintenance regime:

- Phasing
- Transmitter output power
- Modulation depth
- Modulation balance

Ground measurements conducted in the field especially the far field can provide confidence that the radiated signal has not deviated from the previous inspection. These ground measurements consist of measuring the alignment, width and clearance at specified points.

Degree of Correlation Between Ground and Flight Inspections [1] §1.15.7

Correlation between ground and airborne measurements is one of the main factors to consider for the extension of a flight inspection interval.

Correlation provides confidence that the ground measurements are representative of the flight inspection measurements. The initial ground and flight inspection measured values may not be identical because of the different position in space where the measurement are made, however there should be suitable correlation to monitor any drift of the signal in space.

Doc 8071 [1] §1.15.10 to 1.15.14 gives some good guidance on the things to consider to ensure good correlation is achieved and maintained, namely:

- Preliminary requirements
- Techniques
- Tolerances,
- Activities during flight inspection

For more than 30 years, France has been carrying out ILS flight inspection activities utilising correlation between airborne and ground measurements; this has enabled the ILS flight inspection interval to be extended from six months to one year. Where good correlation cannot be established the flight inspection interval remains at six months.

An internal DSNA document approved by the French CAA describes the policy and techniques to be applied both by local ground maintenance units and DTI flight inspection unit in order to use correlation for the extension of ILS flight inspection interval. A summary of the procedures that are followed is provided below:

After commissioning and each routine flight inspection, the following parameters are recorded:
For Localiser:

- Tests points on the transmitter
- Monitor values (course, width and clearance)
- Alignment recorded along the runway with a portable receiver.
- Alignment – For CAT III, Far Field Monitor DDM value.
- Width values at dedicated points beside the runway, located at minimum 1km from the antenna.

For Glide Path:

- Test points on the transmitter
- Monitor values (course, width and clearance)
- Phase and amplitude relationships between lower and middle antenna, and between lower and upper antenna. Those measurements are carried out on the threshold.

After commissioning the following ground maintenance intervals are adopted:

- For Cat I, there are 2 maintenances types: biannual and annual
- For Cat III, there are 4 maintenances types: weekly, monthly, biannual and annual.

The biannual maintenance carried out by ground maintenance, replaces the 180 day flight inspection. If during this maintenance, all measurements are close to those performed just after the commissioning flight; the flight inspection interval may remain at one year. Otherwise, if there is the slightest doubt, a flight inspection is requested to investigate.

Experience has shown that this policy significantly increases the safety, because during the annual flight inspection, there is a cross check between airborne and ground measurement. If there is discrepancy between the measurements, flight inspectors and ground personnel have to explain the causes of this malfunctioning, before any adjustment of the ILS parameters.

There are essential conditions to implement a correlation policy to extend Flight inspection interval:

- The flight inspectors and ground personnel have:
    - Similar and appropriate engineering qualifications
    - Similarly accurate measuring equipment

- There are no potential changes to the environment that will affect the correlation.

Changes in the Operating Environment [1] §1.15.7

Despite all the advances in ILS technology, the effects of the electromagnetic environment external to ILS facilities cannot always be detected by the ground maintenance.

Localizer far-field monitors do provide some far-field performance indications, but are only able to monitor the local environment on and near the runway.

After a facility has been commissioned and between periodic inspections, encroachment can occur around the airport. This could cause signal quality degradation from RF interference or reflecting objects.

The following are examples of reflecting objects that could affect the Signal in Space:

- Trucks and shipping containers parked directly behind a localiser array
- Various types of metallic items or terrain changes in front of a localiser or glide path
- Construction of buildings and/or power lines in the vicinity of the navigation aid.
- Airport perimeter fence construction affecting localiser structure
- Vegetation cleared from terrain in front of a glide path and thus producing coherent reflections which affect the structure. This same effect can also been observed when a rough area of terrain is graded into a smooth surface
- Plant growth affecting navigation aid performance. One specific and interesting example is mangroves which grow very quickly!
- Cutting of commercially grown trees in lines parallel to a runway resulting in coherent reflection of localiser signals back onto the centreline and causing localiser alignment and structure problems

There are many more examples of these types of changes to the external electromagnetic environment which cannot be monitored by the ILS ground equipment. With regular visual inspections of the local environment by a well-trained engineer, many of the adverse affects listed above could be anticipated, evaluated, and possibly avoided.

Some countries have implemented policies, often referred to as safeguarding to protect navigation facilities. ICAO has published ICAO EUR DOC 15 European Guidance Material on Managing Building Restricted Areas [3]. This document set out a process for establishing an area around the facility that needs to be protected and the action needed to assess any proposed changes to the environment.

In the case of the United States, the Federal Aviation has implemented an Obstacle Evaluation/Airport Airspace Analysis (OE/AAA) program. In this process a proponent must file a 7460 Notice of Proposed Construction with the FAA for the following criteria:

- Structures protruding 200 feet AGL
- Structure involves construction of traverse way
- Construction of Airport or Heliport
- Structures emitting frequencies

Obstacle Evaluations are handled by Air Traffic control and are coordinated with different divisions to evaluate the application with regard to potential impact of the signal guidance quality.

Maintenance and technical handbooks and technical in-depth knowledge of the system provides a first line of evaluation prior to more in depth evaluations like computer simulations to quantify the amount of degradation.

One such software tool is called NASWATCH, this contains a screening criteria based on equipment siting criteria.

Manufacturers Recommendations [1] §1.15.3

Doc 8071 [1] provides schedules for ground inspections, this include field checks. Equipment manufacturers may also publish a ground maintenance schedule with instructions for their particular equipment.

Generally equipment manufacturers do not prescribe Flight Inspection Requirements.

Quality of Maintenance

Doc 8071 [1] §1.15.4 & §1.15.8 e) mention the need to consider the quality of maintenance, but does not state what constitutes good quality maintenance.

When extending a Flight Inspection Interval an assessor should consider the following items to ensure that the maintenance is of a good quality:

- Experienced engineers
- Well formed maintenance regime
- Reviews of ground and flight inspection results
- Recording monitor readings
- Keeping record of adjustment

- Cooperation between ground and flight department
- A Quality Management System in place

Closer Tolerances [1] §1.15.13

Tolerances may be developed setting stricter criteria which define the exact value to initiate investigation or adjustment of a particular parameter. Using closer tolerances to initiate adjustment back to its nominal value can help give confidence that the Signal in Space will remain within the acceptance standard for the duration of the flight inspection interval.

An example is given in Doc 8071 [1] §1.15.8 a) using 75 % of the nominal acceptance standard.

Italy has a policy of readjusting critical ILS parameters to close-to-nominal values (Localiser alignment and width, glide path angle and width) if they are found outside the 50% of maximum allowed by ICAO documents".

DUE DATE WINDOW

Doc 8071 3rd Edition [2] provided a due date window on the flight inspection interval i.e. +/- 15 days for periodic inspection and +/- 60 days for annual inspections. The 4th Edition removed these windows.

As can be seen from Table 1, many states still use a due date window as part of their inspection regime.

A due date window should be considered as a period of time in which the inspection should be completed if it has not been operationally possible to conduct the inspection on or before the due date. For example, if the inspection has been delayed due to poor weather conditions.

A due date window is a useful tool for tactical planning of flight inspection missions, improving the efficiency of flight inspection operations. When the inspection is undertaken within the due date window the next inspection can still be performed at the next planned date, meaning that it would not be necessary to change the long term planning of the flight inspection schedule.

The due date window is not designed as a means to systematically extend the flight inspection interval.

The due date window should be considered as part of the overall inspection interval, it should not be so long as to significantly increase the risk of the Signal in Space drifting out of tolerance.

Table 1 gives examples of due date windows applied by ICASC represented countries. The absence of clear specified guidance in Doc 8071 [1] opens the way for various interpretations and figures to be used.

ACTION TO BE TAKEN WHEN FLIGHT INSPECTION INTERVAL HAS BEEN EXCEEDED

If an inspection is not conducted at the appropriate time, different types of action can be considered:

- Due date is extended after engineering evaluation and/or ground maintenance reinforcement
- Degrading of the category of ILS (Cat III down to Cat I). This could be a solution in the counties where intervals vary according to the category of ILS
- The navigation aid is removed from service

In France if the flight inspection interval and due date window is exceeded a commissioning inspection is required to return the navigation aid into service.

Removing an operational navigation aid from service may appear to be a drastic measure; however there comes a point where its continued use can no longer be justified in terms of safety. It is essential that airport authorities are aware of the consequences of postponing flight inspections.

CONCLUSIONS

Doc 8071[1] provides guidance for setting a flight inspection interval. Where possible in this paper, further depth has been added to the Doc 8071[1] guidance to assist in the selection of an appropriate flight inspection interval for a particular navigation aid.

No formula exists to determine the correct flight inspection interval; therefore engineering judgement plays an important role. Engineering judgement should take into account all the relevant information pertaining to the navigation aid.

Whilst Doc 8071 [1] does not include a due date window many states have chosen to adopt this concept. This window should be considered as part of the overall flight inspection interval and should not be so long as to significantly increase the risk of the signal in space drifting out of tolerance.

A review of the ICASC member states identified that the majority of these states use a 180 day flight inspection interval as specified in the schedules of Doc 8701 [1]. France, after a thorough case study determined that they had sufficient policy and historical data to extend the flight inspection interval to 360-days.

RECOMMENDATIONS

The following recommendations are made for the benefit of organisations setting flight inspection intervals.

Recommendation one.
The organisation should have a clear documented policy and process for determining and recording the flight inspection interval.

Recommendation two.
The organisation should have robust safeguarding procedures to protect the navigation aid signals from unwanted reflections.

Recommendation three
Visual inspection of the local environment should conducted by trained engineers to prevent reflecting object inadvertently encroaching close to the navigation aid.

FUTURE WORK

More specific guidance with practical examples will be prepared to assist organisations assessing flight inspection interval. This guidance will be promulgated on the ICASC website.

In the longer term it would be our intention to propose an update Doc 8071 [1] for any areas which could benefit from this work.

ACKNOWLEDGMENTS

The following ICASC members have contributed to this paper:

Larry Brady - Airfield Technology, Inc

Sileno Goedicke - ENAV

John Heiderstadt - Octant Aero Services

Egon Koopmann - DFS

Joseph Kokumo Ayodele – Nigerian CAA

Asbjorn Madsen – Normarc Flight Inspection Systems

Dave Quinet – University of Ohio

Yoshiuki Sasaki - JCAB

Christo van Stratten - South African CAA

Peter Thirkettle - UK CAA

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[1] ICAO, 2000, Doc 8071 Manual on Testing of Radio Navigation Aids Volume 1 Testing of Ground-Based Radio Navigation Systems, Fourth Edition.

[2] ICAO, 1972, Doc 8071 Manual on Testing of Radio Navigation Aids Volume II ILS (Instrument Landing System), 3rd Edition.

[3] ICAO, 2009, EUR DOC 015 European Guidance Material on Managing Building Restricted area, 2nd Edition

APPENDIX 1

Excerpts from Doc 8071 Manual on Testing of Radio Navigation Aids Volume 1 Testing of Ground-Based Radio Navigation System 4th Edition

1.15 GROUND AND FLIGHT INSPECTION PERIODICITY

General

1.15.1 This document contains nominal schedules for each radio navigation aid that should be considered in the light of conditions relevant to each State and each site.

1.15.2 The nominal schedules should be used by States as a basis for determining the appropriate inspection intervals for specific facilities. In some cases, it may be necessary to carry out more frequent inspections, e.g. following initial installation. It may also be possible to extend the inspection intervals in some circumstances, if the factors outlined in this section have been taken into account.

1.15.3 The manufacturer's instruction manual usually contains recommendations which are also useful in this regard.

Determination of test/inspection intervals

1.15.4 Many factors influence the choice of appropriate intervals for both ground and flight tests. These include the reliability and stability of operation of the equipment, the extent of ground monitoring, the degree of correlation between ground and flight measurements, changes in the operating environment, manufacturer recommendations, and the quality of maintenance. The complete programme of ground and flight inspections should be considered when determining test intervals.

1.15.5 Reliability and stability of equipment is related to age, design technology, and the operational environment. Stability of operation may also be affected by excessive maintenance adjustments attributable to either human factors or variation in test equipment performance. This is particularly true with some older test equipment where the accuracy and stability of the test equipment is not significantly better than the equipment under test. A major contribution to the demonstration of stability of navigation aids in recent years is the design of modern flight inspection systems and ground facility test equipment, where the standard resolution and accuracy are very high.

1.15.6 Ground maintenance activity and its frequency is dependent upon the design, reliability and stability of a particular equipment and the quality of the test equipment employed as a transfer standard. It has been shown that equipment reliability may be adversely affected by frequently scheduled major maintenance activity. It is, therefore, desirable to limit such activity to essential testing only, particularly for tests that require the disconnection of cables. There is a requirement for additional supplementary flight inspection when some engineering activities, such as glide path antenna changes or adjustments are made. Further investigation may be initiated if the independent monitor calibration indicates any adjustments are required.

1.15.7 The correlation of air and ground measurement records and historic demonstration of equipment stability have allowed some States to extend the intervals between flight inspections. This is supported by the use of routine monitor readings, strict environmental safeguarding and closer tolerances on flight inspection results to ensure operational stability is maintained. Example criteria for the extension of ILS flight inspection intervals are given in 1.15.8 and 1.15.9.

Example of criteria for the extension of ILS flight inspection intervals

1.15.8 This section gives an example of criteria applied to extend the nominal interval between flight inspections on selected ILS facilities. The procedure requires:

a) an initial demonstration of stability over four consecutive periodic flight inspections with no transmitter adjustments. The tolerance applied to inspection results for glide path angle and displacement sensitivity, localizer alignment and displacement sensitivity is 75 per cent of the normal acceptance standards. Glide path clearance below the path at 0.3 of the nominal glide path angle should be greater than 220 μA;

b) good correlation between concurrent ground and airborne results;

c) a record of independent monitor calibration results;

d) a record of equipment monitor readings taken at least at monthly intervals;

e) evidence that the quality of the maintenance is high; and

f) that the facility is adequately safeguarded against changes in the operational environment, e.g. building development.

1.15.9 The nominal inspection interval should be resumed if these criteria are no longer met.

Correlation as the basis for extending periodicity

1.15.10 A typical basis for extending the interval between required measurements without degrading ILS integrity is correlation. Any individual measurement is normally expected to be repeatable over time without adjustments to the equipment. Correlation between ILS measurements made both on the ground and in the air at the same or nearly the same time is also expected. This places equal responsibility on ground and airborne personnel and helps identify common-mode measurement errors. An additional requirement to extend flight inspection intervals is the influence of near- and far-field environments on the signals. These effects can be determined with a flight inspection aircraft. The following paragraphs give illustrations of the correlation technique.

1.15.11 Preliminary requirements. Certain fundamental requirements should be met prior to any measurement activity if correlation between ground and airborne measurements over time can be expected. Typical requirements include functionally similar training for personnel, appropriate calibrated test equipment, completion of all prescribed ground maintenance tasks, availability of commissioning reports and recent periodic inspection reports, and frequent use of measurement skills by both ground and airborne personnel.

1.15.12 Techniques. Achieving good correlation places the same or similar weight on both ground and airborne testing, and demands that both be conducted with great care. Initial or commissioning-type flight measurements should be made with special care, as the corresponding ground measurements will be used as references for ground maintenance personnel. The portable maintenance receiver is readily used in the far-field for localizer facilities, while glide path facilities may require measurements in the near- or mid-field with an auxiliary antenna placed near the transmitting antennas.

1.15.13 Tolerances. New tolerances may be developed to define acceptable correlation between measurements. A rigorous application of correlation principles might include the following types:

a) Setting tolerance — defines the exact value for a parameter, which should be achieved (within the measurement uncertainty) when adjustment is required.

b) Adjustment/maintenance tolerance — defines the limit within which a parameter may vary without requiring adjustment.

c) Operational tolerance — defines the ICAO Standard for a parameter.

d) Discrepancy tolerance — defines, for certain parameters only, the limits of divergence between various measurements:

i) Ground/ground discrepancy — applies to a divergence over time, or between different methods of measuring the same parameter (e.g. alignment monitor, portable ILS receiver, and far-field monitor).

ii) Ground/air discrepancy — applies to a divergence between measurements of the same parameter at the same or nearly the same time by ground and airborne testing personnel.

1.15.14 Activities during flight inspection. Typical correlation activities begin with a confirmation that airborne and ground test equipment is operating within tolerances. This may be achieved by comparing ground and flight test generators and receivers. (If the tolerances are not met, the flight inspection is delayed until the cause of the problem is eliminated.) If the ground or airborne results are out of discrepancy tolerances during the flight inspection and the cause cannot be determined, then the ground monitor alarm limits should be tightened, the facility declassified appropriately or removed from service. The successful completion of the flight inspection (all tolerances are met) establishes that the ground maintenance activities are effective and the interval between inspections may be maintained at the optimum periodicity.

Extending the ILS/VOR Flight inspection intervals

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ABSTRACT

After years and years with stable and reliable NAV systems, we seldom or never observed any erratic behavior nor any significant changes in the measured signals during flight inspection or ground measurements.

This was mainly due to the newest generation of electronic equipment with its far more stable antenna design, where also snow and ice had less influence. In addition, better maintenance routines and more accurate measuring methods for ground checks gave us better control over the system parameters.

Based on this it was assumed that one could extend the intervals by 50 % without reducing the safety level relative to the earlier years.

To classify the systems we checked all systems for type of electronics, stability the last five years on three parameters and type of terrain (hills and high horizon). It was decided to perform this process this on Cat I systems only, but the organization is ready to continue the process to Cat II and III at a later time.

A final risk analysis was carried out and resulted in an NCAA approval to extend the Cat I ILS 180 days intervals to 270 days, and VOR from 360 to 450 days intervals.

INTRODUCTION

Flight Inspection of the navigation system is performed periodically to check that the radiated signals are within specifications, and to check the part of the radiated signal that cannot be measured from the ground or by monitors. It is particularly important that the Instrument Landing System Guiding, used in precision landings conducted during poor visibility, is checked thoroughly. The earlier tube equipment used in the '60ies and '70ies required daily ground checks and at flight inspections which took place every 120 days, there was quite often a need to readjust the modulation depth and balance and a few other parameters.

MORE STABLE AND RELIABLE

After the solid-state systems and more weather protected antenna systems were introduced, our navigation systems have become far more stable and reliable.

About 15 years ago Norway extended the flight inspection intervals on the CAT I ILS facilities from 120 to 180 days intervals to take advantage of the improved reliability. This was according to the recommended interval in DOC 8071 [1] and the CAA (UK) document CAP581, which later was merged into CAP670 [2].

In the mid '90ies we specified and purchased a new generation of highly reliable and accurate ILS to serve our first CAT III equipped airport. In the following years similar systems have been installed on most of our airports as CAT I, and they are produced according to the same standards, and therefore have the same stability and reliability as the CAT III equipment.

Figure 1. Localiser in high elevation terrain.

At flight inspections of those systems we rarely, if ever, observe any changes in the radiated signal which has not already been indicated on the monitors or observed at the periodic ground measurements.

The latest generation of ground checks instrument have the same accuracy and reliability as the equipment installed in the Flight Inspection Aircraft.

We have purchased one EVS 300 for each airport, and they are calibrated annually against the Norwegian standard at the Technical Center near Oslo, which is also serving as a reference for the Norwegian flight inspection equipment.

Figure 2. EVS 300 used for ground checks.

This means that the "number of generations" backwards to the international standard for modulation depth are identical, which ensures that the CNS ground engineers can maintain the ILS facilities well within the ICAO standards.

Suggest longer intervals

Given this situation a natural consequence was to copy the conclusion we made 15 years ago, namely to suggest another extension of the intervals by 50 %, from 180 to 270 days.

This would even yield a positive side effect by a better overall check of the operating conditions of all four seasons within a three years period. The reason why this may be interesting is that the reflections from the terrain surrounding the plants could be affecting the signals, creating variations during different conditions like snowfall and seasonal changes in foliage. These possible effects may go unnoticed if the intervals were at regular half years periods. See figure 6.

Determine the criteria

In order to learn whether this was a good suggestion or not we had to perform a risk analysis. There were four different criteria for an analysis for each of our ILS equipment:

- The type of electronics
- The type of antenna system
- Stability of the measured signals over the past five years
- The height of the terrain surrounding the approach sector.

For stability criteria we chose the last five years of flight measurements recordings of the course line, course structure and clearance. From piles of flight inspection reports data were transferred to an Excel sheet and stability curves were drawn for all our localiser and glide path systems. This was an extensive work that taking a couple of months to complete.

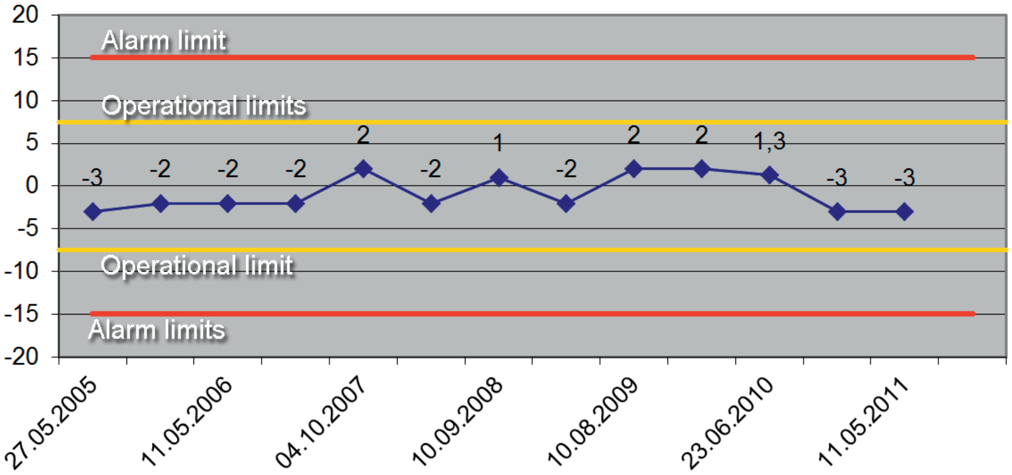


Figure 3. Stability Records for Course Line shifts over a 6 years period.

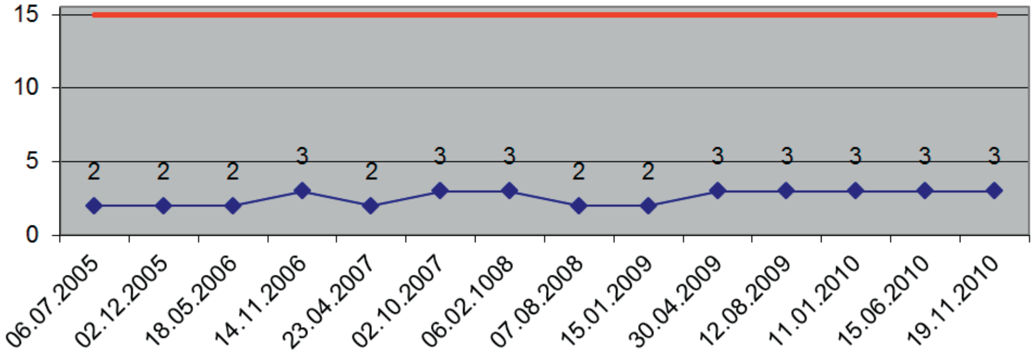
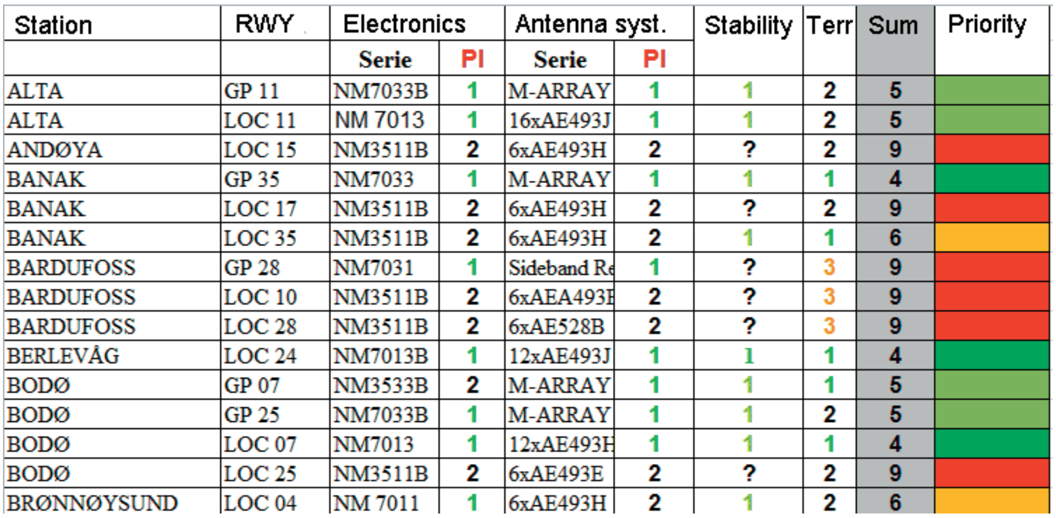


Figure 4. Bend amplitude ILS pt A – B for a given localiser over a 6 years period.



Station	RWY	Electronics		Antenna syst.		Stability	Terr	Sum	Priority
		Serie	PI	Serie	PI				
ALTA	GP 11	NM7033B	1	M-ARRAY	1	1	2	5	🟩
ALTA	LOC 11	NM 7013	1	16xAE493J	1	1	2	5	🟩
ANDØYA	LOC 15	NM3511B	2	6xAE493H	2	?	2	9	🟥
BANAK	GP 35	NM7033	1	M-ARRAY	1	1	1	4	🟩
BANAK	LOC 17	NM3511B	2	6xAE493H	2	?	2	9	🟥
BANAK	LOC 35	NM3511B	2	6xAE493H	2	1	1	6	🟧
BARDUFOSS	GP 28	NM7031	1	Sideband Re	1	?	3	9	🟥
BARDUFOSS	LOC 10	NM3511B	2	6xAEA493E	2	?	3	9	🟥
BARDUFOSS	LOC 28	NM3511B	2	6xAE528B	2	?	3	9	🟥
BERLEVÅG	LOC 24	NM7013B	1	12xAE493J	1	1	1	4	🟩
BODØ	GP 07	NM3533B	2	M-ARRAY	1	1	1	5	🟩
BODØ	GP 25	NM7033B	1	M-ARRAY	1	1	2	5	🟩
BODØ	LOC 07	NM7013	1	12xAE493H	1	1	1	4	🟩
BODØ	LOC 25	NM3511B	2	6xAE493E	2	?	2	9	🟥
BRØNNØYSUND	LOC 04	NM 7011	1	6xAE493H	2	1	2	6	🟧

Figure 5. An alphabetic sample of the assessment sheet. The Sum column gives the class.

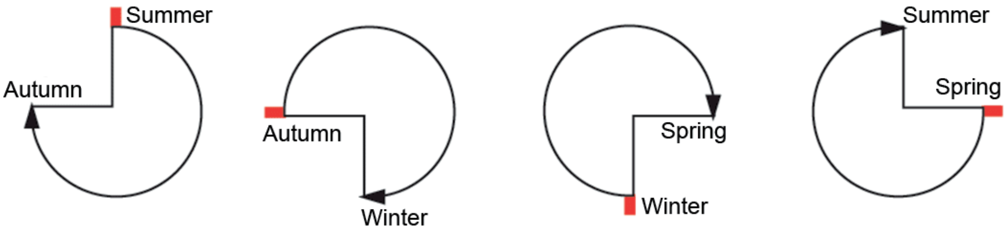


Figure 6. 270 days interval check all four seasons within a three years period.

THE ASSESSMENT METHOD

To assess each facility we chose a "point based" system from 1 to 3, where the highest quality of electronic equipment, the antenna and the lowest terrain height was given a "1", while other less favorable items got a "2" or "3".

In order to classify the system stability, we decided that the maximum permissible operating tolerances should be half the alarm threshold, and this value was divided into three "lanes" on the graph. Curves staying within the inner third, i.e with the least variation, got the value "1", while greater variation was given "2" and even "3" if the curve reached into the outer lanes. See figure 3.

In this way, one could easily classify the different systems with four different sets of criteria. The best score one could obtain was "1" in each set, hence the value “4” was the lowest and best value a system could get. This will later be referred to as class 4 equipment.

We consulted our National Civil Aviation Authority (NCAA) for advice, and the methodology was accepted. They followed the process closely through several meetings as the analysis and results came out.

The end results showed that our ILS throughout the country got values from 4 to 9, and we concluded in consultation with NCAA that all "class 4 and 5" systems would be candidates for the longer intervals. This turned out to be about half of the total number of facilities. To extend the interval for an ILS system, it was necessary that both the localizer and glide path met the requirement.

Another conclusion from the analysis after scrutinizing the recorded curves, was that the periodic inspection of the alarm limits and shut down circuits could be better checked directly on the equipment by the ground engineers. This is obviously more accurate and the results more repetitive than by measuring the parameters in the air. An exception to this is the comprehensive check during commissioning at the first flight inspection of a new facility.

It was not easy to get exceptions from long lasting and well proven regulations by the NCAA without having one or more compensations in our sleeves. The answer was inherent in the most important benefit we got from this new generation of equipment, the vastly improved stability and reliability.

The drifting of the course line, glide path angle, sectors, clearance and modulation on the best equipment are nearly non-existent, so our analysis showed that we could narrow in the alarm limits to CAT II limits without risking any more outages than we already had and have accepted.

Figure 3. Localiser in high elevation terrain.

Having CAT II tolerances set on CAT I facilities provides an interesting opportunity that once was requested by an airline company. They had installed Heads-Up Display (HUD) in a number of B737 aircraft, and had already concluded that they could land on CAT I ILS with CAT II minima where the terrain according to PANS-OPS criteria would allow it. We could not accept that as long as none of our CAT I ILS had CAT II alarm limits, so this was never followed up for a number of reasons. Maybe this could be reconsidered?

For VOR we have done similar studies. The VORs were divided into two groups, the ones that could be used for approach and landing versus area navigation, assuming the former group are more critical. The study did not reveal any significant reason to justify more frequent flight inspection on either of these two groups.

Based on this we suggested a general increase of the VOR intervals from 360 to 450 days in order to cover all seasons during a five years period.

FUTURE WORK

We decided on the first hand to do this assessment of intervals only on CAT I ILS systems, but we are now ready to make similar work on CAT II and III systems in the future.

The implementation of the new and longer intervals has already started, and the new alarm limits are set to CAT II values during periodic checks with guidance from ILS engineers at Technical Center near Oslo.

REFERENCES

[1] ICAO DOC 8071 Manual on Testing of Radio Navigation Aids - Vol 1 Testing of Ground-based Radio Navigation Systems Ed 4.

[2] CAP670 Air Traffic Services Safety Requirements. Second Issue 12 June 2003. Civil Aviation Authority, UK

Interpretation of DOC 8071 - 2 case studies of where experience fills in the gaps

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ABSTRACT

Although Flight Inspection of conventional navigational aids has been carried out for many years, international guidelines such as those presented in ICAO DOC 8071 are, in some areas, still lacking sufficient detail to carry out some inspection requirements in a repeatable or quantifiable manner. In addition, due to the complex and lengthy update process, the information can be out of date for many years. This paper looks at two areas that thought to be insufficient in detail, or have out of date information, which makes Flight Inspection of those facilities subject to interpretation by different organisations.

In particular the paper looks at more effective ways of performing:

a) Analysis of Non Directional Beacon (NDB)'Needle Oscillations'

b) Precision Approach Radar (PAR) inspections

INTRODUCTION

The Flight Inspection of Non Directional Beacons (NDB) is covered in some detail in ICAO DOC 8071 [1] in terms of the measurement parameters that should be considered when carrying out a flight inspection task. Table 5-3 of [1], provides accepetance criteria for Coverage Measurements and Holding Patterns/Approach Procedures parameters which include the measurement of 'needle oscillations'. There is no further definition as to what is considered a "needle oscillation" or how it is to be measured. Some additional guidance is given in the note to table 3 which imply that the oscillations can be considered as acceptable provided their duration is less than a defined time period and are not one-sided in nature. However, the speed of the aircraft is not considered at this point, even when the speed affects both the magnitude and time period of any oscillations present. This can lead to different organizations using varied measurement techniques and/or acceptance criteria for the same facility.

Similarly the Flight Inspection of PAR is also covered in the same manual, however in this case the methods described do not take modern Flight Inspection systems into account that are based on 3 dimensional tracking technologies such as GPS based systems. The technique described is based upon on manual tracking of the aircraft and recording of the individual 'fix' data, both of which can introduce significant error into the results. The number of 'fixes' required to ensure one measures the angles satisfactorily is hinted at, but not specified, allowing significant latitude in how one might assess the results. A further issue to note is that the acceptance tolerances presented in Table 7-3 of [1] are related to the PAR antenna and not to the Touchdown point to which the aircraft is guided to. Whilst this is not a significant issue, it is normal to think of Precision Approach aids as having an alignment accuracy tolerance relative to the runway. Certainly in the experience of the author, all PARs inspected have azimuth and elevation tolerances relative to the Touchdown point; however different countries apply different tolerances to the results.

NDB NEEDLE OSCILLATIONS

The use of Non Directional Beacons for non-precision approaches is still a major use of NDBs worldwide. Even given the implementation of numerous GPS based approaches some countries are progressing with an NDB renewal program. This is the case currently in Australia and has resulted in the evaluation of ICAO DOC 8071 [1] in some detail as the Flight Inspection of NDB approaches have not carried out in some time.

It became evident that the information provided in [1] was not sufficient to determine if a particular

NDB was ‘In tolerance’ or ‘Out of Tolerance’ when assessing needle oscillations.

Assessment reference material

ICAO Annex 10 [2] refers to Coverage and only hints at bearing information being ‘suitable for intended operation’ in paragraph 3.4.1. There are no acceptance standards for bearing errors or needle swings.

ICAO DOC 8071 [1] provides guidance on the assessment of Holding Patterns and Approaches in Table 5-3, with further information provided in the notes section relating to noise effects and cross pointer accuracy.

Neither document specifies any reference speed information or filtering techniques that might be applied to the assessment of an NDB.

An NDB station only provides a radiated carrier wave signal with no positional information associated with it. Therefore, the ‘accuracy’ of the bearing information can only relate to the ability of the aircraft to correctly determine the bearing to the station based on the received signals. Thus ‘bearing accuracy’ of an NDB could be considered irrelevant as the more important aspect is the stability of the information provided. The stability of the information provided must be such that a pilot may determine the relative bearing to the station and use that information to keep the aircraft on the intended path.

The notes in table 5-3 of [1] do provide some information about the characteristics of Needle Oscillations which assist in the interpretation of paragraphs 5.3.9 and 5.3.11. However, the notes also introduce a time element, but do not expand on this further.

Qualitative assessment by Pilots

Typically there are a minimum of two NDB receivers on the Flight Inspection aircraft - one for the Pilot’s normal use and one connected to the Flight Inspection system. Flyablity of the approach is normally assessed by the handling pilot at the time of the inspection. The assessment is therefore qualitative and is subject to interpretation by different pilots with differing experience. Whilst effective training can ensure a relatively consistent standard, once the approach is flown, there is typically no data for detailed review in the case of marginal sites.

For most of the approaches flown, this is of no issue, as the assessment of needle oscillations is relatively easy given a stable signal. However where external influences affect the quality of the received signal, it is more difficult to assess whether an NDB did oscillate for the stated 4 (8 for enroute radials) or less second tolerances and to what magnitude. A further complication is that each aircraft installation may ‘see’ the oscillations to a greater or less effect, depending on the receiver type, its associated display equipment, airframe influences given antenna installation location and any damping of the oscillations within the avionics systems.

This can also be the case for the Flight Inspection receiver.

Quantative assessment by Automated Flight Inspection systems

Whilst the Pilot can assess his ability to make a satisfactory approach (or hold a particular enroute radial) at the time, the flight inspection system is able to record the NDB bearing information for further analysis. However, the data provided may or may not match that as seen by the Pilot. Typically, differences are seen due to the position of the two ADF receiver antennas, which will see the signal slightly differently during the approach and particularly during turn-in.

The data from the flight inspection receiver can be analysed automatically via the flight inspection system, or manually by the flight inspector. The problem occurs when trying to determine what to analyse and what standards or techniques to apply when considering ‘Needle Oscillations’.

Assessment of Needle Oscillations

The data from either the operational ADF receiver or the Flight Inspection receiver must provide similar data in terms of the magnitude and period of any oscillations seen. Most Flight Inspection receivers take digital bearing data and compare this to the actual position of the aircraft to produce a bearing error trace. This is useful for recording the signal as received, but this signal is not always the same as that seen by the pilot. The primary system uses the receiver output to drive a mechanical pointer and thus is typically ‘over-damped’. This is of importance when considering that during a period of ‘needle oscillations’ the flight inspection receiver may show larger swings and for a longer period when compared to the primary system. .In either case, flying at different approach speeds will affect the magnitude and period of any oscillations seen.

Some flight inspection systems try to counter these effects by filtering techniques. By using a high pass filter, any low frequency bearing errors can be removed (they are not used for analysis anyway), leaving the equivalent of needle oscillations. The basis of the filter characteristics, in the absence of other guidance material, could be taken from that used for VOR Bends Analysis or from the MLS Control Motion Noise Filtering requirements specified in [2]. Whilst this is an option, the filter corner frequencies may not be appropriate for the correct analysis of needle oscillations. Further processing can be automatically employed to determine if the resultant needle swings stay within the acceptance criteria of ±5° or ±10° and if not, for how long they appear out of tolerance. A typical set of filtering as applied to a Flight Inspection ADF receiver is shown in Figure 1:

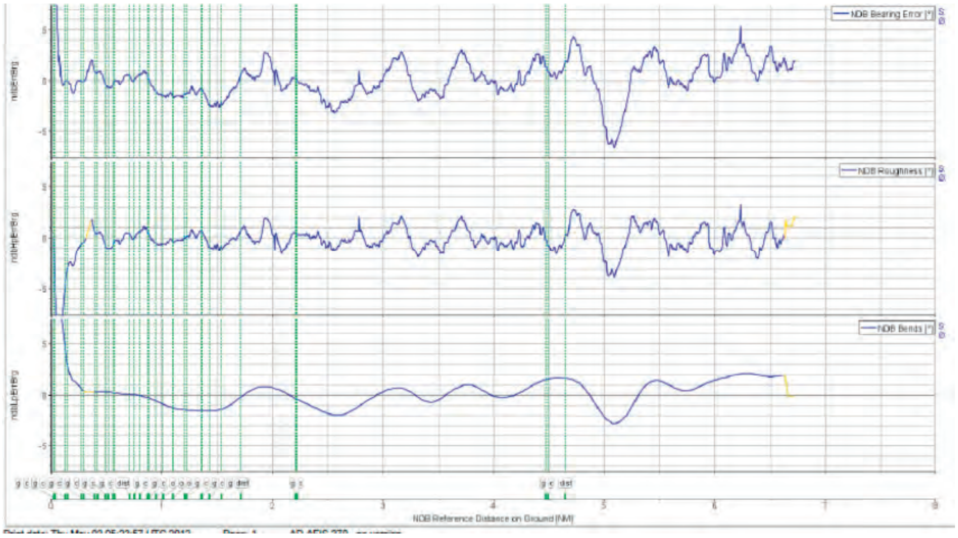

Figure 1: Typical NDB Flight Inspection data.

Here, the top graph shows the raw receiver data with a large needle deflection at around 5 NM. However in this case it is not ‘generally oscillatory in nature’ and therefore the time element of [1] Table 5-3 Note 3 would not apply. The data is shown filtered in the middle graph, with all ‘bends’ removed, leaving a trace that can be interpreted as Needle Oscillations. The magnitude of these were similar to those seen on the aircraft primary EFIS instruments. The lower trace takes the filtering one stage further and considers the VOR radial case in determining whether Bends are present or not. The basis of this is whether there is a smooth deviation of course over a 2 NM radial, with the aircraft flying at 140 knots. This information is not used directly for the analysis of an NDB, but in effect shows the potential path of an aircraft had the NDB bearing guidance been followed by a pilot. Typically, such filtering will yield different results if the aircraft is flown at different speeds.

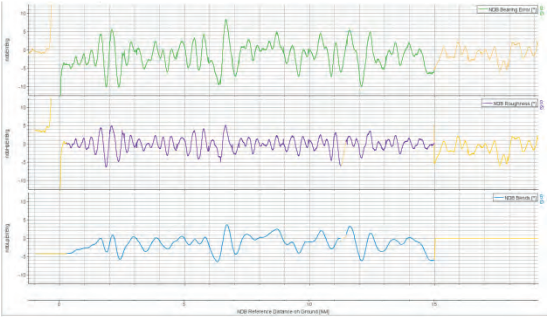

Figure 2. Needle Oscillations

Figure 2 shows more typical Needle Oscillations and the resultant effects on the receiver data. In this case, there are periods during the approach that the observed oscillations are greater than ±5° and for longer than 4 seconds. The approach was flown at 160 knots; therefore 0.18 NM represents 4 seconds of time. As the roughness filter has been seen to model the operational equipment in the previous example, it can be assumed that the Pilot in this case would also have seen oscillations up to ±6°. The question therefore is whether the 4 seconds applies for the amount of time that the data is seen to be in excess of 5° (in which case this approach passes the test) or for the period of time that oscillations were seen at around that period (in which case the approach fails the test). In this case, the level of filtering is also important as a more ‘damped’ roughness trace would result in the approach passing in any case.

Thus, as there is no readily available specification for the filter characteristics, different organisations may report the results differently. Similarly, there is no guidance as to the correct reference speed to be used for enroute radials or approaches, or where the time should be measured from.

Such specifications would aid the analysis of NDB oscillations and should model the specifications of operational equipment. The authors are seeking help from the Flight inspection community to help specify this model further, with the aim to document a quantative assessment method suitable for NDB needle oscillation analysis.

Note: reference [3] and an internal Airservices Document are the only known sources of speed *related information. The FAA use 130 Knots for analysis purposes and Airservices Australia use 140 Knots.*

PAR INSPECTIONS

The information provided in ICAO DOC 8071 [1] was intended to provide a simple method of checking PARs with minimal equipment and training. Whilst the method may be satisfactory given the large tolerances available for acceptance criteria, it does not meet the intended uncertainty recommendations provided in Table 7-3 of [1]. Considering the complete system uncertainties associated with PAR measurements, both the acceptance criteria and uncertainty recommendations could be revised to more suitable and useable figures.

Measuring PAR as a system

There are several subcomponents of PAR system that must be considered as part of the overall Precision Approach aid. In particular it must be clear which parts are subject to the test and acceptance criteria. For simplicity, consider the PAR system to comprise of:

a) The PAR Radar equipment near the runway
b) The PAR display and associated processing
c) The PAR Radar Controller
d) The aircraft being controlled
e) The aircraft positioning and recording system

Each subsystem has an associated measurement uncertainty that needs to be considered when evaluating the overall measurement uncertainty.

Since the PAR radar and display/processing equipment is the unit under test and therefore the unit for which the errors is being determined, the factors contributing to measurement uncertainty to consider are items (c) to (e) of the above list. .

Display considerations

During the last 10 years or more, there have been an increasing number of digital displays used to show the information provided by the PAR equipment. The older analogue displays can have errors associated with the characterization of the line used to represent the angle of approach and the resultant aircraft return as painted on the screen. However, these displays in general show the 'real' return and suffer less from digitization and delays seen in modern PAR systems. Digital displays are generally associated with PARs that have a high degree of signal processing which can introduce unwanted effects due to the resolution of the display (pixilation) and a degree of data lag.

It can be seen that both of the above effects are associated with the PAR system and thus the system under test, the setup of the display is related to the RADAR controller and can be considered a factor contributing to measurement uncertainty.

When configuring the display for use, both in terms of controlling and for use during the calibration of the PAR, consideration should be given to the scaling type (logarithmic or linear) and the scale used. Two conflicting requirements are found in the selection of these aspects:

a) High sensitivity (large scale) is required to improve the accuracy of the 'On' calls. Linear scale selection can be selected to improve the sensitivity near threshold. However there is a tendency to 'over control' an aircraft with this selection.
b) Low sensitivity (smaller scales) is better for seeing the general trend of the aircraft during the approach and avoid 'over controlling' the aircraft on to the desired track. Logarithmic scales can be used to keep the effective variation of movement of the aircraft standardized throughout the approach. The downside is effectively reduced resolution of any measurement.

As well as these aspects, the type of signal processing employed can also affect the result (e.g use of Moving Target Filters, Rain and Clear modes, Small vs large targets).

Radar Controller

A large source of potential error in the measurement of the PAR equipment is the Radar Controller and their ability to not only accurately guide the aircraft to the nominal approach azimuth and elevation lines, but also to call 'On' events at the relevant time. In some countries, the Radar Controller used during the inspection is also the line PAR controller who may use the equipment for normal operational duties. In other cases, specifically trained PAR inspectors are used.

Use of the normal line PAR controller, who may take an operational approach to the 'talk down' and not a measurement approach, introduces a greater measurement uncertainty. In general, their day to day duties require them to guide the aircraft to the approximate position of the azimuth or elevation lines. It is not important for the aircraft being controlled to be exactly on the line. However, for flight inspection requirements, the aircraft needs to be either on the line and an appropriate 'fix' being called out over the radio, or for the controller to record the amount of deviation (by some means) at the time either the controller, flight inspector or theodolite operator calls for a fix to be made.

With a dedicated PAR inspector, the skill level in being able to guide the aircraft onto the appropriate line and then maintain that line for several consecutive fixes is likely to be higher. In some countries, a high skill level is required as the number of fixes required per run is significantly higher than that suggested by [1] (one every 1 NM).

The two methods (normal line PAR controller vs skilled PAR flight inspection controller) result in potentially different measurement uncertainties associated with them. The methods also provide different test depths for the PAR system in its overall context. The use of the line PAR controller in effect also provides a test of the training and standards of the local ATC staff which can be seen as a side benefit of the Flight Inspection of the PAR system.

Aircraft profile

The aircraft itself has an associated measurement uncertainty and is one that is not always considered. ICAO Annex 10 [2] requires that the PAR shall be capable of measuring an aircraft with a Radar Cross Section (RCS) of $15m^2$ at a range of 9 NM. This represents a large aircraft target in terms of the Radar's resolution. The normal profile of a smaller jet aircraft or single prop military trainer aircraft may have a target area of $1\text{-}5m^2$ and be seen perfectly by most PARs systems. The major reflective areas seen by the PAR are the engines (and potentially associated propellers); however the wing and tail leading edges can also be significant reflectors. As the aircraft approaches, the combination of reflective surfaces that the PAR will successfully receive returns from will change as the aircraft attitude also changes. This can lead to the effective center of the RCS changing during the approach. This can potentially be an issue during an approach with cross winds that cause the nose of the aircraft to point away from the PAR site.

It is of note that on analogue displays without digital signal processing it is sometimes possible to observe two distinct returns from aircraft with T-Tails when the aircraft is close to threshold, one being the main fusalage and the other being the T Tail.

The location of the nominal RCS center must be modelled in the flight inspection system (or tracked by the theodolite operator) to minimize the magnitude of effects caused by drift or pitch changes.

Positioning and Recording system

Significant advances in the use of Automatic Flight Inspections systems have been made since the last known change to the PAR section of [1]. Whilst the theodolite method described is practical, it introduces potential measurement uncertainties that can be avoided by the use of 3 dimensional positioning systems. For example, to locate the theodolite on the runway is not always possible for the evaluation of Azimuth data. This necessitates that the Theodolite is positioned offset to the runway (if single site working is used) or at the far end of the runway (to reduce offsets). The single site case can introduce alignment bias errors and involves more complex evaluation of the results, whereas the dual site case can introduce a sensitivity issue due to reduced resolution (the target being further away). Additional sources of error using theodolite systems are the manual operation of the device (tracking error) and that of recording data manually (if non automated theodolites and radio link are not employed).

Modern 3 dimensional systems whether GPS, Camera or ground tracker based, do not suffer from position recording errors. These systems record the position of the aircraft at any given time in relation to the touchdown point, with near continuous calculation of azimuth, elevation and distance data. The measurement uncertainties associated with these systems are therefore minimized and only relate to the reference position survey accuracy, the positioning accuracy of the tracking system used and any timing errors associated with pressing an event button when the PAR controller calls 'on' which may also be compensated for in the calculations.

Latency considerations and Digital processing

PAR data must be updated at a rate of at least 1 times per second (ICAO Annex 10 [2] paragraph 3.2.3.5), however neither [1] nor [2] specify the maximum latency of this data. It is therefore possible for a display to lag behind the actual position of the aircraft at the time a controller calls "on path" or "on elevation". This becomes a significant source of error if the aircraft under observation is moving due to turbulence, wind effects or at the request of the controller. Typically, if an aircraft were to be cutting across the approach path at 15°, with a 120 Knots approach speed, each second equates to a lateral displacement of approximately 16 metres. Any latency in calling "On" and recording the resultant position will introduce lateral errors. This effect is less pronounced in the elevation plane and be ignored in uncertainty calculations.

Modern digital PARs tend to update less frequently than the older scanning analogue systems, primarily due to the number of individual radar sweeps with different characteristics used to gather the data one 'scan'. The systems combine the results from a number of sweeps to provide a filtered display, which will always introduce a lag effect. The additional effect of this is that there are potentially problems in resolving two targets that are close to each other.

If the aircraft is stable on the approach, any latency issues will not be observable. This then provides a contridication in requirements for inspecting PAR:

a) A stable approach is required for accurate 'fixes'
b) A manoeuvering approach (left and right on centreline, or above/below elevation approach angle) is required to establish any latency effects that may contirbute to the PAR overall error.

Resolution Testing

DOC 8071 [1] 7.3.8 refers to resolution testing not being practical by flight testing. Whilst this is the case for Theodolite based methods, the use of 3 dimensional position reference and automated flight inspection systems (AFIS) now makes this test possible. The important part of this testing is to correlate all the results to the same time reference (normally by GPS time stamping). With both aircraft and the PAR system data being recorded, it is possible to determine the point at which the PAR is able to resolve two aircraft that are flying in close proximity to each other. By then analysing the position references from both AFIS at that instant in time, the azimuth, elevation and distance separation between the aircraft can be determined to a high degree of accuracy.

This test should be completed during type approval of a new PAR system or after major software/hardaware upgrades.

Whilst this is not directly associated with the assessment of measurement uncertainty of normal azimuth and elevation measurements, it is interesting to note that this is now possible given the advances in positing fixing and timing capabilities of modern flight inspection systems, which have much improved measurement uncertainties.

Evaluation of acceptance criteria

Considering PAR as an approach aid, it is reasonable to think of acceptance criteria in the same way as one would for ILS and have angular tolerances based around the intended touchdown point. Currently ICAO DOC 8071 [1] and Annex 10 [2] specify the PAR acceptance criteria in terms of a linear offset in feet, dependent on the range of the measurement. In comparison to typical ILS Category I acceptance criteria, when converted to the PAR touchdown point, the two sets of tolerances overlay as shown in Figure 3 (Azimuth) and Figure 4 (Elevation), for a runway of 2000 m, ILS localizer at 2200 m, PAR touchdown at 300 m and the PAR radar approximately 1000m. The two sets of acceptance criteria show very similar characteristics.

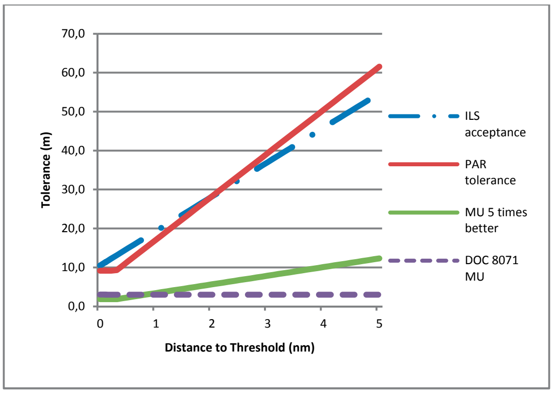

Figure 3: Overlay of PAR Azimuth and ILS tolerances

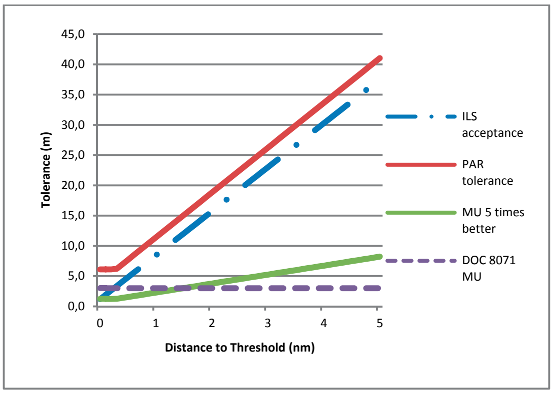

Figure 4: Overlay of PAR Elevation and ILS tolerances

PAR approaches are normally terminated at 0.5 NM (200'), similar to ILS CAT I approaches, thus any tighter tolerance inside 0.5 NM need not be applied for flight inspection purposes. Note, Annex 10 [2] requires the display to be aligned to tighter tolerances at touchdown, however this is more appropriately completed by ground based tests.

From these two graphs, it is possible to visualize that the Azimuth tolerance is tighter than the ILS equivalent between 0.5 NM and approximately 2 NM, whereas the Elevation tolerance is less stringent. In both cases, the note in Table 7-3 of [1] is demonstrated to be a practical acceptance tolerance, since the angular term is the dominate parameter. In the example above, this equates to an Azimuth tolerance of 0.34° and an elevation tolerance of 0.23°. Both these figures could be acceptable given a highly accurate measuring system. However, considering the uncertainty of measuring system, the values must be reassessed to ensure that the PAR is maintained within the tolerances.

Determination of acceptance criteria with realistic measurement uncertainties

With knowledge of the various potential subsystem measurement uncertainties, it is possible to estimate what a practical value for PAR acceptance criteria should be, along with the measurement uncertainty of that criterion.

Considering the case of a digital PAR system, a 3 dimensional tracking AFIS and a line PAR controller; typical error budgets may be assigned as follows:

- PAR Display: 3 m (one pixel)
- Controller error: 3 m (one pixel)
- Aircraft Cross Section Error: 2 m Azimuth, 1 m Elevation.
- Azimuth latency: 2 m
- 3 dimensional AFIS accuracy: 0.3 m

Using the simplified Root Sum Squared method of estimating the overall Measurement Uncertainty (MU), yields figures of:

- Azimuth: 7.3 m
- Elevation: 6.0 m

With an experienced PAR inspector, the pixel error may be reduced by either calling less frequent and more accurate “On” fixes or by increasing the number of fixes an accepting a variation of results around the average line. In either case, the measurement uncertainty may be reduced to:

- Azimuth: 4.1 m
- Elevation: 3.2 m

ICAO DOC 8071 [1] paragraph 1.11.6 recommends that the overall error budget (equivalent to measurement uncertainty) is 5 times better than the published performance of the navigational aid. In this respect, if Azimuth figures of 0.34° and Elevation of 0.23° were to be used, this would require the uncertainty to be 0.07° and 0.05° respectively. Converting to metres, Figure 5 and Figure 6 demonstrates that DOC 8071 [1] Table 7-3 recommendations are not met; however are within the bounds of the average requirement of the run considering the acceptance tolerances calculated earlier.

There are also systems available today that automatically send data from the PAR to the AFIS, thus eliminating two potential sources of error. Such systems may have measurement uncertainties in the order of:

- Azimuth: 2.0 M
- Elevation: 1.0 M

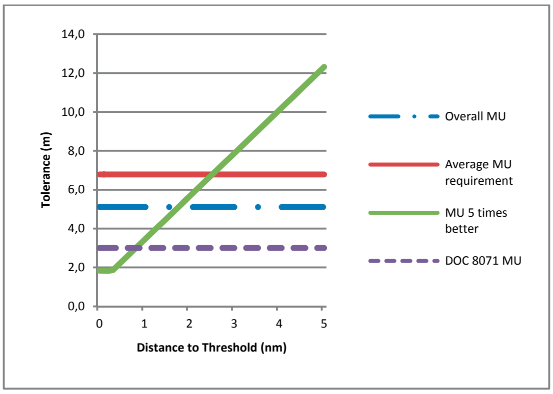

Figure 5: Azimuth Measurement Uncertainties

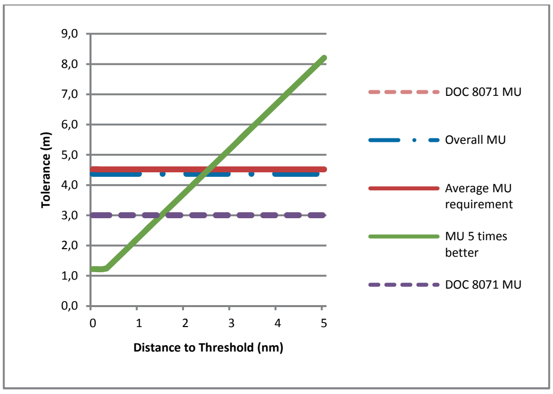

Figure 6: Elevation Measurement Uncertainties

The measurement uncertainty can be demonstrated to be 5 times better than that required, provided a range of measurements are considered. It is therefore necessary to take measurements throughout the approach, typically between 5 NM and 0.5 NM. Further interpretation of the data requirement given these conditions is covered in the presentation accompanying this paper.

Taking each individual measurement uncertainty vs range into account, along with the acceptance criteria calculated earlier, a new set of acceptance criteria relative to range can be calculated as in Figure 7.

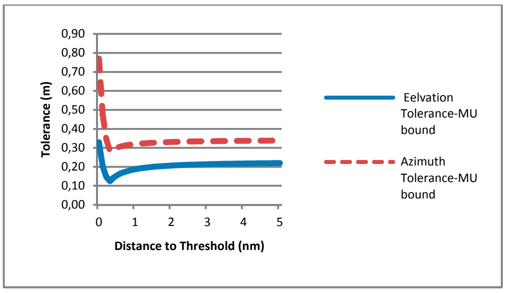

Figure 7: Minimum values for acceptance criteria

To ensure the PAR remains within the acceptance criteria, the worse-case Azimuth and Elevation tolerances should be revised to:

- Azimuth: 0.28°
- Elevation: 0.15°

Note: These figures should be adjusted for each runway installation, as the PAR backset and touchdown data may be different from that used in the analysis provided.

CONCLUSIONS

This paper has conidered two areas where ICAO DOC 8071 is lacking in detail. Both systems have been in use for safely for many years and the issues identified only relate to potential misinterpretation of results provided by a Flight Inspection system.

The paper has found in particular:

1. The information provided in [1] for the assessment of NDBs is incomplete. Further specification of the acceptance criteria for Needle Oscillations should be developed.

2. Reference [1] has unrealistic measurement uncertainties associated with PAR azimuth and elevation parameters. It is not clear if the figure is for a spot fix or a combination of fixes.

3. The current iteration of [1] does not consider modern digital PAR systems. In particular, potential data latency is not considered. Whilst this may be measureable as a side effect of the inspection of PAR, [1] does not include tests that might reveal this as an issue.

4. Paragraph 7.3.8 of [1] is incorrect, in that it is now entirely possible to measure PAR resolution by flight testing.

RECOMMENDATIONS

1. Reference [1] should be reviewed to include more specific information relating to assessment of NDB needle oscillations.

2. PAR acceptance criteria should be based around the intended touchdown point. Values of ±0.28° for Azimuth and ±0.15° for Elevation would appear suitable and practical given modern AFIS systems.

3. Reference [1] measurement uncertainties in Table 7-3 should be revised and it made clear what they apply to.

4. Reference [1] and Reference [2] should be revised to consider modern digital PAR systems and latency issues. Reference [2] should include a specification for maximum data latency.

5. Paragraph 7.3.8 of [1] should reflect current measurement techniques.

FUTURE WORK

Further work is currently being undertaken between AeroPearl and Airservices Australia and to develop more refined NDB needle oscillation acceptance criteria. The authors would appreciate any information in this area that other Flight Inspection experts may have. The intention will be to develop guidance material to be adopted by DOC 8071[1] or be published on the ICASC website.

REFERENCES

[1] ICAO, 2000, Manual on Testing of Radio Navigation Aids, DOC 8071, Fourth Edition.

[2] ICAO, July 2006, International Standards and Recommended Practices, Annex 10 to the Convention on International Civil Aviation, Volume 1, Radio Navigation Aids, 6th Edition, http://www.icao.int

[3] FAA, Oct 2005, United States Flight Inspection Manual, 8200.1C (including Change 6).

Flight Inspection of the Ground Based Augmentation System (GBAS)/ Local Area Augmentation System (LAAS)

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ABSTRACT

The FAA's Next Generation Air Transportation System is a transformation of the National Airspace System using 21st century technologies to ensure future safety, capacity, and environmental needs are met. LAAS is one of the new technologies. The LAAS is a ground based augmentation system designed to provide ILS like precision approaches. A single LAAS may be able to provide Category I precision approach guidance to all runways at an airport. Assets required for the flight inspection and maintaining of a LAAS should be substantially less than those supporting similar operations with ILS.

In December of 2009, the FAA commissioned the first LAAS in the United States. The LAAS provides Category I precision approaches to five runway ends at Newark Liberty International Airport. Each approach utilizes a runway specific RNAV approach procedure for navigation into the LAAS final segment and for the missed approach routing. The LAAS presents new challenges for the flight inspection of the VHF data broadcast signal and validation of navigation data (the Final Approach Segment data). This paper describes flight inspection issues encountered during commissioning along with the policies and flight profiles employed by the FAA to commission and conduct ongoing periodic inspections of the GBAS/ LAAS.

INTRODUCTION

Initially, the LAAS was the FAA version of a GBAS. The international community has adopted GBAS as the term for this type of navigation system. The FAA is now also adopting the term GBAS to be consistent with the international community. This paper will utilize the term GBAS to be consistent.

The GBAS augments the GPS signal in a concentrated area of about a 20-30 nm radius around an airport. With the high accuracy, integrity, and availability the GBAS can provide for precision approach, departures and terminal operations. In the end state the GBAS is expected to provide capability for CAT II/ III operations. The accuracy is expected to be less than one meter laterally and vertically.

The GBAS consists of a ground facility, four GPS antennas, and a VHF data broadcast (VDB) transmitter. Compatible avionics on board the aircraft receive and display the augmented GPS navigation guidance on standard aircraft navigation instruments. In the cockpit, the GBAS display is an ILS look-alike. This will help keep pilot training to a minimal.

Newark Liberty Airport GBAS.

The first GBAS was commissioned by the FAA in December 2009 and is a non-FAA owned system at Newark Liberty International Airport, New Jersey. This is a Honeywell International GBAS, which received System Design Approval from the FAA in September, 2009. The flight inspection at Newark did encounter GPS satellite geometry issues for about a 30 minute time period. Three satellites, in critical geometry positions, were being excluded. This initially caused a condition of flagged course and glide path guidance in the cockpit until the flight inspection aircraft was about 5 miles from the runway threshold. As the satellite geometry improved, cockpit guidance was regained to the full Dmax distance of 23 miles.

The flight inspection system confirmed the same indications as observed in the cockpit.

The GBAS at Newark Liberty Airport has been plagued with intermittent GPS interference issues. The interference issues have stemmed from portable GPS jammers being used in vehicles traveling along a freeway, which runs next to the GBAS antennas. Due to extremely limited space for siting the GBAS, the GPS antennas and the VDB antenna are lined up in very close proximity to a freeway running next to the airport boundary fence. Two changes to the Newark GBAS are being made to help mitigate the GPS interference. A software modification is being made to the facility and the GBAS GPS antennas have been lowered. No interference issues were detected during the flight inspection at Newark.

Figure 1. Newark VDB Antenna Next to a Multi-Lane Freeway

There are five GLS approaches commissioned at Newark Liberty Airport.

Houston George Bush Intercontinental Airport GBAS.

The second GBAS commissioned by the FAA in March, 2012 is also a Honeywell International GBAS at Houston George Bush Intercontinental Airport, Houston, Texas. The Newark and Houston GBAS facilities will provide a city pair route for a major airline in the United States. The GBAS at Houston has not had the GPS interference issues observed at Newark. The GBAS is sited between the parallel runways 08L and 08R and approximately a mile from any heavily traveled highways. No anomalies were observed during the commissioning of the Houston GBAS. There are six GLS approaches commissioned at Houston Intercontinental Airport.

TYPES OF GBAS FLIGHT INSPECTION

The flight inspection or a GBAS is defined as one of three types.

Commissioning.

A commissioning is a comprehensive evaluation of the GBAS system and Standard Instrument Approach Procedures (SIAP(s)).

Periodic.

A periodic inspection evaluates VDB coverage along the lower orbit. Evaluation will be based on signal-strength assessments and loss of signal. The altitude established for the lower orbit during commissioning must be used. The GBAS broadcast FAS data block CRC must be evaluated and documented for each SIAP. Approach obstacle verification must be completed.

Special.

A special inspection will be required when a user complaint is confirmed, an existing approach is modified, or after certain maintenance activities, identified within the appropriate ground equipment maintenance manuals, are completed .

PRE-FLIGHT INSPECTION PREPARATION

The flight inspection starts with the acquisition of the GPS Landing System (GLS) approach procedure package. The procedure package must contain the critical data to be charted, obstruction documentation, as well as the final approach segment (FAS) data. The landing threshold point (LTP) in the FAS data must agree with airport runway data information. The bearing between the LTP and the flight path alignment point (FPAP) must agree with the runway bearing. The cyclic redundancy remainder must agree with the documentation in the approach procedure package. The FAS data must also be in an electronic format for both loading into the GBAS ground facility and into the flight inspection aircraft’s flight inspection computer. The FAS data CRC must be confirmed as the data is loaded into the flight inspection computer.

ARINC 424 Coding for RNAV Segments.

Procedural RNAV transitions into and missed approach segments require ARINC 424 coding to create a database for navigation guidance. This coding goes into the FMS navigation data base and provides lateral and vertical guidance to the GBAS precision final and missed approach guidance.

The ARINC 424 data for transition into and missed approach must be verified using bearing and distance tolerances. Prior to the procedure being flown, the navigation database path/ terminator data accuracy must be evaluated by comparison with the official source procedure documentation. This evaluation can be easiest done with a desktop software tool designed to display ARINC 424 coding from the actual aircraft's FMS navigation database.

FAS data block information must be compared to the procedure data. Errors occur and examination of the procedure package can prevent later frustration with mismatched data during the airborne inspection.

Datum. Due to the criticality of data, the inspector must ensure that all required data is based upon the **same reference datum** (NAD83/ NAVD88, WGS84/ ITRF00, etc.). This includes the facility data, proposed approach procedures, FAS data, GBAS facility reference point (as defined in the facility data and broadcast in the Type 2 message), differential GPS (if used), the runway coordinates, and elevations.

Conversions between geodetic datums can induce errors. Vertical datum differences can result in vertical positioning errors, causing the flight inspection system (FIS) announced Threshold Crossing Height (TCH) for GBAS procedures to be higher or lower than designed. Corruption of ellipsoid height data can have adverse effects on the FIS announced TCH value and the location of the glide path by displacing the glide path forward or aft along track of the intended procedural design.

It is imperative that procedural data and airport data are matched for the flight inspection and for the date of procedure publication. This becomes especially critical when a runway threshold is extended or displaced and a new procedure has to be designed.

Loading of Final Approach Segment (FAS) Data Blocks into the GBAS

The first GBAS commissioning in 2009 did not include a process of electronically transferring the FAS data block from the procedure designer to the GBAS ground facility. The attempts to load the FAS data in a binary file format into the GBAS did not work. The FAS data was "hand-hacked" into the GBAS ground facility. The same binary file was electronically loaded into the FIS on the aircraft. The FAS data in the FIS was compared to the data broadcast in message type 4 along with the CRC value. This provided the assurance that the FAS data had not been corrupted during the "hand-hacking" into the GBAS ground system.

The FAS data block contains eighteen elements of data critical to the guidance of the aircraft. This data provides the course and glide path guidance to the pilot's flight instruments. Corruption of this data could be catastrophic for the aircraft on a precision approach.

The process of transferring the FAS data block from procedure design to loading into the GBAS ground facility is critical in preventing a corrupted file. This process must include a secure method of transferring data. By the time the GBAS at Houston Intercontinental was ready for inspection, an electronic process to move the FAS data from the procedure designer to the GBAS facility and to the flight inspection system had been developed. We believe the FAS data is very critical and that a secure electronic process must be established to transfer that data.

FAS Data Block Information

Data Field	Data
Operation Type	0
GBAS Service Provider	14
Airport Identifier	KIAH
Runway	RW08L
Approach Performance Designator	1
Route Indicator	
Reference Path Data Selector	2
Reference Path Identifier (Approach ID)	GBZU
LTP/FTP Latitude	300025.7780N
LTP/FTP Longitude	0952131.6470W
LTP/FTP Ellipsoid Height	+00005
FPAP Latitude	300025.8600N
FPAP Longitude	0951949.0300W
Threshold Crossing Height	00059.0
TCH Units Selector (Meters or Feet)	F
Glide Path Angle (GPA)	03.00
Course width at Threshold	106.75
Length Offset	00008
CRC Remainder	0AB8904E

Figure 2. Example of FAS Data Block Information

AIRBORNE FLIGHT INSPECTION

The FAA flight inspection aircraft is normally crewed by two pilots and one mission specialist. The pilot's workload begins with validating the data associated with the flight procedure and the

ARINC 424 coding that provides guidance into the precision final and missed approach guidance. The mission specialist is responsible for validating the GBAS FAS data block(s), confirmation of GBAS facility data, operation of the flight inspection system for collecting and documenting signal and data from the GBAS. Jointly, the crew will determine that all parameters of the flight procedure and GBAS meet prescribed tolerances.

Ideally, the inspection should begin with the flight inspection aircraft located at the airport with the GBAS facility. The flight inspection system can be powered while the aircraft is parked on the ramp and monitoring of the GBAS can begin. The GBAS ground system must be configured for the inspection. VDB power is set to the determined RF power setting. The GBAS position, velocity and time (PVT) mode is enabled for the flight inspection system to be able to receive data. If the VDB transmitter has dual channels, they can be checked at this time. The mission specialist can observe the flight inspection system for Very High Frequency Data Broadcast (VDB) signal strength, interference, lateral protection level (LPL), vertical protection level (VPL), FAS data block information in Message Type 4, and facility information in Message Type 2. The pilot can select each GBAS channel in the cockpit and determine if course guidance is available and RPI is correct for each approach. Observing VDB signal strength, Message Type 4, Message Type 2, and LPL/VPL values can give confidence to the inspector of proper flight inspection system and ground facility functions. Anomalies observed here can be resolved before the actual flight begins.

Flight Inspection Profiles

Coverage. The flight profiles may be flown in any order. However, the low altitude coverage orbit may reveal areas of signal strength weakness that may affect approach operations. For FAA flight inspection, the flight profile begins with VDB signal strength coverage and the low altitude coverage orbit at the determined operational range for approach operations. This range is normally about 23 nautical miles and flown at 2500 ft above the VDB antenna elevation. If VDB signal strength remains satisfactory in the low orbit, other coverage profiles should not be an issue. The low orbit allows the mission specialist time to monitor the GBAS Messages Type 2 and Type 4 for accuracy. Next profile is the level run in line with the runway from 20 nautical miles to the runway threshold and at 2500 feet above the VDB antenna. The level run may be continued to 20 nautical miles beyond the opposite end runway threshold if both runway ends are being evaluated for GNSS Landing System (GLS) approaches. If coverage for parallel runways is being evaluated, one flight, parallel and centered between the runways, may be adequate. Environmental issues between the runways must be evaluated before the single flight between the runways can be planned. The orbit and level run coverage profile is repeated at 10,000 feet above the VDB antenna. This completes the basic facility coverage profile.

The coverage profile for each approach to a runway is a series of five approaches. The profile begins at 20 nm from the runway threshold and ends at or abeam the threshold. Two approaches are flown offset from the glide path, one above and one below path. Two approaches are flown offset from the course centerline, one left of course and one right of course. Then one approach is flown on path and on centerline to the threshold.

Runway roll out coverage is completed by taxiing along the runway centerline from the threshold to opposite end threshold. Even though guidance is not required on the runway, this provides an initial assessment of environmental issues between the runway and the VDB site that may affect signal. This coverage data may be useful in considering future GBAS CAT II/ III operations to the runway.

Polarization. The VDB antenna radiates either a horizontally (GBAS/H) or elliptically (GBAS/E) polarized signal. This allows the data broadcast to be tailored to the operational requirements of the local airborne user community. The majority of aircraft will be equipped with a horizontally polarized VDB receive antenna, which can receive the VDB signal from either a horizontally or elliptically polarized VDB broadcast antenna. Aircraft equipped with a vertically polarized antenna will receive the vertical component of the elliptically polarized signal. Polarization is spot-checked once during the inspection and can be completed anywhere valid VDB signal is available. It is expected to see a slight drop in signal strength when switching the flight inspection aircraft antenna from the horizontal polarized antenna to the vertical polarized antenna during this check. FAA flight inspection completes this check during the low altitude orbit, where the signal strength is usually lowest.

FAS Data Block Validation. The FAS data block contains the parameters for defining a single precision approach. This includes the critical data elements that provide the course and glide path deviations to the pilot. These are parameters that the flight inspection system can measure.

The Landing Threshold Point (LTP) and Flight Path Alignment Point (FPAP) are stored in the FAS data block as latitude/ longitude coordinates. The bearing from the LTP to the FPAP defines the approach course. This course must match the runway bearing and final approach course.

The LTP ellipsoid height and the threshold crossing height are parameters that define the GNSS elevation that the glide path will terminate above the runway threshold. Corruption of this data from using different datum references or survey error will skew the glide path forward or aft along the inbound course. Errors can lead to the aircraft being below or above the designed glide path. Being below the path may provide inadequate obstacle clearance. Being above the glide path may cause the aircraft to have insufficient runway for stopping.

The glide path is a set angle in the FAS data block. Provided the angle value is correct in the FAS data block, glide path angle error appears to not be a flight inspection issue.

FLIGHT INSPECTION TOLERANCES

Figure 3.

Parameter	Tolerances
Terminal Area Path	(Reserved)
Airport Surface	(Reserved)
Initial/ Intermediate Approach Segment	FAA Order 8200.1, Chapters 6 and 13
Final Approach Segment	
Approach Reference Path Identifier (Morse Code)[1]	Exact Match
FAS Data CRC	Exact Match
Glide Path Angle	± 0.05°
Lateral Alignment	± 0.1° true course
Threshold Crossing Height	± 2m
Message Type 4 Alert Limits	
FAS Lateral Alert Limit	40 meters
FAS Vertical Alert Limit	10 meters **Note:** Values apply at 200' DA point to LTP/ FTP
Missed Approach Segment	FAA Order 8200.1, Chapters 6 and 13
Broadcast VDB Message	Required Message Types 2 and 4
Coverage VDB, minimum field strength, horizontal polarization	>-99 dBW/m^2 or >215 µV/m
Coverage VDB, minimum field strength, vertical polarization	>-103 dBW/m^2 or>136 µV/m
RF Interference	Interference must not cause out-of-tolerance condition or loss of GBAS data continuity.
Maximum Use Distance (D_{max})	As defined by GBAS Site

[1] The RPI may be verified visually or aurally (via Morse code), depending on the aircraft integration. Flight inspection aircraft will display the RPI for verification with the relevant approach chart.

CONCLUSION.

The flight inspection commissioning of a GBAS is relatively simple when compared to an ILS. The VDB coverage profiles are time consuming, but require much less flight time than commissioning ILS. Once the facility is configured for the inspection, the GBAS ground maintenance personnel requirement is minimal.

Flight time required to commission a GBAS with one approach, using the current FAA profiles, is about 1/3 the flight time required to commission a CAT I ILS.

RECOMMENDATIONS

A process of transferring FAS data block data electronically from the procedure developer to the GBAS and flight inspection is essential to prevent data corruption. The integrity of the precision FAS data block must be protected from procedure design to uploading into and broadcast by the GBAS. Human manipulation of the data leads to the probability of inducing errors. We recommend that a secure process be used by the procedure designer to make the FAS data block available in an electronic format. The electronic format would have to be compatible for entering directly into the GBAS facility and the flight inspection system. Continuity in this process of transferring data is essential.

The alignment analysis of the FAS data to the runway threshold is critical. This analysis is required to determine that the GBAS delivers the aircraft to the designed landing position. The flight path affects obstruction clearance and the landing performance of the aircraft. This analysis becomes extremely critical on runways of shorter lengths or runways that can become contaminated with water, snow, and ice. Aircraft stopping distances multiply significantly when landing on contaminated runways.

The flight inspection VDB coverage profile is based on RTCA/DO-245, Minimum Performance Standards for the Local Area Augmentation System flight coverage tests. A mathematical modeling on the performance of the VDB transmitter/ antenna characteristics for the particular site should have been completed before the flight inspection. The modeling should reveal potential problem areas. The flight inspection profiles encompass the approach coverage and the extended coverage area where positioning service is expected. After a mathematical modeling evaluation, some flight inspection coverage profiles may be unnecessary.

Use of the flight inspection aircraft is expensive and can be disruptive to an airport's normal traffic flow during the commissioning of a GBAS. Flight profiles against the normal flow of departing and landing traffic should be kept to a minimum. Consideration should be given to an engineering analysis of VDB coverage and eliminating unneeded coverage flight profiles. When anomalies in coverage are observed, additional flight profiles may be completed to document issues in the coverage. Coverage issues in areas not affecting a flight procedure should not be cause for a facility restriction.

FUTURE WORK

GBAS implementation is included in the FAA Next Generation Plan. If implemented, airports at Chicago and Atlanta are expected to be the first locations for future GBAS installations.

One privately owned GBAS facility is installed and will be ready for a flight inspection in August 2012. FAA will provide the commissioning and periodic inspections for this facility. An additional privately owned facility is planned for installation in 2013. Both facilities are expected to have public approaches.

ACKNOWLEDGMENTS

Mike DiBenedetto, Ph.D., Avionics Engineering Center, Ohio University

John Warburton, Manager, FAA Navigation Branch, Atlantic City, New Jersey

Mark Perraut, Mission Specialist-Flight Inspection Policy, Oklahoma City, Oklahoma

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[1] ICAO Doc 8071, Manual on Testing of Radio Navigation Aids, Volume II, Testing of Satellite-based Radio Navigation Systems.

[2] FAA Order 8200.1, United States Standard Flight Inspection Manual

[3] RTCA/DO-245, Minimum Performance Standards for the Local Area Augmentation System

[4] RTCA/DO-246, GNSS-Based Precision Approach Local Area Augmentation System (LAAS) Signal-in-Space Interface Control Document

Experiences in Flight Inspecting Ground and Space Based Augmentation Systems (GBAS/SBAS)

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Abstract

Future expansions of capacity at the main flight hubs are dependent on new navigation solutions. The existing techniques are exhausted due to geographic restraints or through separation minima required by conventional ILS.

Ground and space based augmentation systems (GBAS resp. SBAS) are one of those navigation systems, which shall support the global traffic solving these conflicts. Nearly all multimode receivers installed in new cockpits of the commercial air transport have the capability to perform GBAS and/or SBAS approaches. Those navigation devices are certified and the standards are set. The ground segment for GBAS and the space segment for SBAS are still in their infancy. Just a few ground stations respectively satellites are operational and certified for commercial air transport. Those systems have already been flight inspected with flight inspection systems providing GBAS and SBAS capability to show that the systems fulfill their dedicated specification.

This paper summarizes results, experiences and common practices regarding the flight inspection of GBAS and SBAS. Several flight inspection tasks are presented, explained and analyzed. Procedures and necessary hardware are examined and evaluated. Overall the paper identifies and explores the upcoming necessity to upgrade current flight inspection systems with the capability to perform GBAS and SBAS measurements

Introduction

GBAS flight inspection tasks have been performed in the past on several airports on which different GBAS ground station were installed. Recently several flight inspection missions on the GBAS test station owned by the German national research center for aeronautics and space at the research airport in Braunschweig, Germany have been accomplished. The flight inspection tasks were either flown on certified ground stations or at test sites. In Germany one GBAS ground station at Bremen airport has been commissioned and is fully operational since this year.

SBAS in regard to flight inspection has two main topics to analyze. On the one hand is the verification respectively inspection of the transmitted correction data of the SBAS satellite. On the other hand the SBAS corrected GPS position can be compared to the reference position of the flight inspection system for accuracy. In the flight inspection community SBAS is still a new topic and further rules and regulations in regard to flight inspection needs to be considered and defined.

This paper evaluates the latest trials and flight inspection tasks, displays their highlights and summarizes their findings. These flight inspection missions were performed on research bases and airports with a flight inspection aircraft equipped with the latest and state of the art flight inspection system. The requirements for flight inspection systems in the future for GBAS and SBAS calibrations and verifications are explained and explored. Examples from flight inspection systems, which are capable to perform those inspections, are shown.

Flight Inspecting GBAS stations

The latest flight inspection tasks were flown at the research airport in Braunschweig, Germany and at the commissioned GBAS station at Bremen airport, Germany. At Braunschweig, Germany a GBAS test station is installed and can be used temporarily and flight checked accordingly with a suitable flight inspection aircraft. At Bremen airport, Germany the commissioned GBAS approaches were flight checked. The aircraft was a Beechcraft King Air 350 equipped with an AeroFIS© state of the art flight inspection system.

Figure 1: AeroFIS© capable to perform GBAS flight inspection missions

The flight inspection system includes a special Rockwell Collins MMR GLNU-930FI which supports the use of the ILS and GBAS guidance systems. This equipment is connected via the ARINC429 interface and certain discrete connections to the flight inspection computer. The latest windows based flight inspection software enables the operator to record and re-process the gathered online evaluated data from the GBAS and automatically delivers ILS look-a-like reports and graphics including limits and tolerances.

The aircraft is equipped with an additional VOR / LOC-antenna. It is also possible via a suitable connection method to share an existing VOR / LOC antenna, if there is no space for an additional antenna. With this additional or shared antenna it is possible to receive the VDB data of a GBAS ground station. An unshared antenna has the advantage to reduce the loss for the standard ILS antenna. Furthermore the aircraft is equipped with Aerodata information display on which the pilot is informed about the flight inspection track and flight inspection procedure as a standard flight inspection aircraft has no primary GBAS receiver. The system is coupled for flight inspection mission to the autopilot to assure highest accuracy during flight inspecting of GBAS.

Figure 2: Cockpit of Flight Inspection Aircraft highlighting the Cockpit information Display

Data evaluation

For data evaluation the flight inspection system evaluates by comparison with its high accurate reference position results as know from ILS flight inspection tasks. The reference position was determined by a hybrid position algorithm using PDGPS, INS, Baro etc. as sensors. The vertical and horizontal deviation error is calculated by the flight inspection system and displayed online with its tolerance lines (Figure 3).

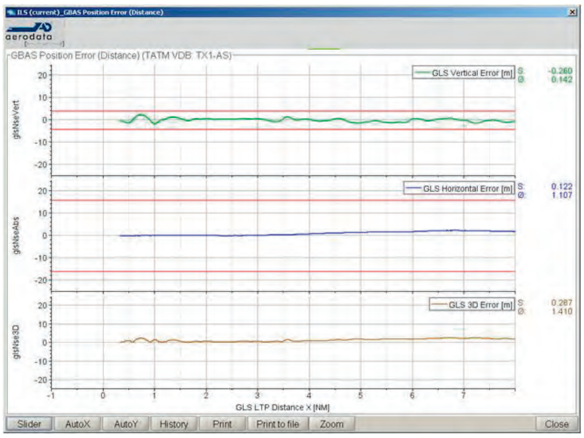


Figure 3: Deviation Error

The time constant of the GBAS receiver has to be evaluated thoroughly and implemented in the flight inspection system to achieve accurate results. In addition, if using ground stations in test mode, the correct mode of the GBAS receiver needs to be used. The evaluation of the antenna null sector is shown in Figure 4. This is one of the most critical issues in regard to the necessary required power density of the VDB signal.

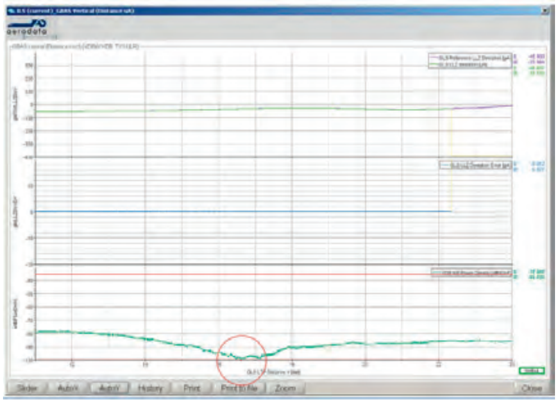


Figure 4: critical antenna null at app. 5,8° elevation

The signal strength measurements of the VDB signal are achieving an accuracy of approx. 1 dBW/m² during these presented missions with a calibrated GNLU receiver and a suitable spectrum analyzer.

Requirements of a Flight Inspection System for GBAS calibration

The flight inspection missions, the ICAO documentation and regulation and the experience from flight inspection systems already equipped with GBAS capability has constituted the requirements and recommendations for flight inspection mentioned in this paper.

From the inspections previously completed, it has been found necessary, that the flying pilot have a visualization of the GBAS signal. This is obtainable through a cockpit which is equipped with a modern multi mode receiver, which you will find in the avionic of nearly all new large aircraft. Unfortunately most flight inspection aircraft - also new ones - are equipped with neither such an avionic nor with such a multi mode receiver. Therefore either the avionic has to be upgraded or the flight inspection system has to be coupled to the cockpit displays to visualize the GBAS data. This can be achieved either through a separate display or through the EFIS itself interfaced to the flight inspection system. Otherwise the pilot is not able to follow the GBAS approach and to deliver the necessary impression of fly-ability. To obtain an accurate flight track and thus the desired positions for the measurement, a flight guidance on the EFIS or the separate display from the flight inspection system is recommended.

To assure the continuity of the GBAS signal the message types 1, 2, and 4 have to be decoded, analyzed, displayed, and recorded by the flight inspection system. The recording will prove the necessity of availability for the flight track during inspection. Interference of the VDB signal has to be investigated with a capable spectrum analyzer connected to a suitable antenna. This can be achieved with an automatic spectrum analyzer program, which displays and records the spectrum in parallel to the GBAS data. If interference is observed, this can be analyzed in detail during replay, or even in multiple replays from different approaches on this particular airfield. Therefore, it is very important that the GBAS data and the spectrum are recorded simultaneously in one common recording file. Otherwise an exact and detailed investigation in the office is difficult, due to the fact that the data has to be time synchronized.

The space segment of these approach techniques has to be checked during flight inspection as well. All satellites and their individual information especially their signal to noise ratio, has to be displayed and recorded to assure the mandatory availability. Interference from the ground should be examined with a downward looking GPS antenna or with another suitable antenna connected to the spectrum analyzer input. Airborne interference can be investigated with the GPS receiver in combination with the spectrum analyzer. The necessary synchronized recording of the GPS data and the spectrum data is applicable here as well.

Some effort has to be spent to confirm the correct coverage of the VDB signal according to the published tolerances. The field strength tolerances according to ICAO of 3dB are only achievable with a calibrated antenna and the compensation of the antenna characteristic by the flight inspection software.

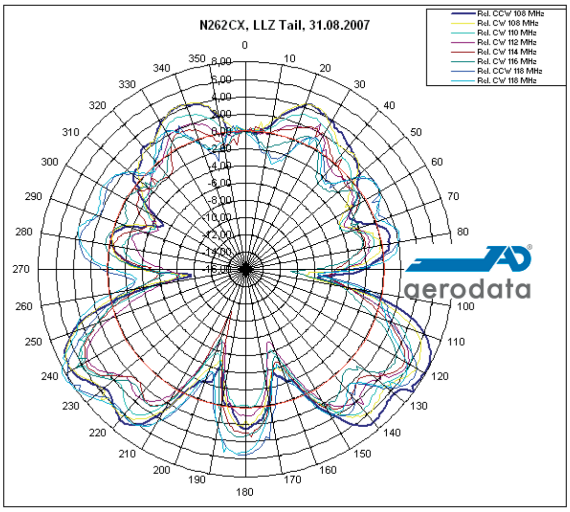


Figure 5: Antenna Pattern Correction

With a calibrated antenna system, a calibrated VDB receiver and a suitable spectrum analyzer accuracies up to 1 db W/m² is achievable. Therefore a connection of the spectrum analyzer to the GBAS antenna and the accurate measurement of the internal signal loss are recommended.

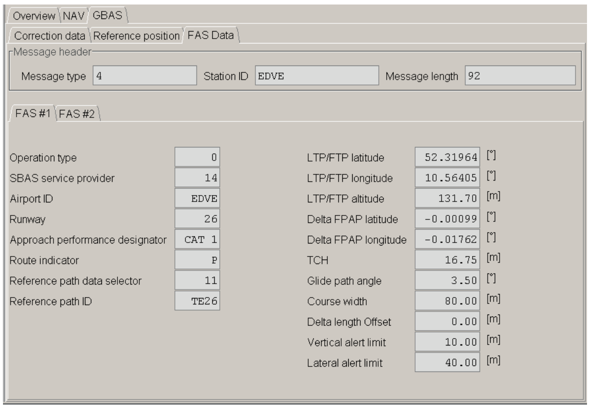
The flight inspection system of course has to be equipped with a GBAS device to receive and decode the message types of the GBAS data. The receiver has to be tuned to the appropriate function on the dedicated frequency of the ground station.

Examples of GBAS Flight Inspection Systems

The Rockwell Collins MMR GNLU-930FI has been flying in the new flight inspection systems since a couple of years. A special software version has to be implemented by the manufacturer in the GNLU-930FI which provides additional useful AGC information and other necessary information.

Figure 6: Rockwell Collins GNLU 930

A few systems have been equipped with the necessary GBAS hard- and software as mentioned above for a couple of years. A screenshot of the GBAS capable AeroFIS© software is shown below. Exemplarily, the alphanumeric page of the decoded message type 4 (FAS) is displayed.



Message type 4
Station ID EDVE
Message length 92

Operation type	0	LTP/FTP latitude	52.31964	[°]
SBAS service provider	14	LTP/FTP longitude	10.56405	[°]
Airport ID	EDVE	LTP/FTP altitude	131.70	[m]
Runway	26	Delta FPAP latitude	-0.00099	[°]
Approach performance designator	CAT 1	Delta FPAP longitude	-0.01762	[°]
Route indicator	P	TCH	16.75	[m]
Reference path data selector	11	Glide path angle	3.50	[°]
Reference path ID	TE26	Course width	80.00	[m]
		Delta length Offset	0.00	[m]
		Vertical alert limit	10.00	[m]
		Lateral alert limit	40.00	[m]

Figure 7: FAS Data Viewer in AeroFIS©

The calibration of GBAS ground stations with an AeroFIS© equipped aircraft is feasible and performable without additional enhancements.

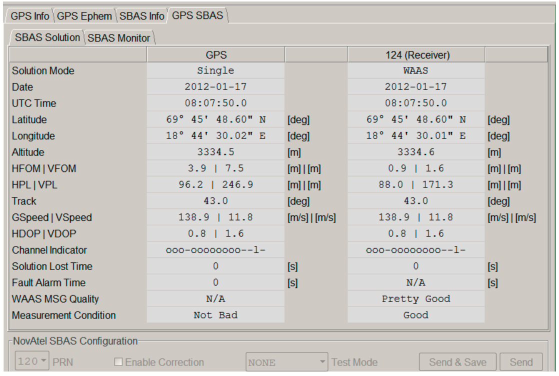
Flight Inspection and SBAS

This paper focuses on the verification and inspection of the SBAS corrected position and compares this position to the reference position of the flight inspection system. The replacement of single GPS by SBAS corrected GPS as the reference position in not examined here.

SBAS is a space based service offered for certain areas by some governments and countries. The abbreviations for the SBAS services are EGNOS (Europe – European Geostationary Navigation Overlay System), WAAS (USA – Wide Area Augmentation System), MSAS (Japan – Multi-Functional Satellite Augmentation System) and GAGAN (India – Geosynchronous Augmented Navigation System). Some other services are under preparation in Russia and China.

New flight inspection systems are capable to perform the inspection of the SBAS corrected positions either to monitor the SBAS corrected position itself or to monitor the raw data of the SBAS satellite to evaluate these data. The common used SBAS receivers are either the primary used GPS receivers and MMRs or the capable flight inspection GPS receiver. In this paper the used SBAS receiver is a Novatel OEM4.

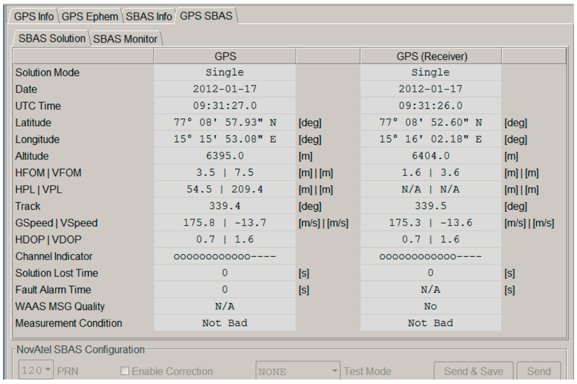
A screen shot of a capable flight inspection system comparing the single GPS position to the SBAS corrected position is shown in Figure 8.



	GPS		124 (Receiver)	
Solution Mode	Single		WAAS	
Date	2012-01-17		2012-01-17	
UTC Time	08:07:50.0		08:07:50.0	
Latitude	69° 45' 48.60" N	[deg]	69° 45' 48.60" N	[deg]
Longitude	18° 44' 30.02" E	[deg]	18° 44' 30.01" E	[deg]
Altitude	3334.5	[m]	3334.6	[m]
HFOM | VFOM	3.9 | 7.5	[m] | [m]	0.9 | 1.6	[m] | [m]
HPL | VPL	96.2 | 246.9	[m] | [m]	88.0 | 171.3	[m] | [m]
Track	43.0	[deg]	43.0	[deg]
GSpeed | VSpeed	138.9 | 11.8	[m/s] | [m/s]	138.9 | 11.8	[m/s] | [m/s]
HDOP | VDOP	0.8 | 1.6		0.8 | 1.6	
Channel Indicator	ooo-oooooooo--1-		ooo-oooooooo--1-	
Solution Lost Time	0	[s]	0	[s]
Fault Alarm Time	0	[s]	N/A	[s]
WAAS MSG Quality	N/A		Pretty Good	
Measurement Condition	Not Bad		Good	

Figure 8: SBAS Position in AeroFIS©

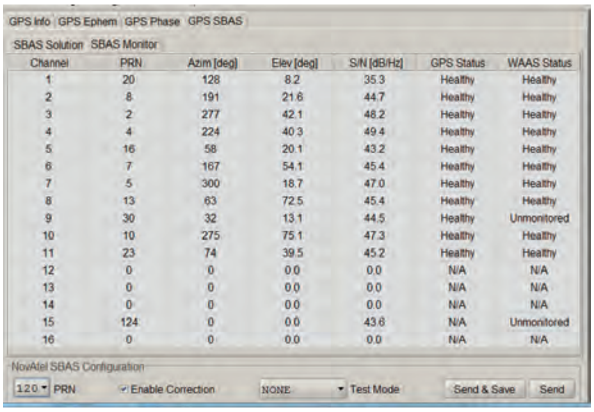
Beside the position accuracy the coverage of the SBAS satellite signal is important. Especially further up to the north coverage outages are expected. An example is displayed in Figure 9.



	GPS		GPS (Receiver)	
Solution Mode	Single		Single	
Date	2012-01-17		2012-01-17	
UTC Time	09:31:27.0		09:31:26.0	
Latitude	77° 08' 57.93" N	[deg]	77° 08' 52.60" N	[deg]
Longitude	15° 15' 53.08" E	[deg]	15° 16' 02.18" E	[deg]
Altitude	6395.0	[m]	6404.0	[m]
HFOM | VFOM	3.5 | 7.5	[m] | [m]	1.6 | 3.6	[m] | [m]
HPL | VPL	54.5 | 209.4	[m] | [m]	N/A | N/A	[m] | [m]
Track	339.4	[deg]	339.5	[deg]
GSpeed | VSpeed	175.8 | -13.7	[m/s] | [m/s]	175.3 | -13.6	[m/s] | [m/s]
HDOP | VDOP	0.7 | 1.6		0.7 | 1.6	
Channel Indicator	oooooooooooo----		oooooooooooo----	
Solution Lost Time	0	[s]	0	[s]
Fault Alarm Time	0	[s]	N/A	[s]
WAAS MSG Quality	N/A		No	
Measurement Condition	Not Bad		Not Bad	

Figure 9: Loss of Coverage of SBAS Satellite

The monitor for the satellite constellation (Figure 10) can be observed during all flight inspection tasks.



Channel	PRN	Azim [deg]	Elev [deg]	S/N [dB/Hz]	GPS Status	WAAS Status
1	20	128	8.2	35.3	Healthy	Healthy
2	8	191	21.6	44.7	Healthy	Healthy
3	2	277	42.1	48.2	Healthy	Healthy
4	4	224	40.3	49.4	Healthy	Healthy
5	16	58	20.1	43.2	Healthy	Healthy
6	7	167	54.1	45.4	Healthy	Healthy
7	5	300	18.7	47.0	Healthy	Healthy
8	13	63	72.5	45.4	Healthy	Healthy
9	30	32	13.1	44.5	Healthy	Unmonitored
10	10	275	75.1	47.3	Healthy	Healthy
11	23	74	39.5	45.2	Healthy	Healthy
12	0	0	0.0	0.0	N/A	N/A
13	0	0	0.0	0.0	N/A	N/A
14	0	0	0.0	0.0	N/A	N/A
15	124	0	0.0	43.6	N/A	Unmonitored
16	0	0	0.0	0.0	N/A	N/A

NovAtel SBAS Configuration

120 PRN ☑ Enable Correction NONE Test Mode

Figure 10: Example of adjustable Monitor page

The automated monitoring during general flight inspection ensures the verification of no outages in the dedicated area. This is also applicable for the coverage of the satellite signal. Figure 11 is showing the vertical performance of the SBAS solution.

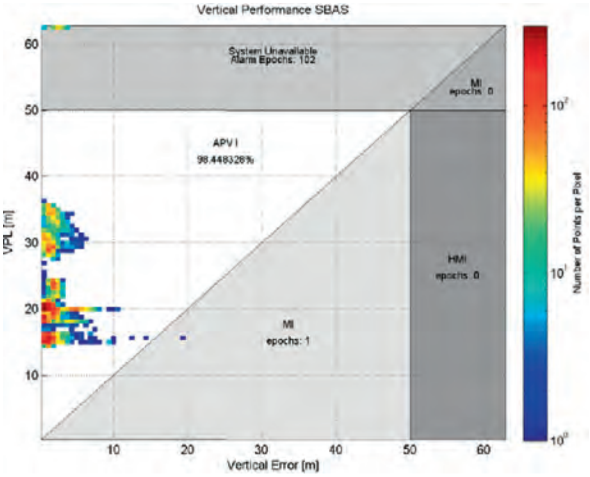


Figure 11: Vertical SBAS Performance

It displays the vertical error in regard to the announced vertical protection limit. For the displayed solution a Novatel OEM4 was used. Nearly no misleading information was recorded.

Conclusions GBAS Flight Inspection

New flight inspection systems are well suitable to perform ILS look-a-like flight inspection at GBAS ground stations up to CAT I. The reports and graphics are comparable to such known from ILS flight inspection tasks. The measurements and their accuracies are on all tasks according to their requirements.

Flight inspection aircrafts performing GBAS inspections needs to be equipped with flight inspection systems including the listed implemented enhancements:

- GBAS receiver
- GBAS flight guidance in the cockpit by primary equipment or from the flight inspection system
- Suitable spectrum analyzer for GPS and VDB
- Calibrated VDB antenna system.
- A software capable of time compensation with correct delay values.

These mandatory main aspects have to be controlled and managed by a capable software, which has to be very sensitive regarding the parallel recording of these necessary signal data. The most critical issue to achieve for new installations of GBAS facilities is the sufficient signal strength at high level at the antenna null.

Conclusions SBAS Flight Inspection

Flight inspection is a useful tool to evaluate the accuracy of the SBAS corrected GPS signal. On equipped flight inspection tasks the SBAS signal can be monitored and crosschecked regarding integrity and accuracy.

The results show that the accuracy of the SBAS corrected position is of course much better than those provided by single GPS. The SBAS signal is sensitive in regards to coverage north of approx. 75 degree north latitude.

In general the SBAS signal can also be evaluated on ground in regards of accuracy and integrity.

The main issue only experienced in the air is the coverage and outages in regard to unavailability of the GPS signal due to jamming or interference.

References

[1] ICAO Doc 8071, Vol. II - Manual on Testing of Radio Navigation Aids, Testing of Satellite-based Radio Navigation Systems, Fifth Edition, 2007

[2] Presentation “Experience with SBAS and GBAS Flight Inspection”, Markus Schwendener, Flight Calibration Services GmbH, Aerodata FIS Club 2011

Feedback on 2 years of APV SBAS Flight Inspection

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ABSTRACT

Since March, 2nd 2011, EGNOS has been available for Safety Of Life (SoL) Applications like LPV (APV SBAS) RNP APCH. French DSNA had anticipated the design of LPV RNP APCH already 1 year ahead.

We had presented in Beijing our concept of APV/SBAS flight Inspection. With a prototype of our new hardware and software for our Flight Inspection System, we flight inspected 5 LPV procedures in 2010. With now an operational capability of LPV RNP APCH on our SAGEM CARNAC Flight Inspection System, we commissioned 25 procedures in 2011 and 20 are planned in 2012, among which, 2 LPVs with offsets.

The presentation will describe:

- Briefly the French concept of LPV design
- the SAGEM CARNAC FIS enhancement,
- the pilots and flight inspectors training,
- the results and feedback after two years of operation and about 40 LPV flight inspected.

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INTRODUCTION

Following 2007 ICAO recommendation for the implementation of approach procedures with vertical guidance (APV) (Baro VNAV and/or SBAS) for all instrument runway ends, either as the primary approach or as a back-up for precision approaches by 2016, the French ANSP, DSNA, has decided to develop and implement primarily APV SBAS (LPV minima) procedures to all runway ends, and in a less extent Baro VNAV (LNAV VNAV minima), on the same chart. To implement the LPV development strategy, France initiated the training of procedures designers and created an implementation working group focusing on APV SBAS as soon as 2005, thus early before EGNOS was declared available for SoL (Safety of Life) applications, which happened on March, 2nd 2011.

This strategy allowed for Pau LFBP airport LPV procedure to be published and available as soon as this D0 date. Five other procedures had already been designed and flight inspected in 2010, and 25 new LPV procedures were flown in 2011, in order to be published in 2012, while some 25 new ones should be designed and flown, leading to a total of 60 procedures published by the end of 2012. These figures show the progressive ramp up of the activity and the paper will present the steps followed by DSNA flight inspection service so that the flight inspection of these procedures becomes a routine task of the annual program.

SETTING UP THE PROCESS

France started to publish non precision RNAV approach procedures (LNAV) as soon as 2004. The French regulation [1] applicable until 2011, tasked flight inspection to fly the procedure only to check for absence of interference on the GPS band along the procedure, other validation aspects being dealt with within the procedure design quality process. Therefore, DSNA spent no money to get the procedure coded by commercial datahouses for the aircraft FMS, all the more that, up to now, all the procedures subject to FI were "standard" RNAV approach procedures with

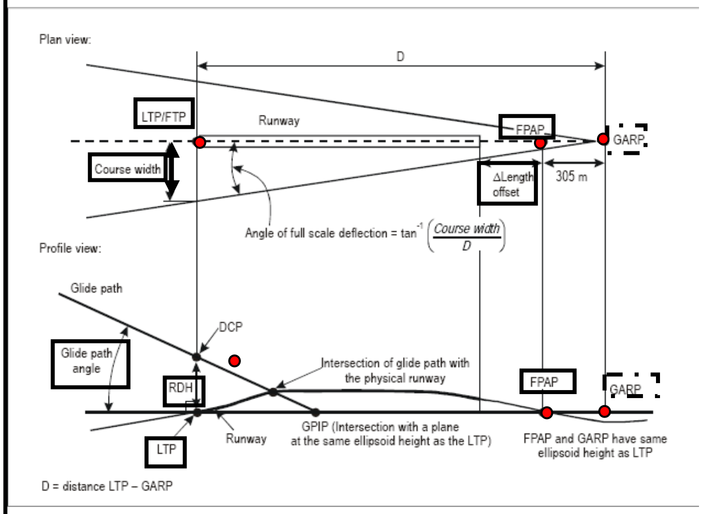
simple path and terminator ARINC codings (only TF (Track to Fix), DF (Direct to Fix) or CF (Course to Fix)).
Before departure, the pilots simply manually enter the WayPoints of the procedures as users WP in their FMS, and elaborate a flight plan with those. Once in flight, the aircraft follows more or less accurately the defined path (with fixed XTK limit of 1NM), meanwhile the AiRFINDeR© tool is used for the task to monitor the spectrum around GPS L1 frequency (tool developed initially by DSNA DTI and further commercialized by CGX AeroInsys).

While the French regulation does not require for it, flight inspectors (engineers operating the FI console) make sure before going to actual flight inspection, that the procedure is correct regarding WP coordinates, legs distances and bearings, and resulting procedure path. This pre-flight validation is performed using the capabilities of the FI Software used by DSNA/DTI (SAGEM CARNAC© SW) which allows defining the procedures as a sequence of WP, computes distances and bearings between the entered WP, and errors comparing charted distances/bearings and computed ones. Once in flight, it allows to record the path following, XTK, distances and bearing to next WP, DOPs, number of satellites and SNR of each GPS satellite.

The participation of some of our flight inspection experts to the APV SBAS Implementation Working Group since its beginning (2005), has allowed our entity to make up its understanding of LPV procedures concept, smoothly over the years, building up the skeleton for a method for inspection. In the mean time, all the DSNA actors involved in the development of these procedures were developing their knowledge and skills on the subject.

Very quickly it became clear that the piece of data that contains the definition of the final approach flight path to the runway, the FASB or Final Approach Segment Data Block, was a critical element of the LPV, since .it contains fields that code directly for the final approach alignment among which:

- Landing Threshold Point (LTP) coordinates
- Glide Path Angle (GPA)
- Final Path Alignment Point (FPAP) coordinates
- Threshold Crossing Height (TCH)



FAS Datablock

Operation Type: 0
SBAS Provider: 1
Airport Identifier: LFLC
Runway: 26
Runway Direction: 0
Approach Performance Designator: 0
Route Indicator: Z
Reference Path Data Selector: 0
Reference Path Identifier: E26A

LTP/FTP Latitude: 454718.3180N
LTP/FTP Longitude: 0031114.4540E
LTP/FTP Height (meters): 372.3

FPAP Latitude: 454705.1260N
Delta FPAP Latitude (seconds): -13.192
FPAP Longitude: 0030900.4790E
Delta FPAP Longitude (seconds): -133.975

Threshold Crossing Height: 15.00
TCH Units: 1

Glidepath Angle (degrees): 3.0

Course Width (meters): 105.00

Length Offset (meters): 48

HAL: 40.0

Figure 1: FASDB content

Corrupted or incorrect data will skew lateral, vertical and along track alignment from the intended design.

In 2009, mandated by the APV SBAS working group, DSNA/DTI was requested to perform a flight inspection of the LPV procedure at Clermont-Ferrand airport, which was the study case retained for the elaboration of the generic LPV Safety File required by the European regulation. The safety case identified the FASDB as a critical piece of data, and identified FI of the FASDB of the procedure as a Risk Reduction Mean against occurrence of feared events. The validation of the FASDB as part of the FI of LPV procedure was then added to the French regulation on IFR procedure design that was reissued early 2012 [2].

To fulfil this requirement, all the documentation available at that time was reviewed, which was mainly ICAO doc 8071 vol II[3]. Doc 9906[4] appeared later on, providing guidance on the flight validation of the procedure and referring back to doc 8071 for FASDB validation.

Regarding FASDB, doc 8071[3] does not say much:

3.2.2- The SBAS Final Approach Segment (FAS) survey data accuracy must meet the requirements of Table II-3-2.(1m in horizontal, 0.25m in vertical).

New ICAO 9906(4] manual mentions:

For SBAS and GBAS FAS data, the LTP/FTP latitude and longitude, the LTP/FTP ellipsoid height and the FPAP latitude and longitude contribute directly to the final approach alignment and angle. Corrupted data may skew lateral, vertical, and along track alignment from the intended design. A direct assessment should be made of the LTP Latitude/Longitude, LTP Ellipsoid Height, and FPAP Latitude/Longitude coordinates used in the procedure design. This may be accomplished using a survey grade GNSS receiver on the runway threshold while making a comparison with the actual final approach segment data to be published. Another indirect method is to evaluate the following IFP characteristics as a means of validating the FAS data.

Horizontal Course Characteristics:

- *Misalignment type, linear or angular*
- *Measured angular alignment error in degrees (when applicable) and linear course error/offset at the physical runway threshold or decision altitude point.*

Vertical Path Characteristics:

- *Achieved/measured TCH/RDH*
- *Glide path angle*

The FI method and tools requirements (update of our FI software) were developed by DSNA/DTI FI entity as early as 2010, answering both of these requirements: verify LTP and FPAP coordinates on the ground, but using the aircraft and deliver flight inspection results (angles, TCH) in flight, all with the same software and installation.

METHOD FOR VALIDATING FASDB:

The LTP and FPAP coordinates accuracy verification is twofold:

Pre-flight validation:

The coordinates of the LTP and FPAP extracted from the delivered FASDB are compared with the ones the flight inspector can collect on the SIA (French AIS provider) “WGS84” survey data server. This server contains the surveyed coordinates for all remarkable locations related to a runway with an accuracy of better than 3cm (0.0001”). The coordinates entered in the FASDB by the designers are not directly taken from this database, but from the official AIP that feeds the designers tool (GeoTitan©), which are rounded values. The SIA survey database has been used by our entity for 14 years for ILS flight inspection using DGPS truth reference. For runways equipped with ILS, these coordinates have been used on many occasions and therefore more than validated by experience.

For the runways where no experience exists on the quality of the runway surveyed data, like most of the time where no ILS was previously installed, a simple rough check with Google Earth© can be envisaged to gain confidence before the flight. But of course, if the points seem misplaced on the Google Earth image, it shall not be a sufficient proof to declare the FASDB or survey server coordinates as incorrect!

The surveyed coordinates data collection is performed by the flight inspector, they are not part of the procedure package received from the designer, allowing for independent data verification, actually in three ways:

- the surveyed coordinates are extracted by the Flight inspector from the most precise database (the survey database)
- the flight inspector selects himself the points in the database among all the available ones (runway threshold, runway end, displaced thresholds….) and is not only just checking coordinates

- the tool used to compute length offset between the FPAP coordinates and the actual opposite threshold is totally independent from the one used by the designer (FI software against designer tool)

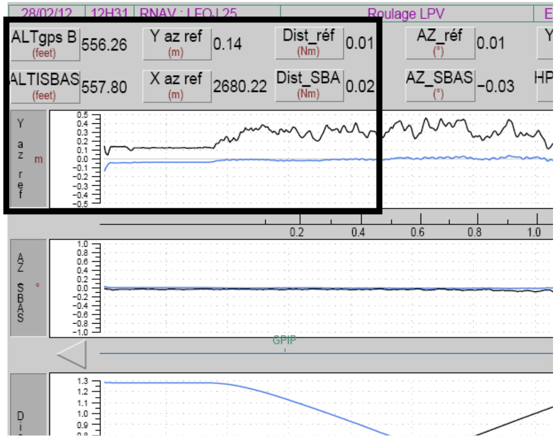
Of course, if the survey database is also in error (survey error or entry error), this ground verification will not permit to detect it, while Ground and flight inspection can

Flight inspection :

The surveyed coordinates must be checked by actual measurements on the runway: this is done the day of the flight inspection, with the FI aircraft, to avoid long lasting runway occupation time that would be required by a human reading a survey GNSS grade receiver on each sides of the runway. The onboard FI DGPS truth reference is used instead.

While pilots locate the FI aircraft as close as possible to the runway threshold (easier when the threshold is displaced), the inspector checks the WGS84 ellipsoid (ell.) height delivered by its FIS DGPS receiver that must be in ambiguity free position solution mode. By substracting the GPS antenna height above the ground to the value read, the “measured” ell. height above the threshold can be compared to the one of the surveyed database and thus to the LTP ell. height of the FASDB. A 1ft tolerance corresponding to the allowed doc 8071[3] 25cm, added to the approximation of the location of the aircraft above the threshold, has been chosen and appears to be reasonable with experience. To double this check, the ell. height delivered by the SBAS receiver is also compared to these ell. heights, this parameter being independent from any surveyed data, unlike the DGPS position. A 5ft tolerance is applied to the delivered ellipsoid height.

Then, in order to validate at the same time, LTP and FPAP lat/long coordinates, and the length offset value, the FI aircraft tracks back on the runway from the landing threshold till the opposite threshold, while the Flight inspector records the along track (X) and cross track (Y) displacement of the DGPS position in the local reference coordinates elaborated from the surveyed coordinates of the AIS server. If, while the pilots follow the central line, the cross track value (Y) stays within 0.5m tolerance, we estimate the lat/ long of the surveyed coordinates used for the flight inspection as reference, are precise enough and actually valuable surveyed data, and thus that LTP /FPAP coordinates which are compared to them, are within the correct tolerance of 1m hor. The along track X value is checked at the opposite threshold, to assess accuracy of the parameter “length offset”.


28/02/12 | 12H31 | RNAV : LFOJ 25 | Roulage LPV

ALTgps B (feet) 556.26
ALTISBAS (feet) 557.80
Y az ref (m) 0.14
X az ref (m) 2680.22
Dist_réf (Nm) 0.01
Dist_SBA (Nm) 0.02
AZ_réf (°) 0.01
AZ_SBAS (°) -0.03

Figure 2: Parameters verified during taxiing

Then, using the same FI installation, the FASDB can be verified in flight, just like it is done for ILS beams. The FI system delivers the requested misalignment errors and achieved TCH while the aircraft flies the final approach on path. To validate the complete FASDB content in flight, the Course Width parameter is checked during a dedicated measurement run, where the aircraft will fly perpendicular to the FAS alignment axis, in order to sweep the total range of the alignment sector.

TOOLS FOR VALIDATING FASDB

To integrate the capability for LPV FASDB inspection as described in the last paragraph, the DSNA/DTI FIS system based on SAGEM Carnac30© system had to evolve. A main driver for the change definition was to keep the same principle as for LNAV approach procedures: remain independent from FMS Navigation Database coding by commercial datahouses, so that the FASDB can be flown without paying for special Test Navigation Database.

The FASDB management and the elaboration of the ILS like deviations based on this data are then tasked to the FIS System. The FIS System shall then apply the DO229D MOPS [7] definitions to read the FASDB and elaborate the deviations from an SBAS receiver. A simple TSO C145 SBAS sensor delivering time, lat, long, alt, Horizontal Protection Level, Vertical Protection Level, number of satellites used and status of the SBAS solution, can be used for that purpose.

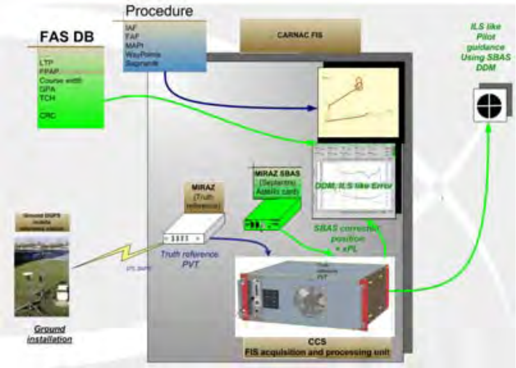


Figure 3: A solution for independent FASDB validation

The following capabilities were added to the Carnac software:

- Mission preparation:
    - import the FASDB file delivered in binary format, decode and display its fields in readable format and check for its redundancy CRC. (This binary format is described in ICAO Annex 10 [5]). Such a FASDB file can be obtained from the Eurocontrol ECACNAV "FASDB tool©" which is used by DSNA procedure designers to generate a FASDB in the appropriate coding.
    - Compare the delivered FASDB to the surveyed coordinates of the runway (manually entered by the flight inspector) and provide displacement values
- In flight computations:
    - Provide angular deviations elaborated from the FASDB and PVT solution of the SBAS receiver, these deviations are then sent to the cockpit FIS EFIS on the final approach path
    - Provide the equivalent ILS like deviations from the DGPS truth reference and the surveyed coordinates of the runway.
    - Compute glide path angle and misalignment errors in degrees, BFSL TCH, SBAS vertical and horizontal errors in meters.

All these recordings can be performed while the FI aircraft is flying the complete LPV procedure from the IAF to the end of the Missed approach, all other "RNAV" parameters remain computed on each segment.

The final version of the SW was delivered in July 2011, meanwhile the Adagio prototype developed internally and other macros were used to validate the FASDB. A beta version of Carnac was exercised during 4 months before the SW was declared operational.

Operation type	0	LTP/FTP lat.	45°47'18.3180"N
SBAS Service Provider	1 = EGNOS	LTP/FTP lon.	003°11'14.4540"E
Airport Id	LFLC	LTP/FTP height	372.30
Runway Number	26	FPAP delta lat.	-13.1920
Runway Letter	00 = none	FPAP delta lon.	-133.9750
Approach Performance	0	Threshold Crossing Height	15.00
Route Indicator	Z	Approach TCH units	1 = m
Ref. Path data selector	0	Glide Path Angle	3.00
Ref. Path identifier	E26A	Course width	105.00
HAL	40.0	Length offset	48
VAL	50.0		

FASDB CRC: CFB3FC4E
FASDB CRC Check: CFB3FC4E
File: LFLC26-CFB3FC4E-26022010.bin
date: 26/02/10

Please Insert your USB key

Figure 4: Carnac: FASDB display

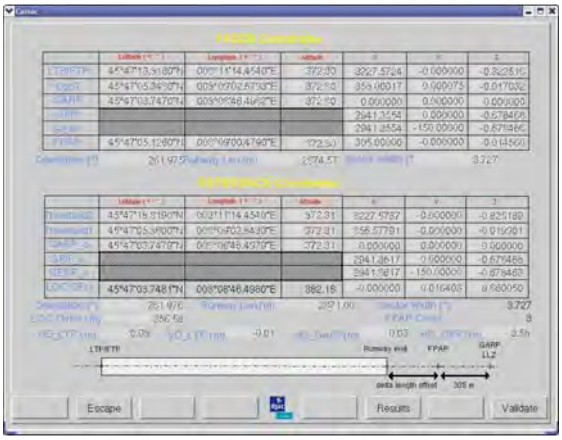


Figure 5: Carnac: automatic comparison of FASDB coordinates

During the Observation Period organized by ESSP before the official declaration of the SoL service, period where EGNOS was broadcasting a SiS without the Don't Use flag (from December 2010 to March 2nd 2011), the Pau LPV approach was then published, but prohibited by NOTAM. The opportunity was taken to perform flight trials with a Garmin GNS 430W receiver to compare with the FI LPV deviations, resulting in no particular differences.

This GNS430W has then been used several times in simulation conditions, particularly just after a new LPV procedure was actually published. A a GNSS constellation simulator was used to test the NAV database and the receiver behaviour on the procedure path. This helped back the APV SBAS WG to understand datahouses' difficulties in coding the intended procedure with the relevant data.

TRAINING

Both flight inspectors and pilots were trained.

Flight inspectors training

The first LPV procedures were inspected by these two RNAV experts from the FI unit who developed the methods and the tools requirements.

At the same time the tools got ready, the number of LPV procedures to be flown increased quite rapidly and necessitated the organization of training material and session for all the flight inspectors.
The training was elaborated internally by the RNAV experts and divided into 2 parts:

- a 3 days training course: generalities on LPV, extensive review of FASDB and its fields, practical exercises on Carnac SW for LPV FI, ARINC 424 coding

- practical application on the preparation and flight inspection on their 3 first RNAV GNSS with LPV mimima, under the supervision of the instructors.

The content of the training course is detailed in appendix.

Two sessions were organized in August and September 2011, all the flight inspectors had performed their 3 required LPV flight inspection by end of January 2012.

Pilots training

In DSNA organization, pilots are not the ones responsible for the FI. During conventional navaids FI they are – just - very talented aircraft manoeuvrers in plain safety. When RNAV procedures flight inspection started, their role has been enlarged to providing them the possibility to give their IFR pilot assessment on the flyability of the procedure regarding aircraft manoeuvres, and workload in the cockpit. In the new issue of the French regulation for IFP establishment issued early 2012[2] after ICAO 9906 manual [4] publication, the need for their flyability assessment has been officially recognized.

A one day session was organized to provide the pilots with the generalities on LPV as described above for the flight inspectors. The generic flight pattern for RNAV procedures with LPV and LNAV minima were also described. Some of them will now participate to the APV SBAS WG, so that they could provide their IFR pilots expertise and get the relevant information.

LESSONS LEARNT FROM THE 35 LPV FLIGHT INSPECTED UP TO NOW

The fact that LPV procedures design started in France well before EGNOS SoL service was declared in March 2011 was a real advantage for us (10 flown before): at each new procedure, this was an opportunity to confront the methods and tools we were developing and maturing, to many new different cases, especially regarding the FASDB validation.

Figure 6: France LPV publications prediction by end of 2012

As a central entity, while the designers belong to different regional entities, who do not share their experience on FASDB and LPV, we were in the position to detect "first time" errors of the newcomers to LPV design, to the extent that almost all procedures packages were detected with errors, either on the chart, or in the FASDB, and required several returns before declared "flight inspectable".

In the following sections, some of the findings detected either at pre-flight validation or flight inspection are provided as examples, but there are a few other traps that are not quoted hereafter.

Le Bourget LFPB27: This was one of the first LPV designed in France, and the first one for the Paris Region designer. While performing the mission preparation, the SW computes the sector equivalent to the Course Width, in degrees. The flight inspector knew that it was a particular ILS on that runway with a reduced sector (4.58°) to ensure triple parallel approaches on Paris Charles de Gaulle and Le Bourget airports. The FASDB was delivered with a standard 105m Course Width that gives a 5.57° sector, so larger than the ILS one, it had to be changed to come to this value.

The FASDB allows only for a range of 80m-143m for the CW parameter. The localizer being closer than 305m from the opposite threshold, the LPV GARP (name of the point equivalent to the localizer, refer to Figure 1: FASDB content) could not be collocated with the loc, but located at 305m from the opposite threshold.

To achieve equivalent Le Bourget 27 LPV and ILS sectors as seen from CDG runways, the CW was reduced to the lowest value: 80m, resulting in a 4.26° total sector. This sector was verified in flight using the FI system.

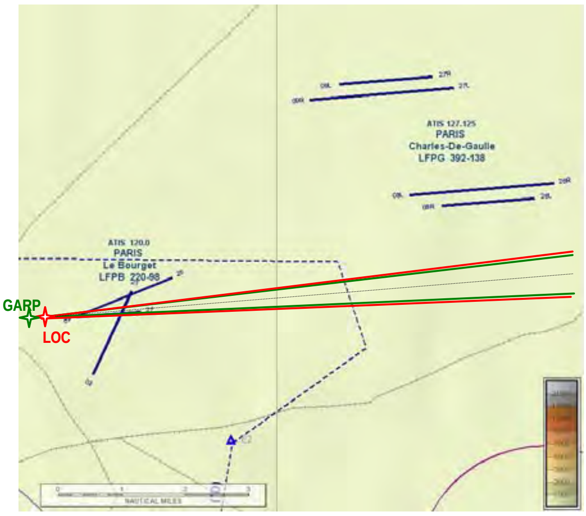


Figure 7: Le Bourget airport triple approach and LTP/ILS sector widths

<u>**Biarritz 27**</u>: too big CrossTrack error while taxiing.

The crosstrack displacement was higher than the tolerance value we had setup (upto 0.7m vs 0.5m max).

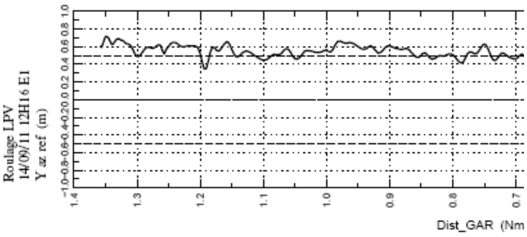


Figure 8: Biarritz – Cross track higher than the tolerance

The actual positioning of DGPS base receiver was checked, the run was performed several times while resetting the DGPS receiver, with no effect.

The flight inspector cancelled the take off to request to go and check himself the thresholds and central line markings: from his observation point, there was obviously a misalignment of the central line with the threshold mark: (at one threshold, the line appeared to be at the left from the runway axis, while on the other side, it looked still on the left). The flight inspection was however performed since the discrepancy remained in the 1m tolerance for surveyed data and the measured misalignment course was 0.01°, which is a very acceptable value.

Back to the office, the regional expert in charge of the aeronautical data was informed of the findings, and could obtain some other measurements made by the surveyor at the time of obstacles survey. New coordinates were obtained for the thresholds, which corrected slightly the taxiing measurements:

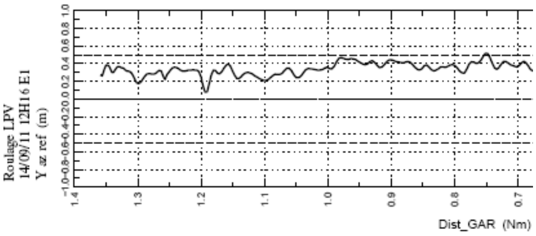


Figure 9: Biarritz: crosstrack measurement corrected after new sureveyed data received

The FASDB update was not requested however, since the coordinates remained in the 1m tolerance. A new survey and runway marking has been requested in the frame of the localizer replacement planned by end of 2012.

<u>**Bordeaux 23**</u>: detection of wrong FPAP coordinates thanks to the survey data coordinates. The FPAP was to be located 305m away from the Localizer towards the runway, the designers had taken the localizer coordinates from the French AIP, as it was mandatory. The survey coordinates and the AIP coordinates differed from 30m. The designer thought it was an issue in the survey server, since on Google Earth©'s the AIP coordinates pointed exactly to the localizer's antenna. It turned out that the localizer had been displaced 2 years before and that both AIP and Google Earth© images had not been updated since.

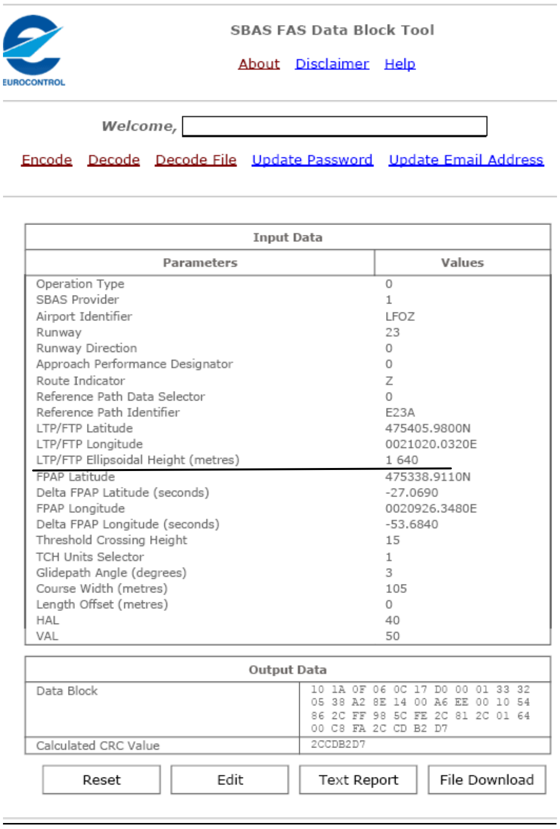
Figure 10: GoogleEarth as a false friend

Pontoise: a “first” LPV. The designer had taken ICAO PANS-OPS [6] as guidance to enter its FAS Datablock findings into Eurocontrol FASDB tool.

PANS-OPS[6] describes the LTP ell. height parameter as it is actually coded in binary, eg multiplied by ten:

LTP/FTP height relative to the ellipsoid (HAE). The height expressed in metres referenced to the WGS-84 ellipsoid. The first character is a + or – sign and the resolution value is in tenths of metres with the decimal point suppressed.
Example: +00356 (+35.6 m), -00051(–5.1 m), +01566 (+156.6 m), –00022 (–2.2 m)

But in the Eurocontrol SBAS FAS DataBlock tool, the true value must be entered (not multiplied by ten), the tool will code it internally while transforming in bin file format.



Input Data	
Parameters	**Values**
Operation Type	0
SBAS Provider	1
Airport Identifier	LFOZ
Runway	23
Runway Direction	0
Approach Performance Designator	0
Route Indicator	Z
Reference Path Data Selector	0
Reference Path Identifier	E23A
LTP/FTP Latitude	475405.9800N
LTP/FTP Longitude	0021020.0320E
LTP/FTP Ellipsoidal Height (metres)	1 640
FPAP Latitude	475338.9110N
Delta FPAP Latitude (seconds)	-27.0690
FPAP Longitude	0020926.3480E
Delta FPAP Longitude (seconds)	-53.6840
Threshold Crossing Height	15
TCH Units Selector	1
Glidepath Angle (degrees)	3
Course Width (metres)	105
Length Offset (metres)	0
HAL	40
VAL	50

Output Data	
Data Block	10 1A 0F 06 0C 17 D0 00 01 33 32 05 38 A2 8E 14 00 A6 EE 00 10 54 86 2C FF 98 5C FE 2C 81 2C 01 64 00 C8 FA 2C CD B2 D7
Calculated CRC Value	2CCDB2D7

Figure 11: LTP ell. height on Eurocontrol FASDB tool (c)

The altitude, being 10 times the correct one, if not detected, was leading to a completely wrong approach plan.

CONCLUSIONS

DSNA strategy for LPV development is a very challenging ambition for all the actors concerned by the procedures design process.

Among these, DSNA/DTI Flight Inspection Unit was involved very early in that strategy implementation, and could therefore smoothly define the methods and tools for the flight inspection required as part of the French regulation [2].

These past two years have permitted to start with confronting these methods and tools with the delivered LPV procedures and refine them gradually. There are certainly still outcomes to discover.

FUTURE WORK

Enlarge the method and tools capabilities for Offset LPV.

REFERENCES

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[2] Ministère De L’écologie, Du Développement Durable, Des Transports Et Du Logement, April 2012, Arrêté du 16 mars 2012 relatif à la conception et à l’établissement des procédures de vol aux instruments

[3] ICAO, 2007, Doc 8071, Manual on Testing Radio Navigation Aids, Volume 2, Testing of Satellite Based Radio Navigation Systems, http://www.icao.int

[4] ICAO, 2010, Doc 9906-AN/472, The Quality Assurance Manual For Flight Procedure Design, volume 5 – Flight validation of instrument flight procedures, unedited advanced version, http://www.icao.int

[5] ICAO, July 2006, International Standards and Recommended Practices, Annex 10 to the Convention on International Civil Aviation, Volume 1, Radio Navigation Aids, 5th Edition, http://www.icao.int

[6] ICAO, 2006, Doc 8168 OPS 611, Procedure for Air Navigation Services, Volume 2, Construction of Visual and Instruments Flight Procedures, 5th Edition, http://www.icao.int

[7] RTCA, December 2006, RTCA DO229D, Minimum Operational Performance Standards for GPS/WAAS Airborne Equipment, http://www.rtca.org

APPENDIX 1

DSNA Flight inspectors LPV training course

- 1 day dedicated to generalities on LPV:
  - 1 session describing the PBN context, with the different APV types, the DSNA strategy and the description of the LPV concept and its impact onboard the aircraft, at ATC level and designers' level. (by APV SBAS WG leader)
  - 1 session dedicated to the description of SBAS systems and Signal in Space.
  - 1 session dedicated to reference and applicable documents to LPV Flight inspection/validation (ICAO level, resp. France level).
- 2nd day dedicated to the FASDB and its verification and flight inspection:
  - Detailed review of each field of the FASDB: crossed checks for consistency to be made with the delivered charts, construction of the FASDB and FPAP/length offset determination
  - Review of the flight pattern of runs to be made with the aircraft to validate an LPV (taxi, approach, perpendicular crossing): what to check, how to check
  - Practical class on how to use the FI SW to perform the pre flight verification and the flight inspection (Sagem Carnac SW)
- 3rd day:
  - Practical class on how to use the CGX Ai-Sky-Data ARINC tool to verify proposed ARINC coding together with extensive review of ARINC 424 different path and terminators
  - Flight inspection report content

Necessities for Flight Inspecting ADS-B and MLAT Signals

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Abstract

The safety requirements arising due to expanding capacity in civil air traffic are generating several new surveillance techniques for commercial airplanes. ADS-B (Automatic Dependent Surveillance Broadcast) and MLAT (Multilateration) are such techniques. They are used in all new commercial air transport and most general aviation aircraft. This safety relevant signal regarding flight information for each individual aircraft is transmitted through different data links. The level of implementation of ADS-B and MLAT ground stations for area-wide coverage is steadily increasing.

What are the requirements to flight inspect such data derived from ADS-B or MLAT stations in accordance to its sensitivity for flight safety during surveillance? What kind of flight checks have to be performed to uphold the accuracy and integrity of this signal?

This paper summarizes experiences, practices and requirements regarding the flight inspection of ADS-B and MLAT systems. It evaluates the hard- and software requirements to flight inspect the ADS-B and MLAT service. Examples of flight inspection of existing ground stations using modern flight inspection systems with ADS-B and MLAT capability are presented and explained. By flight check it can be verified that the surveillance systems fulfill their dedicated specification. The corresponding procedures are examined in detail and evaluated in regard to accuracy and integrity.

Introduction

All modern commercial airplanes a equipped with capable transponders using the ADS-B transmission. In the past three different ADS-B techniques were followed, explored and analyzed in regard to its advantages and disadvantages.

One ADS-B technique is the transmission via a separate VHF data link, which requires special equipped VHF radios to fulfill the requirements according to MOPS ED108A. The second technique focuses on the dedicated Universal Access Transceiver (UAT) working in the 978 MHz band. Each aircraft has to be equipped with such unit which complies with RTCA DO 282B and TSO C154c. This technique is mainly used for the lower airspace in the United States. The third method for transmitting ADS-B signals is the extended squitter technique in the 1090 MHz Band. It complies with RTCA DO 260B and TSO C166b. The extended squitter method is suitable for the lower and upper airspace and used by all commercial airplanes.

MLAT is a well growing pinpointing technique to determine the position of an airborne aircraft in conjunction with ADS-B and Radar.

This paper focuses for ADS-B on the extended squitter method and describes in regard to MLAT the possibilities in flight inspection. It highlights the type of transmitted data and evaluates reason for flight checking such data. Examples from flight inspection systems, which are capable to perform such inspections, and their requirements are shown.

Requirements for ADS-B Flight Inspection

The general requirement to establish an ADS-B link is to have an airborne segment, which encodes and transmits the necessary data in a special format and a ground segment which receives the data and decodes it. The newest flight inspection systems, like the AeroFIS©, are equipped with state of the art transponders, which are capable to transmit the required data for the ground station. The ground stations are normally equipped with ADS-B receivers to display such data to the radar or ADS-B display operator.

Figure 1: AeroFIS© capable to perform ADS-B flight inspection missions

The flight inspection system included a Rockwell Collins TDR 94 latest revision supporting the transmission of elementary and enhanced surveillance and ADS-B messages. Therefore the aircraft is equipped with an additional L-Band antenna for the transponder transmission. Only the newest revision of this transponder complies with TSO C166b capable for the transmission of ADS-B.

Figure 2: Suitable ADS-B Transponder latest revision

To operate a non primary transponder on an airborne system special rules according to airworthiness standards have to be followed. The special and advance design of the certified aircraft installation has to make sure that not two targets are visible for the ATC controller. The airborne flight inspection transponder is fully controlled by the flight inspection operator, which enables him to submit via the data-link special test data. This assures proper decoding at the ground segment and/or allows the ground station to perform fully autonomous checks with such specialized data. The AFIS computer is connected to the transponder via a digital data link. The computer submits automatically the necessary dataset required by the transponder to transmit the desired and requested ADS-B data.

The flight inspection mission of a receiving ADS-B ground segment has to focus on three main tasks:

- Coverage Checks
- Interference Checks
- Data Continuity and Integrity Checks

The coverage checks are performed together or in accordance with the regular radar flight inspection missions. The data continuity and integrity has to be monitored at the ground segment continuously. The time stamped data recordings from the flight inspection system will be compared fully automatically to those recordings from the ground segment. The format of such data is customized and adaptable to the dedicated ground station. During commissioning customized special datasets can be transferred to ease the ground facility installation.

Data transmission

Nowadays a dataset with below listed information is able to be transmitted via the ADS-B link.

- Time
- Altitude
- Track Angle
- Ground Speed
- Position (including horizontal and vertical integrity limits with its accuracy)
- Vertical Velocity
- N/S and E/W Velocity
- Estimated Position Uncertainty
- Radio Height
- True Track Angle
- Selected Heading
- Magnetic Heading
- Wind Speed
- Wind Direction
- Inertial Vertical Speed
- Height above the Ellipsoid
- A/C Registry
- GPS Status

Not all aircrafts are capably to transmit the complete information. This is caused on the one hand due to missing sensors connected to the extended squitter transmitter or on the other hand due to an old standard of the transponder itself. Nowadays only a few of such transponder are fully certified according to TSO C166b, but of course also the availability of such units is growing.

An example picture for a visualization of such received ADS-B data at the ground station is shown in Figure 3. (The mode S code and the call sign is masked on this paper)

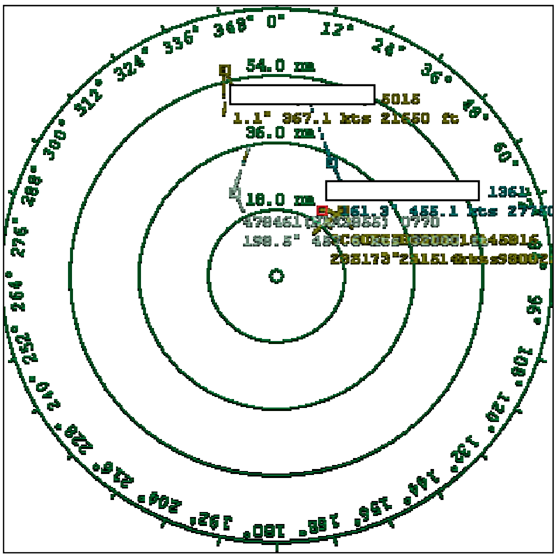
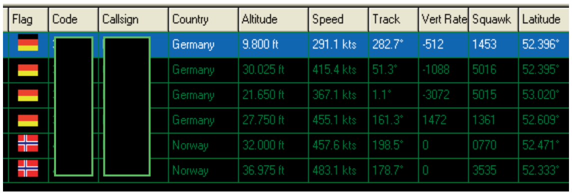


Figure 3: ADS-B information on a polar diagram received on ground

It is generated by a simple commercial of the shelf ADS-B receiver connected to a commercial of the shelf antenna and controlled by Windows based PC. The information of the ADS-B link is decoded on alpha pages and can be recorded for further data evaluation.



Flag	Code	Callsign	Country	Altitude	Speed	Track	Vert Rate	Squawk	Latitude
🇩🇪	[redacted]	[redacted]	Germany	9.800 ft	291.1 kts	282.7°	-512	1453	52.396°
🇩🇪	[redacted]	[redacted]	Germany	30.025 ft	415.4 kts	51.3°	-1088	5016	52.395°
🇩🇪	[redacted]	[redacted]	Germany	21.650 ft	367.1 kts	1.1°	-3072	5015	53.020°
🇩🇪	[redacted]	[redacted]	Germany	27.750 ft	455.1 kts	161.3°	1472	1361	52.609°
🇳🇴	[redacted]	[redacted]	Norway	32.000 ft	457.6 kts	198.5°	0	0770	52.471°
🇳🇴	[redacted]	[redacted]	Norway	36.975 ft	483.1 kts	178.7°	0	3535	52.333°

Figure 4: Alpha page of the ground receiver with ADS-B information

It is recognizable at this real data example that not all information is transmitted. This can be caused by reasons mentioned earlier in this paper or by intention from the aircraft operator.

Flight Inspection of ADS-B facilities

The main aspect for flight inspection nowadays of course is to fulfill the requirement of the stipulated and announced coverage. Interference in those regions of coverage has to be precluded. The full announced observed sector has to rely on the displayed ADS-B data. This is only manageable from the airborne segment. Interference is easily detected by advanced flight inspection systems and can be eliminated once traced. In addition modern flight inspection system can modify the data transferred to the ground station to assure correct decoding of the signal and to adjust settings during commissioning. An example to show the flight track on which the desired ADS-B check is monitored and recorded is shown in Figure 5. This graphic and its alphanumeric values are compared automatically to the graphics and recordings of the ground station.

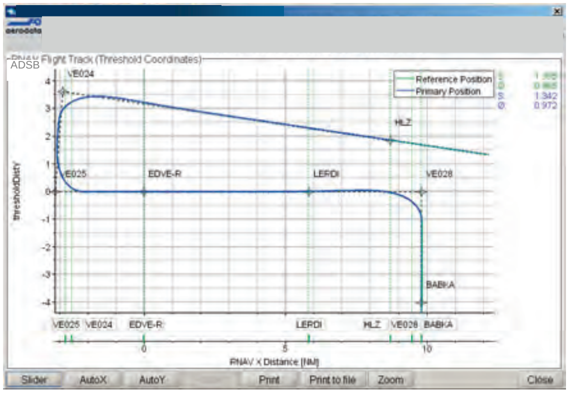
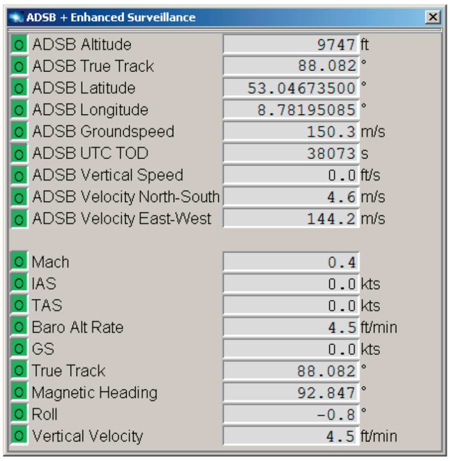


Figure 5: Flight track of flight inspection mission with monitored ADS-B information

An example of alpha pages modifiable by the flight inspection operator is shown in Figure 6. For testing purposes all values a can be set to a definable value.

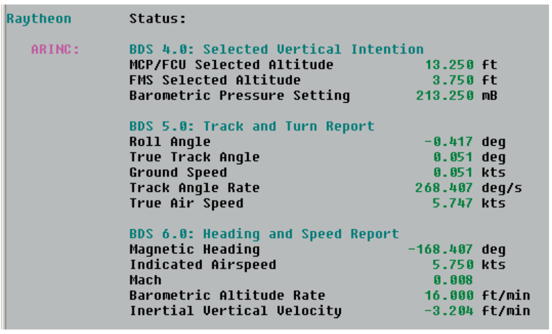


ADSB Altitude 9747 ft
ADSB True Track 88.082 °
ADSB Latitude 53.04673500 °
ADSB Longitude 8.78195085 °
ADSB Groundspeed 150.3 m/s
ADSB UTC TOD 38073 s
ADSB Vertical Speed 0.0 ft/s
ADSB Velocity North-South 4.6 m/s
ADSB Velocity East-West 144.2 m/s

Mach 0.4
IAS 0.0 kts
TAS 0.0 kts
Baro Alt Rate 4.5 ft/min
GS 0.0 kts
True Track 88.082 °
Magnetic Heading 92.847 °
Roll -0.8 °
Vertical Velocity 4.5 ft/min

Figure 6: Alpha page of flight inspection system with ADS-B information

The defined BDS codes as per definition in [1] could also be monitored or influenced (Figure 7).



```
Raytheon        Status:

   ARINC:       BDS 4.0: Selected Vertical Intention
                MCP/FCU Selected Altitude              13.250 ft
                FMS Selected Altitude                   3.750 ft
                Barometric Pressure Setting           213.250 mB

                BDS 5.0: Track and Turn Report
                Roll Angle                             -0.417 deg
                True Track Angle                        0.051 deg
                Ground Speed                            0.051 kts
                Track Angle Rate                      268.407 deg/s
                True Air Speed                          5.747 kts

                BDS 6.0: Heading and Speed Report
                Magnetic Heading                     -168.407 deg
                Indicated Airspeed                      5.750 kts
                Mach                                    0.008
                Barometric Altitude Rate               16.000 ft/min
                Inertial Vertical Velocity             -3.204 ft/min
```

Figure 7: ADS-B information as per BDS-Code

Of course such modified ADS-B transmission has to be communicated with ATC and has to follow such regulations of each country.

Flight Inspection and Multilateration

MLAT is often viewed as a fitting technological bridge between surveillance radar and ADS-B. Lots of different techniques can be summarized under this term. Several transmitters or interrogators can be used therefore.

- SSR Transponder (Mode A/C/S)
- VHF Com
- DME
- Theoretically any other airborne transmitter like RadAlt, Weather Radar etc.

The position is determined by synchronization and correlation of different measurements of the same signal as shown in Figure 8.

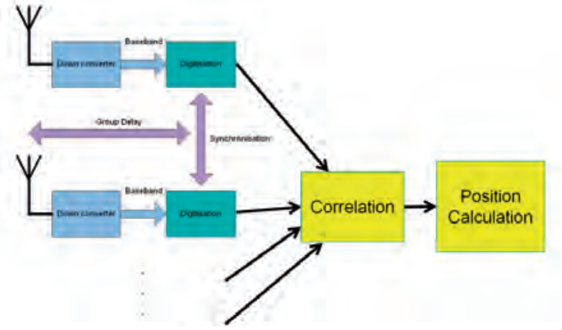


Figure 8: MLAT Position Determination

Data Evaluation and Benefits

During all flight inspection task the position data is collected and the comparison to the MLAT station can be performed. The coverage and the importance of no MLAT signal outages are tracked continuously in parallel. The Flight inspection system delivers its high accurate position due to its hybrid reference position calculation including PDGPS, INS, Baro etc. Commissioning of MLAT ground station is very similar to radar commissioning in respect to the position calculation and its comparison. The main focus is here to determine the coverage of the signal and due to the valid border.

The benefits of MLAT position determination can be summarized as follows:

- Ability to track and identify Mode A/C/S equipped aircraft at a high update rate.
- High interrogation capability and advanced target processing
- First developed for Ground Tracking of Aircraft without Ground Radar (Surface Movement Guidance)
- Identification of a single aircraft by unique address possible
  (Mode S, ADS-B and Mode C only)
- System work well also in mountainous terrain
- Time synchronization of receivers is one critical path

Conclusion

Taking into account the required and intended improvements for the surveillance of aircrafts in regard to air traffic control, and the growing capability of the ADS-B or MLAT links, it is found to be mandatory to flight inspect such ADS-B and MLAT receptions. If ATC has to rely on these data the coverage has to be maintained and interference in these stipulated areas has to be avoided or announced.

The development in future for this surveillance, situation awareness and information technique is not easily foreseeable yet, but its growing capacity in conjunction with possibilities for ATC improvement will definitely require flight inspection of these techniques in the future.

References

[1] ICAO Annex 10, Vol IV – Surveillance and Collision Avoidance Systems, Fourth Edition, 2007

ICAO Doc 9871 – Technical Provisions for Mode S Services and Extended Squitter, First Edition, 2008

ADS-B Flight Inspection

The view of French Flight Inspection Unit

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ABSTRACT

Automatic Dependent Surveillance – Broadcast (ADS-B) is a new surveillance technique by which aircraft automatically transmit and/or receive data such as identification, position and additional data, as appropriate, in a broadcast mode via a data link. ADS-B can support several air/ground and air/air applications. The most common one is the use of ADS-B to provide radar like services in low traffic density area. Several Air Navigation Service Providers (ANSPs) in the world have already decided to implement ADS-B in addition to or instead of radar system.

ICAO has addressed ADS-B aspects in several annexes, documents, circulars but none of them specifically consider flight inspection issue.

The proposed presentation will provide a description of the various flight inspections already performed by the French flight inspection unit on different French sites. Beyond the results that were obtained, the objective of this paper is to give rise to some new thinking on ADS-B flight inspection purposes.

INTRODUCTION

In 2005, DSNA, the French Air Navigation Service Provider took the decision to launch an ADS-B program in order to assess this new surveillance technique. This project took place in several steps, from experimentations up to operational implementation and in the frame of both national and international projects. After a reminder on the main technical characteristics of ADS-B, this technical paper will focus on the applicable regulations, on the DSNA experimental and operational projects. The main validation activities, and in particular flight inspection, will be described. As a conclusion, this paper will describe the flight inspection operations, recommended by DSNA, before any operational implementation..

DEFINITIONS AND TERMINOLOGY

ICAO Doc 4444 defines ADS-B as “A means by which aircraft, aerodrome vehicles and other objects can automatically transmit and/or receive data such as identification, position and additional data, as appropriate, in a broadcast mode via a data link”.

From this definition, two different concepts can be derived.

- A first one where aircraft are only able to transmit data. This requires a so called ADS-B out architecture on board. Combined with ground stations, such architecture allows to implementing air/ground applications.

- A second one where aircraft are both able to receive and transmit data. When several aircraft are fitted with this kind of architecture; air/air applications (also called ASAS applications) can be implemented. These applications do not necessarily require ADS-B ground station installation..

In addition, it is interesting to highlight two other capabilities that ADS-B ground stations may have:

- TIS-B (Traffic Information Service – Broadcast): capacity of the ground station to collect all surveillance data issued from surrounding surveillance sensors and to transmit it on the ADS-B data link.

- ADS-R (Automatic Dependent Surveillance – Retransmit): Capacity of the ground station to receive ADS-B transmitted through one data link and to retransmit it using another data link (such technique is mostly used by the FAA).

TECHNICAL ASPECTS

Airborne Aspects

Taking into account, current worldwide implementation, this technical paper mostly focuses on ADS-B out architecture based on mode-S, also called 1090ES, and air/ground applications that operationally use such ADS-B data.

A typical ADS-B out architecture is shown in the following figure:

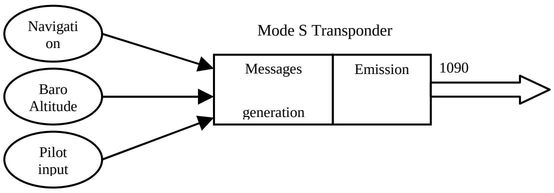

Figure 1: ADS-B out architecture

Onboard aircraft, this corresponds to:

- A mode S transponder
- A navigation system providing the following information:
  - Latitude/longitude
  - Quality indicator
  - Baro-altitude
  - Ground Speed
  - …

With the introduction of elementary and enhanced surveillance in Europe, most avionics manufacturers have implemented the ADS-B capability, also called 1090 Extended Squitter, in their new mode S transponder. Its principle is based on the short squitter (56 bit) defined by ICAO in the early 90, which is transmitted once every second for TCAS acquisition purpose. On the same basis, the following types of extended squitters (112bits) have been defined:

- Airborne position squitter which is sent once every 0.5s and also includes integrity figure.
- Airborne velocity squitter which is sent once every 0.5s and also includes vertical rate and GPS altitude.
- Ground position squitter which is sent once every 0.5s if the aircraft is moving, 5s otherwise.
- Flight identification squitter which is sent once every 5s (or 10s if aircraft is not moving) and contains flight identification as entered, by the crew, in the FMS.
- Emergency status squitter which is sent, if necessary, once every second.

Common point between all these various squitters is the aircraft mode S address.

From an airframe manufacturer perspective, and taking into account that no airworthiness standard was available, this ADS-B capability was:

1) Either inhibited through a pin program,
2) Or activated but not certified
3) Or, very rarely, activated and certified.

For information, case 2 was existing upon request of organisations such as Eurocontrol, FAA …in order both to perform several experimentations and to validate ADS-B concept. In addition to the fact that some airlines do not even know that their aircraft are emitting ADS-B data, case 2 has also led to a situation where some of these architectures transmit data which are erroneous and/or misleading. It is important to note that a large number of aircraft in Europe is equipped thanks to the elementary/enhanced mandate.

From an airworthiness point of view, the only standard existing in Europe is the AMC 20-24 “Certification considerations for the enhanced ATS in Non-Radar Areas using ADS-B Surveillance (ADS-B NRA) Application via 1090 MHz Extended Squitter”. It addresses the use of ADS-B in low density area in order to provide radar-like services such as reduction of separation minima. All aircraft from category 3) above are certified according to the requirements of this AMC.

It shall also be mentioned that the European Implementing Rule 8 for Surveillance requires every new aircraft, with MTOW >5.7t, to be ADS-B equipped and every flying aircraft, with MTOW >5.7t, to be equipped in 2017.

Ground Aspects

In order to implement air/ground applications, one or several ground stations will have to be installed taking into account the intended coverage. These ADS-B ground stations shall provide several functionalities:

- Receipt and decoding of the various squitters
- Time stamping

- Establishment of ASTERIX 21 outputs
- Transmission to ATC Center

Taking into account that none of the various 1090 extended squitters do contain any time stamp information, such function is therefore one of the most critical one performed by the ground station. In order to provide the above mentioned functions, the ground station shall include the following components:

- One or two receiving antennas according to the expected availability and integrity.
- A processing unit which shall perform the coding/decoding of the various squitters emitted by all the surrounding aircraft but also the time stamping based on a local GPS.
- One site monitor whose intent is to allow verification of correct ground station operation independent of environmental conditions. To achieve this, a fixed test message, containing the ground station position, is directly injected into the ADS-B antenna. A bad decoding of this message or an incorrect position will generate an error message.
- A GPS receiver which provides an absolute timing reference for the processing unit, but also a real time position of the GPS antenna used by the site monitor.
- A remote/local control and monitoring system in order to perform the configuration, the maintenance, the monitoring of the ground station. According to the manufacturer, such system may also include several tools allowing to replay the raw data or the Asterix 21 outputs, to perform the conversion …
- Optionally, an ADS-B test generator in order to perform ground validation.

Figure below shows one example of ADS-B ground station used by DSNA.

Figure 2: Example of ADS-B Ground Station

There is currently no ICAO standard describing the minimum specifications of an ADS-B ground station. However, EUROCAE has developed ED-129 “Technical Specification for a 1090 Mhz Extended Squitter ADS-B Ground Station” which is used by most manufacturers. This standard is currently revised by EUROCAE and RTCA to include the multi-lateration functionality.

ADS-B APPLICATIONS

As soon as the ADS-B concept was developed, a lot of applications were envisaged and were developed in documents such as DO-242, DO-242A, the “ADS-B MASPS”. Some of these applications were really promising. However, every new application was potentially requiring transmission of new parameters. Such situation was really penalising for transponder manufacturers; first because the extended squitters payload is quite reduced but also because specifications shall be frozen at one point of time. Eurocontrol, then, decided to define different sets of applications providing short term operational benefits and to derive ADS-B specifications for these applications. A so called Package 1 of applications was rapidly developed and was adopted by most of the aviation community: ICAO, FAA… but also the European Commission. In order to standardise the Package 1 applications, a combined Eurocontrol and FAA group was created: the Requirement Focus Group (RFG). EUROCAE and RTCA were also involved in order to release RFG deliverables. For information, airworthiness standards developed by EASA, such as AMC 20-24, are largely based on these RFG documents. Package 1, as originally defined, includes both Air/Ground and Air/Air, also called ASAS, applications.

Taking into account that no ASAS applications have already been implemented, that they do not necessarily require any ground station installation, this technical paper only focuses on the following Air/Ground applications:

- **Use of ADS-B in non radar area (ADS-B NRA)**: the main purpose is to provide enhanced Air Traffic Services in areas where radar surveillance currently does not exist. Typical environments are locations, where, due to the low traffic density, radar installation is not economically justifiable. It also includes areas where existing radar is to be de-commissioned and the replacement costs are not justified. The ADS-B-NRA application is designed to enhance Air Traffic Control Service and Flight Information Service such as separation minima but also Alerting Service. The introduction of ADS-B will provide enhancements to these services (compared to current capabilities) in a similar way as it would occur with the introduction of SSR radar. In particular, the Air Traffic Control Service will be enhanced by providing controllers with improved situational awareness of aircraft positions and the possibility of applying separation minima much smaller than what is presently used with current procedures. The Alerting Service will be enhanced by more accurate information on the latest position of aircraft. Furthermore, ADS-B is able to broadcast emergency status information which will be displayed to the controller independently from any radio communications.
- **Use of ADS-B in radar area (ADS-B RAD)**: This application supports, and in some cases enhances, Air Traffic Services through the addition of ADS-B surveillance, in areas where radar surveillance currently exists. It is designed to support the following ICAO Air Traffic Services (Area Control Service and Approach Control Service), Flight Information Service, Alerting Service and Air Traffic Advisory Service. The introduction of ADS-B may enhance these services by improving the overall quality of surveillance (i.e. radar + ADS-B such that an operational benefits may include a reduction in the applied separation standards from that applied in the considered environment, but not below the ICAO minima e.g. 10nm to 5nm.
- **Use of ADS-B on airport (ADS-B APT)**: The main purpose is to provide a new source of surveillance information for safer and more efficient ATC ground movements by aircraft and vehicles at controlled airports. The benefits of enhanced management of ATC airport surface surveillance are greatest in low visibility and darkness when the possibility to identify conflicts visually by ATC, flight crews and vehicle drivers is reduced. The application builds on the transmission of ADS-B position reports by aircraft and airport vehicles that operate in airport areas managed by ATC and the display of the information on an airport map at the controller working position (CWP). ADS-B information may be used to support a sole-means surveillance system or to enhance surveillance data from surface movement radar or a multi-lateration system.

Both ADS-B NRA and ADS-B RAD have now been addressed by RFG and both ED126/DO303 (Safety and Performance Requirements for ADS-B NRA) and ED161/DO318 (Safety and Performance Requirements for ADS-B RAD) have been respectively issued. For information, most of the requirements identified in the Technical Specification for a 1090 Mhz Extended Squitter ADS-B Ground Station (ED129) have been derived from ED-126/DO-303.

DSNA EXPERIMENTATIONS

Since 2000, DTI has participated to several projects, funded by the European Commission, and addressing various aspects of ADS-B (tests of the various data links, description of applications, safety analysis, validation…). Until 2005, no 1090ES ground station was available and therefore very few experimentations, with real time data, were performed in Europe. A major step was then passed when Thales delivered its first ground station paving the way for several investigations, especially in the frame of the Eurocontrol CRISTAL projects. DTI has been involved in several of these projects, addressing various air/ground and air/air applications.

CRISTAL Toulouse

This project was the first CRISTAL project funded by Eurocontrol. It was the result of a statement shared by Airbus, Thales and DTI: *several organisations want to implement ADS-B applications based on 1090ES, but the performances of ADS-B have never been assessed extensively*. The project was launched with the following objectives:

- Investigate airborne architectures performances based on opportunity traffic.
- Test a 1090ES ground station in an operational environment.
- Investigate the overall ADS-B performance by comparison with radar data.

Once the ground station installed in Toulouse, all received ADS-B data were recorded permanently. For information, about 20 aircraft were displayed when the projects started in 2005. In 2007, more than 100 aircraft were displayed simultaneously…

In addition to these ADS-B recordings, specific airborne data were collected from Airbus flight test aircraft and several radar recording campaigns were also organised. Analysis, comparison of all these data were then performed allowing:

- Determination of the most reliable airborne architectures.
- Highlight of several major issues.
- .Adjustment of the standards, still under development.

At this stage, it seems important to provide more information regarding the major issues that were highlighted by CRISTAL Toulouse. Most of them were allocated to the airborne side and could be divided into three parts:

- Incorrect implementation leading to “obvious” incorrect ADS-B transmission. Figure 3, below, shows one example of such bad behaviour. A single aircraft is broadcasting position data, with a very good quality indicator, that are located everywhere in Europe.
- Incorrect implementation leading to misleading ADS-B transmission. Figure 4, below, shows one example of such bad behaviour. A single aircraft is broadcasting position data, with a very good quality indicator, but with a constant offset. In a non-radar environment, it would be nearly impossible for the Air Traffic Controller to detect such situation.
- Figure 5 shows one of the main outputs of the CRISTAL Toulouse project: the latency that affects the various airborne architectures, whatever the aircraft type.

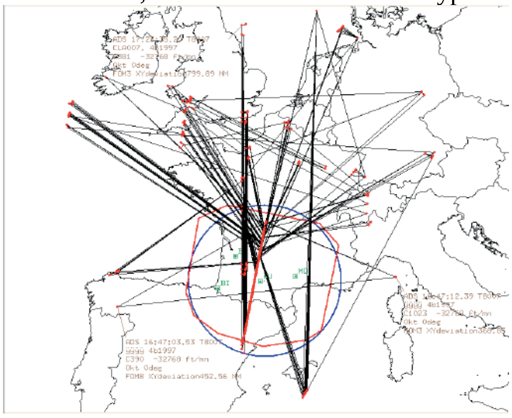

Figure 3: Example of incorrect airborne ADS-B airborne implementation

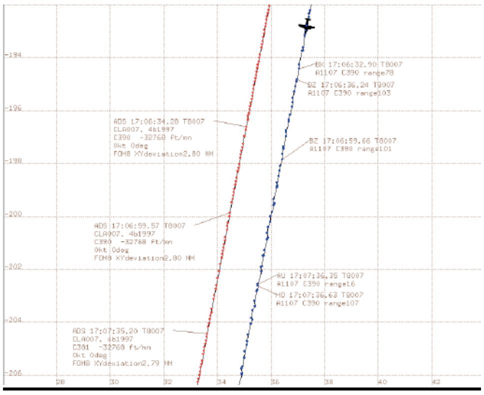

Figure 4: Example of incorrect airborne ADS-B airborne implementation

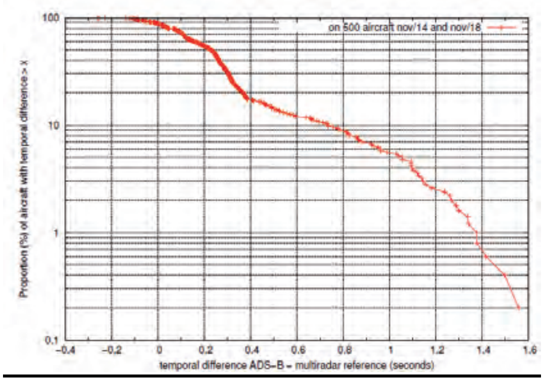

Figure 5: Latency issue

It seems important to spend some time on this latency issues as it impacts all validation activities that may be conducted on ADS-B. With a 1090ES airborne implementation, ADS-B messages are developed based on data transmitted by navigation equipment. In most cases, position data directly come from the GNSS, but in some instances, they may transit through the FMS, or even through the inertial reference system. In addition, there may be some time between the origination of the data and its transmission to the mode S transponder. The problem is that the position data are not time stamped when originated but when they are received by the ADS-B ground station. When this issue was discovered, it was decided to investigate, in depth, this phenomenon. Lots of ADS-B samples were analysed and it appears that the latency was not only reaching 2sec in some instances, but was also varying with the time without any possibility to compensate it. The EASA AMC 20-24, which was still under development, had to be modified in order to incorporate the following requirement “The latency of the horizontal position data, including any uncompensated latency, introduced by the (overall) ADS-B does not exceed 1.5sec in 95% and 3sec in 99.9% of all ADS-B messages transmission cases”.

CRISTAL Toulouse has been the first CRISTAL project and maybe the most theoretical one, compared to the following ones which have addressed the application aspects. It also convinced Eurocontrol to work with the airlines and to partially fund the activation of “clean” ADS-B architecture.

CRISTAL Mediterranean

The very ambitious objective of this project was initially to complete the current limited surveillance coverage above the Mediterranean Sea. However, the States (Italy, Spain, Greece, Malta, Turkey, France), participating to this projectf, had to largely reduce such objective, as the European Commission funding was dramatically reduced. On the French side, it was decided to install one ADS-B ground station in Corsica, in a site close to Ajaccio. This implementation was considered as there is almost no radar coverage in the Ajaccio TMA.

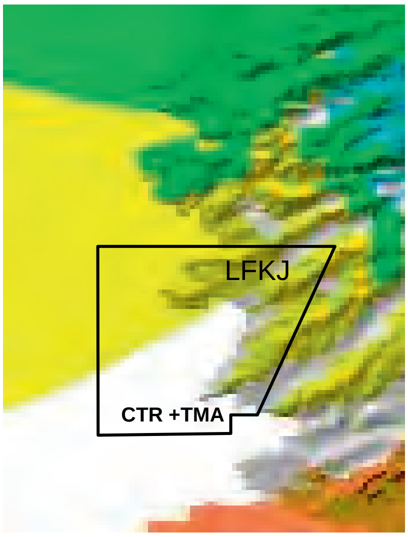

Figure 1 – Radar coverage below FL50 (Ajaccio)

This lack of radar coverage is a major issue, especially, in low visibility conditions, as only one aircraft (landing or taking off) can fly into the bay. This largely reduces the airport capacity. It was anticipated that implementing an ADS-B ground station close to the airport could help in improving this situation.

The DTI objectives within this project were both operational and technical. From an operational perspective, it was intended to validate that the display of ADS-B equipped aircraft in the Terminal area was really a benefit, taking into account that non equipped aircraft were obviously not displayed. Such objective was refined during the project in order also to define which equipped aircraft had to be, or not, displayed. A so-called black list (only from an ADS-B perspective!) was then developed.

Apart from the operational experiment with Air Traffic Controller in the loop, CRISTAL Mediterranean has allowed to investigate the fusion of radar and ADS-B data in various trackers. Fine tuning of the two trackers under consideration had been a very long task for different reasons:

- Much more data are received with ADS-B than with radar, which has an impact on the computer processing load.
- Latency issue, previously mentioned, is not so easy to take into account.

However, from a technical perspective, this project was considered as a success. However, no operational implementation is planned until all aircraft operating locally are ADS-B equipped.

A last benefit shall not be forgotten: in the frame of this project, one of the DTI flight inspection aircraft has been ADS-B equipped and has contributed to several operational tests.

DSNA IMPLEMENTATION

Apart from the various CRISTAL experimentations, DSNA took the decision in 2006 to launch an ADS-B implementation programme for two overseas territories:

- La Reunion Island in the Indian Ocean (2006-2009)
- New Caledonia in South Pacific (2009-2010)

These two sites were chosen for various reasons:

- Traffic density is very low, but even though, hazardous situations may occur with inter-islands traffic.
- Radar installation would be too expensive, considering that at least two radars would be necessary to provide full surveillance coverage.

The following operational objectives were fixed by DSNA:

- Improvement of the Air Traffic Controller Situational awareness in the Terminal and En route Areas under their responsibilities.
- Improvement of Search and Rescue operations.

- If necessary, application of new separation minima.

From a technical perspective, the objective was to implement the simplest architecture, using existing tools within DTI.

Taking into account the local relief, at least three ground stations had to be implemented on sites already occupied by Civil Aviation. Once the sites were chosen, simulations were performed in order to check (theoretically) that the ADS-B coverage was compliant with the operational need.

In addition, to the ground stations, several displays were installed at the ATC Centre to satisfy the operational requirements from DSNA. These displays are similar to the ones used in other French sites but modified in order to display ASTERIX 21 data. Figure 7 shows the ADS-B architecture in La Réunion.

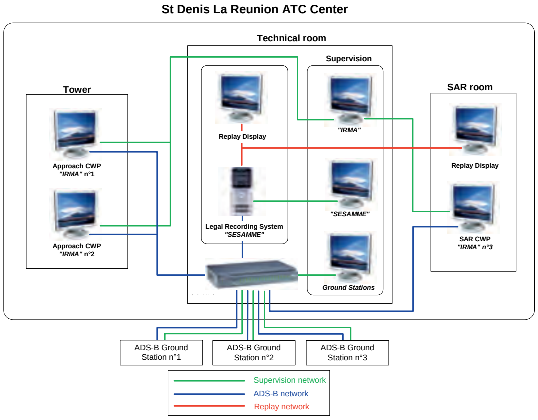

Figure 7: ADS-B implementation in La Reunion

For the first phase (before any separation minima reduction), ADS-B data were directly displayed without any processing.

Between May and July 2007, all the ground architecture was installed in La Réunion allowing the validation activities to begin. The following tasks had to be performed:

- From an operational point of view:
    1) Check that the surveillance coverage is compliant to the requirements.
    2) Validate the proposed display
    3) Contribute to the airborne validation (Obj 5)
- From a technical perspective:
    4) Validate the ground architecture and in particular the ground station performances.
    5) Develop and validate the aircraft green/red lists.

Validation of aircraft

As for the Cristal Mediterranean project, the main issue was the ADS-B certification of the various aircraft operating in the environment. Four categories were rapidly identified:

- Aircraft not equipped corresponding to the local fleet (with very old avionics equipment) or aircraft operating worldwide except in Europe.
- Aircraft operating worldwide but with incorrect architecture
- Aircraft operating worldwide with correct architecture but not certified.
- Aircraft operating worldwide with certified ADS-B architecture.

In order to avoid the display of incorrect data to the Air Traffic Controller, it was decided to establish a green/red lists of aircraft based on the analysis of the recorded ADS-B data but also daily reports prepared by the controllers. The two lists of aircraft were then established, based on the aircraft mode S address. Every new aircraft coming for the first time in the area has to be validated on the same basis, starting initially in the red list.

Validation of the ADS-B ground architecture

In order to perform the ground architecture, several tools were available:

- Ground tools developed either by DTI, or the ground station manufacturers.
- Data coming from opportunity traffic (no the one from the black list obviously)
- Data coming from flight inspection aircraft.

Most important was to validate the ground station performances especially considering the following parameters: coverage, latency, Probability of Detection and accuracy.

In order to validate the surveillance coverage, both opportunity traffic and flight inspection aircraft (ASECNA ATR 42 in La Réunion) have been used. Figure 8 shows the ATS routes that had to be covered, figure 9 shows results obtained with opportunity traffic and Figure 10, results obtained with the flight inspection aircraft.

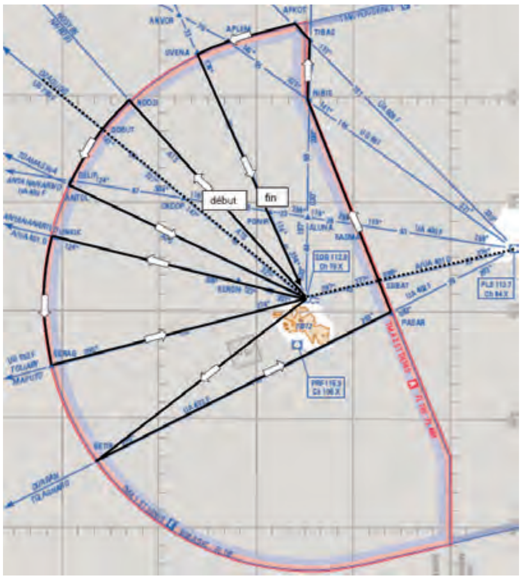

Figure 8: ATS routes in La Réunion

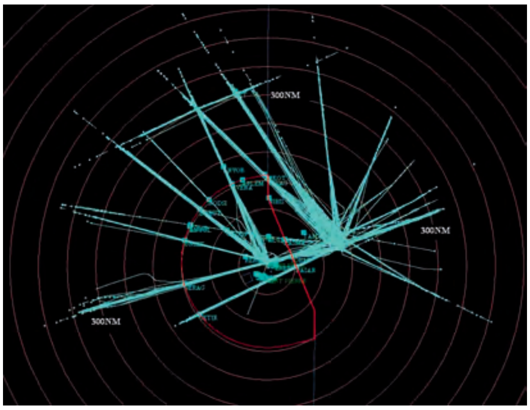

Figure 9: Opportunity traffic

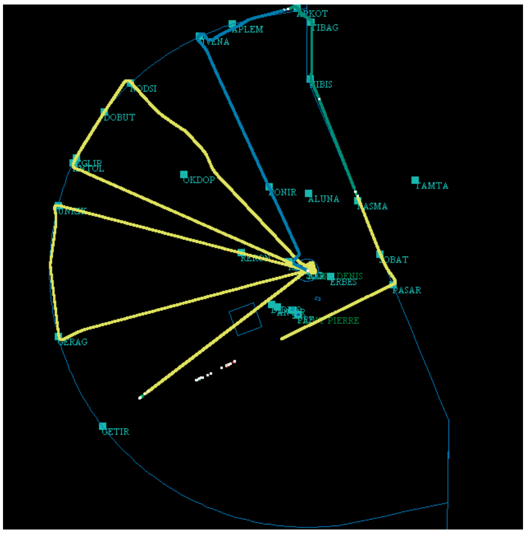

Figure 10: Example of ADS-B flight inspection

All the flights have clearly shown that the final ADS-B coverage was far better than the expected one but close to the estimated one.

Regarding the latency, some analyses were performed comparing position data coming from the flight inspection trajectography and the one received by the ADS-B ground station. As demonstrated during the CRISTAL Toulouse, it was clearly identified that the latency issue was mainly due to the airborne side.

In order to investigate the probability of Detection, two cases were tested:

- The most recent data received every second, for one aircraft, are sent to the ATC centre.
- The most recent data received every 4 seconds, for one aircraft, are sent to the ATC centre.

In both cases, requirement from ED129 [3] on this parameter was reached using both opportunity traffic and flight inspection aircraft. No coverage holes were identified and therefore it is very difficult to establish the reason why some squitters are lost (not received or not transmitted?).

Accuracy aspects were eventually not analysed as this parameter is only impacted by the airborne architecture.

In addition, it shall be noted that during the specific ADS-B flight inspections, emergency messages, Ident were periodically sent by the flight inspectors to ensure that this functions were correctly transmitted to the Air Traffic Controller.

The question was then raised on the necessity and the benefits to use the flight inspection aircraft for other validation purposes. The following aspects had to be taken into account:

- None of the current standards from ICAO, EASA or FAA, EUROCAE/RTCA or Eurocontrol do require any flight inspections.
- An ADS-B ground station only receives squitters emitted by aircraft and do not transmit any signal.
- ADS-B ground station includes an internal site monitor performing periodical tests and ensuring the correct behaviour of the system.
- Correct decoding and encoding of ADS-B messages can be validated, using opportunity traffic, thanks to existing tools.

- Most of the ground station functionalities had already been tested during the extensive factory acceptance tests.

It was therefore decided that no further specific flight inspections were necessary. Nevertheless, some analyses are periodically performed using data collected during ILS and VOR flight inspections.

CONCLUSION

Since 2000, DSNA/DTI has conducted a lot of activities related to ADS-B covering regulatory, validation aspects … and has also operationally implemented ADS-B on two sites (La Réunion and New Calédonia). Existing tools, operational equipment… developed by DTI have been upgraded in order to process ADS-B data, and new ones have been developed when necessary. The main issue remains the airborne side, as a very low percentage of aircraft has certified ADS-B installation. Nevertheless, DTI is ready for new implementation it should be noted that except for coverage aspects, DTI does not intend to perform specific ADS-B flight inspections.

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[1] ICAO Doc 4444 "Procedures for Air Navigation Services"

[2] EASA AMC 20-24 "Certification considerations for the enhanced ATS in Non-Radar Areas using ADS-B Surveillance (ADS-B NRA) Application via 1090 MHz Extended Squitter"

[3] EUROCAE ED-129 "Technical Specification for a 1090 Mhz Extended Squitter ADS-B Ground Station"

[4] RTCA DO-242, DO-242A "ADS-B MASPS"

[5] EUROCAE ED126 / RTCADO303 "Safety and Performance Requirements for ADS-B NRA"

[6] EUROCAE ED161 / RTCADO318 "Safety and Performance Requirements for ADS-B NRA"

Methodologies for the Flight Inspection of ADS-B Systems

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ABSTRACT

The United States Federal Aviation Administration (FAA) is enhancing the nation's air traffic control system from one that relies on swept radar technology to a system that uses precise location data from the global satellite network. Automatic Dependent Surveillance – Broadcast (ADS-B) is an advanced surveillance technology that combines an aircraft's positioning source, aircraft avionics, and a ground infrastructure to create an accurate surveillance interface between aircraft and air traffic control. ADS-B is expected to provide air traffic controllers and pilots with more accurate information to keep aircraft safely separated in the sky and on the surface. Given the scope and complexity of this new system which is key to future operations in the National Airspace System (NAS), the FAA will conduct commissioning flight inspections of ADS-B service volumes as they are integrated into the NAS. This paper provides an overview of the FAA flight inspection requirements, procedures, and analysis methodologies for the evaluation of ADS-B services. The paper also considers the added complexity of testing a system which integrates two different data links. These are the 1090 MHz Extended Squitter (ES) link, and Universal Access Transceiver (UAT) data link which operates at 978 MHz.

INTRODUCTION

The Federal Aviation Administration (FAA) determined that Automatic Dependent Surveillance-Broadcast (ADS-B) with Traffic Information Services-Broadcast (TIS-B) and Flight Information Services-Broadcast (FIS-B), is a viable technology solution to meet the challenges of the future. The FAA has implemented a plan to integrate these new technologies to provide terminal and en route air traffic control (ATC) separation services along with advisory services providing situational awareness to enhance safety throughout the National Airspace System (NAS). The system will be deployed NAS-wide over FY2010-FY2014.

ADS-B operations can be divided into two types based on the direction of data flow relative to an aircraft, "ADS-B Out" and "ADS-B In." The FAA reached an In-Service Decision (ISD) for the ADS-B In Advisory Services TIS-B and FIS-B, otherwise referred to in FAA literature as Essential Services, in November, 2008. These services are currently available over approximately half the continental United States, and most of Alaska. ISD for ADS-B Out ATC Separation Services, referred to as Critical Services, was reached in September, 2010. Use of ADS-B for air traffic separation is currently operational at five key sites, plus a couple of other air traffic locations across the continental U.S., the Gulf of Mexico and Alaska. Future deployment of ADS-B services will include all of the continental U.S., Alaska, Hawaii, Guam, and Puerto Rico.

To put ADS-B Flight Inspection (FI) in context, this paper begins with a description of the U.S. ADS-B system and how it is being implemented.

ADS-B SYSTEM DESCRIPTION [1]

ADS-B Surveillance is a service within the portfolio of services known as Surveillance and Broadcast Services (SBS). The service receives position broadcasts from ADS-B equipped aircraft and distributes this information to ATC automation systems to support separation assurance and traffic flow management. The Surveillance and Broadcast Services Subsystem (SBSS) is the ground-based portion of the SBS. This ground network is comprised of radio stations (RS), Service Delivery Points (SDP), control stations and the necessary network connections. ADS-B messages are received, processed and validated from equipped aircraft and resultant ADS-B target reports (CAT033) are delivered to FAA automation and monitoring systems at designated SDPs. See Figure 1.

The SBSS supports four different services: Automatic Dependent Surveillance - Broadcast (ADS-B), ADS-Rebroadcast (ADS-R), Traffic Information Services - Broadcast (TIS-B), and Flight Information Services - Broadcast (FIS-B). The U.S. ADS-B system works on two separate data communication links. These are the 1090 MHz Extended Squitter (ES) link, and Universal Access Transceiver (UAT) data link which operates at 978 MHz. Because aircraft on one data link cannot receive ADS-B data from aircraft on the other link, a method was established to “translate” ADS-B messages between data links. While the specific implementations on the aircraft may vary within the standards for the avionics, essentially if a message is received by the ground infrastructure via the UAT data link, it is made available for “rebroadcast” via the 1090 data link, and vice-versa. ADS-R enables all aircraft that are equipped with one of the two data links to be capable of receiving and displaying traffic data from either of the two data links.

TIS-B is a transitional service that creates a composite surveillance picture using radar or other existing FAA surveillance systems and broadcasts it on both the UAT and 1090 ES data links for reception by ADS-B In equipped aircraft. ADS-B targets are suppressed in the TIS-B broadcast in order to minimize the display of duplicate targets in aircraft applications. TIS-B is an advisory service that is not designed for aircraft surveillance or separation, and cannot be used for either purpose. FIS-B is a service that provides the broadcast of weather and pilot advisory information. FIS-B is a tool targeted to benefit General Aviation situation awareness and is only available on the UAT link.

Airspace volumes throughout the NAS are divided into En Route, Terminal, and Surface Service Volumes (SV). A Service Volume (SV) is a defined volume of airspace in the NAS within which a set of ADS-B Services are provided and the required performance for the set of services is achieved. A Composite Traffic Volume (CTV) is the aggregation of reports from multiple Service Volumes. A SV or CTV can include anywhere from a couple of radio stations up to as many as 30. The reports within a CTV are filtered spatially according to a specified polygon and to eliminate radio station duplicates. Each SV has one or more defined SDPs to which the service provider delivers data and service status reports to the FAA. The SDP is also the demarcation point for FAA radar and other surveillance data to be converted to TIS-B messages by the service provider.

The SBS Monitor

The FAA monitors ADS-B services with the Surveillance and Broadcast Services (SBS) Monitor. The SBS Monitor receives ADS-B target reports and system status information. It is used to confirm performance, validate contractor compliance, and report service status to the FAA Operational Control Centers (OCC) who track and report service interruptions with NOTAMs. The OCC, either through observations of the SBS Monitor or by contact from the affected ATC facility, communicates maintenance and performance issues to the service provider. FAA Technical Operations uses the SBS Monitor data for analysis and reports data quality and service availability to FAA stakeholders and other authorized local and remote users.

The FAA has full responsibility for reporting on the status of the SBS system. The FAA Operational Control Centers (OCCs) provide 24/7 monitoring of the infrastructure to assure availability and service provider (vendor) responsiveness. The service provider maintains a Network Operations Center (NOC), which continuously monitors system status and performance, and is used to manage the configuration of the system and to coordinate the majority of system maintenance activities.

When an ADS-B system discrepancy is noted at a FAA OCC, the OCC immediately coordinates with the NOC to resolve the problem. Reporting is bidirectional in that either the FAA control center or NOC will report outages to their counterpart.

SBSS (radios and infrastructure) also provide service and system status information to the automation platforms. Discrepancies may also be reported to the associated OCC by a FAA Service Operations Center (SOC) or automation specialist. Additionally, the SOC will coordinate with local Air Traffic regarding any resulting system impacts or coverage degradation.

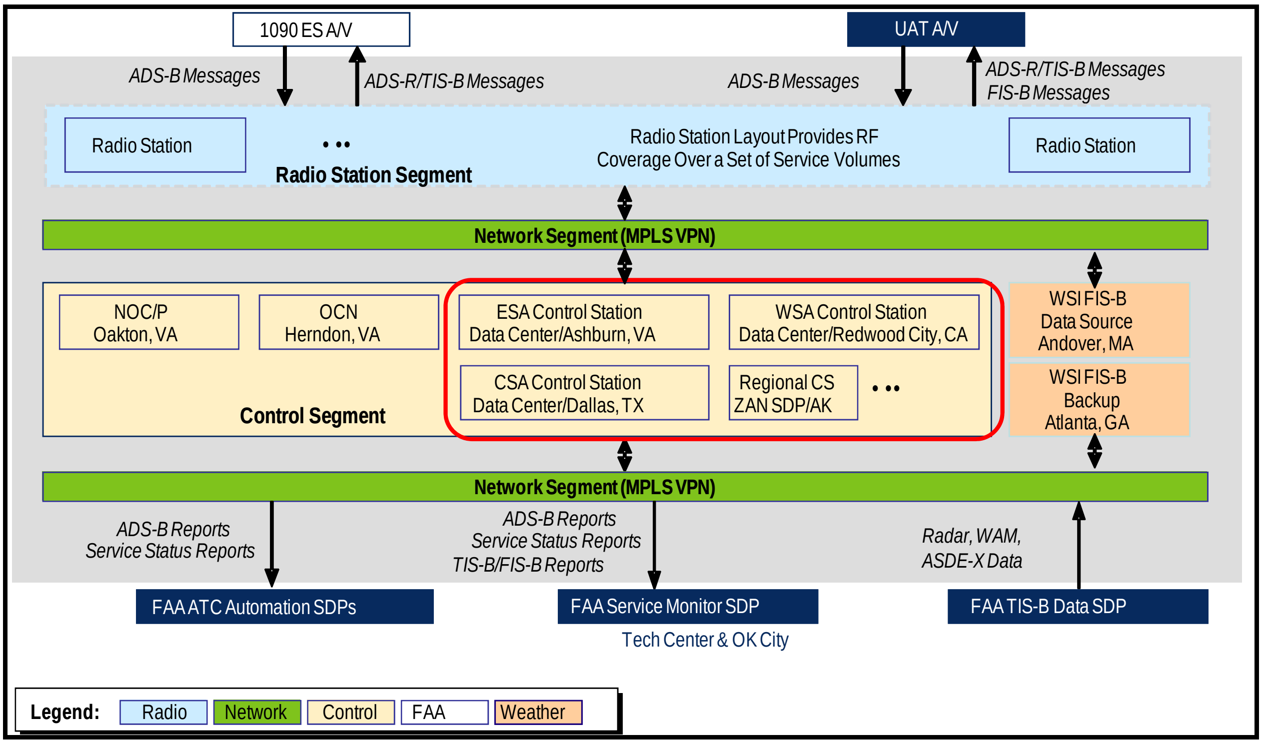

Figure 1. Simplified ADS-B Block Diagram.

Automation Platforms

Automation systems provide the coordination and data display functions required by ATC personnel providing en route and terminal separation services. Automation platforms were modified to process and display ADS-B data to support ATC services. The ADS-B data can either be utilized as single source information or can be fused with other surveillance sources such as radar to provide the target information. The types of automation platforms involved include: Standard Terminal Automation Replacement System (STARS), Common Automated Radar Terminal System (CARTS), Microprocessor En Route Automated Radar Tracking System (MEARTS), En Route HOST computer system, and En Route Automation Modernization (ERAM) system.

IMPLEMENTING ADS-B

The FAA is buying an ADS-B Service rather than building its own ADS-B system. Performance-based service acquisitions define the service itself as the deliverable. In accordance with this acquisition approach, SBS services are designed and developed under a contract between FAA and the service provider, ITT Exelis. The service provider delivers the SBS services to FAA. The FAA has specified performance parameters of the SBS Services. The FAA owns the surveillance and flight data transmitted and received between aircraft and the system design. The government does not, and will not, own the actual hardware and other components necessary to provide the services. All infrastructure equipment within the SBS system is wholly owned and maintained by the service provider, including the radio stations and SDPs.

Responsibilities

Different organizations within the FAA are responsible for maintaining and operating the ADS-B SBS system. The overarching organization responsible for the NAS-wide deployment of ADS-B and associated services is the SBS Program Office. Teams were established to analyze, evaluate, define, and approve separation standards, suitability, maintenance reporting and certification of ADS-B for ATC services on each automation platform. This analysis was completed and separations standards approved prior to operational use of ADS-B on each automation platform.

The Service Provider is responsible for delivering all ADS-B services to the FAA. There are four key equipment areas required for delivering those services:

- Numerous (over 700) Radio Stations
- Service Delivery Point equipment racks
- Control Stations – to provide centralized processing of data (4 planned)
- Network Operations Center (NOS) – for enterprise management of the SBS system

Research, Development and Design Testing

A “key site” concept was used to develop the U.S. SBS system, permitting operational testing and evaluation for each kind of service integrated with each type of automation platform. The SBS Program Office conducted Operational Testing (OT) for each key site, and the FAA Office of Safety conducted Independent Operational Testing and Evaluation (IOT&E) for ISD of Critical Services. A full safety risk assessment was performed on Essential and Critical Services at each key site prior to achieving Initial Operating Capability (IOC).

Service Integration Tests (SIT) were performed at each SBS key site to verify the hardware, software, and functional requirements necessary to integrate with each unique automation platform. Service Acceptance Testing (SAT) was performed at each of the key sites to verify that the SBS Service Volume that is being accepted is completely installed, optimized and ready to proceed with FAA acceptance activities. It verified coverage and technical performance measures including latency, update interval, validation and availability. SAT employed a combination of flight test aircraft, targets of opportunity (TOO), and generated test targets to verify system performance and coverage.

IMPLEMENTING ADS-B AT A SPECIFIC AIR TRAFFIC CONTROL FACILITY

The FAA provides the vendor with a radar coverage analysis to define the existing coverage for the SV. The design approval criteria require ADS-B coverage be at least as good as current radar coverage as a starting point, with some additional caveats. For example, in a Terminal SV, the ADS-B coverage should extend down to the radar line of sight, or established Minimum Vectoring Altitude (MVA) minus 500 feet, whichever is lower. In an En Route SV, the ADS-B coverage should extend at least down to the Minimum IFR En Route Altitude. And for Terminal and En Route SVs, above 1500’ AGL or 5000’ AGL respectively, the network design should ensure that ADS-B covers at least 98% of those areas covered by radar.

The service provider will conduct a design review for the proposed SV with the SBS Program Office, defining the characteristics and coverage performance of the equipment selected. Based on the successful completion of the SV design review, the FAA will conduct a comparative coverage analysis of the SV design to identify any areas of concern with the selected sites and radio station equipment. When the analysis demonstrates the SV design meets coverage requirements, and other key performance metrics, the FAA will provide the service provider with an approval of the design which permits the service provider to proceed with deployment of the SV equipment.

Deployment of Ground Network Infrastructure

The radio stations are wholly owned and maintained by the service provider and therefore do not require direct FAA oversight during installation unless installed within an FAA facility. The SBS Program Office reserves the right to perform inspections of any and all radio stations. However, the inspection is not required and is not expected to be performed at every RS. SDPs are deployed to feed ADS-B reports to automation systems as well as to receive existing FAA surveillance data for conversion into TIS-B.

FAA Conducts Automation Integration

Automation integration is applicable only to Critical Services SDPs and involves local automation specialists, and Service Center or Service Area staff. The SBS Implementation team supports the activities necessary to integrate the SDP with the automation platform. This activity involves only the connection and site-specific optimization and/or adaptation of the automation system. The interface development and data flow has been determined by SBS Systems Engineering and each automation program office.

ISAT

Implementation Service Acceptance Testing (ISAT) is performed at each SBS SV to verify it is completely installed, optimized and ready to proceed for FAA acceptance activities. ISAT is a reduced scope version of a SAT that is performed by the service provider for all SVs, and witnessed by the SBS Program Office. The ISAT is designed to verify that the SV meets key performance and coverage requirements. This verification is achieved by using a combination of targets of opportunity, generated uplink test targets, and in some cases flight test aircraft.

Final Testing and Flight Inspection

After an ISAT for Critical Services, the FAA conducts an end-to-end system test, or Implementation System Test (IST), of ADS-B. This test incorporates the services delivered by the service provider and the integration with FAA automation. Key site automation integration successfully verified the automation interfaces, while IST demonstrates local integration and adaptation. As part of the IST process, the FAA performs commissioning flight inspections using Flight Inspection Services aircraft along with TOOs. This evaluation is completed prior to Air Traffic certification of ADS-B Separation Services and operational use of ADS-B in the SV. The flight inspection is an independent verification of coverage and performance in each SV. Flight inspection is only required for the certification of ATC separation services, ADS-B Out. However, at the time of the flight inspection, data is simultaneously recorded for advisory services. ADS-B Pilot Advisory Services consists of ADS-B In, which includes ADS-R, TIS-B and FIS-B. ADS-R is currently advisory-only in nature. At such time ADS-R is redefined as an ATC Separation Service for ADS-B applications, additional flight inspection requirements may be established for certifying ADS-R. Post-flight analysis of all the data will be used to establish a coverage baseline and to make an overall assessment of system performance.

IOC - Advisory versus Separation Services

The path to Initial Operating Capability (IOC) is different for Advisory and Separation Services. Following ISAT, Advisory Services (TIS-B, FIS-B and ADS-R) may be put into service without further testing. ADS-R is considered fully operational upon achievement of IOC similar to TIS-B and FIS-B. The SBS Program Office will request the OCC take service monitoring ownership of a new SV. The OCC issues a NOTAM to inform operators that Advisory Services will be available in the affected SV(s) and monitored by the FAA on the planned date. In addition, the SBS Program Office notifies all affected ATC facilities. Though ATC does not use Advisory Services, they should be aware that ADS-B equipped aircraft will have traffic and flight information available in the cockpit for situational awareness.

Some additional steps to IOC are required for ADS-B ATC Separation Services. The SBS SDP equipment rack was not interfaced to automation during deployment of Advisory (Essential) Services. After Critical ISAT is completed, the cables to automation are connected by a local FAA automation technician. And following ISAT, Separation (Critical) Services undergo IST, which includes flight inspection. In addition, minimum training for Air Traffic and Technical Operations personnel must be completed, as well as completion of the Safety Risk Management process. And finally, the service must be certified.

Certification

Following a successful completion of the flight inspection, post-flight analysis of the collected data, and a report is issued by Engineering Services, ADS-B use for surveillance and separation of aircraft in the SV or CTV can be certified. The certification is accomplished by an Airway Transportation Systems Specialist (ATSS), which requires certification credentials to do so. FAA ADS-B Separation (Critical) Services are certified at the automation platform as Automatic Dependent Surveillance Service (ADSS). The ADSS is an event-based certification, meaning when there is a scheduled, unscheduled, periodic maintenance, system support modification, etc., the equipment is certified before being returned to service.

Going Fully Operational

After IOC, ADSS is evaluated for operational suitability in a manner similar to traditional FAA systems. Local air traffic control and Technical Operations evaluates system operation for a period of time and identifies any problems. During this time, all appropriate air traffic and Tech Ops personnel at the respective facility are trained for use of the service. When all the respective parties are satisfied, the service is then declared fully operational.

ADS-B FLIGHT INSPECTION GUIDANCE

The Decision to Flight Inspect ADS-B

It is not within the scope of this paper to debate the merits of conducting flight inspection of ADS-B. Flight Inspection is part of a robust safety risk management process. ADS-B is a key component of the FAA Next Generation Air Transportation System (NextGen), driving a major transformation of the NAS and how it operates. The nation’s air traffic control system is changing from one that relies on swept radar technology to a system that uses precise location data from the global satellite network. And the U.S. version of ADS-B is a complex system utilizing two different links, integrating with several different ATC automation platforms. The number of ADS-B equipped aircraft is still limited making the availability of targets of opportunity scarce. In addition, this is the first time the FAA has contracted with a vendor to provide a large scale surveillance service for ATC, rather than owning the system and hardware outright.

FAA Flight Inspection Services enlisted assistance from academic experts, Ohio University Avionics Engineering Center (AEC), to help develop FI requirements for ADS-B. Ohio University AEC recommended flight inspection of ADS-B services. “The intended use of ADS-B system data in the provision of aircraft separation services by FAA ATC necessitates flight inspection of the system to ensure that the ADS-B signal-in-space (SIS) is present, useable, and safe with aircraft operating at minimum transmission power. Additionally, flight inspection of the SIS can identify areas in the service volume(s) where: interference sources may exist, there is SIS blockage by terrain and buildings, obstacles (new or temporary) exist in the intended flight operations area, etc. There is no independent monitoring of the ADS-B SIS (i.e., external sampling of the ADS-B SIS broadcast by the ground facilities) as has been the case in previous navigation and landing systems." [2]

ADS-B Flight Inspection Order

An FAA Order for the Flight Inspection of ADS-B is in the final stages of development. It describes the procedures and requirements for the flight inspection of ADS-B services. The flight inspection is designed to be an end-to-end check of ADS-B based ATC Surveillance and Separation Services. The commissioning inspection is for ADS-B Out (Critical) services. Simultaneously, an assessment is made of ADS-B In or SBS Advisory Services: TIS-B, FIS-B and ADS-R. The objective of the commissioning inspection is to evaluate system performance, determine and document whether the coverage meets Air Traffic requirements, and provide a baseline for the detection of deterioration in performance.

"The purpose of a commissioning flight inspection is to provide a means (i.e., data) for FAA engineering/air traffic services to verify and quantify the extent to which the service meets ATC operational requirements." [2] The overall purpose of the flight inspection is for engineering to assess the coverage, functionality and accuracy of the ADS-B system. The coverage of the airways, approaches and airports will be documented in a post-flight inspection analysis report. The report will be used as a baseline report documenting the coverage of the system in the areas flown during the flight inspection.

While the flight inspection order allows for use of targets of opportunity (TOO) in analysis of system performance, a flight inspection aircraft provides many advantages over TOOs. The flight inspection aircraft provides "truth" data (position and vector data), known power levels, recorded ADS-B In data, ADS-R data, and it can be scheduled.

Dedicated periodic flight inspections of ADS-B are not required. However, it was decided that after 3 years a series of special flight inspections will be conducted to sample ADS-B performance across a representative group of service volumes and automation platform types. The results of those inspections will determine any future periodic inspection requirements. Flight Inspection Services will also investigate the feasibility of equipping flight inspection aircraft with the ability to autonomously record ADS-B data while performing other flight inspection missions. This would provide a means to randomly monitor ADS-B performance throughout the NAS on a regular basis.

Development of a Flight Inspection Plan

Preparation for the flight inspection begins with Engineering Services writing the specific flight inspection plan for the SV or combination of SVs supporting an air traffic facility. With the ISAT as a reference, Engineering Services works with local air traffic to determine specific flight inspection requirements, and what may be accomplished with recorded TOO data. Engineering then works with Flight Inspection Services to refine the plan and schedule the actual flights.

FLIGHT INSPECTION PROCEDURES

The checklist items identified by an "X" are mandatory. The checklist items in Table 1 must be completed as indicated.

Table 1. ADS-B Critical Services FI Checklist

	Inspection Type		
	C	RS Ant or Radio Change	Xpndr Setting (1)
General Coverage	X	X (2)	L
Airways/ Route Coverage	X	X (2)	L
MSAW	X		E
Fix/ Map Accuracy	X (2)		E
Modes/ Codes	X		E
Hand-off with Radar-only	X (3)		E

Footnotes:
(1) Settings for 1090 Transponder: E = Either Normal or Low Power; L = Low Power.
(2) May be completed using targets of opportunity.
(3) Only applicable when SV is adjacent to radar-only airspace.

Coverage is checked using a flight inspection aircraft equipped with both links transmitting at or below the minimum power specified in the rule, A1 class for 1090ES and A1H class for UAT. In order to maximize efficiency and activate the ADS-R feature continuously, the flight inspection aircraft transmits on both ADS-B links simultaneously using different ICAO addresses in order to appear as two different aircraft to the system.

Appearing as two different aircraft in the same place can cause problems for an automation system, namely a Conflict Alert (CA). Some automation platforms, like STARS, permit suppression of CA for specific aircraft. However, when this is not possible, it is desirable to have a means to prevent such alerts. The service provider adapted a feature to create an altitude offset for a few very specific aircraft ICAO address and Flight Identification (ID) combinations. The UAT transceiver ICAO address is set to one of the provided test addresses. If the +1000 foot offset is required during the inspection, then the corresponding Flight ID is used to activate the altitude offset feature. Depending on the address and codes used, an altitude offset of +1000', -1000', or -500' can be activated. The altitude change is only seen in the automation, and not by other ADS-B equipped aircraft. The altitude offset allows for use of both ADS-B links at the same time utilizing different ICAO addresses without triggering a conflict alert in the automation.

General Coverage

Engineering will determine exactly which areas must be checked with a flight inspection aircraft. They consider the following when designing the plan:

- Coverage prediction based on validated modeling tools
- Areas of predicted marginal coverage
- Data collected from targets of opportunity
- Ensure enough of the SV interior is sampled (the profile should allow contact with every RS)
- ATC requests to check areas with gaps in radar coverage, specific airports and other areas of interest
- Perimeter checks if warranted

It is not mandatory to fly any of the perimeter of a SV. The intent is to ensure coverage along the edges of a SV that does not border another SV, or in areas of questionable line-of-sight with ADS-B radio stations. When checking a perimeter boundary, fly offset to the inside of the SV boundary, both horizontally and vertically, to preclude the loss of coverage due to crossing outside the SV. Perimeter checks are never flown for a Surface SV.

Airways / Route Coverage

Verify ADS-B Out coverage on the airways and routes identified in the flight inspection plan on both ADS-B links. Engineering will use TOO data and validated modeling tools to determine which areas should be checked by flight inspection. The intent is not to fly every airway or route, but a smart sample including areas where coverage may be marginal, or in heavily used areas where ATC wants to ensure coverage is adequate. In an En Route SV, fly at the floor of radar coverage, but no lower than minimum obstruction clearance altitude (MOCA). In a Terminal SV, fly 500' below the minimum en route altitude (MEA)/ minimum vectoring altitude (MVA), but no lower than MOCA. However, when there is a specific establishment of surveillance coverage below or beyond current radar coverage, ADS-B coverage must be checked with a flight inspection aircraft to ensure it supports the planned air traffic operations.

MSAW Functionality

Perform an end-to-end check of Minimum Safe Altitude Warning (MSAW) features activated solely by an ADS-B only target, thus verifying a target processed through the ADS-B network will trigger a low altitude alert correctly. There are two different components of MSAW: General Terrain Monitor (GTM) and Approach Path Monitor (APM). An APM check can be accomplished at any airport with an APM adaptation. The GTM must be in an area away from any airports and not in a MSAW inhibited area. During both the APM and GTM checks, the aircraft will switch off the Mode S and ADS-B 1090ES transmissions, while transmitting the proper Mode 3/A code on UAT only. This ensures an ADS-B only target. If the UAT transceiver altitude offset feature is in use, it must be disabled so the ADS-B network will forward the actual altitude to automation. Proper attention to the correct configuration on the ATC automation system is required, including selecting the proper Mode-3/A code and associating the aircraft with an instrument flight rule (IFR) flight plan. Testing 1090ES activated MSAW end-to-end functionality is nearly impossible due to fusing of ADS-B and radar targets by ATC automation, and is not required.

Fix / Map Accuracy

A post flight analysis is made to determine ADS-B position accuracy, however there is no established method for post flight verification of correct target position on the air traffic control display, (i.e., all the way to the "glass"). The controller should compare reported aircraft position relative to the airway, route, or fix with the video map presentation. At least one time during the inspection, the controller observing the ADS-B enabled display will call out over the radio to the flight inspection aircraft when passing over a marked fix or NAVAID. The flight inspection crew will either confirm over the fix, or provide the distance from it.

Modes and Codes

Check ADS-B Out for proper operation and handoff of information when changing Mode-3/A codes. Conduct this test using the UAT link only unless the aircraft is outside the range of all radar coverage. Verify that the controller reads the entered code. Change code to 1200 and another discrete code containing the number 7, (e.g., 0707, or 7070). There is no need to check any of the emergency codes. ADS-B data should be recorded on the aircraft in case a discrepancy is identified to aid in analysis of the problem. Along with the codes, ensure that the ATC altitude readout is within ±125 feet of the indicated aircraft altitude.

Hand-off with Radar-only

Demonstrate on both ADS-B links the proper operation of target hand-off moving from ADS-B coverage to radar-only coverage and vice versa. This check is only applicable to SVs with adjacent radar-only airspace. This test requires the flight inspection aircraft to record time-stamped aircraft position (including altitude) and vector data, referred to as "truth" data, and ADS-B data for post-flight analysis.

Facility Status

The Flight Inspection Services flight inspection report will only reflect a record of what was accomplished during the inspection and will not designate a facility status. Technical Operations Engineering and Air Traffic will determine if the inspection results are satisfactory following post-flight analysis of the data. This information will be published in an Engineering Report. Any NOTAM action is the responsibility of the associated OCC.

Assessment of ADS-B Advisory Services with Flight Inspection Aircraft

ADS-B Pilot Advisory Services consists of ADS-B In, which includes ADS-R, TIS-B and FIS-B. Flight inspection will collect ADS-B In data in conjunction with the commissioning flight inspection of ADS-B Out ATC Separation Services. Analysis of the data will be used to establish a coverage baseline and to make an overall assessment of system performance. The assessment should also investigate anomalies or any misleading information being broadcast.

Automation monitors digital test targets located at each RS. It compares the GPS position against the known surveyed coordinates, effectively monitoring GPS performance. During the commissioning flight inspection of the Service Volume ADS-B Out Critical Services, the radio frequency (transmit) function of the test targets should be turned on. The test targets, typically at FL600 over every RS within the subject SV, continuously broadcast their position on both links. When seen by the flight inspection aircraft ADS-B avionics, it proves communication with that particular RS and demonstrates signal coverage, and helps identify areas of single station coverage.

Evaluation of TIS-B. While checking coverage, general observations can be made during the flight to verify that known radar targets are appearing in the correct relative position on the flight inspection aircraft's ADS-B display(s). Analysis should concentrate on missing and false targets.

Evaluation of FIS-B. FIS-B data reception can be spot checked visually in flight, but post-flight analysis should check for reception coverage, content, and availability. The specific products that are available and display quality can be considered satisfactory if it has already been validated with the same version of ADS-B system software.

Evaluation of ADS-R Coverage and Functionality. This check requires the "dual-link" flight inspection configuration. This test can be performed simultaneously with other coverage checks so that it is checked in multiple areas of the SV. Special attention should be placed on high traffic areas. Service filters and their proper operation are also of primary interest. Assessment of ADS-R performance is accomplished by comparing the recorded flight inspection aircraft position truth data to the corresponding rebroadcast ADS-R positions. These time-stamped truth and ADS-R positions are then compared to evaluate coverage, accuracy, latency, and availability. Verify the ground system's ability to continue ADS-R operation as the aircraft transitions from one SV to the next (vertical or lateral). Any SV that is contained within the SV being inspected should be transitioned also.

AIRCRAFT EQUIPMENT

The FI aircraft, a Learjet 60, is equipped to provide and record the ADS-B Out messages (Separation Services) and record ADS-B In messages (Advisory Services). In order to mirror the equipment available to the flying public as much as possible and because the equipment also acts as the standard aircraft ATC equipage, the equipment is Technical Standard Order (TSO) compliant and installed under the appropriate Supplemental Type Certificate (STC) requirements.

1090 ES Equipment

Equipment manufacturers are now adding ADS-B capabilities to their standard 1090 MHz Mode S/A/C ATC transponders. FIS chose an ACSS XS-950 Data Link Transponder due to it being the first 1090ES transponder compliant to the latest RTCA DO-260B "ADS-B 1090ES Minimum Operating Standard (MOPS)" [3] and TSO-C166b "Extended Squitter ADS-B & TIS-B Equipment Operating on 1090 MHz." The Global Positioning System (GPS) source for the XS-950 is from a Multi-Mode Receiver, Rockwell-Collins GNLU-

955M. ADS-B 1090ES In data is received through a Honeywell TPA-100B Surveillance Processor. The data is routed to the aircraft cabin via an ethernet cable, and displayed and recorded on a laptop computer.

UAT Equipment

The UAT equipment currently available on the market is not compliant with the latest versions of RTCA DO-282B "ADS-B UAT Minimum Operating Standard (MOPS)" [4] and TSO-C154b "UAT ADS-B Equipment Operating on 978 MHz." The FI aircraft currently are equipped with the latest commercially available versions of Garmin GDL 90 UAT Transceiver and GMX 200 Multi-function Display (MFD). The GDL 90 provides the transmit and receive functionality for UAT messages. The GMX 200 provides control and display for the GDL 90. The FI installation ties into a data port provided on the GDL 90 for recording and display of UAT messages, Out and In. The data port is connected to a carry-on laptop computer. Using proprietary software the laptop can display the data for real-time analysis as well as record raw data for post-flight analysis.

Truth Data

The FI aircraft currently provides two sources of "truth" position or vector data. One source is from the Automated Flight Inspection System (AFIS), generated by a Honeywell GPIRS Hybrid Inertial Reference System. The other source comes from a carry on ProFlex 500 AshTech GNSS receiver, which will eventually be installed permanently. The ProFlex data can be post processed if reduced uncertainty is desired.

POST-FLIGHT ANALYSIS

The ADS-B system data, including ASTERIX Category 33 surveillance messages, are taken from the FAA's William J. Hughes Technical Center SDP servers. The Report formats, FAA CAT033 and FAA CAT023, are based upon ASTERIX [5] and are being harmonized with EUROCONTROL. Data from the FI aircraft includes: Position Truth Data in NMEA and ProFlex ATOM formats; ADS-B 1090ES data in a Honeywell MonTPA proprietary format; and, ADS-B UAT data in a MITRE/CAASD proprietary format.

SBS Analysis and Final Engineering Report

Post-flight analysis of data collected by the flight inspection aircraft and that recorded from the ADS-B system and associated automation system will be conducted by Technical Operations Engineering. ADS-B data, including TIS-B, FIS-B and ADS-R, will be collected by the flight inspection aircraft and delivered to SBS Systems Engineering for analysis.

Analysis Software

The FAA's William J. Hughes Technical Center in Atlantic City, NJ is responsible for the Test and Evaluation of new FAA systems. The FAA has several software analysis programs that are utilized in the evaluation of the flight inspection data recordings. The two main analysis programs are called Common Data Analysis Tool (CDAT) and SBS Analysis Tool (SAT) and are available for download from the Technical Center's website. The analysis tools utilize the SBS ASTERIX CAT033 data files and also data recordings taken onboard the aircraft.

Google Earth is also utilized for viewing various SV/CTV information. This information includes radio station locations, radio station predicted coverage, SV/CTV boundaries and target information once the files have been converted to .kml format.

PERFORMANCE CHECKS [6][7][8]

ADS-B Positional Accuracy

The onboard GPS position data (truth data) is compared to the reported ADS-B positions contained in the CAT033 track messages. This positional difference is the measured accuracy.

Another method of measuring track accuracy using the analysis software is called nine-point accuracy which uses a trajectory curve fit method. The difference between the target position and the predicted curve fit position is the reported accuracy. This method is beneficial in that it does not require an independent position source; however a constant error might not be detected.

Figure 2 shows an example of the ADS-B positional accuracy plots shown in the FI reports. The limits are 0.1 nm for En Route SVs, and 0.05 nm for Terminal SVs (per FAA SBS ADS-B Out Final Rule).

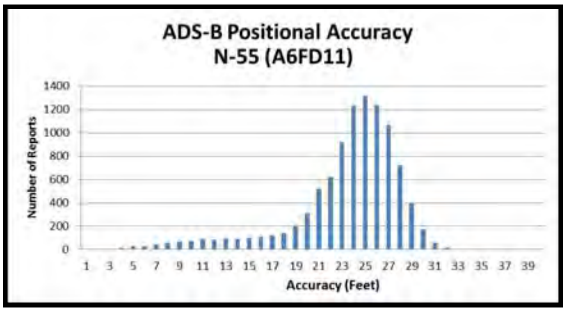

Figure 2. Typical Positional Accuracy Plot

ADS-B Latency

The message latency can be measured between two different data points within the system by comparing the two different timestamps recorded in each file. Latency can also be measured by comparing the Time of Applicability (TOA) to the recorded message timestamp within the SDP CAT33 messages.

Figure 3 shows an example of the ADS-B Latency plots used in the FI reports. The limit is 700 ms (per FAA SBS ADS-B Out Final Rule).

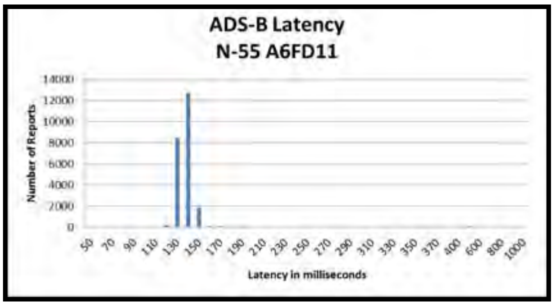

Figure 3. Typical ADS-B Latency Plot

ADS-B Update Interval

Update interval is a measurement of the time between receptions of successive updates. The ADS-B CAT33 SDP messages were used when calculating the update interval.

Figure 4 shows a typical ADS-B Update Interval plot shown in the FI report. The limits are < 6 sec for En Route SVs, and < 3 sec for Terminal SVs (per FAA SBS ADS-B Out Final Rule).

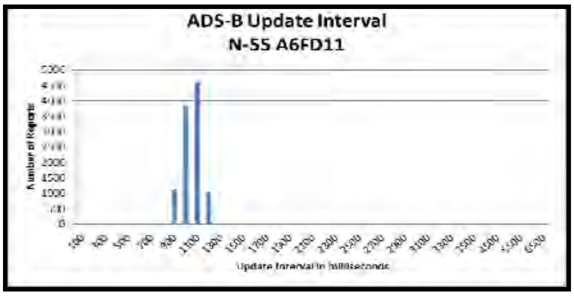

Figure 4. Typical ADS-B Update Interval

ADS-B NACp

The Navigational Accuracy Category for Position (NACp) is reported so that surveillance applications may determine whether the reported position has an acceptable level of accuracy for intended use. The Estimated Position Uncertainty (EPU) is a 95% accuracy on horizontal position. The FAA SBS ADS-B Out Final Rule requires that the system reports a NACp of 8 or greater, which is equivalent to 0.05 nm or better. This accuracy performance value supports all separation minima permitted in the NAS, while lower thresholds may be usable for less stringent applications.

ADS-B NIC

The Navigational Integrity Category (NIC) is reported so that surveillance applications may determine whether the reported position has an acceptable level of integrity for the intended use. It utilizes the integrity parameter containment radius, Rc. The FAA SBS ADS-B Out Final Rule requires that the system be capable of providing a NIC of 7, which is equivalent to better than 0.2 nm. This accuracy performance value supports all separation minima permitted in the NAS, while lower thresholds may be usable for less stringent applications.

ADS-B Validation

The ADS-B service performs a reasonableness test, or validation, of reported ADS-B position data. The reporting criteria for ADS-B Validation as provided in the ADS-B CAT33 message requires a value of '3' to be considered valid.

Radio Station Location Accuracy

The radio stations transmit a Radio Frequency (RF) test target with the RS location. This RS GPS position is used to verify that the location correlates to the system adaptation for the RS's.

Fix / Map Accuracy

During the course of the inspection, aircraft position relative to one or more displayed map fixes should be verified by ATC, i.e., verbal confirmation at time of overflight.

Gap Analysis

Known radar deficient areas are checked for ADS-B coverage. The FAA is evaluating the use of ADS-B as an independent surveillance source. To support the evaluation of the ADS-B only areas, the FI will fly in areas with known radar deficiencies.

Coverage

The flight inspection will be used to evaluate actual coverage of the various airways and airports. The actual coverage is also compared to the predicted coverage plots to verify the predicted system performance for the associated SV/CTV. The Engineering report will provide the actual coverage altitudes for the various fixes and airports.

Various means are used to visualize the coverage data. One method is to show the aircraft track data overlaid onto a coverage plot using Google Earth. Further analysis using the track messages provide more detailed position/altitude values and confirm that the actual coverage is exceeding/meeting the predicted coverage. See Figure 5.

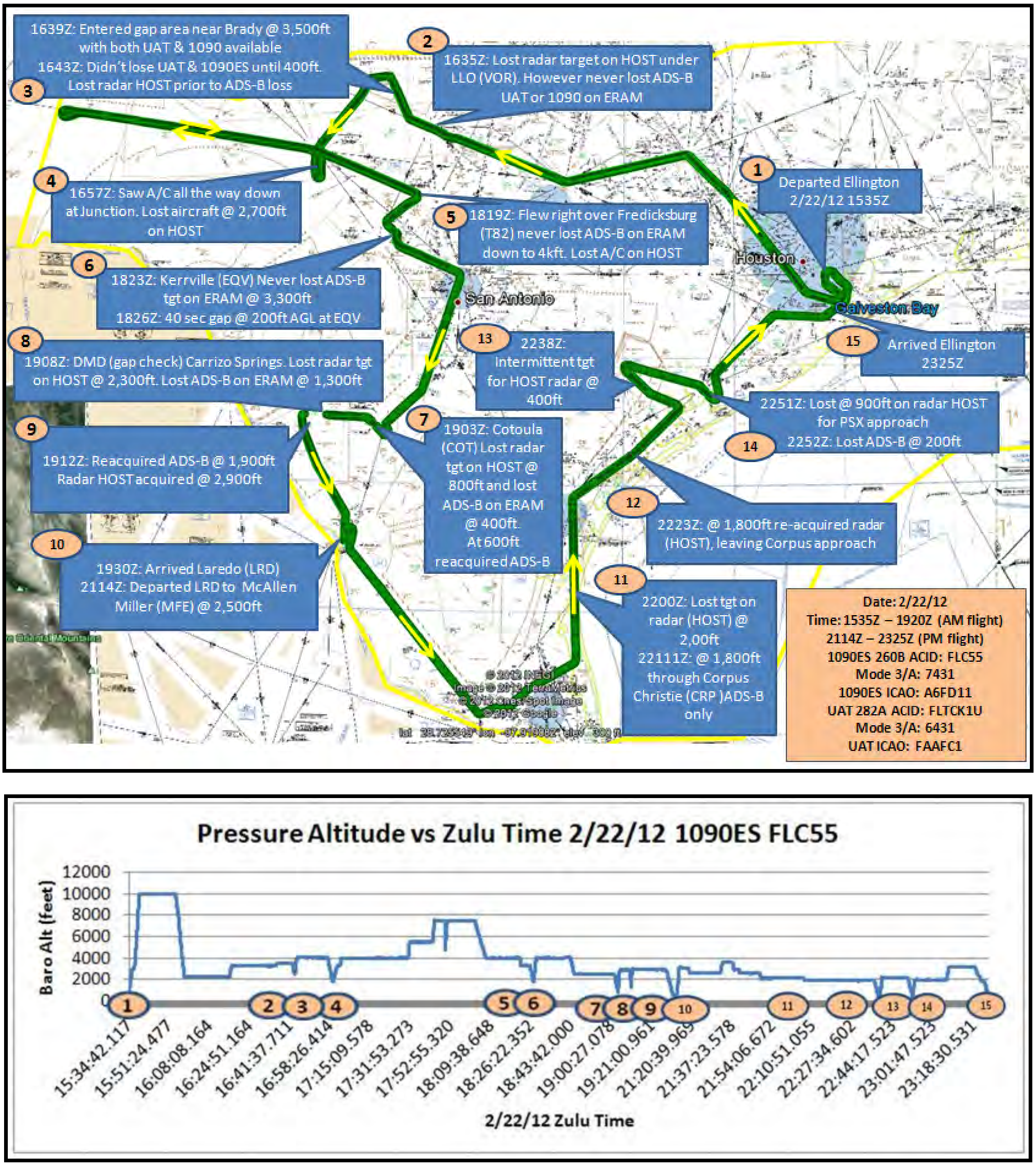

Figure 5. Example Coverage Summary.

ADS-R Positional Accuracy

The aircraft navigation source and avionics are contributors to aircraft-broadcasted ADS-B Report position and velocity accuracy. The avionics broadcast ADS-B Messages that include accuracy parameters in the ADS-B Report. The ADS-R function shall preserve the target position and velocity accuracy represented in each ADS-B Report. ADS-R positional accuracy is verified in the post-flight analysis.

ADS-R Latency

ADS-R latency is the difference between the time of ADS-B Message reception and the time of ADS-R Message transmission. The latency of ADS-R Reports shall be less than 1 second. ADS-R Latency is verified in the post-flight analysis.

RESULTS OF FLIGHT INSPECTIONS TO DATE

The overall performance of the ADS-B system has meet or exceed nearly all expectations of the system. The coverage results have almost always met or exceeded the predicted coverage and the ATC evaluations of the SBS system have been overwhelmingly positive.

SBS Issues

The flight inspection of the SBS services has shown significant improvements in the surveillance coverage delivered to the ATC system. One issue that is typically observed during the FI is the slightly better coverage provided by the UAT link as compared to the 1090ES link. Even though the radio stations are co-located, the UAT link has shown slightly better coverage due to higher link margin for UAT, reduced RF frequency congestion and reduced target loading.

FUTURE WORK

The FAA is developing a Compliance Monitor, which will evaluate ADS-B data to help identify issues with signals in space and ensure aircraft are compliant with regulatory requirements. Along with the SBS Monitor, the Compliance Monitor will ensure that the service performance level is maintained to support continuation of separation services after a flight inspection.

ACKNOWLEDGMENTS

The following people also contributed to this paper:

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The sections in this paper that describe the ADS-B system and its implementation in the U.S. have large amounts of material taken directly from the SBS Program Implementation Plan. [1]

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[8] FAA, August 2007, Final Program Requirements for Surveillance and Broadcast Services, Version 2.1

For Examples of a Flight Inspection Plan and an Engineering Report for an ADS-B Flight Inspection, follow this link and select, ADS-B: http://www.faa.gov/air_traffic/flight_info/avn/flightinspection/onlineinformation/

Flight Testing for ADS-B and Wide-Area Multilateration

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ABSTRACT

For a large country such as Canada, it is not practical to attempt to provide conventional radar service at low altitudes everywhere in our airspace. Consequently, NAV CANADA is investing in Automatic Dependent Surveillance – Broadcast (ADS-B) and Wide Area Multilateration (WAM) at various sites to provide surveillance where radar coverage is not available.

Prior to the commissioning of each of these systems, flight testing is conducted to confirm coverage and performance.

This paper identifies the objectives of NAV CANADA's flight test programs for ADS B and WAM, examines the results, and discusses the particular challenges associated with conducting this type of testing and analysis.

INTRODUCTION

ADS-B and Wide Area Multilateration (WAM) technology offer many advantages over radar for providing aircraft surveillance, especially for a large country like Canada (at 9,984,670 km², it's the second largest country, after Russia). These include:

- Greater accuracy
- Position updates as fast as 1 Hz
- Greater reliability
- Improved site selection flexibility
- Graceful system degradation
- Reduced acquisition and maintenance costs

NAV CANADA has been involved in the flight testing of WAM systems since initial evaluations were conducted in Calgary, Alberta and Twenty-Nine Palms, California in 2006; and Vancouver and Fort St. John, British Columbia in 2008. A system has just been installed in Kelowna, British Columbia. Multilateration is also being used to supplement surface radar in Montreal, and, by the end of the summer of 2012, Calgary, and Toronto.

Between 2009 and 2012, the company has also installed and tested ADS-B equipment to provide surveillance capability over 850 000 square kilometres of Hudson Bay, 1.9 million square kilometres of north-eastern Canada, and a 1.3 million square kilometre portion of the North Atlantic.

BASICS OF OPERATION

WAM

Wide-Area Multilateration consists of a network of ground-based receiver units (RUs) that share an accurate time standard, typically GPS. These receivers detect Mode A/C transponder replies and compute 2-D target positions based on the time of arrival of aircrafts' transmissions. Decoded Mode C replies are used to report altitude.

Selected RUs may also interrogate in areas where there are insufficient radars to ensure a steady supply of replies, or for range aiding (whisper-shout technique).

WAM has the benefit of not requiring any additional avionics, but the aircraft's signal must be seen by several RUs with good geometry to calculate an accurate position.

ADS-B

In ADS-B, data, including aircraft ident, position, and vector, is broadcast using a Mode S transponder. These transmissions may be received by other aircraft or ground-based equipment.

For surveillance purposes, the signals need only be seen by one receiver, which reduces the ground infrastructure somewhat, compared to WAM, but aircraft modifications and specialized avionics are required. In addition, many of the operational advantages of ADS-B are forfeit by the nearby presence of non-participating aircraft.

PRE-COMMISSIONING ACTIVITIES

Before we could use either system in an operational environment, there were two issues that needed to be addressed.

The first is the regulatory approval. Our regulator, Transport Canada, needed to be satisfied that the technology was suitable for this application.

One particular challenge to obtaining the authorization to use ADS-B for surveillance was the lack of a coherent avionics standard. There existed (and still exists) a wide range of capabilities among aircraft that claim to be equipped for ADS-B. As a result, we had to develop an implementation plan that incorporated special restrictions. For example, through a survey of operators, we developed a list of aircraft having known, approved avionics configurations; our controllers are permitted to use ADS-B to separator only aircraft on the list.

The second is the verification of site-specific performance requirements. These are developed in cooperation with Air Traffic Control (ATC) personnel who will be using the system, and typically form part of the contractual agreement with the provider of the equipment.

Performance Standards

The international community was in the process of developing guidance material standards for ADS-B [1],[2][3],[4] when our interest in this area began.

For WAM, there was no material at all, so we developed our own Operational Performance Requirements Document (OPRD).

Our strategy for obtaining approvals for emerging technologies has been to demonstrate that the proposed system is at least as good as others currently in use. For WAM, this is radar. Thus, our OPRD refers to the signal characteristics from Annex 10 Volume IV and borrow heavily from the performance metrics in defined in our company radar requirements and ICAO documents[5][6].

This enables our government regulatory agency to assess the candidate system against existing, well-understood technologies.

This approach has been successful; in fact, NAV CANADA is the first air navigation system provider in the world that has been granted permission to use WAM in any environment where radar can be used, including supporting a 3-NM separation standard.

Operational Requirements

There are also operational requirements that are site-specific. These typically involve the definition of a coverage volume, and form part of the contractual agreement with the equipment supplier. These are typically negotiated between the local ATC unit and Level-of-Service personnel.

FLIGHT TESTING

Flight testing is used first to assess the system under test, first, in order to demonstrate equivalence with existing, approved technologies, and second, to determine site-specific performance and to ensure that contractual conditions were met.

For the flight tests, recording equipment is installed on the aircraft. This typically consists of a GNSS receiver, preferably with SBAS or local differential capability, and a computer for control, acquisition, and storage. Enhanced user interface features, like eventing and operator comment recording, are desirable.

Aircraft selection is made based on the operational environment. For example, a Beech Duchess was used for the Vancouver Harbour trials, where the traffic is predominantly low-flying, slow, float planes and helicopters, while a company Canadair Regional Jet normally used for flight inspection was used for Hudson Bay and the NAT programs.

On the ground, time-stamped target report data is recorded by the WAM or ADS-B system.

Assessed Parameters

The parameters assessed during the flight testing included:

- Probability of detection;
- False target report rate;
- Target accuracy within the defined service volume;
- Overlap of multiple sensors;
- Graceful degradation of performance as RUs fail;
- Position resolution;
- Latency;
- Ground speed accuracy (WAM); and
- Service volume (coverage).

Other parameters of interest, such as emergency code processing, update rate, coasting, et cetera, are assessed outside of the context of the flight test.

Analysis Challenges

Parameters such as detection probability are relatively simple to assess, with enough samples.

The measure of accuracy, however, is not so straightforward. What position data does one use as the truth system? There is an argument to be made that if you're attempting to demonstrate that the candidate surveillance system is at least as good as radar, then you should be showing consistency with radar. Those with radar backgrounds are generally supporters of this concept. However, this is fundamentally flawed, since radar itself has inherent accuracy limitations, and the general rule of thumb is that a truth system should be three to five times more accurate than the system you're testing. Thus, it makes more sense to compare ADS-B and WAM target report positions with GPS, ideally differentially corrected using local or wide-area systems.

But the greatest challenge associated with flight testing is the determination of latency, since we had no practicable method to determine the exact time of transmission of the transponder reply. As a result, it is impossible to measure the end-to-end transit time directly. Furthermore, latency appears as an along-track position error, and so compensation for this delay must be made before accuracy can be assessed. Consequently, we devised two methods to estimate the latency.

However, each method requires that some processing be done before it can be performed. The truth position data from the aircraft is recorded at 2 Hz and are aligned on the GPS second, but are completely asynchronous with the WAM and ADS-B data. Fortunately, though, the latter are time-tagged and referenced to GPS, and for each target report, we locate the truth data records that bound it, and interpolate to estimate the aircraft position at the instant the target report was generated. (We consider the assumption that the aircraft's vector won't change appreciably in 0.5 second to be valid.)

Now we have two sets of data: position truth, and target reports, with a one-to-one correlation.

The first of the methods involves applying a time offset to one of the data sets, and adjusting it until the standard deviation of the 2-D position error is minimized.

The second method is to separate the along-track and cross-track error components, and then apply the time offset as before, until the average along-track error is minimized.

In each case, the offset provides a measure of the latency, and the resulting time-shifted error file may then be used to compute the target report position accuracy. The two methods yielded similar estimates of latency.

Results

The generic flight testing conducted in order to demonstrate the general performance of WAM consisted of an arc of 15 NM around the airport at 800' AGL, a 25-NM at 1500' AGL, a 40-NM arc at 8500' AGL, and several published instrument approach procedures., and showed that it exceeded that of SSR.

Figures 1 and 3 show the distribution of target report position errors for the 40-NM arc and approaches, respectively. Figures 2 and 4 depict the same data as a probability diagram. It should be noted that the 40-NM arc was particularly challenging for the system, since the receiver units were situated mainly around the airport, and so the geometry on the arc was expectedly poor. However, the WAM system still outperformed radar.

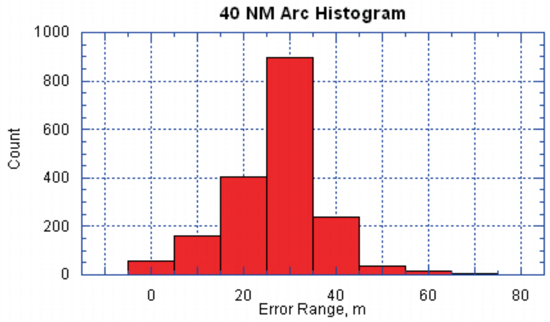

Figure 1 - Target Accuracy (40 NM Arc)

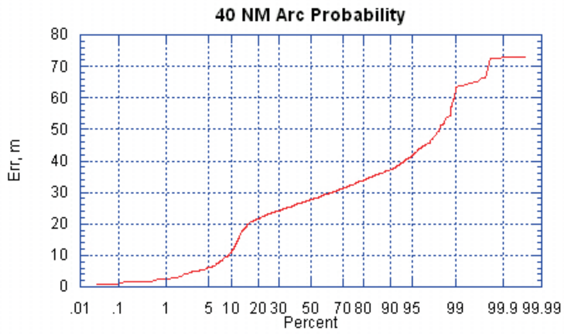

Figure 2 -Target Accuracy (40 NM Arc)

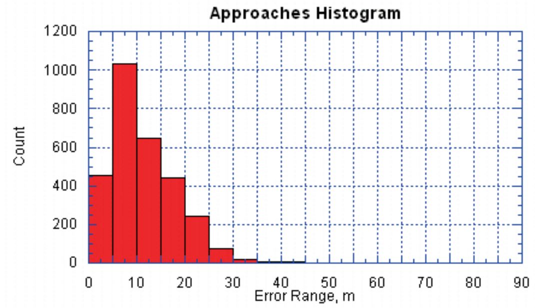

Figure 3 - Target Accuracy (Approaches)

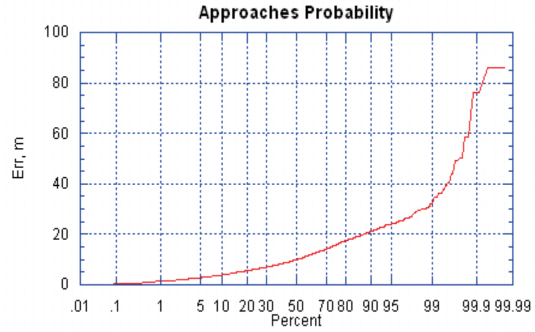

Figure 4 - Target Accuracy (Approaches)

Site-specific testing consists of confirming service coverage and system performance over the entire area in which WAM or ADS-B surveillance is required. Typically, this includes airways, tracks, terminal procedures (arrivals and departures), instrument approaches, and possibly VFR routes or practice areas.

Figure 5 shows the tracks flown for the coverage and accuracy testing at Vancouver Harbour. Multiple tracks will be observed over the same region; this is because tests were conducted over a period of several days, during which system configuration was adjusted changed to improve performance. In retrospect, it would have been better to assess coverage using targets of opportunity, and bring in the flight test aircraft only after the performance had been optimized.

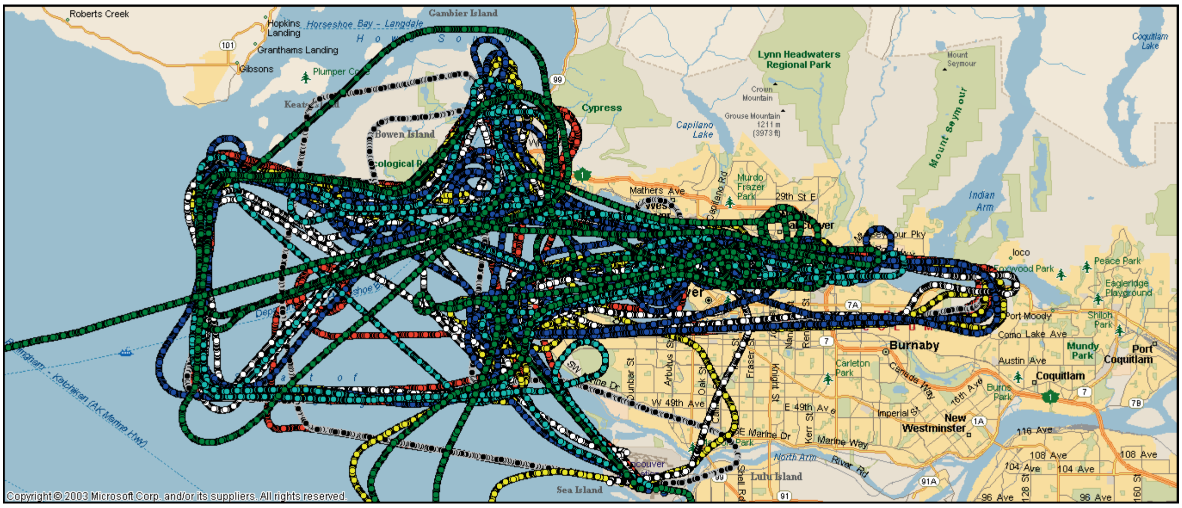

Figure 5 - Vancouver Harbour Flight Test Tracks

Where deficient performance is identified during flight testing, additional ground receivers or directional antennas were incorporated to provide the required level of service.

In the case of WAM, local test results are also used to assist the equipment supplier to adjust the system adaptation for maximum performance.

Table 1 lists the various performance parameters specified in various sources, and the corresponding values measured on the candidate WAM system

Parameter	NAV Radar Performance	ICAO 8071 Vol III	FAA ASR-11 Terminal	WAM
Range Accuracy	1/8th NM (760' / 231 m)	Mean < 50 m Max < 150 m	190' (58m) RMS	28 m (92 ft) with 40 NM arc included 25 m (82 Ft) Without the 40 NM arc
Azimuth Accuracy	±0.25°	< 0.1°	0.8° RMS	
Probability of Detection	97%	Mode A 98.0%, Mode C 96.0% Mode S N/A	99.5%	Mode A 99.7%, Mode C 99.7% Mode S 99.7%
False targets /scan	< 1	< 0.1%	< 1	< 1
Range Resolution	1/16 NM	Pd 98% ≥ 100 m	0.05-0.5 NM at 95% >0.5 NM at 99.9%	0.0625 NM
Azimuth Resolution	1°	Pd 98% ≥ 1.5°	2.1° at 95% (identical targets) 1.5° at 99.9%(different mode A or C)	
Total Latency	1.67s	N/A	2.2s	0.463s
Max Possible Update Rate	5s	N/A	4.8s	1s
Availability	99.92	N/A	0.99998	0.999996
MTBF	5000 Hrs	N/A	1070 Hrs	8760 Hrs
Target Capacity	400	N/A	700	>600*

Table 1- WAM Performance Summary

*limited by the 56k telecom link at the test site. Increases to >2000 targets when high-speed communications are available.

CONCLUSIONS

Flight evaluation of surveillance systems that provide alternatives to radar is not particularly difficult or complex, but the tests must be designed to meet the basic objectives, namely to demonstrate the overall performance of the system, and to confirm that local operational requirements are met. A GNSS-based position and time truth system is required, ideally augmented by SBAS, for example, which provides not only improved accuracy, but a measure of guaranteed integrity in the position data generated.

Access to the raw target reports provides the means to evaluate performance parameters such as probability of detection, accuracy, and latency.

ADS-B and WAM offer significant advantages where radar service is not possible or practical, and their performance can be assessed by flight testing using relatively simple onboard equipment.

ACKNOWLEDGMENTS

The assistance of Dave Ferriss, Mike Botting, Olivia Orwin, and Marty Tate, all of NAV CANADA, in reviewing this paper is gratefully acknowledged.

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Use of Digital Filtering Techniques to Assess VOR Accuracy

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ABSTRACT

The ICAO Manual on Testing of Radio Navigation Aids (Doc 8071) provides guidance for assessment of VOR accuracy, and recommends flight inspection tolerances for alignment, for bends and for roughness and scalloping.

For VORs installed in challenging environments, the raw measurements of VOR error on a radial or orbit may be noisy and complex. In such cases it can be difficult for a flight inspector to distinguish between various error components and to accurately estimate the amplitude of each. In such cases, pass/fail decisions can become subjective, and may be different from inspector to inspector or from one flight inspection to the next.

Taking as a conceptual model the digital filters proposed for MLS in Attachment G of ICAO Annex 10, NAV CANADA has implemented in its flight inspection system a set of digital filters to facilitate the assessment of VOR errors.

This paper outlines the rationale used to define these filters and the associated tolerances, and presents practical results of their use in flight inspection of Canadian VORs.

INTRODUCTION

NAV CANADA performs regular flight inspections of some 120 conventional and Doppler VOR facilities, applying flight inspection procedures and tolerances consistent with the guidance of Doc 8071.

Traditionally, NAV CANADA's flight inspection system computed the VOR bearing error and plotted it on a graph for the technical flight inspector, who visually inspected the graph to estimate the amplitudes of bends, scalloping and roughness.

VOR are occasionally sited in non-ideal environments, leading to high bearing error, particularly for conventional VOR. The bearing error characteristic will typically consist of several superimposed error components of varying magnitudes. It is sometimes difficult to subjectively separate the graphed errors into bends, scalloping and roughness, and to decide whether each component exceeds its tolerance. In such cases, pass/fail decisions may be different from inspector to inspector or from one flight inspection to the next.

Uncertainty and variability of pass/fail decisions can result in additional costs and scheduling issues for the flight inspection organization. Users of the air navigation system can also be affected in the event of VOR procedures being removed by NOTAM. In an environment with separate air navigation service provider and regulatory organizations, the uncertainty also complicates the demonstration of regulatory compliance.

In support of flight inspection efficiency and regulatory acceptance, NAV CANADA decided to incorporate into its flight inspection system suitable filter algorithms to separate and calculate VOR bends and roughness and apply tolerances, in an automated and repeatable fashion. This paper outlines the rationale used to define these filters and the associated tolerances, and presents practical results of their use in flight inspection of Canadian VORs.

ICAO STANDARDS AND TOLERANCES

ICAO Annex 10 standards for VOR do not include well-defined signal-in-space accuracy tolerances. Guidance material concerning recommended VOR accuracy parameters and tolerances is provided in Doc 8071.

Doc 8071 calls for assessment of the overall VOR station alignment as the average bearing error measured throughout an orbit of the facility (or the average error from a series of at least eight radial measurements). The Annex 10 tolerance of ±2° for "the ground station contribution to the error in the bearing information" is considered applicable to this measurement.

For assessment of radials, the Doc 8071 guidance is to separate the lower frequency bends and the higher frequency scalloping and roughness from the original signal, and then assess each individually [reference Doc 8071 figure I-2-2 and para 2.3.48 and 2.3.49]. The recommended tolerance for bends is the lesser of 3.5° from the average measured course line or 3.5° from the nominal course line. For scalloping and roughness, a tolerance of ±3.0° is proposed.

DEVELOPMENT OF DIGITAL FILTERS

General Approach to Filtering

In describing the analysis of course structure for VOR radials, Doc 8071 states:

> *"Modern flight inspection systems can automatically carry out the analysis of a course structure."*

Unfortunately, Doc 8071 does not provide any further guidance on implementation of this automated analysis. On the other hand, fairly complete guidance on the analysis of course structure is provided for the microwave landing system (MLS), in Attachment G to Annex 10.

MLS structure is specified in terms of three parameters:

a. Path Following Error (PFE) represents slow deviations, including any alignment bias, and is analogous to bends measured with respect to the nominal course line.

b. Path Following Noise (PFN) also represents slow deviations, but excluding any alignment bias that is included in PFE, and is analogous to bends measured with respect to the average course line.

c. Control Motion Noise (CMN) represents higher frequency deviations within the bandwidth of the autopilot, and is analogous to scalloping and roughness.

Attachment G to Annex 10 outlines filter types and equations for the measurement of PFE and CMN. PFE is measured at the output of a two-pole low-pass filter, whereas CMN is measured at the output of a single-pole high-pass filter. An additional single-pole low-pass filter provides an upper limit on the CMN spectrum, representing the bandwidth of the auto-pilot.

NAV CANADA concluded that the MLS methodology for PFE and CMN parameters and filters could reasonably and justifiably be applied as a basis for the automation of VOR error assessment.

Selection of PFE and CMN Filter Frequencies

Doc 8071 does not formally define a dividing line between bends, scalloping and roughness, but hints at one by means of an example:

> *"A smooth deviation of the course over a distance of 3.7 km (2 NM) would manifest itself as a bend for a flight inspection aircraft at a ground speed of 140 knots. An aircraft of greater speed would not detect such smooth deviations of the course as a bend, unless it was over a much greater distance."*

This text was used as a starting point to select filter corner frequencies. The bend was envisaged as a deviation to one side of nominal track followed by a return to nominal, thus representing approximately one-half wavelength at the corner frequency. For an aircraft flying at a ground speed of 140 knots, the wavelength of 4 NM then corresponds to a frequency of 0.0097 Hz. This frequency may be scaled upward if the flight inspection ground speed is faster than 140 knots. As typical ground speeds used in Canada for VOR flight inspection are in the range of 200 to 220 knots, this frequency would scale up to approximately 0.015 Hz. An informal sensitivity analysis concluded that small changes in the corner frequency would not significantly affect the flight inspection results. NAV CANADA settled on corner frequencies of 0.02 Hz for both PFE and CMN as a matter of convenience, rather than have the frequency dynamically adjusted by the actual ground speed of the flight inspection aircraft.

Selection of Low Pass Filter Frequency

The MLS filter model includes a low-pass receiver output filter with a corner frequency of 10 rad/s (approximately 1.6 Hz). Experienced NAV CANADA pilots advised that it is normal practice to fly noisy VOR radials by operating the autopilot in heading mode, and then manually enter heading corrections based on observed drift with respect to the desired course. This has the effect of heavily damping the noise as if by a low-pass filter with a very low corner frequency. Although selection of an exact corner frequency was somewhat subjective, a consensus was reached for 0.125 Hz based on reasonable empirical results from examples of real VOR radial measurements.

Low-Pass Filter for Orbit Assessment

It has been a long-standing practice at NAV CANADA to assess the distribution of errors for an orbit as an indicator of certain ground facility problems, and as an indicator of possible poor radials in a sector. Part of the orbit assessment is to look for cyclic errors of various indicative of certain faults or misadjustments of the ground equipment. The highest frequency among these signature cyclic errors is 18-cycle error (i.e. a cyclic error component with a period of 20 degrees of arc). It was concluded that a PFE-style low-pass filter would be an appropriate tool to damp out higher frequency components of the orbital bearing error measurement, with a corner frequency selected to avoid attenuating any 18-cycle error.

During routine flight inspections, NAV CANADA normally flies VOR obits at a radius of 10 NM. At flight inspection ground speeds of 200 to 220 knots, the angular velocity is approximately 0.33 degrees/s. Thus, 18-cycle error would be detected with a period of 60 s, or a frequency of 0.017 Hz. To pass this signal without attenuation, a corner frequency of 0.05 Hz was selected for the low-pass orbit error filter.

Final Configuration of VOR Error Filters

The final configuration selected for the VOR error filters is as follows:

a. A two-pole low-pass filter with a corner frequency of 0.02 Hz for the assessment of bends along radials;

b. A one-pole high-pass filter with a corner frequency of 0.02 Hz, cascaded with a one-pole low-pass with a corner frequency of 0.125 Hz, for the assessment of scalloping and roughness along radials; and

c. A two-pole low-pass filter with a corner frequency of 0.05 Hz for the assessment of orbit structure.

95% Sliding Window

Annex 10 Attachments C and G describe the use of a sliding time window for the assessment of errors against tolerances not to be exceeded by 95% of measurement samples within a short period of time (typically 40 s). NAV CANADA did consider the option of implementing a sliding window calculation for VOR errors. Given the relatively low corner frequencies selected for the VOR filters, however, it would appear that a only a sliding window of very long duration would have a significant effect on the error assessment. As a result, it was decided not to include a sliding window calculation for VOR error assessment.

VOR FLIGHT INSPECTION TOLERANCES

With the introduction of the digital filters for assessment of VOR accuracy, the flight inspection system has been configured to automatically apply the following error tolerances, which are reflected in NAV CANADA's VOR flight inspection standards and procedures document:

a. Bends along a radial must not exceed 3.5° from nominal course line or 3.5° from average course line.

b. Scalloping and roughness along a radial must not exceed ±3°.

c. Average alignment error around an orbit must not exceed 2° (tolerance at commissioning is 1°).

d. Structure around an orbit should not exceed ±3° from nominal alignment. If exceeded, an additional radial must be inspected in the sector where the tolerance was exceeded.

EXAMPLES OF APPLICATION OF VOR ERROR FILTERS

Figures 1, 2 and 3 illustrate actual examples from recent flight inspections of three conventional VOR facilities. (All figures in this paper have been regenerated from flight inspection data as Microsoft Excel charts, for ease of formatting for presentation.)

Figure 1 is from a VOR sited on rocky terrain. This graph for an inbound measurement on a published radial shows a series of bends, including a relatively large bend centred at a distance of approximately 8 NM from the facility. The filtered bend (PFE) trace is smoother and somewhat attenuated compared to the raw error trace, and the abrupt end of the deviation generates a noticeable jump in the roughness (CMN). It is clear from the filtered traces that the bends do not exceed 3.5° from nominal and that the scalloping and roughness do not exceed ±3°.

Figure 2 compares two approaches at different altitudes for the same radial of a VOR. In the graph on the left, the scalloping and roughness (CMN) trace shows very strong scalloping exceeding the tolerance of ±3°. The graph on the right, from a flight at a higher altitude, clearly shows that the scalloping is in tolerance at that altitude.

Figure 3 is a graph generated from an orbit measurement. The low-pass filtered trace shows the presence of 18-cycle error from interaction with the 18 monitor antennas installed on the edge of its counterpoise. (Some 2-cycle error from a small imbalance between the two pairs of Alford loop antennas is also visible.)

CONCLUSION

The implementation of digital filter algorithms for the assessment of VOR errors has been successful in reducing the subjectivity in assessing cases of marginal VOR performance. This will improve the measurement repeatability and thereby contribute the efficiency of flight inspection operations.

FUTURE WORK

The Working Group of the ICAO Navigation Systems Panel has an open work task to review and update Doc 8071 as appropriate. The development of guidance material on digital filters for the assessment of VOR errors has been identified as a candidate component of this task. NAV CANADA intends to contribute to this effort, drawing on the experience gained from the implementation of the filters discussed in this paper.

ACKNOWLEDGMENTS

The authors would like to acknowledge the efforts of the Direction des Services de la Navigation Aérienne (DSNA, the Department of Air Navigation Services, France). This organization undertook development of VOR filters in a similar time frame to NAV CANADA's initial efforts. Although the implementations by the two organizations have some differences, DSNA's sharing of ideas and test results at working group meetings of the ICAO Navigation Systems Panel was very helpful.

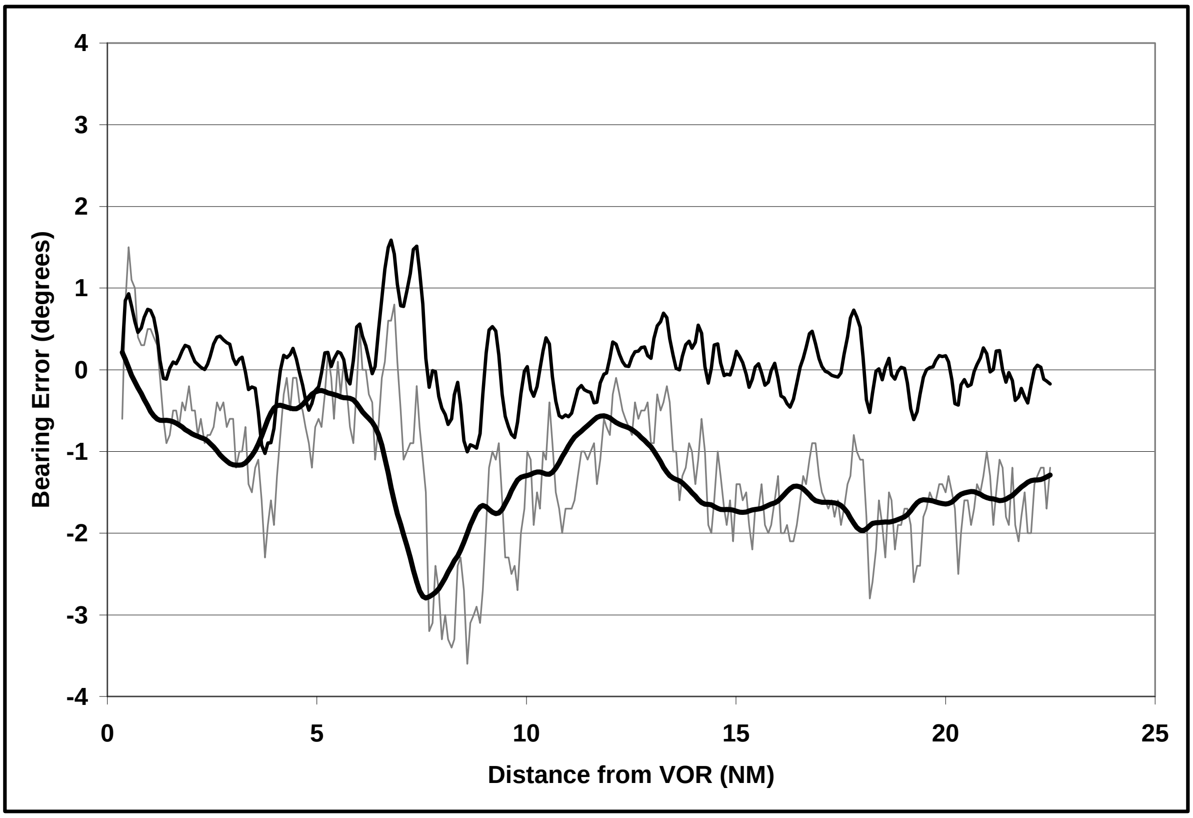

Figure 1. Raw and Filtered (PFE and CMN) Radial Errors for a Conventional VOR with a Marginal Bend

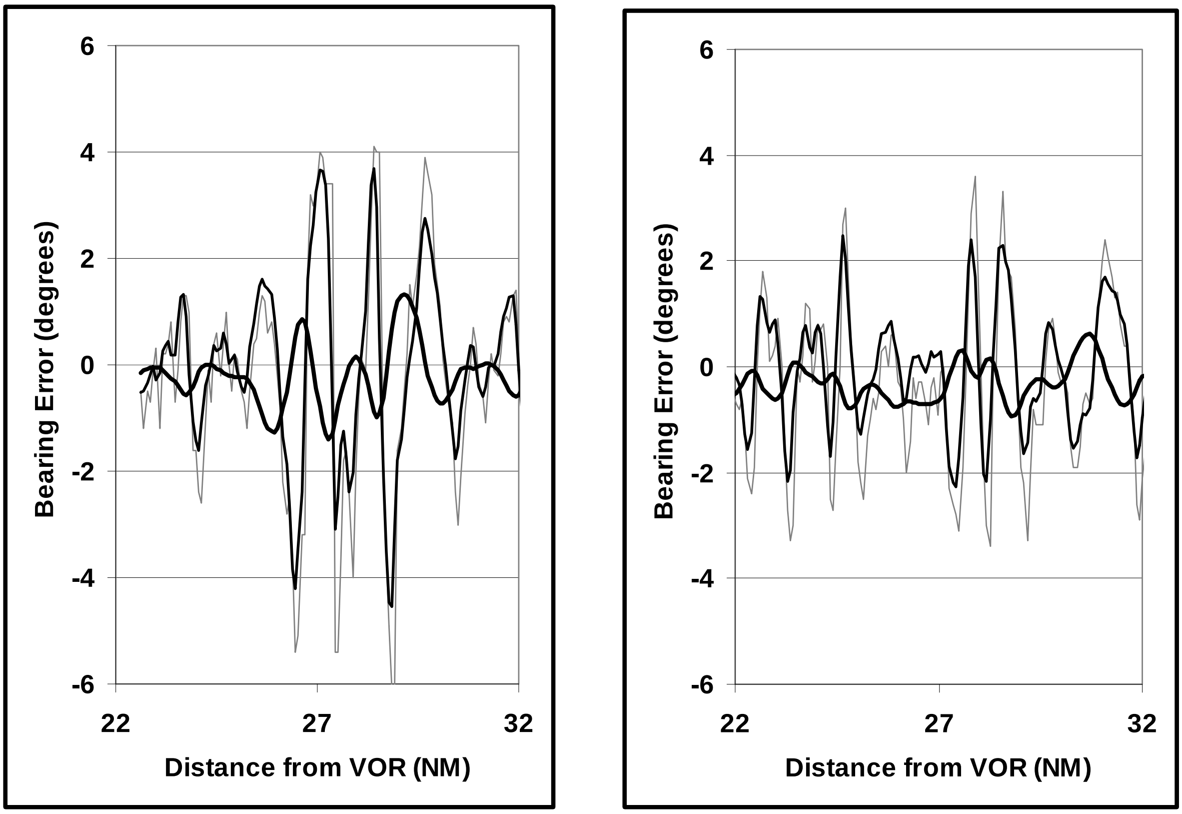

Figure 2. Raw and Filtered (PFE and CMN) Radial Errors at Two Altitudes for a Conventional VOR with Marginal Scalloping

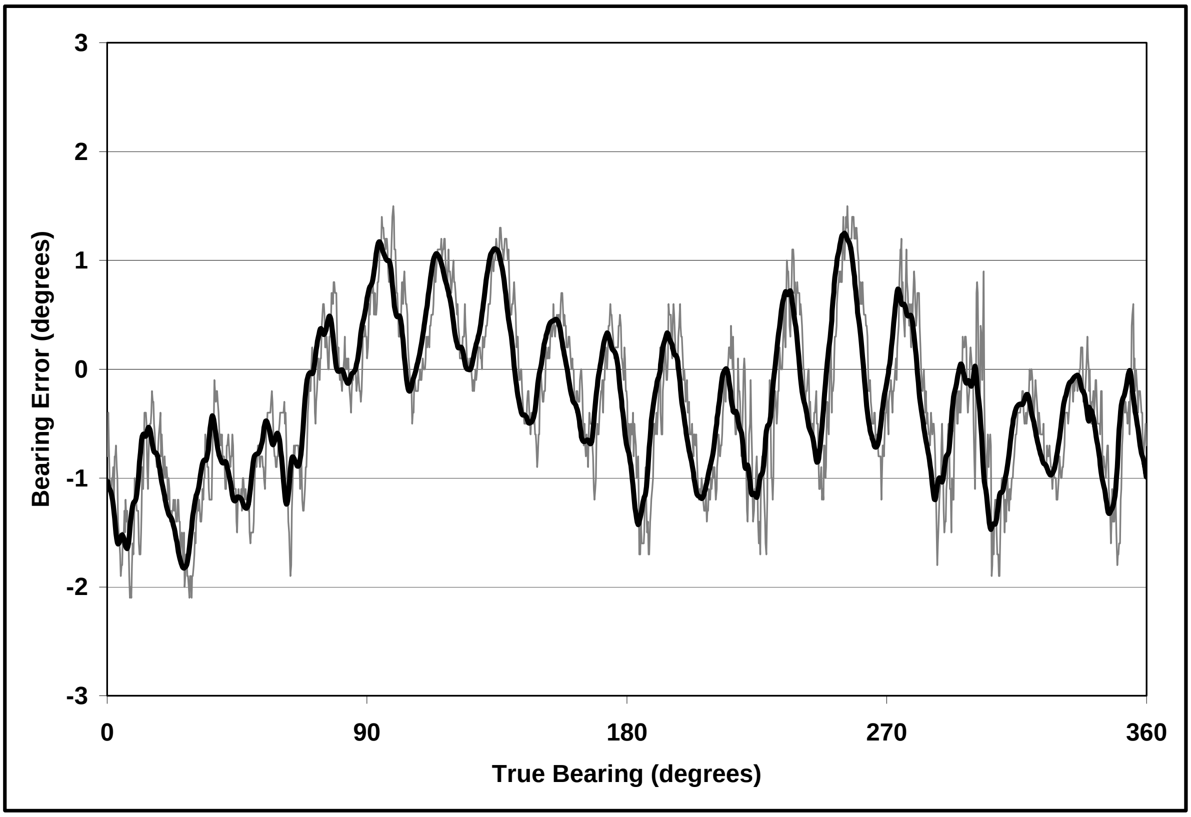

Figure 3. Raw and Filtered Orbit Errors for a Mountaintop Conventional VOR

How to get a good correlation between ILS ground measurements and flight checks?

Thanks to modern and accurate ground measurement techniques this is a solvable challenge.

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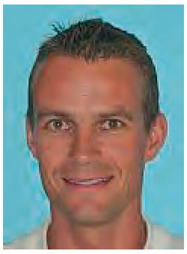

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ABSTRACT

According to the ICAO norms, ILS ground measurements for preventive (and corrective) maintenance are highly recommended. They also represent complementary measurements to flight inspection.

Moreover, a high degree of correlation between flight and ground measurements is more than a quality indicator. It is indeed a key point recommended by ICAO Document 8071!

Ground measurement techniques such as GPS integration (for vehicle positioning), very high sampling rate (100 measurements per second) and dissociated Course / Clearance analysis make it possible to reach new quality standards in terms of:

- Accuracy
- Repeatability
- Resolution
- and thus flight check correlation

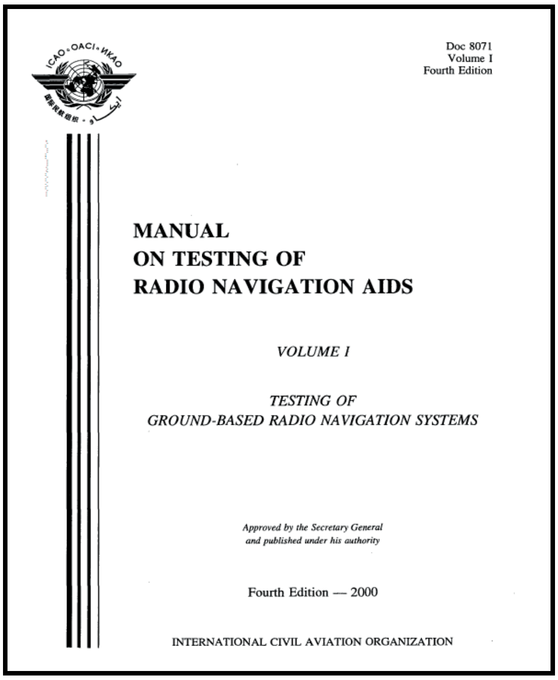
The R&S®TS6300 is such an ILS Test System, composed of the ILS receiver R&S®EVS300 from Rohde&Schwarz and the software “ILS Checker” designed by skyguide, the swiss air navigation services. It is in use in several countries in Europe. The experience shows not only a high degree of correlation in Localizer and Glide Path modes, but also the possibility to conduct deeper analysis.

The high resolution indeed permits to discover and understand perturbations and even new effects, thatwhich can not be measured by flight inspection. Moreover, its use aboard an aircraft

has shown new possibilities in terms of signal correlation, analysis and understanding.

INTRODUCTION

According to the ICAO norms, ILS ground measurements for preventive maintenance are strongly recommended. Indeed, ICAO Document 8071 "Manual on Testing of Radio Navigation Aids" (Volume 1 Testing of Ground-Based Radio Navigation Systems) provides guidance on the extent of testing and inspection carried out to ensure that radio navigation systems meet the SARPs (Standards And Recommended Practeces) in ICAO Annex 10. This document describes the ground and flight testing in terms of periodicity, tolerances (in reference to the SARPs) and methods.



Doc 8071
Volume I
Fourth Edition

MANUAL
ON TESTING OF
RADIO NAVIGATION AIDS

VOLUME I

TESTING OF
GROUND-BASED RADIO NAVIGATION SYSTEMS

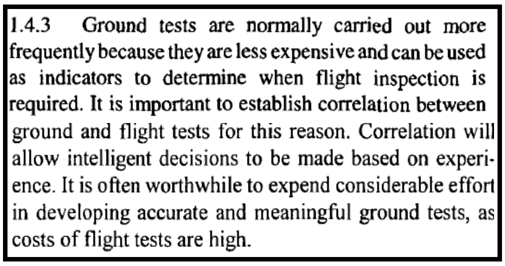
Approved by the Secretary General
and published under his authority

Fourth Edition — 2000

INTERNATIONAL CIVIL AVIATION ORGANIZATION

Figure 1. FrontPage of ICAO Document 8071

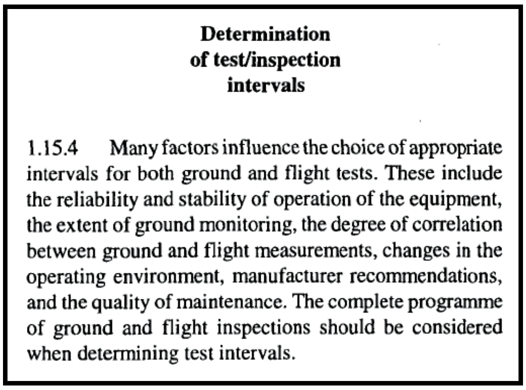
ICAO Doc 8071 explicitly mentions and recommends the use of the correlation between ground and flight tests, for example in paragraph 1.4 "Ground Versus Flight Testing / Inspection":



1.4.3 Ground tests are normally carried out more frequently because they are less expensive and can be used as indicators to determine when flight inspection is required. It is important to establish correlation between ground and flight tests for this reason. Correlation will allow intelligent decisions to be made based on experience. It is often worthwhile to expend considerable effort in developing accurate and meaningful ground tests, as costs of flight tests are high.

Figure 2. Extract from Document 8071, Paragraph 1.4 "Ground Versus Flight Testing / Inspection"

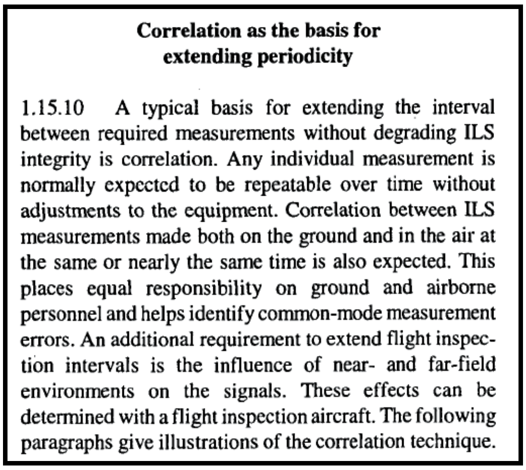
Moreover, Document 8071, especially paragraph 1.15 "Ground and Flight Inspection Periodicity" which contains nominal schedule, as a basis for determining the appropriate inspection intervals, raises the question of the possible extension of these intervals based on several criteria, such a "good correlation between concurrent ground and airborne results".



Determination
of test/inspection
intervals

1.15.4 Many factors influence the choice of appropriate intervals for both ground and flight tests. These include the reliability and stability of operation of the equipment, the extent of ground monitoring, the degree of correlation between ground and flight measurements, changes in the operating environment, manufacturer recommendations, and the quality of maintenance. The complete programme of ground and flight inspections should be considered when determining test intervals.

Figure 3. Extract from Document 8071, Paragraph 1.15.4 "Determination of test/inspection intervals"



Correlation as the basis for
extending periodicity

1.15.10 A typical basis for extending the interval between required measurements without degrading ILS integrity is correlation. Any individual measurement is normally expected to be repeatable over time without adjustments to the equipment. Correlation between ILS measurements made both on the ground and in the air at the same or nearly the same time is also expected. This places equal responsibility on ground and airborne personnel and helps identify common-mode measurement errors. An additional requirement to extend flight inspection intervals is the influence of near- and far-field environments on the signals. These effects can be determined with a flight inspection aircraft. The following paragraphs give illustrations of the correlation technique.

Figure 4. Extract from Document 8071, Paragraph 1.15.10 "Correlation as the basis for extending periodicity"

Thus, according to the ICAO recommendations, the achievement of good correlation places same or similar weight on both ground and airborne testing. That's why it is worth developing and using modern and accurate ground measurement techniques in terms of repeatability and resolution.

MODERN AND ACCURATE GROUND MEASUREMENT TECHNIQUES

The R&S®TS6300 ILS Test System from Rohde&Schwarz and skyguide

Thanks to the new functionalities of the R&S®EVS300 ILS/VOR Analyzer (very high sampling of 100 Hz, dissociated Course / Clearance analysis, GPS integration for the vehicle positioning) and its associated ground measurement software, the so-called R&S®ILSChecker Software, it is now possible to conduct accurate and repetitive ground measurements.

This modern ILS test system covers the different ILS modes:

- For Localizer: Course Structure along the runway centerline and Localizer azimuth Coverage around the LOC.

Figure 5. Measurement Vehicle in the LOC Mode Configuration

- For Glide Path: Elevation profiles for image arrays and transverse structure profiles for End-Fire Glide Path.

Figure 6. Telescopic Mast and Measurement Vehicle in the GP Mode Configuration

The R&S®ILSChecker has been developed by the technical maintenance users and field engineers from skyguide, the swiss air navigation services.

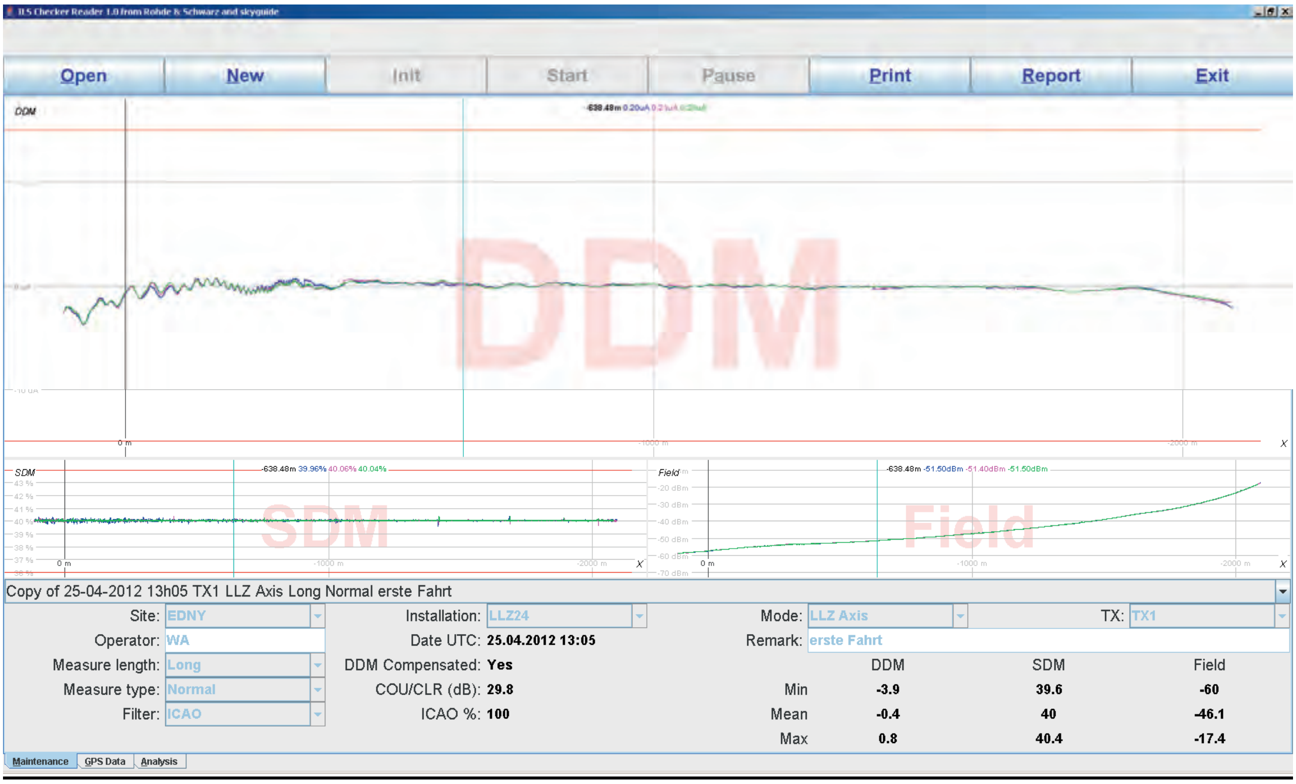
Not only recommended by ICAO Document 8071, such ground measurements also enable an excellent and necessary preparation for commissioning flight checks:

- They represent indeed a very accurate and valuable pre-tuning of the systems. This ground pre-tuning can be so accurate that a retuning of the parameters during the calibration flights is not necessary. Since 2009, several ILS commissionings have confirmed that such ground pre-tunings have not been modified during flight check.

- Thus, they also enable a substantial gain of time and efficiency for flight checks.

Repeatibilty

In order to assess and demonstrate the quality and the accuracy of a measurement system, repeatability is one of the key factors which has to be demonstrated and documented. During the development, introduction and deployment phases of the R&S®TS6300 ILS Test System, several repeatability tests have been conducted and validated in each measuring mode: LOC Course Structure and Coverage, GP (elevation) Coverage and End-Fire Transverse Structure modes.



Copy of 25-04-2012 13h05 TX1 LLZ Axis Long Normal erste Fahrt

Site: EDNY
Installation: LLZ24
Mode: LLZ Axis
TX: TX1
Operator: WA
Date UTC: 25.04.2012 13:05
Remark: erste Fahrt
Measure length: Long
DDM Compensated: Yes
Measure type: Normal
COU/CLR (dB): 29.8
Filter: ICAO
ICAO %: 100

	DDM	SDM	Field
Min	-3.9	39.6	-60
Mean	-0.4	40	-46.1
Max	0.8	40.4	-17.4

Figure 7. Repeatability tests for the LOC Course Structure Mode (DDM , SDM and Field versus Distance to the Threshold)

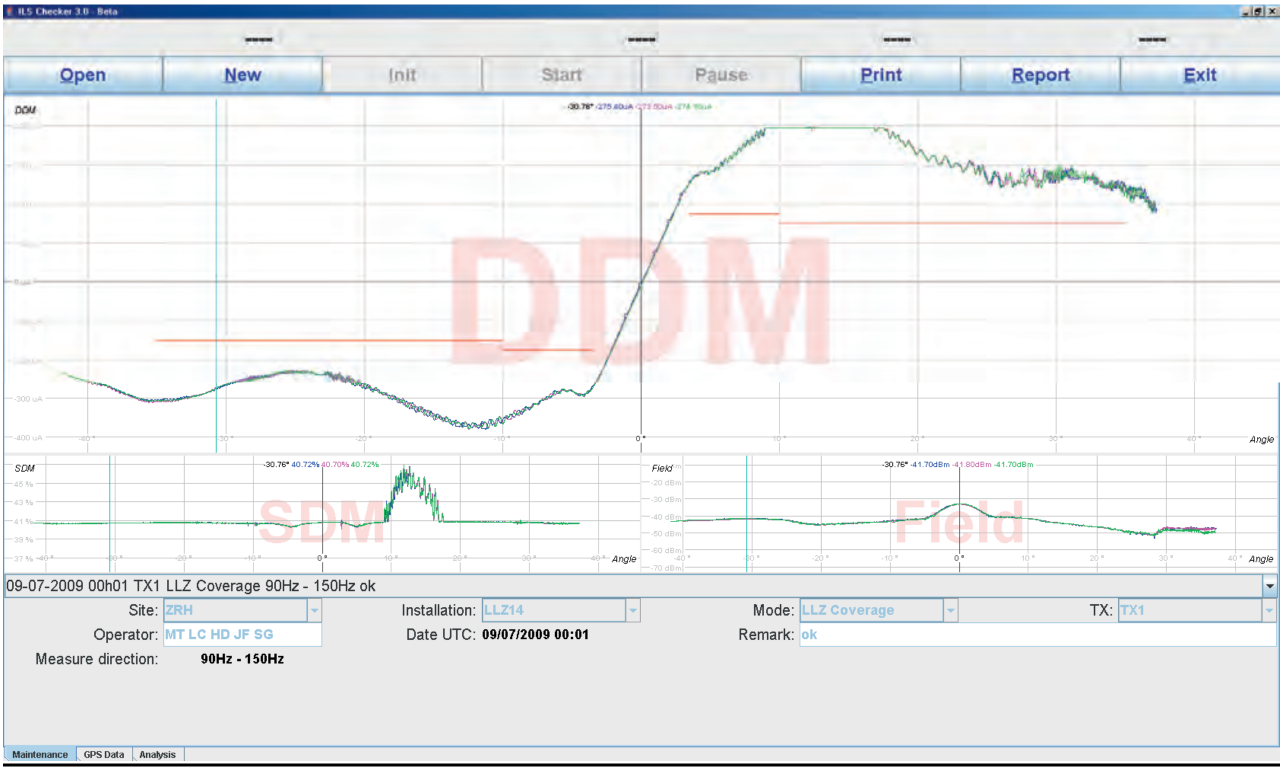
For the LOC Course Structure mode, thanks to the GPS positioning, the repeatability tests have been successfully validated, as illustrated by Figure 7 above:

- X-Axis (distance to threshold):
  The lateral accuracy of the vehicle positioning can be improved by current and validated satellite positioning techniques: GPS / SBAS (EGNOS augmentation system in Europe for example) or even GPS RTK (Real Time Kinematic) ensure a much better accuracy (typically a 2 - 3 cm accuracy in Switzerland)

- Y-Axis (DDM) :

If the operator activates the compensation of the vehicle trajectory, the R&S®TS6300 behaves like any mobile flight inspection system. The vehicle trajectory compensation can only be activated if positioning is performed using GPS RTK mode, with an accuracy of 2 – 3 cm. Then, the result of the measurement (averaged DDM along the centerline) does not depend on the driver any more, but only on the Localizer signal in space.

In these conditions, such a repetitive ILS test system enables to detect any small change (smaller than 0.5 µA) of the Localizer itself. Besides, it has also been shown that these ground measurements correlate very well with the stability data of its field and integral monitors.



09-07-2009 00h01 TX1 LLZ Coverage 90Hz - 150Hz ok

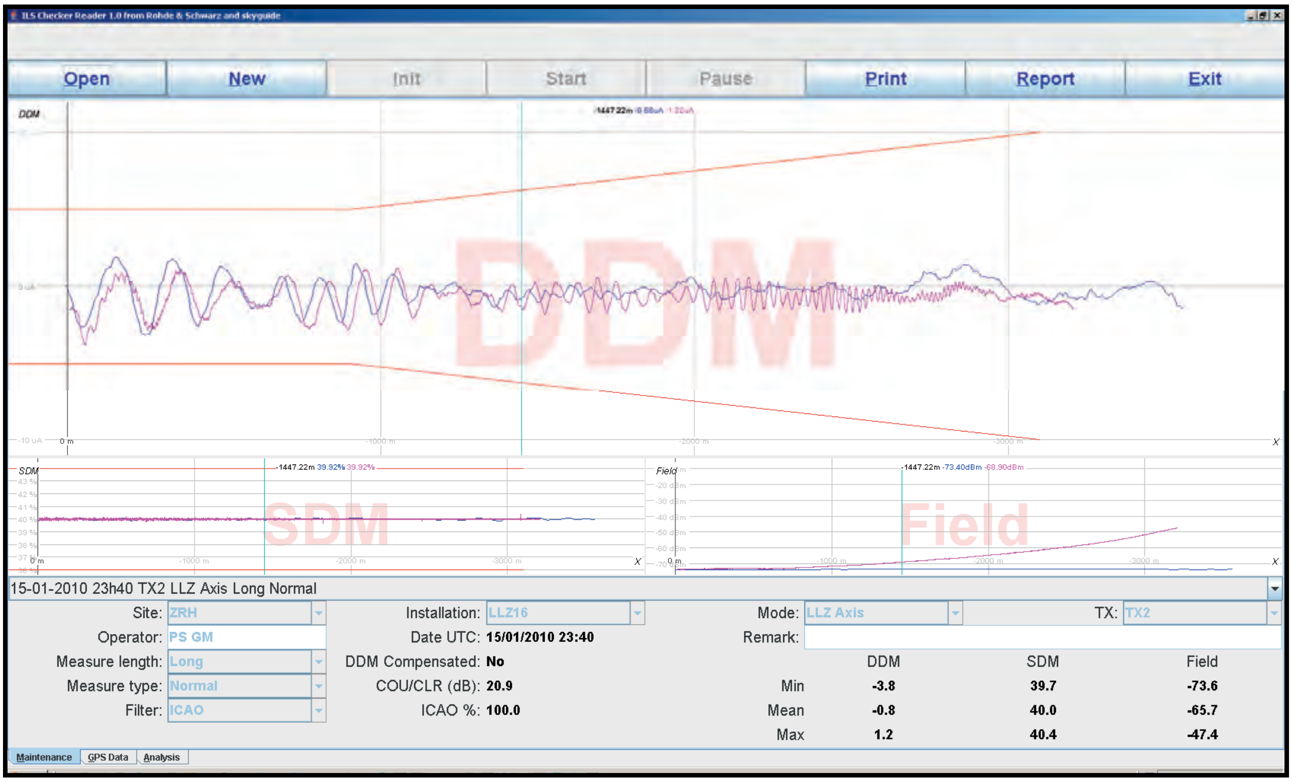
Site: ZRH
Installation: LLZ14
Mode: LLZ Coverage
TX: TX1
Operator: MT LC HD JF SG
Date UTC: 09/07/2009 00:01
Remark: ok
Measure direction: 90Hz - 150Hz

Figure 8. Repeatability tests for the LOC Coverage Mode (DDM, SDM and Field versus Azimuth Angle)

High resolution and accuracy

With a sampling rate of 100 measurements per second, the R&S®EVS300 ILS/VOR Analyzer provides a very high resolution:

- For the LOC modes, if the ground speed of the vehicle is 60 km/h (37 mph), the distance between samples is only **17 cm** (6.5 inches). Whereas this inter-sample distance can be more than **8 m** (27 feet) for an aircraft flying with a speed of 300 km/h (186 mph) and with a typical current sampling rate of 10 Hz. With a spatial resolution of 17 cm, this ILS test system is able to capture and measure high frequency phenomena and perturbations. In case of Localizers multipath effects, as it can be demonstrated that the spatial wave-length of perturbations cannot be smaller than 1.3 m (half of the LOC wavelength), a resolution of 17 cm (with a sampling rate of 100 Hz and with a vehicle speed of 60 km/h) permits that **such ground measurements are never under-sampled** and that the conditions of the Nyquist–Shannon theorem are always respected. This is unfortunately not always the case with flight check measurement techniques. With a inter-sample distance of 8 m, the conditions of the Nyquist–Shannon theorem are not always respected: high frequency perturbations whose wavelength is smaller than 16 m (according to this theorem) are not correctly sampled and then filtered. The next two figures 9 and 10 illustrate the high degree of correlation between ground and flight check data for low-frequency perturbations and the poor quality of this correlation for high frequency perturbations (because flight check data are under-sampled)

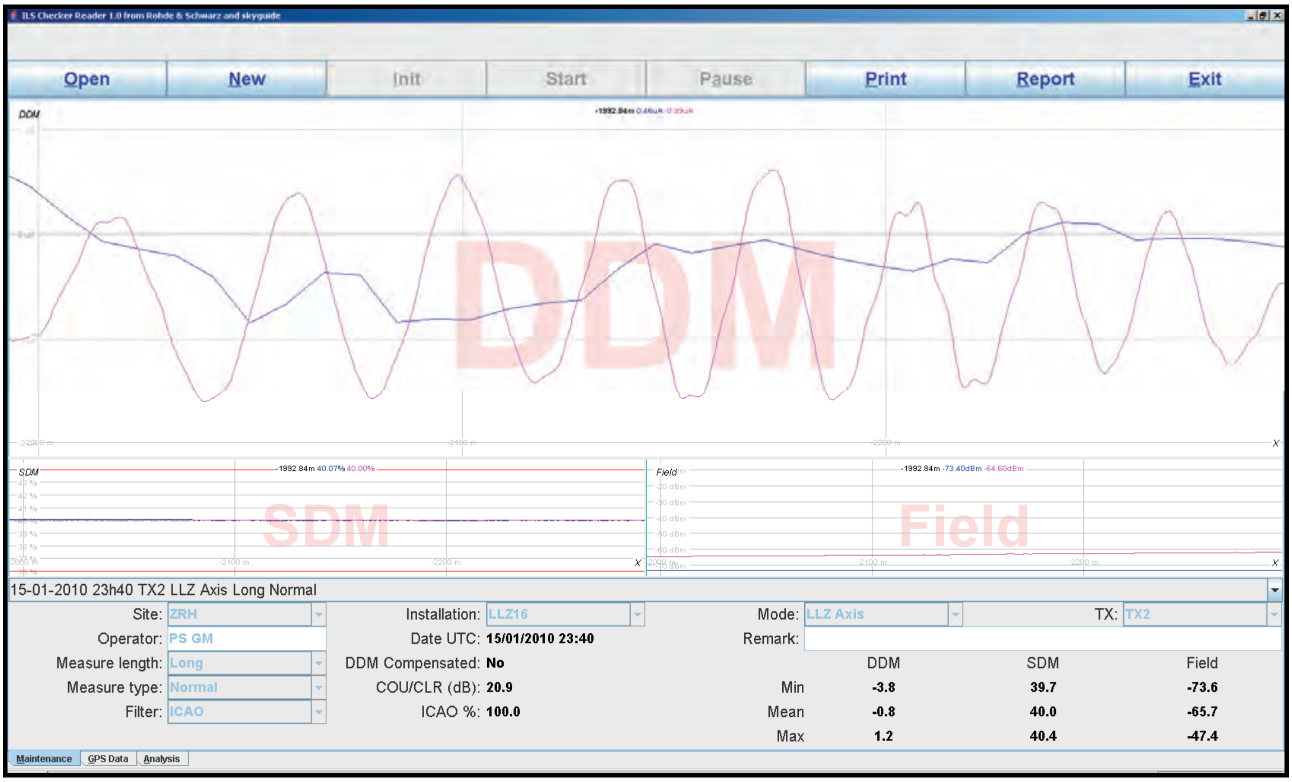


15-01-2010 23h40 TX2 LLZ Axis Long Normal

Site: ZRH
Installation: LLZ16
Mode: LLZ Axis
TX: TX2
Operator: PS GM
Date UTC: 15/01/2010 23:40
Remark:
Measure length: Long
DDM Compensated: No
Measure type: Normal
COU/CLR (dB): 20.9
Filter: ICAO
ICAO %: 100.0

	DDM	SDM	Field
Min	-3.8	39.7	-73.6
Mean	-0.8	40.0	-65.7
Max	1.2	40.4	-47.4

Figure 9. LOC Course Structure: Good Correlation between Flight Check (in blue) and Ground Measurements (in pink) for Low-Frequency Perturbations (left part of the curve)



15-01-2010 23h40 TX2 LLZ Axis Long Normal

Site: ZRH
Installation: LLZ16
Mode: LLZ Axis
TX: TX2
Operator: PS GM
Date UTC: 15/01/2010 23:40
Remark:
Measure length: Long
DDM Compensated: No
Measure type: Normal
COU/CLR (dB): 20.9
Filter: ICAO
ICAO %: 100.0

	DDM	SDM	Field
Min	-3.8	39.7	-73.6
Mean	-0.8	40.0	-65.7
Max	1.2	40.4	-47.4

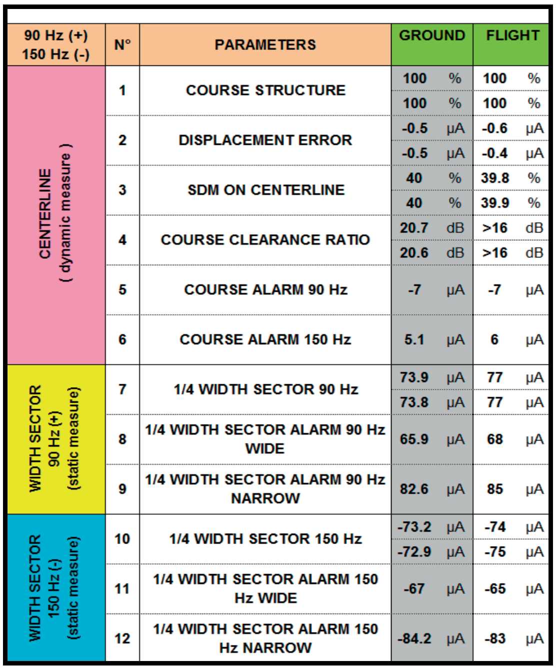
Figure 10. (Zoom of Figure 9 in the middle part) Under Sampling Effect on LOC Course Structure: Under sampled Flight Check Data (in blue) versus Ground Measurements (in pink) for High-Frequency Perturbations

- For GP measurements: if the raising speed of the telescopic mast is 0.1 m/s, a sampling rate of 100 Hz enables to achieve a vertical spatial resolution of 1 mm. **This corresponds to an angular resolution of 0.0002°**, if the distance between the GP mast and the telescopic mast is approximately 300 m.

CORRELATION OF LOCALIZER MEASUREMENTS

In line with the maintenance preventive ground checks and routine flight checks, systematic and automatic comparisons of the results have been started in Switzerland by skyguide since 2002. As illustrated below by Table 1, the typical maintenance datasheets integrate the automatic correlation checks between ground and flight check data.

Table 1. Typical Localizer Maintenance Datasheet



90 Hz (+) 150 Hz (-)	N°	PARAMETERS	GROUND	FLIGHT
CENTERLINE (dynamic measure)	1	COURSE STRUCTURE	100 % 100 %	100 % 100 %
	2	DISPLACEMENT ERROR	-0.5 µA -0.5 µA	-0.6 µA -0.4 µA
	3	SDM ON CENTERLINE	40 % 40 %	39.8 % 39.9 %
	4	COURSE CLEARANCE RATIO	20.7 dB 20.6 dB	>16 dB >16 dB
	5	COURSE ALARM 90 Hz	-7 µA	-7 µA
	6	COURSE ALARM 150 Hz	5.1 µA	6 µA
WIDTH SECTOR 90 Hz (+) (static measure)	7	1/4 WIDTH SECTOR 90 Hz	73.9 µA 73.8 µA	77 µA 77 µA
	8	1/4 WIDTH SECTOR ALARM 90 Hz WIDE	65.9 µA	68 µA
	9	1/4 WIDTH SECTOR ALARM 90 Hz NARROW	82.6 µA	85 µA
WIDTH SECTOR 150 Hz (-) (static measure)	10	1/4 WIDTH SECTOR 150 Hz	-73.2 µA -72.9 µA	-74 µA -75 µA
	11	1/4 WIDTH SECTOR ALARM 150 Hz WIDE	-67 µA	-65 µA
	12	1/4 WIDTH SECTOR ALARM 150 Hz NARROW	-84.2 µA	-83 µA

Correlation of Localizer Course Structures

Thanks to the R&S®TS6300 ILS Test System and the very good quality and accuracy of FCS (Flight Calibration Services) measurements, this example shows a very high degree of correlation for:

- The displacement error: a correlation of +/- 0.1 µA for this example. According to the accumulated experience, this displacement error correlation should be better than +/- 0.5 µA.

- The averaged SDM on centerline: a correlation of +/- 0.2 % for this example. According to the accumulated experience, this SDM correlation should be better than +/- 0.5 %.

- The Course Alarms (on the 90Hz and 150 Hz sides, averaged value along the centerline): a correlation of +/- 1 µA for this example. According to the accumulated experience, this course alarms correlation should be better than +/- 2 µA.

As illustrated by Figure 9 above, the Localizer Course Structure mode shows a high degree of correlation between the ground and flight check curves for low frequency perturbations (on condition that flight check data are not under-sampled)

Correlation of Localizer Coverages

The so-called "Localizer Linearity Coverage" mode enable the **continous** measuring (on the ground) of the ¼ sector width parameters, by driving nearly on a circle with the vehicle (like a measuring aircraft flying an orbit for the coverage measurements). The measured averaged slopes of the curve during this "pseudo-orbit" run are then computed and used for the assessment of the ¼ sector widths, as illustrated by Figures 11 and 12 below. These ground results are then compared to the ones measured by FCS. As for the Course Structures, Table 1 above illustrates the correlation checks between ground and flight check data for the ¼ sector widths in normal condition and alarms conditions (wide and narrow). This example shows a good degree of correlation for:

- The ¼ sector widths in normal conditions: a correlation of +/- 3 µA for this example. As the ground measurements are not conducted in the far field of the Localizer like flight check orbits, these results may differ by approximately +/- 5µA. As this is an understandable reason, this difference is of course acceptable.

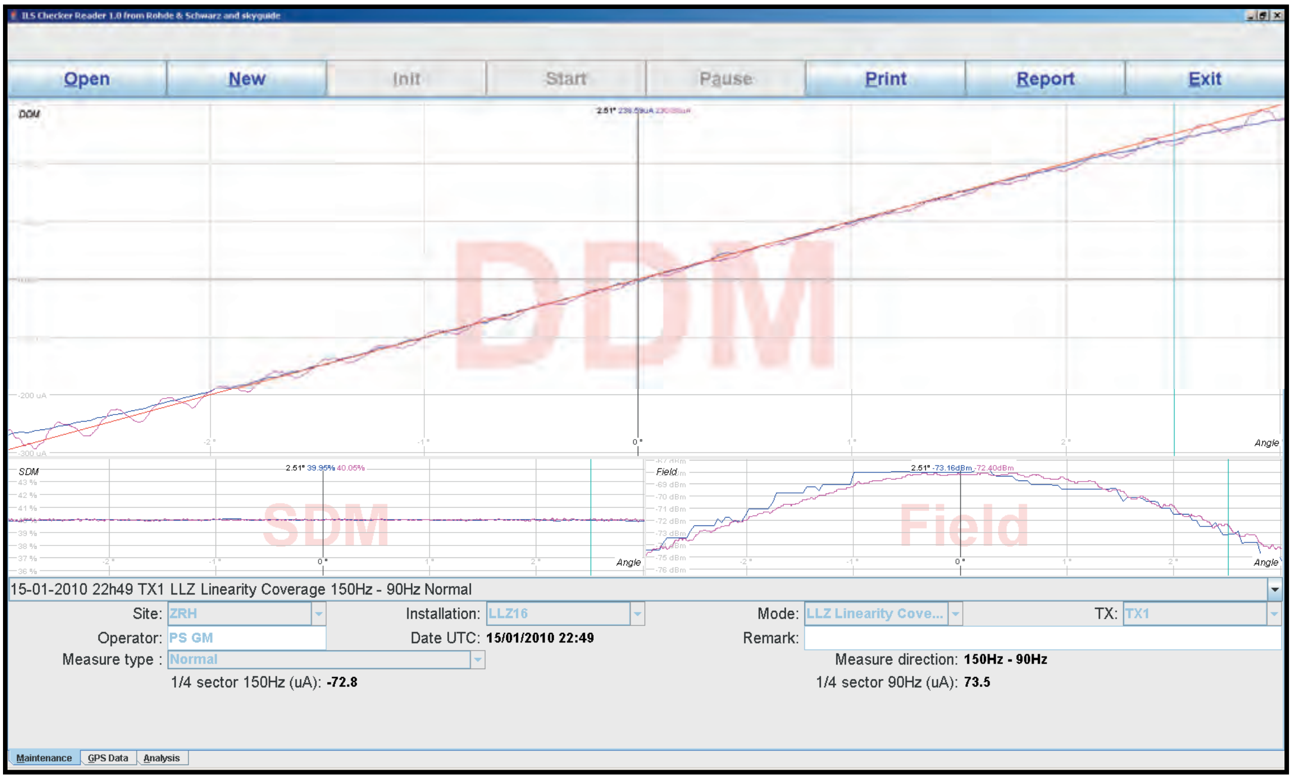
- The ¼ sector widths in alarms conditions (wide and narrow): a correlation of +/- 2.5 µA for this example.

The next two Figures 11 and 12 illustrate the very good correlation between Localizer Coverage curves, specially for the DDM and the SDM parameters. In this example, the correlation for the Field parameter is also quite good because these ground measurements have been conducted nearly on a circle (+/- 4° at a constant distance), nearly in the farfield region.

15-01-2010 22h49 TX1 LLZ Linearity Coverage 150Hz - 90Hz Normal

Site: ZRH
Installation: LLZ16
Mode: LLZ Linearity Cove...
TX: TX1
Operator: PS GM
Date UTC: 15/01/2010 22:49
Remark:
Measure type : Normal
Measure direction: 150Hz - 90Hz
1/4 sector 150Hz (uA): -72.8
1/4 sector 90Hz (uA): 73.5

Figure 11. LOC Coverage: Correlation between Flight Check (in blue) and Ground Measurements (in pink)



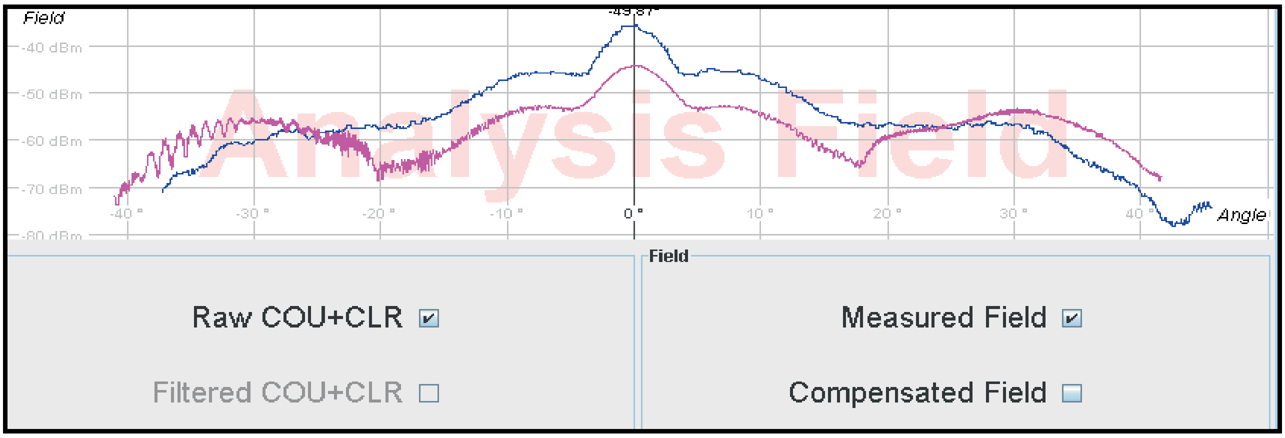
15-01-2010 22h49 TX1 LLZ Linearity Coverage 150Hz - 90Hz Normal

Site: ZRH
Installation: LLZ16
Mode: LLZ Linearity Cove...
TX: TX1
Operator: PS GM
Date UTC: 15/01/2010 22:49
Remark:
Measure type : Normal
Measure direction: 150Hz - 90Hz
1/4 sector 150Hz (uA): -72.8
1/4 sector 90Hz (uA): 73.5

Figure 12. LOC Coverage, Zoom into the Course Domain : DDM, SDM and Field Correlation between Flight Check (in blue) and Ground Measurements (in pink)

How to measure a typical coverage of +/- 40° on the ground? Unfortunately the vehicle is not able to conduct this run in the farfield region, because it would be outside the airport without any line of sight to the LOC (screening and reflection effects of buildings, hangars and terminal). That's why this ground Coverage measurement can only be conducted in the nearfield region of the LOC:

- Either on a special dedicated circular road around the LOC, with a typical radius of 300 m (of even sometimes smaller), which is located in the "very-nearfield",
- Or on the standard access roads of the airport and then on the taxyways crossing the runway, which represent hardly a circular trajectory, but a nearly rectangular one. Anyway, as soon as a transverse structure of +/- 40° can be measured, such LOC Coverage measurements are valid and very useful. In this case, as the distance between the vehicle and the LOC and as the elevation angle of the receiving antenna seen from the LOC are not constant, one should not expect to measure a valid LOC antenna diagram. As illustrated by Figure 13, the "Measured field", which is influenced by the changes in distance (and thus elevation angles) must not be interpreted as a valid LOC antenna diagram.



Raw COU+CLR ☑

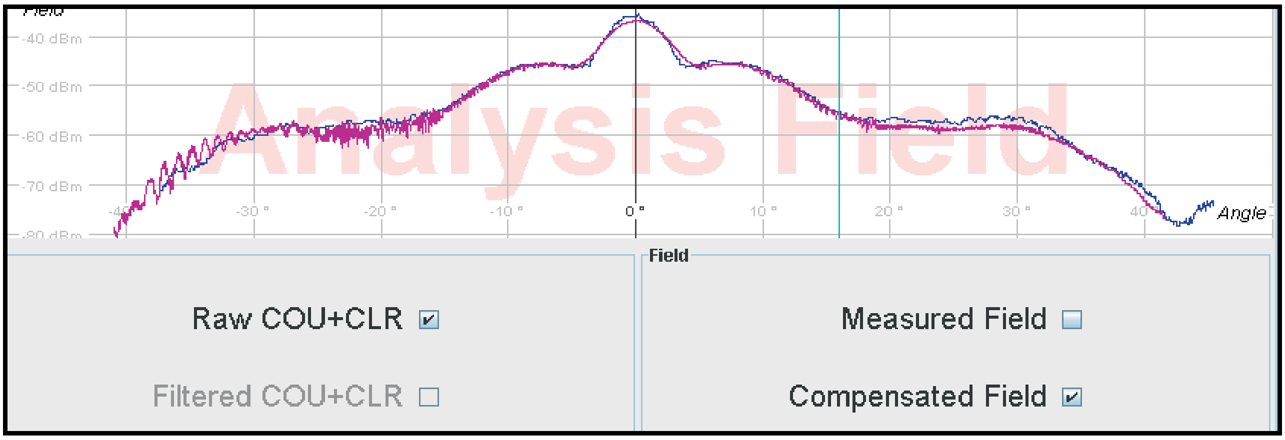
Filtered COU+CLR ☐

Measured Field ☑

Compensated Field ☐

Figure 13. LOC Coverage: Bad Field Correlation between Flight Check (in blue) and Non-Compensated ("Measured") Ground Measurements (in pink)

Figure 13 above illustrates the "Measured Field", which represents the raw RF Level at the receiver input. However, as the R&S®TS6300 ILS Test System is aware of the vehicle trajectory (thanks to its GPS positioning) and specially its distance to the LOC, it enables a post-processing computation and can display the "Compensated Field". This "Compensated Field" can be interpreted as the LOC antenna diagram, virtually measured on a circular trajectory. The next Figure 14 illustrates the effect of this compensation and consequently shows a very good correlation between LOC antenna diagrams measured by flight check and measured (and then compensated) on the ground.



Raw COU+CLR ☑

Filtered COU+CLR ☐

Measured Field ☐

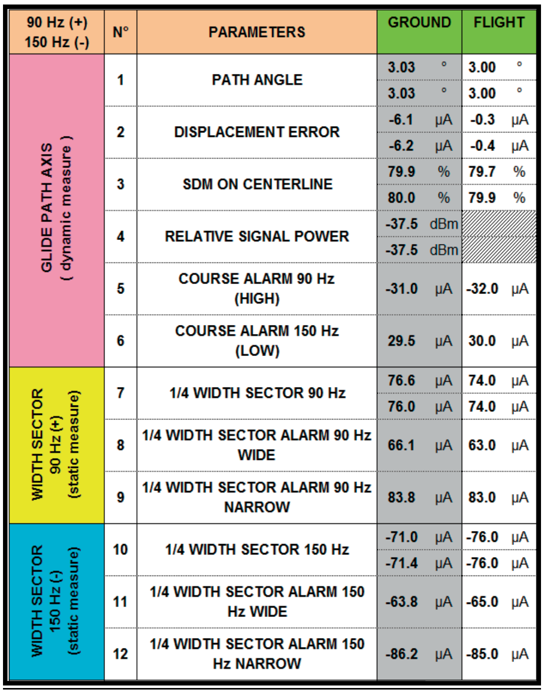
Compensated Field ☑

Figure 14. LOC Coverage: Good Field Correlation between Flight Check (in blue) and "Compensated" Ground Measurements (in pink)

CORRELATION OF GLIDE PATH MEASUREMENTS

As for the Localizer, in the context of the maintenance preventive ground checks and routine flight checks of the Glide Path, systematic and automatic comparisons of the results have been started in Switzerland by skyguide since 2002. As illustrated below by Table 2, the typical maintenance datasheets also integrate the automatic correlation checks between ground and flight check data.

Table 2. Typical Glide Path Maintenance Datasheet



90 Hz (+) 150 Hz (-)	N°	PARAMETERS	GROUND	FLIGHT
GLIDE PATH AXIS (dynamic measure)	1	PATH ANGLE	3.03 °	3.00 °
			3.03 °	3.00 °
	2	DISPLACEMENT ERROR	-6.1 µA	-0.3 µA
			-6.2 µA	-0.4 µA
	3	SDM ON CENTERLINE	79.9 %	79.7 %
			80.0 %	79.9 %
	4	RELATIVE SIGNAL POWER	-37.5 dBm	▨
			-37.5 dBm	▨
	5	COURSE ALARM 90 Hz (HIGH)	-31.0 µA	-32.0 µA
	6	COURSE ALARM 150 Hz (LOW)	29.5 µA	30.0 µA
WIDTH SECTOR 90 Hz (+) (static measure)	7	1/4 WIDTH SECTOR 90 Hz	76.6 µA	74.0 µA
			76.0 µA	74.0 µA
	8	1/4 WIDTH SECTOR ALARM 90 Hz WIDE	66.1 µA	63.0 µA
	9	1/4 WIDTH SECTOR ALARM 90 Hz NARROW	83.8 µA	83.0 µA
WIDTH SECTOR 150 Hz (-) (static measure)	10	1/4 WIDTH SECTOR 150 Hz	-71.0 µA	-76.0 µA
			-71.4 µA	-76.0 µA
	11	1/4 WIDTH SECTOR ALARM 150 Hz WIDE	-63.8 µA	-65.0 µA
	12	1/4 WIDTH SECTOR ALARM 150 Hz NARROW	-86.2 µA	-85.0 µA

Correlation of Glide Path Coverages (in Elevation)

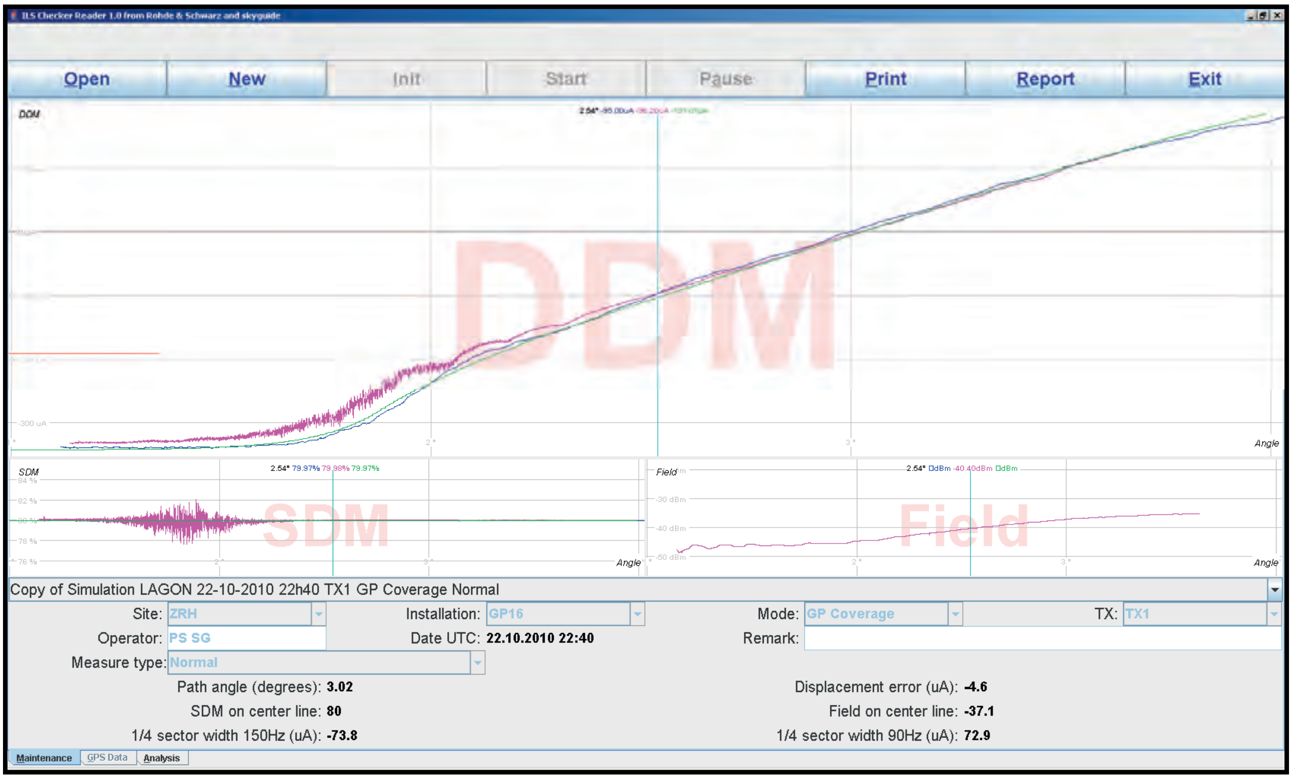
Also this example shows a good degree of correlation for:

- The path angle and its displacement error: a correlation of +/- 0.03° or +/- 6 µA for this example. As the telescopic mast is located at the runway threshold in the nearfield region of the Glide Path, the correlation process is not as easy as it can be for the Localizer displacement error. Indeed, despite of the fact that the GP antennas should be in phase at the runway threshold, this ground measurement is also influenced by the geometry of the site: forward slope and side slope do also have an influence on the ground results, and this is of course normal. As this can be understandable and modeled by ILS simulators (in particular LAGON V4.0 from the ENAC), this difference is acceptable.
- The SDM on centerline: a correlation of +/- 0.2 % for this example. According to the accumulated experience, this SDM correlation should be better than +/- 0.5 %.
- The Course Alarms on the 90 Hz (high angle) and 150 Hz (low angle) sides: a correlation of +/- 1 µA for this example. According to the accumulated experience, this course alarms correlation should be better than +/- 2 µA.

The measured averaged slopes of the curve (below and above the path) during the GP coverage run are computed and used for the assessment of the ¼ sector widths on the 90 Hz and 150 Hz sides. These ground results are then compared to the ones measured by FCS. Table 2 above illustrates the correlation checks between ground and flight check data for the ¼ sector widths in normal and alarms (wide and narrow) conditions. This example also shows a good degree of correlation for:

- The ¼ sector widths in normal conditions: a correlation of +/- 5 µA for this example. Again, as these ground measurements are not conducted in the far field of the Glide Path, these results may differ by approximately +/- 5 µA. As this is an understandable reason, this difference is acceptable.
- The ¼ sector widths in alarms conditions (wide and narrow): a correlation of +/- 3 µA for this example.

As illustrated by Figure 15 below, the Glide Path Coverage mode shows a high degree of correlation between the ground and flight curves (respectively in pink and blue).



Copy of Simulation LAGON 22-10-2010 22h40 TX1 GP Coverage Normal

Site: ZRH
Installation: GP16
Mode: GP Coverage
TX: TX1
Operator: PS SG
Date UTC: 22.10.2010 22:40
Remark:
Measure type: Normal

Path angle (degrees): 3.02
SDM on center line: 80
1/4 sector width 150Hz (uA): -73.8
Displacement error (uA): -4.6
Field on center line: -37.1
1/4 sector width 90Hz (uA): 72.9

Figure 15. GP Coverage: DDM Correlation between Flight Check (in blue), Ground Measurements (in pink) and Simulation from LAGON V4.0 (in green)

From Relative to Absolute Measurements

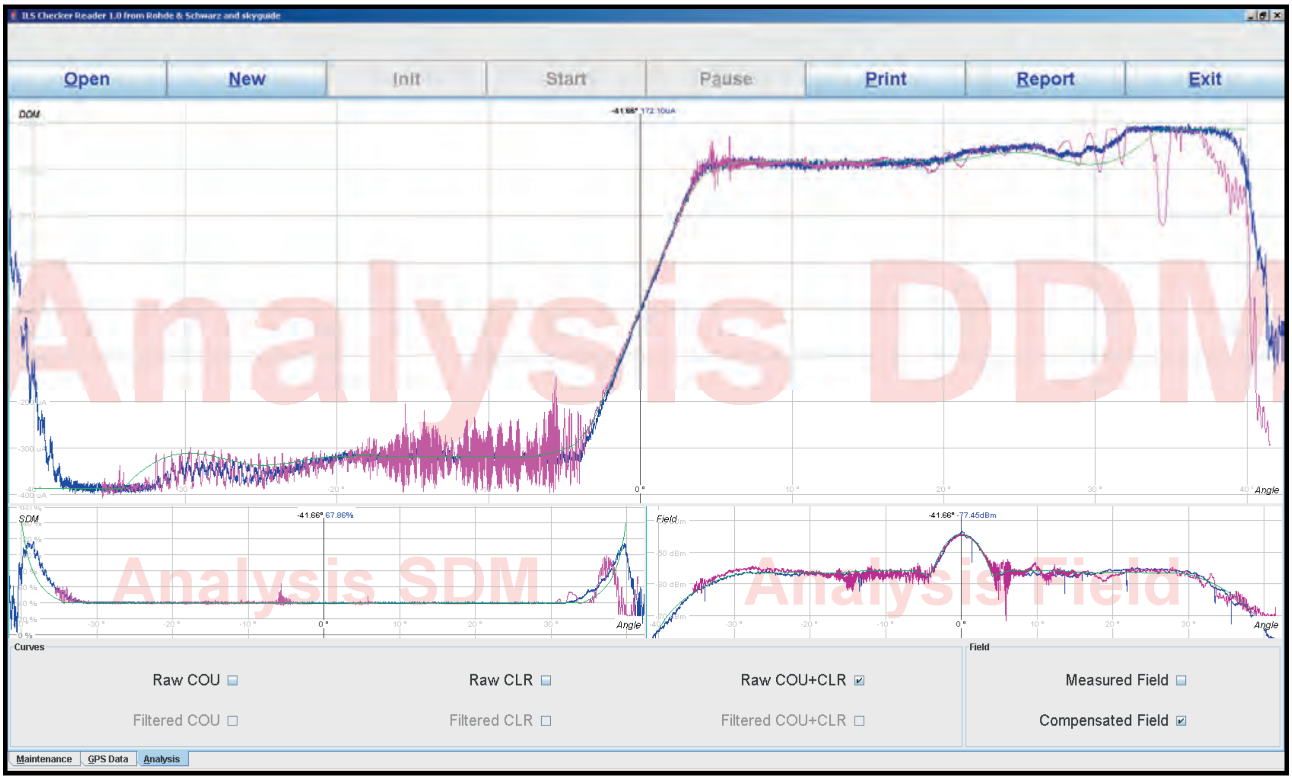
Thanks to the demonstrated repeatability and stability of the R&S®TS6300 ILS Test System, the comparison of the produced curves and results enables the user to detect any small change in the GP signal in space (transmitter, cables, antennas, reflection area …). However, by using adequate ILS simulation software and modeling accurately the GP (transmitting system and terrain geometry, forward slope and side slope), it is possible to give ground results not only a relative weight (comparison from month to month), but a **real absolute weight**: in case of a new GP and also in case of a new LOC commissioning, the ground measurements can enable the user to predict and anticipate the flight check results, and thus finally modify and correct the initial ground pre-tuning. Such examples in Switzerland have shown that it is possible to interpret and trust the GP and LOC ground measurements. This can of course save many hours during the initial commissioning flight check. This multiple correlation ground – flight – theory is illustrated by Figure 15 above.

ILS CHECKER ABOARD A MEASURING AIRCRAFT

In cooperation with FCS, it has also been possible to test and use the R&S®TS6300 ILS Test System aboard a measuring aircraft, in the context of commissioning a new ILS on a new site. The goal was to validate this mobile bench, demonstrate the ground /flight correlation and also understand the differences, if any …

More than a ground – flight correlation, the produced curves and their analysis again represent a good example of the multiple correlation ground – flight – theory. Figure 16 below illustrates that point for the Localizer Coverage Mode:

- The general shapes of the three curves are very similar.
- The noticeable differences and scalloping of the ground curves can be explained by the proximity of hangars, by local reflections of them and finally also by screening effects (when the vehicle is passing behind the GP shelter for example). These phenomena are understandable and repetitive, thus acceptable.
- The correlation with the theoretical curve could even have been improved, if the real measured antenna feedings have been modeled.

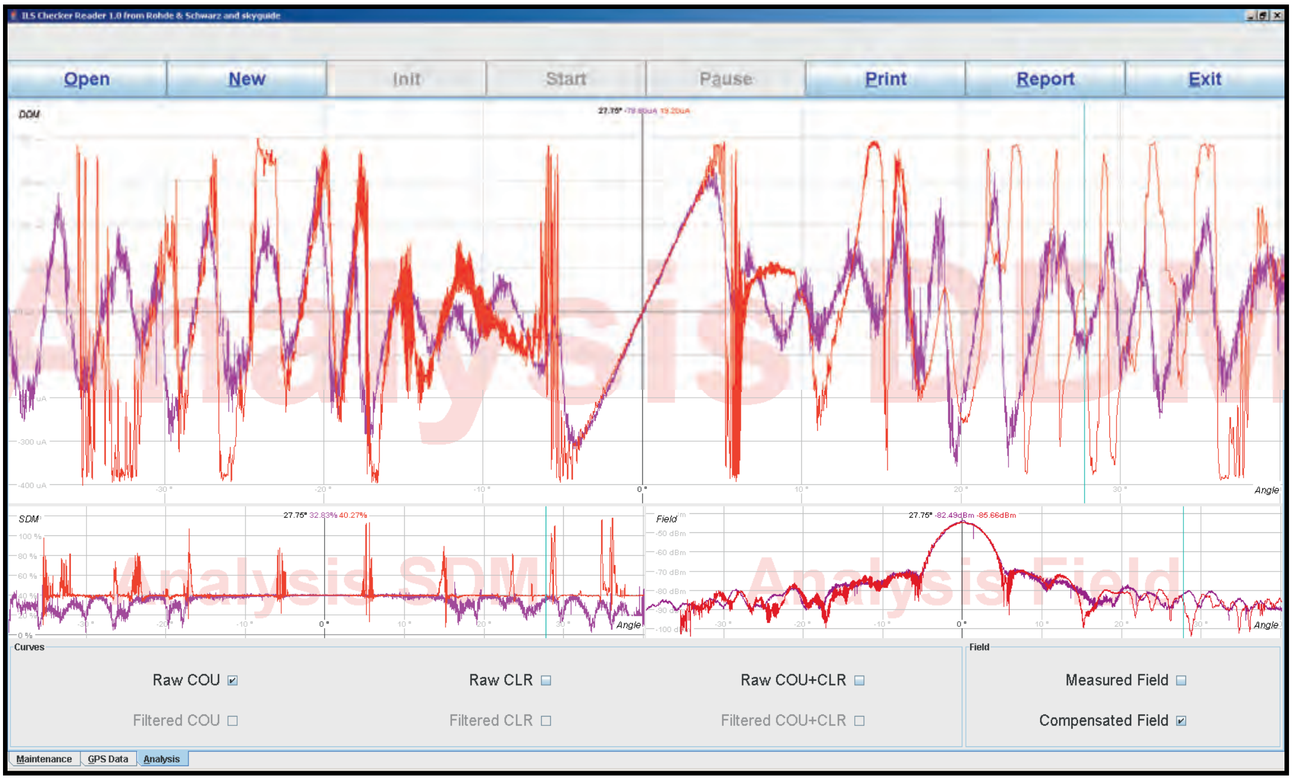


Raw COU ☐
Raw CLR ☐
Raw COU+CLR ☑
Filtered COU ☐
Filtered CLR ☐
Filtered COU+CLR ☐
Measured Field ☐
Compensated Field ☑

Figure 16. LOC Coverage with ILS Checker aboard FCS Aircraft, Course + Clearance Signals : DDM, SDM and Field Correlation between ILS Checker Data aboard FCS aircraft (in blue), Ground Data (in pink) and Simulated Data from ATOLL V13.2(in green)

Thanks to the unique functionality of the R&S®EVS300 ILS/VOR Analyzer and its dissociated Course / Clearance analysis, it is possible to conduct three measurements in one run: Course only, Clearance only and Course + Clearance signals. This represents a substantial gain of time and it can be very useful for the understanding and the analysis of interference and multipath problems.

Figure 17 below illustrates a very good ground – flight correlation for the Course signal only during a Localizer Coverage measurement. Both curves (in red and violet) for DDM, SDM and Field parameters are very similar.



Raw COU ☑
Raw CLR ☐
Raw COU+CLR ☐
Measured Field ☐
Filtered COU ☐
Filtered CLR ☐
Filtered COU+CLR ☐
Compensated Field ☑

Figure 17. LOC Coverage with ILS Checker aboard FCS Aircraft, Course only Signal : DDM, SDM and Field Correlation between ILS Checker Data aboard FCS aircraft (in violet) and Ground Data (in red)

As illustrated by Figure 18 below, the dissociated Course / Clearance analysis is helpful to:

- show a very good correlation of the Course only and Clearance only Fields (or antenna diagrams) from the flight check and from the simulation,
- thus also validate the principles of the Field compensation

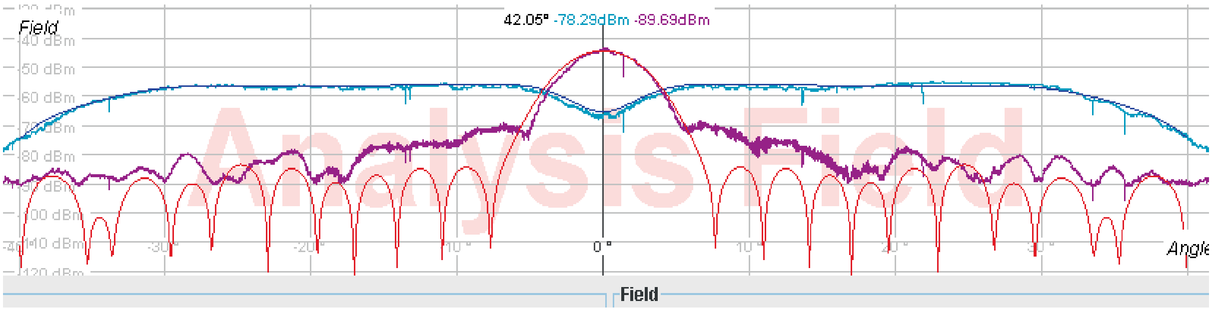


Figure 18. LOC Coverage with ILS Checker aboard FCS Aircraft: Course and Clearance Fields Correlation between ILS Checker Data aboard FCS aircraft (in violet and light blue) and Simulated Data from ATOLL V13.2 (in red and dark blue)

CONCLUSIONS

Based on the data presented in this paper, the following conclusions are reached:

1. According to the ICAO Document 8071, ILS ground measurements and their correlation with flight check results are highly recommended.

2. Thanks to modern and accurate ground measurement techniques, the repeatability, the accuracy and the high resolution of the R&S®TS6300 ILS Test System make it possible to reach a very high degree of correlation between ground measurements and flight check, both in Localizer and Glide Path domains.

3. Thanks to adequate modeling and simulations and based on the demonstrated multiple correlation between ground, flight and theory, it is possible to trust and give an absolute weight to ground measurements.

4. The R&S®TS6300 ILS Test System can also be used aboard a measuring aircraft for tests, special analysis or validation purposes.

REFERENCES

[1] ICAO, International Standards and Recommended Practices, Annex 10 to the Convention on International Civil Aviation, Volume 1, Radio Navigation Aids, 6th Edition, Amendment 86, 17th November 2011 http://www.icao.int

ICAO Document 8071, Fourth Edition, 2000, Manual on Testing of Radio Navigation Aids, Volume 1, Testing of Ground-Based Radio Navigation Systems.

Accuracy Evaluation of DME Coverage Predictions Using Software Tools

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ABSTRACT

The implementation of Performance Based Navigation (PBN) is an essential cornerstone for improving the efficiency of aircraft operations. While RNAV and especially RNP applications are primarily based on GNSS, DME/DME currently provides the most suitable alternative RNAV capability. However, ANSP are often reluctant to invest flight inspection resources to verify DME coverage in areas that are normally not part of a DME facility inspection program and wish to rely on software-based coverage prediction tools using terrain databases. Consequently, Eurocontrol undertook a validation campaign to provide more insight into the strength and weaknesses of such tools, with the aim to enable sensible decisions about which areas of a DME-based RNAV procedure should be flight inspected.

The paper builds on previous work already presented at IFIS. However, results from a new flight measurement campaign are presented. This campaign targeted specific obstacle geometries and took results from propagation modeling tools into account. Consequently, the limitations of previous results are overcome and specific guidance can now be made available to the flight inspection community.

INTRODUCTION

At the last IFIS, results were presented from a coverage prediction tool validation effort that involved a passive recording of flight inspection data [1]. In other words, data collected primarily during ferry flights was used to collect DME field strength data of facilities near the limits of coverage. While a specific tuning strategy was employed to ensure that relevant signal transitions could be captured and a lot of data was collected, the results were only indicative because of their spatial sparseness. Due to this limited density of data, it was difficult to draw specific conclusions on the accuracy of coverage predictions from software tools. Another limitation of the collected dataset was that quite often, it was difficult to distinguish whether the coverage boundary was due to reaching the limit of the link budget (free-space loss) or if it was due to terrain masking. Simple tools, which provide only geometric line-of-sight coverage prediction, require this distinction since they rely on use of the facility within Designated Operational Coverage (DOC) in line with frequency protection constraints.

To overcome the limitations of the previous effort, a new validation campaign was launched using a more systematic approach. The exercise was conducted very similar to what would be done for an actual evaluation of RNAV coverage – first, simulation tools were used to identify where data should be collected. Second, a flight test was conducted and third, the results were fed back into the prediction tools for evaluation and analysis. The value of an integrated approach with targeted flight inspection quickly became obvious.

In order to reduce flight inspection time, the effort was concentrated on a single facility having a wide variety of obstacle geometries. This permitted the preparation of a test program where the trajectory would encounter many transitions from inside to outside of coverage due to terrain shielding (and vice-versa). Such a facility was found in the DME GRE installed in Grenchen, Switzerland. The plains between the Jura and Alpine mountains along the Zurich – Geneva axis provided for shallow geometries, while the nearby Jura to the North exhibits steep geometries and the first portions of the Alps in the South the medium range obstacle geometries. An additional step in the preparations was to conduct comparisons between simple line of sight predictions with results from an RF propagation tool, in order to further concentrate the flight inspection to relevant areas.

DME GRE is a standard low power facility. While a high power facility would have been more ideal (greater link budget margin), it is more representative of a terminal area facility, where coverage limitations to support RNAV-1 [2] operations at low altitudes are most relevant.

PREPARATION USING SOFTWARE COVERAGE PREDICTION TOOLS

The identification of a facility with a large variety of obstacle geometries is greatly assisted by the summit and horizon visualization feature of DEMETER [1, 8]. Figure 1 below shows the variation of elevation angle with azimuth as described above. The associated summits (terrain peaks relevant for the line of sight limitation) are ranging from 2 to 20 NM from the GRE station.

The RF propagation coverage calculation was conducted using the EMACS tool [9] from IDS. In addition to many other capabilities, EMACS provides functionalities that are similar to the DEMETER tool provided by Eurocontrol. For the analysis of DME coverage, EMACS employed the Deygout method. The Deygout algorithm [10] represents the solution to the problem of multiple diffraction of radio waves (f>30 MHz) over knife-edge obstacles. The path loss is obtained directly and quickly by alignment of distances and heights adequately selected from a path profile.

The Deygout algorithm works as follows.

- ✓ A terrain profile is generated for the path between transmitter and receiver intersecting the vertical plane containing the antenna phase centre and the observation point with the digital terrain model.
- ✓ Terrain heights are then corrected to take into account the curvature of the earth.
- ✓ The Fresnel ellipse is calculated along the path.
- ✓ The terrain profile is processed to evaluate the level of penetration of the Fresnel ellipse (interfering peaks or knife edges)
- ✓ The attenuation factor due to the interfering peaks is calculated (extra losses)
- ✓ The field strength is computed by adding the free space losses to the extra losses caused by the interfering peaks.

When more than one knife edge obstacle is present along the terrain profile, the cumulative effect is evaluated. A short description of other coverage prediction methods suitable for use with digital terrain elevation data models is given in the appendix. The Deygout method has been found to provide a good accuracy of results within reasonable computation times. Digital terrain models with different resolutions can be used to describe the terrain within the area of interest.

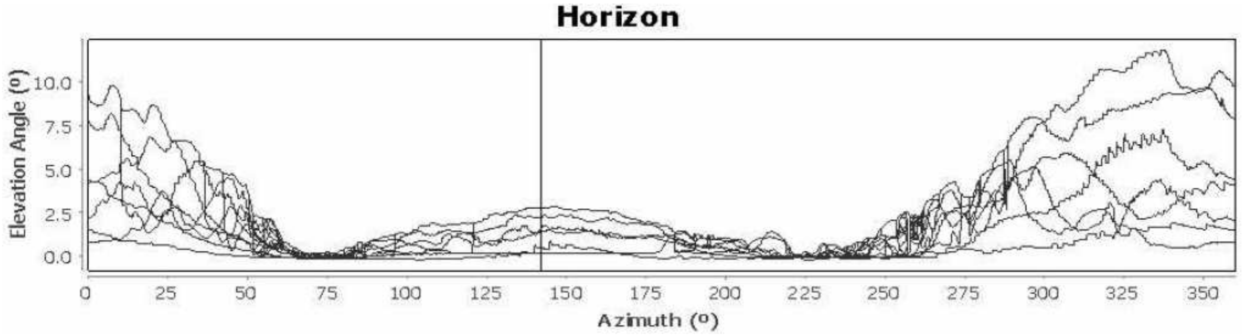

Figure 1: DME GRE Horizon

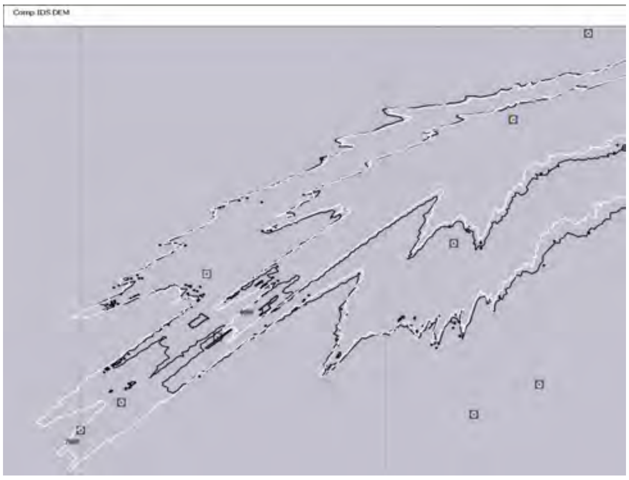

Figure 2: Comparison of Coverage Prediction Tools

Using an identical set of DTED Level 1 terrain data, coverage predictions were generated for different altitudes and the geo-referenced simulation results from EMACS were imported into DEMETER for comparison. Figure 2 shows one such comparison at altitudes of 4'000 and 7'500 feet AMSL. The white contour is the DEMETER prediction, while the black contour is the EMACS result. While the contours are largely similar, some small differences can be observed in the southeast, while larger discrepancies exist in the southwest. The latter are due to radio link budget limitations not taken into account by DEMETER.

The "RF nature" of the propagation prediction can be observed as "geographic noise" in the coverage contours. Based on these plots (and the various airspace constraints), a flight test program was designed to optimize the number of transitions into and out of coverage. These transitions included both radial and orbit flights to evaluate either range or azimuth prediction accuracy.

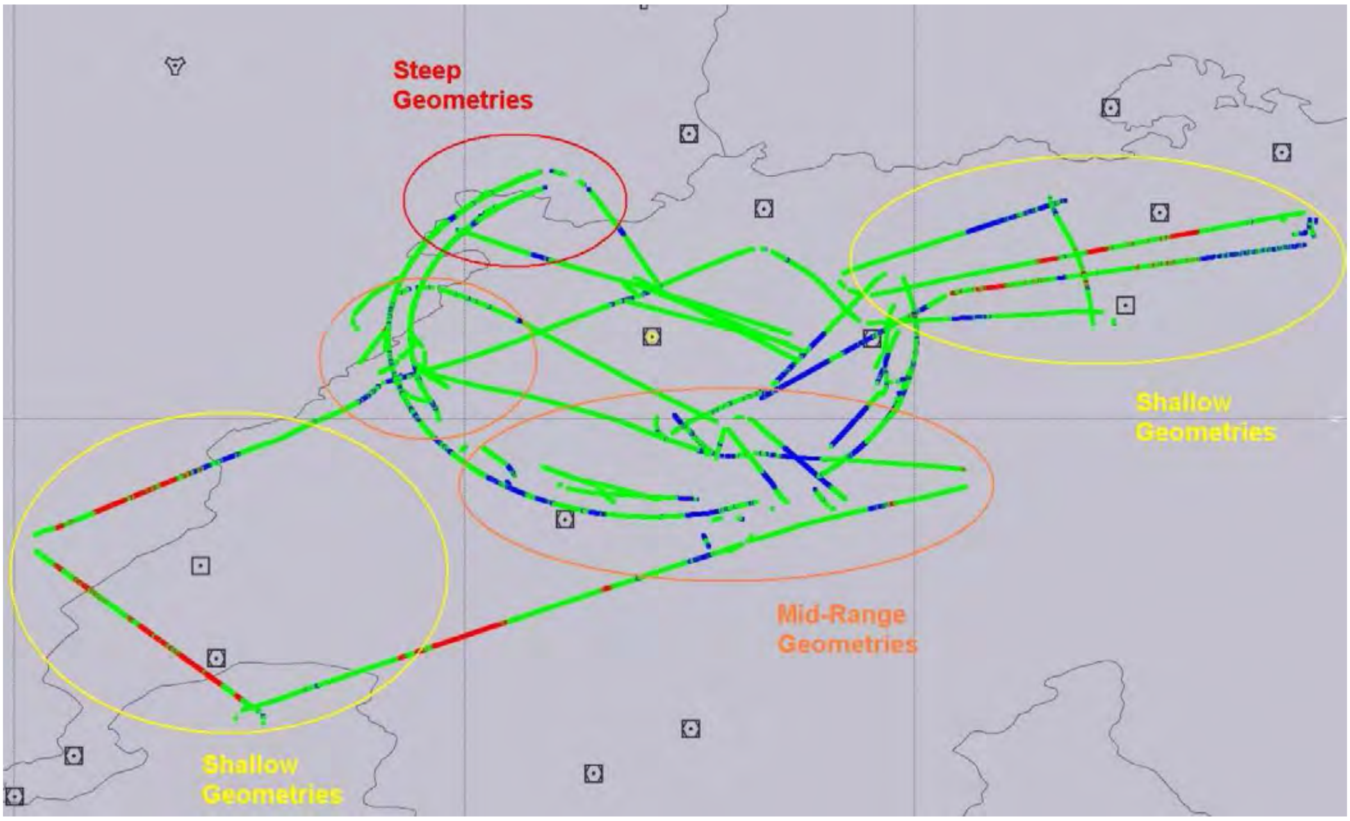

Figure 3: Overview of Flight Trajectory

PREPARATION AND EXECUTION OF FLIGHT TEST

The flight inspection was carried out using a Beech Super King Air B300 from FCS equipped with the SISMOS/DME system described previously [3]. The flight profile with associated regions of interest and initial results is shown in figure 3.

A green track is used to illustrate a correct prediction (which can be either inside or outside of coverage), while red is used for optimistic predictions (signal not available despite being inside predicted coverage) and blue for conservative predictions (signal available despite being outside of predicted coverage). Because the decision of coverage boundary for EMACS is based on a calculation of the minimum power density limit of minus 89dBW/m^2 [4], an exact measurement is also required from the flight test equipment. It is particularly relevant in this case because a few dB difference in level can have a large geographic impact. Nonetheless, the flight inspection system DME interrogators and associated status flags were also used in the data analysis.

Designing the test plan was a relatively complicated affair since it involved significant civil and military airspace (including Zurich and Geneva TMA) as well as cross-border coordination (Basel-Mulhouse / nearby France). Caution was also required to ensure terrain clearance – when evaluating coverage limitations due to terrain obstruction, by definition the terrain cannot be very far away. Only a portion of the flight was eligible for operation in IFR conditions. The flights were conducted in late August 2011 in VFR conditions. The measurement portions of the flight targeted all the identified geometries using stabilized flight (DME radials or arcs) at discrete altitudes. The altitudes were flown at AMSL heights in order to provide the best possible match to the software tool predictions.

TEST RESULTS

It is known from previous work [1] that the more difficult obstacle geometries are the shallow ones. The analysis presented here consequently starts with the simpler (steep) cases and progresses to the lower elevation angles. The subsequent quantitative analysis reverses the sequence.

Steep Obstacle Geometries

The nearby mountains of the Jura chain to the north of the facility create terrain obstacles at elevation angles of 10 degrees and more. For the purposes of this paper, no distinction is made between manmade obstacles or terrain – a terrain peak or summit is considered an obstacle here. The steep geometries available at such close facility ranges provide an opportunity to test the theory that a line of sight prediction tool will be inaccurate in places where terrain shadowing occurs while significant link budget margin remains. It is argued that diffraction losses can be absorbed and tracking maintained longer, especially if the aircraft is flying out of coverage. Such a difference could be clearly observed between DEMETER and EMACS predictions. The flight check result shows an exact agreement with the RF propagation prediction in figure 4, which is a remarkable result both for the accuracy of the propagation modeling tool as well as the quality of the in-flight measurement. The tracks color contour corresponds to power density here, with values below -89dBW/m^2 in red and the transition from red to orange occurring exactly at the black EMACS contour.

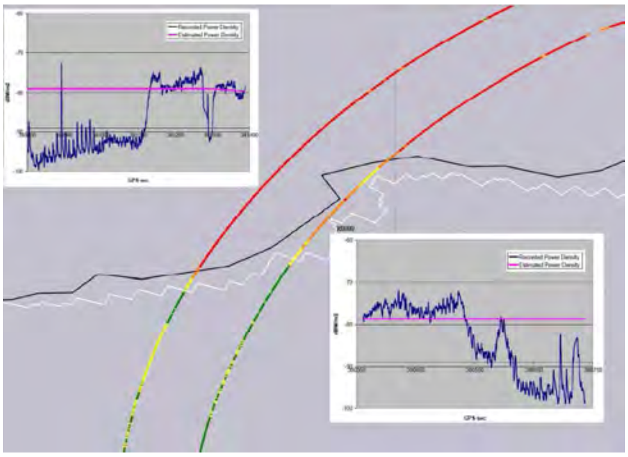

Figure 4: Steep Obstacle Geometry Result

It is also observed that there isn’t any relevant difference between flying into coverage and flying out of coverage (due to the difference between receiver acquisition and tracking thresholds). When looking at the DME receiver tracking status, solid tracking is even achieved some small distance outside of predicted coverage, since the receiver sensitivity exceeds the ICAO requirement by a margin. The only difference is that when flying into coverage, acquisition is immediate while when flying out of coverage, the receiver still tries to hang on for some distance in memory mode. The case shown here is clearly due to terrain shadowing since the power level switches abruptly between a level well below the minimum power density specification to a level well above. This is shown in the figure insets, where the top left inset corresponds to the counterclockwise path into coverage at 20’000 feet on the outer arc. The bottom left inset corresponds to the clockwise track out of coverage on the inner arc. The magenta line in the insets shows the expected power level from a free-space calculation, e.g., differences with respect to that line are essentially due to terrain effects. While in this case DEMETER does indeed provide an overly conservative coverage prediction, the difference in terms of geographic distance is not substantial. Such steep geometries are quite rare and the more shallow the obstacle geometry becomes, the farther the aircraft will be from the station, which should reduce the link budget margin and consequently the significance of the effect. Additionally, the difference between the EMACS and DEMETER coverage contours does become smaller when using the finest available computation settings for DEMETER. A similar effect is observed when using DTED2 (higher resolution terrain data), but it is not certain if this would hold for all cases because DTED level 1 is essentially an averaged version of DTED level 2.

Mid-Range Geometries

For these geometries, the elevation angles are between 1.5 and 5 degrees. The results indicate a lot of valid predictions, with some optimistic and some conservative cases. An example case of a conservative prediction for both EMACS and DEMETER is shown in figure 5 on the upper track.

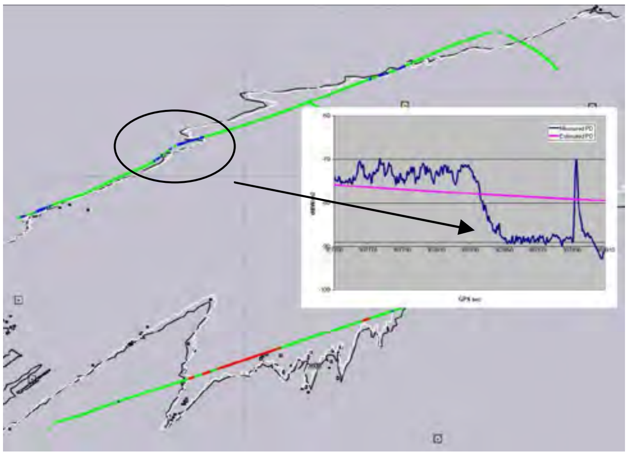

Figure 5: Mid-Range Geometry Result 1

When inspecting the signal level evolution, the drop in signal level can be clearly seen (flight is from right to left). However, the signal level drops to a value very close to the ICAO threshold, with dynamic fluctuations in signal level. Not far afterwards, the signal is lost completely, restoring the correctness of the prediction (colors scheme as in figure 3). An optimistic case is shown on the bottom half, where again the black and white nature of these inside or outside predictions does not match the normal erratic behavior of signals near their coverage boundary. In a second mid-range case, the EMACS prediction provides a match to the flight test result, while the DEMETER result is not far off but to the wrong (conservative) side, as seen in figure 6. Similar to the steep geometry case, the signal level is still above the minimum (e.g., not red as in figure 4), but also visibly reduced compared to obstacle-free propagation (see inset). The difference between line of sight and coverage taking diffraction into account is slightly larger than in the steep geometry case. This counters the argument made for the steep geometries, which downplayed the significance of the diffraction zone. While the hypothesis is right from a pure geometry point of view, it needs to be remembered that the main lobe of a typical DME antenna has its peak at 3 degrees elevation. The insets show that despite similar distances, the expected free-space power is higher in the mid-range geometry. The fact that the terrain in the steep geometry case is a rocky edge while the medium geometry propagates over round hills may play an additional role. Nonetheless, the differences between EMACS and DEMETER predictions are still not excessive.

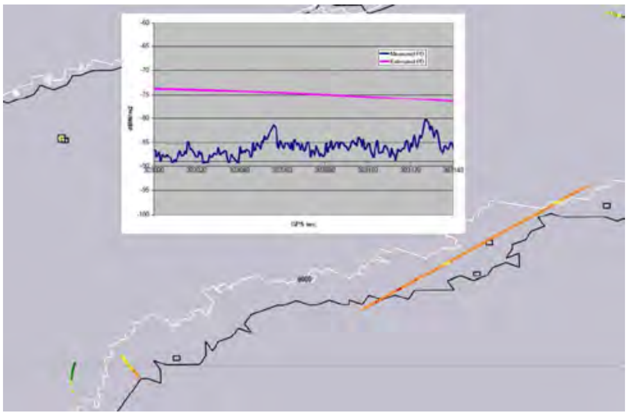

Figure 6: Mid-Range Geometry Result 2

Another medium geometry result was obtained at a far-out range (not shown here), about 65NM from the station, where the DEMETER prediction was optimistic. As alluded to in the discussion of figure 2, the DEMETER DOC restriction had to be removed, providing line of sight results even outside of radio coverage. Since the EMACS tool uses radio range in the calculation, a far out “soft” propagation boundary can be recognized by dynamic variations of the coverage contour, corresponding to a case where path loss provides the coverage boundary instead of line of sight. Despite being closer to the mark, EMACS also provided optimistic predictions in these areas. Even if the actual signal power can obtain values above the minimum threshold, it is still weak and erratic, e.g., at the limits of utility especially from an infrastructure point of view which needs to protect the least capable user. This emphasizes the need to use DEMETER together with a correct DOC limit as well as a means to recognize EMACS contours where reception could be problematic.

Shallow Obstacle Geometries

The shallow geometries are the most difficult to verify in the sense that flying near the optical line of sight requires profiles far out and at low altitudes, near the limit of radio propagation. Even here there is a good general match between prediction and measured signal levels, however, only minor variations in either computational settings or assessment of measured (noisy) power levels can alter the results. In general, there appear more conservative results both for DEMETER and EMACS. Figure 7 shows an actual example that was flown to the east of the GRE station.

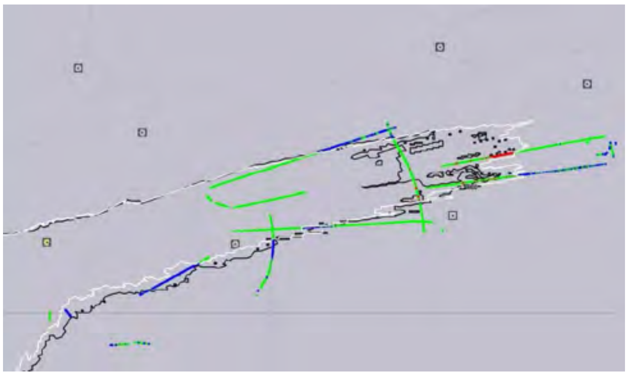

Figure 7: Shallow Geometry Result

A somewhat surprising effect can be observed in the shallow geometry results. A number of conservative cases were encountered where the power density level was sufficient (above -89 dBW/m^2), while the DME receivers did not succeed in tracking the signal reliably. An evaluation of the baseband video provided by SISMOS in these areas shows significant levels of short distance multipath. An example is shown in figure 8. An echo with a delay of only some microseconds or less is overlaying the pulse pair, impacting the pulse width and potentially even the spacing.

As per the DME interrogator specification [5], any multipath at levels higher than 10dB below peak cannot count on rejection filtering. However, the receiver does monitor pulse width and spacing such that any pulse pair not meeting the established parameters is rejected. In other words, shallow angle propagation can be so fraught with high short-distance multipath levels that despite sufficient signal strength, the reply efficiency is reduced, limiting reliable tracking by prospective user avionics. This effect requires some caution to be used when attempting to rely on such facilities and propagation geometries in infrastructure assessments.

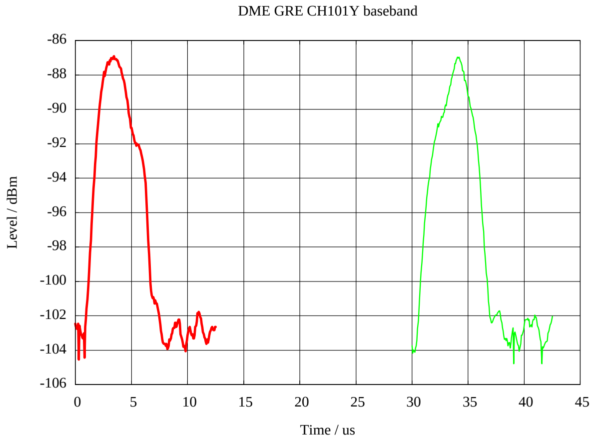

Figure 8: Pulse Pair with Short Multipath

The optimistic case (red line in figure 7) is again far outside a realistic DOC for this facility, as can be seen from the black EMACS contour.

Further Analysis and Quantitative Results

With this more targeted flight inspection, prediction accuracy is again analyzed in histograms [1]. As remarked in the previous work, the results depend a lot on the chosen trajectory; if the trajectory is chosen such that most of the flight is conducted in areas where coverage prediction is straightforward, then the results will also look better. This effect can be eliminated by only looking at prediction errors, throwing out all points where the prediction was correct and only contrasting optimistic against conservative errors. Even then it can be argued that the resulting distribution depends on the chosen profiles. However, the flight planning aimed at achieving a comprehensive and balanced distribution between obstacle geometries and time spent inside or outside of predicted coverage. Thus, while there may be some limitations in being able to draw conclusions from the distribution shapes, at least in terms of tail magnitudes the results have validity. Figures 9 to 15 show some of the computed histograms. These histograms have been generated using the shortest distance between the measured coverage boundary point and the DEMETER coverage prediction contour. The previous analysis used only the radial distance, which produced large deviations especially if there were errors in azimuth. Due to the complexity of the problem it does not appear useful to split up error terms into (station-) radial and azimuth components. The minimum distance approach also appears most useful for deriving assessment guidance that can be used for what will essentially remain a visual inspection process.

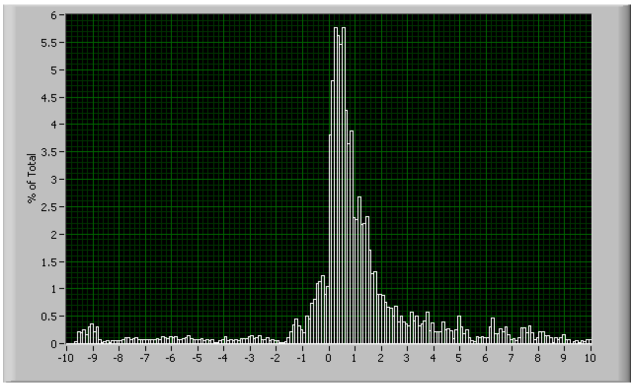

Figure 9: Prediction Accuracy, Pd, k=1, DTED1

Figure 9 shows the prediction accuracy histogram for DEMETER using a k-factor of 1 on DTED1 data, against the power density measurement. The horizontal scale indicates optimistic predictions to the left (in NM, from -10 to +10NM for all plots) and conservative predictions to the right (positive values). This overall result is quite good in that it shows a reasonable balance between optimistic and conservative predictions – very few optimistic results while the magnitudes of the conservative errors are limited. While some noise can be observed in the tails up to 10NM, an interesting clipping effect takes place when plotting the histogram using the DME receiver tracking status flag; this is shown in figure 10.

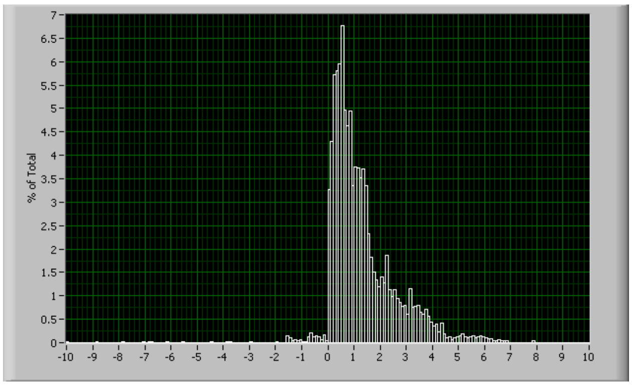

Figure 10: Prediction Accuracy, DME Status, k=1, DTED1

Both the optimistic and conservative predictions get reduced significantly. For optimistic cases (inside predicted coverage but insufficient power density), these cases get reduced by the DME receiver tracking margin, e.g., the interrogator having a higher sensitivity than required. Another reduction is from flight profiles with high bank angles, where the power density measurement drops down briefly but the receiver keeps tracking.

For the conservative cases, the DME receiver refuses to track both due to the short distance multipath effects discussed with figure 8 as well as simply insufficiently stable signals. For this analysis, both the tracking status of “memory mode” and “search” were interpreted as not tracking.

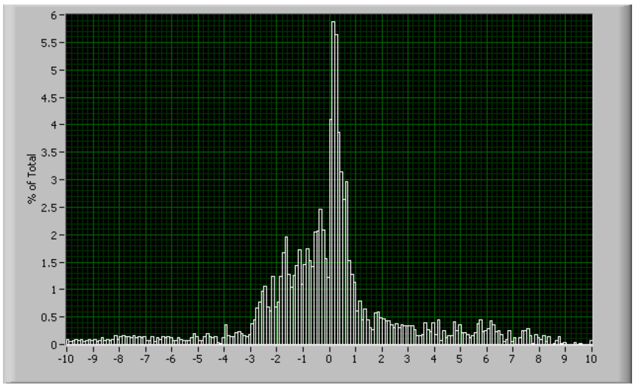

Figure 11: Pred. Accuracy, Pd, k=1.33, DTED2

Given the plausibility of the result, the use of different k-factors and terrain data resolutions was evaluated. When using a k-factor of 1.33 (corresponding to normal refraction levels, 4/3 earth radius), the coverage predictions become slightly more generous, shifting the distribution more to the optimistic side. Similarly, with higher resolution terrain data, the tendency is that more coverage is available due to summit sizes being reduced. The cumulative effect of k-factor and terrain data resolution is shown in figure 11, where the mass of optimistic cases is clearly increased. This now brings the distribution close to a zero mean, which is very good from an academic point of view. However, for infrastructure assessment, erring on the side of conservatism is preferred.

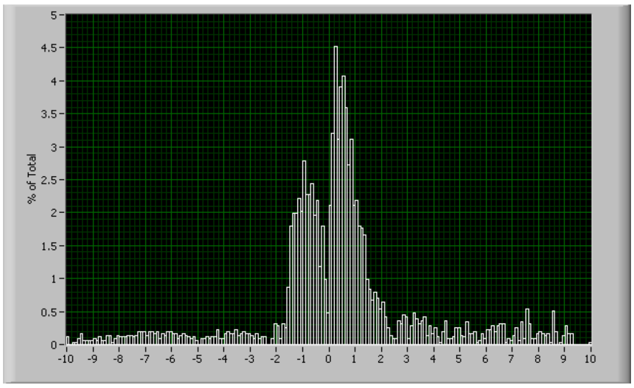

Figure 12: Shallow Geometry, Pd, k=1.33, DTED1

While this result indicates that the utility of higher resolution terrain data may be limited for these purposes, the receiver characteristics again provide for a significant clipping especially of the optimistic cases, very similar to figure 10. In light of this, the specific obstacle geometry scenarios were analyzed further. Figure 12 shows the histogram sorted for shallow geometries only, e.g., with elevation angles below 1,5 degrees.

When looking at the associated receiver tracking, benefit of above minimum receiver sensitivity can be seen clearly (figure 13): the shorter hump on the optimistic side disappears almost completely and the tails are reduced overall. On the conservative side, the maximum magnitude of prediction errors is reduced from 9 down to 6NM, due to short distance multipath and other signal anomalies not passing receiver quality checks.

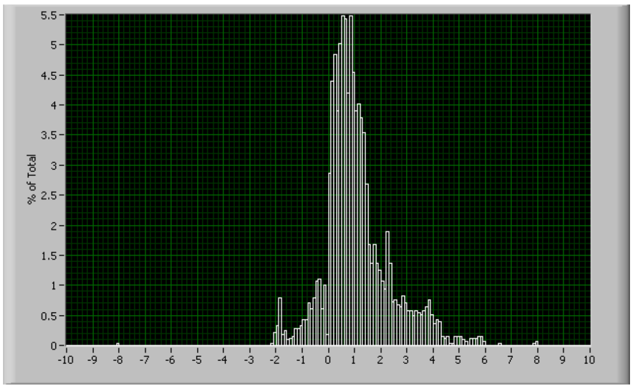

Figure 13: Shallow Geometry, DME Status, k=1.33, DTED1

Progressing further to the mid-range geometries (elevation angles between 1.5 and 6 degrees), we can see in figure 14 that the prediction behavior cleans up on the optimistic side and remains within normal expectations on the conservative side. The receiver clipping effects remain minimal in this case.

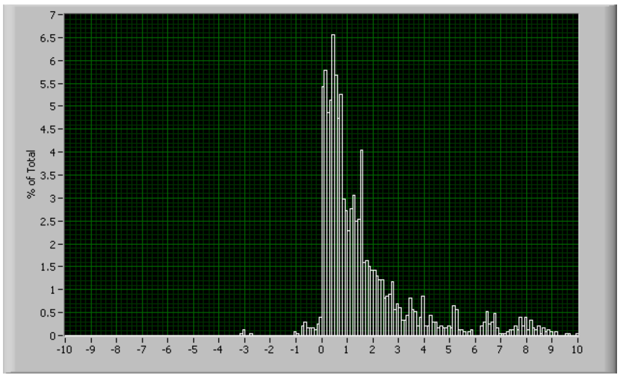

Figure 14: Mid-Range Geometry, Pd, k=1.33, DTED1

Finally, figure 15 shows the steep angle geometries above 6 degrees. Here the conservatism of ignoring the diffraction zone, as well as its limited impact, is evident. The outliers are again cut out by the receiver; the -8NM cases and those above +2NM are eliminated (not shown).

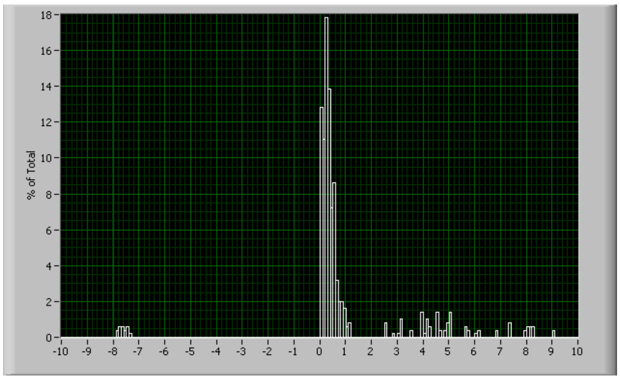

Figure 15: Steep Geometry, Pd, k=1.33, DTED1

These histograms show that prediction errors generally remain well within a -1 to +3NM margin for line of sight predictions using DTED1. Rather conveniently, the DME receiver further reduces the magnitude of more significant errors by either not locking on to unstable signals or maintaining tracking through short duration effects, regardless of geometry scenario and error sign.

Analysis of Specific Cases of Inaccurate Prediction

One area of the histograms above was found to deserve a more detailed investigation: the conservative predictions of the mid-range geometries. As can be seen from figure 14, even if the errors taper down significantly at +3NM, a non-negligible portion of errors does extend out to the tail of the distribution. Looking at receiver tracking status, the errors are contained between +3 and +7NM. These cases correspond to flight profiles to the south of the station. To support this study, skyguide generated a precise horizon profile using very accurate elevation data with a 25m post spacing from swisstopo. Comparing this with the DEMETER horizon profile in figure 1 at the relevant azimuths, discrepancies of up to half a degree were noticed; the swisstopo data suggests that the actual line of sight is better than predicted. The controlling summit on azimuth 155 degrees lies at about 3km from the station. Comparing both the station and the controlling summit elevations showed that the DTED data was about 5,5m low at the station and 18m too high at the summit. This falls well within the accuracy limits of the DTED specification [6]. Further inspection of the obstacle summit shows that the summit coordinate with an elevation of 578m AMSL according to DTED falls nicely between two mountain peaks of 565 and 572m. The little orange cross in the center of the map in figure 16 indicates the location of the DEMETER summit with a true elevation of only 560m. Here the geo-sampling effects of both DTED and DEMETER can be observed – the DTED tile size and/or the summit calculation likely pulls in the nearby peak, blending out the valley which poses little obstacle to propagation. It should be noted that such small angle inaccuracies can occur almost anywhere depending on the terrain data set being used, however, the effect will be most pronounced at lower angles and short range obstacles.

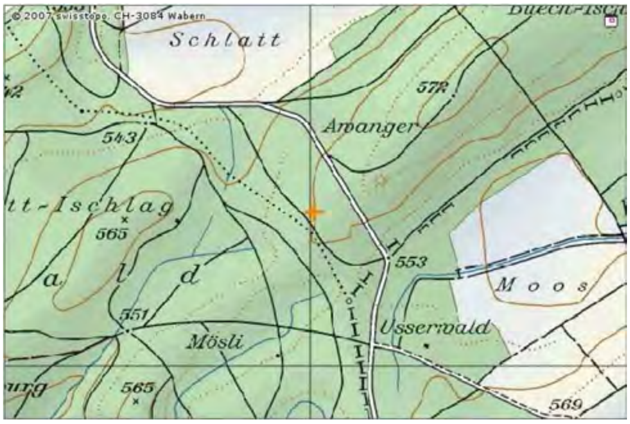

Figure 16: Location of DEMETER summit at R155 (DME GRE located ca. 3km NNW)

While analyzing this specific scenario further is beyond the scope of this paper, it illustrates the need to ensure that the terrain data used for coverage predictions is of sufficient quality. Even if high quality terrain data is not available, a normal horizon measurement with a theodolite, ideally conducted at DME antenna height, can easily be used to detect such data quality issues and perform the necessary optimizations.

GENERAL CONCLUSIONS

The initial aim of the work to derive some analytical link between a given terrain data quality, specific line-of-sight computation settings, obstacle geometries, etc., and a quantifiable prediction accuracy estimation or error bound remains elusive due to the complexity of the problem. However, the ultimate aim to get a quantification of achievable accuracies using currently available terrain data and a line-of-sight tool has been achieved. This enables to give some guidance on which cases can forego a flight inspection and others where measurement would be highly advisable. The errors of line of sight coverage prediction, using publicly available DTED level 1 data meeting its specified tolerances, generally remain within the limits of -1 / +3NM regardless of obstacle geometry. While higher levels of terrain data resolution may be useful in some cases, the potential additional expense for such data will be difficult to justify. This also reduces the computational burden.

The conclusions for the operation of DEMETER are that it is worthwhile to use the most demanding computation settings (highest resolution) with good DTED1 terrain data. Also, in cases of prediction quality issues the summit visualization and horizon display features are very useful. While EMACS does provide more accurate results the differences are not dramatic. In EMACS, areas of limited coverage can be recognized by looking at the regularity of the contour – noisy blotches indicate that coverage may be less than expected.

In terms of agreement between simulation and measurement, excellent results have been achieved. While a high quality power density measurement is essential for such a validation effort, it is important to remember the effects of receiver processing, which turns out to be beneficial here in terms of reducing both optimistic and conservative errors.

While more validation data is always welcome, it is felt that the current effort is sufficiently conclusive, at least for producing guidance for terminal area assessments. It would be interesting to perform the same evaluations in a higher level, en-route context, especially since the extension of the findings to such scenarios is not straightforward. Typically, en-route facilities are better sited than those located on airports, but they are also more likely to be used at shallow angles and large distances. However, the effort in terms of flight hours for a similarly targeted exercise would be substantial. Revisiting the passive recording approach with a better tuning strategy could be considered at some point if the need arises.

GUIDANCE FOR DECIDING ON RNAV FLIGHT INSPECTION PRIORITIES

Analyzing three-dimensional facility coverage in an RNAV context is quite complex. Before conducting a large number of terminal area assessments (such as for implementing SIDs and STARs), where only the along-track vertical coverage profiles are calculated, it is recommended to first get familiar with the horizontal coverage at various relevant altitudes for each facility under consideration, and perform some assurance that terrain data quality and any obstacle-driven coverage limitations are sufficiently understood. It is also essential to know the radio range of the facility and set the DOC accordingly. Once such a basis is established, line of sight assessments should give reliable results as long as there is sufficient coverage margin. A flight inspection evaluation is clearly necessary if a procedure or airspace boundary is only just barely covered (such as the partial coverage of a procedure width). Care needs to be exercised in particular in low angle propagation scenarios near the coverage limit. The k-factor is not highly relevant for a TMA assessment, but should be used for higher altitudes and larger facility usage ranges.

SUMMARY AND FURTHER WORK

The work presented here and the mentioned similarity to the regular infrastructure assessment process as described in [7] highlight again the efficiency gains that can be achieved if software tools are used as part of an overall cooperative process between navaids engineering and flight inspection personnel. The prediction tool is used to decide on which inspections are needed where and plan the flight inspection runs. Post mission results can then be fed back into the tool to finalize the analysis as well as build up the experience database, which in turn may reduce the efforts required in future assessments.

The DEMETER tool is used by many users worldwide. The findings discussed here will be used to optimize some features in DEMETER, for example to generate some type of warning if the DOC boundary is extended beyond link budget limits. The generated guidelines for determining areas of flight inspection interest as well as further optimizations of the existing flight inspection preparation capabilities will also be considered. At this stage it is not foreseen to integrate any radio frequency propagation tool capabilities, since the added value for such an open distribution package is limited. There are sufficient suitable products on the market such as EMACS that do this at almost any desired level of sophistication.

Flight inspection organizations and other relevant parties are invited to provide comments, suggestions or feedback on their infrastructure assessment experiences to Eurocontrol (demeter@eurocontrol.int) in order to continue progress and the establishment of best practices on the subject.

ACKNOWLEDGEMENTS

The authors and their organizations would like to thank skyguide, Air Navigation Service Provider of Switzerland, for the coordination and assistance provided.

The infrastructure coverage tool validation work has been supported by SESAR and conducted specifically within the frame of the SESAR 15.03.02 project on navigation infrastructure rationalization. Thales ATM, EUROCONTROL, NATS Ltd and ENAV participate in the 15.03.02 project. The authors would also like to thank the project partners for supporting this work.

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Appendix: Short Description of Propagation Models used with Terrain Data

Sophisticated numerical tools for propagation modeling (such as EMACS) are based on widely known computational electromagnetic techniques, such as (3-D methods):

- Geometrical Theory of Diffraction (GTD/UTD)
- Physical Optics (PO/PTD/ITD)
- Method Of Moments (MOM)

However, these are computationally demanding and require a highly accurate environment model. This is normally not given when using large area terrain data such as DTED. Consequently, the problem can be simplified to 2D terrain slices and optimized for simulations such as those performed for navigation facility coverage predictions.

Overview of 2D Algorithms Suitable for Coverage Simulations:

The Deygout method used by EMACS for this work has already been described in the body of the paper. Other options (also available in EMACS) are listed below. All the implemented numerical tools execute their computations taking into account the propagation mechanisms within the vertical plane passing through the antenna phase centre and the observation point to derive the signal strength:

1) **IF77 method:** this method is applicable to air/ground, air/air, ground/satellite, and air/satellite paths. It can also be used for ground/ground paths that are line-of-sight or smooth earth. Model applications are restricted to telecommunication systems operating at radio frequencies from about 0. 1 to 20 GHz with antenna heights greater than 0.5 m. In addition, radio-horizon elevations must be less than the elevation of the higher antenna. The radio horizon for the higher antenna is taken either as a common horizon with the lower antenna or as a smooth earth horizon with the same elevation as the lower antenna effective reflecting plane. At 0.1 to 20 GHz, propagation of radio energy is affected by the lower, non-ionized atmosphere (troposphere), specifically by variations in the refractive index of the atmosphere. Atmospheric absorption and attenuation or scattering due to rain become important at SHF (Super High Frequencies). The terrain along and in the vicinity of the great circle path between transmitter and receiver also plays an important part. In this frequency range, time and space variations of received signal and interference ratios lend themselves readily to statistical description.

   G. D. Gierhart, M. E. Johnson "The IF77 Electromagnetic Wave Propagation Model" Sept. 1983.

2) **GTD-2D method:** this method is based on the use of a 2D formulation of the Geometric Theory of Diffraction (GTD) in its uniform formulation, also known as Uniform Theory of Diffraction (UTD). This theory is based on an asymptotic solution of the Maxwell equations which is obtained under a high frequency approximation. Such a formulation is applicable in the evaluation of the interaction between a radiating source and a scattering structure whose dimensions are much larger than the field wavelength. The total scattered field can be described as the combination of discrete contributions from a number of 'hot points' distributed over the body according to relatively simple geometric laws relating to the propagation of rays.

   J. B. Keller, "Geometrical Theory of Diffraction", Journal of the optical society of America vol. 52, Nr. 2, February 1962

3) **Parabolic Equations method:** the PE solution is a full wave solution (i.e. exact solution). This method is used to solve the two-dimensional (2-D) Helmholtz equation.

   Amalia E. Barrios, "A Terrain Parabolic Equation for Propagation in the Troposphere", IEEE Transaction on antennas and propagation, VOL 42, NO. 1, JANUARY 1994

A Study of Testing DME Facility Signal Quality

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ABSTRACT

DME is an internationally standardized pulse-ranging system for aircraft. The ground DME beacon receives the paired pulses that is transmitted by the aircraft DME interrogator and retransmits them back to the aircraft. Using those replied pulses, the DME interrogator can figure out the range value from the ground beacon. Obviously the replied pluses signal quality influences the ranging accuracy. DME facility signal is easily worsen by interference and multipath.

The recently introduced chapter 3.3 of ICAO Doc 8071 describes the need to conduct flight inspection for the DME facility signal quality such as pulse shape and pulse spacing.

There are some methods to do flight testing for the DME facility signal quality. But usually they need a lot of common equipments, example spectrum analyzer and digital oscilloscope. This paper introduced a new process to test the facility signal quality. Authors modified the Collins DME interrogator DME442 and designed a special hardware platform to measure facility signal quality. The testing includes pulse shape, pulse spacing, reply efficiency and PRF. This module can finish testing for DME facility just by a simple hardware platform.

OPERATING PRINCIPLE OF DME

DME is an internationally standardized pulse-ranging system for aircraft, operating in the 960 to 1215MHz band. The operation of DME can be described by means of Figure1 where the aircraft interrogator transmits pulses, 12usec apart, each pulse lasting 3.5usec, with the pulse-pair-repetition rate ranging between 5 pulse-pairs per sec up to a maximum of 150 pulse-pairs per sec. Paired pulses are used in order to reduce interference from other pulse systems.

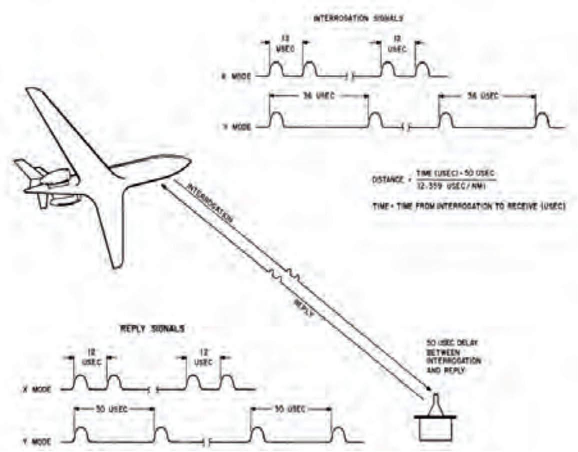

Figure 1. DME Operating Principle

The ground beacon receives these pulses and, after a 50usec fixed delay, retransmits them back to the aircraft on a frequency 63MHz below or above the airborne transmitting frequency. The airborne interrogator automatically compares the elapsed time between transmission and reception, subtracts out the fixed 50usec delay, and displays the result on a meter calibrated in nautical miles, each nautical mile representing about 12.359usec of round-trip time.

Each beacon is designed to handle at least 50 aircraft at the same time, with 100 being a more typical number. The pulse-repetition rate of the interrogators is deliberately made randomly unstable, a time correlation technique. The interrogator is designed to recognize only those replies whose pulse-repetition rate and phase are exactly the same as its own.

The interrogators receive all pulses transmitted from the ground beacon, and it therefore must perform two major functions. Recognize its own replies and reject all others and convert these into a meaningful display.

TESTING ITEMS OF DME PULSE

According to ICAO Doc 8071 3.1, pulse shape, pulse spacing, pulse repetition frequency(PRF) and reply efficiency should be tested during the flight inspection. Authors tried to do some experiments in lab to verify the testing program is good for future flight inspection of DME.

About DME signal flight inspection, a digital oscilloscope is advised for testing DME pulse shape, pulse spacing and pulse repetition frequency(PRF). In Doc 8071, DME reply efficiency is also needed. It can be used to indicate problem areas due to multipath and interference. But It's hard to measure the reply efficiency by a digital oscilloscope. And It's difficult to measure those parameters automatically and statistically by a digital oscilloscope. Digital oscilloscope is a common equipment not a special test equipment for DME.

Another question is how can we recognize the pulses-paired those DME beacon reply to our aircraft from all the pulses-paired DME beacon transmitted. No standards give us any suggestion about this.

Authors created a program for those testing. By this program requested pulse-paired can be recognized easily and testing procedure is automatic and statistical.

TESTING PROGRAM INTRODUCTION

In order to measure the DME pulse-paired, a time domain data acquisition equipment is needed. It should have trigger function. The most commonly used is the edge trigger function. It's useful for catch a burst signal, example the DME pulse-paired signal. What kind of signal can be used to trigger the acquisition ? This trigger signal should be time correlation with DME beacon pulse-paired. It means that we can easily get the pulse time if we get the trigger signal time. So DME interrogation transmitting signal could be used as the trigger signal. We can use follow formula to get the delay time between interrogating signal and DME beacon reply signal. T_d is the delay time in microseconds. D is the distance between aircraft and DME beacon in nautical mils. T_b is the constant delay time 50 microseconds. This formula is a inverse formula of the distance computation.

$$T_d = (D \times 12.359) + T_b$$

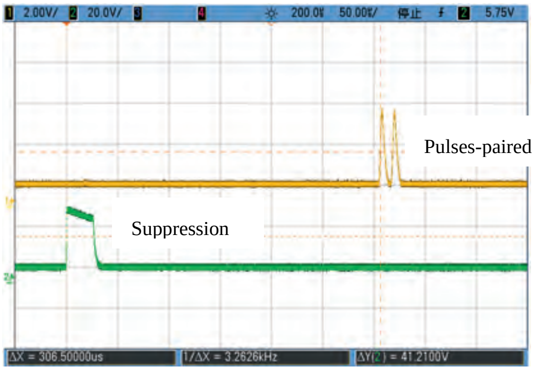

Figure 2. Suppression and DME Pulses

As some other inspectors did, a spectrum analyzer was used to receive interrogation transmitting RF signal and output a normal trigger signal for the pulse-paired acquisition equipment. Obviously it's complex to use so many equipments. Additionally

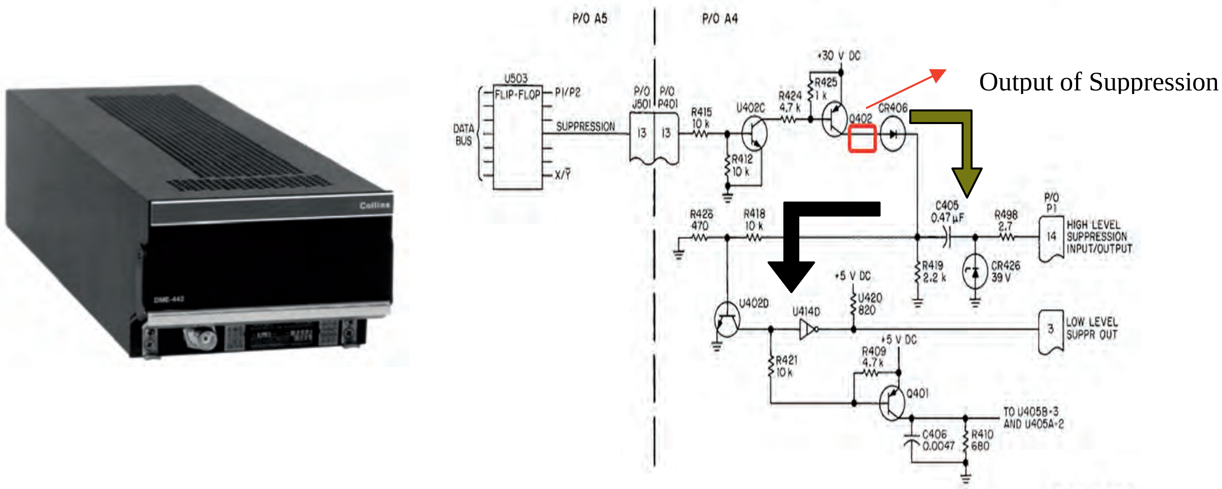

Figure 3. DME442 and suppression circuit

most of spectrum analyzer will be overloaded if receiving the interrogation RF signal directly. Protection should be done for spectrum analyzer. In author's program, spectrum analyzer isn't needed.

As we know, there is a suppression signal between all the L band aviation transmitter. L band transmitters output a suppression pulse during transmitting. So DME suppression pulse time is the same time as the interrogation transmitting time. Suppression signal should can be used for a trigger.

But the question is that the suppression bus is bidirectional. How can we recognize the suppression pulse that come from our DME interrogator not from some other transmitters? Authors modified the DME442 to get the DME output suppression signal. In the DME442, Suppression wire is divided to one input wire that for receiving suppression from other units and one output wire that support suppression for other units. What we need is just the output wire from the bidirectional suppression wire.

TESTING PLATFORM OF DME PULSE

The DME beacon Pulse testing Platform include a modified DME442 interrogator, a data acquisition module with trigger function and a laptop. This is a lab testing platform. During the flight inspection the laptop will be replaced by the flight inspection computer.

The modified DME442 can output a special suppression signal to trigger the data acquisition module. By USB2.0 bus, the laptop can receive the acquired data from the module. According to above formula, the testing application can compute out the delay time between suppression signal and reply pulses. It means we can get the position of reply pulses-paired. Than using the digital signal procession, we can get the pulse shape and pulse spacing parameters.

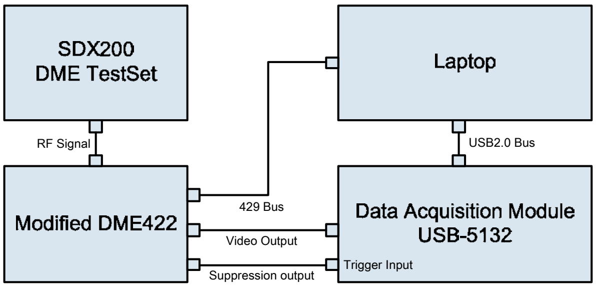

Figure 4. Testing Platform

DATA ACQUISITION MODULE

In order to get good accuracy of pulses-paired testing, hight simply frequency should be selected. At the same time we need to get enough data during every trigger those data should have enough duration. For example DME operating range is about 200nm, so the maximum delay time between interrogating pulses-paired and reply pulses-paired .

$$T_{dMax} = D_{Max} \times 12.359 + T_b = 2521.8\mu s$$

The test required accuracy is better than 0.1us. We select the simply frequency to be 50MHz. The simply interval is 0.02us. So the data space should be $2521.8 \div 0.02 = 126090$. About the simply digitalizing bits, 8 bits is enough for 1% amplitude testing requirement.

Figure 5. USB5132 picture

The data acquisition module, USB-5132 is a suitable one for this testing. It's made by National Instruments corp. Followed is the main specifications of this module:

- Bus-powered format
- Portable design, USB2.0 bus
- 50 MS/s real-time sampling
- 50 MHz bandwidth
- 2 simultaneously sampled channels with 8-bit resolution
- 1 MΩ input impedance
- Input ranges from 40mVpp to 40Vpp
- 4 MB of memory per channel

These USB digitizers have 10 input ranges from 40mV to 40V and programmable DC offset.They also come standard with 4MB per channel of onboard memory for measurements requiring extended data captures.

We can configure a suitable input range for this testing to suit the DME video signal value.

THE APPLICATION DEVELOPMENT

By USB bus, the laptop can read the captured data. During this project, we used visual 2010 C# to develope the application. NI supported NI-SCOPE.NET component for developer to driver USB-5132 in C# language.

The application gets the range value from the DME Arinc429 bus. Than computes the delay time. Using delay time, we can decide the data position.

$$D_d = T_d \times F_s$$

Fs is the simply frequency, 50MHz.

The most important arithmetic in this application is the peak search arithmetic. In our application, a gaussian pulse signal fitting arithmetic is used to get the pulse amplitude A .

As we know, DME pulse is gaussian signal. It can be described by followed formula.

$$f(t) = Ae^{-\left(\frac{t-t_0}{\tau}\right)^2} + C$$

A is the gaussian pulse amplitude. In followed example figure, A is ten. τ is the gradient parameter. Pulse rise time will be bigger when τ is bigger. C is the current parameter. t_o is the current time offset.

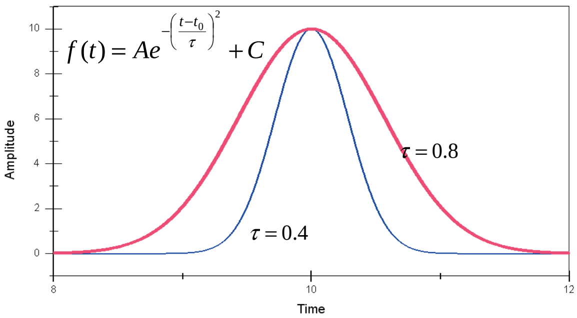

Figure 6. Gaussian Pulse Example

By the gaussian pulse signal fitting arithmetic, we get the A value. Than we can used this parameter and traverse algorithm to measure the required DME pulse-paired parameter. Now we explain the method for computing parameters.

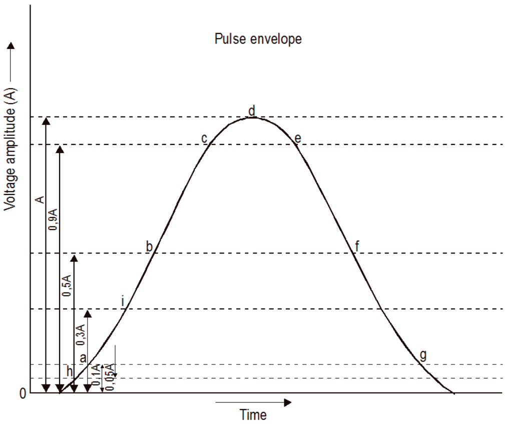

Figure 7. DME Pulse Envelope

Partial rise time. The time as measured between the 5 and 30 per cent amplitude points on the leading edge of the pulse envelope, i.e. between points h and i.

Pulse amplitude. The maximum voltage of the pulse envelope, i.e. A in Figure 7.

Pulse decay time. The time as measured between the 90 and 10 per cent amplitude points on the trailing edge of the pulse envelope, i.e. between points e and g on Figure 7.

Pulse duration. The time interval between the 50 per cent amplitude point on leading and trailing edges of the pulse envelope, i.e. between points b and f on Figure 7.

Pulse rise time. The time as measured between the 10 and 90 per cent amplitude points on the leading edge of the pulse envelope, i.e. between points a and c on Figure 7.

Reply efficiency. The ratio of replies transmitted by the transponder to the total of received valid interrogations.

About reply efficiency and pulse repetition, we use A value to detect if there are reply pulses. Than we counter reply pulses-paired to compute those two parameters.

Here is a example for computing pulse decay time T_{pdt}. Followed is the formula for T_{pdt}. τ can be gotten by gaussian signal fitting.

$$\begin{cases} e^{-\left(\frac{t_1-t_0}{\tau}\right)^2} = 0.9 \\ e^{-\left(\frac{t_2-t_0}{\tau}\right)^2} = 0.1 \\ T_{pdt} = t_1 - t_2 \end{cases}$$

Followed is the application flow chart and interface.

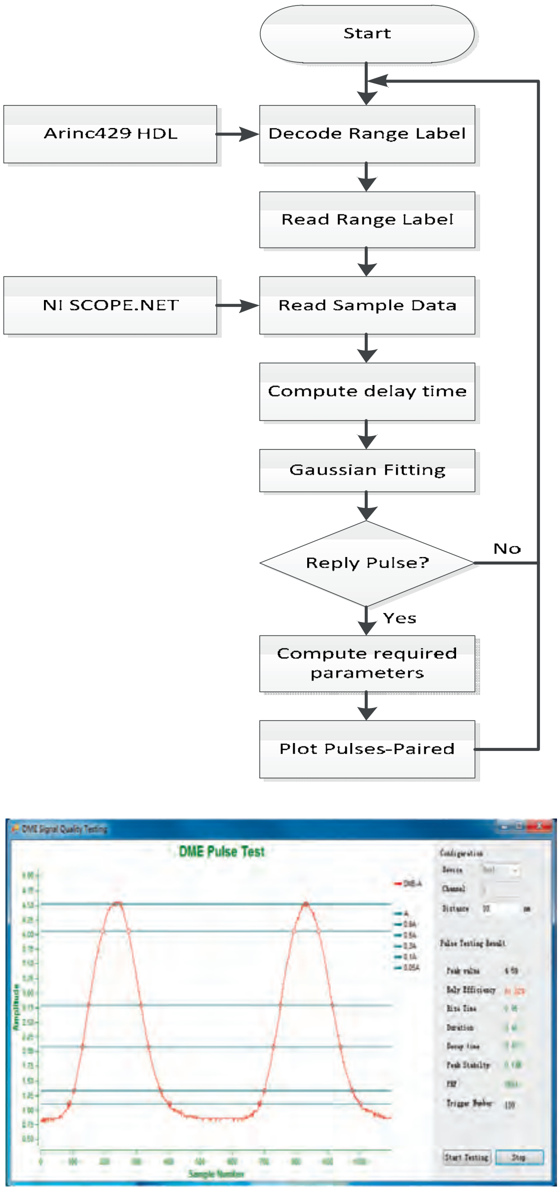

Figure 8. application flow chart and interface

CONCLUSIONS

During the lab testing, we prove that this program can support one DME beacon pulses testing. The next work we need to do is adding the spectrum analysis function and multi-beacons testing function. About spectrum analysis, FFT will be used. In order to do three beacons testing simultaneously, we need the VCO signal of DME interrogator to recognize which beacons pulses DME interrogator is receiving.

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Aircraft Antenna Calibration: Methods, Accuracy and Results

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ABSTRACT

In-Flight-measurements of absolute field strength values are an important task for monitoring, respectively maintaining navigation systems, e.g. the instrument landing system (ILS). One precondition for accurate measurements is the calibration of an antenna with the antenna factor (AF) under the antenna's real operating and mounting conditions. The AF relates the actual field strength at the antenna's location to the voltage at the antenna's feeding point. This paper presents calibration results of ILS-localizer and glidepath antennas mounted on a flight inspection aircraft. On-ground measurements are done at the airfield Stendal in Germany, the environment of which is tested for the absence of multipath propagation that would degrade calibration accuracy. Two continuous wave reference sources provide a well defined test signal for the antenna calibration under far field conditions. The aircraft antenna calibration is done with the substitution method, which directly relates field strength values obtained with a calibrated field probe with the power received by the respective aircraft antennas. This method and calibration results are qualitatively related to other methods, such as the three antenna method. Finally, measurement results are assessed in terms of accuracy and reproducibility to draw conclusions for such measurement applications in practice.

INTRODUCTION

Monitoring the field strength of navigation systems in space via in flight measurements require accurate calibration of the respective measuring antennas mounted on the aircraft. Common calibration techniques such as the three antenna method [1] or the substitution method, that is applied here and has already successfully been applied in other research projects [2], face difficulties in their application simply due to the size of the aircraft itself and its antenna. However, the substitution method is chosen since in that particular configuration the accuracy of this calibration method is supposed to be less sensitive to non-idealities of the measurement environment, such as the ground. This paper describes a calibration chain from a fundamental well controlled, thus traceable measurement environment to the actual measurement configuration with the aircraft to obtain its antenna factors for the ILS localizer and glide antennas. Consequently, this paper is organized as follows. In the first section fundamental aspects of antenna calibration are explained. The second section describes the traceable calibration of the reference antenna that is later used to calibrate the aircraft antennas. Finally, calibration measurements with an aircraft are presented and assessed, including the validation of the measurement site at the airfield in Stendal and a discussion of the ground plane's influence.

FUNDAMENTAL ASPECTS OF ANTENNA CALIBRATION

There are actually two measures for characterizing a receiving antenna. The antenna factor *AF* relates the electric field strength *E* at the location of the antenna to a voltage U that is measured at the feeding point of the antenna according to

$$AF = {}^{E}\!/\!_{U} \; . \tag{1}$$

Another measure often stated to be equivalent to the antenna factor as derived from reciprocity is the antenna gain. In the following some considerations are described concerning these two measures with respect to the actual calibration task. The transmission between two antennas, i.e. the emitting navigation system and the receiving antenna mounted on an aircraft is described with the so-called Friis transmission equation (2)

$$P_r = \underbrace{\frac{P_S \cdot G_S}{4\pi r^2}}_{power\ flux\, density} \cdot \underbrace{\frac{\lambda^2}{4\pi} G_r}_{\substack{effective\ area \\ of\ receiving\ antenna}} \quad , \tag{2}$$

where P_r is the received power at the antenna with a gain G_r, P_s the emitted power of the antenna with a gain G_s, λ the wavelength and r the distance between the two antennas. It must be stated that the applicability of this fundamental equation (2) implies free space propagation and plane wave incidence. The actual measure of interest, the electric field strength E, minimum values of which need to be met by operating navigation systems as demanded in [3], are only implicitly represented in this formula via the power flux density S

$$S = \frac{E^2}{377\,\Omega} \; . \tag{3}$$

The receiving power P_r is related to a voltage U at the feeding point of the receiving antenna in a 50 ohms environment

$$P_r = \frac{U^2}{50\Omega} = \frac{(E/AF)^2}{50\,\Omega} \; . \tag{4}$$

Inserting (3) and (4) into (2) following equation between the antenna gain and the antenna factor is obtained:

$$G_r = \frac{377}{50} \cdot \frac{4\pi}{\lambda^2} \cdot \frac{1}{AF^2} \; . \tag{5}$$

There are two types of calibration techniques yielding directly either the gain or the antenna factor. Common methods to determine the gain of an antenna are the three antenna method [1] or the reference antenna method. These methods are based on evaluation of respective power transfer functions between two antennas. If a gain of one antenna is known, typically standard gain horns or simple dipoles, which can be calculated with high reliability, equation (2) can be solved for the unknown gain. If no such reference antenna with known gain can be used, the three antenna method gives three evaluations of respective power transfer functions for different combinations of receiving and transmitting antennas that allow derivation of all three unknown gains. Such calibration methods yielding a gain depend on the evaluation of transfer functions assuming an ideal propagation model that is hard to realize in practice. In particular, additional boundary conditions giving reflections or a coupling ground or the mounting fixture of the antennas itself are non-idealities for such a propagation model. Moreover, once the gain might have been measured accurately anyhow, the derivation of the antenna factor, respectively the actual field strength with (5) requires the same preconditions of free space propagation and plane wave incidence.

Consequently, for calibration of aircraft antennas the substitution method is chosen since non-idealities in the measurement setup with an aircraft on ground can be supposed to have less influence on measurement accuracy. The substitution method is a direct evaluation of equation (1), measuring a field strength and a receiving voltage. The evaluation of this equation actually is not bound to a particular propagation model. Especially the ground, the conductivity of which is not negligible, is a boundary condition that cannot be in accordance with plane wave incidence for horizontal polarization of the localizer and glide slope antennas. Whereas this plane wave assumption is always implied in gain measurements as described above, the evaluation of equation (1) with the substitution method can allow arbitrary types of plane wave incidence. Moreover, the substitution method works without any characterization of the emitter, such as emitted power or gain of the emitting antenna.

However, the substitution method requires one direct measurement of absolute field strengths with reliable accuracy, to which all other measurements are referring. The following section describes how such field strength measurements are done as a basis for the calibration of a reference antenna that is used for the actual measurement campaign with an aircraft.

CALIBRATION OF THE REFERENCE ANTENNA

As traceable calibration standard an electro-optical field sensor is used, the antenna factor of which is determined in the well controlled environment of a µTEM-cell. Such TEM cells are a preferred and well-established environment for EMC-testing as they provide a homogeneous field inside, the intensity of which can directly be calculated analytically from the feeding power. The calibration procedure of the electro-optical sensor in a µTEM-cell is explained in detail in [4]. In [4] convincing accuracies in field strength measurements in the near field of large antennas are described. Thus, this electro-optical sensor, respectively its performance in a µTEM cell, is the calibration transfer standard, all other measurement results are traced back to in the calibration chain. However, as the dynamic range of the sensor is quite limited due to its small size it cannot directly be used in a later measurement setup with an aircraft. Consequently, a reference antenna is calibrated based on measurements with this electro-optical sensor. Calibration measurements of the reference antenna are done at the open area test site at the national metrology institute (PTB) in Germany. This open area test site (OATS) has a conducting ground plane in accordance with the later measurement environment with the aircraft. In the measurement setup a biconical antenna emits into the direction of the calibrated electro-optical sensor that is then replaced by the reference antenna. The receiving powers are respectively measured with a spectrum analyzer. The distances between emitting antenna and receiving antenna, respectively the sensor is 20 m. Fig. 1 shows both the field sensor and the calibrated logarithmic-periodic antenna at the measurement site.

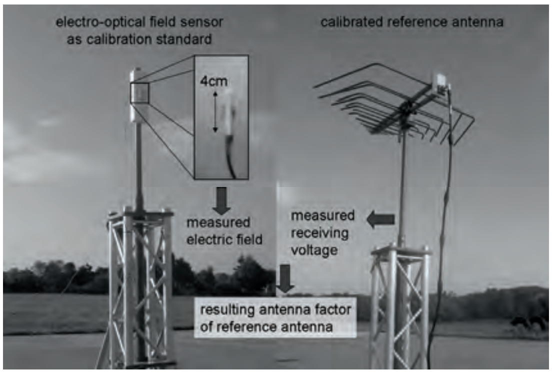

Figure 1. Sensor and Reference Antenna at the Open Area Test Site

It has to be stated that the reference antenna and the sensor are used in the exact measuring condition on the mounting fixture that is used in the later campaign with the aircraft. Fig. 2 shows measurement results of the antenna factor of the reference antenna, respectively at three frequencies in LOC and GLIDE bands and in different measurement setups, such as the varying height. Additionally, the reproducibility, thus the measurement accuracy is assessed, as the calibration measurement is done at two different days, respectively setups, after a complete re-assembly of the measurement setup.

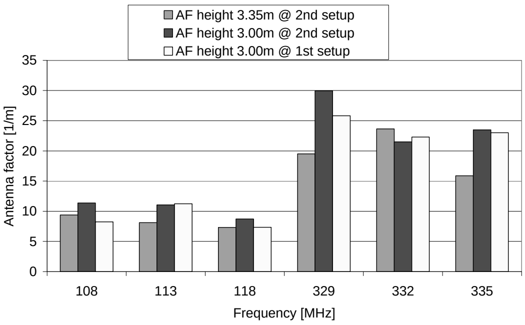

Figure 2. Calibration Results of Reference Antenna

The reproducibility of the calibration corresponds to the difference of the values between the two setups ranging from a maximum of 2.8 dB at 108 MHz to typical values of about 1 dB at other frequencies. Additionally, slight dependencies on the frequencies in the respective bands can be observed with largest deviations in the GLIDE band at an antenna height of 3.35 m of 3.5 dB. As expected values also depend on the antenna height, that has influence both on the ground reflections and the coupling between the antenna and its mounting fixture. In conclusion, the calibration of the reference antenna allows absolute field strength measurements with an accuracy of better than 3 dB. Even in the narrow frequency band of the navigation systems, a frequency-dependent, respectively channel-dependent calibration might be useful. It has to be stated that the reference antenna is used in exactly the same configuration as it was calibrated, that is including its connecting cable and the mounting fixture. For measurements in the later configuration with the aircraft it is advisable to apply the lowest antenna factor from the calibration uncertainty as it corresponds to the lower field strength at the later measurement site, thus also yields lower antenna factors for the aircraft. A lower antenna factor of the aircraft gives the lower value for measured field strength of navigation systems.

MEASUREMENT OF AIRCRAFT ANTENNAS

In this section measurement results are presented for the antenna factors of the aircraft antennas. The measurement procedure is similar to the calibration of the reference antenna. An emitting antenna radiates a field strength towards the later measurement location of the aircraft. This field strength is measured with the calibrated reference antenna and only needs to be related to the received voltage at the antenna connector of the aircraft according to equation (1). These measurements already include cable losses and cable coupling in the aircraft, as the received voltage is directly measured at the connectors of the aircraft's interface panel as shown in Fig. 3.

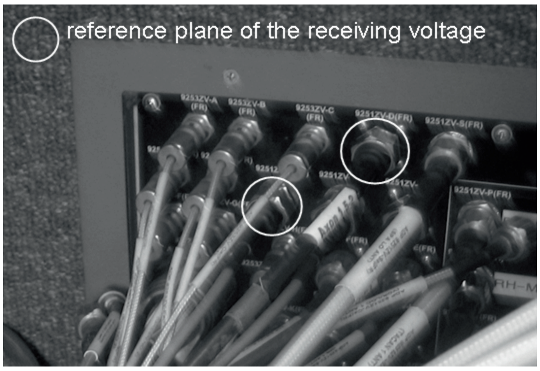

Figure 3. Reference Plane of Receiving Voltages inside the aircraft

Received powers inside the aircraft are measured with a spectrum analyzer that is connected to the four interfaces of the respective antennas (Localizer and Glidepath antennas, respectively on top of the fuselage and within the tail) with a high frequency switch. Measurements with the aircraft, Cobham FL-424 G-COBI, Beechcraft King Air 350, took place at the airfield in Stendal and comprise the reference field strength measurement with the calibrated antenna at one position of the emitting antenna, a measurement with the aircraft with the same configuration and a directional scan of the aircraft antennas where the emitter is moved along a circle around the aircraft. The distance between emitter and reference antenna, respectively aircraft is 100 m.

Measurement Setup

Fig. 4 shows the configuration of the emitter. Though its absolute characteristics are not relevant for the measurements as stated above, it is mandatory to ensure that its properties remain constant during the whole measurement campaign. Thus the power sent to the emitting antenna is monitored via directional couplers and power meters as shown in the sketch in Fig. 4.

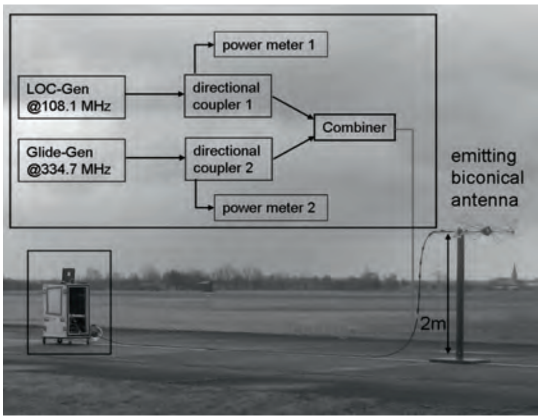

Figure 4. Configuration of Emitter

The portability of the emitter was important in this measurement campaign as the directional pattern of the aircraft is measured by moving all components shown in Fig. 4 and an additional power supply. The measurement frequencies were limited to only single ones at continuous wave for LOC and GLIDE because of restrictions from national regulation authorities in Germany. The emitted power for each frequency was about +5 dBm and provided sufficient signal-to-noise-ratio at all measurement positions. The monitoring of the emitted power showed no deviations. Fig. 5 shows the configuration of the reference measurements with the calibrated antenna at the airfield and the corresponding measurement with the aircraft from rearward direction at the position of the reference antenna.

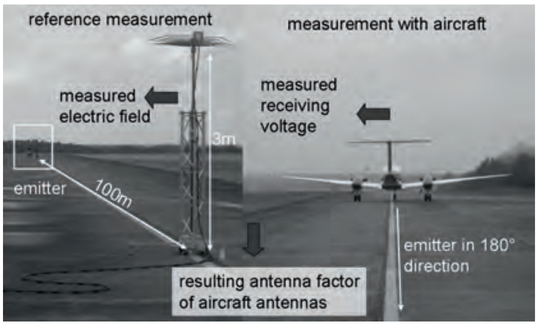

Figure 5. Configuration of Reference and Aircraft Measurements

Based on the measurements shown in Fig. 5 the antenna factors of the aircraft antennas are known in the rearward direction. Antenna factors for all other directions from a directional scan are related to this value.

Measurement Results

Fig. 6 is a sketch denoting the respective measurement positions with the moving emitter around the aircraft in a radius of 100 m.

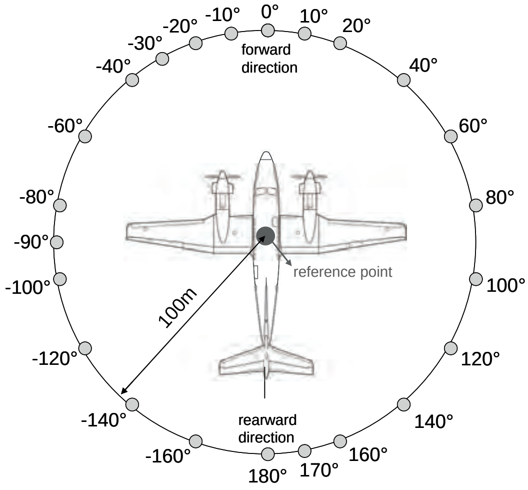

Figure 6. Measurement Positions and Angle Notation

Fig. 7 shows the measured received power for the denoted emitter positions.

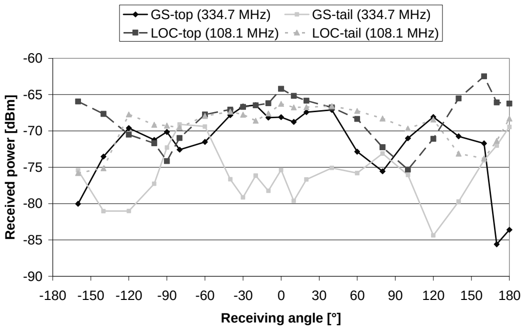

Figure 7. Measured Received Power for Respective Incidence Angles

At the emitter point at the angle of 180° measurements were done twice, once at the beginning of the measurement campaign and one after having measured for all emitter positions around the circle. The comparison of these equivalent configurations is listed in table 1.

Table 1. Reproducibility of Emitter Positions

	received power at aircraft's interface [dBm]	
	1st measurement	2nd measurement
channel 1 (GS-top)	-83,6	-83,03
channel 2 (LOC-top)	-66,23	-66,25
channel 3 (LOC-tail)	-68,29	-68,26
channel 4 (GS tail)	-69,45	-68,94

Table 1 shows a reproducibility of the measurements that is better than 0.6 dB for Glide frequencies and even better for the Localizer frequencies. This is also consistent with the monitoring results of the emitted power ensuring that there were no changes at the emitter stage.

From the measured received power, respectively received voltage at the aircraft's interface, and the known field strength, that has initially been measured with the calibrated reference antenna, the resulting antenna factors are derived. Figs. 8 and 9 show the results for the localizer and the glide antennas.

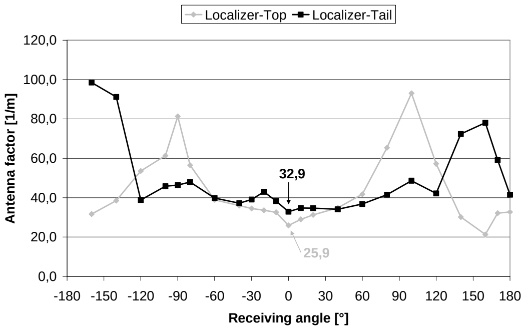

Figure 8. Antenna Factors of LOC-Antennas

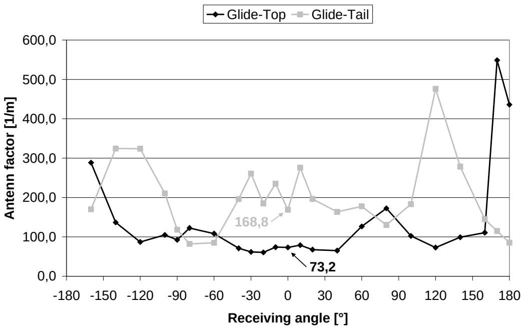

Figure 9. Antenna Factors of Glide-Antennas

Validation of the Measurement Site

In addition to the actual calibration measurements of the aircraft the measurement environment was tested for the presence of multipath propagations that could deteriorate the measurement accuracy. The directional pattern of the logarithmic-periodic reference antenna and its antenna factor have been measured at the open area test site where there are no multiple reflections in the environment. Consequently, measuring the directional pattern of this reference antenna at the actual measurement environment of the airfield would be the same if that environment also had no multiple reflections. At the measurement site, the airfield of Stendal, two directional patterns of the reference antenna located at the reference point (cp. Fig. 6) have been measured with two different positions for the emitting antenna, respectively in 100 m distance at the angles 0° and 180° (cp. Fig. 6). Figs. 10 and 11 show these measurement results of the directional patterns, respectively at the Localizer and Glide frequency. For comparison the directional pattern as obtained at the open area test site (OATS) is also inserted in the figures.

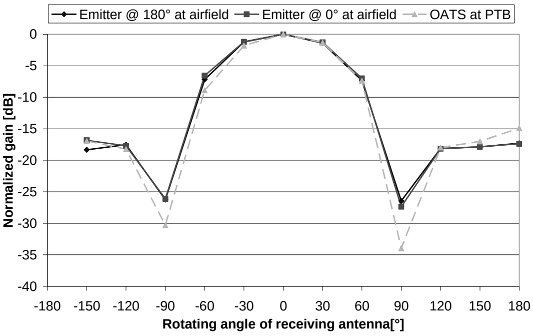

Figure 10. Measured Directional Patterns of Reference Antenna at Glide Frequency

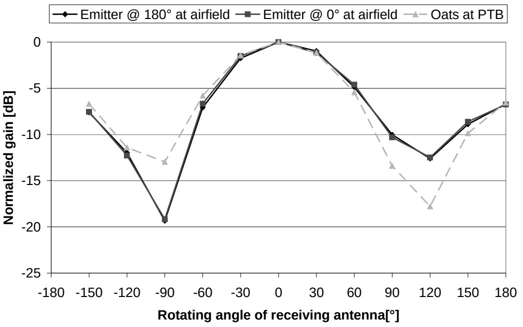

Figure 11. Measured Directional Patterns of Reference Antenna at Localizer Frequency

The directional patterns obtained at the airfield are nearly identical for both the glide and the localizer frequency. Comparing them to the directional patterns measured at the open area test site small deviations at the minima can be observed. Differences are much smaller for the higher glide frequency and nearly 30 dB below the main lobe. Deviations are supposed to be an issue of different measurement distances that were 100 m at the airfield but only 20 m at the open area test site. If the antenna was not rotated exactly at its phase center, which is very likely for logarithmic-periodic antennas the minima of the directional patterns might depend on the measuring distance. Thus it is plausible that the influence is larger for the smaller frequency of the localizer. However, as the two pattern measured at the airfield are nearly identical and only their minima slightly deviate of measurement results at the open area test site, the environment of the airfield is considered as an adequate measurement environment without relevant multipath propagation. The influence of multipath propagations can be neglected.

Considerations on the Ground Plane Issue

The reasons why measurements of the aircraft are performed on ground are twofold. A practical one is that the geometric accuracy in a static measurement setup is supposed to be higher on ground, in particular the angular alignment for measuring the directional pattern of the aircraft. Another reason is that, if calibration measurements were done in flight, the measurements for the site validation are much more demanding, just due to the much larger environment.

Additionally, with larger distance the probability of such multiple reflections increases and the reproducibility of calibration measurements is very likely to suffer from that, especially if the scatterers themselves can hardly be identified, are badly reproducible and so can only roughly be considered with respect to their influence. Thus, the reference measurements of the field strength and the measurements of the aircraft are supposed to be much more reliable and accurate on ground.

However, the validity of measurements on ground for the later in-flight measurement application has not been discussed so far. But in order to give at least a guess on how the influence of the ground might be, rudimentary simulations are performed with a generic structure, that is a horizontal dipole over a conducting cylinder to resemble the aircraft fuselage and the antenna mounted on it. Simulations are done with CST-Microwave Studio [5]. The simulation scenarios are a resonant half wavelength dipole located half a meter over a conducting cylinder with a diameter of 1.8 m and length of 5 m. The simulation scenario is shown in Fig. 12. It also shows the ground plane the material properties of which are changed from vacuum to perfect electric conductor to investigate the influence of the ground's conductivity.

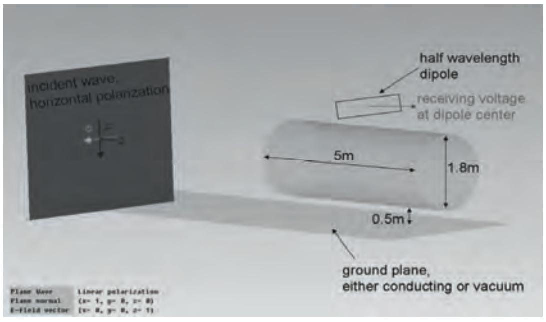

Figure 12. Simulation Scenario to Investigate Influence of Ground Plane

Fig. 13 shows the simulation results, which are the voltages at the discrete dipoles as localizer, respectively glide antenna on top of a fuselage.

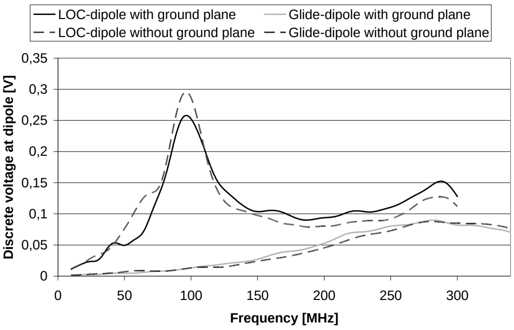

Figure 13. Simulation Results for the Influence of the Ground Plane

Comparing the receiving voltages at the dipoles, which directly would correspond to the measured antenna factors, the maximal influence of a conducting ground plane is 1.6 dB for the localizer case. However, it should be stated, that this value is not meant to be an accurate quantitative measure, as the simulation scenarios are quite rudimentary, and a sophisticated numerical analysis on this issue is beyond the scope of this contribution. But at least simulation results are an indication that the presence of a conducting ground plane does not fundamentally change the antenna factor of the aircraft, thus can be transferred to in-flight measurements, of course with some uncertainty. This conclusion is only valid for antenna mounted on top of the fuselage, where the conducting fuselage of the aircraft itself seems to dominate the coupling behavior between the aircraft antenna and its environment.

CONCLUSIONS AND OUTLOOK

An on-ground measurement campaign is presented for calibration of aircraft antennas for the ILS localizer and glide antennas. The accuracy of calibration measurements with a reference antenna turned out to be better than 3 dB in the ideal environment of an open area test site. This accuracy is the basis for the actual calibration measurements of the aircraft antennas with at least the same measurement uncertainty. The uncertainty in the reference measurement of the field strength is taken into account such, that results for the aircraft antennas will yield measured field strength in space as a lower limit for safety reasons in the actual application of navigation systems.

As a future outlook it is suggested to perform also aircraft antenna calibration measurements in-flight to compare results with measurements on ground. The main challenge for that is to provide a known field strength in space, that is unaffected from multipath propagation in the entire measurement environment including the ground plane’s influence. Therefore the use of a standard gain horn is suggested. Its field strength can be reliably calculated anywhere in the entire free space where the aircraft needs to be calibrated in flight. Additionally, as this is a high gain aperture antenna the provided field strength at larger distances in space might be unaffected from any multipath propagation. However, the realization of such a standard gain horn, especially at such low frequencies might be challenging due to the needed dimensions. But even if there were non-idealities due to the fabrication process, common near field measurement facilities could characterize its radiation characteristics three dimensionally for the later application. Of course, the horn’s dimensions are very large, but a corresponding grid construction is not out of range.

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Quasi-stationary Signal-in-Space Measurements using Traceable Antennas

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ABSTRACT

A helicopter-based measurement process to complement conventional flight inspection of terrestrial navigation aids is described. As opposed to the rapid penetration of areas of interest with a fixed-wing flight inspection aircraft the platform is suspended in a stationary hover in critical areas thus providing an increased observation time at a its quasi-stationary position.

A reference antenna with an antenna factor (AF) traceable to national calibration standards and therefore to the International System of Units (SI) is used to measure the true field strength of the electromagnetic far field. The hovering helicopter carries the autonomous payload on its external load hook which consists of the reference antenna and the receiving/recording system. In contrast to conventional methods, the raw bandpass signal-in-space covering the complete channel bandwidth is sampled at a high data rate and is directly recorded without any preprocessing. This grants a maximum opportunity for any signal post-processing in order to extract the essential parameters of interest.

The paper describes the deployment of a reference method to measure the absolute field strength within a known uncertainty. This facility is then used to validate the installed performance of flight inspection ILS LOC/VOR antennas.

INTRODUCTION

ICAO Annex 10 [1] requires a minimum field strength of all terrestrial navigation aids within the specified coverage. According to DOC 8071, this must be measured with an uncertainty of 3dB. This uncertainty criterion was introduced in the Fourth Edition (2000) [2], whereas the previous edition of 1972 [3] required “the initial determination of the performance of the airborne receiving system. This is essentially the calibration of the airborne antenna and feed system to determine the conversion factor between the field strength of the signal-in-space and the signal at the input to the receiver."

However, no information on how this could be achieved nor on any uncertainty requirements was provided.

In Germany, several inconsistent absolute field strength measurement results of ILS Localizer facilities drew the attention of both the regulator and the ANSP. On the same ILS LOC, field strength measurements of aircraft belonging to different flight inspection companies showed significant deviations in the order of 6dB. Depending on the flight inspection service provider, full ILS LOC coverage +/-35° at 17NM was either granted or had to be restricted.

As a consequence, the German regulator BAF demanded the flight inspection units to prove the traceability of their absolute field strength measurements to national calibration standards, referencing the DIN EN ISO9001:2008 and DIN EN ISO/IEC 17025 norms [4].

In the safety and risk management context the presence of a lower LOC field strength than required by ICAO fortunately does not usually represent a significant problem for landing aircraft. Modern navigation receivers have smaller noise figures than decades ago, and digital signal processing allows to implement steep narrow-bandwidth IF and audio filters, resulting in a sufficient signal-to-noise-ratio (SNR) of the desired signal (here: DDM) despite low field strength values.

The provision of precise absolute field strength measurements are a well understood problem in the community. This means that a "real" and hitherto unresolved issue with some relevance to safety exists.

DESIGN OF A MEASUREMENT SYSTEM

According to the regulator's requirement the inconsistencies had to be resolved. FCS asked the German National Metrology Institute (PTB) for help, and within a common project a reference measurement platform was designed and set up. The most important goal was to validate the correctness of the simulated 3D patterns of the installed ILS LOC antennas with respect to the absolute field strength values computed by the Flight Inspection System (FIS). The 3D (+ frequency) antenna patterns of FCS aircraft flight inspection antennas had been subject of a previous complex project.

In order to validate results obtained through numerical simulations, only measurements of accessible physical quantities may be used. The resulting electrical field strength composed of all incident field components is the most relevant parameter. It can be directly compared with results gained from computations and is the only tangible quantity for measurements.

A purpose-designed reference antenna was developed of which the electric far-field antenna factor is known. It was calculated from the antenna gain obtained during calibration. For the intended purpose of monitoring ILS LOC field strength with a hovering platform, an omni-directional radiation pattern in the horizontal plane is required. Since the antenna is placed below a rotatable load hook of a helicopter, no specific direction towards the ILS LOC antenna can be selected when airborne.

Figure 1 shows the simulated 3D radiation pattern of the designed magnetic loop antenna. It is rotationally symmetrical and has directional nulls on the z-axis. This is an important feature when using this antenna below the helicopter, since it diminishes the electromagnetic influence of the carrier system.

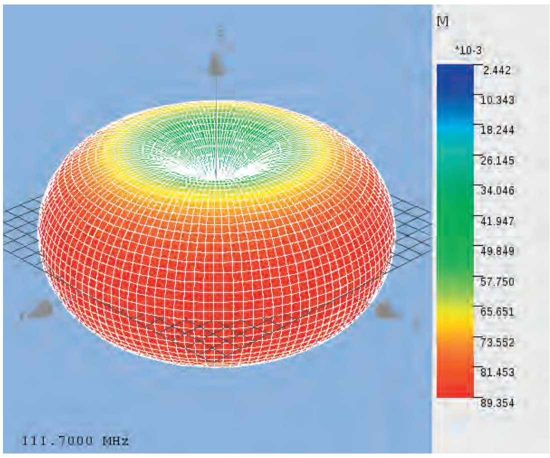

Figure 1: Radiation pattern of magnetic loop antenna

Field strength and Traceability

The well-known fundamental context to calculate the incident electric far-field strength E is

$$E_{inc} = AF^{electric} \cdot V_{receiver} \quad . \qquad (1)$$

The antenna factor AF describes the conversion factor of the incident electrical field strength into a voltage $V_{receiver}$ across a 50 ohms load impedance of the receiver.

Both the antenna factor and the measured voltage must be traceable to calibration standards in order to document a traceable field strength. In case of V, traceability can be proven in a lab by calibrating the on-board navigation receiver with a signal generator, which is itself traceable. For the AF, this task is difficult since the antenna installed performance of an aircraft in free space (not on the ground) must be known. It depends on several input measures such as frequency, aspect angles, polarization, cable and connector losses.

The applicability of a ground-based method to validate numerical simulations on their part referenced to ground is discussed in [7].

Typically, the antenna gain refers to the maximum directivity taking the losses into account. For each antenna one can use the relation between the effective aperture A_{eff} and the power gain G given in equation (2) [5].

$$A_{eff} = \frac{\lambda^2}{4\cdot\pi}G \qquad (2)$$

The effective aperture A_{eff} describes the ability of the antenna to convert the incident power density S_{inc} into a received power P_{rec} at its terminals.

$$A_{eff} = \frac{P_{rec}}{S_{inc}} \qquad (3)$$

Assuming an impedance match with R= 50 Ohms a maximum receiver input voltage of

$$V_{receiver} = \sqrt{P_{rec}\cdot R} \qquad (4)$$

is obtained. In a next step, describing the fields as planar waves, one can use

$$S_{inc} = \frac{E_{inc}^2}{Z_0} \qquad (5)$$

with Z_0 = 377 Ohms. Using (2)-(5) in (1) provides the antenna factor:

$$AF^{electric} = \frac{1}{\lambda}\cdot\sqrt{\frac{4\pi\cdot Z_0}{G\cdot R}} = \frac{9.73}{\lambda\cdot\sqrt{G}} \qquad (6)$$

This turns into the effective antenna factor if the effective power gain is used. Based on *Friis' formula* [5] the *three-antenna method* can be used to obtain the absolute power gain for each of the three antennas.

$$G_{TX,lin}\cdot G_{RX,lin}\cdot\left(\frac{\lambda}{4\cdot\pi\cdot R}\right)^2 = \frac{P_{RX}}{P_{TX}} \qquad (7)$$

The power transmission for three combinations of antennas (1, 2, 3) as receiver (RX) or transmitter (TX) is measured and the three sets of eq. 7 for their G1, G2 and G3 are solved. For usual passive antennas the reciprocity theorem guarantees that $G_{TX} = G_{RX}$. Using a vector network analyser (VNA) to measure the power ratios $P_{RX}=P_{TX}$ one directly obtains the effective gain values, as all the losses of the antennas and their input reflection coefficients are considered. In order to achieve traceability of the effective antenna factors calculated from the effective gain, two concepts apply. Firstly, after internal calibration of the VNA, the scattering parameters of precision attenuators and mismatches are measured, for which a calibration certificate traceable to national standards is held. Comparing the S-parameters from the VNA measurement and those of the certificate, a good agreement within the specified uncertainties is expected. Secondly, the three-antenna method is applied to the group of the unknown antenna, a theoretically known reference dipole and another antenna, for which a calibration certificate traceable to national standards is available. A comparison of the AFs obtained from the measurements, the theoretical value, and from the calibration certificate finally showed a good agreement. Figure 2 illustrates the calibration setup in an absorber chamber.

Figure 2: Antenna calibration in absorber chamber

Measurement Uncertainty

The uncertainty of measurement is an estimate characterising the range of values within which the true value of a measurand lies. The method of calculating the total uncertainty of a measurement is to calculate the standard deviation for the distribution of the accumulated error. This method is known as the BIPM-method proposed by the International Bureau of Weight and Measures.

A tool according to "The Guide to the Expression of Uncertainty in Measurement (GUM)" [6] was used to specify the value for the designed system. The overall expanded measurement uncertainty (k=2) for the measured power density was determined to be 2.8dBW/m^2.

FLIGHT TESTS AND RESULTS

A "BO 105" helicopter of the German Aerospace Center (DLR) in Braunschweig was chosen as the carrier for the measurement assembly (see Figure 3). The antenna (white disc) was placed on a load hook 8m below the BO 105, and another 8m further down the measurement receiver was placed in an orange cabinet. Both parts are connected with nylon ropes.

Figure 3: Helicopter carrying reference antenna

Measurement Principles

The helicopter is directed to locations of interest within the ILS service volume and then made to hover for a specific amount of observation time. It is then possible to compare the measured field strength with flight inspection (FI) aircraft results at the same position. Naturally, this is not a full 3D validation of the complete simulated 3D model but more a random sample designed to validate the overall 3D model.

Since it is not a fixed assembly, the reference antenna may either rotate horizontally or swing laterally. The former is without influence due to the antenna's omnidirectional pattern. The latter is compensated by monitoring the maximum swings of the received level. This is included as an additional input to the overall measurement uncertainty budget (see section above).

On the hardware side (orange box), an embedded processor hosted on a FPGA-based design manages the data streams from various sources.

A Rohde&Schwarz EVS300 serves as the ILS receiver. This features an additional intermediate frequency (IF) output which provides a full channel band pass signal. It is directly sampled at a rate of 100kHz and then recorded without any further processing on a solid state disk. Standard, EVS300 ILS-related output is recorded in parallel fully time-sychronized. Position information is obtained from a GPS/EGNOS receiver and recorded as well. The stored raw band pass signal allows to derive any specific signal contents in post processing. This is performed through specific algorithms implemented in "C++".

The carrier of a time-continuous signal is of prime relevance to determine the signal strength. As explained above, the maximum signal level during hovering must be captured for the real ILS signal-in-space field strength.

In post-processing, the carrier signal is derived in the frequency domain after applying a Short-Time Discrete Fourier Transformation (STDFT). An example of an ILS spectrum is shown in Figure 4. Since the 90Hz sideband prevails, this signal is taken left of the centerline.

Under far field conditions, the field strength derived from equation (1) can be easily converted into power density, which is used in all further diagrams. The high sampling rate allows good tracking of the receiver level maximum in the observation period which is then used to determine the power density.

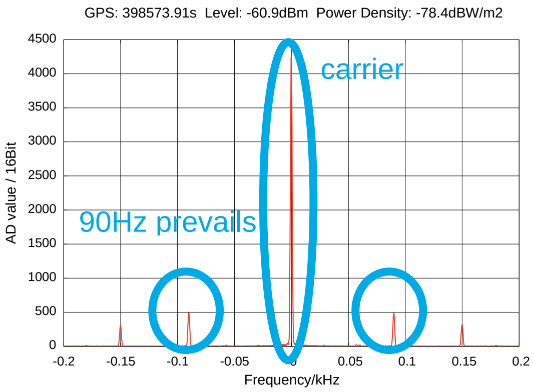

Figure 4: ILS spectrum left of centerline

Besides the ILS application, the measurement equipment is also suitable to capture a VOR signal-in-space. A spectrum example is provided in Figure 5. It shows the carrier, the 9960Hz FM modulation and the spectral lines of the 1020Hz ident.

Since the full band bass signal is recorded, it can be up-converted to the original RF frequency, serving as a signal-in-space source to be fed into a navigation receiver. In context with investigations on wind farm interference this has the potential to trace the impact on the VOR signal and, ultimately, the bearing information.

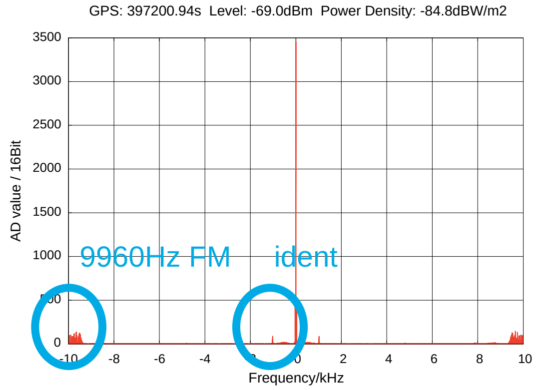

Figure 5: Spectrum from a VOR signal

Airborne Power Density Measurements

Two measurement campaigns were carried out at Braunschweig (EDVE) and Bückeburg (ETHB) airports to cover the lower (108.5MHz) and the upper (111.55MHz) frequency ranges.

The helicopter was deployed at various positions which are subsequently passed by in periodic flight inspection missions. The power densities gained with the traceable reference antenna was then compared with the most recent flight inspection results. Both FCS aircraft use the simulated 3D antenna patterns which are processed in real-time by the FIS. The antenna used for comparison is the VHF top dipole.

Figure 6 shows the FI power density measurements obtained from an orbit at 10NM distance and 2500ft. Two areas of interest (red) at 0° and -35° offset from the LOC antenna are outlined and the corresponding density values are noted.

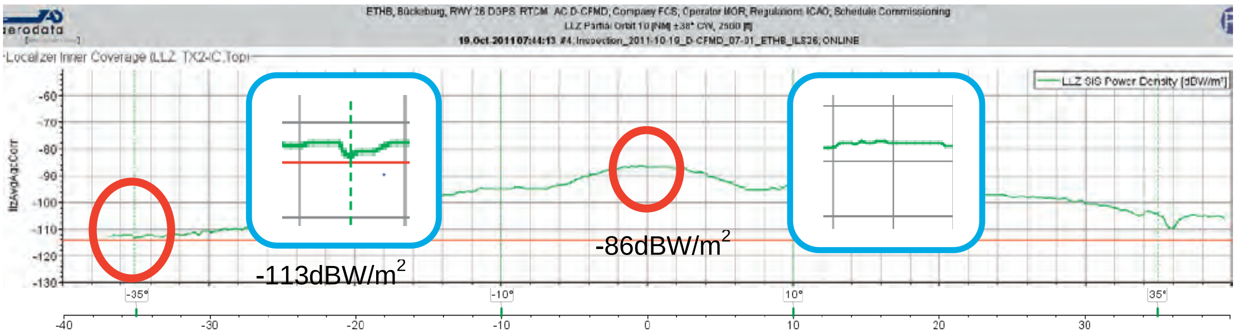

Figure 6: LOC Power Densities on Orbital Flight 10NM, 2500ft at Bückeburg ETHB

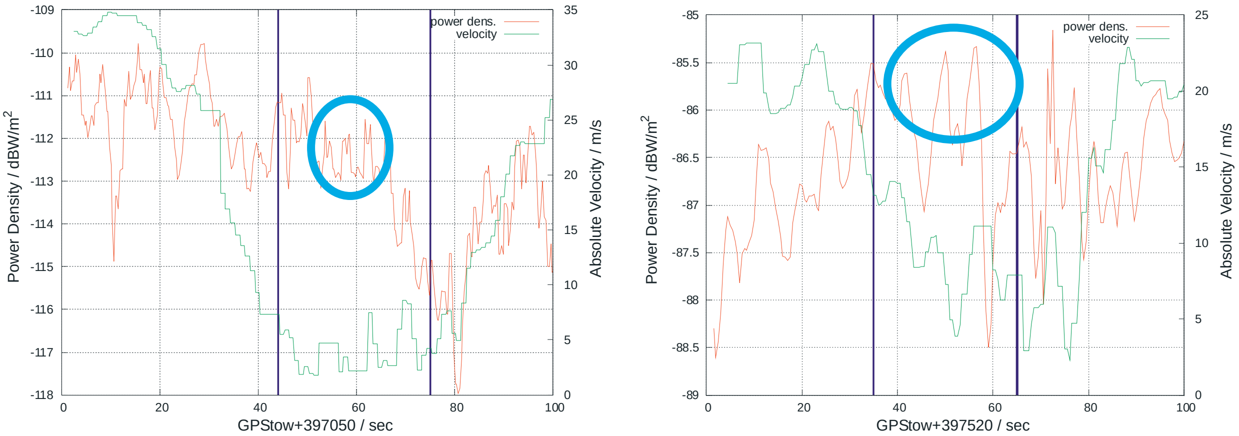

Figure 7: Power Densities obtained from Reference Antenna

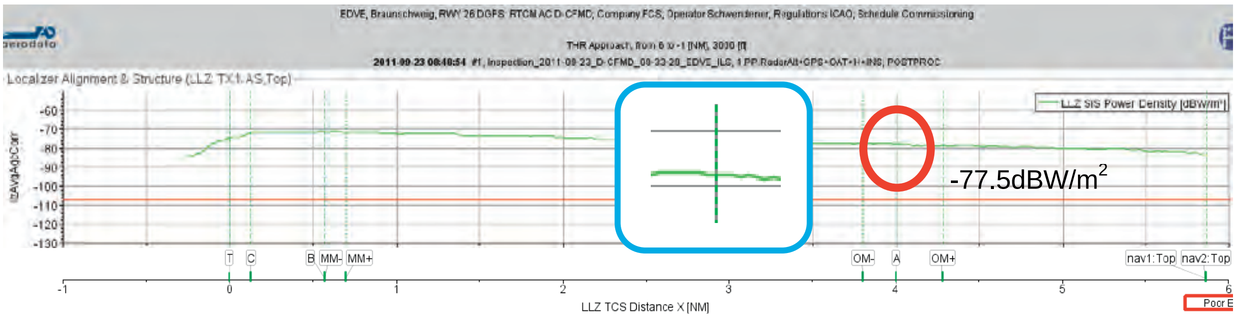

Figure 8: LOC Power Densities on Approach 26 at Braunschweig EDVE

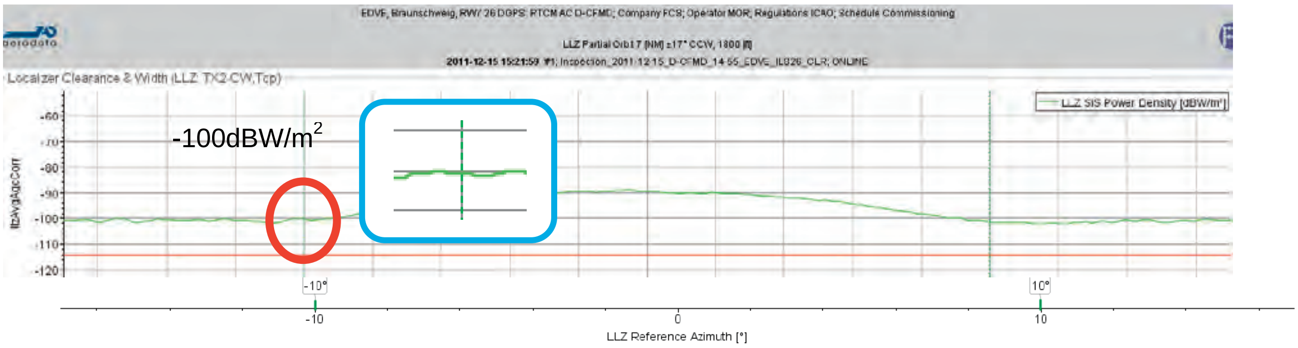

Figure 9: LOC Power Densities on Orbital Flight 7NM at Braunschweig EDVE

Similar values are depicted in the red curves (left Y-axis) in diagrams of Figure 7, representing the helicopter measurements. On centerline the variation is about 1.7dB, whereas 1dB can be observed at -35° offset. Within the marked areas (blue circles) the helicopter was kept relatively stable along a period of time (X-axis) and clear maximum power densities can be traced. On the right Y-axis the absolute 3D velocity according to the GPS receiver (green curve) is mapped. Depending on the air speed and the pilot's flight control the absolute speed (vertical and ground) may vary.

Around Bückeburg the terrain has some elevations so there is no unrestricted line-of-sight at 10NM for all directions from the ILS LOC antenna. At -35° offset the 1st Fresnel zone is partly shadowed which reduces the power density nearly to the ICAO limit of -114dBW/m². Values at 17NM and at 2500ft are therefore expected to be below that limit.

FI measurements at Braunschweig LOC are shown in the above two diagrams. An ILS approach on centerline with the corresponding power densities is depicted by Figure 8. At ILS Point "A" 4NM before threshold a value -77.5dBW/m² can be read.

From the reference measurements a value of -79.5dBW/m² is obtained, which is 2dB below the FI aircraft result.

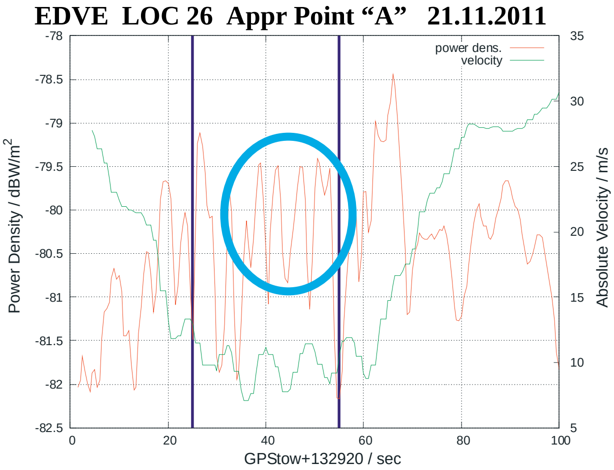

Figure 10: Power Density / Reference Antenna, Approach 26

On the orbital flight with the FI aircraft at 7NM distance and 1800ft altitude a value of about -100dBW/m² is given in Figure 9 at -10° offset from the LOC antenna. Figure 11 shows the results gained from the helicopter measurements at the same position. The curve shows a maximum of roughly -99dBW/m² in the highlighted area.

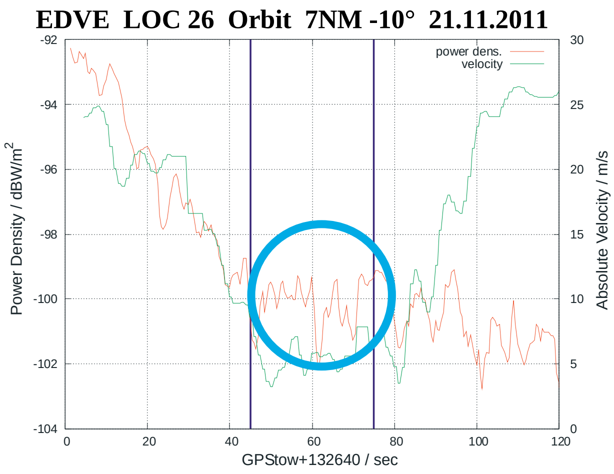

Figure 11: Power Density / Reference Antenna, Orbit 7NM

CONCLUSIONS

A new method based on a hovering platform was introduced to calibrate the installed performance of ILS LOC aircraft antennas in free space under far field conditions. Absolute field strength measurements from FI aircraft using simulated 3D antenna patterns are directly compared to reference values obtained from a reference antenna traceable to national and thus to the global SI standards.

Some sample checks on different LOC frequencies were performed. This revealed a satisfactory agreement (max. deviation 2dB) between the power densities gained from simulated antenna patterns and those from the traceable reference.

RECOMMENDATIONS

ICAO should carefully revise the minimum field strength values of terrestrial navigation aids based on an in-depth signal-to-noise-ratio analysis of the target guidance parameter (e.g. DDM). A strong requirement to solve this task is to have available traceable state-o-the-art field strength measurements. This should be provided by flight inspection companies.

Furthermore, a practical method to carry out calibrations of the antenna installed performance should be introduced in the next edition of DOC8071. This should also pave the way to determine and to achieve the already required measurement uncertainty of 3dB with respect to metrological standards.

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Aircraft Flight Inspection Systems Installations and Certifications

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ABSTRACT

This paper will describe the basic Supplemental Type Certificate (STC) certification process for the installation of an automatic flight inspection system (AFIS). The application process will be discussed including what is involved in the Project Specific Certification Plan, (PSCP). The documents required for the STC will be described, including the substantiation reports, design data, testing and compliance information. The required testing for the STC will also be described, including ground, flight and EMI/RFI testing.

Aircraft installation discussions will include antenna installation, paying particular attention to separation, shadowing, mounting on composite panels and using general aviation approved antennas. AFIS wiring discussions will be on the system separation, automatic load shedding, electrical loads and cockpit displays. Console installations discussions will include dual configuration aircraft, single verses dual consoles, head strike, aisle width issues, and dynamic certification.

The flight inspection console design subjects discussed will be maintenance issues such as ease of installation and removal and equipment access. The durability of the console external finishes and flammability concerns will be discussed. The use of COTS (commercial off the shelf) equipment such as computers, monitors, printers and keyboards will be discussed. Conducted and radiated emission testing concerns will also be discussed.

INTRODUCTION

At first thought the Supplemental Type Certificate (STC) installation of an Automatic Flight Inspection System (AFIS) may not seem that involved. But when looking into it in more depth we will see what is actually involved to obtain a FAA STC and realize it is not a quick or easy process to issue this certificate. The actual installation of the AFIS into an aircraft may not take that long however when the STC process is involved it adds a significant amount of time. After the STC has been issued subsequent installations of the STC will be much less time consuming.

SUPPLEMENTAL TYPE CERTIFICATE

Basically there are two entities who issue STCs. The FAA Aircraft Certification Office (ACO), or a company which holds an Organization Designation Authorization (ODA) issued by the FAA. The advantage of using an ODA is you do not run the risk of having your project sequenced if there are not resources available at the ACO to support the project.

An STC ODA is an authorization by the FAA for an organization comprised of ODA unit members using approved procedures to conform product, and find compliance on behalf of the FAA. Essentially an organization that has ODA acts on behalf of the FAA and is not tied to the schedule and resources available at the FAA.

There are many steps involved in STC development. The different phases of the STC process include:

- Application
- Design
- Design Substantiation
- Inspection/Test
- Show Compliance

STC Application Phase

The first step in the STC application phase is to develop a Project Specific Certification Plan

(PSCP). The purpose of the PSCP is to define and document a product approval plan between the Aircraft Certification Office (ACO) of the FAA and the applicant. The PSCP is required for the issuance of the STC.

The STC application phase will include but not limited to:

- Conceptual design development for the project
    - Electrical block diagrams
    - Proposed cabin layout changes
    - Cockpit changes
    - Antenna layouts
- Project schedule
- Certification requirements, based on the aircraft Type Certificate Data Sheet (TCDS)
- Compliance checklist including means of showing compliance to applicable 14CFRs as defined by product TCDS and PSCP.
- List of certification documents, to include
    - Design Data
        - Wiring diagrams
        - Assembly drawing for the consoles
        - Structural drawings
        - Installation drawings
    - Substantiation Data
        - EMI/RFI Ground Test Procedure
        - EMI/RFI Ground Test Report
        - Flammability Test Articles
        - Flammability Test Plan
        - Flammability Test Report
        - Functional Hazard Assessment (FHA)
        - Failure Modes and Effects Analysis (FMEA)
        - Substantiation Report – Equipment
        - Ground Test Procedure
        - Ground Test Report
        - Flight Test Procedure
        - Flight Test Report
        - Electrical Load Analysis (ELA)
        - Interior Compliance Evaluation Plan
        - Interior Compliance Evaluation Report
        - Icing Analysis
- Aerodynamic Performance Analysis
- Substantiation Report - Cockpit and Cabin Crashworthiness
- System Safety Assessment (SSA) (If required based on the FHA)
- Structural Analysis Reports

STC Design Phase

In this phase of the STC project the design work will be completed. Design work will include electrical installation drawings, console assembly/installation drawings and antenna installation drawings. Also to be completed during this phase of the project will be the Instructions for Continued Airworthiness (ICA) and the Airplane Flight Manual Supplement (AFMS).

All of this data must be approved by a FAA Designated Engineering Representative (DER) or an ODA Engineering Unit Member (UM). The ICA is required to be accepted by the Aircraft Engineering Group (AEG) in coordination with the ACO. If airworthiness limitations change as a result of the AFIS, the ICA may contain an airworthiness limitation which will require ACO approval or may be approved by a qualified ODA. Conformity must be performed by an ODA Inspection Unit Member or FAA Designated Airworthiness Representative (DAR).

STC Design Substantiation Phase

In this phase of the STC project the design work will be validated. All of this data must be approved by a FAA DER or ODA Engineering Unit Member. The substantiation documents will include the following:

- FHA
- SSA
- FMEA
- ELA
- Icing Analysis
- Structural Analysis
- EMI/RFI Reports
- Flammability Test Plan & Report

At the completion of the Substantiation a Type Inspection Authorization (TIA) is issued. For STC projects accomplished under the ACO the TIA is issued by the ACO to a FAA DAR or FAA Manufacturing Inspection District Office (MIDO) and a FAA DER Flight Test Pilot or the FAA may elect to perform the test flight themselves.

For STC projects accomplished under the ODA the TIA is issued by the ODA to an ODA Inspection UM and ODA Flight Test UM.

STC Inspection and Test Phase

In this phase of the STC project any test or inspection procedures required will be produced.

In a AFIS project this may include a Ground Test Procedure, EMI/RFI Test Procedure, Flight Test Procedure and Interior Compliance Evaluation Plan. All of these will be need to be approved and witnessed by an ODA Engineering or Flight Test UM or FAA DER.

STC Show Compliance Phase

This is the final phase of the STC project. At this point the Flammability would have been completed. The company conformity, walk thru, ground test and flight test are performed. Once the company functions are completed, the FAA conformity, walk thru, ground test and flight test are performed and witnessed by an ODA Unit Member or FAA DER.

Once all the ODA UM have witnessed the inspections, evaluations and testing they will complete test reports and include this information in an FAA Supplemental Type Inspection Reports (STIR). A Certification Summary will be completed showing all of the required FAA rules have been met. The Certification Summary will be submitted to the ODA Administrator and they will approve the Master Drawing List (MDL) and Aircraft Flight Manual Supplement (AFMS) and then issue the STC.

FLIGHT INSPECTION SYSTEMS AIRCRAFT INSTALLATION

There are several critical parts of the installation that if not taken into consideration during the design phase could cause problems at the end of the project and potentially delay the delivery of the end product. These critical segments of the project can include antenna installations, wiring, instrument panel modifications, interior modifications and console construction.

Antenna Installations

The first item to complete on antenna installations is to determine the number and type of antennas to be installed. The more antennas and the smaller the aircraft, the more difficult the antenna farm layout will be. Placement of the AFIS antennas must not interfere with the existing aircraft antennas or systems. Issues with this are that an AFIS antenna may cause problems with the existing aircraft systems but this will not be discovered until you are in the testing phase of the project.

Possible interference issues may be comm to comm bleed over. This could be caused by poor bonding of the antenna to the airframe or the new comm antenna being mounted too close to an existing aircraft comm. Comm antennas must also be mounted as far away from GPS antennas as possible; manufacturers recommend 25 feet (7.5 meters) separation between comm and GPS antennas. DME to DME and DME to transponder interference can also be an issue. Some radio manufacturers recommend 40 dB of isolation between L-band systems to prevent front end damage to the radios. Even with factoring in the cable and antenna loss there will still need to be about three feet of separation if they are mounted on a common ground plane. Interfacing to the aircraft suppression system should always be done but it does not prevent the installer from following the manufacturer’s guidelines for system separation.

Another possible issue with antenna installation could be shadowing. It is advisable not to install a VHF, UHF, telemetry or other large antennas close to a DME, GPS or ADF antenna where it could block the signal being received. The location of large antennas on the aircraft can also be an icing issue. It is advisable to keep the larger antennas aft of the engines to prevent ice intake into the engines. Mounting and bonding of the antenna, if not have done correctly, can cause problems. With many of the newer aircraft now being manufactured with composite panels the process of bonding and mounting is different from an aircraft with aluminum panels.

The use of antennas that have a Technical Standard Order (TSO) will generally reduce the work involved in the certification process. Antennas with a TSO have already been shown to meet a minimum performance standard issued by the FAA.

Aircraft Wiring

The aircraft wiring can be fairly simple or very involved depending on the customer requirements of the flight inspection system. On a small portable system with minimal antennas and aircraft interface, the aircraft wiring will be fairly straight forward. More complex systems will consist of multiple consoles, a cockpit indicator, a large number of antennas and interfaces to the aircraft avionics system.

On any installation, large or small, there are certain FAA requirements that must be followed. RTCA/DO-313 is a very good guide to follow for the installation of an AFIS. DO-313 is the Certification Guidance for Installation of Non-essential/Non-required Aircraft Cabin Systems and Equipment. This document states that for installations that include high voltage sources, (110V, 60Hz or 220V, 50Hz) the power will be removed in the event of a cabin decompression. This will not be required if the cabin equipment has been tested to RTCA/DO-160 to verify the equipment’s ability to survive cabin decompression without arcing.

DO-313 also states that the installation must provide a means for the crew to de-power the cabin equipment at any time without adding undue workload to the flight crew. A circuit breaker may not be used as a switch and the removal of the power should occur as close as practical to the source of power, (electrical bus).

Aircraft systems separation must also be taken into consideration when interfacing the AFIS to the aircraft. If interfacing to data from the avionics platform, wire routing must be taken into consideration if data is being acquired from both the pilot's and copilot's equipment. These wire bundles must be kept separate. In the event of a failure in one area of the airplane it should not cause damage to both pilot and copilot systems. Basically when interfacing an AFIS to the aircraft equipment, system separation must be maintained.

Cockpit Modifications

The majority of AFIS installations will consist of several cockpit switches, event switches and possibly some sort of display. Any switches or equipment installed in the cockpit must follow the FAA regulations for color, location and information that is being displayed. Any added cockpit switches or annunciators added to the cockpit must be viewable under all probable cockpit lighting conditions while the pilots are seated in the normal position. Any cockpit display that may be showing information from the AFIS such as offset guidance must be clearly placarded as such. A major risk of the display is that it could display erroneous information, which is worse than displaying no information at all.

Cabin Modifications

Cabin modifications include the removal of chairs to make room for the added AFIS console or consoles, possible galley or cabinet modifications, and sidewall or floor modifications. The type of aircraft the system is being installed in will have a major effect on the FAA rules that must be met. For example on a Part 25 aircraft the forward loading for a console installation must meet 16g where as on a Part 23 aircraft the forward loading must meet a minimum of 21g. Head injury criteria (HIC) must also be taken into consideration when selecting the location/position of the console. The HIC value is going to vary from aircraft to aircraft.

Aisle width is a concern and must be taken into account when removing a seat and installing a console. Per CFR 25.815; the passenger aisle width at any point between seats must equal or exceed the values in the following table:

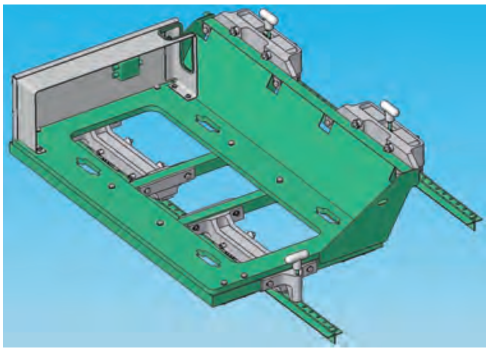
Passenger Seating	Minimum Passenger Aisle Width (inches)	
Capacity	Less Than 25 Inches From Floor	25 Inches and More From Floor
10 or Less	12 A narrow width not less than 9 inches may be approved when substantiated by tests.	15
11 To 19	12	20
20 or More	15	20

Part 25 Aisle Width Example

Emergency lighting should not be affected by the installation of a console. If the installation does affect the emergency lighting then the cabin lighting will need to be evaluated in accordance to CFR 25.812. This rule also applies to emergency exit signs and floor proximity escape path marking.

In a dual configuration aircraft, flight inspection or VIP there will be duplicate tasks involved in the installation and certification, such as measuring the weight and balance of the aircraft. The original weight and balance will not be able to be used for the VIP configuration as there will still be added equipment that remains with the aircraft such as interconnect panels, antennas and wiring. Therefore two weight and balance sheets will be required. Dual configuration aircraft will most likely also include interconnect panels in the floor or sidewall that can be easily covered when not in use.

There will be instances when the existing floor structure will not be adequate to support a flight inspection console. Existing floor structure will need to be evaluated and an adapter plate may need to be designed to support the installation of the console. In some cases the floor structure will need to be modified to support the console while maintaining the original appearance of the interior for VIP configurations. In the optimum installation the consoles will attach to the existing seat rails but this is not always possible.



Seat Rail Adapter

FLIGHT INSPECTION CONSOLE DESIGN

Proper console design can make for a satisfied end customer, an efficient installation, and testing and certification process.

Console Construction

AFIS consoles will need to be designed for the type of aircraft for which it will be installed. As stated above if the console is going to be installed in a Part 23 aircraft it will need to be designed and built to withstand at least a 18g forward load and 16g forward load for a Part 25 aircraft.

AFIS Equipment Cabinet

The selection of the external material used on the console should be of high quality and durability to withstand the frequent use of the plane. Aluminum construction will help with EMI issues and flammability certification. For a cabinet used in an STC, any external material will need to go through flammability testing. Corners will need to be beveled or rounded to prevent injuries to occupants who encounter turbulence while moving around in the aircraft cabin.

Ventilation and cooling of cabinet equipment should also be taken into consideration. Without adequate cooling inside of the console excessive temperatures could cause unreliable operation of radios and other equipment. Airflow direction should be designed into the console for optimum cooling for all components.

During the cabinet design, the wire routing must also be accounted for. Access holes will need to be placed in the proper locations for wire routing and inserts installed for radio racks. The wire harnesses will require proper securing. All shelves and components should be properly bonded for EMI issues.

Cabinet Wiring

Console Equipment

The majority of the equipment installed in the consoles is typically TSO radios but quite often there will be commercial off-the-shelf (COTS) equipment. This equipment could consist of power supplies, computers, keyboards, printers and monitors. Modifying radios, such as DMEs or transponders will void the TSO and need to have a separate part number assigned and placard to indicate it is to be used for flight inspection purposes only.

The COTS equipment has been known to cause issues during testing and certification but selecting the correct equipment in the beginning can reduce the problems later on. Most of the signal generators, oscilloscopes, spectrum analyzers and routers have not been tested to meet the requirements for aircraft installations. These items can cause problems in the EMI/RFI testing, especially the conducted emissions. COTS switching power supplies are notorious for putting out excessive noise and if used in a console extra filtering on the input lines will most likely be required.

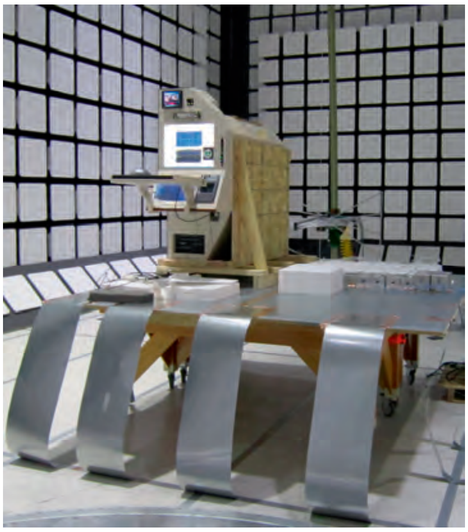
DC-DC power supplies can be an EMI issue

Any items that are not mounted inside of the console will be subjected to flammability testing. Keyboards are a good example. Using a basic keyboard may cause flammability problems as they are made up of mostly plastic components. There are several companies that build "ruggedized" keyboards. These keyboards use more metal parts and some have already been burn tested to meet FAA requirements. Many of these keyboards have also gone through some level of EMI/RFI testing.

Ruggedized Keyboard

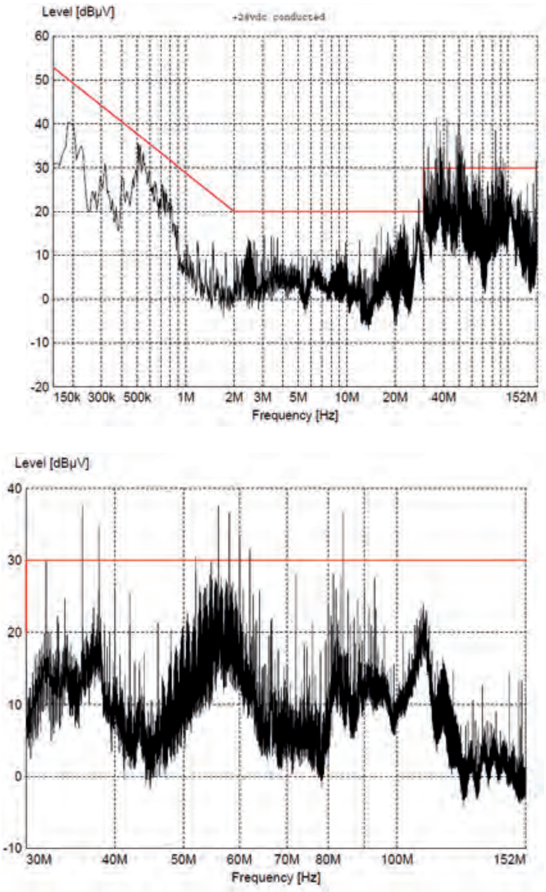
Electromagnetic Compatibility (EMC) Testing

A flight inspection console is considered a piece of COTS equipment. Testing the console to the RF emissions requirements from RTCA/DO-160 Section 21 provides some assurance that when the equipment is installed in the aircraft the system should not cause unacceptable aircraft system interference. However, even if the console does pass the DO-160 test criteria it does not eliminate the requirement to complete aircraft EMC testing.



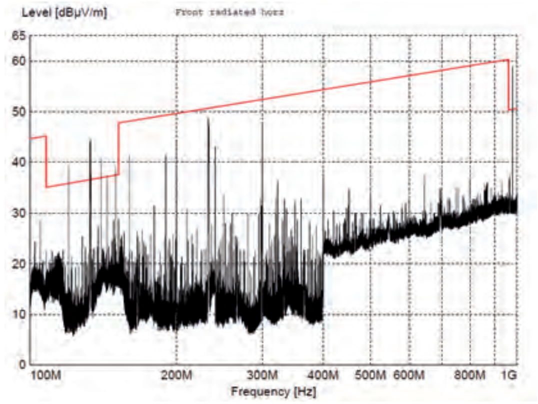
EMC Testing

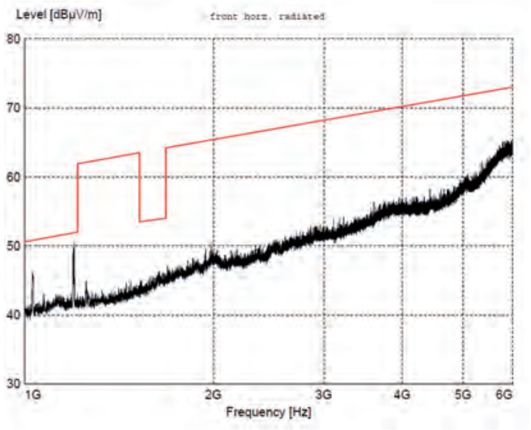
During the DO-160 testing the entire console will be required to be operating as if it were in the aircraft. There will be essentially two types of measurements made. 1) Conductive emissions, the electrical lines from the console connected to the aircraft such as the 28 volt power will be analyzed for excessive noise being produced. This noise could possibly be fed back into other critical avionic equipment and cause erroneous data.



EMC Conducted Emissions Test Results

2) Radiated emissions, are stray RF signals that are being emitted from the console. Aircraft radios are frequent victims of EMC because the receivers are designed to detect very low RF signals. The test results from the DO-160 report will show if there are any particular frequencies to be aware of that may be in the range of the radios in the aircraft. For example if there is a noise spike at 121.22Mhz, that comm frequency would be monitored closely during the aircraft EMC ground testing.





EMC Radiated Emissions Results

CONCLUSIONS

To produce a quality AFIS installation STC in a timely manner it would be best to obtain it through an organization that has obtained an FAA ODA. This organization should have experience working with the FAA and have a history of completing multiple STCs simultaneously. The ODA organization should also have a history of good project management.

RECOMMENDATIONS

When planning a Flight Inspection System installation, the qualifications and experience level of the integrator is very important. A Maintenance and Repair Organization (MRO) has more complete capabilities over the average Avionics shop. Flight Inspection System integration is important but equally important is wider range of services offered by a quality MRO. Qualities to consider when selecting a FIS integrator are:

Program/Project Management

Program oversight by a Program Manager is essential to insuring the terms of the contract are adhered to and the project is kept on schedule. The Project Manager administers to the day-to-day activities insuring adequate manpower and materials are available. Together these individuals will insure a successful partnership of customer, FIS manufacturer and integrator.

Aircraft Original Equipment Manufacturer (OEM) Authorization

Calendar inspections which come due during the FIS installation must be completed prior to Return to Service. Elective and mandatory factory Service Bulletins can only be accomplished by an authorized Service Center. Aircraft airframe and engine preservation tasks must be done in accordance with the maintenance manual.

Interior Design and Modification

In most FIS installations, allowances must be made to accommodate the FIS cabinet and equipment in the aircraft cabin. Floorboard, drink rail, sidewall, cabinet and baggage areas often need modifications and, sometimes, reconstruction to accept the FIS equipment and operator. Design and execution of these modifications must be carried out in accordance with the appropriate Aviation Regulatory Agency and match the decor and aesthetics of the aircraft interior.

Paint

Installation, and often relocation, of multiple FIS antennas will require at least partial paint capability. Reallocation of an existing aircraft asset may require a complete repaint to a Flight Inspection theme. The exterior paint is the first line of defense against corrosion especially in wet and salty environments.

Machine Work

The custom nature of FIS cabinets, seat rail adapters and equipment mounts require the expertise of a competent machine shop. Often, during the course of the construction and/or installation of the equipment, modifications become necessary. An on-site machine shop can react in a direct and responsive manner to eliminate costly delays.

Avionics Upgrades

Upgrade or reallocation of an existing aircraft asset for Flight Inspection duty often requires upgrades to the existing conventional avionics suite. TCAS, TAWS, RVSM, Flight Management Systems and Cockpit Displays are just a few of the capabilities that may be required for the Flight Inspection aircraft. These upgrades can be accomplished in concert with the FIS integration and will enhance the safety and value of the aircraft.

A quality organization possessing the above capabilities will insure the Flight Inspection System integration and the associated work will flow smoothly and result in the delivery of a safe, operational Flight Inspection platform.

ACKNOWLEDGMENTS

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[2] RTCA/DO-160D, Environmental Conditions and Test Procedures for Airborne Equipment

[3] Rockwell Collins Pro Line II Installation Manual

[4] AC 21-40A, Guide for Obtaining A Supplemental Type Certificate

[5] FAA Order 8110.4C, Type Certification

[6] FAA Order 8100.15A, Organization Designation Authorization Procedures

Certification Aspects about Commercial-Of-The-Shelf Equipment for Flight Inspection

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ABSTRACT

Due to the availability of technology with high technical performance for home and office use, ideas come up to use **C**ommercial-**O**f-**T**he-**S**helf units on board aircraft as flight inspection equipment.

On the first glance the consumer price level and rapid development of this technology may have a positive effect on the hardware cost and performance when used for flight inspection.

On the other hand to ensure flight safety all equipment installed in aircraft must be certified according to national or international airworthy standards.

In order to achieve lowest prices the consumer electronics are permanently optimized for minimum production costs. This leads to product changes with almost every production cycle.

How does COTS equipment comply with the regulations and what are possible hazards to the aircraft, crew and third parties?

This paper gives examples of applications of COTS equipment for flight inspection and evaluates pro´s and con´s regarding air safety, certification and operation.

INTRODUCTION

Why COTS equipment?

- Due to the availability of technology with high technical performance for home and office use, ideas come up to use COTS units on board of aircraft as part of flight inspection equipment.
- On the first glance the consumer price level and rapid development of this technology may have a positive effect on the hardware cost and performance when used for flight inspection.
- On the other hand to ensure flight safety all equipment installed in aircraft must be certified according to national or international airworthy standards.
- In order to achieve lowest prices, the consumer electronics are permanently optimized for minimum production costs. This leads to product changes with almost every production cycle. The next unit bought in a normal shop may look the same, but be different

Typical COTS equipment used on board

Typical COTS equipment is:

- Displays
- Laptops
- Computer or Computer parts
- Printer
- Radios/Telemetry
- Data router
- Keyboard/Mouse
- Cameras

- Audio Equipment and telephones
- Laboratory Test Equipment (Spectrum Analyzer, Oscilloscopes, Direction Finder, NAV Test transmitter, ..)
- Seat adoptions/cushions
- Non- aircraft quality wiring
- Lithium Batteries

This list is not complete.

One common issue is:

`This equipment is not designed, built or certified to be used in aircraft installations`.

Hazards

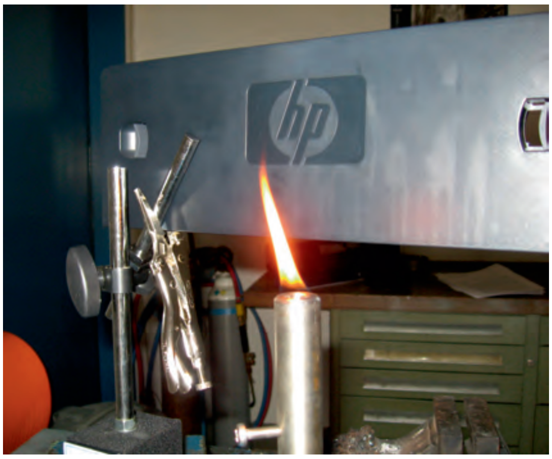
Typical hazards of non-aircraft equipment are:

- Fire
- Electro Magnetic Interference (EMI)
- Cabin Safety
- Loose equipment
- Readability (sun/night)
- Environmental (Cooling,…)
- Unclear product specification and identification

Non-function (total loss of function) of these systems is typical no hazard to the aircraft, it is only an operational or economical problem.

Fire

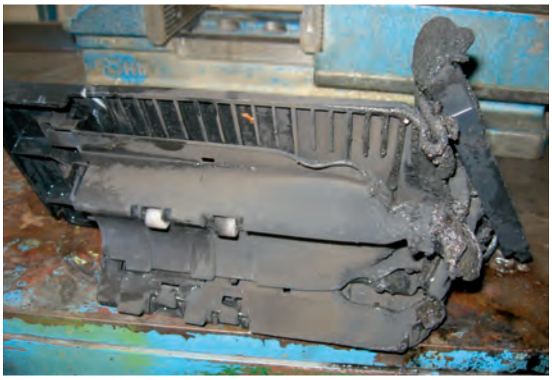
As an example, a standard office printer was tested.



Start of Test with FAA standard flame. This is not much more than a cigarette lighter

60 seconds later the aircraft cabin is full of open fire, toxic gases and black smoke

End of Flammability Test of COTS printer:



Printer cover after 60 seconds of fire

Other fire hazards

A well known problem is a fire of Lithium Batteries as used in Laptops or in backup power system. These fires can ignite other equipment or expose toxic gases

Lithium Battery burning

EMI / HIRF

- Any electrical equipment can cause electro-magnetical interference to essential aircraft systems.
- COTS equipment is typically tested for home or office use, not airborne installations.
- New installations can have a negative effect on the aircraft´s capability to operate under **H**igh **I**ntensity **R**adiated **F**ield environment.

Examples taken from real installations:

- Oscillators of electronic equipment interfering VHF COM (humming, blocking or permanently opening the squelch)
- Oscillators of electronic equipment interfering LLZ and VOR (flagged or wrong, but valid deviations)
- Switching power supplies interfering ADF and HF-COM
- Harmonics of radios or oscillators interfering GPS
- Cell-phones or data links interfering Audio systems
- Aircraft XPDR and DME interfering cabin intercom/audio systems

For more information see: FAA Special Airworthiness Information Bulletin

Cabin Safety

- All parts installed in a cabin must meet the criteria of FAR 23.561 or EASA CS23.561(for part 23 aircraft)
- Ultimate Inertia Forces / Emergency Landing Conditions

  Typical aircraft in use:

  - Upward 3g
  - Forward 9g
  - Side wards 1.5g

  brand new aircraft designs:

  - Upward 3g
  - Forward 18g
  - Side wards 4.5g

These forces can only be applied, if all components are properly fixed. Typical examples and questions are:

- What happens to the mouse in turbulence ?
- What happens to the laptop on the knees of the operator in turbulence?
- Can any equipment not proper fixed block any controls or emergency exits?
- Will the equipment disassemble in a crash ?

For some more examples see: "Cockpit Clutter", FAA Special Airworthiness Information Bulletin, CE-10-35

View to the outside with display on glare shield

Any display on top of the Glare Shield blocks view to the outside. It can block recognizing other aircraft. Flight inspection is often under VFR, outside controlled airspace (e.g. LLZ orbit, outside the CTR), so clear view to the outside is essential for the safety of the aircraft.

Readability

Any indicator, switch, label or display installed in the cockpit must be readable under all foreseen lighting conditions. This includes direct sunlight and night operation.

A typical general purpose display or laptop does not match this requirement.

Unreadable displays increase the workload in the cockpit and may confuse the flight crew.

Placards with no special lights are not readable in night operation.

Source: **EASA CS 23.1311: …** Be easily legible under all lighting conditions encountered in the cockpit, including direct sunlight, …

Environmental

An aircraft operates in other environmental conditions than an office or laboratory. Test conditions are outlined in RTCA DO160. Critical issues are:

- Operating temperature: Cooling and heating is a problem in non-pressurized and/or non air-conditioned cabins (Cooling performance is about half in 10.000 ft, in winter equipment does not start up, LCDs invisible in low temperatures)

- Humidity: (rapid changes in temperature create moisture and condensing humidity). COTS equipment is not made for this environment
- Vibration makes displays unreadable, typical in propeller aircraft and helicopters. Vibration causes mouse and trackball to move.
- Electrical Power (Spikes and short outages): COTS equipment is made for stable mains or DC power, no power source switching
- Rapid decompression is not tested, but may cause harm to operators (exploding displays, ..)
- Altitude: typically COTS equipment is made for use on ground. Low pressures result in loss of cooling (CPU, power supplies), high voltage arcing or sparking (CRTs, background illumination)

Unclear product specification

All equipment installed must be properly labeled.

- Identification of COTS equipment is often not possible in detail
- Is a proper datasheet available?
- Does a part-number on COTS equipment clearly identify all production details?
- How can you be sure the spare-part you buy is identical to the part initially delivered and tested?
- How long is this part available in the market, product cycles of COTS equipment is much quicker than in aviation.

Paperwork, Legal issues

All equipment must be certified for use on aircraft. Typical, commonly used procedures are:

- Certified by the aircraft manufacturer (Type certificate, TC)
- Certified by an authority approved design organization with **S**upplemental **T**ype **C**ertificate STC
- Not certified
  (Illegal installed or kept as baggage only (loose equipment))

All components installed in an aircraft must have an „airworthines approval tag” or “Authorized Release Certificate“, e.g. FAA Form 8130-3 or EASA Form One.

No aviation maintenance shop is allowed
to install any equipment without these tags

Version control

All equipment installed must be identifiable. This includes its hardware version, firmware version and the software version for control of the unit for proper function.

- A hardware version is typically not labeled on a COTS unit
- Modern components are often built using programmable devices as micro-controllers, FPGAs or similar. These devices need Firmware. New consumer products are developed and shipped with the current version, but after unpacking the unit the first step is to connect to the internet and update the firmware to the newest available.
- Components are controlled by a central computer with need of special drivers. Update rate of drivers is high in the consumer sector. A new driver may inhibit other operational functions without notice.

If you have two Flight Inspection Systems not built exactly at the same time and absolutely identical, you cannot simply change (COTS)-parts.

Summary, Conclusion

- Any equipment in an aircraft must be certified
- COTS equipment seems to be cheap in buying, but create high costs in certification
- Spare parts are often illegal
- COTS equipment may create hazards to the airplane
- Problems with COTS equipment are very common in general aviation.
- They should not be used in commercial operation until proper tested and qualified

Nearly anything can be qualified for use in aircraft, but cheap equipment does not necessarily save money.

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[3] European Aviation Safety Agency, EASA, Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes CS-25

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Application of Signal Detection Theory to RNAV Flight Inspection Tolerances

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ABSTRACT

With respect to all RNAV approaches, accuracy of final segment positional data loaded in aircraft avionics is just as important as the radiated signal from an Instrument Landing System (ILS). Experience with over 2,700 RNAV approaches in the United States demonstrates that positional data errors exceeding ICAO Annex 14 data quality standards are the norm rather than the exception. For this reason, the United States currently uses a FIS to assist pilots in assessing data accuracy. While the Federal Aviation Administration (FAA) was completing testing and analysis of a new Flight Inspection System (FIS) configuration, it was discovered that ICAO Document 8071 does not specify measurement uncertainties or flight inspection tolerances for a FIS used to assess RNAV approach data accuracy. This presents a problem for making an operational recommendation. The approach used was to assess the FIS uncertainty first; then, signal detection theory was used to characterize the relationship between FIS uncertainty, flight inspection tolerances, and the system's ability to detect data errors. The analysis concludes that signal detection theory is a method that can be used to easily visualize the relationship between FIS uncertainty and its ability to detect positional data errors, including RNAV final segment data.

INTRODUCTION

A key element of any FIS certification includes assessment of the measurement system uncertainty for the measurands within each flight inspection mode. In 2011, the FAA began uncertainty testing on a new FIS configuration for the King Air and Challenger aircraft. The overall objective of this testing and analysis was to make recommendations for using these aircraft configurations to complete operational flight inspections. One aspect of analysis was to consider any recommended updates to current flight inspection tolerances and procedures. This paper focuses exclusively on the Wide Area Augmentation System (WAAS) Mode of the FAA FIS which is used to evaluate final approach segment data for RNAV(GPS) approaches. In addition, the only measurand discussed will be the realized threshold crossing height (TCH), concluded by Flynn to be the best figure of merit for WAAS/LPV approaches.

The test sequence was well planned, documented, and sought to improve on previous efforts with the following characteristics:

a. Following other flight inspection aircraft to compare results, comparing results from previous reports, and doing spot checks on facilities to see if the new FIS configuration results looked "reasonable" were all considered the least desirable test methods.

b. All possible error sources were considered and discussed in the test planning process.

c. An independent truth estimation method was formulated for each measurand.

d. Following the truth estimation, the system was used normally for a goal of 30 measurements. Runs included parametric variations considered normal in day-to-day operation.

e. Comparison of the OVERALL system performance against a truth estimate based on a traceable standard was always the goal.

In many cases, the effort was successful, and in some cases it was a learning experience to improve future test planning. With respect to the

WAAS Mode TCH measurand, the truth estimation was perfectly straightforward and the uncertainty assessment was completed without difficulty. Once the system uncertainty is quantified, it is necessary to determine its suitability for the flight inspection task.

This paper will provide a brief overview of RNAV flight inspection concepts, signal detection theory, and one application of signal detection to RNAV flight inspection.

RNAV FLIGHTINSPECTION CONCEPTS

Data is the Facility

It is now widely understood that the RNAV inspection task is fundamentally different than the traditional signal-in-space flight inspection. Whereas the goal for ILS or VOR facility flight inspections is to calibrate or verify accuracy of the signal in space, the goal of RNAV flight inspection for RNAV(GPS) or RNAV(RNP) approaches is never to validate the accuracy of GPS or GPS/WAAS. So wait a minute! What is the facility we are flight inspecting then? This is an interesting question that may fundamentally turn the corner for those grappling with what role a flight inspection aircraft plays in RNAV flight inspection. One good way to think about this question is that the spatial data in the approach is the facility. The data is the facility. After all, a key objective in flight inspection is to calibrate facilities so a facility to inspect is needed. If a crew is to produce meaningful results on an RNAV flight inspection, the results must be quantifiable and capable of communicating suspected data errors to procedure designers and/or survey crews.

Data elements making up the RNAV(GPS) LPV final approach segment data are shown below in Table 1. Only the highlight rows contain data elements that cannot be checked by ground validation (GV) alone. Visualize all the data elements that can be checked completely by just the ground validation program, including the angle and TCH. Also note the absence of explicit alignment data. Visualize that all of the elements requiring a flight are spatial data: latitude, longitude, and height. Another way to think of the flight validation is that it verifies accurate survey data has made its way through the aeronautical data chain into the coded final approach segment data. Nothing else requires a physical visit to the airport for validation.

Table 1. RNAV(GPS) Final Approach Segment Data for LPV Minimums

Data Field	Field Size	Data Type	When Checked
Operation Type	2 characters	Unsigned Integer	GV
SBAS Service Provider Identifier	2 characters	Unsigned Integer	GV
Airport Identifier	4 characters	Alphanumeric	GV
Runway	5 characters	Alphanumeric	GV
Approach Performance Designator	1 character	Unsigned Integer	GV
Route Indicator	1 character	Alpha	GV
Reference Path Data Selector	2 characters	Unsigned Integer	GV
Reference Path Identifier (Approach ID)	4 characters	Alphanumeric	GV
LTP/FTP Latitude	**11 characters**	**Alphanumeric**	**GV / Flight**
LTP/FTP Longitude	**12 characters**	**Alphanumeric**	**GV / Flight**
LTP/FTP Ellipsoidal Height	**6 characters**	**Signed Integer**	**GV / Flight**
FPAP Latitude	**11 characters**	**Alphanumeric**	**GV / Flight**
FPAP Longitude	**12 characters**	**Alphanumeric**	**GV / Flight**
Threshold Crossing Height (TCH)	7 characters	Alphanumeric	GV
TCH Units Selector (meters or feet used)	1 character	Feet or Meters	GV
Glidepath Angle (GPA)	4 characters	Unsigned Integer	GV
Course Width at Threshold	5 characters	Unsigned Integer	GV
Length Offset	4 characters	Unsigned Integer	GV
Horizontal Alert Limit (HAL)	3 characters	Numeric	GV
Vertical Alert Limit (VAL)	3 characters	Numeric	GV

Data Quality Requirements

What then is the flight validation task? The data quality requirements for the spatial data used to define the LPV final approach segment data are contained in ICAO International Standards and Practices Annex 14. These are the initial ground based survey accuracy requirements:

Table 2. Data Quality Requirement

Data Field	Accuracy Data Type	Integrity Classification
LTP Latitude	1 meter	10^{-8}
LTP Longitude	1 meter	10^{-8}
LTP Ellipsoidal Height	.25 meter	10^{-8}
FPAP Latitude	1 meter	10^{-8}
FPAP Longitude	1 meter	10^{-8}

With respect to the integrity classification, the 10^{-8} figure means that one error in 100 million procedures is allowed. This is equivalent to saying that no spatial data errors are allowed outside the accuracy data type. In general, a measurement system used for calibration should have a system uncertainty well less than tolerances being used for the calibration task; however, an airborne survey system cannot possibly achieve better accuracy results than the initial ground based survey.

While it is not the role of flight inspection to refine the spatial data, flight validation does act as a quality control for the data. If there is an obvious or suspected problem with the spatial data, flight inspection may trigger the action to correct the data, or in traditional terms to "calibrate the facility". So what method should be used to set the flight inspection tolerances to effectively perform the flight validation task: visual flight validation or a FIS?

What Kinds of Spatial Data Errors?

Regardless of the method, what kinds of spatial data errors are we expecting to detect? As of April 5, 2012 there were 2,785 RNAV(GPS) approaches with authorized LPV minimums in the United States. It is helpful to briefly examine the types of spatial data errors that have been experienced in the course of these flight inspections/validations. Of course all spatial data has some error; the only question is how much. Based on experience in examining data errors for RNAV(GPS) approaches in the US, the following error categories and error probabilities are expected:

Datum Differences: Flight guidance to the pilot will always be reference to the WGS-84 datum for SBAS approaches using GPS/WAAS. If the spatial data in the approach spatial data references any other datum, errors to the intended flight path will exist. The vast majority of procedures in the United States were designed using the NAD83 datum. The induced horizontal and vertical errors for the domestic Unites States are shown below In Figures 1 and 2. The vertical error distribution can be see to approximately vary evenly from zero to 5.5 feet.

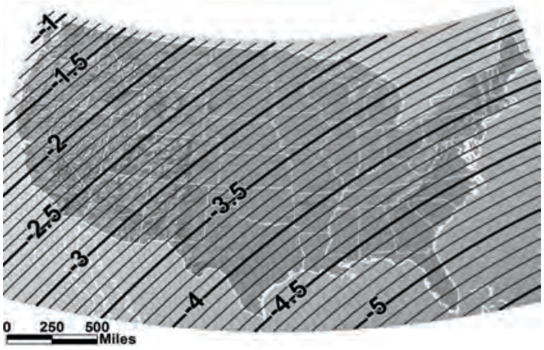

Figure 1. Vertical difference (feet) between NAD83 and WGS-84 (G1150)

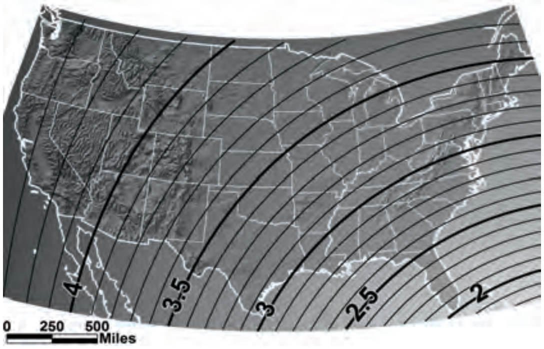

Figure 2. Horizontal difference (feet) between NAD83 and WGS-84 (G1150)

Survey Accuracy: Just as every measurement system has errors, every survey ever done has errors too. These errors are expected to be extremely small and well within the accuracy data type. The error distribution for these errors is expected as a normal distribution with a standard deviation of less than 0.1 feet.

Incorrect Survey Point: Infrequently, the survey crew may do a perfectly accurate survey but use the incorrect or unintended location. These errors could range from a few inches or feet to the entire length of the runway. These errors are expected less than 1 in a 1,000.

Data Processing Blunder: With the advent of the US Gold Standard, human and/or machine errors in the data processing has resulted in fewer and fewer of these errors; however the risk of these errors is always present for an airspace system with multiple data sources and complex processes. These errors are expected less than 1 in a 1,000.

Wrong/Old Data: Although data has been corrected or amended for runway changes, sometimes old data is "persistent". In cases where the runway data has changed and a good survey was re-accomplished, the approach data continues to use the old data. These errors are expected less than 1 in a 1,000.

The following table summarizes the expected frequency and assumed probability distribution of these error types:

Table 3. Spatial Data Error Approximations

Error Type	Probability Distribution	Standard Deviation / Distribution	Frequency
Datum Differences	Uniform	0 – 5.5 feet	100%
Survey Accuracy	Normal	< .1 feet	100%
Incorrect Survey Point	Uniform	0-6,000 feet	< 0.1%
Data Processing Blunder	Uniform	0-6,000 feet	< 0.1%
Wrong/old Data	Uniform	0-1,000 feet	< 0.1%

Impact of RNAV Spatial Data Errors

Whereas the correctness of spatial data maintained for an ILS facility or lighting system has no impact on the user aircraft, the correctness of the spatial data maintained for any RNAV approach has a direct impact on the flight path. The impact of coding the LTP elevation 10 feet lower than the real-world threshold has the same impact as physically moving the glideslope antenna 200 feet towards the runway threshold. In either case, the end result would be a wheel crossing height over the threshold that is 10 feet lower than designed. While no accidents have been attributed to this type of data error yet, the implications of unintentionally changing the designed flight path high, low, or sideways are obvious.

In 2007, a Global 5000 jet was lost after touching down 7 feet 6 inches short and 18 inches below the surface of RWY 33 at Fox Harbour, Nova Scotia. One of the factors analyzed in this accident involved the visual glidepath system indicator (VGSI) in use. The system in use was very near the threshold as opposed to systems that are located farther back resulting in a higher TCH. Figure 3 was used in the accident analysis description to show the effect of VGSI location on flight path; this is identical to the effect of using incorrect spatial data in an RNAV approach. The impact of incorrect data resulting in a low path or short landing is frequently emphasized; however the impact of landing long must be considered a safety risk as well. In data analyzed from 1982 – 2006, runway overruns outnumbers runway undershoots by a factor of three to one. Incorrect spatial data potentially impacts landing overshoots too, particularly at shorter fields where the RNAV approach may be infrequently used and the impact is more significant.

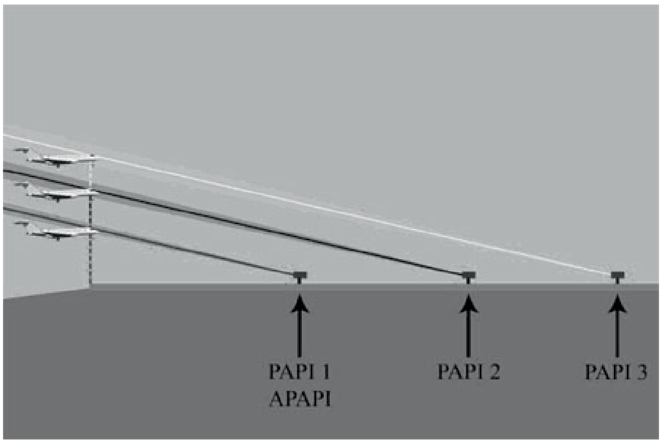

Figure 3. PAPI Location Effect on Flight Path

Spatial Data Quality Control Task

The case for flight validation of spatial data is understood after recognizing errors greater than ICAO Annex 14 requirements and understanding the impact on flight safety. One potential method for validating the data is a visual observation by the pilot. The evaluation criteria given to the pilot is "Does it look right?" During uncertainty testing, this method was unscientifically evaluated with the following estimations of data validation:

Table 4. LTP Elevation Error Visual Detection

LTP Elevation Error Visual Detection	Flt Insp Pilot	Line Pilot
Experienced / Trained	15 feet	30 feet
Untrained	30 feet	40 feet

In addition to the visual method, the US flight inspection system currently analyzes and reports the "realized TCH" for the RNAV(GPS) LPV final approach segment data. This method should be able to benefit by an order of magnitude, the quality control task of validating spatial data. Any differences between the coded TCH and the realized TCH are suspect as spatial data errors to report during the flight validation. Like all other flight inspection, the operator needs some tolerance above which a suspected error is reported.

The FIS is a measurement system. Traditionally, the goal is to have the measurement uncertainty be at least 1/5 of the flight inspection tolerance so it can be generally concluded that the facility is calibrated within the flight inspection tolerances. The author has frequently witnessed this assumption during discussions about the entire uncertainty assessment process. Almost without fail, the first question that comes up when a measurand uncertainty is larger than desired has been “Is the uncertainty within the flight inspection tolerance?” Then the fatal assumption is that if the uncertainty is within the flight inspection tolerance then everything is good without further analysis. This could not be farther from the truth. The measurement uncertainty and flight inspection tolerances are two separate and distinct entities that must work together. When the measurement uncertainty is small with respect to the flight inspection tolerance it is safe to conclude that the quality control guarantee is within the flight inspection tolerance. Unfortunately, for the task of airborne survey verification, the uncertainty is much larger than desired. The challenge is how to make an operational recommendation for flight validation with a very uncertain system. To date, the flight inspection tolerances were generally established based on bounding the repeatability of multiple test approaches. During this assessment an attempt was made to apply knowledge of expected errors and system performance to recommend flight inspection tolerances for data error detection performance.

SIGNAL DETECTION THEORY

Signal detection theory provides a framework for analyzing the problem of making binary decisions with uncertain data. This seems to fit well since the overall result from a flight validation should be “satisfactory” or “unsatisfactory”, and the current FIS mode for assessing threshold data accuracy has about 24 times more uncertainty than the initial survey accuracy requirement. The signal detection model in Table 5 illustrates the 4 possible outcomes: MISS, HIT, CORRECT REJECTION, and FALSE ALARM. The goal is to maximize HITS (correct data error detections) and CORRECT REJECTIONS (correct assessments of good data). And while it is undesirable to have FALSE ALARMS (data error suspicions that turn out untrue), it is far more undesirable to have MISSES (missed data error detections). This is discussed further in the application section.

Table 5. Signal Detection Response Model

CONDITION	Flt Validation SAT	Flt Validation UNSAT
Real LTP Elevation Error > Threshold	MISS (BAD)	HIT (GOOD)
Real LTP Elevation Error < Threshold	CORRECT REJECTION (GOOD)	FALSE ALARM (NOT GOOD)

What the flight inspection organization needs is the relative percentage of each quadrant to know how “good” the flight inspection system is at detecting spatial data errors. This requires knowledge of both the FIS performance and the probability distribution of errors likely to encounter.

The most common application of signal detection theory is to a single detection condition where the signal absent and the signal present condition are modeled by a normal Gaussian distribution. See Figure 4. While the initial concept of this analysis was to use that common application, it was determined that the signal absent and present condition needed was far more complex than just a normal distribution.

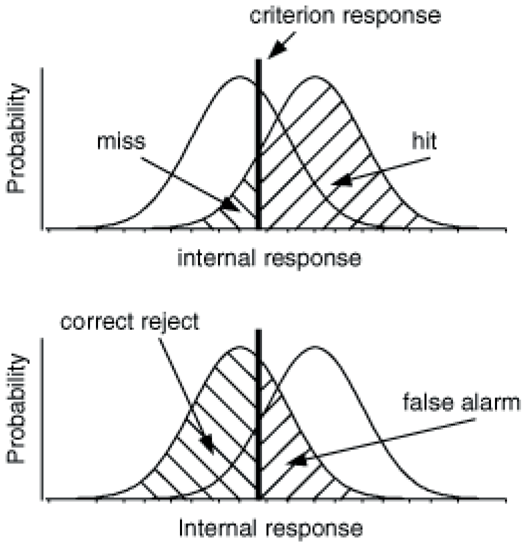

Figure 4. Common Signal Detection Distribution Model

For the purpose of this analysis the following definitions under the signal detection theory were adopted.

Signal Absent Probability Distribution: Expected distribution of FIS results when data errors are within the design Bias chosen

Signal Present Probability Distribution: Expected distribution of FIS results when data errors exceed the Bias chosen

Criterion: Threshold FIS result between calling the validation SAT or UNSAT. The flight inspection tolerance used by the operator.

Bias: Threshold data error value between calling the actual data condition “GOOD” or “BAD”. This is different and by definition must be larger than the Criterion or flight inspection tolerance.

By understanding the probabilities under each curve above and below the selected Criterion, the percentage of HITS, MISSES, CORRECT REJECTIONS, and FALSE ALARMS can be quantified for operational decisions and system risk assessment. It is desirable for system performance and flight inspection tolerances to maximize HITS and CORRECT REJECTIONS, minimize MISSES, and do so without too many FALSE ALARMS. While the flight inspection crew may interpret FALSE ALARMS as a poor flight inspection system, this is actually quite common within industries where the signal detection model is commonly applied. For example, FALSE ALARMS for medical diagnosis, fire departments, burglar alarms, etc. are tested again and either ruled out or trigger further testing. As long as such uncertainty exists in the FIS, the data validation expectations cannot be very high or FALSE ALARMS should be expected.

APPLICATION TO FLIGHT INSPECTION

Flight Test Setup and Results

Reference the test methodology outlined in the introduction, error sources for the WAAS Mode were considered and determined to be:

a. GPS/WAAS position uncertainty
b. Radio altimeter
c. Camera positioning system
d. FIS software algorithms

Any data errors were intentionally zeroed out for KOKC runway 17R, 35L, 13, and 31 using the following method. The National Geographic Service (NGS) conducted a survey of the FAA DGPS base station so that its position was verified and refined. Positional data from existing procedures were converted to WGS-84 using NGS available tools. The WGS-84 coordinates were manually loaded into the FIS for analysis, and the runway was marked using the same coordinates. The runway marking effort used a roving DGPS unit which was moved until the coordinates matched the coded data at each runway threshold. Once located, the position was marked with a 2' x 2' "+" so it could be unmistakably identified using the camera positioning system. During the runway markings with the DGPS, the coded runway elevations were verified to be within 0.2 feet of the test procedures; however the elevations were still adjusted in the test procedure to be the same as read by the DGPS.

With all possible data errors eliminated from the flight validation tests, a perfect flight inspection system would provide a realized TCH results the same as coded every time. In reality, systematic and random errors are present which cause the results to vary, even though that data (facility) has not changed and the runway has obviously not moved. A total of 32 approaches were flown while varying conditions including time, runway, airspeed, pitch over threshold, bank over threshold, and IRU alignment condition. Figure 5 shows a scatter plot of the results. Raw data are presented in Appendix 1 and the statistical results are as follows:

Mean TCH Measurement Error:	-0.446 feet
Std Deviation (σ):	2.349 feet
2 Std Deviations (2σ):	4.698 feet

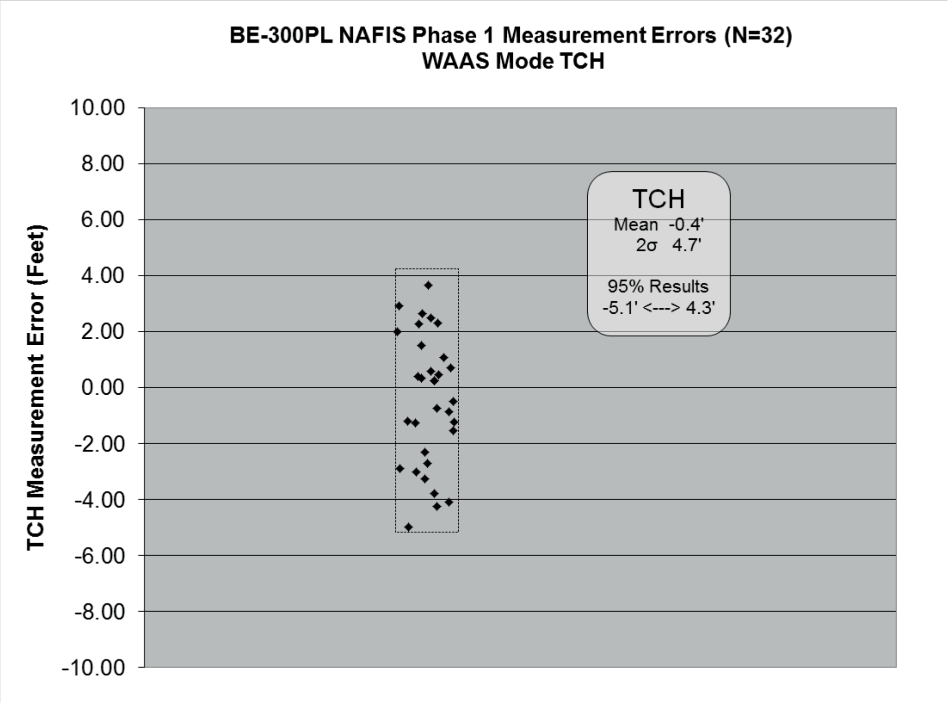

Figure 5 – BE-300PL NAFIS Phase 1 WAAS Mode TCH Measurement Errors (N=32)

Data Analysis and Application

A histogram of the data is compared against a normal distribution in Figure 6. While it does not match exactly with a normal distribution, it is not far off. Additional samples would probably show closer correlation to a normal distribution. From this data, it is seen that systematic errors are less than one foot and random errors are normally within 2 meters. Another way to interpret the results is to say that 95% of the time the true realized TCH is within 2 meters of the measured TCH. For the remainder of analysis, FIS system performance measuring TCH in the WAAS Mode was assumed to have a normal distribution with a mean of -.446' and a standard deviation of 2.349'.

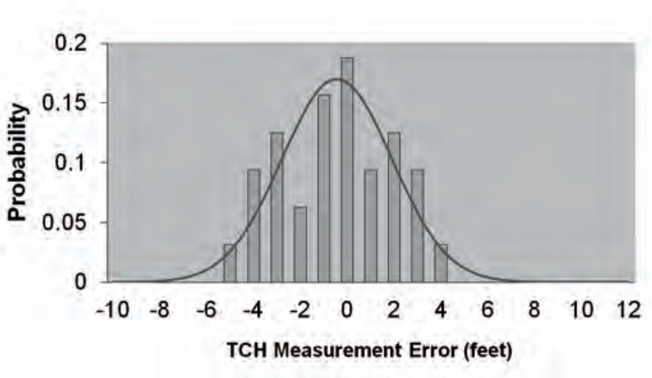

Figure 6 – TCH Measurement Error Histogram Comparison to Normal Distribution

Based on the principle of measurement uncertainty being 1/5 or less of the flight inspection tolerance, the typical flight inspection tolerance would be set at around 25 feet; this is roughly equivalent to how well the pilots can validate the data from looking out the window.

Using the signal detection model, the flight inspection tolerance can be significantly reduced. The signal absent probability was modeled using the assessed FIS uncertainty and the selected bias (see SDT definition above). The signal present probability was modeled using the expected error distribution in Table 3 and the assessed FIS uncertainty. While it was hoped to derive relatively elegant mathematical models for these probability distribution, this proved too difficult so they were modeled using Microsoft Excel. The data error model was extended from -6,000 to +6,000' with increments of 0.1 feet. The overall probabilities above and below the selected flight inspection tolerance were computed using basic numerical integration. The spreadsheet was built such that the following parameters could be varied to assess their affect on the data error detection task:

a. FIS systematic error
b. FIS random errors (uncertainty)
c. SDT Criterion (FI Tolerance)
d. SDT Bias (Error detection threshold)

Figure 7 shows a plot of both the signal absent and signal present distributions for the case where the FI tolerance was set to 6 feet and the data error threshold was set to 8 feet. This results in a 99% HIT rate and a 30% FALSE ALARM rate (See Table 7).

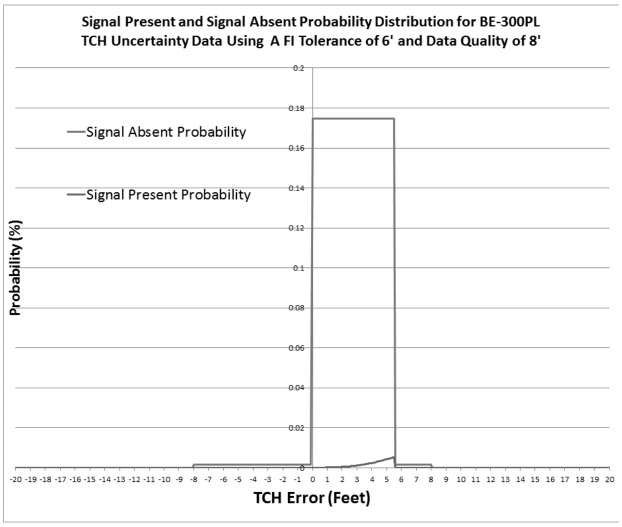

Figure 7 – Signal Present and Signal Absent Probability Distribution

Tables 6, 7, 8 and 9 show data error detection task performance in 4 cases evaluated. Note that as the flight inspection tolerance and data error threshold is lowered, the FALSE ALARMS go up but the overall HIT rate remains high.

Table 6. System Performance
using FI Tolerance of 3'

CONDITION	Flt Validation SAT	Flt Validation UNSAT
Real LTP Elevation Error > 4'	MISS (5%)	HIT (95%)
Real LTP Elevation Error < 4	CORRECT REJECTION (48%)	FALSE ALARM (52%)

Table 7. System Performance
using FI Tolerance of 6'

CONDITION	Flt Validation SAT	Flt Validation UNSAT
Real LTP Elevation Error > 8'	MISS (1%)	HIT (99%)
Real LTP Elevation Error < 8'	CORRECT REJECTION (70%)	FALSE ALARM (30%)

Table 8. System Performance
using FI Tolerance of 8’

CONDITION	Flt Validation SAT	Flt Validation UNSAT
Real LTP Elevation Error > 10’	MISS (1%)	HIT (99%)
Real LTP Elevation Error < 10’	CORRECT REJECTION (99%)	FALSE ALARM (1%)

Table 9. System Performance
using FI Tolerance of 10’

CONDITION	Flt Validation SAT	Flt Validation UNSAT
Real LTP Elevation Error > 12’	MISS (1%)	HIT (99%)
Real LTP Elevation Error < 12’	CORRECT REJECTION (99%)	FALSE ALARM (1%)

Flight Test Setup and Results

In the context of operational performance, consider the system parameters in Table 7. Let’s say that on the first flight inspection run, the TCH result is unsatisfactory; there is a 30% chance this was a false alarm and a 70% chance the LTP data error is within the accepted limit of 8 feet. Let’s say on the second run, the TCH result is satisfactory; there is a 99% chance this is the correct decision and only a 1% chance that an actual data error was missed. In most flight inspection circles, this would be considered “cheating” or “flying it into tolerance”, but in the context of signal detection theory, the integrity of making a satisfactory call is well justified and the correct one.

Examination of the results here indicates that with the current FIS performance, the flight inspection tolerance could potentially be lowered to 6’ with acceptable results and a significant improvement to the data validation task. The same application could be used for other flight inspection tasks where the FIS uncertainty is higher than desired and a “satisfactory” or “unsatisfactory” decision is required.

CONCLUSIONS

Following are general conclusions from the FIS uncertainty testing and data analysis:

a. Each aircraft type and FIS configuration must be considered individually with respect to measurement system uncertainty. The flight inspection policies must be individually considered as well since they affect the decision outcome.

b. Empirical uncertainty assessments require careful planning and execution to ensure the data collected is meaningful.

c. Application of signal detection theory could be used for other flight inspection tasks where the FIS uncertainty is higher than desired and a “satisfactory” or “unsatisfactory” decision is required.

d. The development of FIS modeling to perform stochastic uncertainty assessment is always helpful if the technical data and qualified personnel are available

e. The technical knowledge gleaned during this effort, provided and is providing intangible benefits in the planning and design of future flight inspection systems.

f. The capability to manipulate data used by the FMS and by the FIS can significantly improve confidence in the system’s ability to detect errors. Doing multiple approaches where there are no errors can give the theoretical answer, but proof is in the actual detection.

RECOMMENDATIONS

a. Future FIS RNAV approach mode should evaluate all final segment data not just the path point records

b. Future FIS RNAV modes should report spatial data quality in the same terms as procedure designers and surveyors: latitude, longitude, and elevation. The method of reporting TCH, angle, and alignment is outdated and provides flight inspection personnel with almost no useful information to report when a data error is suspected.

c. States should collect metrics on the magnitude and types of spatial data errors experienced in RNAV procedure design. This seems obvious but the challenge in collection is complex and next to impossible to do correctly without a dedicated effort to do so.

d. If possible, a FIS simulation using high fidelity modeling can greatly reduce the cost of conducting uncertainty testing in improve confidence in the results.

FUTURE WORK

The FAA continues to analyze data for all FIS modes and measurement parameters where flight inspection tolerances are applied. The King Air data is completed and the Challenger data analysis continues. Each future aircraft with new flight inspection software or configuration receives the appropriate level of testing or regression testing to quantify measurement uncertainty. This initial effort to quantify the spatial data validation task should be advanced considering the emerging world of RNAV and the critical nature of spatial data to safe flight operations.

ACKNOWLEDGMENTS

The author would like to express gratitude to the FAA Flight Inspection Services engineering staff for their support in the flight test preparation process and to the crew members who assisted in conducting the flight tests. In addition, the support from FAA management to take uncertainty testing of the FIS to the next level was overwhelmingly positive and beneficial to improvements in FIS performance, certification, and in-house technical knowledge.

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APPENDIX 1

Flight Test Data

Aircraft	Date	ID	RWY	Flight Condition	Coded TCH	Datum Diff	Expected TCH	Measured TCH	Measurement Error (TCH)
BE-300PL	6/22/2011	OKC	35L	Normal	49.1	0.00	49.1	51.42259	2.32
BE-300PL	6/22/2011	OKC	35L	Normal	49.1	0.00	49.1	51.40136	2.30
BE-300PL	6/22/2011	OKC	35L	Normal	49.1	0.00	49.1	49.83269	0.73
BE-300PL	6/22/2011	OKC	35L	Normal	49.1	0.00	49.1	49.68515	0.59
BE-300PL	6/22/2011	OKC	35L	Normal	49.1	0.00	49.1	49.52761	0.43
BE-300PL	6/22/2011	OKC	35L	Normal	49.1	0.00	49.1	50.60985	1.51
BE-300PL	6/22/2011	OKC	35L	Bank	49.1	0.00	49.1	50.18209	1.08
BE-300PL	6/22/2011	OKC	35L	Bank	49.1	0.00	49.1	51.61789	2.52
BE-300PL	6/22/2011	OKC	35L	Bank	49.1	0.00	49.1	52.04171	2.94
BE-300PL	6/22/2011	OKC	35L	Bank	49.1	0.00	49.1	49.35409	0.25
BE-300PL	6/22/2011	OKC	35L	Pitch	49.1	0.00	49.1	47.88791	-1.21
BE-300PL	6/22/2011	OKC	35L	Pitch	49.1	0.00	49.1	48.25102	-0.85
BE-300PL	6/22/2011	OKC	35L	Pitch	49.1	0.00	49.1	49.4415	0.34
BE-300PL	6/23/2011	OKC	35L	ISS	49.1	0.00	49.1	47.56744	-1.53
BE-300PL	6/23/2011	OKC	35L	ISS	49.1	0.00	49.1	48.62998	-0.47
BE-300PL	6/23/2011	OKC	35L	ISS	49.1	0.00	49.1	47.86283	-1.24
BE-300PL	6/24/2011	OKC	17R	Normal	55.0	0.00	55.0	51.75605	-3.24
BE-300PL	6/24/2011	OKC	17R	Normal	55.0	0.00	55.0	51.9872	-3.01
BE-300PL	6/24/2011	OKC	17R	Normal	55.0	0.00	55.0	52.318	-2.68
BE-300PL	6/24/2011	OKC	17R	Normal	55.0	0.00	55.0	50.02187	-4.98
BE-300PL	6/24/2011	OKC	17R	Normal	55.0	0.00	55.0	50.91674	-4.08
BE-300PL	6/24/2011	OKC	17R	Normal	55.0	0.00	55.0	50.76924	-4.23
BE-300PL	6/23/2011	OKC	17R	Drifted	55.0	0.00	55.0	51.23322	-3.77
BE-300PL	6/23/2011	OKC	17R	Drifted	55.0	0.00	55.0	53.8055	-1.19
BE-300PL	6/23/2011	OKC	17R	Drifted	55.0	0.00	55.0	52.13026	-2.87
BE-300PL	6/23/2011	OKC	31	Baro	52.0	0.00	52.0	52.27191	0.27
BE-300PL	6/23/2011	OKC	31	Baro	52.0	0.00	52.0	52.46576	0.47
BE-300PL	6/23/2011	OKC	31	Baro	52.0	0.00	52.0	49.71163	-2.29
BE-300PL	6/23/2011	OKC	31	Baro	52.0	0.00	52.0	51.2689	-0.73
BE-300PL	6/23/2011	OKC	13	Baro	52.0	0.00	52.0	54.01216	2.01
BE-300PL	6/23/2011	OKC	13	Baro	52.0	0.00	52.0	54.67098	2.67
BE-300PL	6/23/2011	OKC	13	Baro	52.0	0.00	52.0	55.6749	3.67

* All TCH values in feet

** Flight conditions varied were airspeed, pitch, bank, and IRU alignment condition

*** Datum difference built into data analysis model but intentionally zeroed out for this test

Airborne RFI Detection

Examples of solved cases

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ABSTRACT

RF interferences and jamming are significantly affecting civil aviation frequency bands and have non-negligible consequences on safety and continuity of services provided to users.
For more than fifteen years now, the flight inspection service of the French ANSP (DSNA) is a major actor in the fight against interferences and jamming in France. Thus, the flight inspection department was required to conduct numerous flight detections and researches on a wide variety of cases. These interventions have, in most cases, succeeded in eliminating the problem, while allowing the development of dedicated methods, equipments and software.
The proposed presentation will, through several examples from the VHF band (conventional navaids, COM frequencies) to GNSS band, showing the wide variety of phenomena encountered so far, their impacts, challenges and tactics implemented to solve them.

INTRODUCTION

Interferences on the aeronautical bands have long been regarded as a marginal and inevitable issue which had to be coped. This is unfortunately still somewhat the case among crews and, to a lesser extent, in the population of air traffic controllers. However, the actions taken by the DSNA (Direction des Services de la Navigation Aérienne ; French ANSP) during the past fifteen years at various levels have greatly improved the situation on the French territory.

These actions concern :

- Both information and training of different actors (Air Traffic Safety Electronics Personnel, Air Traffic Controllers, ...)

- Communication with external services to civil aviation (Army, ANFr : Agence Nationale des Fréquences / French Frequencies Regulator, CSA : Comité Supérieur de l'Audiovisuel / Audiovisual Authority ...)

- Research and deployment of technical facilities and associated methods.

Among these means, flight inspection aircrafts are essential.

Over the actions that have been conducted, their role has become major. Cases that could have been considered unsolvable have often been treated by the intervention of flight inspection. Initially anecdotic, this activity has become recurrent and is now part of the tasks of the flight inspection service of the DSNA.

This activity is based both on a comprehensive and effective technical equipment and experience based on lessons learned from cases encountered. The feedback is at least as important as the receivers and systems used! This topic has been discussed several times, mainly in a technical perspective. Therefore in this paper we will present practical examples, how they were solved and the lessons it has been possible to draw.

ORGANIZATION AND INVOLVED SERVICES

Actions taken by the DSNA to fight against aeronautical harmful interference involve several services, each with a particular skill.

Regional technical services (SNA : Services de la Navigation Aérienne) are equipped and trained to conduct investigations on the ground.

The french civil aviation academy ENAC (Ecole Nationale de l’Aviation Civile) trains and informs ATSEPs and controllers.

The central technical entities (DTI) are involved in :

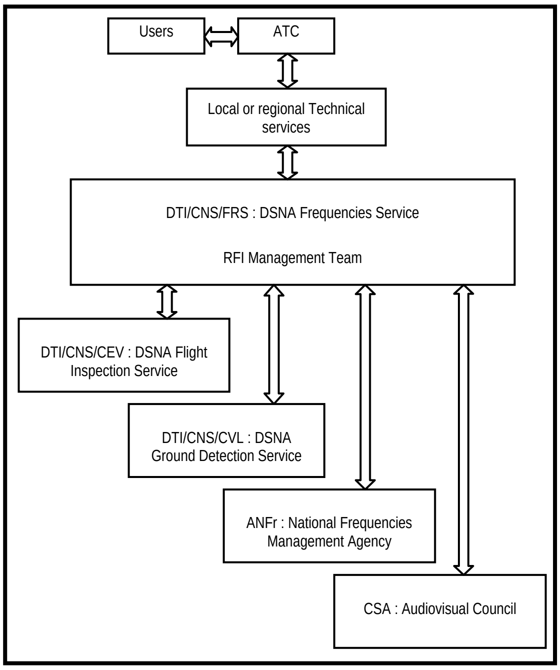
- Organization and coordination
- Technical expertise
- Ground and in flight detection.

Flight inspection Service is part of a global organization and often acts in coordination with other teams. (DTI Flight inspection entity operates three aircrafts; 1 ATR42-300 and 2 Be200)

DSNA also use outside civil aviation service:

The ANFr is the authority in charge of spectrum regulation in France.

The CSA, which oversees all broadcasters (FM, TV,…)



FLIGHT INSPECTION SERVICE AND RFI

Organization

Each aircraft used by the DSNA Flight Inspection Service is equipped with devices for detecting and locating sources of interference. Moreover, the flight inspectors Heads of Mission are all trained in this type of activity. It often happens that during a flight inspection campaign (generally over a period of one week) flight inspectors are required to monitor a reported jammed frequency. It is therefore necessary that the aircraft and the crew are able to fulfill this task.

In most cases, a search for interference is planned during a ferry flight. However, some critical cases may require a dedicated flight. In this case, coordination has to be made prior to the flight, especially with ATC.

The operation of FI aircraft is decided in coordination with the DSNA frequencies Management Departement (DTI/CNS/FRS) which received all the complaints of interference coming from operational centers (en route or regional). This organization optimizes the use of airplanes and limits their intervention on cases where they can be useful.

Equipment

The RFI Detection System is based on two main facilities, a receiver and a direction finder. This system is versatile enough to solve most problems.

RFI Equipment onboard of ATR42

The receiver used since 1999 is an R&S EB200. Their progressive replacement by R&S EB500 is planned during 2012.

This choice is dictated by

- The forthcoming obsolescence of EB200
- The need for software compatibility. The EB500 and EB200 use the same communication language.
- The need for a faster receiver able to work on interferences more and more encountered (digital broadband signals, etc. ...)

EB200

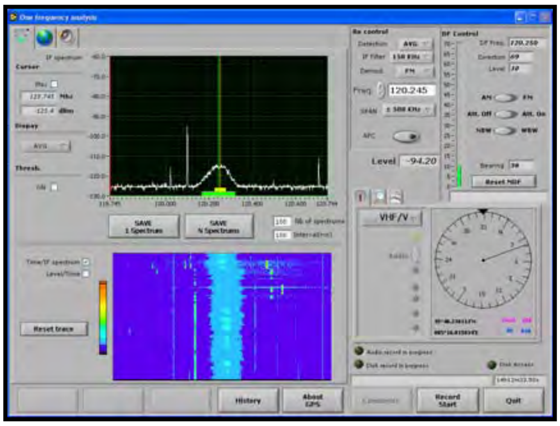
EB500

Onboard direction finding is based on the Rockwell Collins MDF-124F(V2). This DF is available on both ATR-42 and Be200. It covers frequencies from 108MHz to 406MHz and is used to deal with most of interferences undergone so far.

VHF/UHF DF and L band array below Be200

With the increasing deployment of GNSS procedures (LNAV, LPV), a second DF is used for the L band. The Cubic/OAR DF4400 has been chosen for this purpose.

The Cgx-Aero Airfinder© software allows the control of these equipments and is installed either on a dedicated computer if enough space is available (ATR-42) or on the Carnac 30© SAGEM FIS if the aircraft does not allow the installation of a console fully dedicated to RFI detection (Eg Be200).



AiRFInDeR© software (Airborne RFI Detection and Radiolocation)

Specific aspects

The most specific aspect of the fight against RFI in France and especially from the point of view of flight inspection is that the frequency bands, mainly the VHF, are systematically scanned during the ferry flights or during flights where the flight inspector is available for this task (typically high altitude flights for VOR/DME inspection).

This scan allows establishing a fairly exhaustive list of interferences found in the VHF band. Thus it is possible to quickly eliminate some interference before they affect operating frequencies.

The fact remains that the vast majority of cases does not impact a frequency in use in the area where they are perceived. Yet they are treated with equal importance as “proved to be disturbing” jamming cases.

This particular method has several advantages. In the short term, it is possible to remove signals that - if they are not troublesome at the moment they are detected - may become so by moving slightly in frequency. It also helps to identify in advance interfering materials or equipments that may later become important sources of interference and prevent their proliferation (eg long range cordless phones, see example below). Finally it maintains a constant pressure on the most interfering sources by now; FM radios. The repair of an FM station, identified as generating an RFI, allows most of the time to ensure that the problem will not reoccur in the future.

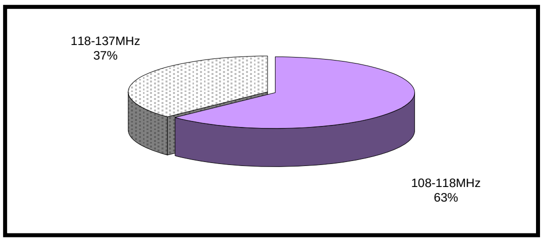
STATISTICS

This chapter presents an overview of cases reported since the Flight Inspection Service was requested to fly RFI detection and research missions. Much of the data below are drawn only from cases that required intervention of aircrafts or detected by them. They do not necessarily include the interferences solved by the intervention of ground services only. However, they provide a good overview of observed phenomena.

Number of cases and frequency distribution

Approximately 700 detections of interference in our bands have been recorded since 1999.

As explained above, in these 700 cases, only a small part affected a civil aviation operational frequency, the rest was detected in CA bands without being tied to a user complaint.



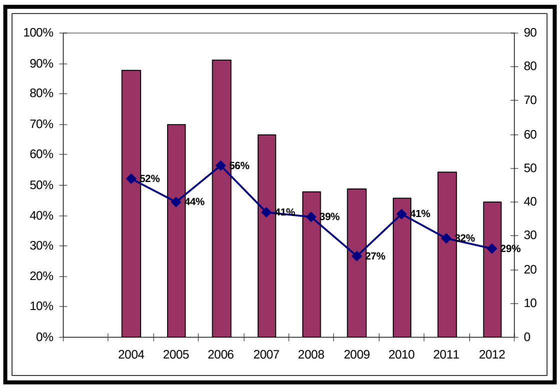
RFI distribution in VHF band

The frequency distribution is very simple, only 1% of cases does not concern the VHF 108-137MHz band.

This is clearly due to the close proximity of the FM broadcast band and fully justifies the effort that was led in the fight against interference on this band. In addition to this observation, it may be useful to recall that Civil Aviation can have all the modern CNS and ATC systems, without VHF frequencies, there is no air traffic control! The VHF band is subject to the highest percentage of RFI and is still the backbone of Air Navigation.

Resolutions

In these 700 cases, 29% have been solved or are being solved. As mentioned, these 200 cases of interference have been solved by the intervention of flight inspection. This percentage, which may seem low, is simply because a lot of the reports are obtained by systematic scanning of the band and the information and/or location obtained are insufficient to bring a quick resolution. Some cases are pending detailed information. In addition, many interference are no longer heard thereafter and often disappear spontaneously.



Ratio of French vs. foreign origin / Number of detection per year

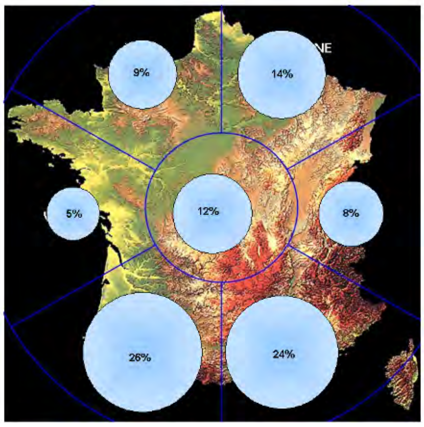
In these 200 cases, 25% are interventions in response to complaints on operational frequencies, the rest concerns resolutions of cases not affecting (not yet) operational service.

Geographic distribution

The map below and previous graph show that the distribution of sources identified and therefore airspace affected by interference is not homogeneous. Many sources of interference are identified outside the French territory and in particular near the southwest border with Spain and south to Italy. These two countries account for 15% and 13% of all cases reported.

Distribution of cases (blue : operational impact, white : no reported impact)

It also appears that the sources of foreign origin accounted for 41% in solved cases that had an impact on an operational frequency.



Geographical distribution

As previously stated, the fact of trying to resolve interference even if they do not impact operational results in maintaining a constant "pressure" on FM french radio operators. We see that every year the number of detected interference due to these radios decreases, it is not the same for foreign radio stations whose proportion increases accordingly.

Classification by origin

Given the numerous cases encountered family of interference sources may be cited, each with its features and requiring a different approach and appropriate means to obtain a quick resolution.

Interference caused by a source inside the Civil Aviation :

- After a technical malfunction. (Drift or failure of a transmitter, intermodulation between frequencies on the same pylon, ...)

- Due to misuse.

  Typical examples are the misuse by crews of 8.33kHz separation (selection of a 25kHz frequency instead of 8.33kHz matching channel) or operation of a frequency outside its protection volume either by ATC (omission of frequency changes when regrouping control positions) or crews.

- Due to poor choice of location or frequency adjustment, which can occur on overloaded TX/RX pylons (in France sometimes up to 40 different frequencies on the same site)

- Due to an open mike. Problem at the limit of what can be considered as an interference but still very critical when it occurs.

For all these examples, careful application of technical or operational procedures and constant monitoring of facilities are the best solutions. The intervention of flight inspection does not generally bring more benefits, except in special cases such as frequency climax.

Interference caused by a source outside civil aviation :

- Weather. Propagation ducts for example. No possible actions in this case.

- Technical malfunctions. This category includes the vast majority of cases. The problems mentioned above with FM broadcasters obviously fall into this category.

  Some of the examples below illustrate this type of interference which is characterized by the wide variety of causes. Most RF systems can generate out-of-band signals if nonlinearity occurs. Non RF equipments can also radiate under certain conditions (high voltage insulators, motors, VCR, lighting are few non-exhaustive examples of cases actually encountered)

  The characteristics of signals generated by such defects are particularly unpredictable. If an interference due to an FM radio is easily identifiable, it is not the case for a signal from industrial sources that can be narrow or broadband, frequency-agile, temporary or continuous.

- The illegal use of civil aviation frequencies. We find in this category, equipments operating intentionally on unauthorized frequencies. This is the case, for example, of long range cordless phone or video surveillance cameras data links.

  Signals encountered in these cases are easily identifiable because generally stable and well characterized. However the fact that these emissions are sometime temporary with a low recurrence may make detection and identification lengthy and hazardous.

- Malicious misuses. Among all sources of interference, they are without any doubt the most feared and unfortunately those against which civil aviation is the most helpless.

  It regroups both intentional communications to traffic or ATC by individuals seeking to interfere with air traffic and jammers or spoofers of some systems, especially GNSS.

EXAMPLES

In the following, we will describe different cases that had an actual operational impact on aviation and originating from a source external to civil aviation.

Technical malfunctions

There are many examples for such problems, we will present here three of the most symptomatic ones.

1. FM Radio vs ILS

This example shows that a systematic monitoring of civil aviation bands can sometimes solve interference problems even before their operational impact is proven.

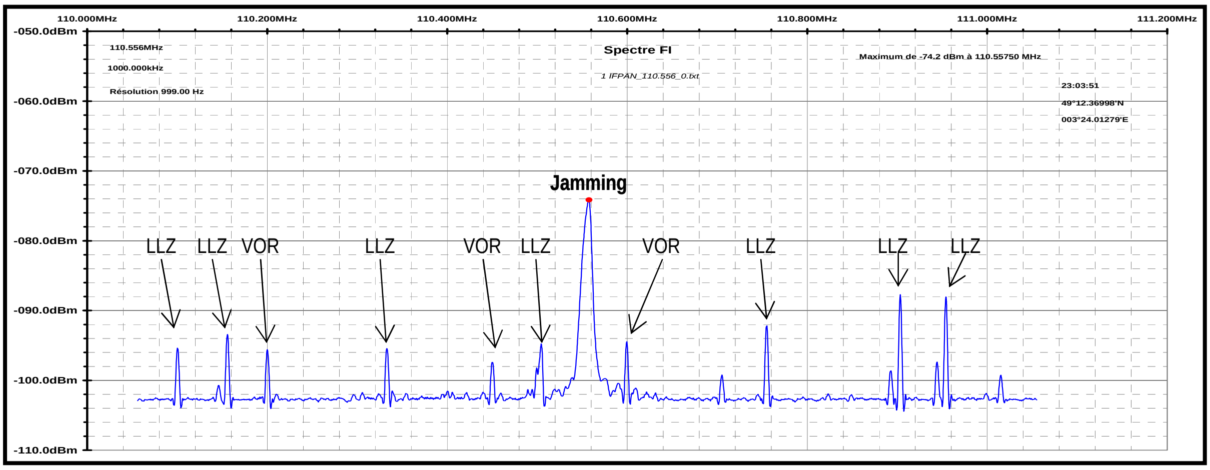
During different VOR/DME flight inspections, an FM radio has been quickly identified as the source of two interferences in the VHF band on

110.55MHz and 128.30MHz. The signal was clear enough to identify the name of the FM radio (Music Box). The different recordings of bearings made during flights were then used for computing a triangulation (using CARL DTI Software).

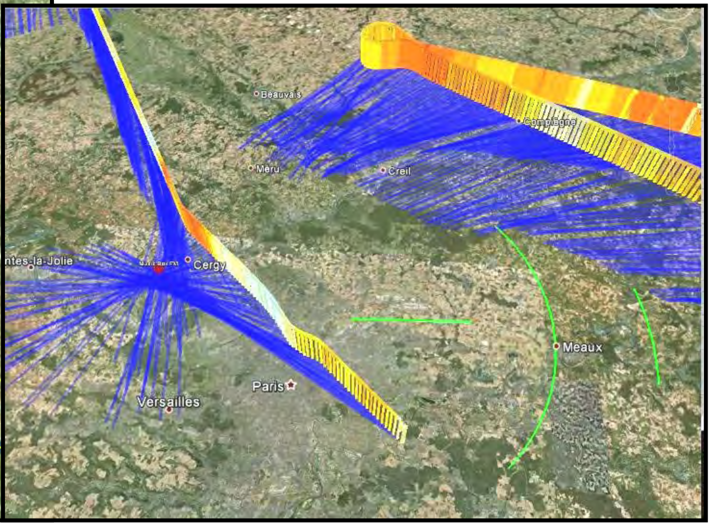
From these coordinates, the radio name and the estimation of the base frequency of the transmitter by simple calculation :

111.55-(128.30-111.55) = 92.8

it was easy to solve the interference. ANFr came two days later and forced the radio owner to adjust the 2kW amplifier. The same day, the first complaints of crews using the RWY27 Cat III ILS of Paris Le Bourget airport on 110.55MHz (Localizer) began to be communicated to the local technical service, reporting music on the ILS ident.



Flight detection trajectory (global view)



Flight detection trajectory (Detail with ILS in green and DF bearings in blue)

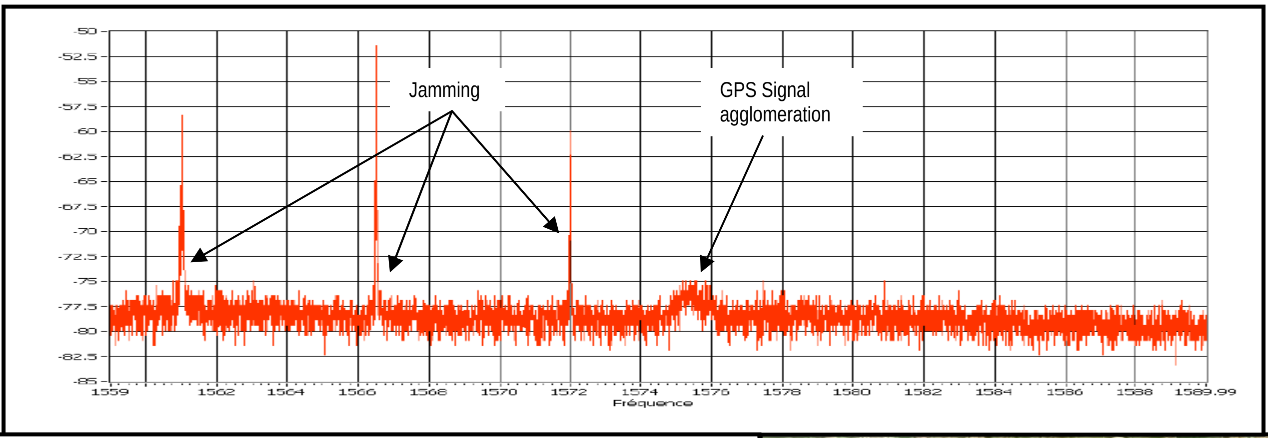
2. <u>TV transmitter vs LNAV GNSS</u>

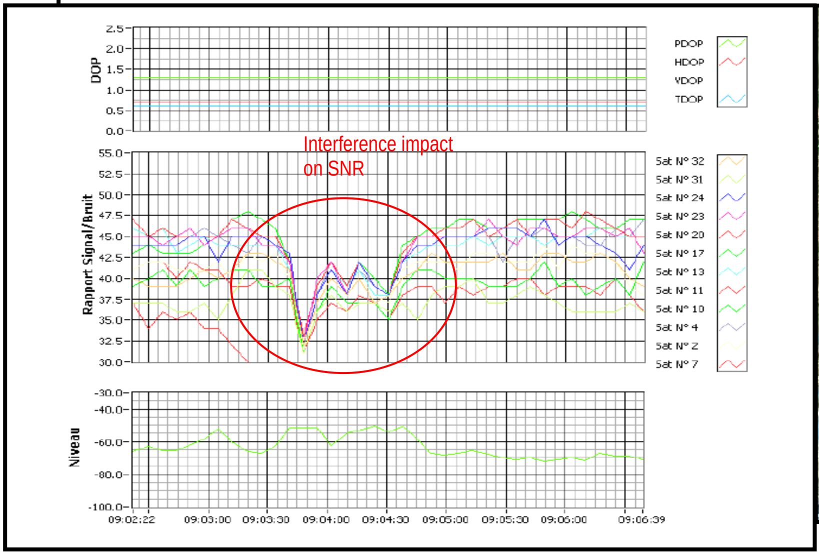
This example illustrates that the L1 spectrum monitoring during a GNSS commissioning is far from being too much.

During the flight inspection required prior to publication of a new LNAV procedure on Nimes Garons airport, the monitoring of GPS L1 spectrum allowed to detect the presence of several signals near the center frequency of GPS L1 1575.42MHz.

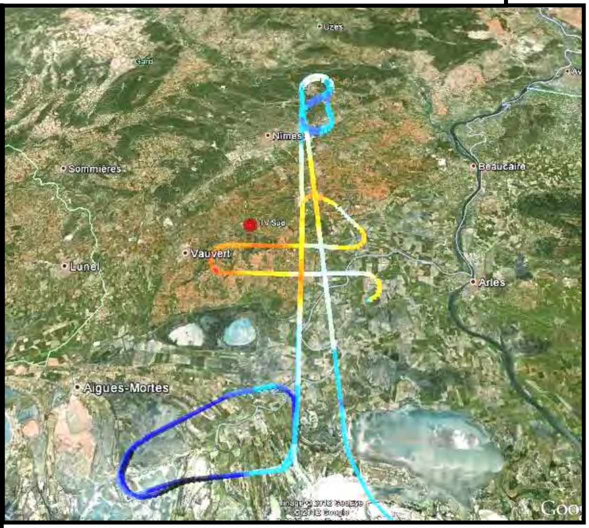
The analysis of one of these signals allowed to demodulate an audio signal that was quickly identified as coming from a television show. Monitoring of the signal led to an approximate location of the transmitter site. The three signals were spaced of 5.5MHz and centered at 1561MHz, 1566.5MHz and 1571MHz. It was fairly easy to deduce that this was an harmonic 2 of analog television channel 60 (picture carrier of channel 60 = 783.25MHz). The only transmitter on that frequency corresponding to both the recorded audio and the estimated location was operated by a local television station. The ground resolution was then very quick and led to a shutdown of the TV transmitter.

Note that the impact on board GPS equipment was not noticeable at first sight, but an analysis of the signal / noise ratio for each satellite showed that they were highly degraded (40 to 45dB normally, and decreasing to 30dB on the LNAV final close to the source of interference)





SVS SNR Analysis (Airfinder©)



Flight Inspection trajectory. The color is function of the RFI field strength.

3. HF dryer vs DVOR

Renewal of Cat III ILS of Lille Airport (LFQQ) has made this navaid unserviceable for a long period during which the only available landing procedures were the VOR/DME on the preferential runway end and LNAV on opposite runway. The VOR/DME (LEQ 109MHz) was much used during this period than it is when the ILS is operational. Many crews have reported very important variations of the VOR indication in final approach causing most of the time go-arounds. Since no interferences were detected on ground, a detection flight with the ATR42 was undertaken at low altitude around Lille airport.

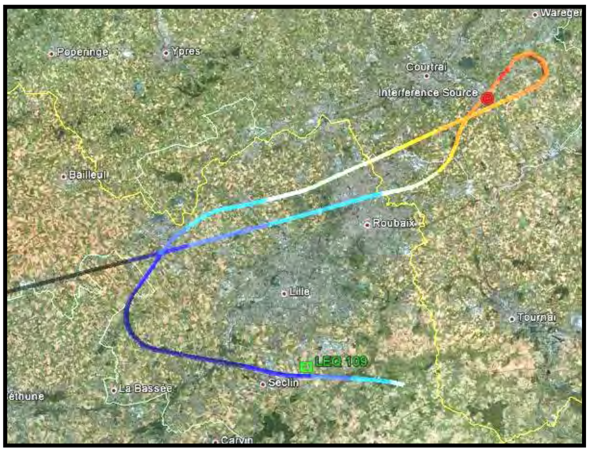
An interfering signal has been quickly detected and located, without being able to clearly identify the origin. This signal of a few kHz wide without specific modulation had the characteristic to evolve slowly in frequency over a few hundred kHz around 109MHz.

All characteristics of this signal and the location of the emission source in an industrial area about twenty Nm of Lille were sent to French and Belgian spectrum management entities.

The ground search, conducted by BIPT (Belgian Institute for Postal Services and Telecommunications) allowed the identification of an RF dryer used in a textile company. The very high power radiation (50kW in this case) of this type of dryer is on a frequency of about 27MHz. The moisture of elements to be processed changes the oscillation frequency of the circuit and causes a variation of the radiation between

27MHz and 28MHz. In this case, the harmonic 4 of this furnace was evolving between 108 and 112MHz as it was observed on board. This also explains the random nature of the disturbance observed by the crew on approach to Lille airport.

The 5th harmonic (between 135MHz and 136MHz) has also created a significant interference with an en-route frequency of Brussels ACC.



Flight detection trajectory

Ground measurements showed that the radiated field on H5 was 89dBµV/m and 79dBµV/m on H4.

Although the resolution of the problem was not very clear, it seems that the only possible solution was to stop the equipment and replace it by a model that meets the standards of spurious emissions. After that, no more disturbances were reported.

Illegal use

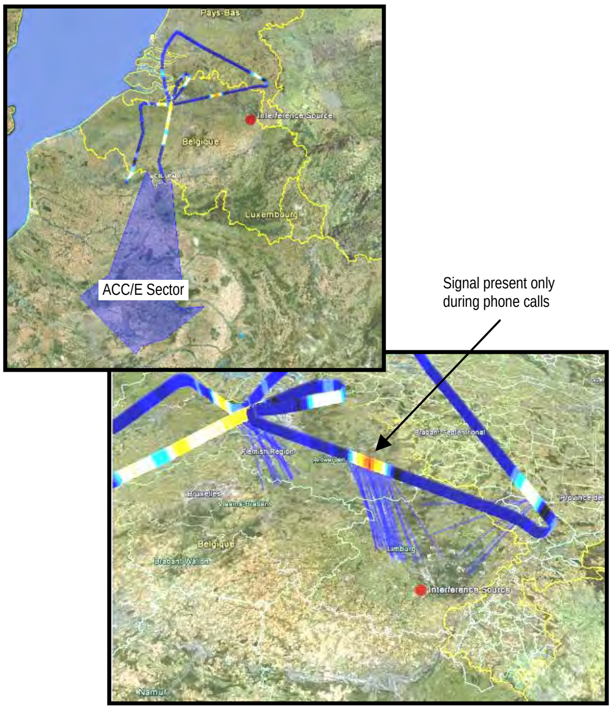
Although more rare than the malfunctions, this type of interference occurs fairly frequently. Some of these unauthorized uses of CA frequencies were found frequently enough for DSNA to take actions in order to make them disappear permanently. This is the case of long range cordless phones.

4. Cordless Phone vs ATC

These cases of interference would certainly have been much more difficult to solve without the action of flight inspection. Because of the nature of this interference its treatment involved a fairly high number of flight hours of research, but once detected the resolution was obtained pretty quickly.

The french ACC/East reported, on numerous occasions, that the 8.33kHz channel "135,505" (frequency 135.50MHz) was jammed to the point that, according to the crews, its use was no longer possible. The busy traffic sector in northern France on which the frequency was assigned has been closed several times requiring ATC to group the traffic on another adjacent sector.

Several research flights were required to finally succeed to hear non-aeronautical phone calls (FM modulation). The carrier signal appearing only during communications, it was not possible to follow it to its source. However, from bearings obtained during transmissions and thanks to the audio records of communications heard, it has been pretty easy to identify the source wich was in a store in the city of Bilzen in Belgium.



Detection flight trajectory

The intervention of ground services led to the identification of a long-range cordless telephone operating on 135.500MHz. This kind of unauthorized equipment can radiate 20W up to reach a range of use of a few tens of kilometers (on the ground). Of course the free-space ranges obtained are so much larger so that the aircrafts separated by more than one hundred Nm in the relevant control area received the phone better than the controller. Before it was possible to identify it, this simple phone has alone generated more than 14,000 minutes of delay for the companies. As a reminder the cost of one minute of delay is estimated at 150€ for the companies (Source Eurocontrol)

In the months that followed this detection, two other devices of the same brand were identified thanks to the intervention of flight inspection aircrafts:

- In England on 135.96MHz : interference with an en-route frequency of Paris ACC.
- In Paris on 135.98MHz : interference with an en-route frequency of Maastricht ACC.

Subsequently a joint action of the DGAC and ANFr led to a legal obligation to withdraw from the market any equipment of this manufacturer. This decree was then applied at European level.

CONCLUSION

The installation of RFI detection equipment on a flight inspection aircraft is undoubtedly one of the most effective ways to quickly solve most problems. The vast majority of interference perceived only on board has been solved by our interventions. Moreover, the systematic monitoring of aeronautical bands can sometimes stop interferences before they have an actual operational impact and, in the longer term, it reduces the number of potential sources by requiring operators to set up appropriate means or results in the removal of unauthorized systems.

However, these airborne means, even if they are efficient, are only useful if they are integrated into an overall architecture of struggle against interferences, implementing human resources (technical and organizational) and technical resources on ground.

However, Civil Aviation remains very vulnerable to malicious and intentional interventions. At the present time, the traffic at Paris Charles de Gaulle Airport is disturbed by unauthorized VHF communications to approaching or departing aircrafts with false control messages. Of course, many services are in search of this “frequency pirate” and several interventions of our aircraft have already taken place. The short length of the messages and the need for immediate and perfect coordination between air and ground support makes this research particularly difficult.

From a technical point of view, the equipment used on board now responds to all needs. In the short term, expected developments are for the management of obsolescence of certain equipments, optimizing the size by a greater integration and software evolutions. In the medium term risks associated with these malicious interventions whether on VHF or GNSS bands (simple jamming or spoofing) will no doubt lead to reconsideration of the onboard direction finding means to move towards high resolution direction finding systems that, until recently, were reserved for the military.

Challenges in Near-Threshold Flight Inspection Measurements

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ABSTRACT

This is a continuation from previous International Flight Inspection Symposia of a series of discussions and papers by the authors on demanding flight inspection FI measurements. It presents investigations into current technical problems encountered during simulations and ground/airborne measurements.

We have experienced decades of development and application of traditional ground-based navigational aids. Several generations of Automatic Flight Inspection System (AFIS) have been fielded. Yet a variety of signal-in-space characteristics actively used to disqualify procedural uses (e.g., airways and approaches) of navaids continues to need definition or standardization. As the use of advanced simulations becomes more prevalent to approve or disapprove proposed development near the navaids, the missing or insufficient definitions become even more evident.

This paper addresses three cases of such FI and installation problems,

- Inconsistent CATIII ILS FI measurements of effects close to threshold, and their solution by a short term mitigation resulting from combined theoretical analysis and advanced simulation techniques,
- FI measurement of a measured and surprising effect close to threshold, and its parallel analysis by advanced simulation techniques
- DDM-measurement by airborne recorder and double dynamic advanced numerical simulations.

While maintaining neutrality by not mentioning location or equipment manufacturers, the paper contrasts results between simulation predictions (e.g., for terminal and aircraft distorting effects) and actual measurements, and analyzes calculation, presentation, and potential misapplication errors experienced with modern flight inspection systems. The paper concludes with recommendations in areas such as improved international policy recommendations, more detailed guidance material, and further harmonization of flight inspection practices and measurements.

DISCLAIMER

In general, measurement locations and methods are intentionally kept anonymous. The authors intend only the constructive use of the examples included in this paper.

CASE 1: DISTORTION EFFECTS AT A CATIII ILS LOC

Introduction of the case; Facts

An existing ILS (**Fig. 1, Fig. 2**) has been upgraded for CATIII operation by installing a new Localizer and Glide Slope equipment. This airport is very much prone to CATIII operation in the winter.

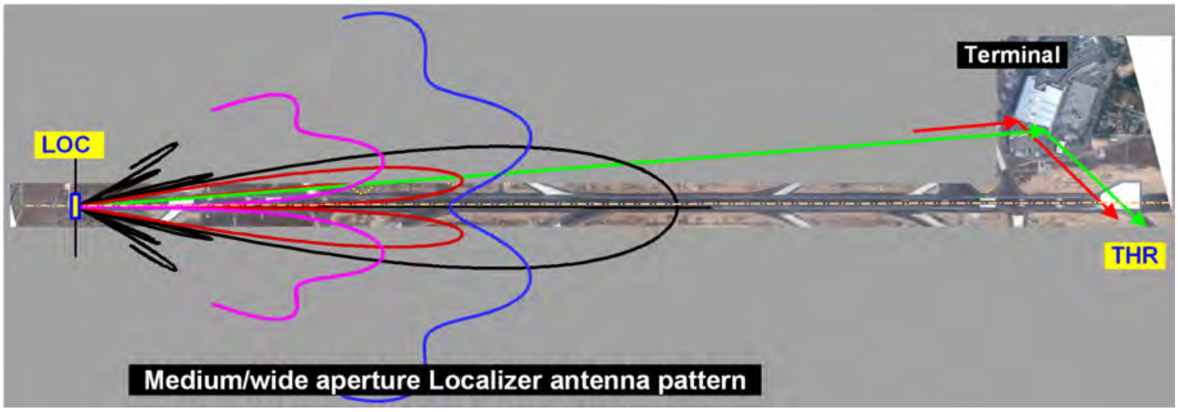

Fig. 1: ILS CATIII Localizer Operation and DDM-Distortion Effects; Inclined Facade of a Terminal

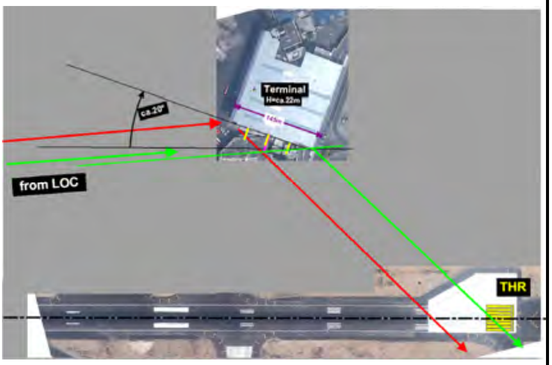

Fig. 2: Layout Details of the THR and Terminal

The installation and commissioning efforts were apparently successful in the uncritical summer time, and the ILS began CATIII operation before the next winter season. The following FIs were also successful without any noticeable effect. However, one year later the FI discovered very surprisingly a sharp DDM peak far exceeding the applicable ICAO limits of 5µA, between the related THR and the touch down TD (**Fig. 3, 4**).

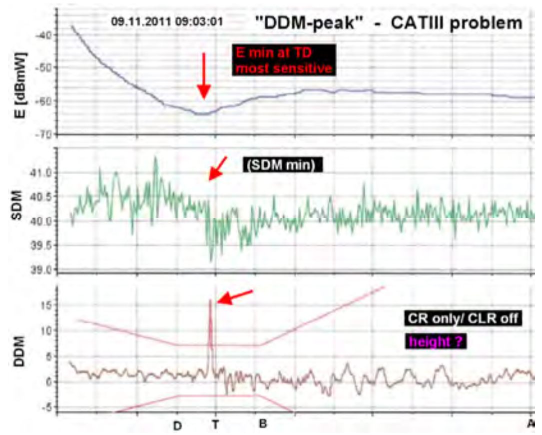

Fig. 3: FI Measurement Showing the Outlier; Nominally 50 ft height above the RWY

This result is despite the fact that nothing has been changed on the airport in the area of the RWY in question. No relevant buildings, tower cranes, etc., could be identified by site survey which might be responsible. Several other potential causes could be excluded, such as spectral issues by jamming or temporary ILS transmitter effects.

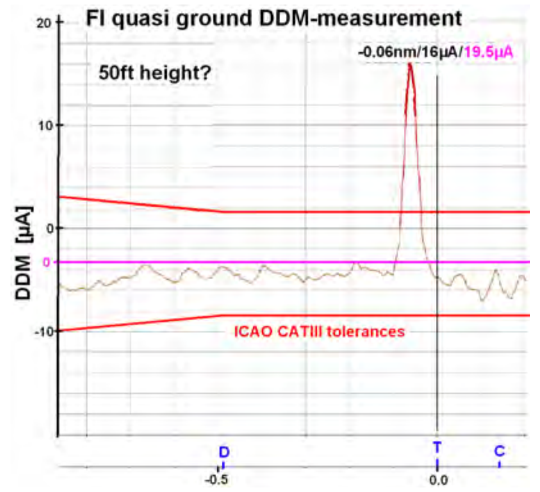

Fig. 4: Details of Fig. 3

Evaluation by measurements

Further systematic repeated FI measurements have shown variable maximum DDM peaks while flying nominally at the height of 50ft above the RWY. The typical ground measurements using a dedicated van and antenna and RX equipment had not been conducted. Such results, but obtained using a slowly-rolling aircraft, are shown in Figure 5. Some SDM-effects were detected as well, but yielding no clue about the technical cause for the observations.

Theoretical and Numerical Evaluation

A closer theoretical analysis has resulted in the conclusion that the FI-measurements are not consistent for some reason. As the most likely general cause, an inclined façade of a terminal has been identified. This terminal was existent several years before the time of the upgrade of the ILS.

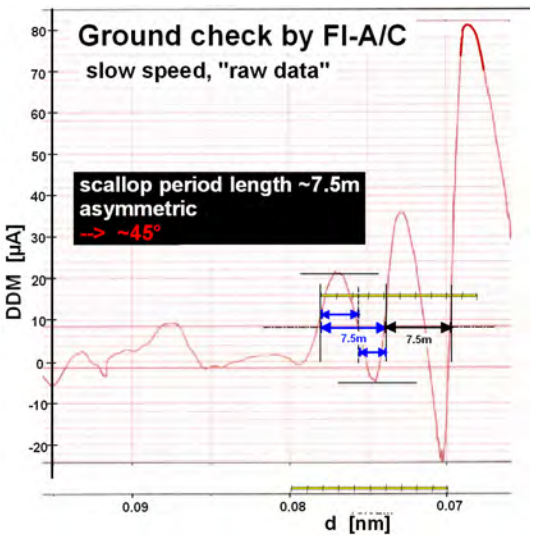

Fig. 5: Quasi-Raw Data Ground Check by slowly rolling FI A/C; Evaluation of Scallops

A systematic 3D modeling study and the numerical analysis with an advanced 3D methodology [2], [3] was conducted; some results are shown in **Fig. 6**. The following results were achieved which were iteratively cross-checked with the measurements:

- The location of the DDM-peak is reproduced **(Fig. 6)**.
- The maximum DDM-error could be reproduced under certain technically reasonable assumptions (**Fig. 6,** top, 2nd top and others).
- The analytical evaluation of the length of the scallops (**Fig. 5**) indicates the distorting source is in the direction of the facade.
- The DDM-peak is strongly dependant on the observation height above the RWY (**Fig. 6**, three top sub-graphics). At a height of 100 ft above RWY, the DDM is already clearly within the ICAO CATIII limits (**Fig. 6,** 2nd lowest graphic).

Conclusion, Mitigation, Recommendations – Case 1

The numerical results combined with the measurements indicate that the inclined façade of the identified terminal is responsible for the observed DDM-peak. It is suspected that the variable amplitude of the DDM-peak and the earlier successful commissioning results, etc., are due to measurement heights deviating from the nominal height of 50 ft; a measurement height of 100 ft and higher seems likely.

Due to the extreme urgency of the problem, an easily realizable, short term, “wire deflector screen” has been designed, iteratively numerically analyzed, and optimized (e.g. **Fig. 6** bottom). This deflector screen was erected within days **(Fig. 7)**, and subsequently the ILS was flight checked immediately. The FI measurements confirmed the numerical analysis consistently, and the CATIII-operation was safely back within CATIII specifications just before the bad weather period.

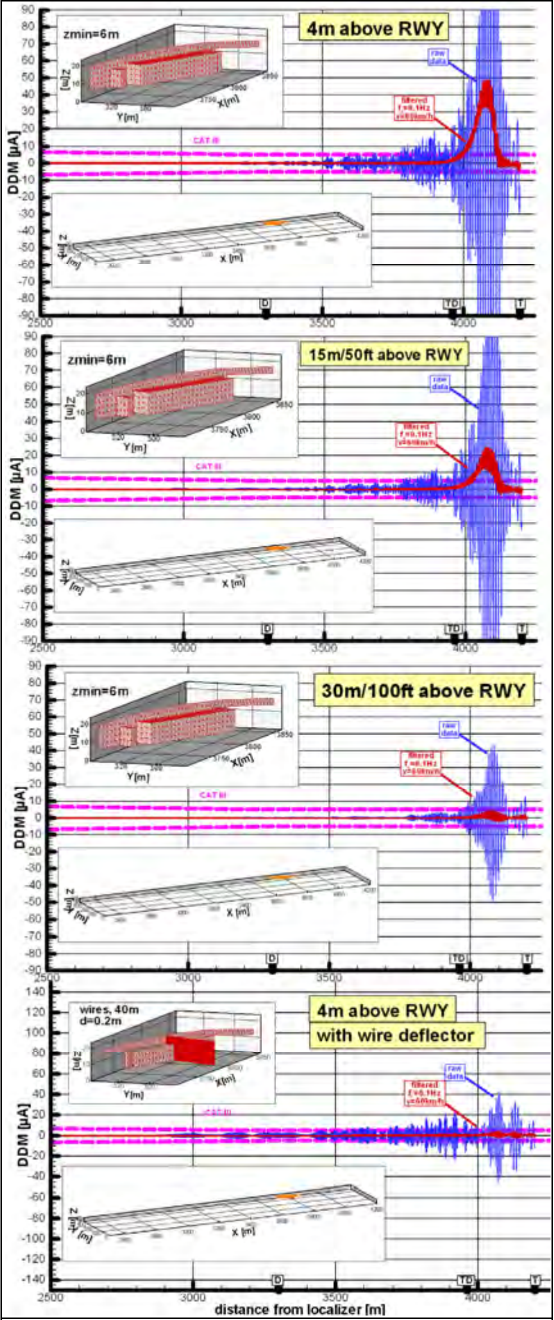

Fig. 6: Results of Numerical Simulations of the Effects of the Terminal and of a Mitigation

The following recommendations are derived:

- Each planned major building on airports should be evaluated and modeled, in particular for CATIII operation by a reliable and accurate numerical 3D analysis.

- Defined ground check measurements should be conducted; substitution for them by a low flying FI-A/C will not be sufficient in many cases.
- Effects in FI measurements should be openly cross checked and combined with adequate state-of-the-art numerical 3D simulations.

Fig. 7: Realized Wire Fence, Numerical Design

CASE 2: UNIDENTIFIED DDM PEAK AT A CATIII ILS LOC

Introduction of the case; Facts

A flight inspection measurement of a long-established ILS produced an unexpected DDM peak near Point D. Flight inspection personnel believed the cause may be a B747-400, since the airport allows parking of inclined aircraft outside the sensitive area. This is in particular in the discussed case of at least 400m from RWY centerline, and immediately in front of (inside) the related THR (**Fig. 8**). The analysis of the Localizer array and its siting does not show any significant DDM distortions to be expected.

Measurement Effects

The flight inspection measurement of the DDM peak is shown (**Fig. 9)**. This peak distortion was measured only once; thus there is no evidence whether it is a reproducible effect or a transient event by some un-identified reason.

Numerical Modeling and Analysis

As a numerical analysis test of the suspicion about the parked aircraft as the cause, a 3D model of the B747-400 was used in an application of advanced numerical 3D methods, namely the IPO and MLFMM methods. The 3D model and its geometry for the B747-400 are shown in **Fig. 9**.

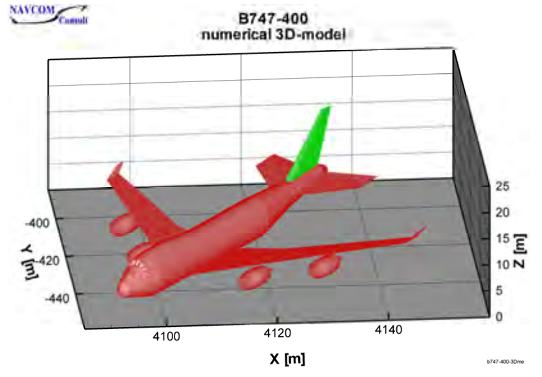

Fig. 9: 3D Model, B747-400 (IPO, MLFMM)

The numerical results are shown in **Fig. 10**. As might be expected from the analysis of LOC antenna patterns and the B747, only very small DDM distortions are predicted, and the peak distortion occurs outside THR. The raw (unfiltered) data shows ~2 µA high frequency scalloping, which is indicative of a Course (vs Clearance) residual effect. The ICAO-filtered DDM distortions are nearly negligible. These results are a poor fit to the one-time measured data.

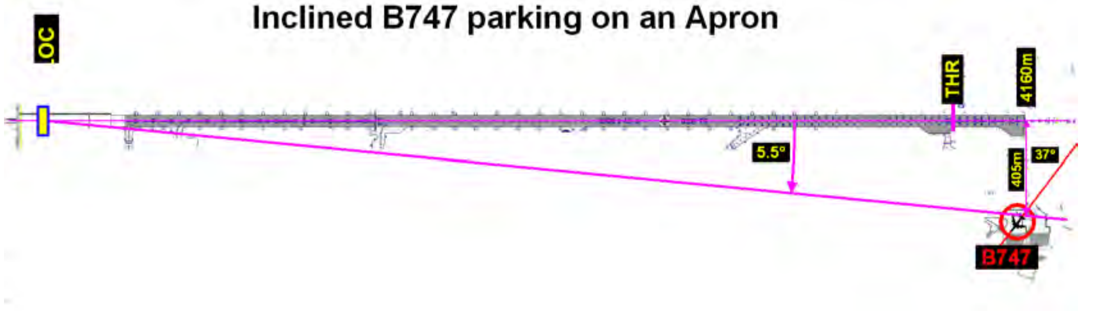

Fig. 8: ILS CATIII Localizer Operation and DDM-Distortion Effects; Inclined Parking B747-400

Conclusions, Mitigation, Recommendations - Case 2

By comparing the measurement results with the numerical analysis results, the B747-400 cannot be responsible for the one-time observation. This is based on the location of the DDM peak (near Point D for the measurements, outside Point T for the simulation), as well as the form and amplitude of the peak. Also, the earlier systematic measurements for the A380 and the B747 and the derived definitions of the safeguarding zones contradict clearly this suspicious case.

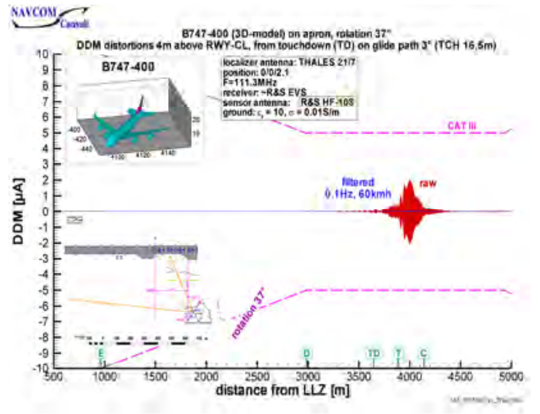

Fig. 10: Simulation results for the inclined B747-400

At this point, mitigations cannot be suggested, as the cause of the measurement results has not been sufficiently and firmly identified.

The following recommendations are derived:

- Unexpected results should be repeated and their cause identified, before implementing mitigations. All mitigations have a cost in some way, either direct or indirect, and many may create operational consequences.
- Each effect with consequences should be compatible with physical theory and system characteristics.
- Conclusions should not be drawn from non-reproducible effects.

A similar example was presented by the authors during the last IFIS 2010 [1]. In that case, it was shown that noise like effects measured on a single orbit could not be explained by the suspected wind turbines.

CASE 3: DDM-DISTORTIONS BY STARTING AIRCRAFT FOR LANDING AIRCRAFT CLOSE TO THRESHOLD

Introduction of the case; Facts

Starting aircraft have the potential to distort the ILS-signal for the next landing aircraft during mixed mode operation (**Fig. 11**). In the ideal case, the starting aircraft climbs while remaining directly above the runway centerline, and no DDM-distortions occur for the landing aircraft due to symmetry reasons.

However, if the starting aircrafts deviates from the ideal climbing path/slope, asymmetric scattering components generate large distortions until shortly after the localizer is crossed.

Measurement data

Fig. 12 shows an example of measured height and DDM-distortions taken from a data recorder in the final landing phase caused by a preceding starting aircraft. The DDM data is clearly heavily low-pass filtered, and likely has a low sampling rate as well. During the touchdown and rollout phases of the landing (during which the aircraft is normally constrained to remain over the centerline), the DDM distortions from the departing aircraft initially exceed ± 50 µA, but they stabilize for a period of approximately ten seconds at nearly 150 µA in this specific case.

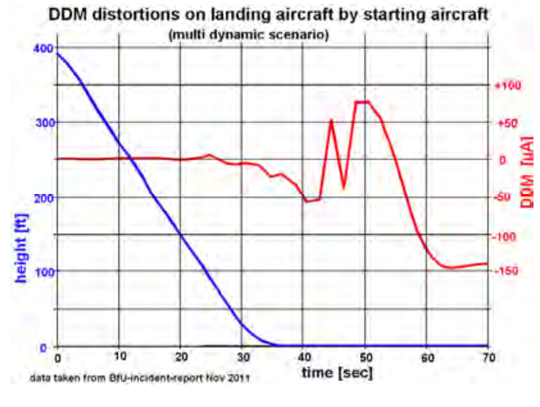

Fig. 12: Height and DDM-data (data recorder)

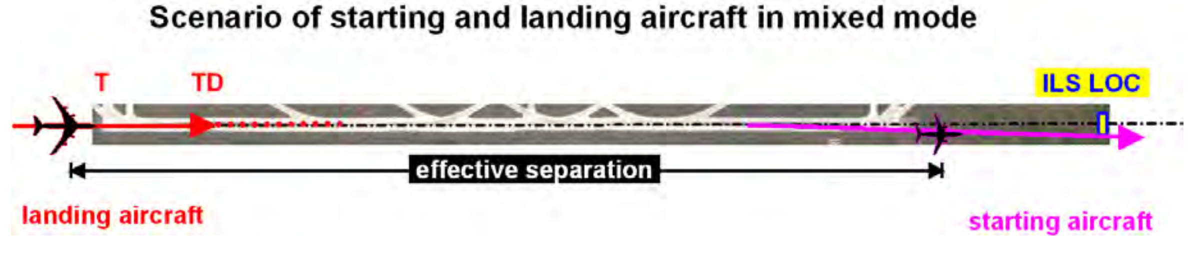

Fig. 11: Scenario of starting and landing aircraft in mixed mode

The example **Fig. 12** recorded results will not surprise practitioners who have monitored Far-Field Course monitor indications or conducted extensive ground checking of Localizers during busy airport operations.

Numerical Modeling and Analysis

Fig. 13 shows numerical results of the effects of a small starting aircraft on the next landing aircraft. This was prepared in a "double dynamic" scenario – i.e., both aircraft are moving. The DDM is calculated for a landing aircraft as it proceeds from right to left, beginning at a distance of 7 km on a typical glide path (3°) descent until touchdown. Upon touchdown, the rollout phase continues with the receiving antenna at a constant 4m height above the centerline. At the touchdown point, the horizontal scale changes to show the distance remaining to the Localizer. The starting aircraft is assumed to be taking off with an effective separation, a climb angle of 6.3° and a continuous deviation angle of 0.7° from the center line, such as would occur with a crosswind.

Fig. 13 shows that as the landing aircraft nears touchdown, the DDM distortions from the departing aircraft on the specified flight path are generally at least 50µA, and can easily exceed 200µA at specific points for the two aircraft. Note that unlike the measured data in **Fig. 12**, the **Fig. 13** results are raw, unfiltered results, and therefore cannot be compared directly. However, the results show the same general result to be expected – i.e., an aircraft climbing toward the Localizer on a flight path that does NOT remain over the centerline can introduce major DDM effects.

Conclusions – Case 3

Starting aircraft can seriously distort the ILS signal for the next landing aircraft, potentially yielding dangerous effects. This has been shown by measured data and by double dynamic simulations using advanced 3D methodology [2],[3]. This problem is particularly relevant for "autoland" operation.

The critical/sensitive areas of an ILS Localizer extend in height as shown by this example.

DDM-distortions from a departing aircraft are larger for lower heights of the simultaneously arriving aircraft, due to the reduced level of the direct signal from the Localizer, from horizontal polarization.

More details on this case are presented during the conference.

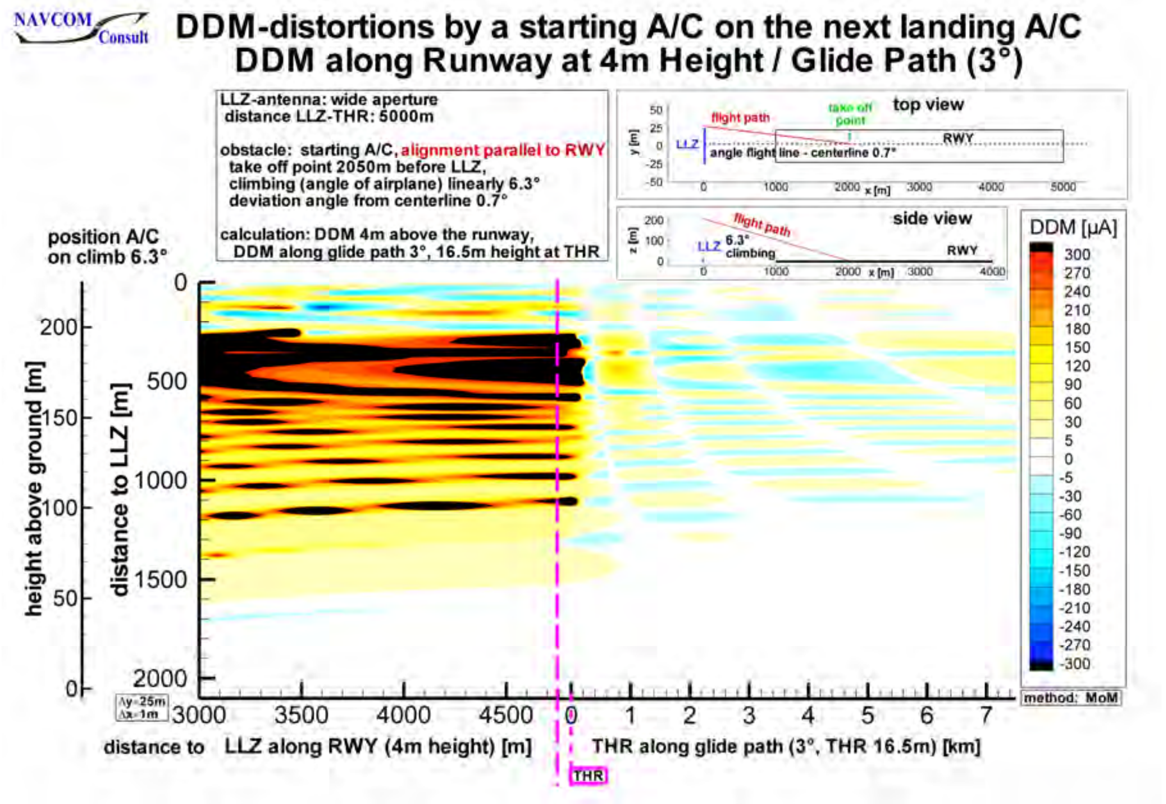

Fig. 13: DDM-simulations of 2 Moving Aircraft in Mixed Mode Operation

OVERALL CONCLUSIONS

1. It is possible for near-threshold distortion effects to exist for some time before being detected, due to inconsistent flight paths of the measurement aircraft at low altitudes and during transition from descent to level flight over the runway.

2. Localizer measurements in Zones 4 and 5 are most consistently made by ground measurements.

3. One-time measurements should not be used as the basis for implementing airfield practices which have substantive impact on airport operations.

4. Simulations made with sufficiently reliable 3D methods can be used to validate or invalidate surprising flight measurements, especially those which cannot practically be repeated.

5. Mixed mode operations (simultaneous approaches and departures on a common runway) can create large DDM distortions of sufficient duration to affect the landing aircraft.

6. Critical and Sensitive Area protection during mixed mode operations must include the vertical dimension.

OVERALL RECOMMENDATIONS

1. Evaluate and model proposed relevant changes on major airports, in particular for CATIII operation, using a reliable and accurate numerical real 3D analysis.

2. Perform Zone 4 and Zone 5 analysis of CAT III (between ILS points C and E) Localizers using well defined ground measurements (sensor antenna, receiver).

3. Repeat unexpected flight measurements, and evaluate them against state-of-the-art 3D simulations.

4. Resist drawing conclusions from non-reproducible effects.

5. Implement mitigations for measured effects only after their cause is identified in a way compatible with physical theory and the relevant established system characteristics.

ACKNOWLEDGMENTS

The numerical simulations are carried out by Mr. Biermann und Mr. Mundt of NAVCOM Consult.

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Detection and Location of RF Interference Sources

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ABSTRACT

Radio frequency noise and interferences degrade the performance of radio navigation aids and are a major threat to air safety. In this paper, an advanced high frequency direction finding system is described that includes the capability to detect and locate interference sources.

Using a sequential and recursive data collection method in real time, the author present analysis from different datasets. Using the direction finding system as a noise and interference detection sensor is an excellent first step toward identifying and mitigating the emitters causing radio navigation aids degradation.

Also this paper presents a way how to measure, filter and display the direction finding results clearly and simple to the system operator.

INTRODUCTION

Detection and location of interference sources is not a simple, fully automated process.

A basic investigation of the signal to be detected has to be performed before the DF system is operated.

With the results of this investigation sometimes the source is already identified and/or located.

Unknown stations are to be investigated in depth.

If the signal is understood, the DF system comes into operation.

Through special flight maneuvers the signal source can be located and the system generates a graphical and numerical result plot.

STEPS TO IDENTIFY A SIGNAL

The following questions should be asked to understand the signal:

1) What signal is to locate?
2) What information is available beforehand?
3) How can I receive the signal? → Which frequency band, antenna selection
4) Which polarization/antenna? → horizontal, vertical or circular, antenna selection
5) What is the expected signal strength → close to station or far away?
6) What is the expected modulation → use demodulator to listen
7) What is the expected bandwidth → use spectrum analyzer
8) What is the expected timing → continuous or intermittent

After answering theses questions, the DF system can be used.

In the following, more detailed questions and answers with a fictitious example are shown.

Step 1) Gathering details

What signal to detect? Who reported the interference and on which system did the interference show up?

Example Answer:
Interference on 135,25 MHz, airport approach frequency
unreadable, but seems to be voice

Step 2) Gathering details

What information is available beforehand?

Example Answer:
Was not reported before, showed up two days ago.

Step 3) antenna selection

How can I receive the signal? → Which frequency band, antenna selection

Example Answer:
VHF COM band, standard antenna as available on aircraft

Step 4) antenna selection

Which polarization/antenna → horizontal, vertical or circular, antenna selection

Example Answer:
Interference on VHF COM, which is vertical polarized. First choice is vertical VHF COM antenna.

Step 5) Signal strength

What is the expected signal strength → close to station or far away?

Is there any noise on the signal or clear?

Is it a single signal transmitter or multiple TX?

Example Answer:
Signal strength opening the squelch, but strong aircraft radios are clearly readable above the signal.

It seems to be a single station; all signals have the same quality. No different operators talking.

Step 6) Bandwidth

What is the expected bandwidth → use spectrum analyzer

Example Answer:
Occupied bandwidth is about +/- 20kHz

Step 6) Modulation

What is the expected modulation → use demodulator to listen to the signal.

Example Answer:
Distorted readability was reported in AM, as used in A/C VHF COMs.
Tests in FM-narrow showed over-modulated signal, closing the squelch if spoken louder. Signal could be identified as voice.

Tests in FM-wide showed under-modulated signal, squelch opening properly, clear voice could be identified.

Step 8) Timing of Signal

What is the expected timing → continuous or intermittent?

Example Answer:
Intermittent, typical two way communication, single channel operation with PTT, only one station could be heard.

First interpretation of all information found until now

In this example, it looks and sounds like a two way communication radio station. The demodulated contents matches with a typical illegal TAXI cab company communication. No station ID was transmitted. No knowledge until now about location and why the FM-modulation has an untypically, high occupied bandwidth.

USE OF THE DF IN THE AIRCRAFT

Set up of the DF

With the information found until now, the DF will be set up:

Frequency:	130.25 MHz,
Bandwidth and modulation:	FM wide (100 kHz)
Antenna of DF:	set to VHF array

Briefing with the flight crew

A procedure shall be flown, if high activity on this channel is reported.

The DF indication shall be transferred to the pilot´s bearing indicator, the pilots shall roughly try to overfly the station. If the needle swings back, around this point an orbit of roughly 5 NM radius shall be flown. Flight track need not be very accurate, but high bank angles should be avoided.

The flight inspector / DF operator shall activate the DF software with tracking capability of the signal.

The aircraft needs no view to ground; it can be flown under IFR, if safe operation of the aircraft can be assured in the area.

RESULTS OF REAL FLIGHTS

The following plots have been taken from target search in VHF, UHF and L-Band DF search flights. Altitude was 6500 ft above the ground station, IMC conditions, IFR operation.

All plots were made in real time, progress continuously presented to the operator in flight.

The system continuously shows an estimated position error (data taken from the signal quality and the variation of the bearings) of the expected TX location.

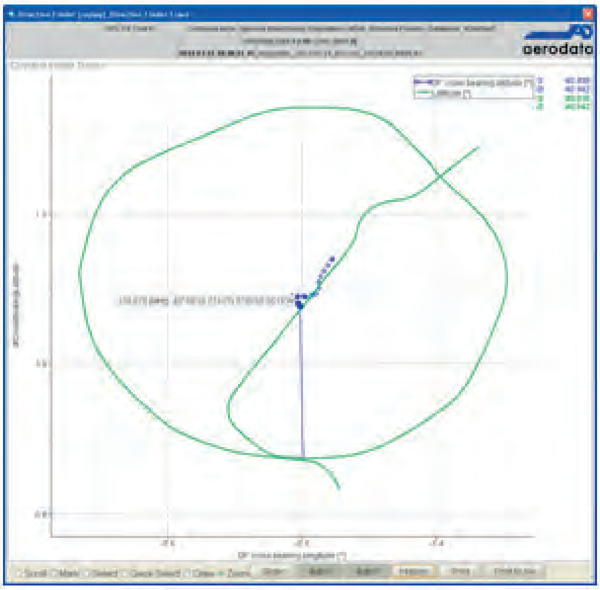
The real position of the TX was not known to the software.

In-flight plots VHF

The estimated position error as shown by the system in flight was 0.15 NM when flown in an orbit with 10 NM diameter.

The transmitted signal was simulated COM traffic from one location.

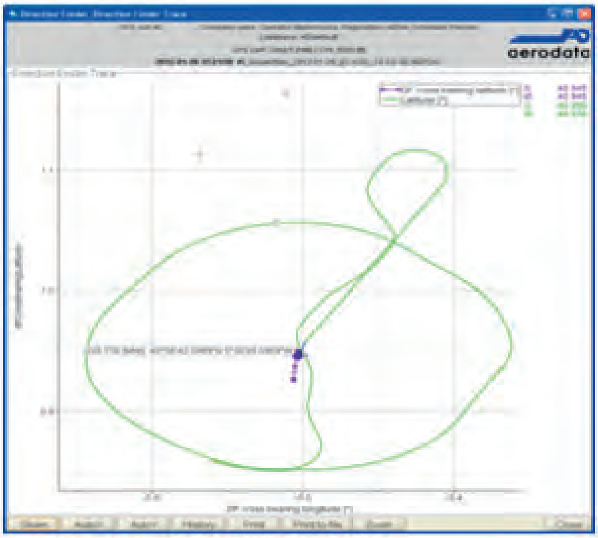
Range	6.6	NM
Bearing	352.8	°
Estimation Error	284.4	m
Frequency	130.675	MHz



The final position was calculated in LAT and LON coordinates and shown to the operator.

In-flight plots UHF

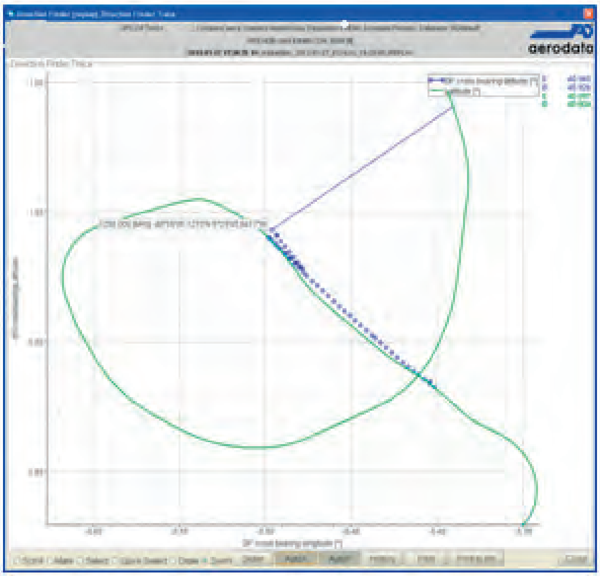
The estimated position error as shown by the system in flight was less than 0.1 NM when flown in a orbit with 10 NM diameter. An Omnidirectional antenna with 5 Watt output power was used.

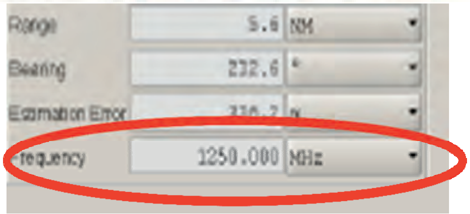


In-flight plots L-Band

The estimated position error as shown by the system in flight was 0.2 NM when flown in a orbit with 10 NM diameter.

Frequency used was 1250 MHz, TX antenna had a 3dB opening angle of about 60°. Signal power was only 20mW with a 6dBi directional antenna.





Range	5.6	NM
Bearing	232.6	°
Estimation Error	[illegible]	m
Frequency	1250.000	MHz

Data exported to a map

Data from the flight can be exported in KML-Format to be presented on a map, e.g. Google maps.

Flight track and position found can be shown.

On this map the location of the TX source can clearly be identified to be in the south-east of the airport. The second yellow pin (left) shows the real position.

Final interpretation of the (fictitious) example data

The transmitter was operating in the CB-Band, frequency of 27.050 MHz in FM. The fifth harmonic (135.250 MHz) was modulated with 5 times the standard FM deviation of about 4 kHz. The station was close by the interfered receiver, and the harmonic resulted in a level of -75dBm on the VHF COM antenna.

The radio was modified a few days before; the output power was turned up without watching the harmonics of the signal.

The mobile stations had unmodified radios not transmitting on the harmonics.

With this knowledge the basis frequency of 27.050 MHz could be demodulated with a normal FM-narrow receiver.

Summary, Conclusion

DF operating is still challenging and not fully automatic.

It needs understanding of the signal and radio theory by the operator of the system.

Special hardware and software on board of the flight inspection aircraft is required to get optimal results and minimum flight time.

Finally the interference source (transmitter) must be found by people on ground using detailed information supplied by the flight inspection DF system.

Validation of GNSS RNAV Instrument Approach Procedures

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ABSTRACT

There are currently approximately 750 RNAV (GNSS) instrument approach procedures published for airports in Canada. Of these, eighty also have Localizer Precision with Vertical (LPV) minima. New procedures are being added with each aeronautical publication cycle. NAV CANADA has been performing flight validation of these procedures for over a decade.

This paper describes the evolution of NAV CANADA's RNAV procedure validation program, and examines the challenges of meeting the various regulatory requirements, especially for LPV.

INTRODUCTION

GNSS represents a new way of providing the basic navigation function to the pilots of most aircraft. Instead of being tied to ground-based traditional navigation aids, aircraft are now flown along lines drawn in space, usually connecting two waypoints which exist only in terms of a geodetic coordinate system. Flight inspection has historically consisted of a verification of the signal in space transmitted by a radionavigation aid against technical parameters and an aircraft position reference. For GNSS, however, it is primarily a matter of checking that survey data, waypoint coordinates, and obstacle data are correct. The term "flight validation" has been coined for the latter to make the distinction. This concept can sometimes be difficult for those with ground-based navaid flight inspection experience to appreciate, and an explanation of the specific objectives of validation of GNSS-based procedures, as presented in this paper, may be helpful.

HISTORY

NAV CANADA has been involved in the publication of satellite-based instrument procedures since the first approval to use GPS in Canada was issued in 1995.

Since there were no standards for RNAV flight validation available when we started, we developed our own, and company personnel have since been contributors to various ICAO (Doc 8071[1] and Doc 9906[2]) and Transport Canada[3] documents that govern the design and validation of instrument procedures in Canada.

Our internal standards have evolved over the past several years, and now include processes and supporting systems for validating terminal procedures and LPV approaches, known as Approaches with Vertical guidance (APV) by ICAO.

VALIDATION TASKS

The following tasks must be completed prior to the commissioning of a GNSS RNAV instrument approach procedure:

- Confirm the geodetic survey accuracy;
- Confirm data integrity and Final Approach Segment (FAS) Cyclical Redundancy Check (CRC);
- Verify that the waypoints are loaded into the avionics accurately;
- Verify the threshold/Missed Approach Waypoint position;
- Check the FAS alignment and vertical profile;
- Confirm topographic map waypoint plotting;
- Confirm the delivery point for Lateral Navigation (LNAV) and LPV paths;
- Verify obstacles for each segment and the Minimum Sector Altitude (MSA);
- Perform an interference check;
- Evaluate operational acceptability.
- Confirm GNSS signal reception on all segments.

These are discussed in the sections that follow.

Survey Accuracy

The waypoints of most GNSS approaches are computed based on tracks and distances from a single surveyed reference point on the ground, usually the runway threshold. The accuracy of the coordinates of this point, therefore, is paramount, and must be confirmed.

Data Integrity and FAS CRC

The coordinates of each waypoint in the procedure must be validated. This may be accomplished by using them to compute the track and distance for each defined leg, and comparing the results to the design values. This creates a link of confirmed tracks and distances between each waypoint and the survey reference. Since the latter is verified spatially during the survey accuracy check, the accuracy of each waypoint is thus assured.

For LPV approaches, the CRC is also calculated and confirmed to agree with the design value.

Avionics Waypoint Accuracy

A means of confirming that the procedure waypoints have been entered accurately into the avionics used for the flight validation is necessary. This ensures that what is being flown is identical to what was designed. This confirmation may be done manually, or automated.

FAS Alignment and Vertical Profile

During the flight validation of an LPV procedure, the final approach alignment and vertical profile are confirmed. This is a subjective assessment performed by the pilot, and may be supplemented by altitude/distance and bearing-to-threshold calculations.

Topo Map Waypoint Plotting

There is currently a requirement in Canada to overfly each waypoint in the procedure, and confirm its position visually with reference to physical features on a topographic map. The rationale for this is poorly understood, and it is often incorrectly assumed that it has something to do with verifying the accuracy of the GNSS guidance.

This requirement actually arises from the time when instrument procedures, particularly approaches, were designed manually on a map. The waypoints were measured off relative to each other, and their geodetic coordinates were read from the scales on the edges of the map. The obstacle clearance surfaces were then drawn, and the controlling obstacle for each segment was identified, which, in turn, determined the minimum IFR altitudes. If a plotting error occurred, then the obstacle surfaces would be incorrect, and an obstruction that might otherwise be controlling could be excluded.

Performing the visual confirmation of the waypoints is intended to ensure that the proper obstacles are considered in the procedure design. However, modern techniques use obstacle databases and automated procedure development tools, which render this requirement superfluous. Canada's official flight validation standard[3] still includes this requirement, although it is anticipated that it will be deleted in a future revision.

Delivery Point

This is a subjective assessment of approaches made by the pilot that verifies that the guidance delivers the aircraft to a point from which a landing may be safely completed.

Note that if an approach provides both LNAV and LPV minima, the intermediate and final approach segments must be flown using both LNAV minimum IFR stepdown altitudes for each segment and the 3-D path through space defined in the FAS data block.

Obstacle Verification

The obstacle verification confirms that all significant obstructions (not just the controlling ones) have been considered in the design.

In the past, crews were often provided with only a description of the controlling obstacle in each segment. If, while assessing the procedure, they observed a significant obstacle that, in their opinion, could possibly be controlling, then they had no way to determine if that obstacle had been duly considered in the approach design, or if it was a new obstruction that did not exist in the obstacle database. Therefore, it is important to provide the flight validation crew with a sketch of the approach that depicts all significant obstacles, which is used to confirm each obstacle visually during the mission.

If significant obstacles are noted during the flight validation that do not appear on the sketch, their location and estimated height are noted, and a review is conducted by the designer to determine if the procedure needs to be amended.

Interference

Because GNSS signals are very weak, it is generally accepted that the ability of a GNSS receiver to track satellites implies the absence of interference. Nevertheless, if a flight inspection aircraft equipped with spectrum analysis apparatus is used for procedure validation, then a baseline spectrum may be recorded for reference in the event that interference is suspected later.

Having said that, though, not too much effort should be expended in attempting to characterize the RF environment during a flight validation, since most interference is temporal, and the presence or absence of

Radio-Frequency Interference (RFI) at any moment does not imply that the same conditions will persist in the future.

Operational Acceptability

There is traditionally a "flyability" assessment made during flight validation. This is a subjective evaluation by the pilot, and consists of such considerations as descent gradients, leg lengths, turns, and workload. However, we have expanded this to encompass communications availability, infrastructure (wind indicators, runway markings, local altimeter setting) and the accurate depiction of all required information on the procedure plate, and have named this comprehensive assessment "operational acceptability". Doc 9906 calls it "associated validation tasks".

GNSS Signal Reception

It is widely acknowledged that, in the absence of indicators of anomalous behaviour and having integrity parameters within allowable tolerances, a properly-certified GNSS receiver will give a correct (within known limits) indication of the position of the aircraft. Thus, interference and basic signal coverage checks notwithstanding, flight validation does not include an assessment of the signal in space, nor of the ability of the GPS constellation and receiver to provide an accurate position fix. This concept represents a significant departure from the traditional flight inspection function.

Thus, it is adequate for validation purposes to confirm that the receiver is able to track satellites throughout the procedure.

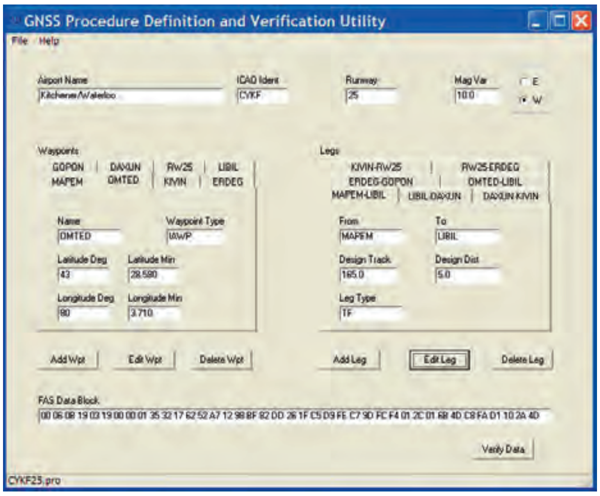
For approaches based on space-based augmentation systems (SBAS), a confirmation of continuous reception of the correction and integrity broadcasts throughout the procedure should be performed. This is of particular interest in areas where the vertical angle to the geostationary satellites is low, or where high terrain is present adjacent to the approach.

FLIGHT VALIDATION SOFTWARE

NAV CANADA has developed software to automate certain aspects of flight validation and to reduce the crew workload during a mission. It is described in the sections that follow.

Procedure definition utility

This application permits the designer to enter procedure-related data – waypoints, leg tracks and distances, and, for LPV approaches, the FAS data block. Figure 1 shows the Procedure Definition Utility main screen.



Airport Name: Kitchener/Waterloo
ICAO Ident: CYKF
Runway: 25
Mag Var: 10.0
○ E
● W

Name: OMTED
Waypoint Type: IAWP
Latitude Deg: 43
Latitude Min: 28.580
Longitude Deg: 80
Longitude Min: 3.710

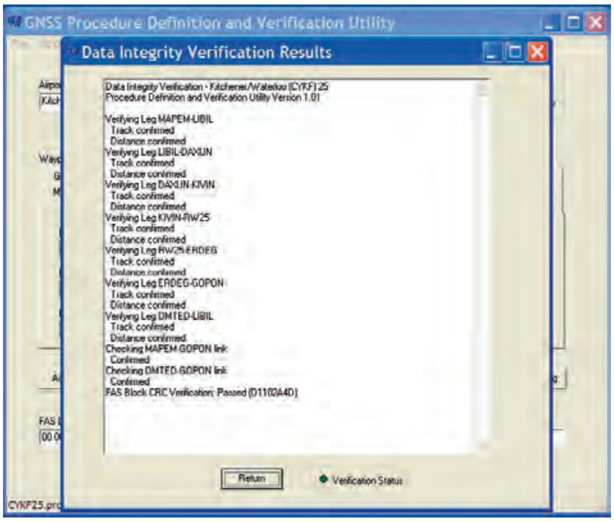
From: MAPEM
To: LIBIL
Design Track: 165.0
Design Dist: 5.0
Leg Type: TF

FAS Data Block: 00 06 08 19 03 19 00 00 01 35 32 17 62 52 A7 12 98 BF 82 DD 26 1F C5 D9 FE C7 9D FC F4 01 2C 01 68 4D C8 FA D1 10 2A 4D

CYKF25.pro

Figure 1 - Procedure Definition Utility

The utility performs the integrity checking described earlier (the output of this function is shown in Figure 2), and generates a file that defines the procedure for use in the airborne system.



```
Data Integrity Verification - Kitchener/Waterloo (CYKF) 25
Procedure Definition and Verification Utility Version 1.01

Verifying Leg MAPEM-LIBIL
  Track confirmed
  Distance confirmed
Verifying Leg LIBIL-DAXUN
  Track confirmed
  Distance confirmed
Verifying Leg DAXUN-KIVIN
  Track confirmed
  Distance confirmed
Verifying Leg KIVIN-RW25
  Track confirmed
  Distance confirmed
Verifying Leg RW25-ERDEG
  Track confirmed
  Distance confirmed
Verifying Leg ERDEG-GOPON
  Track confirmed
  Distance confirmed
Verifying Leg OMTED-LIBIL
  Track confirmed
  Distance confirmed
Checking MAPEM-GOPON link:
  Confirmed
Checking OMTED-GOPON link:
  Confirmed
FAS Block CRC Verification: Passed (D1100A4D)
```

Figure 2 - Integrity Check

In-flight software

To support flight validation, a special version of the avionics database containing the procedures to be commissioned is generated. This database is loaded into the Flight Management System (FMS), which the aircrew uses for guidance during the mission.

On the flight inspection system computer located in the cabin is the flight validation software application (although this could also be run on a carry-on computer, like a laptop). The operator loads the procedure definition file, and the integrity check is performed again. This fulfils the requirement to verify leg tracks and distances, and the FAS CRC.

The system then begins to record data – aircraft position, track, ground speed, current waypoint, distance, cross-track error, horizontal and vertical protection levels, etc.

Document 8071 indicates that data recording is not necessary, but Document 9906 seems to suggest that it is. In any event, the electronic recording of flight data during a mission is helpful to support investigation if anomalous behaviour is observed, and to provide evidence that the validation was conducted properly in the event of a subsequent query or audit.

During the flight, the FMS outputs its current flight plan on an ARINC 429 interface, consisting of the name and coordinates of each waypoint in the procedure. These are compared with the values contained in the procedure definition file. This achieves the "avionics waypoint accuracy" requirement described above.

Figure 3 shows an example of this function during a validation flight.

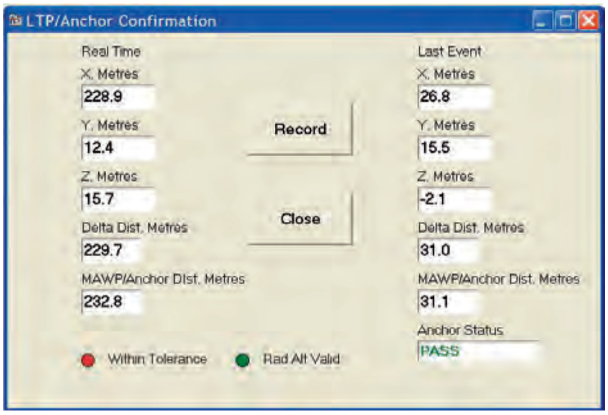
Waypoint	Status
RIGOT	PASS
TARTI	PASS
RW34	NOT CHKD
SEKEM	FAIL

Figure 3 – Avionics Waypoint Accuracy

For approaches, the aircraft is flown over the reference point, usually the threshold. The operator presses a key, and the system compares its current position (corrected for the radio altimeter height above ground) to the value in the procedure definition file. Interpolation between position fixes enhances the resolution of this check. This provides an automatic confirmation of the reference point.

Figure 4 shows an example of this capability. The operator presses "Record" at the instant that the aircraft's GPS antenna is over the reference point, and the "Last Event" column on the right is populated. The "Real Time" column displays the current position of the aircraft.

The aircraft may also be taxied to the reference point, but in this case, the pilot positions the aircraft so that one wingtip is over the point and the GPS antenna is on the runway centreline. The system automatically adjusts the aircraft's position to compensate the wingspan.



	Real Time	Last Event
X, Metres	228.9	26.8
Y, Metres	12.4	15.5
Z, Metres	15.7	-2.1
Delta Dist, Metres	229.7	31.0
MAWP/Anchor Dist, Metres	232.8	31.1

Anchor Status: PASS

Figure 4 - Survey Accuracy Confirmation

If the survey reference point is not situated at the runway threshold, then a special leg is defined in the procedure definition utility that links the point to a waypoint in the procedure.

During the validation mission, the GPS and SBAS status is displayed to the operator, as shown in Figure 5. Outages or losses of service are recorded and provided in a post-mission report.

WAAS SENSOR

WAAS I/F Status: OKAY
UTC Time: 21:02:37
Sats Tracked: 12
Sats Used: 12
Latitude: 51.069689
Longitude: -114.377302
WGS84 Ht, m: 1363.75
Geoid Ht, ft: 4531
HDOP: 0.7
VDOP: 1.3
HPL, m: 9.3
VPL, m: 14.8
TK, T: 359
Groundspeed, kts: 130

NAV DATA (IOC)

IOC I/F Status: OKAY
Latitude: 51.069603
Longitude: -114.377289
Baro Alt, ft: 4558
Rad Alt, ft: N/A
To Wpt: IBW01
Wpt Brg, T: 265
Distance, NM: 22.00
DTK, T: 089
XTE, NM: +1.33
MagVar: 15.5 E

SESSION

Airport: Calgary/Springbank
Ident: CYBW
Runway: 34
Log File Name: CYBW34 Log.txt
Report File Name: CYBW34 Report.txt
Data File Name: CYBW34 Data.txt
Data Recs Written: 3
Event Number:

Figure 5 - In-Flight Software (Main Window)

CHALLENGES

Survey Accuracy Check

Annex 10[4] specifies an accuracy requirement of better than 1 metre horizontally, and 0.25 metre vertically. Unfortunately, the only way to confirm that this is met is to perform another survey. However, in practice, it is usually sufficient to review the survey report for solution convergence and goodness-of-fit indicators, and then, during the flight validation, to taxi or fly the aircraft over the point of interest, and compare the GNSS position to the surveyed coordinates. This will not detect sub-metre discrepancies, but will reveal gross errors in survey technique or data transcription.

The accuracy of this technique is quite high when the aircraft is on the ground, but is decreased somewhat when the aircraft overflies the reference point. It is a function of the reaction time of the operator, the resolution of the computer timer, and the speed of the aircraft. Currently, a simple 3-D (2-D for LNAV-only approaches) position comparison is performed, although separating the error into along-track and cross-track components, and relaxing the tolerances of the former, while tightening the latter, might yield better results.

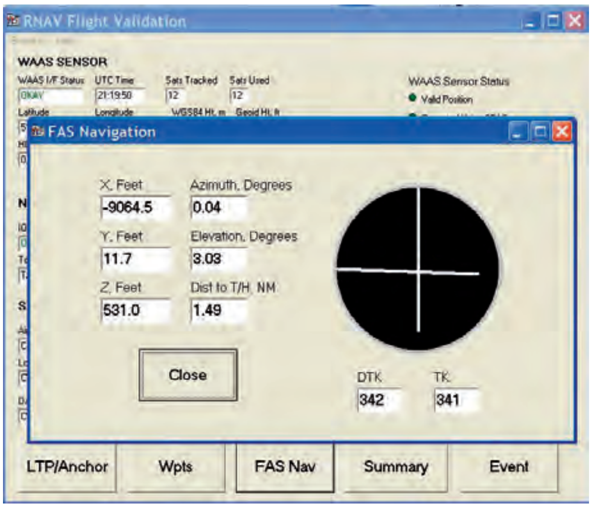
LPV FAS Data Block

The 40-byte FAS data block used for LPV approaches is designed to ensure the highest level of data integrity. Operationally, it is retrieved by the avionics, the CRC is calculated to detect corruption, and the various parameters contained in it are used to define the path through space, from which lateral and vertical guidance are provided to the pilot. For flight validation, this means that either one has to develop a system to decode the data block and generate the necessary guidance, or to find a method to get the data into commercial avionics database.

NAV CANADA has used both these techniques, but recently has opted to use the latter exclusively. We have an arrangement with our database provider to supply us with special FMS databases containing the procedures to be commissioned. Once we have completed the flight validation, then the approaches are transferred to the public database for general use.

One unfortunate characteristic of the design of commercial avionics is that it is impossible to view or output the CRC of the FAS data block. Thus, it becomes difficult to ascertain if the database contains exactly the version that was coded. To compensate for this shortcoming, the FAS data block from the procedure definition file is decoded by our in-flight software, and lateral and vertical guidance information are displayed to the operator during the intermediate and final segments of an LPV approach. As the approach is flown, the guidance is monitored, and a comparison is made with the information being presented to the pilots from the FMS. Divergence between the two guidance sources indicates a mismatch between the procedure definition file FAS data block and that in the FMS database.

Figure 6 shows the FAS guidance monitor.



WAAS I/F Status: OKAY
UTC Time: 21:19:50
Sats Tracked: 12
Sats Used: 12
WAAS Sensor Status: ● Valid Position

X, Feet: -9064.5
Azimuth, Degrees: 0.04
Y, Feet: 11.7
Elevation, Degrees: 3.03
Z, Feet: 531.0
Dist to T/H, NM: 1.49
DTK: 342
TK: 341

Figure 6 - FAS Guidance Monitor

CONCLUSIONS

The proliferation of RNAV instrument flight procedures has resulted in greatly increased availability of airports that could not previously be accommodated by traditional ground-based navigation aids.

In Canada, where a program is underway to replace ILS equipment across the country, the new systems do not provide a back course, and these approaches are being replaced with GNSS-based procedures, often with lower minima.

Where SBAS services are available, LPV approaches provide ILS-like guidance down to minima as low as 200 feet, and the accompanying vertical guidance has been shown to reduce workload and the incidence of controlled flight into terrain[5].

While the design of GNSS-based RNAV procedures is similar to those that are based on traditional navaids, the in-flight pre-commissioning checks are considerably different, both in philosophy and method. Fortunately, the task of GNSS flight validation can be performed at a lower cost, and using minimally-equipped aircraft.

When developing processes for RNAV flight validation, it is important to understand the objectives and the rationale for each, and to establish systems and procedures to ensure that every published procedure meets the most rigorous standards for accuracy, integrity, and safety.

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Flight Validation with complex judgment RNP AR procedure in JAPAN

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Abstract

These days, the navigation performance of aircraft has been upgraded significantly. As a result, we can introduce new flight procedures into the complicated airspace in which it was occasionally difficult to use signals from ground-based navigation facilities due to the limited coverage, and the needs to PBN flight procedures, particularly RNP-AR, are getting higher all over the world. Therefore, ICAO is now developing documents concerning Flight Validation to ensure the safety and quality of a high-performance instrument flight procedure.

Under these circumstances, JCAB started studying about Flight Validation in 2009 to establish Flight Validation system. Following the investigation, we developed criteria for Flight Validation and trained our staff who might be engaged in the new task, and then we just started Flight Validation activities in 2011 in addition to flight inspection activities.

In this presentation, we will talk about how we have prepared new duties. Also we will explain unique cases with specific examples we encountered during our validation activities. We assume those cases to be peculiar to PBN world and we believe we had never met the same situation in Flight Inspection world. We hope we can frankly exchange opinions on our activities with audience who will introduce Flight Validation scheme or has already started same duties.

1. INTRODUCTION

The quality of procedure design and other data in RNAV procedures are much important compared with those in conventional procedures.

Especially, for the higher required navigation accuracy like RNP-AR procedures, the more detailed evaluation is required to guarantee the safety of flight.

So far, not many countries have introduced RNP-AR procedures, we will present our effort in starting flight validation in Japan. It is our pleasure that we can share knowledge and experience in flight validation activities.

2. PREPARE FOR FLIGHT VALIDATION

JCAB planned to introduce the first RNP-AR approach in Tokyo international airport, and in 2009, flight inspection division started investigating how to validate RNP-AR procedures.

2.1 Development of flight validation manual

As we have to know what kind of items we should evaluate for validating instrument flight procedures (IFPs), we started investigating international regulations and activities on flight validation in other countries and ICAO. We referred to the rules or regulations listed on the table below.

Table. 1

ICAO	● Doc8071 ● Doc8168 (PANS-OPS) ● Doc9613 (PBN Manual) ● Doc9906 (QA Manual) *DRAFT*
FAA	● O8200.1C (Flight Inspection Manual) ● N8260-66 (FV of PBN and WAAS IFP) ● TI8200.52 (Flight Inspection HANDBOOK) ● AC90-101 (APPROVAL GUIDANCE for RNP SAAAR)
EURO	● Guidance Material for the Flight Inspection of RNAV Procedure ● Guidance Material for the Validation of RNAV Procedure
CAA (UK)	● DAP policy Statement Validation of IFP
CASA (AU)	● Manual of Standards, Part 173 Standards Applicable to Instrument Flight Procedure Design

We sent our pilots to FAA and observed how FAA validates RNP-SAAAR procedures and learned following things.

- ✓ How to evaluate flyability of IFPs.
- ✓ What kind of tools are used in validation activities
- ✓ The data flow from procedure design to publication and the contents made by procedure designers
- ✓ How to prepare navigation database for FMS used in flight validation
- ✓ Training and check for flight validation pilots(FVPs)

We also continued to follow the draft QA manual (ICAO doc.9906 vol.5 and vol.6) discussed by IFPP.

After completing our research on flight validation, we revised our manual in 2011. This revision includes items to be evaluated, criteria and procedures of flight validation. We defined flight inspection and flight validation as definitely independent activities in our manual. The items to be evaluated and the criteria are below. (table.2)

Table. 2

Items	Criteria
Charting	✓ Information on the chart is correct. ✓ Necessary information is shown legibly and pilots can easily understand it without misinterpretation. ✓ Terrain and obstacles are depicted in correct position.
Navigation Data	✓ The route shown on the navigation display is consistent with that depicted in the chart. ✓ Course and distance of each leg calculated by the FMS are; ✧Course: Charted value ±1[deg] ✧Distance: Charted value ±0.1[NM]
Obstacle	✓ Obstacle clearance is enough as specified in the design criteria.
Flyability	✓ There is no factor that might cause human error, and the procedure might not require pilots an excessive attention. ✓ The procedure might not require pilot's excessive controls nor judgments.

	✓ The procedure should be flown safely and properly with auto-pilot coupled with aircraft navigation system. ✓ TAWS alert does not occur
Infrastructure	✓ All infrastructures required for the procedure satisfy flight inspection criteria. ✓ Lighting facilities can be clearly visible and pilots may not confuse them with civil lights. ✓ Runway marking should be properly visible.

2.2 Training for FVPs

FVP should have the abilities to verify the quality of IFPs. In addition to the knowledge and skills in flight inspection, knowledge in Doc.8168 (PANS-OPS), Doc.9613 (PBN Manual), ARINC424 coding and geodesy will be required.

To set up a new syllabus for flight inspection pilots to give them these knowledge and skills, we surveyed standards on training for FVPs in other countries.

a) Survey on international standards

Documents we referred are listed on table.3.

Table. 3

ICAO	● Doc.8168 (PANS-OPS) ● Doc.9906 (QA Manual) draft
FAA	● N8260-67 (FV of PBN and WAAS IFP) ● O8240.3B (Certification of Flight Inspection Personnel) ● O4040.3A (Flight Inspection Proficiency and Standardization Evaluation Program) ● TI4040.57B (Flight Inspection Training Manual)

We sent two pilots to FAA and made them take a training course, “Flight validation of satellite-based performance-navigation IFPs”. The contents of the course are,

- ✓ Outline of PBN and the difference between conventional procedures
- ✓ Validation of ARIN424 navigation data and path-and-terminators
- ✓ Outline of ground validation, simulator evaluation and obstacle assessment
- ✓ Outline of flight validation, requirements for FVP
- ✓ Requirements for validation aircraft, training program

b) Training program

We arranged our initial and recurrent training program for flight inspection pilots and added new items required for flight validation. (table.4) The recurrent training is aimed to make FVPs catch up with new technology and change of criteria in procedure design.

Table. 4

No.	Contents
1	Flight validation and flight inspection
2	AIS (outline)
3	WGS84 (outline)
4	PBN concept
5	Geodesy (outline)
6	ATM (outline)
7	IFP design (outline)
8	Aerodrome (outline)
9	Quality assurance (outline)
10	ARINC424 coding (outline)
11	Aeronautical chart
12	FOSA (outline)
13	Human factor (outline)
14	Aircraft operation/performance
15	Simulator evaluation
16	Documentation for the results of flight validation

Flight inspection pilots already have a lot of knowledge and experience in IFPs, so we established our training course to fit these personnel. After completing the initial course, all of flight inspection pilots will be able to conduct flight validation.

2.3 Introducing the tool for IFP validation

As ICAO Doc.9906 vol.5 (Draft) requires us to conduct simulator evaluation for RNP-AR IFPs, JCAB had to introduce some tools that satisfy these requirements.

The benefits of introducing validation tools are,

- ✓ Possible to set various flight conditions (temperature, wind etc.)
- ✓ Possible to specify hazards prior to actual flight
- ✓ Possible to evaluate lateral and vertical track deviation

- ✓ Possible to conduct evaluation any time and repeatedly without interrupting congested schedule of simulators used for flight crew training.

Required function for validation tools

Table. 5

1	FMS and Control Display Unit (CDU) work with the same navigation database used in actual aircraft
2	Cyclic redundancy check (CRC) available
3	Navigation Display (ND)
4	Flight characteristics and aircraft performance of specific type of aircraft
5	Flight director and auto-pilot
6	Navigation system works same as actual aircraft
7	Systems that affect flight characteristics can be operative
8	Able to set wind direction / speed
9	The ability for flying RNP-AR procedures
10	TAWS (equivalent to Class-A TAWS)
11	FTE indication
12	Simulates the effect of thrust, drag, altitude, temperature, aircraft weight and C.G.

The visual system, motion system, cockpit sound and handling quality on the ground are not necessary for flight validation.

2.4 Candidates for validation tool

There are three types of tool to be used for flight validation.

a) Full Flight Simulator (FFS)

FFS simulates aircraft performance, flight characteristics and flight deck layout completely. Though it is closest to the actual aircraft, the cost for introducing and operating is much higher than other tools.

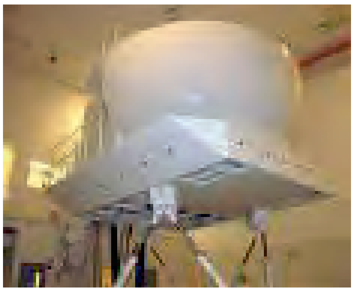

Fig. 1 FFS

b) **Integrated Procedures Trainer (IPT)**

IPT simulates physical layout in flight deck and aircraft systems to make pilots familiarize cockpit procedures. Although it has no visual system, it is possible to fly and evaluate flight path using FMS, autopilot and navigation display.

Fig. 2 IPT

c) Desktop simulator

This is a PC-based simulator that simulates most of all aircraft systems, performance and flight characteristics. Because the flight characteristics are based on the data provided by aircraft manufacturer, the behavior of aircraft steered by autopilot coupled with navigation systems is simulated faithfully. Though it has no visual system, all systems in the cockpit can be shown and controlled using a mouse. It works with the same software as it is used in a FFS.

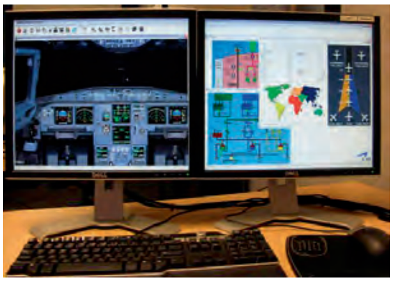

Fig. 3 Desktop Simulator

We finally chose a B737-800 desktop simulator because it satisfies all of our request at the lowest cost. B737-800 is the most popular aircraft that will fly RNP-AR in Japan.

2.5 TAWS function

As default, desktop simulator does not have TAWS function, we customized and added it TAWS Class-A function. (fig.4)

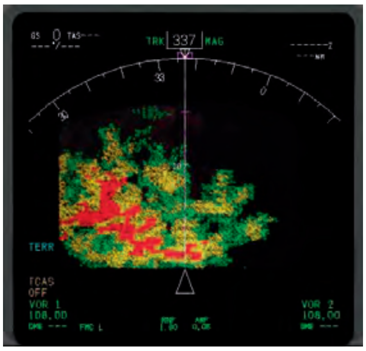

Fig. 4 Terrains on Navigation Display

2.6 Tools for making custom navigation database.

The most challenging thing in introducing validation tools is making custom navigation database for new procedures. Because it takes too much time (about two months) to complete simulator evaluation if we order tailored procedures to the data packer (i.e. FMS manufacturer), we introduced a computer program that would make us possible to edit and pack navigation database including tailored procedures by ourselves.

Fig.5 shows the flow of coding and packing data for simulator evaluation.

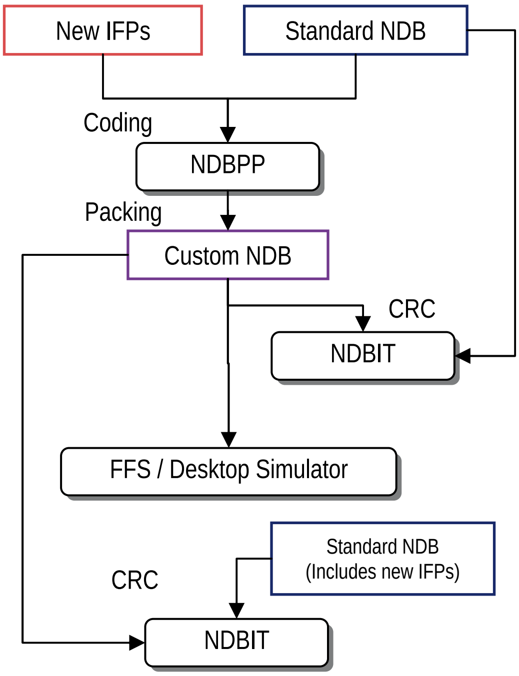

Fig.5 Custom Navigation Database

a) NDBPP (Navigation Database Packing Program) / This is a computer program that GE Aviation has developed to edit and pack navigation database for flight management system.

b) NDBIT (Navigation Database Inspection Tool) / This is computer software that GE Aviation has developed to compare two databases using CRC. We can find the difference between custom database and standard database.

c) Standard NDB
We use standard NDB (ARINC424 coded) provided by JEPPESEN. It includes standard (published) airports, NAVAIDS, airways and IFPs that are necessary for flight management computer.

3. The activities for validation

Fig.6 shows the validation process for RNP-AR in Japan.

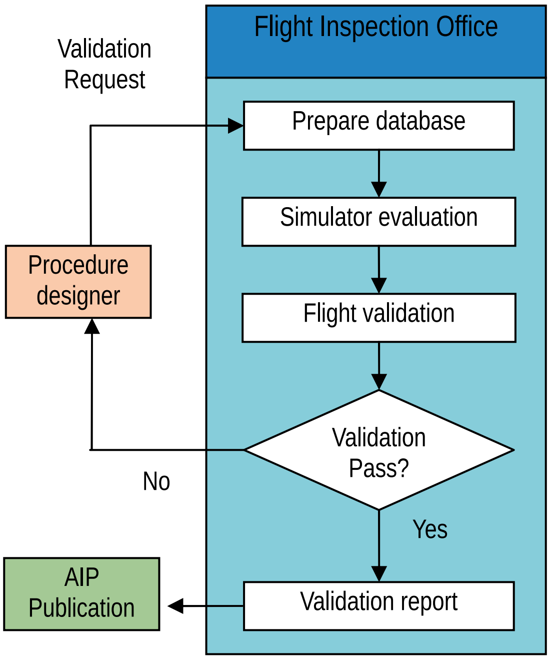

Fig. 6 Validation Process

Following evaluations are conducted during simulator evaluation and flight validation.

a) Chart Evaluation

The chart evaluation is divided into "before" flight item and "during" flight item. The chart evaluation before flight is to confirm there is no error in write, and the chart is in accordance with the standards. During flight, pilots asses if it can be understood easily and there is not misleading representation. Also we make sure that the obstacle information in the chart does not differ from the actual obstacle.

b) Navigation Database Evaluation

The new IFPs are coded into ARINC424 format

and packed together with standard data by NDBPP. The packed NDB is then decoded to text format by NDBIT and is confirmed it does not have a typo, coding errors, nor a lack of necessary data.
Therefore the check is done by comparing the printed data, it has the chance to make an error. The goal is to eliminate manual procedure throughout data handling.

c) Obstacle Evaluation

Obstacle evaluation is done through an actual flight. We compare actual obstacles with the information depicted in the aeronautical chart or documents provided by a procedure designer.

d) Flyability

The assessment for flyability is done in simulator evaluation and/or actual flight. We defined that flyability consists of two factors, namely, technical factors and human factors. In the simulator evaluation, we mainly evaluate the technical factors, and in flight validation we evaluate human factors.

- ✓ Technical factors
  For example, bank angle in an RF turn, flight technical error and TAWS alerts.

- ✓ Human factors
  For example, procedure complexity, cockpit workload and possibility of misunderstanding.

4. FLIGHT VALIDATION IN ACTUAL FLIGHT

JCAB has implemented 8 RNP-AR procedures at 5 airports (Tokyo international airport, Odate-Noshiro airport, Hakodate airport, Kochi airport and Kitakyushu airport). We will introduce our efforts in flight validation activities for implementing RNP-AR approaches.

4.1 Tokyo international airport (RJTT)

RJTT RNAV (RNP) RWY23 approach was the first RNP-AR procedure in Japan.
At that time we had no suitable tool for validating RNP-AR procedures, we used Japan Airlines' FFS.
As RJTT is located on Tokyo bay, there is no significant obstacle around the airport. Implementing RNP-AR approach in RJTT is intended for noise avoidance. Like other airports in large city, limited airspace is available for the procedure designers.

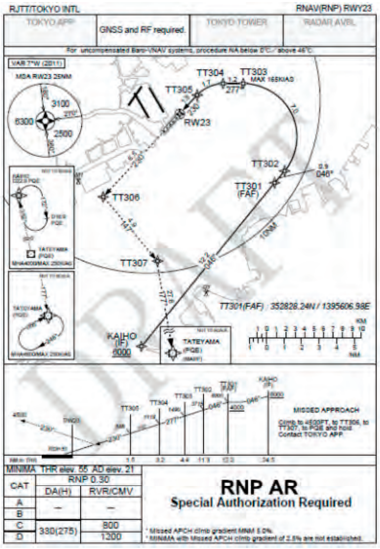

Fig. 7 RJTT RNAV (RNP) RWY23 approach

RNP-AR for RWY23 was designed within Tokyo bay. Designed procedure was sent to Jeppesen and coded into ARINC424 format, packed into loadable format for B737's FMS. After checking the data in the custom navigation database, we load it with the FMS on FFS.
The first thing we had to do was to compare the procedure depicted on the navigation display with the approach plate and check each leg's data (magnetic course and distance, altitude constraint and speed restriction) on the CDU.
Prior to the simulator evaluation, flight conditions to be evaluated must be determined. The flight conditions used were the worst case in the procedure design criteria.

Our points of focus were,

- ✓ Maximum bank angle in the RF turn with maximum tail wind
- ✓ Maximum flight technical error (FTE) at start and end points of RF leg
- ✓ Timing of leg transition
- ✓ Stability from final rollout point (FROP) to missed approach point
- ✓ Human factors
- ✓ Cockpit workload
- ✓ Possibility of human error

Table.6 shows the flight conditions for 12 trials in simulator evaluations.

Table. 6

Nr.	Validation Item	TEMP	Wind Dir.	IAS [kts]
1	All Item	ISA	135	Normal
2	All Item	ISA	315	Normal

3	All Item	ISA-35	225	Vref+10
4	All Item	ISA+25	050	Normal
5	All Item	ISA-35	135	Normal
6	Lateral Deviation	ISA	225	250/165/200/230
7	Lateral Deviation	ISA	180	250/165/200/230
8	Lateral Deviation	ISA	135	250/165/200/230
9	Lateral Deviation	ISA	095	250/165/200/230
10	Lateral Deviation	ISA	050	250/165/200/230
11	Lateral Deviation	ISA	005	250/165/200/230
12	Lateral Deviation	ISA	315	Normal

In trial 1 through 5, we evaluated technical and human factors using normal approach speed. In trial 6 through 12, we evaluated only technical factors with maximum approach speed assumed in procedure design.
Winds were selected so as to give worst case in RF turns, and highest/lowest temperatures were also evaluated.

Result of simulator evaluation

In trial Nr.9, though we expected it as the worst case for FTE at the end of the second RF turn, the result was only 0.05[NM].

Table. 7

Trial Nr.	Evaluation item	Max value	Location
9	FTE on RNP 0.3 segment	0.05 nm L	just after the second RF turn
4	FTE on RNP 1.0 segment	0.11 nm R	during Fly-by turn on missed approach course
6	Bank Angle on RF leg	20 °	just after the first RF turn

In trial Nr.10, flight time between FROP and DA measured exactly 15[sec]. This means that the procedure was designed properly.

Pilot's comments on every trial showed that this approach procedure had no factor of unsafe and difficulty to fly

The only thing to be mentioned was that we observed FTE 0.02[NM] left of course after the FROP, and it continued until DA under strong wind from the east. We never experienced such tendency on final approaches of ILS or Baro-VNAV having enough length in straight segment.
We presume that flight director and auto-pilot tried to keep aircraft slightly upwind under strong wind, and the leg after RF turn was not long enough to correct the error.

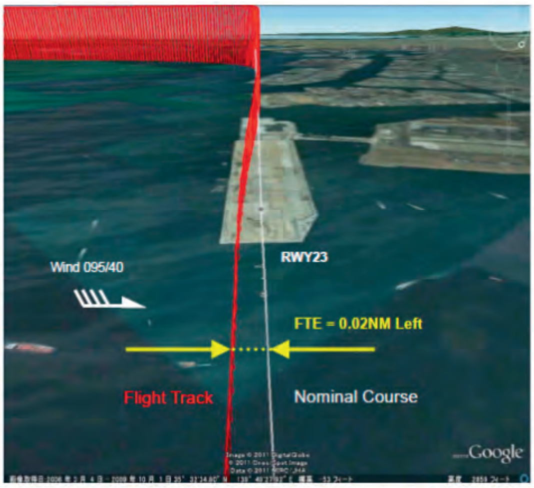

Fig. 5 FTE to the upwind on final

The weight and temperature did not give significant impact on the result of the evaluation.

Flight validation

JCAB has upgraded the FMS of flight inspection aircraft (DHC8-300) to fly RF turns and evaluated basic flyability (cockpit workload) and obstacle clearance.

Assessment of desktop simulator

The data obtained in evaluation with FFS were also used in assessment of the desktop simulator.

We did the same thing with our desktop simulator and compared the results.

In various conditions, the flight tracks obtained by our desktop simulator were quite similar to those by the FFS. In the simulator evaluation, it is important that the tendencies of flight track, FTE value, bank angle and the behavior of FMS and auto-pilot are close to those of actual aircraft and the results are repeatable.

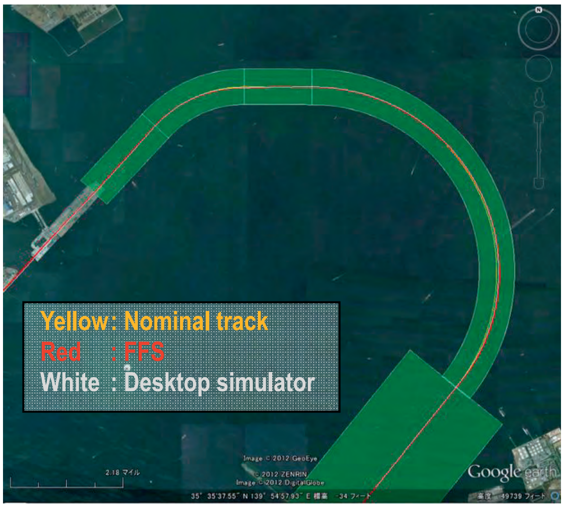

Fig.9 Flight track of the desktop simulator and FFS (overall)

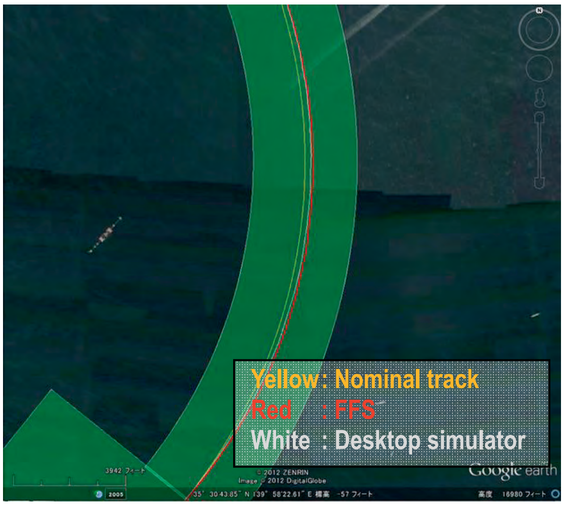

Fig.10 Flight track of the desktop simulator and FFS (RF leg1)

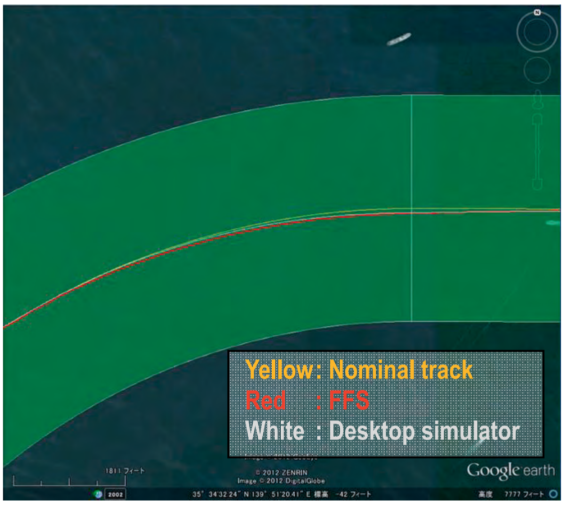

Fig.11 Flight track of the desktop simulator and FFS (RF leg2)

The desktop simulator did a good job and we concluded that it was worth using for simulator evaluation.

4.2 Kochi Airport (RJOK)

RJOK RWY14 had no instrument approach procedure due to the terrain on the north quadrant of the airport.
As the sea breeze forces pilots to make circling approach, two RNP-AR approaches (RNAV (RNP) Z and RNAV (RNP) Y) with RF leg were designed.

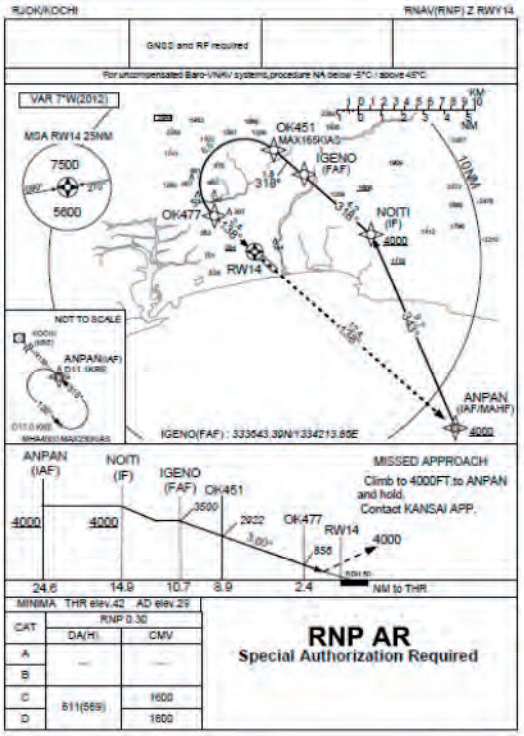

Fig. 12 RJOK RNAV (RNP) Z RWY14

Simulator evaluation

The designs of these two approaches were not so challenging that our interest was only if TAWS alert would be activated or not.

Simulator evaluations were conducted with maximum airspeed (165KIAS) in RF leg over mountainous area, but there were no TAWS alert during approach. Table.8 shows the flight conditions in 5 trials.

Table. 8

Nr	Temp	Wind Dir	IAS [kts] IAF~/FAF~/MAPt~/Holding
1	ISA+30	140	250/165/200/250
2	ISA-20	140	〃
3	ISA+30	320	〃
4	ISA-20	320	〃
5	ISA+30	050	〃

Flight Validation

Flight validation was conducted using DHC8-300 aircraft. Table.9 shows the flight conditions in 3 trials.

Table. 9

Nr	VPA (assumed temp)	Airspeed
1	ISA	Normal Approach Speed used in DHC-8
2	ISA-20	Normal Approach Speed used in DHC-8
3	ISA	165KIAS

During trial Nr.3, TAWS alert had occurred twice as described below.

First activation:
"TERRAIN" caution message followed by "PULL UP" warning message at the midpoint of RF leg

Second activation:
"CAUTION TERRAIN" caution message at almost the end of RF leg.

After analyzing the record of radio altitude, it was revealed that sudden decrease in radio altitude occurred and the closure rate was up to 6,000 [ft/min].

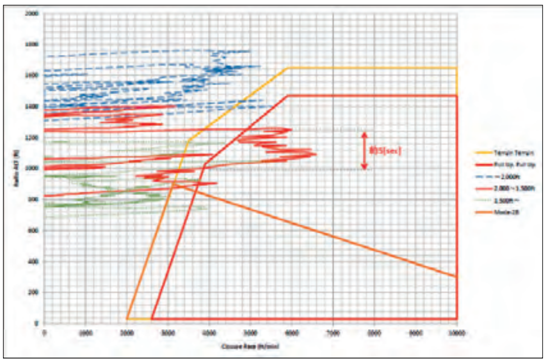

Fig. 13 Radio altitude and closure rate

The first activation was MODE-2A caused by rapid changes in radio altitude. TAWS will alert when the aircraft penetrates the MODE-2A envelope if the aircraft is not in landing configuration. In this case, TAWS activation can be avoided by making landing configuration before FAF.

The second activation was made by "LOOK AHEAD" function. In trial Nr.3 we flew the lowest path assuming the lowest temperature used in procedure design with maximum airspeed (165KIAS).

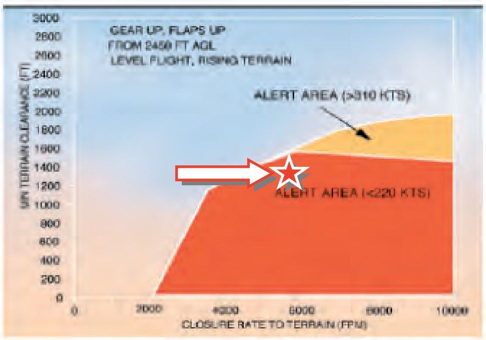

Fig. 14 Mode-2A envelope

We concluded that both TAWS activations can be acceptable because they will not occur in the real world if aircraft is operated with normal procedures.

4.3 RNAV1 arrival for RJOK

JCAB uses desktop simulator for evaluating RNAV1 procedures in addition to RNP-AR procedures, if necessary.

Though YOSAKOI WEST RNAV arrival had already been used as an arrival route for ILS RWY32 approach, the speed restriction was revised to connect to the new RNP-AR procedure.

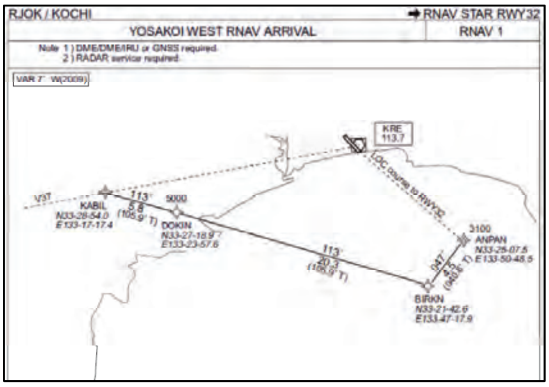

Fig. 15 YOSAKOI WEST arrival

We determined that the flight validation would not be required because there was no change in flight route, and the altitude constraint was changed to the higher.

But the leg length from BIRKN to ANPAN looked short comparatively (fig.15), we conducted evaluation with the desktop simulator.

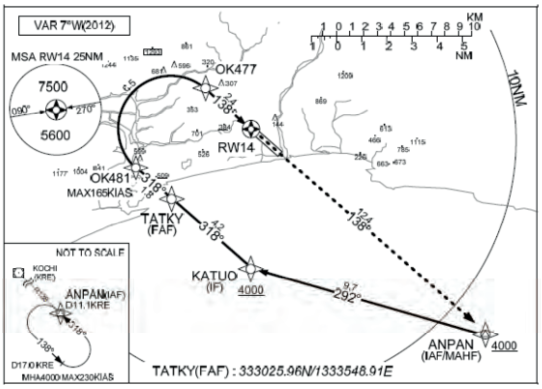

Fig. 16 RNAV (RNP) Y RWY14 approach

Under maximum tail wind (60[kts] at 4,000[ft]) on the leg to ANPAN, the following phenomenon were observed.

- ✓ The FMS bypassed the leg “BIRKN-ANPAN”. (fig.17)
- ✓ The FMS overshot the leg “ANPAN-KATUO”. (fig.18)
- ✓ The indication of FTE shown for flight crew maintained almost “zero”.

```
MOD RTE   LEGS      1/3
 HOLD AT  1.0NM
KABIL          189/ 8000
  112°    5.8NM
DOKIN          240/ 5000A
  113°    20NM
BIRKN          210/ 8000
  48°     3.7NM   BYPASS
ANPAN   <CTR> 210/ 4000A
  300°    13NM
TATKY          139/ 3500
-----------------MAP CTR
<ERASE             STEP>
```

Fig. 17 “BYPASS” indication on CDU

Under strong tail wind, the FMS bypassed the leg to ANPAN even at the airspeed of 180[KIAS]. At 230[KIAS] with 60[kts] tail wind, lateral deviation from the nominal track grown up to 2.1[NM] For these reasons, we determined that when aircraft uses YOSAKOI WEST arrival, RNAV (RNP) Z approach should be used.

This example shows that even procedures were designed in accordance with procedure design criteria, some aircraft cannot follow the expected track under certain condition.

Fig. 18 Flight tracks (190[kts] and 230[kts])

Evaluation using a simulator that simulates real aircraft systems is effective in determining issues that could occur in actual aircraft operations.

4.4 Kitakyushu airport (RJFR)

Like Tokyo international airport, RJFR was constructed on the reclaimed land in the sea. But the airspace is quite limited because the airport is located between RJFZ and RJOZ. Avoiding these control zones, RNP-AR approach procedure was designed for each runway.

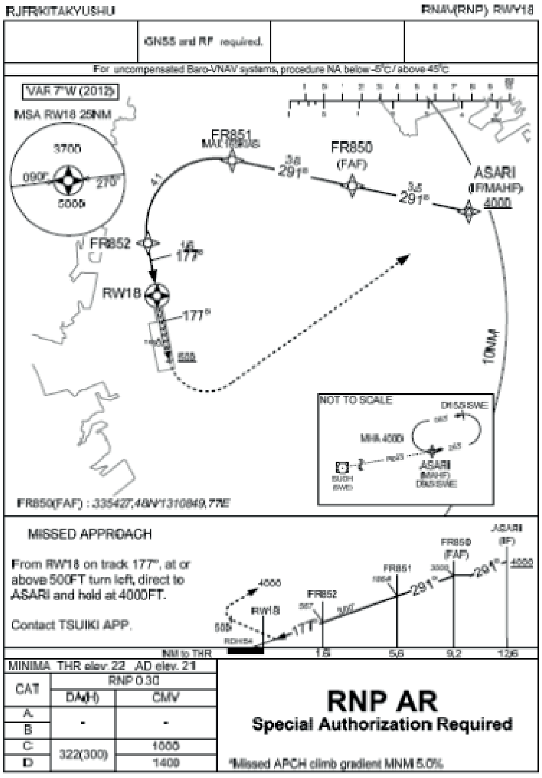

Fig. 19 RJFR RNAV (RNP) RWY18 approach

To minimize the area for missed approach segment, the procedure designer used FA (Fix to Altitude)-DF (Direct to Fix) leg in the missed approach segment.

Because the timing of starting turn is defined by altitude, and the course to the missed approach fix is not defined, we expected that the track would vary with climb gradient, and the wind would affect the track a lot.

Simulator evaluation

Table.10 shows the flight conditions in 6 trials.

Table. 10

Nr	Validation Item	Temp	Wind Dir.	Wind Speed[kts]	IAS [kts]
1	RF turn	ISA-20	110	60/25 (@4,000/SFC)	250/165/ 200/250
2	RF turn	ISA+30	110	60/25 (@4,000/SFC)	250/165/ 200/250
3	M.Apch	ISA+30	No wind		250/V_{REF}/ 190
4	M.Apch	ISA+30	No wind		250/V_{REF}/ 190
5	M.Apch	ISA-20	180	60/25 (@4,000/SFC)	250/V_{REF}/ 190
6	FROP~	ISA	360	15	250/165

Trial Nr.1 and 2 were for assessing RF turn. Trial Nr.3 through 5 were for the missed approach segment. Trial 6 was to measure the time between FROP and DA.

ASARI (IF) to DA

The deviation from the nominal track was small enough and the bank angle during the RF turn also satisfied the criteria under the maximum ICAO wind condition.

Missed Approach Segment

As we expected, the flight tracks varied with airspeed, rate of climb and wind. Such combination of path-and-terminator will also be affected by the type of FMS, flight director, auto-pilot and flight characteristics. Operators should assess these effects with their aircraft and navigation systems.

Table. 11

Nr.	Flight method	Result
3	Final APCH: V_{REF30} (133KIAS) After DA: climb on V/S1000ft/min DA~ASARI: LNAV Mode	After passing RW18, intercepted to ASARI direct route with bank 30 degrees and overshoot(max 0.36NM)
4	Final APCH speed: V_{REF30} (133KIAS) After DA: climb on V/S1000ft/min DA~FROP: HDG Mode (Bank Limit15°) FROP~ASARI: LNAV Mode	When turning with HDG Mode, greatly overshoot (max1.25NM)
5	Final APCH: V_{REF40} (120KIAS) After DA: climb on V/S2000ft/min DA~ASARI: LNAV Mode	After passing through RW18 intercept to ASARI direct route without overshoot with bank angle 30 degree

Fig. 20 Overshoot during missed approach

Fig. 21Tracks in trial 4 and trial 5

Flight validation

There was no remarkable result for the flight validation.

4.5 Report result of the validation

After completing validation, we report the result to the procedure designer and the secretariat of FOSA.

The procedure designer prepares documents necessary for AIP publication.

The validation pilot responsible for the IFP checks published documents and finishes validation process.

5. CONCLUSIONS

JCAB has designed and validated 8 RNP-AR approach procedures in 5 airports. Through the activities in validation process we learned,

- Under designed wind limit, RF turns are repeatable and aircraft can keep flying center of the course
- Although the flight validation is essential for evaluating workload and obstacles, it is not always necessary for minor amendments in the procedure design.
- Except for procedures established over the sea, the verification of TAWS activation by both simulator and actual flight is required

The criteria in procedure design do not guarantee the appropriateness of IFPs. Like a trial in arrival route at RJOK, simulator evaluation will give us useful information.

Though simulators can simulate various conditions and make us possible to fly repeatedly, still some differences from actual flight exists. We cannot omit an actual flight because it is the only way to confirm the real world.

6. FUTURE WORK

Still we have a lot of factors in validation process that might cause human errors. Data exchange without manual input is mandatory for the quality of instrument flight procedures.

Oversight of 3rd Party Flight Validation Providers for Satellite Based PBN IFP

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ABSTRACT

Instrument flight procedures developed using conventional ground-based navigational aids have always demanded a high level of quality assurance during all phases of the implementation process, including that of flight inspection. Historically, such flight inspection within the National Airspace System of the United States has been accomplished by the government's Federal Aviation Administration (FAA). The implementation of PBN procedures and the associated demand to accelerate implementation of such type procedures has led to a need to expand authorization for Instrument Flight Procedure Validation (IFPV) of Performance Based Navigation (PBN) procedures to entities outside the government.

Although flight validation of PBN flight procedures does not require the same validation of signal strength as conventional ground-based procedures, these PBN procedures present an increased criticality of airborne data such as procedure coding and accuracy. A small error in data could lead to significant effects during actual operations. The IFPV process requires stringent guidance be provided for third-parties authorized to conduct such validations, including guidance for establishing an IFPV training program.

This paper addresses the FAA's implementation of the third-party IFPV program. It will also address providing the necessary oversight to ensure the safety of implementing new or revised PBN procedures that are developed, validated and maintained by third-party providers.

INTRODUCTION

Due to the significant benefits of satellite-based, performance-based navigation (PBN) instrument flight procedures (IFP), the United States Federal Aviation Administration (FAA) has made the proliferation of PBN procedures a cornerstone of its Next Generation Air Transportation System (NextGen). Recognizing the demand for these types of procedures, the FAA, in 2008, agreed to allow the development of Public-Use PBN procedures by non-governmental IFP development service providers. In order to ensure that third party procedures provided the same level of safety as all other public procedures, the FAA created an IFP Implementation and Oversight Office whose main responsibility was to safely integrate third party procedures into the National Airspace System. The oversight office quickly identified flight inspection as an element that needed significant attention. Flight inspection has always been performed by experienced flight inspection pilots and engineers in highly equipped flight inspection aircraft. In order to guarantee the safety of third party procedures, the FAA had to find a method to ensure that service providers could perform the same function to the same level of safety using personnel with less experience and aircraft with considerably less equipment. The solution was the creation of the Instrument Flight Procedure Validation (IFPV) program and a well defined and executed oversight system.

WHAT IS INSTRUMENT FLIGHT PROCEDURE VALIDATION?

IFPV is the final quality assurance step in the procedure development process for satellite-based PBN IFP. The purpose of IFPV is the verification of pertinent obstacle and procedural data as well as an assessment of the flyability of the procedure. IFPV is broken down into three elements: ground validation, preflight validation, and flight validation.

Ground validation consists of the quality assurance review of the proposed procedure. Subject matter experts in the field of satellite-based procedure development review the procedure's build and documentation for adherence to criteria. To ensure an unprejudiced review of the procedure, the FAA requires that ground validation be conducted by someone not directly involved with the procedure's development. The ground validation is a critical component of IFPV as it is the starting point for all other validation activities.

The next step in the IFPV process is the preflight validation. This step provides a preliminary review of the elements that will be evaluated during the flight validation. Preflight validation includes an onsite obstacle assessment to properly identify any obstacle data inaccuracies. Historically, flight inspection crews have provided this quality assurance step by identifying whether any obstacles penetrate an underlying surface of the procedure. Third parties have the option of conducting an airborne obstacle assessment according to the guidance provided to FAA flight inspection pilots. However, with IFPV, the organization also has the option to conduct a ground based obstacle assessment. The advantage of ground-based assessment is twofold. First, obstacle assessment performed from the ground reduces the overall amount of flight time required resulting in reduced procedure development costs. And second, the accuracy of the obstacle data can be significantly better when assessed from the ground. Airborne obstacle assessments provide an estimated accuracy of 50 feet vertically and 250 feet horizontally. By following an FAA approved ground based assessment method, obstacle data can be corrected to within 10 feet vertically and 20 feet horizontally. Because of the benefits of starting with the best possible data, third parties often elect to conduct a ground-based obstacle assessment prior to the procedure's development in order to ensure the most efficient flight path and lowest possible minimums.

The preflight validation step also includes a simulator evaluation. Due to the additional aircraft and crew requirements to conduct Required Navigation Performance (RNP) Authorization Required (AR) procedures, all RNP AR procedures are evaluated in a level C or D simulator for data accuracy and flyability. Since the procedure must be coded according to the manner described in the procedure documentation, simulator evaluation crews are able to identify potential coding errors or database anomalies. The simulator also provides an exceptional means to determine flyability throughout a wide range of weather conditions. Worst case winds can be programmed to determine the aircraft's ability to maintain the intended vertical path in a descent or lateral track in a Radius to Fix (RF) turn. Minimum temperatures can be programmed to assess the proximity to terrain. For example, The Terrain Awareness and

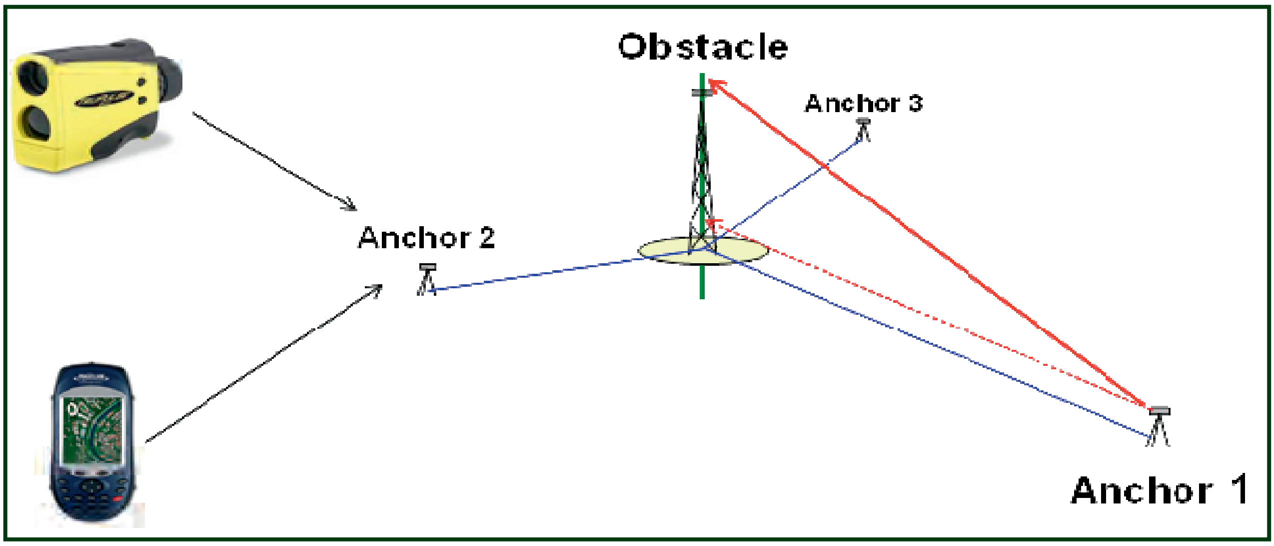

Figure 1. Example of an FAA Approved Method of Conducting Ground Obstacle Assessment

Warning System (TAWS) may generate an alert when the aircraft flies the procedure at the low temperature limit but not at the high temperature limit. By evaluating the procedures at the maximum allowable airspeeds, crews can determine the need for airspeed restrictions. Each simulator session is recorded and the flight parameters can be analyzed to determine how the procedure compares to the developer's intent. All of this information can be given to the procedure developer who can reevaluate the procedure and make corrections as appropriate. The simulator evaluation is the first and best opportunity to see weaknesses in the procedure design or the aircraft's capabilities and is an excellent method to identify data errors and flyability issues. Although simulator evaluations are required only for RNP AR procedures, the FAA recognizes the benefits and is conducting simulator evaluations of other types of IFP when special procedural design or operational conditions exist.

The final step in the IFPV process is the Flight Validation. Flight validation is the in-flight, on-speed, on-course evaluation of a satellite based IFP. Unlike flight inspection, which refers to the evaluation or "inspection", of ground-based navigation aids, flight validation focuses on the accuracy of the data that the onboard navigation equipment uses to provide the pilot with vertical and lateral track information. Where flight inspection crews are concerned with issues such as reference radial checks and frequency interference of rho-theta systems, flight validation crews are interested in issues like how the aircraft's Flight Management System (FMS) programs the vertical descent to maintain the desired path or whether the autopilot is able to maintain the intended course in an RF turn. In addition to validating the navigation database and evaluating the procedure's flyability, the flight validation pilot also conducts a controlling obstacle verification to provide the final assurance that the controlling obstacle has been correctly identified for each segment. The pilot will also verify that all airport infrastructure, such as runway markings, lighting, and communications, are in place and operative as defined in the appropriate FAA Flight Inspection Order.

HOW DOES THE FAA CONDUCT OVERSIGHT OF THIRD PARTIES?

As the IFPV program has grown, the FAA's oversight role has evolved. Initially the FAA's priority was to provide clear direction on how third parties could conduct IFPV. With multiple organizations requesting IFPV authorization, the FAA's focus has changed to managing IFPV program compliance. To provide FAA personnel with guidance for the authorization and oversight of third parties, FAA Notice 8260.66 was incorporated into FAA Order 8900.1, Flight Standards Information Management System. To increase standardization among third parties, the FAA published Advisory Circular (AC) 90-113, Instrument Flight Procedure Validation of Satellite Based Instrument Flight Procedures. The new guidance contained more detailed information concerning process approval, company authorizations, training, and individual authorizations. Concurrently, the FAA began developing a broad oversight program detailing all facets of third party procedure development. FAA Order 8260.57, Oversight of Third Party Instrument Flight Procedures Service Providers, defines how the FAA will conduct specific oversight functions like on-site surveillance, and periodic audits.

In addition to describing the IFPV program, current guidance provides information on how the FAA will authorize third parties to conduct IFPV. The first step to authorization is for third parties to document in an IFPV manual the processes and policies the company will follow when conducting each IFPV activity. The manual must contain general company information, like the credentials of personnel conducting IFPV work, documentation of personnel training, data transfer methods, and the company's process for maintaining the currency of regulatory and reference guidance material. The manual must also explain how the organization will accomplish each IFPV activity. For Ground Validation, the company must outline their internal review process explaining how they will ensure the accuracy of the procedure development and documentation. For Preflight Validation, the company must define how they will conduct Simulator Evaluations, including the process they will use to ensure the integrity of the procedure coding and how to evaluate flyability in various environmental conditions. They must also address their process for conducting Obstacle Assessments. Whether conducted in the air or on the ground, the organization must provide a step-by-step process for determining an obstacle's location and height. Concerning Flight Validation, the guidance requires that the company describe how they will conduct FV and how they will address incorrect obstacle data or flyability issues discovered during the FV. Since safety is the primary concern, each manual must describe the company's Safety Management System that defines the safety policies, processes and practices for managing the various aspects of each IFPV activity.

When an organization provides their IFPV manual to the FAA, the oversight office evaluates the proposed program for conformance with current IFPV guidance. This also gives the FAA an opportunity to assess the organization's understanding of the IFPV program and provide feedback to improve the company's program. For example, the FAA approves equipment and processes for Ground Based Obstacle Assessments that allow the procedure developers to improve obstacle accuracy codes. During the evaluation of the manual, the FAA can make equipment or process suggestions that will result in considerably better obstacle data, improving the quality of the procedure. Once the FAA approves the IFPV manual, a company specific LOA is issued stating that all IFPV work must be conducted in accordance with the processes described in the manual. Whenever the FAA conducts surveillance or audits the service provider, the manual is used to ensure that the service provider is adhering to their approved guidance.

After the company's IFPV manual is approved, the FAA will issue individual LOAs for personnel within the company. For the FAA to consider issuing an LOA, individuals must first meet the experience requirements defined in AC 90-113, this includes the completion of an FAA approved IFPV training course. LOAs are issued for Simulator Evaluation, Ground Obstacle Assessment, Airborne Obstacle Assessment, and Flight Validation. The FAA will issue an LOA for any combination of activities but the individual must satisfactorily demonstrate compliance with their company's manual and FAA requirements for each activity. Only aviation safety inspectors trained in IFPV and approved by the oversight office are permitted to conduct the applicant's evaluation. The oversight office is responsible for coordinating authorization activities and managing the LOA issuance process.

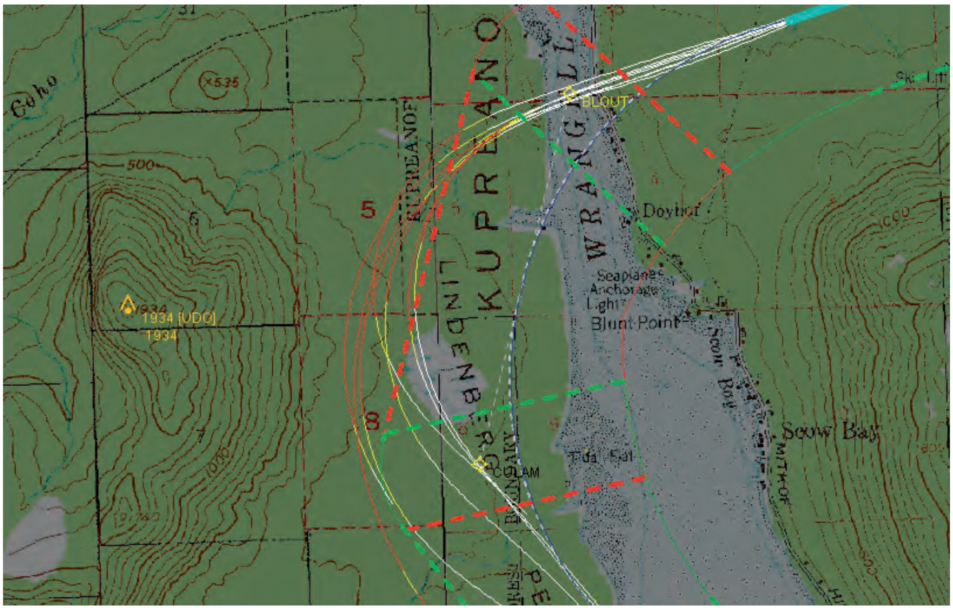

Figure 2. Graphic Depiction of Simulator Track Data Superimposed Over Procedure Containment Boundaries and Topographic Map

Once the company receives the appropriate authorizations, company personnel are able to conduct IFPV activities and submit the official paperwork. However, whenever LOA holders plan to exercise the privileges of the LOA they are required to notify the FAA. The oversight office will determine the level of oversight required for each company and each activity. FAA inspectors will often accompany new LOA holders during each activity they perform. However, as the oversight office gains confidence in the company's processes and individual capabilities, surveillance will be reduced. Regardless, all LOA holders will undergo on-site surveillance once per year at a minimum. In addition to ensuring proficiency, the annual surveillance provides the FAA with an opportunity to ensure proper implementation of changes to the IFPV program and to educate the LOA holder on IFPV issues, like upgraded equipment or improvements to FAA administrative processes.

In addition to providing on site surveillance, the FAA utilizes information gathered by the service provider to conduct other forms of oversight. Use of an Autonomous GPS Recording System (AGRS) is required for all obstacle assessment and flight validation work. The AGRS is independent from the aircraft's navigation system and records date, time, and location information. The data generated from the AGRS files can be used by the oversight office to evaluate whether the IFPV personnel correctly identify the controlling obstacle or if the ground track matches the course intended in the procedure design. Simulator sessions can also be recorded and the files provided to the FAA for an evaluation of flyability issues. If the procedure warrants, the oversight office can code the procedure from the submitted paperwork and conduct an independent simulator evaluation.

Audits are another method used by the FAA to oversee third party developers. FAA Order 8260.57, Oversight of Third Party Instrument Flight Procedures Service Providers, establishes FAA policy, guidance, and standardization for the oversight of third IFP service providers. It defines how the FAA will oversee all facets of procedure development and it details audit requirements. Audits can be conducted on a periodic basis or as necessary and the scope can be wide or narrow based on the discretion of the oversight office. Generally a portion of every audit is dedicated to ensuring that the service provider is in compliance with current IFPV guidance and that their approved IFPV manual accurately reflects their established processes.

Intentional and frequent collaboration between the FAA and service providers is one of the simplest and most effective methods of oversight. Open lines of communication provide third parties the opportunity to contact the oversight office for advice on techniques when addressing unfamiliar situations. The collaboration also gives the FAA an opportunity to recognize when the service provider deviates from standard operations. Early identification of issues allows the FAA to make corrections before systemic problems are created.

EVOLVING OVERSIGHT

The FAA has authorized two companies to perform IFPV for public use procedures. Although the oversight requirements are the same for both companies, the methods of oversight must be tailored to accommodate each companies' operation. Meanwhile, the methods of oversight have necessarily evolved as the companies have gained experience with IFPV.

Initially AFS-460 had an internal policy to provide 100% oversight of both companies. This meant that AFS-460 personnel conducted all initial authorizations and performed on-site surveillance of every subsequent IFPV activity. After a year of operations, AFS-460 conducted an audit of all third party development policies and practices, including IFPV manuals, equipment, and guidance. The result of the audit demonstrated each companies' satisfactory understanding and capabilities with regard to IFPV. As the companies' personnel consistently demonstrated a high level of proficiency, confidence in each program increased, and AFS-460 was able to adjust the internal policy of 100% oversight.

For example, one company recently provided AFS-460 with a request to conduct a periodic obstacle assessment of a Public RNAV (RNP) IFP. Historically AFS-460 would have accompanied the company for this activity. However, the company's proven ability to conduct IFPV successfully provided AFS-460 with the confidence to allow them to conduct the activity without on-site surveillance. Instead, AFS-460 joined a telephone conference between the IFPV evaluator conducting the airborne obstacle assessment and the flight crew. AFS-460 requested that the company provide the AGRS files from the activity. With the files, AFS-460 was able to import the AGRS data into Google Earth and review the actual flight tracks to determine whether the evaluator properly assessed the procedure.

AFS-460 conducted an additional telephone conference when the activity was complete. The Google Earth image provided a method for the evaluator to describe the event in detail and AFS-460 was able to easily follow in the conversation. AFS-460 was also able to import the AGRS data into the FAA's software development tool to compare the obstacle data discovered during the activity with existing obstacle data. Without being physically on location, AFS-460 utilized available resources to maintain a high level of oversight of IFPV personnel.

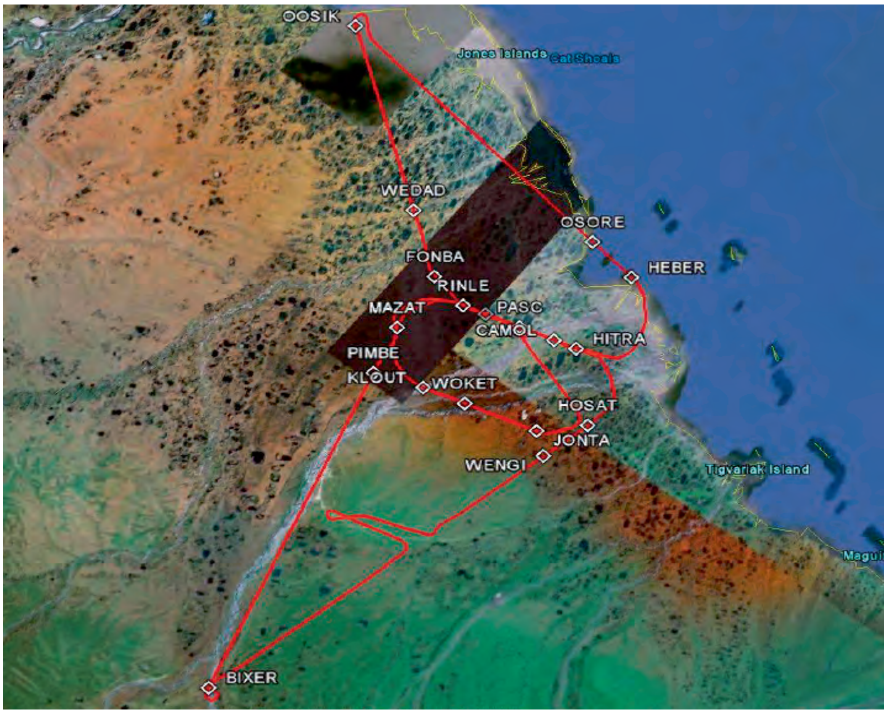

Figure 3. AGRS Track Data Superimposed over a Google Earth Image

CONCLUSIONS

Introducing third party developed procedures into the National Airspace System required that the FAA develop new processes and oversight programs. Replacing the FAA's role in providing flight inspection services posed significant challenges. By working with flight inspection experts, industry leaders, and safety professionals to determine equivalent levels of safety, the FAA developed the IFPV program. The IFPV program provides guidance that third parties must follow to introduce their procedures into the NAS. The oversight program provides guidance that the FAA must follow to ensure that third parties are compliant with IFPV requirements.

Both the IFPV program and the oversight program have been very effective. Both organizations have successfully developed and flight validated procedures that are now published in the U.S. Aeronautical Information Publication (AIP). Their IFPV programs authorize them to fulfill the ongoing maintenance responsibilities and to date there have been no reported issues with any of the procedures. While conducting surveillance of IFPV LOA holders, they continually demonstrate their knowledge of relevant FAA guidance and their capability to perform the work. This was reinforced during recent audits of both companies. The audit evaluated all development processes, many specific to IFPV. Only minor administrative issues were identified and the organizations were able to incorporate corrections immediately.

The program's success has been illustrated in other ways. Based on the quality of the procedures and the FAA's ability to oversee the development organizations, the U.S. recently allocated three million dollars for additional 3rd party development of satellite-based procedures. Certain States, after evaluating the FAA's third party program, are allowing the two FAA authorized organizations to develop and publish procedures into the country's AIP. Those states, and others, are requesting expertise from the FAA oversight office as they develop similar IFPV and oversight programs.

An added benefit of the IFPV program is the reduction in FAA resources required for certain types of procedure development. By following IFPV guidance and attaining authorization, companies are able to develop and flight validate procedures for private use. These procedures are not published in the AIP and are not typically a high FAA priority. By conducting their own development and flight validation, they no longer must rely on FAA resources and in turn FAA resources can be focused on procedures providing public benefit.

RECOMMENDATIONS

Regulatory agencies should:

1. Publish oversight guidance prior to authorizing companies or individuals to conduct IFPV,
2. Consider how third party IFPV providers will work with procedure development and maintenance organizations to receive and disseminate information pertinent to the procedure (i.e. Notice to Airman issuance, evaluation of obstacle data, etc.),
3. Work to establish open lines of communications with third parties to identify and resolve issues as soon as possible,
4. Train personnel from other regulatory offices to provide support and to increase awareness of the IFPV program.

FUTURE WORK

Due to the success of the IFPV program and the benefits attained by implementing 3rd party IFPV, the FAA envisions substantial growth in third party procedure development. To properly manage the growth, the FAA will work to continually improve. Embracing technology will be a primary focus of the FAA's oversight office. For example, the FAA currently uses specialized software that can graphically compare the designed lateral flight track and the actual data recorded during simulator evaluations and flight validations. But the software is constantly improving. Soon it will allow vertical path comparisons and in the future may provide the oversight office with additional benefits, such as evaluating various aircraft types or navigation systems for any given procedure. Technological advancements in desktop simulators have significantly improved their flight characteristics. The FAA is considering their use to replace certain Level C or D Simulator Evaluations, which could yield substantial savings in cost and time. Technology may even provide a method to improve basic procedure data. Recent obstacle data studies have shown the ability to achieve nearly survey grade accuracy when using FAA developed software and recreational survey equipment. When third parties follow the guidance for ground based obstacle assessment, their improved obstacle data may be incorporated into the national obstacle database benefiting all instrument procedures.

Implementation of the Next Generation Air Traffic System (NextGen) may require substantial non-governmental resources. This may result in an increased number of procedures and/or procedure developers. The FAA will seek out technologies and methods that improve the NAS, and the IFPV and oversight programs will evolve to accommodate whatever role third parties may play.

REFERENCES

FAA Order 8900.1 Volume 11 Chapter 12 Section 1 – Requirements to Conduct an Instrument Flight Procedure Validation

FAA Order 8900.1 Volume 11 Chapter 12 Section 2 – Issue a Letter of Authorization to Conduct an Instrument Flight Procedure Validation

FAA Advisory Ciruclar 90-113 – Instrument Flight Procedure Validation (IFPV) of Satellite-based Instrument Flight Procedures (IFP)

FAA Order 8200.1 – United State Flight Inspection Manual

FAA Order 8260.57, Oversight of Third Party Instrument Flight Procedures Service Providers

ARINC 424 Coding Preflight Validation

(Formerly Ground Validation of ARINC 424 Coding)

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ABSTRACT

The Federal Aviation Administration (FAA) Flight Inspection Services (FIS) uses Procedure Validation to ensure safety, quality and efficiency in the aviation environment. Instrument Flight Procedures (IFPs) are ARINC 424 coded with an automated system. Flight Inspection utilizes ARINC 424 Coding Preflight Validation (CPV), during preflight to ensure 100% data accuracy of ARINC 424 coded IFPs and reduce work for flight crews prior to publication. This process was formerly known as Ground Validation of ARINC 424 coding. Minimizing the amount of duplication in Procedure Validation promotes an efficient process to meet organizational goals, enhance safety and data accuracy and reduce required flight time.

CPV evaluates ARINC 424 coding for each IFP from a flight inspection operational perspective. The CPV process evaluates statistics to track the time required to validate each procedure, the types of errors found, applied solutions and enables feedback for improvements to the IFP development process.

This paper describes the process, analyzes resources and explains the future outlook for CPV in FIS. The short-term objective is to validate each IFP package ARINC 424 coding prior to flight inspection. The long-term objective is to reduce the required flight inspection time by eliminating use of an aircraft to check procedure segments that can be safely Coding Preflight Validated.

INTRODUCTION

The Validation Process of Instrument Flight Procedures (IFP) consists of Coding Preflight Validation (CPV) and Flight Validation (FV). The FAA's Flight Inspection Services organization is responsible for flight inspecting IFPs within the United States National Airspace System (NAS) and other international areas. The preflight validation for a flight inspection mission requires a considerable amount of time reviewing the itinerary and IFP packages and verifying the aircraft is capable of completing the mission. Coding Preflight Validation is an addition to the flight crew's preflight validation. The mission of CPV is to improve the efficiency of future flight inspections and eliminate the Airspace System Inspection Pilots (ASIP) preflight time analyzing ARINC 424 coding.

CPV consists of an operational analysis of the ARINC 424 coding and a reasonableness-of-flight evaluation on an approved desktop avionics simulator. This process requires an exact match of the data provided on the IFP source documents. These source documents include the procedure's design data and ARINC 424 coding.

The objective of CPV is to ensure 100% data accuracy of ARINC 424 coded IFPs to reduce rework for flight inspection prior to publication. This supports the FAA's mission to provide the safest, most efficient aerospace system in the world.

BACKGROUND OF CODING PREFLIGHT VALIDATION

Each IFP is designed and coded for use in various manufacturers' avionics. Flight Inspection is required to inspect the design and coding prior to the publication of each procedure. CPV evaluates ARINC 424 coding for each IFP.

A procedure package is developed for each IFP with information regarding the design of the procedure, the ARINC 424 coding of the procedure and specific points the developer wants the flight inspection pilot to check. The procedure is electronically coded by the procedure developer or by a coder.

Each procedure is coded in a standard format and a tailored format. The standard format is for use by the public once the procedure is published. The tailored format is used by the FAA for flight inspection. The coding is compiled into two electronic ARI files (one standard and one tailored). An ARI file is an electronic ARINC coded file. These files are distributed to the Flight Inspection fleet Flight Management System (FMS) avionics manufacturers for packing. Once packed, the avionics manufacturer provides Flight Inspection with one custom database that consists of the standard and tailored procedures in addition to the worldwide database.

IFPs that are currently evaluated using CPV include: Instrument Landing System (ILS), Localizer (LOC), Area Navigation Global Positioning System (RNAV (GPS)), Area Navigation Required Navigation Performance (RNAV (RNP)), Standard Terminal Arrival (STAR) and Standard Instrument Departure (SID).

CPV is responsible for validating the source documents of the IFP package and evaluating the procedure on a desktop avionics simulator. The desktop avionics simulator is analogous to the avionics in the flight inspection fleet.

Benefits of Coding Preflight Validation

Analyzing certain segments through CPV decreases required flight time, crew preflight time and various other costs.

1. CPV decreases flight time by only requiring Flight Validation of at least two nautical miles of the intermediate segment and the entire final and missed approach segments, as well as anything deemed necessary by the pilot-in-command for new or amended IFPs.
2. CPV decreases preflight time for the flight crew.
3. CPV reduces costs associated with aircraft, fuel, flight crew and time spent to complete a flight inspection mission.
4. CPV reduces human error by incorporating the approved software for ARINC 424 coding validation and requiring an exact match philosophy.

IMPLEMENTATION PROCESS

The implementation process for Coding Preflight Validation contains an initial testing phase and a final implementation phase. The initial testing phase promotes the implementation of CPV with designated personnel at one defined location. This phase utilizes previously defined step-by-step instructions to complete the process. Upon completion, the procedure packages are scheduled for flight inspection.

Originally, the process discussed in this paper was titled Desktop Validation of ARINC 424 Coding to identify a narrow scope of Ground Validation. Then, the title changed to Ground Validation of ARINC 424 Coding. The change was a result of standardization with FAA Order 8900.1 - Flight Standards Information Management System (FSIMS) and ICAO Volume 5 - Validation of Instrument Flight Procedures.

After review and discussion of how this process incorporates with Instrument Flight Procedure Validation (IFPV) and FAA Flight Inspection, the FAA Flight Inspection Technical Services Team finalized the title as ARINC 424 Coding Preflight Validation (CPV).

Preflight Validation begins when the Flight Validation organization receives the procedure package. The procedure package data is verified and the procedure is reviewed from an operational perspective. The intention of Preflight Validation is to evaluate on the ground, to the extent possible, those elements that will be evaluated during Flight Validation, and may require an assessment in an appropriately equipped aircraft simulator.

CPV is a portion of the Preflight Validation and is defined as an extensive desktop review of the ARINC 424 coding contained in an instrument flight procedure package, including the use of software tools. The review consists of a comparison and evaluation between the procedure design data (example: FAA Form 8260-3), ARINC 424 coding and contents of the FAA custom database.

The final implementation phase proceeds with the complete involvement of FAA FIS. All validation personnel are trained and ready to complete the roles and responsibilities of the position. The flight crews are informed of the new process and understand their roles and responsibilities. All documentation is finalized and the process is ready for execution.

CURRENT PROCESS

Coding Preflight Validation consists of an operational analysis of the ARINC 424 coding and a reasonableness-of-flight evaluation on an approved desktop avionics simulator. CPV is completed prior to scheduling a procedure on a flight inspection itinerary.

Required Information

The required information to complete this process includes:

1. A weekly report of the new and amended ARINC 424 coded IFPs.
2. The electronic IFP package.
3. Weekly standard format and tailored format ARI file.
4. Weekly FAA custom database revisions.

The weekly report identifies the new and amended ARINC 424 coded IFPs. The information gathered from this report updates the workload list for CPV. The specialist pulls a procedure from the workload list and begins the validation process.

Process Steps

The first step is to review the FAA source documents in the procedure package. CPV requires an exact match of the data provided on the procedure package source documents. The FAA source documents include the procedure's design data and ARINC 424 coding. The ARINC coding is validated against the procedure design data.

The second step is validation of the standard ARI file against the IFP ARINC coding. An FAA software tool is used to import the standard ARI file and validate this with IFP ARINC coding. This comparison requires an exact match.

The third step is an observation assessment of accuracy and reasonableness based on the tailored ARINC coding. The most current database is loaded onto the desktop avionics simulator. The simulator is positioned for the appropriate procedure and the IFP is loaded into the FMS. Each procedure is evaluated for reasonableness of the lateral flight track. This observation does not satisfy the requirements to check flyability on the final approach segment or the vertical navigation performance on final, when the procedure includes vertical guidance.

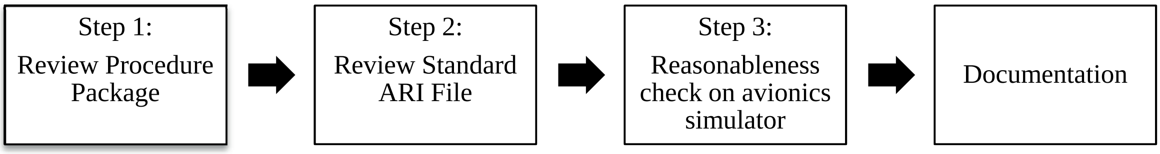
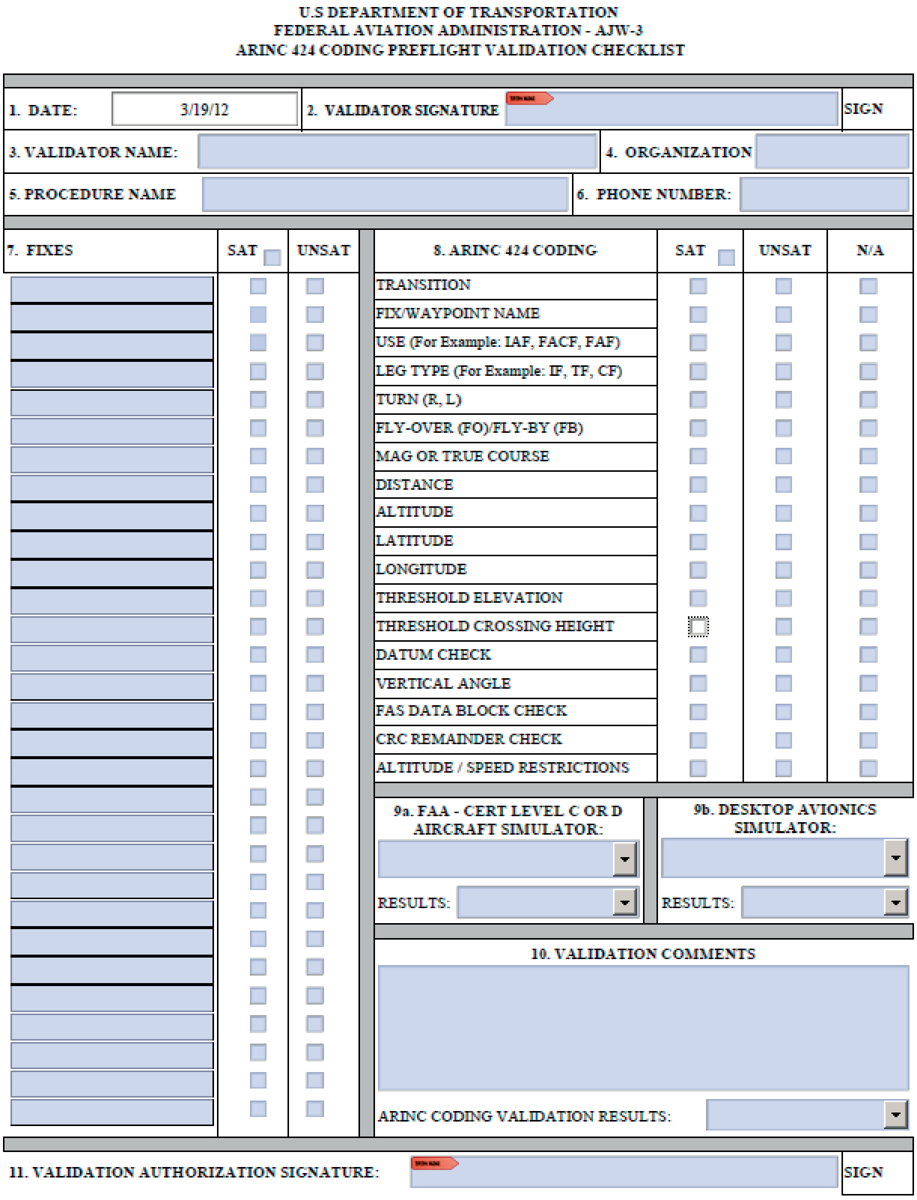


Figure 1. Coding Preflight Validation Process

Documentation

The documentation required for CPV is the Validation Checklist (VC) (see Figure 1) and the Procedure Control Form (PC Form) (see Figure 2). The VC is based on the procedure design data and what is identified from a flight inspection operational perspective. The items listed in Table 1 provide an explanation of the VC "ARINC 424 Coding" section.

The PC Form is attached to each IFP placed on an itinerary for the flight crew. The form specifies the procedure, type of flight inspection and any comments. A Preflight Notes section is available to state if ARINC 424 coding is verified



U.S DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION - AJW-3
ARINC 424 CODING PREFLIGHT VALIDATION CHECKLIST

1. DATE: 3/19/12
2. VALIDATOR SIGNATURE: SIGN
3. VALIDATOR NAME:
4. ORGANIZATION:
5. PROCEDURE NAME:
6. PHONE NUMBER:

7. FIXES	SAT ☐	UNSAT
	☐	☐
	☐	☐
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	☐	☐
	☐	☐
	☐	☐

8. ARINC 424 CODING	SAT ☐	UNSAT	N/A
TRANSITION	☐	☐	☐
FIX/WAYPOINT NAME	☐	☐	☐
USE (For Example: IAF, FACF, FAF)	☐	☐	☐
LEG TYPE (For Example: IF, TF, CF)	☐	☐	☐
TURN (R, L)	☐	☐	☐
FLY-OVER (FO)/FLY-BY (FB)	☐	☐	☐
MAG OR TRUE COURSE	☐	☐	☐
DISTANCE	☐	☐	☐
ALTITUDE	☐	☐	☐
LATITUDE	☐	☐	☐
LONGITUDE	☐	☐	☐
THRESHOLD ELEVATION	☐	☐	☐
THRESHOLD CROSSING HEIGHT	☐	☐	☐
DATUM CHECK	☐	☐	☐
VERTICAL ANGLE	☐	☐	☐
FAS DATA BLOCK CHECK	☐	☐	☐
CRC REMAINDER CHECK	☐	☐	☐
ALTITUDE / SPEED RESTRICTIONS	☐	☐	☐

9a. FAA - CERT LEVEL C OR D AIRCRAFT SIMULATOR:
RESULTS:

9b. DESKTOP AVIONICS SIMULATOR:
RESULTS:

10. VALIDATION COMMENTS

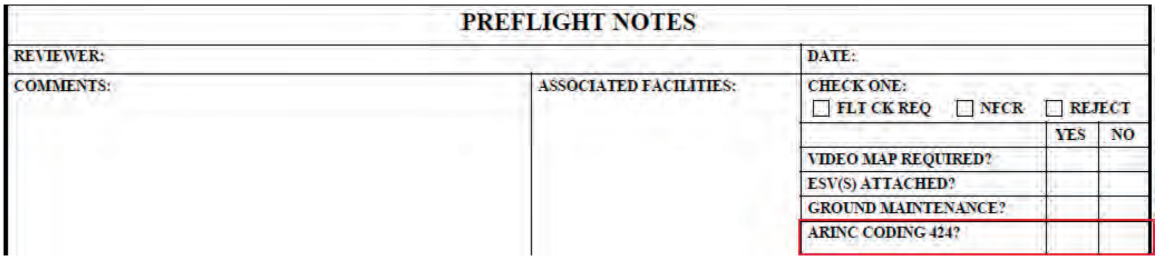
ARINC CODING VALIDATION RESULTS:

11. VALIDATION AUTHORIZATION SIGNATURE: SIGN

Figure 2. Validation Checklist

ARINC 424 CODING	VALIDATION
TRANSITION (for example: 010, 020, 030)	Segments are in the correct sequence (order).[1]
FIX / WAYPOINT NAME	Fix / Waypoint name is exact match and spelling is correct
USE (for example: IAF, FACF, FAF)	Fix use is accurately listed.
LEG TYPE (for example: IF, TF, CF)	Leg type is in correct sequence and exact match. [1]
TURN (right, left)	Turn is exact match on documents and the aircraft flies the correct turn on desktop avionics simulator
FLY-OVER (FO) /FLY-BY (FB)	FO /FB is exact match on documents
MAG OR TRUE COURSE	Magnetic course is exact or within tolerance [2] True course is exact or within the tolerance [2]
DISTANCE	Distance is exact match or within the Tolerance [1], [2]
ALTITUDE	Altitude is exact match.
LATITUDE	Latitude is exact match.
LONGITUDE	Longitude is exact match.
THRESHOLD ELEVATION	Threshold elevation is exact match.
THRESHOLD CROSSING HEIGHT	Threshold crossing height is exact match.
DATUM CHECK	Observe the DATUM used is exact match.
VERTICAL ANGLE	Vertical Angle is exact match.
FINAL APPROACH SEGMENT (FAS) DATA BLOCK CHECK	Conduct a FAS DATA BLOCK check with the Instrument Approach Procedure Automation (IAPA) Calculator. The calculation and the FAA Form 8260-3 Final Approach Course is an exact match.
CYCLIC REDUNDANCY CHECK (CRC) REMAINDER CHECK	CRC is exact match.
ALTITUDE AND SPEED RESTRICTIONS	Review the multiple Altitude and Speed restrictions. Apply the descent gradient formula. Determine if further review is required in a FAA-certified C or D aircraft simulator, and/or a recommendation should be made to evaluate in an aircraft.

Table 1. Description of Items Coding Preflight Validated



PREFLIGHT NOTES

REVIEWER:

DATE:

COMMENTS:

ASSOCIATED FACILITIES:

CHECK ONE:
☐ FLT CK REQ ☐ NFCR ☐ REJECT

	YES	NO
VIDEO MAP REQUIRED?		
ESV(S) ATTACHED?		
GROUND MAINTENANCE?		
ARINC CODING 424?		

Figure 3. Procedure Control Form: Preflight Note

Coding Preflight Validation Results

When CPV is complete, a results folder is created on the FAA Flight Inspection Services Knowledge Services Network (Microsoft Sharepoint) to compile the validation information. This folder is used to reference the procedure information and for archiving purposes.

The results are recorded on the VC and the PC Form for the flight crew to reference. The results include: Satisfactory (SAT) or Unsatisfactory (UNSAT). A SAT result fulfills the Preflight Validation and Flight Validation requirement to ensure the ARINC coding is consistent with the procedure design and simulates the flight track. A SAT result has the option of being scheduled for flight inspection or completed as a No Flight Check Required (NFCR).

An UNSAT result determines that an inconsistency is found or the flight track is outside of reason. The Validation Checklist is marked as UNSAT and sent back to procedure design.

The VC will state SAT or UNSAT under ARINC Coding Validation Results. Any comments are listed under Validation Comments.

The PC Form provides the flight crew a quick reference to see if ARINC 424 coding is verified.

1. ‘Yes’ is marked if the ARINC 424 coding is verified and completed as satisfactory.

2. ‘No’ is marked if the ARINC 424 coding is verified but is completed as unsatisfactory.

3. The field is blank if ARINC 424 Coding is not complete.

Any Coding Preflight Validation notes are listed in the Preflight Notes Comments box.

PERFORMANCE METRICS

There are four main performance metrics during implementation of CPV. These include:

1. Number and type of IFPs,

2. Total time to complete each IFP,

3. Result of each IFP, and

4. Errors found, solutions applied.

Number and Type of IFP

Objective**:** Track the number of IFP packages Coding Preflight Validated per month

1. Evaluate the trends of IFPs.
2. Evaluate the workload count for CPV.
3. Discuss what other duties could be implemented during months that have a low count.

Total Time to Complete each IFP

Objective: Track the amount of time it takes to complete CPV for each IFP.

1. Evaluate time required for each procedure type.
2. Increase or decrease in amount of time spent doing CPV, per procedure type, with increased experience.

Result of Each IFP

Objective: Track the results of CPV.

1. Track the total number of Satisfactory and Unsatisfactory.
2. Compare the type of results to the total number of procedures validated for that month. Evaluate if an increase in procedures increases the number of unsatisfactory results.

Errors Found, Solutions Applied

Objective: Maintain a record of what types of errors were found and the solution(s) applied.

1. Evaluate trends: types of errors and consistency.
2. Discuss if the solutions applied resolve the issue.

CONCLUSION

The ever-increasing demand for satellite-based instrument flight procedures and the associated time to meet this demand opened the door for implementation of Coding Preflight Validation. The process described for CPV requires flexibility with changing criteria for procedure design, flight inspection requirements and advancement in software tools.

Utilizing ARINC 424 Coding Preflight Validation is the solution to ensure 100% data accuracy and reduce rework prior to publication of instrument flight procedures. Creating an efficient process to enhance safety, increase data integrity and reduce required flight time is appealing to the flight inspection industry.

This process continuously supports the FAA’s mission to provide the safest, most efficient aerospace system in the world.

FUTURE OUTLOOK

Aerospace industry growth is significantly dependent on increased use of performance based navigation procedures to facilitate more dynamic management of air traffic. The future demand for Flight Inspection’s involvement in satellite-based instrument flight procedures poses a high impact on Coding Preflight Validation. CPV is expected to integrate its resources with those of the flight department to allow for a more on-time completion of flight inspection. This anticipates new roles and responsibilities to encompass new requirements. The process must remain adaptable to meet organizational goals and flexible to ever changing requirements for Flight Inspection.

The future of CPV revolves around its long-term objective. The objective is to reduce the required flight inspection time by eliminating use of an aircraft to check procedure segments that can be safely Coding Preflight Validated. This is expected to help manage future workload to gain efficiency and meet organizational goals.

REFERENCES

[1] Aeronautical Radio, Inc., 23 November 2005, ARINC 424-18 Specification

[2] FAA, November 2007, Flight Inspection Services Flight Inspection Handbook, TI8200.52

FLIGHT INSPECTION OF GNSS IFR PROCEDURES FOR HELICOPTERS

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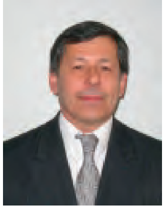

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ABSTRACT

The resolution A37-11 «Performances Based Navigation global goals» has been adopted by the ICAO assembly during his 37th session in October 2010.

A « PBN France plan », national reference document, has been adopted by the French CAA (DGAC). It describes the PBN concept, the way it will be implemented in France and the expected gains in short, medium and long term. This document includes some decisions acted for helicopter domain:

- ✓ Design of specific IFR procedures based on GNSS on airport none interfering with commercial aircraft.
- ✓ For sanitary transportation also based on GNSS use :
- ✓ Progressive general implementation on hospitals of RNP approaches and departures based on PIN's concept (Point In Space),
- ✓ Beginning of the implementation on hospital of APV-SBAS, also based on PIN's concept,
- ✓ Progressive implementation of an RNP IFR low altitude network between hospitals.

All these RNP approaches dedicated to helicopters must be flight inspected by the Flight Inspection Department (DTI) of the DGAC using a dedicated Flight Inspection System (CARNAC MS) designed by Sagem.

The presentation will be divided into the following parts:

I. PBN general information with different approaches dedicated to helicopters
II. Non precision approaches (RNAV LNAV, APV SBAS/RNAV LPV)
III. Dedicated requirements and problems to perform such flight inspections
IV. Operational and Flight Inspection System solutions used to solve “Helicopter RNAV-LPV checks” constrained environments difficulties.

FOREWORD

Development of specific IFR procedures is considered as key for enhancing flight safety and service reliability of helicopter operations. This concerns Emergency Medical Service which today is conducted most of the time in VFR, even at night or (and) in adverse weather conditions, and also operations at busy airports where, because of congestion problems, helicopter operations are discouraged and even rejected.

This is a new challenge for the Flight Inspection Service which will have to manage with slow speed evolution, steep angles, and flights in constrained environment …

INTRODUCTION

PBN PLAN IN FRANCE

- ICAO Navigation strategy Performance Based Navigation (PBN) concept
- Resolutions of the **ICAO 36&37th** Assembly
- Eurocontrol Navigation strategy & GNSS policy
- SESAR
- Rationalisation of Conventional Navaids (VOR, NDB, ILS cat I)
- Understands the possible benefits, costs and challenges of implementing PBN for the different operators and users (Airlines, Business aviation, General aviation and Helicopters)
- Gets maximum benefits of **EGNOS**
- Strategy (ANSP level)

PBN Implementation Plan (State level) for Enroute, TMA and for Runway ends

ICAO RESOLUTIONS A36-23 ET A37-11

In 2007 the International Civil Aviation Organization (ICAO) passed Resolution A36-23 which amongst other things required member States to put in place measures aimed at mitigating against the threat of CFIT and approach and landing type accidents for Instrument Flight Rules (IFR) aircraft.

ICAO Resolution A36-23 urged member States to complete a Performance Based Navigation implementation plan by 2009 for implementation of APV (by barometric vertical navigation (Baro-VNAV) and/or augmented Global Navigation Satellite System (GNSS) – such as SBAS) for all instrument runway ends that serve aircraft with a mass of 5,700kg or more, either as the primary approach or as a back-up for precision approaches by 2016, with intermediate milestones of 30% by 2010 and 70% by 2014.

At the 37th ICAO Assembly in October 2010 Resolution A36-23 was superseded by Resolution 37/11 which stated, inter alia:

States complete a PBN implementation plan as a matter of urgency to achieve:

1) implementation of RNAV and RNP operations (where required) for en route and terminal areas according to established timelines and intermediate milestones; and

2) implementation of approach procedures with vertical guidance (APV) (Baro-VNAV and/or augmented GNSS), including LNAV only minima, for all instrument runway ends, either as the primary approach or as a back-up for precision approaches by 2016 with intermediate milestones as follows: 30 per cent by 2010, 70 per cent by 2014; and

3) implementation of straight-in LNAV only procedures, as an exception to 2) above, for instrument runways at aerodromes where there is no local altimeter setting available and where there are no aircraft suitably equipped for APV operations with a maximum certificated take-off mass of 5 700 kg or more.

EGNOS

EGNOS (European Geostationary Navigation Overlay Service) is the European Satellite Based Augmentation System (SBAS), it is the equivalent of the US WAAS.

EGNOS, entered into service early 2011 and is already available for operational use. WAAS and EGNOS are fully interoperable and consequently, both are usable with standardized SBAS receivers. All recent aviation certified GPS receivers include the SBAS function.

EGNOS “augments” the GPS L1 signal:

- Accuracy of positioning is improved up to 1 and 2 meters horizontally and between 2 and 4 meters vertically.
- Accuracy of timing is improved to better than 10 nanoseconds.
- Integrity and safety is improved by broadcasting alerts within a few seconds of the occurrence of a failure in GPS and by providing a level of confidence on the position computation.

One major advantage of SBAS over basic GPS is the availability of vertical guidance which is recognized as key factor for enhancing the safety of IFR approaches. In terms of performance, SBAS is similar to an ILS CAT I. The main difference is in the vertical plan where precision at runway threshold is slightly less than an ILS glide.

SATELLITE BASED AUGMENTATION SYSTEM

The SBAS signal is broadcasted from geostationary satellites and delivers both GPS position corrections and integrity information. SBAS can be used everywhere within the SBAS coverage area as no specific installation on ground is required.

Consequently, it is particularly well adapted to helicopter IFR operations at isolated helipads (hospitals, off-shore helidecks, etc.).

HELICOPTER ISSUES

Nowadays, the lack of IFR helicopter infrastructures results in continued visual operations in very low ceilings and visibilities.

In PBN French plan, some decisions have been acted for the helicopter domain; the objective is to improve the safety by moving helicopter operations from VFR to IFR infrastructure (En Route, Terminal and Heliport Instrument Procedures):

- Design of specific IFR procedures based on GNSS on airport non-interfering with commercial aircraft (Simultaneous Non Interfering procedures).
- For Emergency Medical Service, also based on GNSS use:
    - ✓ Progressive general implantation on hospital of RNP approaches and departures based on PINS concept (Point in Space)
    - ✓ Beginning of the implementation on hospital of APV-SBAS, also based on PINS concept
    - ✓ Progressive implementation of an RNP 0.3 IFR low altitude network between hospitals

HELICOPTER SPECIFIC IFR PROCEDURES

Thanks to SBAS it’s now possible to design and assess helicopter specific IFR approach procedures with vertical guidance to enhance safety and take the best benefits of steep approaches.

Steep Approaches

SBAS as guidance means for Simultaneous Non Interfering (SNI) procedures allowing fully independent aircraft and rotorcraft traffics. SNI procedures are present needs for helicopter IFR access to busy airports where runway approach slots are reserved to transport airplanes.

These SNI must take in charge the Approach and Landing engine failure management in steep approach and aircraft wake vortex encounter risk.

Point in Space (PinS)

Another important design option which was used in the definition of the procedures is the Point-in-Space (PinS). This concept, which is already in use for Helicopter GPS NPAs, consists of terminating the IFR final approach segment at a given point in space which is also the Missed Approach Point (MAP). Upon reaching the MAP, depending on the remaining distance to the FATO, the pilot shall proceed either visually or VFR toward the landing spot.

LPV

SBAS guided approaches are categorized as LPV (Localizer Performance with Vertical guidance). Minimum Decision Height (DH) today approved by ICAO for LPV is 250 ft but is expected to be reduced to 200 ft in the near future.

FLIGHT INSPECTION OF SPECIFIC PROCEDURES

All the RNP approaches dedicated to helicopters must be inspected by the Flight Inspection Service of DSNA/DTI. It consists basically in:

- Ground validation:

  - ✓ Data validation (Distance and track between WP)
  - ✓ Charting
  - ✓ Coding

- Flight inspection:

  - ✓ Integrity of the procedure data
  - ✓ Adequate signal reception
  - ✓ FAS data block validation for LPV
  - ✓ Absence of interferences
  - ✓ Flyability (Workload, charting, manoeuvring)

All these tasks are performed today for the standard RNP procedures with Sagem CARNAC Automatic Flight Inspection System installed on DTI flight inspection fleet (ATR42 and Beech 200).

FLIGHT INSPECTION DIFFERENCES AIRCRAFT / HELICOPTERS

DTI must perform heliport standards evaluation and RNAV/LNAV or APV FI but not only!

Here are some constraints of the Flight Inspection of a helicopter procedure:

- ❖ Maximimum ground speed of 70 knots, certified Vmini.
- ❖ Capability for steep approach angles, more than 6°and up to 10°.
- ❖ Distance from DA to heliport is critical and impose a deceleration during approach, Vmini or higher at DA and stop above heliport.
- ❖ Flyability with obstruction evaluation /obstacle identification must be performed.

These will be special procedures, for specific operators only, that require specific training (let alone heliport environment) and specific approach evaluation. For this reason DTI shall use operator's helicopter and crew (generally EMS operators).

Performing an approach in such an environment with a Beech 200 at DA 250', could create some trouble with the neighborough !

FLIGHT INSPECTION SYSTEM

Needs and Constraints

There is a necessity to have at DTI disposal a FIS installable in the operator's helicopter.

The DTI Flight Inspection System installed in Beech 200 or ATR42 FIS is too bulky and heavy to be installed in all kinds of helicopters.

This FIS requires specific modifications in the FI helicopter.

This FIS can't be easily certified in different helicopters.

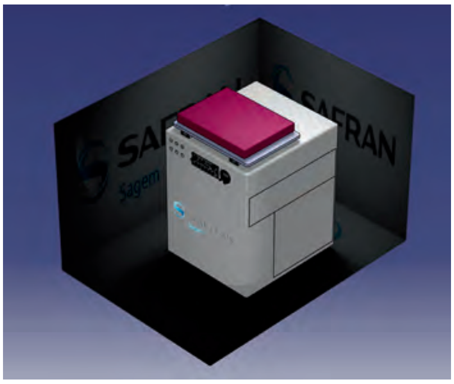
Suggestive solution

A Laptop, some receivers GPS/EGNOS and tailored software could be conceivable. But it is for DTI an unsatisfactory answer:

- Two different systems depending if performing aircraft or helicopter approach Flight Inspection.
- Two different systems to maintain and keep advancing.
- In case of co-established procedures (Aircraft and helicopter), two different reports would be edited.

Sagem solution

The solution was to take advantage of one of the small and adaptable CARNAC racks using the same IHM, software, and GNSS receivers than the full FIS.



CARNAC L

CARNAC MS

DTI selected CARNAC MS design (CARNAC Modular System) implementing dedicated equipment to helicopters limited to GNSS.

The main advantages are:

- The software performances, characteristics and capabilities are totally similar to those of the complete CARNAC 30 when used for GNSS RNP flight inspection.
- Design compliant with helicopters and very small aircrafts requirements.
- Only one software version to maintain and keep advancing.
- No specific training for the Flight Inspector during the Flight and when preparing the report.
- Data format issued from CARNAC MS are identical to others CARNAC racks and can be stored and processed on the same preparation ground station.

Dedicated CARNAC Modular System

Hereafter is the physical description of a CARNAC MS dedicated to the Flight Inspection of the GNSS procedures.

This system includes airborne equipment and ground equipment.

Ground equipment :

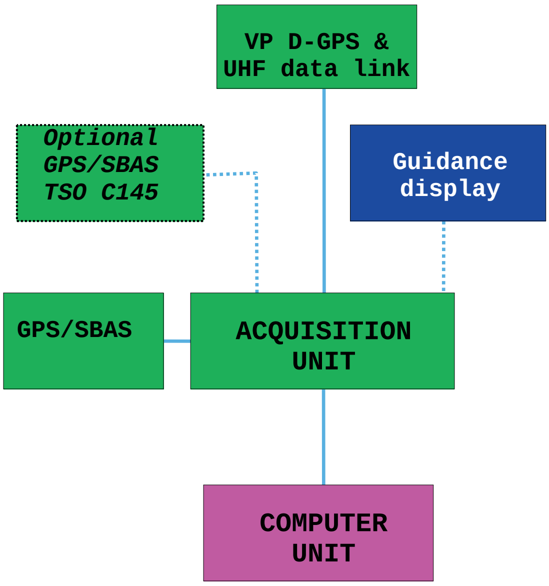
Performing dual-frequency L1/L2 processing and carrier phase differential measurements GPS receiver for reference trajectography,

- UHF data link,
- UHF/GPS antennae.

GPS and UHF antennae

Airborne equipment:

- ❖ Notebook computer
- ❖ Only one module of CARNAC MS containing:
  - Computer for data acquisition,
  - Performing dual-frequency L1/L2 processing and carrier phase differential measurements GPS receiver for reference trajectography,
  - GPS/SBAS receiver,
  - Optional GPS/SBAS TSO C145 receiver,
  - UHF data link (for Very Precise DGPS),



Guidance display

For helicopters DTI considers that the procedure has been “published” (ie is present in the helicopter FMS), before the flight inspection.

The FMS data base contains all the information required for navigation, departure and approach procedures. In particular, it includes the flight plan and the FAS data blocks of the LPV procedures to be flown under SBAS guidance using helicopter’s displays.

If the procedure has not been “published”, Sagem may install a specific guidance system in the cockpit. This portable display shall not require any certification process (Portable Electronic Device).

CONCLUSIONS

French CAA Flight Inspection Service managed all constrained environment and requirements of RNP approaches dedicated to helicopters.

In addition and thanks to CARNAC “light and small” design, DTI is able to perform GNSS-RNP checks in accordance with the « PBN France plan » within helicopters as well as within very small or standard aircraft.

All DTI results of helicopters procedures checks will be presenting during the 17th IFIS.

Efficient
Procedure Flight Checks

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ABSTRACT

Flight checking of instrument procedures based on conventional NavAids or based on RNAV/RNP (GNSS or DME/DME) is a demanding task. Multiple sensors are involved in the flight check, some need to be re-tuned in a short sequence with every flight leg of the procedure. Procedure inspection requires rather the inspection of the overall procedure with all related elements than flight checking single Navigation Aids (Navaids).

To avoid numerous calibration flights, efficient flight checking of instrument procedures requires a transition from the conventional way of single Navaid inspection to a flight inspection multi sensor management system. Such a system must be able of processing multiple facility calibrations simultaneously with the capability to reconfigure all sensors from one leg to another.

For flight checks of unpublished procedures an interface to procedure-design-tools as well as to primary aircraft avionics is required.

This paper describes the implementation of such a flight inspection multi sensor management system for the various kinds of procedure inspection.

INTRODUCTION

The main objective of the flight inspection evaluation of instrument flight procedures is to assure

- That the navigation source(s) support the procedure
- The Flyability of the design

This paper distinguishes between three different types of Instrument Flight Procedures since the requirements for flight checking differ significantly:

1) Conventional Procedures
2) RNAV procedures GNSS based
3) RNAV Procedures DME/DME based

Flight checks of Conventional Procedures

Flight inspection of conventional procedures requires checking, if each navigation source required to fly the procedure can be received and fulfills the requirements of [1].

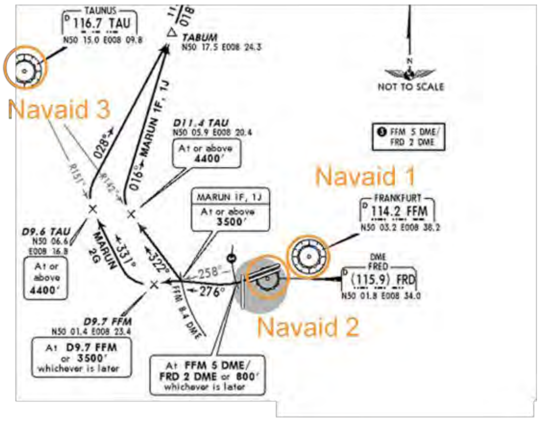


Figure 1. Convention Flight Procedure

Typically conventional procedures are based on Navaid types like VOR, DME and NDB. In order to define different legs of the procedure the navigation source changes from leg to leg, re-tuning or independent navigation receivers are required.

Flight Checks of RNAV GNSS Procedures

The navigation signal for GNSS based procedures is provided by satellites. Coverage of these navigation signals is required at each point of the procedure. An aircraft GNSS receiver must be able to perform Receiver Autonomous Integrity Monitoring (RAIM) while flying the procedure. Since the GNSS satellite configuration varies with time a prediction of the availability of RAIM is required prior to flight. Flight checking only makes sense, if no RAIM outages are predicted for the duration of the inspection. The actual RAIM status during the flight check shall be recorded. Any change of the RAIM status would indicate something unexpected and might be a first sign of GNSS interference.

For documentation and analysis various GNSS parameter need to be recorded, e.g:

- No of SVs
- Signal to Noise
- Satellite Constellation (DOP)
- Protection Limits (HPL, VPL)
- …

The position as determined by the GNSS receiver is provided to a Flight Management System (FMS) for navigation. Based on this position and according to a navigation database the FMS provided guidance signals to the pilot and the flight director (FD) and autopilot (AP). Both the position estimation and the database accuracy are essential for the navigation performance and therefore subject to inspection.

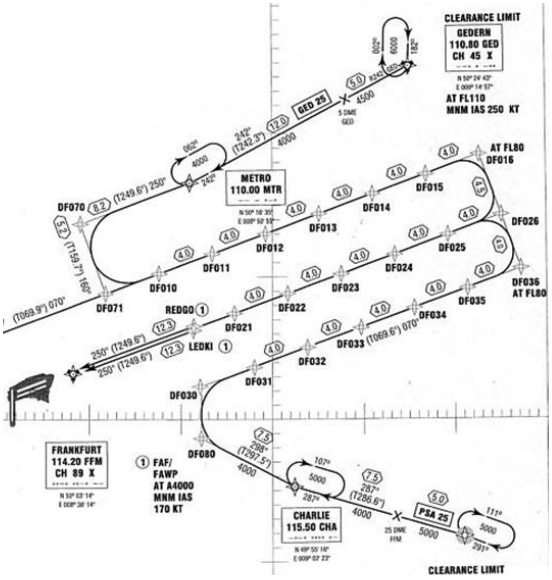


Figure 2. GNSS RNAV Flight Procedure

Since navigation waypoints are typically defined by just a pair of coordinates without a collocated facility on ground the correctness of the database must be seen critically. Any error in the database would have direct impact to the navigation.

Flight Checks of RNAV DME/DME Procedures

DME/DME navigation is another mode of FMS navigation. FMS typically switch to this mode of navigation as a fall-back mode in case GNSS is not available. By tuning one channel of a DME receiver to different DME facilities in range of reception the FMS is able to determine its position.

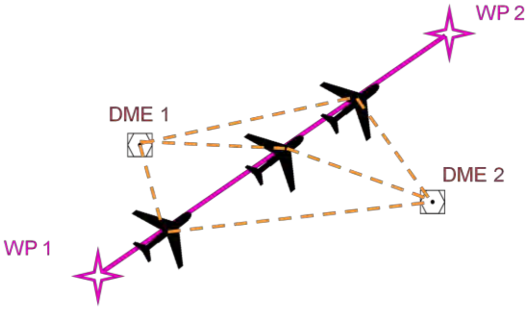


Figure 3. DME/DME Navigation

The accuracy of the DME ground stations, the geometrical constellation and the number of available DMEs affect the position estimation in this mode. The minimum number of DMEs for position estimation is two. If there is part of the procedures where just two DMEs are receivable the two DMEs are treated as critical DMEs. If one of those DMEs would become unavailable the entire procedure would be unusable.

The flight check shall evaluate how many DMEs are available on each part of the procedure. Further the range accuracy of all supporting DMEs has to be determined.

In order to evaluate the position estimation in DME/DME mode the FMS has to be configured to use just DME/DME navigation during flight check. The FMS navigation performance in DME/DME navigation mode is evaluated during flight check. The FMS database accuracy check is also mandatory.

CONVENTIONAL FLIGHT INSPECTION SYSTEMS

Many flight inspection systems are designed to calibrate a single Navaid only. Basically they provide setups to fly a radial for accuracy and alignment check or an orbit for coverage. Only one ground facility (one VORDME or one NDB) is inspected at a time. In flight the operator configures the system accordingly. Once the run is completed he re-configures the system for the next run.

Due to their complexity flight checking Instrument Flight Procedures is a demanding task for the operator. A radial flight needs to be setup and flown for every leg of the procedure, and for every Navaid supporting the procedure. Numerous runs with high frequent re-tuning of the navigation receivers are required. This causes a very high workload and stress level for the operator. Setup mistakes due to human factors are very likely, so runs might need to be repeated for this reason. The overall flight time for flight checking a conventional instrument flight procedure is very high.

Inspection of RNAV procedures requires a detailed accuracy and correctness check of the FMS database. The procedure as created by the procedure designer serves as reference. Conventional flight inspection systems do not provide tools to perform this task. Manually the flight inspector compares the reference data from the procedure designer to the navigation database loaded to the FMS. During this boring task also human errors can occur likely.

For GNSS RNAV checks, some flight inspection systems provide basic GNSS data recording. Detailed access to parameters like Signal to Noise, Number of SVs, RAIM status is missing.

DME/DME procedure flight checking with a conventional flight inspection system requires numerous flights. Different radials need to be flown for each DME possibly supporting the procedure.

REQUIREMENTS FOR AN EFFICIENT FLIGHT INSPECTION SYSTEM

In order to provide efficient flight checking of instrument flight procedures the operation of the flight inspection system must be completely different. The transition from conventional way of single Navaid inspection to a flight inspection multi sensor management system is required. Such system must be able of processing multiple facility calibrations simultaneously with capability to reconfigure automatically all available flight inspection sensors from one leg to another.

The requirements for such system are:

General Requirements

- Provide a procedure oriented AFIS setup by means of procedure legs and waypoints (instead of radials and orbits)
- Store waypoints and complete procedures in the AFIS database
- Provide means to define AFIS setups for the complete procedure(s) in the office for later loading to AFIS
- Record the real flight track (horizontally and vertically) while flying along the procedure to support the pilots in evaluating flyability.
- Provide a correlation of measured data / graphs and the procedure legs.

Requirements For Conventional Procedures

- Provide means to calibrate different Navaids using every available flight inspection receiver for another facility simultaneously
- Provide means to define leg by leg for each receiver the facility to be checked.
- Provide error calculation, graphs and reports for each inspected Navaid.

Requirements For RNAV Procedures (General)

- Provide means to import ARINC424 coded procedure design data to AFIS database
- Provide automatic means to check the FMS database for correctness
- Provide means to record and evaluate the FMS navigation performance in different modes of navigation (GNSS, DME/DME)

Requirements For GNSS based RNAV Procedures

- Recording of each GNSS SV:
    - Signal to Noise
    - Elevation and Azimuth
- Recording of GNSS Parameters:
    - Number of SVs used
    - DOP (HDOP, VDOP; PDOP; TDOP)
- Recording of detailed RAIM Status:
    - OK, FD, FDE, unavailable

Requirements For DME/DME based RNAV Procedures

- Provide means to evaluate the range error of multiple DMEs simultaneously
- Allow identification of critical DMEs by just one flight

IMPLEMENTATION IN AFIS

For the implementation of the above listed requirements the AFIS provides the following interfaces:

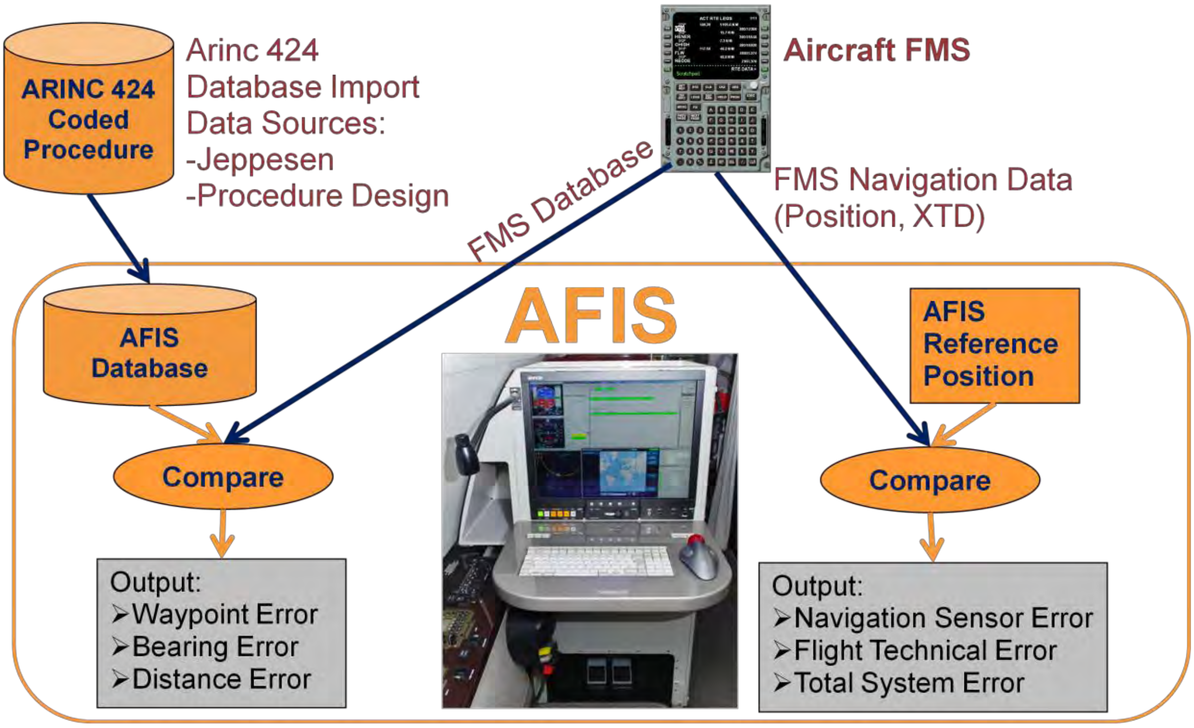


Figure 4. AFIS interfaces

AFIS Database

Single waypoints or complete Instrument Flight Procedures can be stored in the tree structured AFIS database.

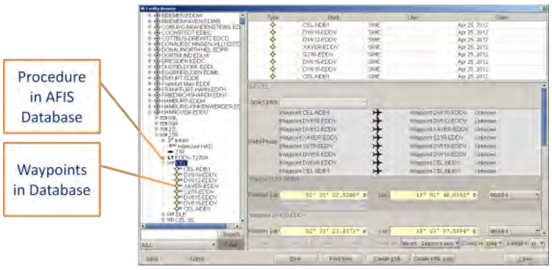


Figure 5. AFIS database

In order to avoid erroneous manual data input the AFIS can import Procedure Design Data in Arinc 424 to the AFIS database. By this the reference procedure data for the flight check can be directly loaded to the AFIS within seconds.

FMS Database Verification

For automatic FMS Database verification the AFIS has an Arinc 429 interface to read the FMS database / flightplan. The coordinates of FMS waypoints as well as leg distances and tracks are automatically compared against the reference procedure data. By a click of a button the data can be exported to a report.

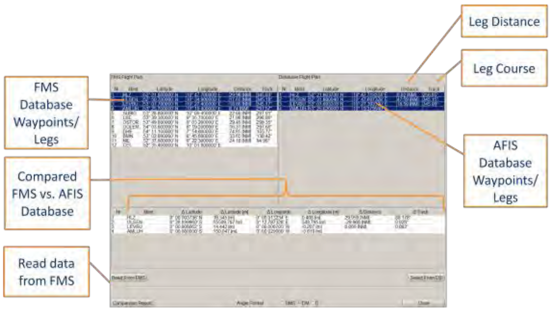


Figure 6. FMS Dabase Verification

AFIS Procedure Setup

The AFIS provides a user interface for setup of procedure checks:

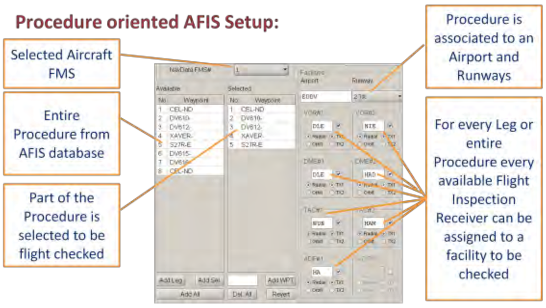


Figure 7. AFIS Procedure Setup

Based on the AFIS database the definition of the procedure to fly is configured. The procedure can be flown in whole or in parts. Additional evaluation is available for runway related procedures like IAP or SID. For each part of the procedure each available flight inspection receiver can be assigned to a Navaid to be checked. The complete AFIS setup for entire missions can be prepared in the office and loaded to the AFIS in the aircraft. Without any time pressure the operator can prepare the flight.

AFIS Data Evalutaion

The AFIS records and displays the flight track during the inspection overlaid to the reference procedure:

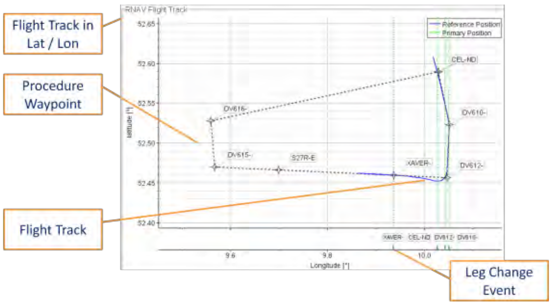


Figure 8. Procedure Track

Whenever a leg change occurs an event marking is automatically created. The event is labeled with the identifier of the just passed procedure waypoint.

The flight track plot is used for supporting pilots in their flyability evaluation.

If a procedure is directly related to a runway, the AFIS provides the flight track plot in an XYZ threshold coordinate system also:

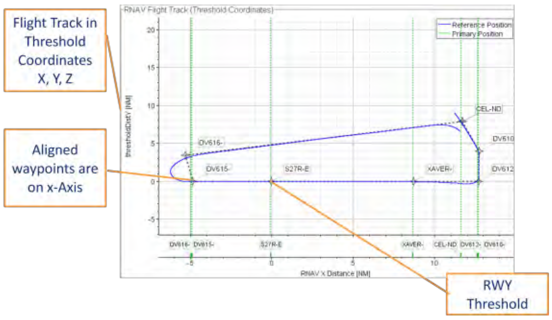


Figure 9. Procedure Track in Threshold Coordinates

The display of the flight track in threshold coordinates allows easy detection of final approach waypoints not being aligned with the runway. In such case the waypoint would be displaced from the X-axis of this graphic.

For each Navaid that has been setup for inspection during the procedure the corresponding flight inspection parameters are calculated, displayed and compiled in a report:

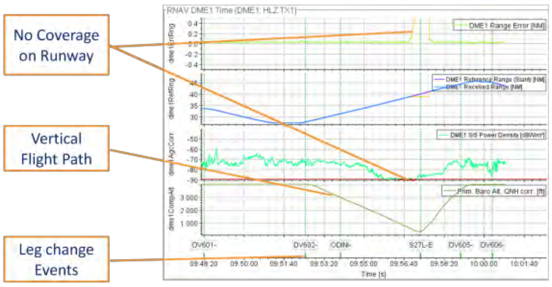


Figure 10. Navaid Graphic (Example: DME)

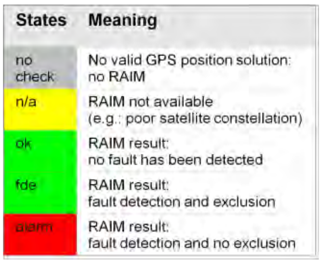
All relevant Navaid parameters are calculated and displayed e.g.:

- Alignment Error (VOR, TACAN)
- Range Error (DME, TACAN)
- Signal in Space Power Density

Leg change event marks allow easy correlation to the procedure legs. For VNAV evaluation the vertical flight path is displayed.

GNSS Procedure Inspection

Predicted availability of RAIM is mandatory for using GNSS based RNAV procedures. The AFIS provides detailed evaluation of RAIM :



States	Meaning
no check	No valid GPS position solution: no RAIM
n/a	RAIM not available (e.g.: poor satellite constellation)
ok	RAIM result: no fault has been detected
fde	RAIM result: fault detection and exclusion
alarm	RAIM result: fault detection and no exclusion

Figure 11. RAIM States

If during flight inspection of a GNSS procedure any unpredicted change of RAIM occurs a corresponding RAIM event is created:

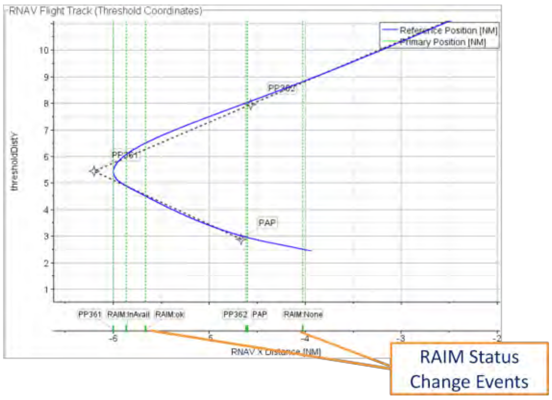


Figure 12. RAIM Change Events

An unpredicted change of RAIM state could be caused by a faulty satellite or interference. The RAIM events allow easy detection of such abnormal situations while flying the procedure. For subsequent detailed analysis of GNSS the AFIS provides a variety of GNSS data:

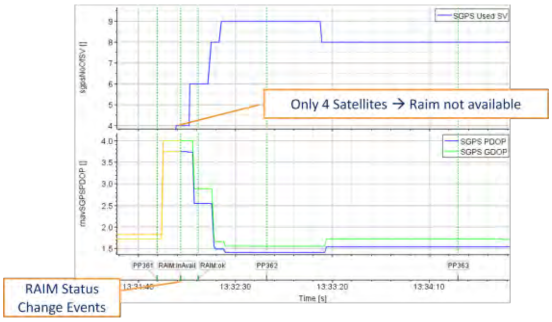


Figure 13. GNSS Analysis (DOP, NoSVs)

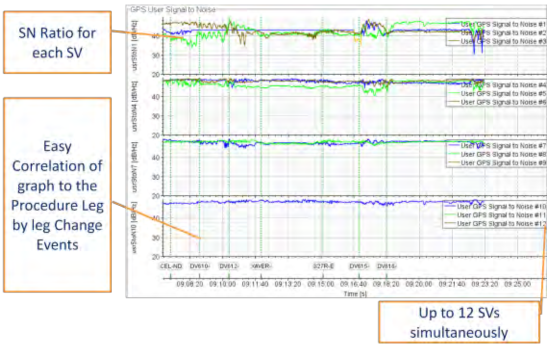


Figure 13. GNSS Individual Signal To Noise

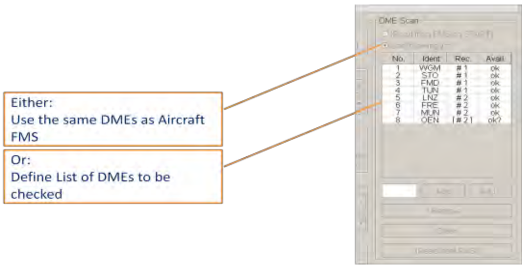
DME/DME Procedure Inspection

A typical AFIS integrates a dual installation of the AD-RNZ850 flight inspection receiver. Each AD-RNZ850 includes:

- VOR receiver
- ILS receiver
- MKR receiver
- DME interrogator

The DME part of each AD-RNZ850 provides 4 channel DME scanning capability; 8 channels are available in the dual installation.

Each of the eight DME channels can be assigned to an individual DME for inspection of DME/DME based procedures:



No.	Ident	Rec.	Avail
1	WGM	# 1	ok
2	STO	# 1	ok
3	FMD	# 1	ok
4	TUN	# 1	ok
5	LNZ	# 2	ok
6	FRE	# 2	ok
7	MUN	# 2	ok
8	OEN	[# 2]	ok?

Figure 13. Multi DME AFIS Setup

The DME channels can be coupled to the DMEs being scanned by the FMS or can be individually defined by the operator. Assigning all eight channels to the closest DMEs, even to DMEs that are unlikely can be received, allows to check the DME infrastructure along the procedure by just one flight.

Graphical display of Range Error, Ident and Lock Status are provided for each DME channel:

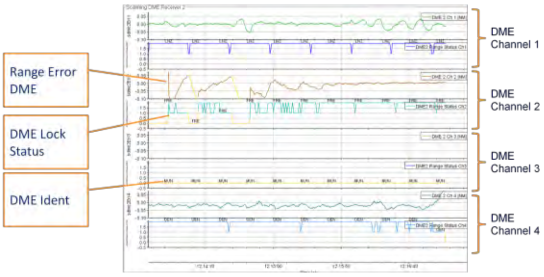


Figure 14. DME Scan Graphic

CONCLUSIONS

The implementation of new capabilities for efficient flight checking of instrument procedures as described in this paper provides the following benefits:

Reduction of Flight time required for procedure checks

- AFIS setup for complete mission can be prepared in the office
- Flight Procedure oriented AFIS setup
- Simultaneous check of various Navaids along the procedure
- Individual receiver assignment for each leg with automatic re-tuning
- 8 Channel DME Scan capability

Higher Integrity by automation:

- Arinc 424 database import function to AFIS
- Automatic check of FMS database

Simplified Data Analysis

- Correlation of Graphs with Procedure Leg
- Easy detection of non aligned waypoints
- Documentation of Flight Track in relation to nominal Procedure
- Detailed GNSS data for each SV
- Detailed access to RAIM status

REFERENCES

[1] ICAO, July 2006, International Standards and Recommended Practices, Annex 10 to the Convention on International Civil Aviation, Volume 1, Radio Navigation Aids, 5th Edition, http://www.icao.int

Regulatory framework and Aircraft avionics update for GNSS procedures verification

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ABSTRACT

AENA, the Spanish Navigation provider has been participating through different EC co-funded projects like OPTIMAL and GIANT in the introduction of GNSS based procedures in the commercial aviation. Furthermore, in the wake of the ICAO recommendation for the implementation of approach procedures with vertical guidance (APV) (Baro-VNAV and/or SBAS) for all instrument runway ends, either as the primary approach or as a back-up for precision approaches by 2016, this process has accelerated. Thus, it arise the need to verify these procedures before they are issued. In this frame Aena Internacional, the main Flight Inspection provider for AENA, has initiated a process to equip its Beechcraft Air King to flight and verify the first GNSS/SBAS procedures in Spain. This paper describes the changes implemented at FMS and Flight Inspection equipment level. It compares the different alternatives from the technical perspective, trying to fulfil the future requirements finding a balance with the budget. The paper will also review the regulatory framework for GNSS procedures verification.

INTRODUCTION

Regarding this kind of procedures it is important to say that in Spain preliminary experiences have already taken place through pan European projects like OPTIMAL, GIANT and ACCEPTA. Apart from the clear advantages of this kind of procedures, it has been definitive the impulse given at international level by the International Aviation Organization (ICAO) in its 36th Assembly of September 2007, recommending:

"*implementation of approach procedures with vertical guidance (APV) (Baro-VNAV and/or SBAS) for all instrument runway ends, either as the primary approach or as a back-up for precision approaches by 2016 with intermediate milestones as follows 30% by 2010, 70% by 2014*"

In this context AENA, the Spanish Air Navigation Service Provider asked our unit to equip the aircraft accordingly in order to validate the deployment of this new family of instrumental procedures.

FMS AND AFIS SYSTEM UPGRADE

In order to cope with the validation of SBAS based navigation procedures an upgrade of the Calibration aircraft King Air B300 was necessary at two levels; the Flight Management System (FMS) an the Automatic Flight Inspection System (AFIS) on board. The objective is to have, at the end of the modifications; a system (Aircraft/AFIS) able to validate flight procedures based in SBAS/EGNOS in particular LNAV/VNAV as well as LPV up to 250 feet (76m) minima.

The aircraft object of the upgrade is a Beechcraft B300 (Super king Air 300), S/N FL 255, registration number EC-KJQ, manufactured by Hawker Beechcraft Corporation of USA in 199, and purchased by Aena Internacional in July 2007 (see fig 1)

Figure 1. Aena Internacional FI aircraft

This model was selected because its suitability from the point of view of both performances and advanced avionics (Rockwell Collins Pro Line II).

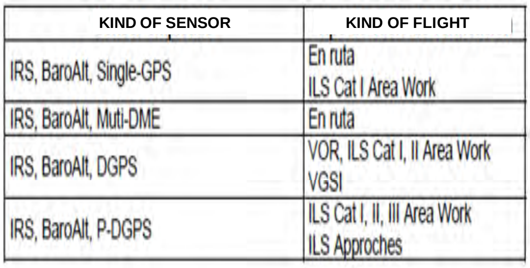
The aircraft was modified to hold an AFIS system manufactured by Aerodata AG from Braunsweig (Germany). The system is able to calibrate all conventional Nav aids (i.e. ILS Cat. I, II y III VOR/DVOR, DME, NDB), visual aids ((i.e. VASI & PAPI) and instrumental procedures standard and RNAV. In addition the aircraft has interference analysis capabilities as we will see later

Figure 2. AFIS console view

The AFIS system is equipped with its own positioning system independent of the aircraft. The primary positioning reference system is a combination of the data coming from an Inertial Reference Unit (IRU), differential GPS (DGPS), Dual frequency phase ambiguity differential GPS (PDGPS) and Air Data Computer (ADC), that allows performing In flight Calibration independently of the Meteorological condition and accomplishing with the requirements for up to ILS CAT III calibration.

The secondary positioning reference system is based in Scanning DME and Multi-DME), Inertial Reference System (IRS) and barometric altitude (BaroAlt). The Table 1 shows the different combinations.

Table 1. Positioning sensor Vs kind of Calibration



KIND OF SENSOR	KIND OF FLIGHT
IRS, BaroAlt, Single-GPS	En ruta ILS Cat I Area Work
IRS, BaroAlt, Muti-DME	En ruta
IRS, BaroAlt, DGPS	VOR, ILS Cat I, II Area Work VGSI
IRS, BaroAlt, P-DGPS	ILS Cat I, II, III Area Work ILS Approches

The current FMS is a Universal UNS-1c, containing a GPS receiver and connected to the autopilot Collins APC65J. The FMS is also connected to another GPS receiver Universal GPS-1000.

Neither of these receivers is SBAS capable (WAAS or EGNOS). In the other hand the AFIS receiver is a Novatel OEM4-G2L-L1L2W SBAS capable. This receiver cannot be MOPS compliant due to the need to have access to specific raw data. Currently AFIS software is not actually using that information for the Position solution.

Let´s see what was is the implemented solution to cope with those limitations. To make a proper trade-off we must take into account the requirement for aviation EGNOS receivers. For OACI, the term GNSS SBAS receiver describes the avionic achieving the requirements for SBAS in the Annex 10, Vol I and the specifications included in the RTCA MOPS (SBAS Minimum Operational Performance Standards) DO-229C (this is the accepted standard baseline for EGNOS) and the FAA (USA's Federal Aviation Agency) technical orders, TSO-C145A y TSO-C146A, or their European equivalents known as ETSO (European Technical Standard Order):

- ETSO-C145: Airborne Navigation Sensors using the GPS augmented by WAAS.
- ETSO-C146: Stand-alone Airborne Navigation Equipment using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS).

The equipment installation must accomplish with the guides established in the following documents:

- EASA CS: Certification specifications as per aircraft category. For the weight of our aircraft (6849 kg max. Weight):
  - CS-29: Certification Specification for Large Rotorcrafts (applicable to Category A and B units)
- EASA AMC: this document defines the so called "Acceptable Means of Compliance". These are means whose implementation assures that the equipment will achieve the standard specified performances, the RTCA DO-229C in our case. In this case the AMC 20-28 "Airworthiness Approval and Operational Criteria for RNAV GNSS approach operation to LPV minima". It defines the operational and airworthiness criteria for approaches RNAV GNSS with LPV minima including provisions for functional requirements accuracy and integrity, continuity and limitations. Currently the status of this document is

the “Proposed Amendment” and although its provisions are not yet incorporated in the EASA’s AMC 20 (its issue was expected by the end of 2011) they constitutes nonetheless a guide.

The RTCA DO-229C introduces two classifications (see Table 2). The functional one or how the equipment works in relation with avionic (classes beta, gamma and delta) and the operational one or to what phase of flight applies (classes 1, 2, 3 & 4).

Table 2. GNSS receiver classification matrix

Section		Must be met for Equipment Class						
		Beta			Gamma			Delta
		1	2	3	1	2	3	4
2.1.1	General Requirements	Y	Y	Y	Y	Y	Y	Y
2.1.2	Requirements for En Route/ Terminal	Y	Y	Y	Y	Y	Y	
2.1.3	Requirements for Nonprecision Approach	Y	Y	Y	Y	Y	Y	
2.1.4	Requirements for LNAV/ VNAV		Y	Y		Y	Y	
2.1.5	Requirements for Precision Approach (APV-II, GLS)			Y			Y	Y
2.2.1	General Class Gamma Requirements				Y	Y	Y	
2.2.2	Class Gamma En Route/ Terminal				Y	Y	Y	
2.2.3	Class Gamma Nonprecision Approach				Y	Y	Y	
2.2.4	Class Gamma LNAV/VNAV					Y	Y	
2.2.5	Class Gamma Precision Approach (APV-II and GLS)						Y	Y
2.3	Class Delta Requirements							Y

Regarding the AFIS system, as already mentioned, it incorporates already an SBAS/EGNOS capable receiver

From Table 2 we may easily conclude that to cover all kind of operations in the same architecture, we need an equipment Gamma, Class 3.

To facilitate the installation and in order to mitigate technological risks as well as to achieve the approval by EASA (a Supplemental Type Certificate issuing will be mandatory since this upgrade is considered a major change by EASA), it has been decided to choose an integrated architecture encompassing both the GNSS receiver and the FMS. In addition Universal manufacturer has been selected for compatibility reasons. This manufacturer has an equipment family WAAS certified, that is also applicable to EGNOS because of the homogeneity of the Standards. Models are UNS-1Ew, UNS-1Fw,UNS-1Lw.

Figure 3. FMS UNS-1Ew appearance

The three of them has similar performances but UNS-1Ew (see Figure 3)model is the selected one, due to its depth of 9 inches may allocate in the same box the display the navigation computer and the GNSS receiver. The shape factor is the same as the former FMS and the pedestal in the cockpit has enough depth as to allocate it (see figure 4).

Figure 4. FMS position in the pedestal

Following the manufacturer indications to be compliant with the safety requirements imposed in PART 25.1309, for integrity during approach phase of flight, it is mandatory to have dual SBAS receivers to achieve LPV minima in approaches.

To avoid installing two FMS UNS-1Ew, which in this case is not feasible because of space availability and budget constraints, Universal offers a remote unit called LP/LPV monitor. It is basically a second SBAS capable receiver giving redundancy to the one integrated in the FMS.

The LPV monitor will take the place of the GPS 1000 that worked with the old FMS (see Figure 5). This configuration allows also for the reuse of the old wiring GPS/FMS and the same bulkhead pass between avionic bay and cockpit (this is important to avoid structural re certifications)

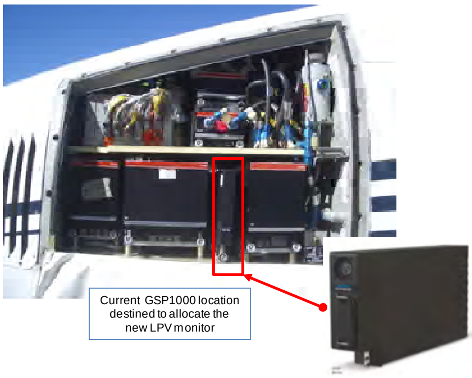


Figure 5. Position of LPV monitor

The other aspect to consider in the new configuration is the antennae subsystem. The FMS system has already two dedicated antennae, for the mentioned GPS 1000 and for the FMS integrated receiver.

These antennae are not SBAS compliant and must be replaced. Fortunately the new ones are similar in shape and the holes in the airframe may be reused avoiding again structural problems.

The more remarkable characteristics of the FMS UNS-1Ew, is that it may generate guiding displays, vertical deviation indications, it may send to the autopilot commands to generate totally coupled descents.

It also incorporates a huge database storing procedures STAR (Standard Terminal Arrival), approaches, runways, airways, intersections, Nav aids, airfields as well as the procedures that the pilot may define. It may store test databases. This feature is relevant in our case, because test databases are used in the validation process before the issuing the definitive one.

Regarding the AFIS system, as already mentioned, the GPS Novatel receiver is SBS/EGNOS capable, and is giving the proper information for RNAV GPS based procedures (i.e. RAIM alarms). Now we want the EGNOS position to be incorporated in the positioning solution. To that purpose the manufacturer Aerodata will incorporate it in a new evolution of the software. A new connection RS232 between the receiver and the AFIS real time computer will be also necessary.

Figure 6 shows a high level block diagram with the main interfaces between the aircraft avionic and the AFIS. It shows the major elements suffering the upgrades namely the new FMS and LPV monitor (SBAS certified) and the software evolution in the AFIS to make I able to use EGNOS data in the position reference solution.

The use of standard ARINC 429 for the interfaces, as can be seen in the Figure 6, makes it simpler the units upgrade.

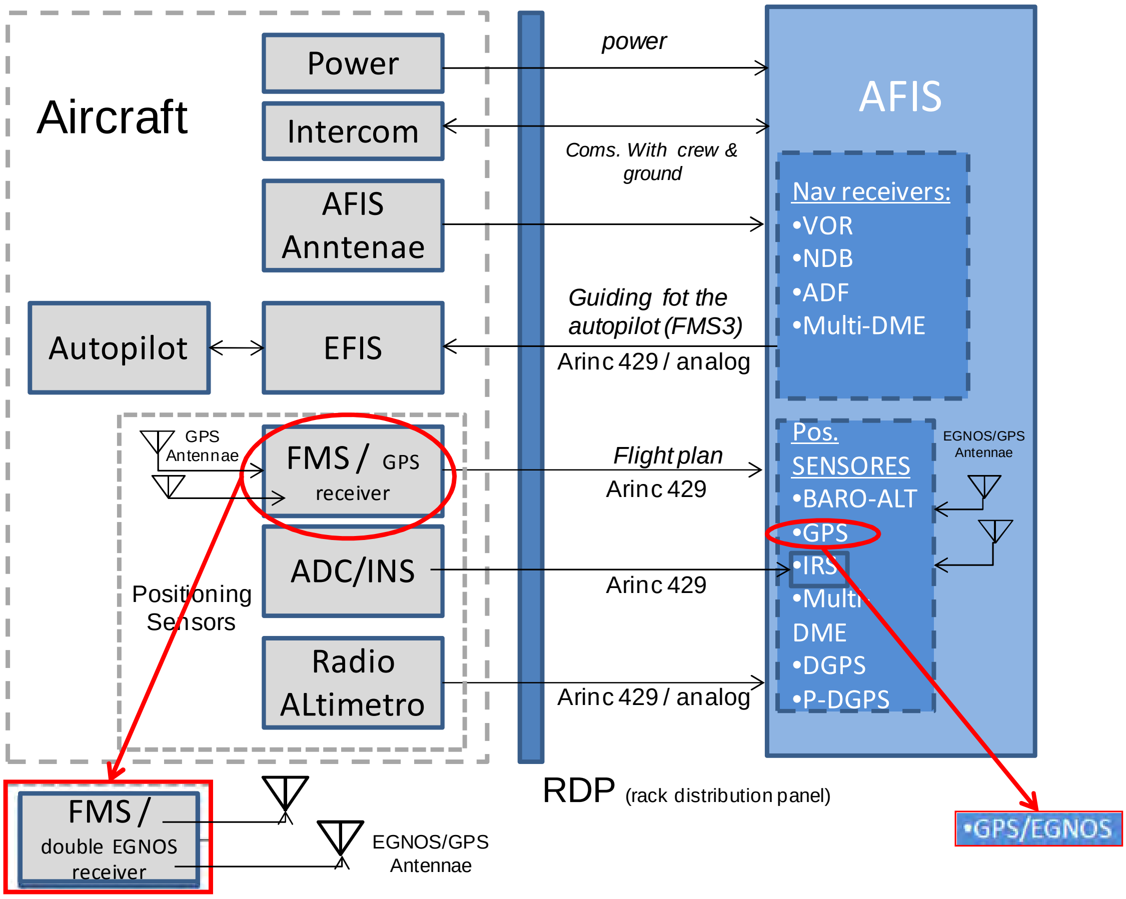


Figure 6. Aircraft avionics/AFIS block diagram evolution

Finally for safety reasons, another required modification will be the addition of LPV annunciators in each cockpit panel in the primary field of view of the pilots, via EFIS or external as will be our case see Figure 7.

Figure 7. LPV annunciators

SBAS PROCEDURES VALIDATION

The following figure depicts the process of generation of a new procedure in Spain. As can be seen, the flight validation enters into action before the procedure is sent to the inter-ministerial commission (Transports/Defence) for final approval (see figure 8).

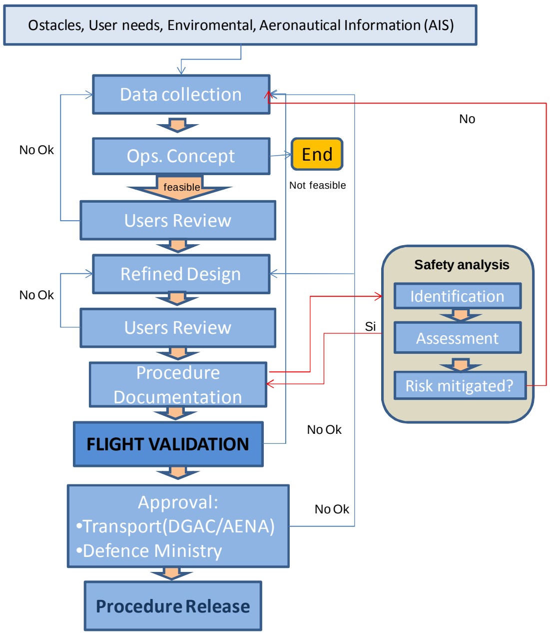


Figure 8. Procedures Validation process

In this section the regulatory grounds for the validation process in the European frame, will be reviewed. The main regulation emanates from ICAO from the point of view of the validation process:

"Manual on Testing of Radio Navigation Aids" doc 8071 de ICAO, Vol I, "Testing of Ground – based Radio Navigation System"

- Chapter 8: "Flight inspection of instrument flight procedures" in particular 8.3.15 to 8.3.18, for "Area navigation (RNAV)"

"Manual on Testing of Radio Navigation Aids" doc 8071 de ICAO, Vo II,: "Testing of Satellite – based Radio Navigation System"

- Chapter 1, General purpose requirements applicable to all GNSS based procedures. Includes annex 2 with requirements for the aircraft dedicated to the validation of those procedures and annex 3 regarding RF interferences.
- Chapter 3, deals with Tests/FI of SBAS
- Chapter 5, on validation of instrumental flight procedures in general.

PANS-OPS, Volume II, ICAO Part 1, Section 2, Chapter 4, Quality Assurance 4.6.3 Flight validation

The Verification process must be focused on assuring that Radio-navigation System are compliant with SARPs (Standards and Recommended Practices) of ICAO Annex 10, Volume I. In particular with the ones in:

- Chapter 2.4(Global Navigation Satellite System)
- Chapter 3.7 (Requirements for GNSS)
- Attachment D (Information and guiding material for application of SARPs for GNSS

Eurocontrol has produced the document, "Guidance Material for the Flight Inspection of RNAV Procedures". It intends to supplement the ICAO 8071 document giving guiding on specific aspects of RNAV procedures.

The JAA (Joint Aviation Authority) as the regulatory authority in aviation matters in the European Union except for Safety issues (in charge of EASA) has produced a regulation concerning in some aspects with PRNAV operations.

- Airworthiness and Operational Approval for Precision RNAV Operations in Designated European Airspace: JAA TGL 10 (Temporary Guidance Leaflet). Para el autopilot

Finally another regulation of reference although from USA's Federal Aviation Agency (FAA):

- US Standard Flight Inspection Manual (FAA 8200 I-C).

VALIDATION PRINCIPLES

The GNSS/SBAS RNAV procedures must as the conventional ones validated in flight. Following the regulations from previous section, we may say that this process is supported in three pillars:

- Identification of RF interference presence in the L1 frequency (1575,42 Mhz).
- Verification of the accuracy of the waypoints included in the procedure and in the case of the LPV approaches the Final Approach Data Segment (FAS, data blocks).
- Documentation of the procedure flyibility.

This validation process is a combination of subjective assessments made by the flight crew and analysis of data gathered during the flight.

L1 RF spectrum monitoring and interference detection

In the first place it must be said that the quality of the signal in space itself, must be taken care of for the service provider (i.e. European Satellite Service Provider for the case of EGNOS), thus function of the flight validation will be verify that the radio electric environment in that geographical area is free from interferences that may affect the SBAS signal. The RF distortions may proceed from external RF sources or from multipath in the GNSS signal due to reflections in the surrounding man made or natural infrastructures.

RF Interferences may come from electronic and telecommunications systems that are operating in adjacent bands, or bands relatively far from the GPS, such as harmonics of FM, TV, AM stations and mobile networks

• Harmonics and inter-modulation products from of TV stations carriers.

• The mobile satellite service (i.e. Iridium, Thuraya) operating in bands adjacent to GNSS, or the fixed service operating in the GNSS band in some states.

• Most networks use coaxial cables that may leak radio signals, causing interference.

• High power military radar, can generate enough power harmonics to cause interference

Special attention must be paid to harmonics, especially within the 10 MHz GPS/EGNOS signal in the L1 band (1575.42 MHz). If it is suspected the presence of RFI interference, geographic area throughout the procedure should be evaluated in the domain of the spectrum, time and signal/ noise ratio.

To accomplish with this task the AFIS system is equipped with a "Direction Finder", consisting of a Cubic receiver 4400 (see Figure 9), highly integrated into the AFIS system. Its sensitivity ranges from 0.1 MHz to 2.0 GHz, therefore it will be useful for detecting interference in the L band and hence in the L1 GPS/SBAS signal.

Figure 9. AFIS DF Cubic 4400

To locate the RF interferences, this receiver is connected to an array or set of L-band antennas, sensitive from 800 MHz to 2000 MHz (see Figure 10), located in the belly of the plane, nadir looking to be able to directly receive the ground coming interferences. The four antennas are arranged in a cross shape for “playing” with the phase different of the signal reaching each one of them, allowing locating the direction of the tuned signal. Moreover the intersection of successive received courses (DF cross-bearing) on the plane, allows estimating the distance of the plane to the interfering source and therefore the geographical coordinates.

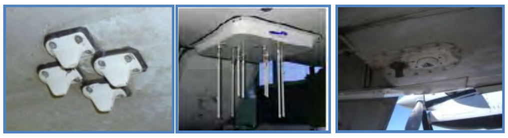


Figure 10. DF antenna arrays

The DF receiver can also be connected interference detection to antennae arrays in the VHF (30 to 300 MHz) and UHF (300 MHz to 3 GHz) bands. These are also located in the belly of the plane, as shown in Figure 10 and have vertical polarization (most of the interferences comes from the horizontal component of vertical polarized non aeronautical signals). The initial purpose is to use them to detect interference in aeronautical communications band and certain terrestrial radio Nav aids.

In principle, these bands are outside the GPS / EGNOS FRECUENCIES. However since, as we have seen, sometimes the interference comes from harmonics generated by emissions from these bands, it may be a complementary tool for tracing the source of the unwanted signal.

In this interference detection task, these antennae sets as well as the navigation GPS ones may be connected in flight, to Spectrum Analyzer and oscilloscope respectively, to observe the interference in both the frequency and time domains.

As benchmarks to inspect the radio environment, the already mentioned RTCA MOPS DO-229C, in its Appendix C, specifies the IRF environment around the L-band frequencies by means of a RF interference mask

Once the presence of the interference has been detected, we may want to find it and isolate it in order to let the competent authorities to eliminate it (whether it is intentional or accidental).

Here bellow in Figure 11, an example of interference finding test making use of the mentioned tools is presented. It was carried this year on January, in our base, Matacán (Salamanca), with an emitter in the 1250 Mhz frequency. Apart from the bearing and range data that the DF shows in real time, that info is passed to the AFIS SW, allowing to record it and to present guidance information to the pilots. It is the so called FMS 3 option in the FMS menu.

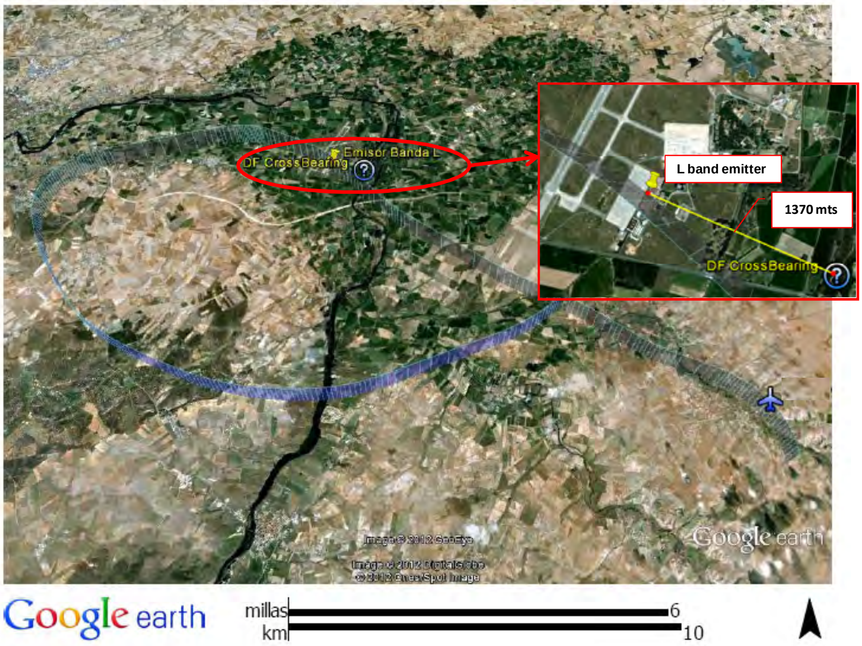


Figure 11. L1 band interference detection test case

GPS/EGNOS Noise/Signal ratio

One way to assess the potential impact of RF interference in the received signals is to compare the received spectrum against the masks specified in ICAO SARPs. If no continuous wave (CW), is detected, the environment can be considered satisfactory. Interference masks are valid only for CW interferences that are the ones we will we face more frequently. For wideband or impulse signals that exceed the mask interference, it will be necessary further analysis and post-processing of the spectrum.

Another effective and subjective way to observe the interference on GNSS signals is monitoring the signal to noise ratio for each satellite in view of the receiver. The so-called window of minimum signal to noise ratio can be used to assess the presence of moderate RF interference and determine if they pose a problem for the operation. We are talking about interferences that are not strong enough to prevent the receiver to acquire and follow the various satellites of the constellation in view, but that can degrade the performance of GNSS.

Some authors have proposed a threshold value based in different field test. A technical memorandum by the University of Ohio for the FAA [1], suggest that C/N value should be greater than 30dB along the most part of the time.

The AFIS system may monitor and record the SRN values for each used SV. figure bellow shows an example.

Figure 12. S/N or C/N values for the acquired GPS sats

The chart corresponds to a real flight and as can be seen, for all satellites the C/N value is above 40 dB which would be an indication of a favourable radio electric environment for reception of GNSS signals.

Verification of Way Points

The FI aircraft must fly the RNAV procedure following the ground track proposed by the designer. It may use a FMS with RNAV functions like the one being implemented, with the procedures coded in ARINC 424 format and packed for the specific FMS. For this purpose a special test database will be provided. Once the procedure is validated it is incorporated to the Spanish AIP.

On the other hand the AFIS, allows us to introduce the procedure waypoints or to take them from the FMS database. From, the 3 main components of the Total system error shown in Figure 13, "path definition error" (PDE) may be considered negligible, provided that there are no errors in the database generation or population. "The flight technical error" (FTE) may be minimized by using autopilot coupled with the FMS.

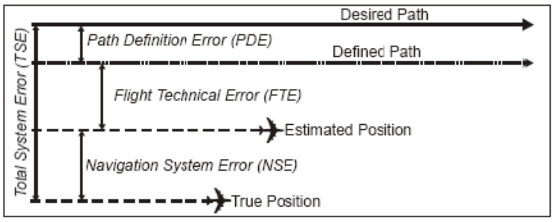


Figure 13. Navigation Total system Error components

This coupling feature is strongly recommended by different regulations on RNAV capabilities. In the case of precision approaches with Final Approach Data block (FAS DB) it is mandatory:

- JAA (Joint Aviation Authorities), through its Temporary Guidance Leaflet (TGL) 10, Airworthiness and Operational Approval for Precision RNAV Operations in Designated European Airspace
- El US Standard FI Manual (FAA 8200 I-C) in its section 13.12a
- FAA Advisory Circular AC 90-105

In this context NSE value, as the difference between the real position of the aircraft and that provided by the navigation system or FMS, is our parameter of interest. In fact this is the value whose integrity protects the EGNOS system or RAIM techniques. It can be said that the existence of an event of no integrity corresponds to a situation in which a user NSE in the vertical or horizontal direction, is greater than the vertical alert limit (VAL) or horizontal alert limit (HAL), respectively, without the system providing valid warning messages on time (Time to alarm) [2].

SARPs for GNSS, gathers these limits for each phase of flight [3].

To assess this error, the AFIS system compares the position provided by the FMS (which tries to fly the flight plan stored in the database) with the reference position it generates, using various sensors, including the GPS/EGNOS

Flyability

Although many parameters of the procedure have been verified in the design phase, some checks may only be performed in flight by the pilots themselves, in a subjective way, flying the procedures with a FMS equipped with SBAS receivers.

The Flyability has a close relation with the safety of the procedure. As prescribed in ICAO document 8071 Vol II, the procedure must be evaluated to ensure compliance with safe operating practices and a reasonable level of workload for the flight crew. Expanding on the concept, we can say that it is a verification or system of verification that ensures that the procedure can be flown safely and as designed. The checks include, among others: compliance with the design criteria of the procedures, roll angles, vertical profile, air velocity, gradient descent, flight distances, speeds, levels of cockpit workload, complexity of procedure, etc.

Obstacles clearance is made in a visual way while flying the procedures.

SELECTION OF PARAMETERS FOR IN FLIGHT MONITORING

It has now reached a consensus on the parameters to be recorded, during the validation of GNSS procedures, based on the experience of the client, AENA. There is a first set of them which are common to all procedures:

• Time and 3-D position as a function of time recorded with a frequency adequate (at least 1 Hz).

• Head, pitch and roll angles of the plane as a function of time, to explain loss of GPS signals

• Electronic and graphic file that containing the horizontal and vertical track of the path followed, referenced to the desired path included in the flight procedures, including "procedures fixes"

• Pseudoranges and GPS satellite almanac (1Hz)

• Number of GPS satellites in view and used a function of time

• Signal to Noise (C/N) of the observed GPS signals as a function of time.

• Minimum number of GPS satellites during flight validation

• For each flight segment, the maximum and minimum altitude, the ground speed and "climb rate" and "climb gradient"

• Flag for interference detection (an event is recorded when you register an interference)

• Graphs and tables recommended for inclusion in the report of flight validation of procedures using as GNSS sensor:

- Chart including the path followed referenced to the desired trajectory
- Minimum and maximum altitude
- Ground Speed
- Climb rate and climb gradient

Table 2, includes the parameters required for every specific kind of GNSS procedure.

Table 2. GNSS specific Parameter list

Type of Procedure	Type of Navigation Specification	GNSS Sensor	Parameters to monitor and record
Airways or Enroute	B-RNAV(GNSS)	GPS + RAIM	-Position Dilution Of Precision (PDOP) as a function of time - Max. observed Horizontal Dilution of Precision (HDOP) as a function of time - Identified RAIM alerts
		GPS + EGNOS	
Departures (SID) & arrivals (STAR)	P-RNAV (GNSS)	GPS + RAIM	- The same as for Airway or Enroute with GPS sensor + RAIM
		GPS + EGNOS	-The same as for Airway or Enroute with GPS sensor + EGNOS
Approach	RNP APCH, LNAV (GPS NPA) minima	GPS + RAIM	-Position Dilution Of Precision (PDOP) as a function of time -Max. observed Horizontal Dilution of Precision (HDOP) as a -function of time -Identified RAIM alerts -Max. observed Vertical Dilution of Precision (VDOP) as a function of time
		GPS + EGNOS	-PRN of the used GEO -EGNOS message received as a function of time -Position Dilution of precision (PDOP) as a function of time -Max. observed Horizontal Dilution of Precision (HDOP) as function of time -Horizontal Protection Level (HPL) value as a function of time -Max. observed Vertical Dilution of Precision (VDOP) as a function of time -Vertical Protection Level (VPL) as a function of time
	RNP APCH, LNAV-VNAV (APV Baro) minima	H: GPS + RAIM V: Baroaltimeter	-Position Dilution of precision (PDOP) value as a function of time -Max. Observed Horizontal Dilution of Precision (HDOP)as a function of time -Identified RAIM alerts -Max. observed Vertical Dilution of Precision (VDOP) as a function of time -Barometric information used for the vertical guidance as a function of time -QNH (TBC)
		GPS + EGNOS	-PRN of the used GEO -Received EGNOS message as a function of time -Position Dilution of precision (PDOP) as a function of time -Max. observed Horizontal Dilution of Precision (HDOP) as a function of time -Horizontal Protection Level (HPL) value as a function of time -Max. observed Vertical Dilution of Precision (VDOP)as a function of time -Vertical Protection Level (VPL) as a function of time
	RNP APCH, LPV (APV SBAS) minima	GPS + EGNOS	-PRN of the used GEO -EGNOS message received as a function of time -Position Dilution of precision (PDOP) as a function of time -Max. observed Horizontal Dilution of Precision (HDOP) as a function of time -Horizontal Protection Level (HPL) value as a function of time -Max. observed Vertical Dilution of Precision (VDOP) as a function of time -Vertical Protection Level (VPL) as a function of time

Conclusions

An upgrade of a system AFIS/Aircraft for validation of SBAS based procedures has been presented along with the trade-off for the best technical solution while observing the relevant regulations.

The regulatory frame for the flight validation has been reviewed and a guideline for SBAS flight procedure validation in Spain derived. The regulatory framework is currently under development and results at this point are very vague to have a clear picture about the future requirements for SBAS Procedures Flight Validation.

The improvement in the reference position solution accuracy by adding EGNOS data could potentially enable the flight inspection of ILS Cat I as well as PAPI without on ground support for DGPS/PDGPS. This must be evaluated by on flight tests.

FUTURE WORK

By the time of the writing of this paper, the first SBAS based procedures implemented in Spain, should have been validated, but due to some delay in the final design, the flights will take place by June of this year, so the results of the firsts GNSS/SBAS based procedures verification flights in Spain must be evaluated in order to refine all aspects of the process.

ACKNOWLEDGMENTS

I wish to express my appreciation for the advice and help given by the flight inspectors of the Aena Internacional Calibration Unit:

Carlos Gimenez, Eduard Marín and Sajeel Ahmed

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Combined GNSS Position Reference for Flight Inspection

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ABSTRACT

The ongoing establishment of new and the renewal of the existing Global Navigation Satellite Systems (GNSS) leads to an enormous increase of available data sources for positioning of flight inspection aircrafts in the near future.

The accuracy, availability and reliability of the positioning results are quite dependent on the number of visible satellites.

Since GPS alone is a vulnerable system and does not provide sufficient coverage in high latitude regions, integrate positioning is used to improve the geometry of the position estimation. The benefit for flight inspection from such integration is dramatically.

The use of fully combined observations from the GPS and GLONASS systems pave the way for more accurate and reliable real time positioning systems. World-wide reliable reference position for flight inspection means the future integration of GALILEO observations as well as the integration of the new triple-frequency signals from the latest generation of GPS satellites additionally.

This paper points out the benefit of combined GPS, GLONASS, COMPASS and future GALILEO systems to hybrid flight inspection position reference regarding accuracy, availability and integrity.

INTRODUCTION

On July 17, 1995 the U.S. Air Force Space Command (AFSC) formally declared the United States NAVSTAR Global Positioning System (GPS) satellite constellation as having met the requirement for Full Operational Capability (FOC). Requirements include 24 operational satellites functioning in their assigned orbits. In September 2008 the U.S. Department of Defence (DoD) declared the Standard Positioning Service (SPS) providing a global average position domain accuracy of ≤ 9 meters (95 percent) horizontally and ≤ 15 meters (95 percent) vertically base on the 24 satellite constellation [1]. Today with 31 GPS satellites available the GPS accuracy even exceeds the published standard by approximately a factor 4.

The limits for the GPS are given by its poor coverage at high latitude regions. An indication for the quality of the system's availability is the Geometric Dilution of Precision (GDOP) as a measure for the geometry of the satellites in view (SV) [2].

An increase of the number of satellites by adding one or even more Global Navigation Satellite Systems (GNSS) helps to overcome those limitations.

Such combination of GNSS, which can be made by use of GPS, the Russian *Globalnaya Navigatsionnaya Sputnikovaya Sistema* (GLONASS), the Chinese 北斗卫星导航系统 (COMPASS) and in near future the European Community "Galileo" satellite navigation system, will increase globally the accuracy of position determination by single receiver usage (SGNSS), by use of differential techniques (DGNSS) and by use of ambiguity solution based phase differential techniques (PDGNSS).

GNSS STATUS AND FUTURE AVAILIBILITY

As of October 2011, only GPS and GLONASS are fully globally operational satellite navigation systems. China is in the process of expanding its regional Beidou navigation system into the global COMPASS navigation system by 2020. The European Galileo is in an initial deployment phase, scheduled to be fully operational by 2020. Several regional navigation systems are in the process of developing, i.e. the French Doppler

Orbitography and Radio-positioning Integrated by Satellite (DORIS), the Japanese Quasi-Zenith Satellite System (QZSS) and the Indian Regional Navigational Satellite System (IRNSS).

Table 1 shows an overview of the current (GPS and GLONASS) and planned (COMPASS and Galileo) GNSS constellation status.

Table 1. Current and Planned GNSS Constellation

	GPS	GLONASS	COMPASS		Galileo
Number of SV	31	24	27	3	30
Orbital Planes	6	3	3	3	3
Inclination	55°	64.8°	54.8°	55°	56°
Height	20,200 km	19,100 km	21,500 km	36,000 km	23,200 km
Period of Revolution	11 h 58 min	11 h 15 min	12 h 35 min	24 h	14 h 07 min

Status of GPS

The U.S. NAVSTAR GPS provides currently the use of 31 satellites, whereby already 9 Block IIR(M) satellites are equipped with a second civil signal (L2C) and additional two Block IIF satellites utilize L2C and transmit on a third (L5) frequency.

The current modernization of GPS satellite will last in 24 SV with L2C approximately in year 2016 and 24 SV with L5 approximately in year 2020 [3].

L2C enables the use of ionospheric correction for greater position accuracy and robustness as well as faster signal acquisition, enhanced reliability and greater operation range than the current L1 C/A-code signal [4].

L5 will be broadcasted with higher output power and wider signal bandwidth in the protected Aeronautical Radio Navigation Services (ARNS) band to improve jam resistance. It supports the calculation of ionospheric correction with use of all three frequencies in parallel. Robustness of position calculation using differential or phase-differential techniques will be increases as well via signal redundancy.

Status of GLONASS

GLONASS has currently 24 satellites in operation including the first GLONAS-K type as first representative of the next generation GLONASS satellites.

From 2012 to 2020 the system will be modernized by adding code-division multiple access (CDMA) to the existing frequency-division multiple access (FDMA) [5]. This will result in a significant quality improvement and easier combination to other existing GNSS.

Status of COMPASS

COMPASS is designed to facilitate 30 satellites in final operation. Currently, nine satellites are already in geostationary orbit (GEO) and inclined (55°) geosynchronous orbit (IGSO) supporting mainly the Asia-Pacific region.

Until the year 2020 COMPASS will be developed to form a global positioning system using 5 GEO, 3 IGSO and 27 medium Earth orbit (MEO) satellites.

Status of Galileo

Galileo is planned to operate with 30 MEO satellites in the year 2020. However, only three experimental satellites GIOVE-A, GIOVE-B and GIOVE-A2 are launched for the in orbit validation phase up to April 2012.

GDOP CALCULATION

The current status of the GNSS allows the usage of 31 GPS satellites, 24 GLONASS satellites and 9 COMPASS satellites. The three experimental Galileo satellites are not considered here.

The following example calculations for five dedicated locations distributed around the globe show the above mentioned increase of GDOP near to the equator, in moderate latitude regions and high latitude regions. All calculations are made for the GNSS constellation of April 21, 2012 whereby the time zones are adapted to the locations. The time interval is 30 minutes. The elevation mask is set to 7°.

Punta Arenas, Chile (S 53° 00' / W 70° 51')

Calculation of the GDOP for GPS, GLONASS and COMPASS coverage for a location in high southern latitudes in South America results in the values shown in Table 2.

Table 2. Number of SV and GDOP Punta Arenas

	Number of SV			GDOP		
	Min.	Max.	Average	Min.	Max.	Average
GPS	7	12	10	1.38	2.81	1.86
GPS & GLONASS	15	20	18	1.22	1.81	1.45
GPS, GLONASS & COMPASS	15	22	18	1.22	2.06	1.59

Sydney, Australia (S 33° 51' / E 150° 12')

Calculation of the GDOP for GPS, GLONASS and COMPASS coverage for a location in moderate southern latitudes in Australia results in the values shown in Table 3.

Table 3. Number of SV and GDOP Sydney

	Number of SV			GDOP		
	Min.	Max.	Average	Min.	Max.	Average
GPS	7	12	10	1.43	5.30	1.97
GPS & GLONASS	14	20	17	1.38	2.23	1.62
GPS, GLONASS & COMPASS	20	28	23	1.32	2.05	1.58

Djakarta, Indonesia (S 6° 11' / E 106° 50')

Calculation of the GDOP for GPS, GLONASS and COMPASS coverage for a location near to the equator in the Southeast-Asia region results in the values shown in Table 4.

Table 4. Number of SV and GDOP Djakarta

	Number of SV			GDOP		
	Min.	Max.	Average	Min.	Max.	Average
GPS	9	13	10	1.33	2.37	1.82
GPS & GLONASS	15	20	18	1.25	1.95	1.50
GPS, GLONASS & COMPASS	24	29	27	1.30	1.77	1.49

Astana, Kazakhstan (N 51° 10' / E 71° 25')

Calculation of the GDOP for GPS, GLONASS and COMPASS coverage for a location in moderate northern latitudes in Central Asia results in the values shown in Table 5.

Table 5. Number of SV and GDOP Astana

	Number of SV			GDOP		
	Min.	Max.	Average	Min.	Max.	Average
GPS	9	13	10	1.27	2.81	1.88
GPS & GLONASS	16	21	18	1.17	1.98	1.49
GPS, GLONASS & COMPASS	20	26	23	1.28	1.90	1.55

Longyearbyen, Norway (N 78° 13' / E 15° 38')

Calculation of the GDOP for GPS, GLONASS and COMPASS coverage for a location in high northern latitudes in Europe results in the values shown in Table 6.

Table 6. Number of SV and GDOP Longyearbyen

	Number of SV			GDOP		
	Min.	Max.	Average	Min.	Max.	Average
GPS	9	14	11	1.60	2.82	2.11
GPS & GLONASS	18	23	20	1.40	1.92	1.60
GPS, GLONASS & COMPASS	19	25	22	1.59	2.35	1.90

BENEFITS FOR POSITIONIING TECHNIQUES

Stand-Alone Positioning

GNSS stand-alone position calculation bases mainly on determination of the range between a number of satellites and the receiver's antenna. With a sufficient number of ranges and the known position of the satellites the receiver position is geometrically defined. The range measurements are made by propagation time measurement of the satellite signal.

Thus, a minimum of four satellite signals are needed to solve the position unknowns, i.e. three coordinates of user position, and the time unknown, i.e. the biases of the receiver clock, in the navigation equations. With the combination of GNSS additional time unknowns must be considered as the global navigation systems use different time systems. Nevertheless, the combination of GPS, GLONASS and COMPASS leads to abundant redundancy in the navigation equations, because of the high number of available satellites.

With the increase of satellite availability for positioning all GNSS applications which are normally constrained by obstructions will benefit, e.g. positioning in urban canyons.

The use of GLONASS satellites ensures position determination in high latitudes on a larger scale.

Differential Positioning

Differential techniques were used with satellite navigation systems from the very beginning to enhance the accuracy of the position calculation. For this two receivers are needed, one on a fix reference position and the other, that's position needs to be determined. If both receivers are fairly close to each other, the signals reaching their antennas will have passed the same part of atmosphere, and so will have the same errors. All errors not relating to the receivers itself, i.e. multipath effects and receiver errors, can be calculated on the reference site and can be applied to the mobile receiver either by postprocessing or radio transmission.

An other differential method uses the calculation of pseudorange errors. It calculates pseudorange corrections (PRC) and pseudorange rates (RRC) for each satellite by use of the reference receiver's position. For transmission the international standard RTCM SC-104 is used since the early 1990's. Position calculation of a mobile rover receiver is accurate up to 1.0 to 2.5 meters in a 70 km to 200 km range to the reference station, but it is depending on:

- the quality of the reference receiver,
- the quality of the rover receiver,
- the communications bandwidth,
- the distance from reference to rover and
- the local effects at receiver's site.

The accuracy of the reference receiver's position calculation to determine the non-receiver related error sources is related to the geometry of the satellites used for calculation. Thus, an increase of satellite availability resulting in low GDOP by using combined GNSS improves the overall accuracy of differential position calculation. It raises the reliability and robustness of the rover's position.

These enhancements will support the regional operating Space Based Augmentations Systems (SBAS), as namely the U.S. Wide Are Augmentation System (WAAS), the European Geostationary Navigation Overlay Service (EGNOS), the Indian GPS Aided Geo Augmented Navigation (GAGAN), the Japanese Multi-Functional Satellite Augmentation System (MSAS) and also the locally operating Local Area Augmentation Systems (LAAS) and Ground Based Augmentation Services (GBAS). The main advantage is the redundancy in additional information for determination of ionosphere corrections from other then the original GNSS.

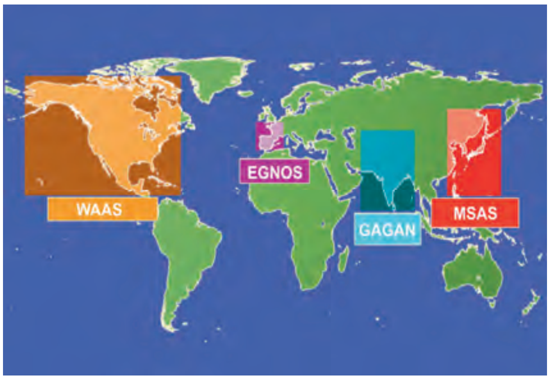

Figure 1. SBAS Coverage

Ambiguity Resolution

Most accurate results in differential position calculation is done by carrier-phase differential techniques. Hereby the number of full carrier cycles, so called ambiguities, between satellite and receiver are counted. Since the uniformity of the carrier cycles, the determination of the correct number of full cycles is difficult. Therefore, the search area for the ambiguity search is reduced by other methods, e.g. code differential position calculation, differential observations, frequency linear combinations and float ambiguity resolution.

Differential observations are constructed to cancel common effects shared by signals travelling from a satellite through different paths to the reference receiver and the mobile receiver antennas, between satellites and between stations as well as between observations of different epochs. Mainly the satellite clock error is cancelled and the tropospheric and ionospheric delay residuals are negligible as the antennas are close together [7]. Cycle slips are detected and preliminary site coordinate solutions are obtained by this observations.

Linear combinations of simultaneous observations between frequencies are used to determine the integer ambiguities. Subtraction or addition of the signals lead to longer (wide lane) or smaller (narrow lane) wave length with dedicated advantages for the ambiguity resolution. Even ionospheric-free and geometry-free signals can be formed.

It is important to determine the correct integer ambiguity, because an error of even one cycle on a single satellite can result in a position bias of many centimetres or decimetres while the user believes the position is much more accurate.

Once the integer ambiguity is fixed and verified at the reference receiver, phase differential corrections are calculated and applied to the mobile rover receiver either by postprocessing or radio transmission. The accuracy of the rover's position is in local areas in the range of centimetres to decimetres even for real-time applications.

The combination of different kind GNSS gives a number of benefits for the ambiguity resolution.

It results in smaller search areas using code measurements and Doppler count methods. Independent search areas are calculated for redundancy and reliability checks.

With availability of GLONASS CDMA observations the number of combinations for single, double and triple differencing increases dramatically. Adding GLONASS observations in a high-precision GNSS solution can certainly improve positioning performance compared to GPS alone [8].

In future GNSS with multiple frequencies geometry-free and ionospheric-free linear combinations become available. Triple-frequency combinations of phase measurements can be translated into linear relationships between phase ambiguities to set limits to ambiguity resolution algorithms. This will lead to simplification and performance improvements [9].

Statistical tests or consideration of changing satellite geometry over a time to validate the ambiguity resolution are supported by the greater number of observations. It results in a higher confidence level and faster reliability checks.

The performance of On-The-Fly (OTF) ambiguity solution using combined GPS/ GLONASS with a mask angle of 30 degrees is similar to that of GPS with a mask angle of 10 degrees [10].

BENEFITS FOR FLIGHT INSPECTION

The flight inspection aircraft reference position relies on the positioning techniques described above. It uses code differential, DGNSS or PDGNSS methods in combination with other sensors, like inertial reference systems (IRS), attitude and heading reference system (AHRS), air data computer (ADC), radio altimeter (RadAlt) or even optical instruments, i.e. Laser Tracker or theodolite.

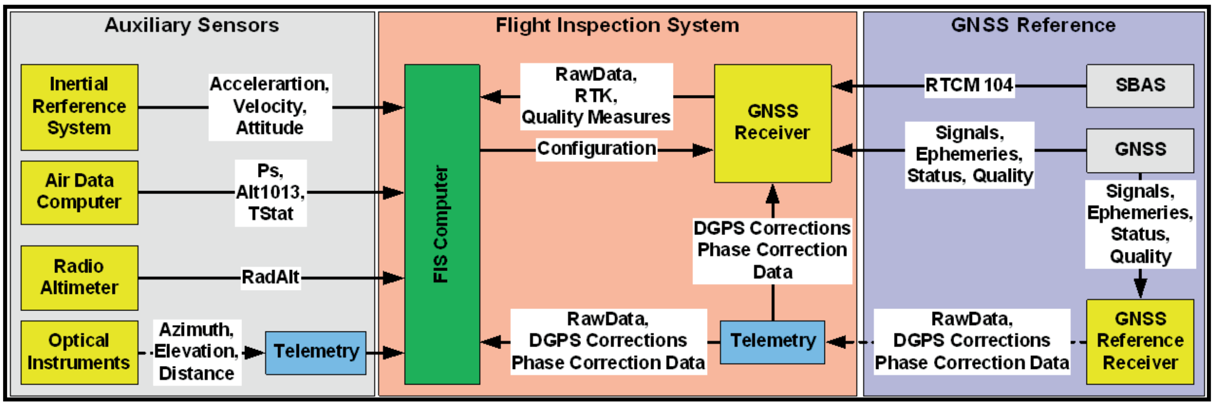

Figure 2. Integrated Flight Inspection System Position Reference

Therefore, all the benefits as described in the chapters above will enhance reliability and integrity of the flight inspection aircraft's position determination. Especially during high dynamic manoeuvres of the aircraft the avoidance of signal loss can improve the overall performance.

Flight inspection of GNSS related procedures as RNAV, non-precision approaches (NPA), SBAS procedure inspection as well as inspection of GBAS and LAAS stations is only secondarily affected, since the benefit comes from the already mentioned improvements of the aircraft position calculation.

CONCLUSION

Starting from the simple approach to have a number of 64 GNSS satellites available today, and finally ending in an approximately 100 satellite GNSS constellation in the year 2020, it is shown, that the advantages for the users are numerous.

The GDOP as one main parameter for the estimation of position accuracy will improve for all regions of the globe. Positioning techniques will reap the multiple benefits of the dramatically increase in observations as well as of introduction of new technologies, i.e. GPS L5 and GLONASS CDMA.

Future flight inspection systems will integrate multi-GNSS receivers into the flight inspection aircraft reference position solution. They will combine information from the aircraft’s attitude sensors, i.e. IRS or AHRS, and altitude information from ADC and RadAlt in hybrid position solutions.

The near future flight inspection aircraft’s reference position will be quicker determined, more accurate, more reliable and much better integrity proofed.

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Assessment of Localizer and VOR Polarization Effects Using Offset Aircraft Antennas

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ABSTRACT

Vertically-polarized components of localizer (LOC) and VOR signals have the potential to distort the guidance signals.

The International Civil Aviation Organization (ICAO) provides standards and guidance material concerning the assessment of polarization effects.

The traditional flight test procedure for polarization measurements, banking the aircraft alternately to the left and right while attempting to maintain track on the nominal course line, is neither technically thorough nor operationally desirable.

NAV CANADA has installed polarization antenna arrays, consisting of two pairs of fin-type LOC/VOR antennas on the sides of the fuselage, offset from the horizontal axis, on each of its three flight inspection aircraft. These additional antennas are intended to permit the assessment of polarization effects while maintaining level flight, by electrically switching between the pairs of antennas and measuring changes in course deviation.

The polarization antenna arrays are not yet used in routine flight inspection service, but have proven valuable in tracking down an unusual problem with a localizer at Canada's busiest airport.

This paper describes the polarization antenna arrays installed by NAV CANADA, and documents their role in the investigation of the localizer problem.

INTRODUCTION

ICAO Annex 10 specifies accuracy tolerances for the polarization effect on a localizer, at a specified aircraft roll attitude, and the ICAO Manual on Testing of Radio Navigation Aids (Doc 8071) proposes polarization test procedures and tolerances for localizer and VOR.

Vertically-polarized radiation emanating from the navigation aid itself can be measured on the ground. However, determination of far-field effects caused by ground reflections, for example, can only be achieved with a flight test. The flight test procedure typically involves banking the aircraft alternately to the left and right, while attempting to maintain track on the nominal course line of the localizer or VOR. This procedure provides only spot checks of polarization effects, which will not generally provide a complete assessment, since polarization effects will vary with position. The procedure is also less than desirable for crew comfort, positioning accuracy, and, at low altitudes, safety.

To address these technical and operational shortcomings, NAV CANADA has installed polarization antenna arrays on its three flight inspection aircraft. This paper describes the polarization antenna array and its first practical use in the investigation of operational problems with a Category III localizer at Canada's busiest airport, L.B. Pearson International Airport in Toronto.

POLARIZATION ANTENNAS

Late in 2006, NAV CANADA signed a purchase contract to replace two of its three flight inspection aircraft. The two replacement Bombardier CRJ-200 aircraft required refurbishment to convert them from airline passenger service to their new flight inspection role. This refurbishment work included the installation of various flight inspection antennas, and provided the opportunity to fit additional antennas dedicated to the measurement of polarization effects. A major overhaul of NAV CANADA's third aircraft, a DeHavilland Dash-8, was completed in 2009, allowing for a similar installation of a polarization antenna array.

The array consists of four fin-type LOC/VOR antennas, installed on the sides of the fuselage. On the CRJ aircraft, these antennas are aft of the main door; on the Dash-8, they are forward of the door. Each antenna is offset 30° above or below the horizontal axis of the aircraft. Opposing antennas are combined to form two pairs prior to routing to the antenna switching unit of the flight inspection system.

The polarization antenna array is depicted in Figure 1, and the actual CRJ antennas are shown in Figure 2.

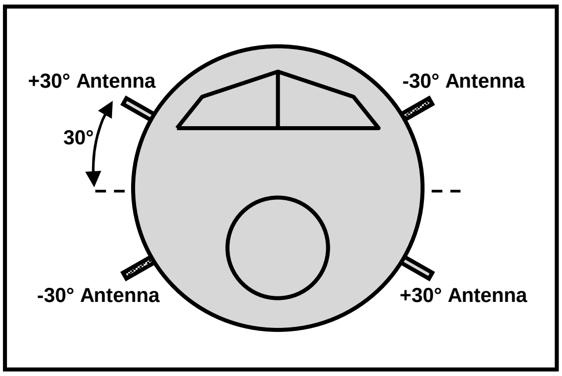

Figure 1. Polarization Antenna Array

NAV CANADA's flight inspection system includes two identical navigation receivers, and can record the outputs of both receivers. This allows the option to simultaneously measure and compare signals through the two polarization antenna pairs, or to measure and compare one polarization antenna pair with the standard horizontally polarized antenna.

Figure 2. Polarization Antennas on CRJ

INVESTIGATION OF LOCALIZER PROBLEM AT PEARSON AIRPORT

Problem Identification

In December 2010, air traffic controllers reported that some aircraft had not been able to correctly capture the localizer centreline for a recently replaced ILS at Pearson International Airport. An initial flight inspection using traditional measurements indicated that the localizer course and clearance signals were operating well within prescribed tolerances, as shown in Figure 3. As the problem reports had been for a single aircraft type, the cause was initially suspected to be an avionics issue. After further aircraft reports, however, a more detailed investigation of the localizer was launched, adding test instrumentation and data recording capabilities on the ground, as well as additional flight tests.

A breakthrough came when a flight inspection crew was able to duplicate the symptoms reported by other aircraft, by banking and turning at the same points as recorded on the flight tracks of those aircraft. The fact that banking and turning the aircraft led to the symptoms hinted strongly at a polarization-related issue.

Investigation of Polarization Effects

With attention now fixed on polarization effects, a program of flight tests was defined to measure the polarization effects on the problem localizer and to compare these measurements against equivalent measurements from a problem-free "baseline" localizer with similar ground equipment. This flight test program made extensive use of the polarization antenna array, with conclusive results.

For these tests, the flight inspection system was configured with the horizontal antenna feeding one receiver and one of the polarization antenna pairs feeding the other. The flight profiles used to collect measurements were primarily arcs, flown clockwise (CW) using the -30° antenna pair and counter-clockwise (CCW) using the +30° antenna pair, through the clearance and course sectors of the localizer.

Flight tests at the baseline site showed only a small difference of approximately 20 µA between LOC deviation measurements from the horizontal and polarization antennas, as shown in Figure 4. The problem site, however, showed very different results. The polarization antennas each received clearance deviation signals as much as 150 µA lower than the horizontal antenna on one side of centreline, as shown in Figure 5.

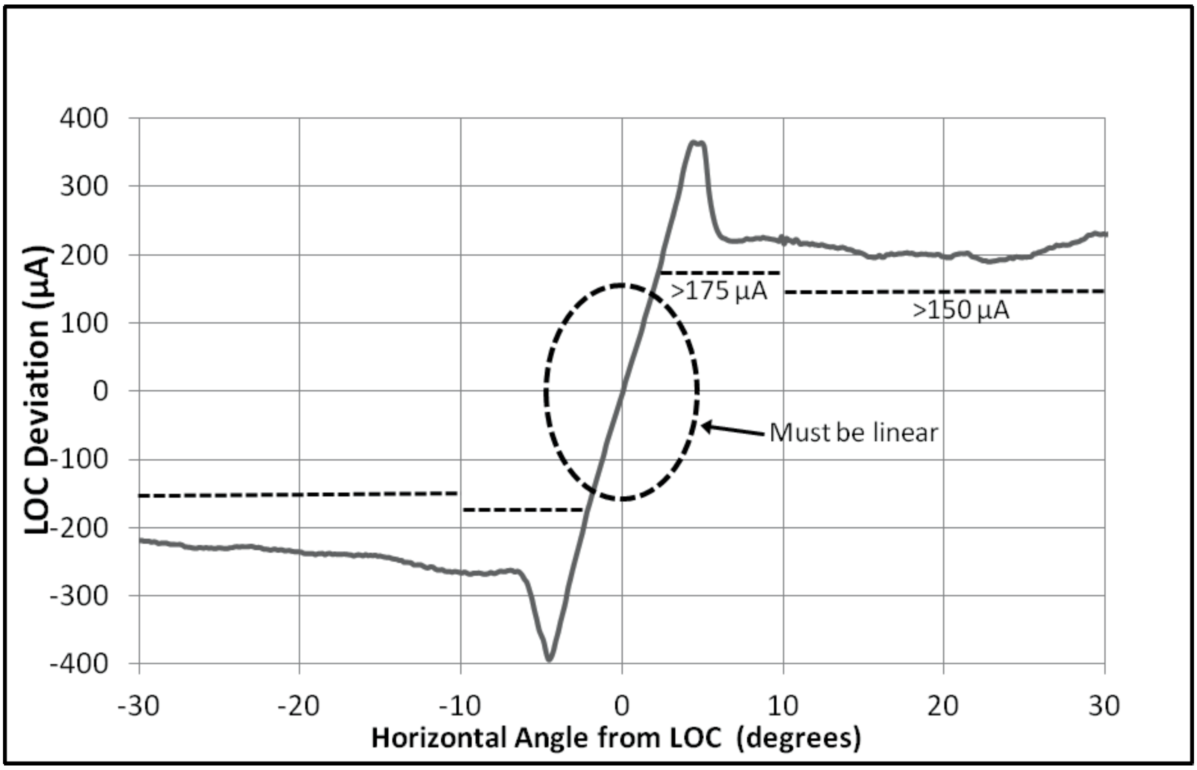

Figure 3. Initial Flight Inspection Measurement for Course/Clearance Arc at Problem Site (transmitter configured such that monitor indicated wide alarm condition)

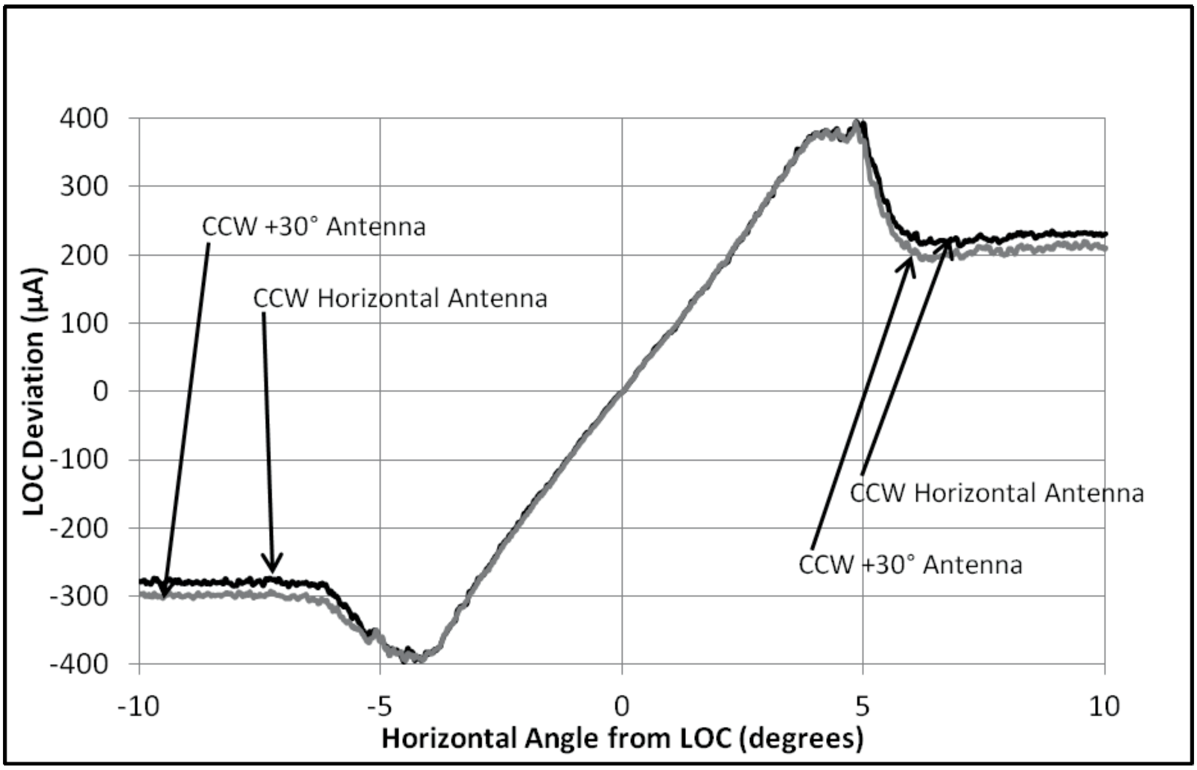

Figure 4. Localizer Polarization Measurements for Course/Clearance Arcs at Baseline Site

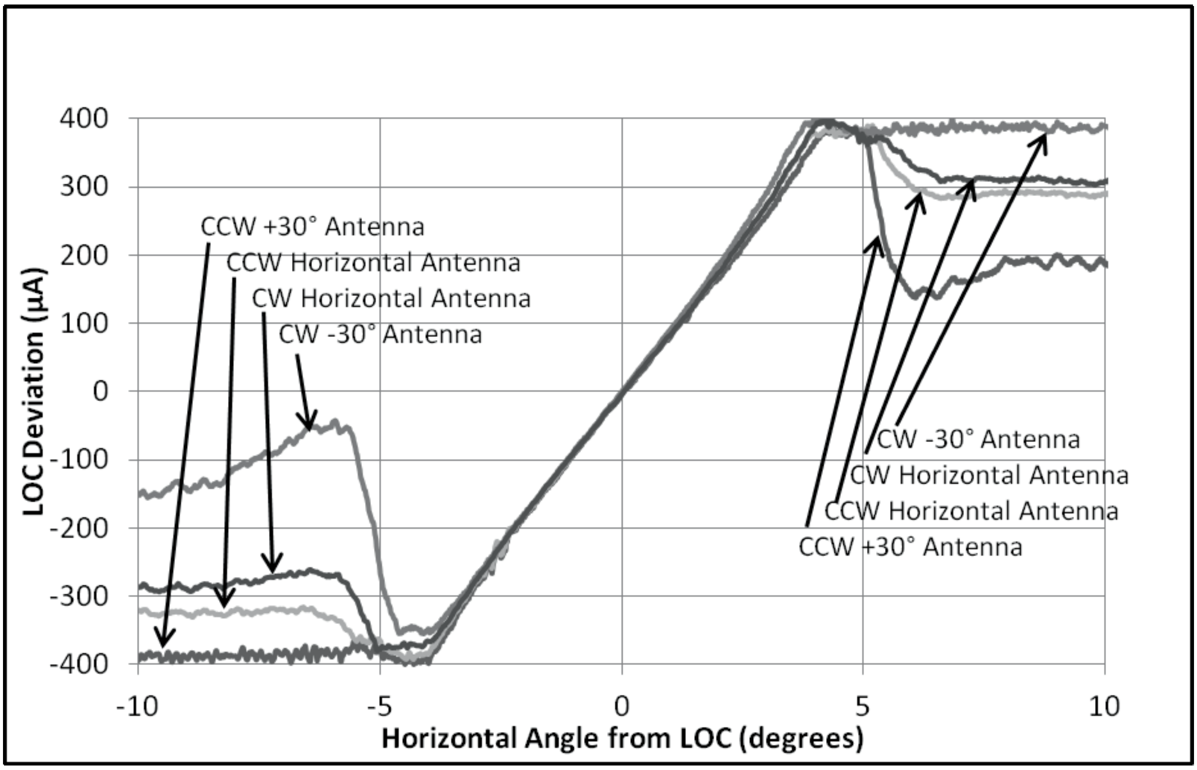

Figure 5. Localizer Polarization Measurements for Course/Clearance Arcs at Problem Site

These test results clearly demonstrated that polarization effects were responsible for the incorrect capture of the localizer centreline. An aircraft following a typical arrival procedure would fly a base leg at about 90° to the localizer centreline. After receiving an ATC vector for a standard 30° intercept of the centreline, the aircraft would bank to turn toward the new heading, causing its now-tilted antenna to receive the lower deviation signal. Rolling back to the horizontal on the intercept heading, the received LOC deviation signal would increase back to its nominal value, suggesting that the aircraft was in fact flying away from centreline rather than toward it. If the auto-pilot was engaged to capture the localizer at this time, it would then incorrectly command a turn in the opposite direction.

Identification of the Root Cause

With this understanding of the problem, what remained was to determine the root cause of the site-specific polarization effects. Fine adjustments of transmitter parameters and replacement of the antenna distribution unit with a newer design did not significantly improve the situation, as confirmed by repeating the flight test measurements after these changes.

The problem localizer has one obvious feature different from all other Canadian localizer facilities: it is installed immediately behind a non-metallic blast fence. Attention was therefore shifted to the blast fence as a potential contributor to the problem. This was reinforced when, in the course of the investigation, the localizer experienced a monitor alarm of the clearance signal parameter, during heavy rainfall. Subsequent analysis of recorded integral monitor and far field monitor data indicated a history of small shifts of localizer course alignment during and after each rainfall. To assess the effects of rainfall, a special set of ground and flight tests was organized with the cooperation of the airport fire crew to saturate first the antenna and then the blast fence (see Figure 6). These tests demonstrated that the blast fence had lost its original water-repellent coating, and would temporarily absorb water during rainfall. The absorption of water had a small effect on the radiated signal and a larger effect on the integral monitor signal, which impacted continuity of service, but did not significantly change the polarization effect seen in the clearance sector.

The root cause of the polarization problem was identified a short time later. A small support crossbar had been incorrectly installed in the wrong location, very close to the radiating elements of the centre pair of antennas, as shown in Figure 7. After removal of this crossbar, flight test measurements with the polarization antennas confirmed that this localizer then behaved similarly to the baseline site. No localizer capture problems have since been reported. The airport arranged for the blast fence to be re-coated to repel water, and has instituted an annual inspection program to avoid future problems.

Figure 6. Water Saturation Test of Localizer Antenna and Blast Fence

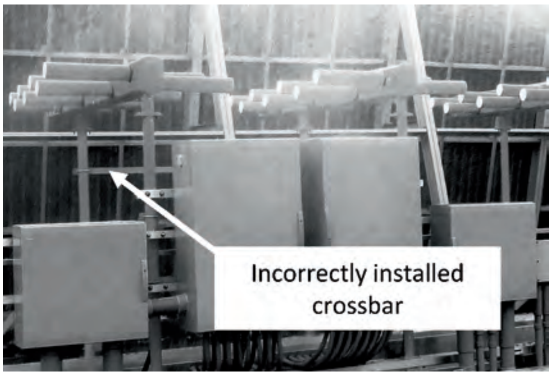

Figure 7. Root Cause of Polarization Problem

The investigation of this problem showed the polarization antenna array to be very useful in flight tests of certain site issues, particularly if the signal from the polarization array is recorded simultaneously with that from the standard antenna.

FUTURE WORK

NAV CANADA intends to conduct additional work to incorporate the use of the polarization antenna array in routine flight inspection operations. This work will include:

a. Characterization and calibration of antenna factors, to allow for measurement of power density of signals received by the polarization antennas.

b. Testing of sample sites to establish appropriate flight inspection procedures and tolerances for polarization effects on localizer and VOR.

c. Updates of company flight inspection standards and procedures documents to include polarization.

ACKNOWLEDGMENTS

The authors would like to acknowledge the efforts of members of NAV CANADA's Engineering, Flight Operations and Technical Operations groups, as well as staff from the Greater Toronto Airports Authority, who worked diligently to investigate and successfully resolve the problem with the localizer at Pearson International Airport.

Data Management for the Future

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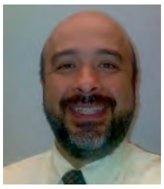

ABSTRACT

As the guidance for Instrument Flight Procedures evolve from ground based navigational aids to satellite and on board navigation technology, aeronautical data management becomes even more critical. Due to the various sources, methods and datum used in aeronautical data, it is difficult to achieve the data integrity levels needed to assure flight safety.

The aeronautical community has been dealing with many complex data management issues in the past few years as this problem has surfaced. The goal of this paper is to report the ongoing efforts to improve aeronautical data integrity, point out the challenges and provide some ideas on how to proceed. We must recognize that data management processes may differ depending on specific conditions of each organization responsible to ensure data integrity. But, at the same time, standardized data management principles are critical for successful operations.

We will explore the efforts of the Federal Aviation Administration and EUROCONTROL in establishing the Aeronautical Information Exchange Model (AIXM) and related models. A critical part of flight inspection and flight validation will involve data management considerations. We will address how changes in data management processes relate to flight inspection practices.

INTRODUCTION

Data Management has historically been a challenge for the aviation community. All States have some common and some unique problems the hinder the ability to maintain a flawless level of data integrity. In the United States, there are multiple data bases that house aviation data within the civil and military systems. The issue is exacerbated in Europe and other parts of the world with sovereign States having their own data sources while sharing highly integrated aviation systems.

As aviation moves to Performance Based Navigation (PBN), the Instrument Flight Procedures (IFPs) are heavily dependent on data accuracy to guide the user aircraft for safe navigation guidance. Flight Inspections role is evolving to one of flight validation, which to a large degree involves verification of data accuracy.

This has been recognized in the last few years and there have been many efforts to improve data integrity. Some of these initiatives are ongoing to improve aeronautical data management.

Another driving force in the improvements of data management comes from the Information Technology community. Although their interests are focused on improving data processing and reducing database management costs, they are partners to accomplish the goals of automating data processes to avoid human error, avoid duplication of data and increasing the accuracy and availability rates of aeronautical data.

Specific improvement efforts in aeronautical data management

Within the FAA, data organizations have been reorganized because databases maintained by different internal organizations inhibited the ability to create seamless data architecture. In 2010, the FAA realigned the Airport and Navigation Aid (AIRNAV) database and the National Airspace System Resources (NASR) into the same organization, under the same immediate management chain. These databases are now managed by the Aeronautical Information Management Office within the FAA. The Agency is already seeing some of the data management improvements as these databases are being aligned. The AIRNAV system is the primary system used for Instrument Flight Procedure Development and Flight Inspection, NASR is the primary system for publication and dissemination to the public. Both databases have their strengths and weaknesses, and some data elements exist in both databases while others exist in only one or the other.

In order to leverage the best of each while automating the processes within the data systems, the Information Technology organizations are a critical partner. The FAA has initiated the Aeronautical Data Management (ADM) project. This project will be executed in three initiatives. They are the Data Stewardship Certification Initiative, Temporal and Geospatial Model Initiative, and the Designate Authoritative Sources Initiative.

The Stewardship Certification initiative addresses the need to identify data stewards for specific data elements, eliminate duplication of data, address discrepancies, and clarify stewardship responsibilities.

The Temporal and Geospatial Models initiative addresses the need to provide past, present, and future conditions. The ability to handle temporality is critical for data accuracy in a constantly changing environment.

The Designate Authoritative Sources Initiative addresses the need to have a clear source of data for a given data set. Developing the information products from the authoritative source or an approved replicated source with proper integrity checking will bring consistency to the aeronautical information.

Each of these initiatives has a scope and approach to accomplish their respective goals. These are ongoing processes that the FAA is supporting to improve data management practices.

Eurocontrol has also been busy in addressing the data management problem. They acknowledge that the majority of airspace users still receive information from a number of sources, including paper copies. These sources are not accurate, consolidated, prone to errors, and with potential inconsistencies and misrepresentations.

To address these problems, EUROCONTROL has initiated the Airspace Data Repository (ADR). This has been driven by the need for a common, consolidated, and accurate network view of airspace data, which is kept up to date in real time.

Some of the benefits of ADR are to develop a virtual airspace data Repository providing access to consistent sources of airspace information containing both static and dynamic elements that will support the Airspace Management Planning Charts (ASM), Air Traffic Flo Capacity Management (ATFCM), and Air Traffic Control (ATC) collaborative process.

Today, ADR is already delivering the first benefits with the enabling of optimized flight planning through e-RAD and e-AMI publications.

The main objective of e-RAD and e-AMI is to facilitate flight planning. It will lead to a higher acceptance rate of flight plans sent to the IFPS through an integrated flight planning system.

While the approach by the FAA and Eurocontrol has been a bit different, it will be importance for some standardization to allow seamless traffic flow between North America to/from Europe and the rest of the world.

Importance of Standardization

Today, Aeronautical Information Management (AIM) involves information flows that are increasingly complex and made up of interconnected systems. (AIM is also the same name/acronym that the FAA uses for the organization responsible for this effort). The flows involve many actors including multiple suppliers and consumers. Throughout, AIM must ensure: The quality of aeronautical information required by modern air navigation and ATC systems, the efficiency and the cost effectiveness of the system, and real time information.

The pursuit of these goals is to move from a product centric operation to a data centric operation.

One method of achieving this is to use a single data source, allowing a more efficient way to handle data. The data source must be made up of models with standards that can be consumed by all users. Consistent methodologies will allow an efficient use of the data without unnecessary replication. The data must be able to be exchanged between different systems.

While the approaches of the FAA and Eurocontrol differ slightly, they have a lot in common. Both efforts focus on streamlining data flows, reducing duplication, and removing error prone processes.

A key point for successful data integration between aviation authorities is some sort of standardization in data transfer processes. Eurocontrol and the FAA have been collaborating on a standard data exchange model. While there is still much work to be done, we have had some success in this area.

Standardization Model

A key common feature of standardization is the agreement to use Aeronautical Information Exchange Model (AIXM) as a standard exchange model. The AIXM model has been accepted by both the FAA and EUROCONTROL as the temporal model for exchanging aeronautical data. The temporality model being developed is a standard event temporality model to be implemented in FAA databases.

AIXM is a specification designed to enable the encoding and the distribution in digital format of the aeronautical information, which has to be provided by the service providers in accordance with the ICAO Convention. AIXM was originally developed by EUROCONTROL. The initial version handles static data contained in the national Aeronautical Information Publications (AIP). It also enabled exchanges of data between national databases and the centralized European AIS Database (EAD).

Since 2003 AIXM has become a joint effort between EUROCONTROL and the FAA with support from the international community. The goal is to deliver an internationally agreed upon standard which enables the provision of real time aeronautical data in digital format. A standard exchange is critical to be able to attain Aeronautical Data Management Systems that support a tactical, real-time data processing. The latest AIXM 5.1 version is a result of this joint effort.

Previous versions of AIXM (version 4.5 in particular) have been in use since 2005 internally in Europe and a number of States worldwide (Canada, Japan etc.). Starting in 2010 data provider systems are moving toward AIXM 5.1, which is the latest version released on February 2nd,2010. The actual UML model, XML schemas and AIXM 5.1 components can be found on the Eurocontrol website.

The UML model provides a formal data descriptions based on ICAO standards, aeronautical publications, recommended practices and other relevant industry standards, such as the ARINC 424 specification.

The AIXM XML Schemas are a data encoding specification for aeronautical data. They are an implementation of the AIXM UML Model as an XML (Extensible Markup Language) schema. Therefore, the schemas can be used to send aeronautical information to others in the form of XML encoded data, enabling systems to exchange data using a standard process.

Information Management Improvements

Enterprise information management refers to the people, processes, and technology used to gather, manage, and disseminate the information assets used by and aeronautical service provider.

Data management is the function of managing data used in manual or automated business processes. Data is managed by developing data architectures, practices and procedures dealing with data and executing these aspects. It includes the activities of strategic data planning, data element standardization, data management control, and data synchronization.

The “as is” architecture must be analyzed to determine best practices and what needs to change, then a transition plan will be created, and finally to “to-be” architecture is developed and implemented. (See figure 1)


As-Is Architecture
Transition Plan
To-Be Architecture
DATA GOVERNANCE
Data Architecture Management
Enterprise Data Modeling
Value Chain Analysis
Related Data Architecture
Data Development
Analysis
Data Modeling
Database Design
Implementation
Database Operations Management
Acquisition
Recovery
Tuning
Retention
Purging
Data Security Management
Standards
Classification
Administration
Authentication
Auditing
Reference & Master Data Management
External Codes
Internal Codes
Customer Data
Product Data
Dimension Management
Data Warehousing & Business Intelligence
Architecture
Implementation
Training & Support
Monitoring & Tuning
Document & Content Management
Acquisition
Backup & Recovery
Content Management
Retrieval
Retention
Metadata Management
Architecture
Integration
Control
Delivery
Data Quality Management
Specification
Analysis
Measurement
Improvement

Figure 1

EUROCONTROL has also published methods to improve aeronautical information processes. The EUROCONTROL approach uses the Aeronautical Information Regulation and Control (AIRAC) from ICAO Annex 15 – Aeronautical Information Services document.

AIRAC defines a series of common dates and associated standard aeronautical information publication procedure for States. (Figure 2)

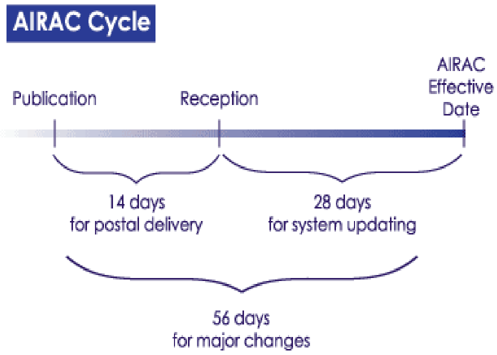

Figure 2

Information Management Process Flow

The FAA data management functions and activities contribute to the goals of meeting regulatory requirements. They establish practices to help Aeronautical Service Providers undertake various data management practices to meet the data/information needs of the public. As such, Enterprise Data/Information Management is critical to the FAA's strategic investment planning and acquisition management focusing on what is needed to support the agency's business and technical programs – managing data, information, and knowledge as strategic assets.

The diagram below describes the process the FAA has developed to manage the implementation of enterprise data management using these principles. Each step has its own artifacts; inputs and outputs, and outcomes. Further information to describe this process is available by the FAA data management office. (See figure 3)

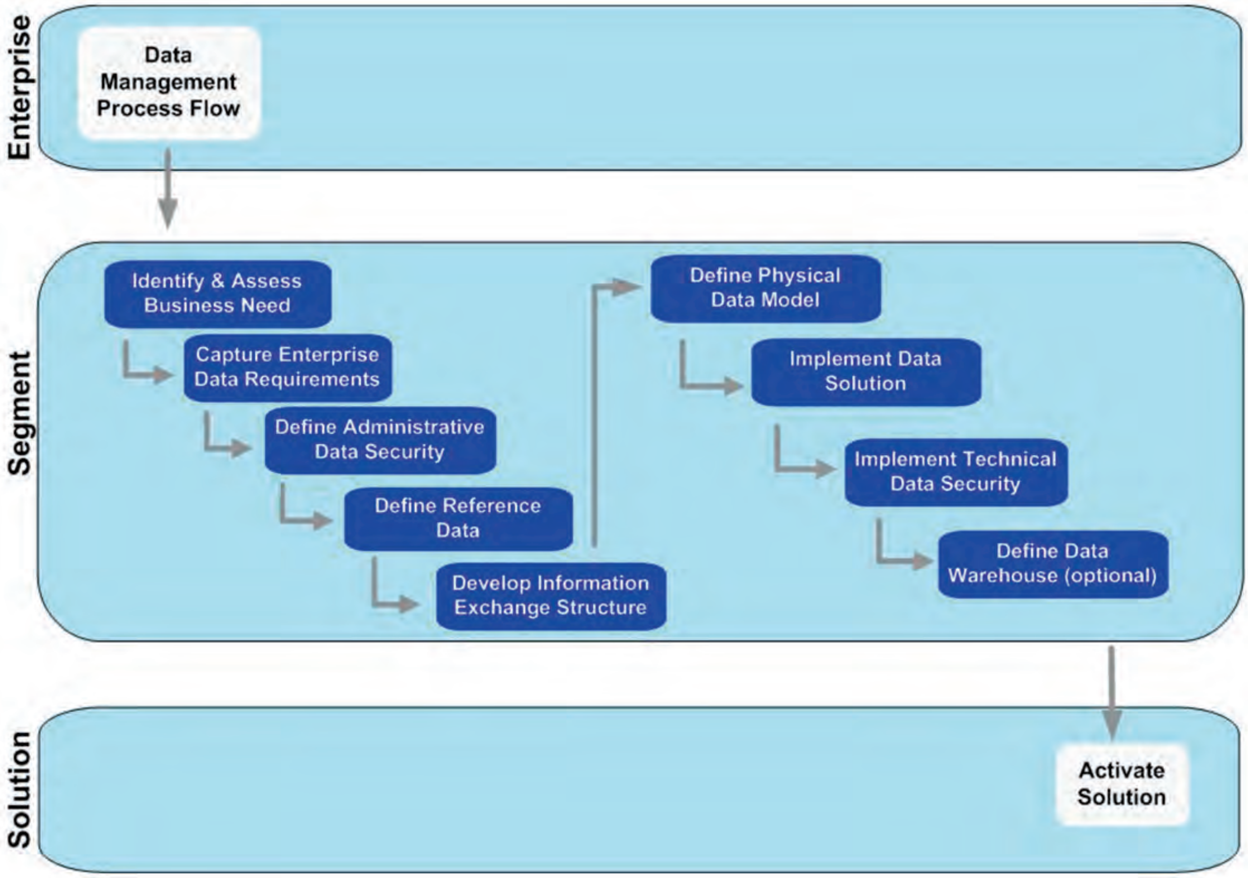

Figure 3

Key Data management terms

For a successful transition to effective data management, a common understanding of terms is very important. The following terms have been accepted by the FAA for a common understanding of data management terms.

AERONAUTICAL DATA: In the context of this document, this refers to NAS-base and air transport infrastructure data.

MASTER DATA MANAGEMENT: A set of processes and principles that consistently define and manage the core data entities of an organization (which may include reference data). The objective is to provide processes for collecting, aggregating, matching, consolidating, quality-assuring, persisting and distributing such data throughout an organization to ensure consistency and control in the ongoing maintenance and application use of this information.

DATA: Representation of facts, concepts, or instructions in a formulated manner suitable for communication, interpretation, or processing by human or automated means. Data are the fundamental components of information.

INFORMATION MANAGEMENT: The leading, planning, organizing, structuring, describing, and monitoring of information throughout the lifecycle; including distribution of information to one or more audiences.

INFORMATION: Data organized and made available for a purpose.

STEWARD: The designated organization that originates and is accountable for quality and timeliness of data and information.

AUTHORITATIVE SOURCE: The designated repository for authoritative data or information provided by the steward.

TECHNICAL STEWARD: The designated person or organization responsible for the design and implementation of the infrastructure (data, applications, or technology).

CUSTODIAN: The organization designated as the party responsible for the integrity of data that has been transformed or copied for a business need. The designated organization is accountable for the proper handling of the resource they receive upholding any policies or regulations governing its use, in accordance with agreements made with that authoritative source. When the steward is external to the FAA, the custodians will quality control (QC)/audit the data prior to making it available in the authoritative source. In this case, Custodians will work with external stewards to make any necessary corrections.

INTEGRITY: A degree of assurance that data and its value have not been lost or altered since the data origination or authorized amendment.

COORDINATOR: The designated organization that provides user assistance and supports stewards in the use of the Authoritative Source or Approved Replicated Source, but are not responsible for content.

APPROVED REPLICATED SOURCE: A designated duplicative repository linked to an authoritative source fulfilling a specific business purpose (e.g. data warehouse) that is electronically updated when the authoritative source is changed. The data or information replicated from the authoritative source is read only.

Flight Inspection’s Role in data integrity validation

What is flight inspection and flight validation’s role in this environment? Flight inspection’s role is no longer limited to collecting signals in space. AS we have seen this theme in the papers submitted in the last few years, Flight Inspection now has a responsibility to verify data accuracy before authorizing the publication of new and amended instrument flight procedures.

Flight Inspection organizations must stay in tune with the evolving data sources to ensure that Flight Inspection Systems (FIS) continue to have the capacity to ingest the best sources of data to accomplish the flight inspection mission. Temporality must be considered as many times flight inspection will be validating instrument flight procedures before the airport environment is in its final configuration.

The FAA has established a process that allows FAA's flight inspection aircraft to ingest the ARINC 424 coded procedure into its Flight Management System (FMS) prior to publication. The coded procedure data is verified prior to publication and is compared to the data in the Automatic Flight inspection System (AFIS) for the Final Approach Segment (FAS) in the case of Localizer Precision with Vertical guidance instrument flight procedures (LPV). This provides a comprehensive validation of the instrument flight procedure.

Recently, the FAA has enhanced the instrument flight procedure validation process by instituting the Coding Preflight Validation (CPV) process. CPV is an analysis of the ARINC coding and a reasonableness of flight evaluation on an approved desktop avionics simulator. CPV processing verifies conformity between the digital data provided on the IFP source documents. These source documents include the procedure's design data and ARINC 424 coding. This allows the FAA to validate flight data prior to flying the instrument flight procedures, thereby creating a more efficient process and minimizing the likelihood that data errors will surface during the airborne flight validation process.

CONCLUSION

The efforts to improve data integrity cross many disciplines within the aviation community. The FAA and EUROCONTROL have developed some specific best practices that can be utilized by Aeronautical Authorities and should be employed for consistent data management practices.

Flight Inspection Service organizations must continue to evolve and participate with Aeronautical data providers to coordinate both the input of Aeronautical data into its Flight Inspection System (FIS) and coordinate the effective dissemination of the flight inspection results.

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Flight Safety on Flight Inspection Missions – Past Statistics and Future Strategies

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ABSTRACT

By their very nature – flying low, often in densely populated airspace - , flight inspection missions do implicitly incur a higher potential risk than regular airline operations in transporting passengers and freight.

This paper identifies the specific risks involved in performing various flight inspection missions. It continues to analyse the past safety record the flight inspection community has achieved so far, and compares this safety record with other types of operation in the aviation world.

Having identified the individual risks involved, the author continues to outline potential mitigation tools to deal with these safety challenges – aspects of operational setup, training and equipment will be covered.

In closing, the paper uses the mitigations tools identified to start a discussion towards a common standard in flight inspection operations, looking at standards and recommended practises other branches of the aviation community (airlines, business aviation, survey operators) have produced so far.

INTRODUCTION

It is a well established fact that aviation is an extremely safe mode of transportation. Major progress in the fields of aircraft, engines and system design, infrastructure (like ATC, navigational systems etc.) and, almost as important, the way we operate aircraft today (introducing checklists, Standard Operating Procedures SOPs, focussing on Human factors, Crew Resource Management CRM etc), all lead to an imprecedended low level of accidents and incidents in civil aviation.

The look across the spectrum of aviation, though, reveals a wide variety in safety statistics among the various branches of the industry, with the public transport sector (airlines) featuring a very low accident rate, followed by other sectors like business aviation and general aviation.

In order to establish the current safety status of our flight inspection industry we have to look into the more general statistics mentioned above in more detail.

ACCIDENT AND INCIDENT STATISTICS

The metrics against which safety in aviation is measured are varied; a common unit is the number of hull losses per year, as indicated in Figure 1 below:

Figure 1: Accidents and Fatalities by Hull Losses

According to this statistics of Flight International of 2011, the number of hull losses in the airline industry in 2010 has been 26, the number of fatalities 817.

Another fairly common approach is to measure the annual fatal accident rate against millions of departures, see Figure 2 below:

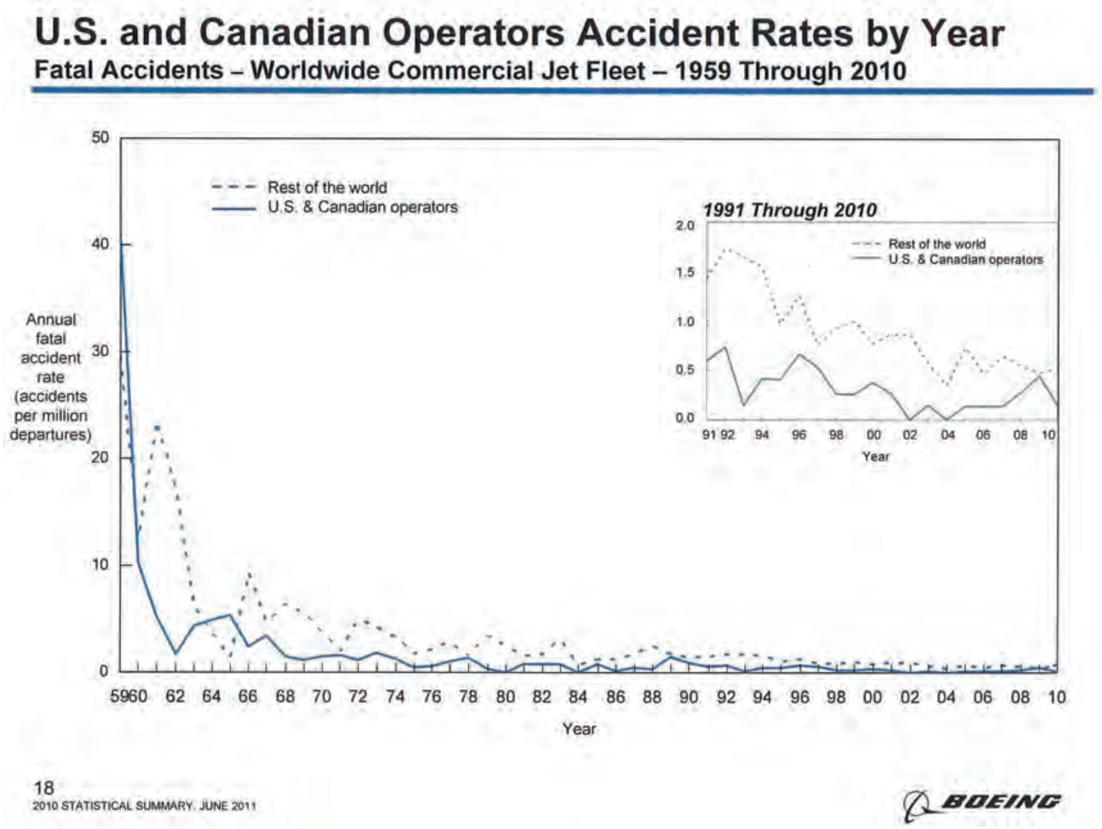


Figure 2. Annual Fatal Accidents per Million Departures

So according to this graph by Boeing, in 2010 there were 0,3 fatal accidents per 1 million departures in the U.S. & Canada within the commercial jet fleet. Note the difference against the rest of the world with 0,6 fatal accidents. It is important to note that this Boeing graph is based on an everage sector length of 1,5 hrs per departure, so as a proximation it is fair to say that the 0,3 fatal accidents per 1 million departures in the U.S. & Canada translates into 0,2 fatal accidents per 1 million flight hours, or 0,4 fatal accidents per 1 million flight hours for the rest of the world. This will later help us compare these numbers against other sectors of the industry.

There are other metrics available to document the accident rate of the commercial airliner industry, like hull losses and fatalities against hours flown, distances covered and seat capacitiy offered and used.

All these data indicate a very low accident rate, it further shows a steady decline in both accident rates as well as fatalities over the last 30 years, albeit with the number sort of plateauing around 0,5 fatal accidents per 1 million departures per year for roughly 12 years now.

These are all values for the airline industry – finding similar data for our industry proved to be much harder.

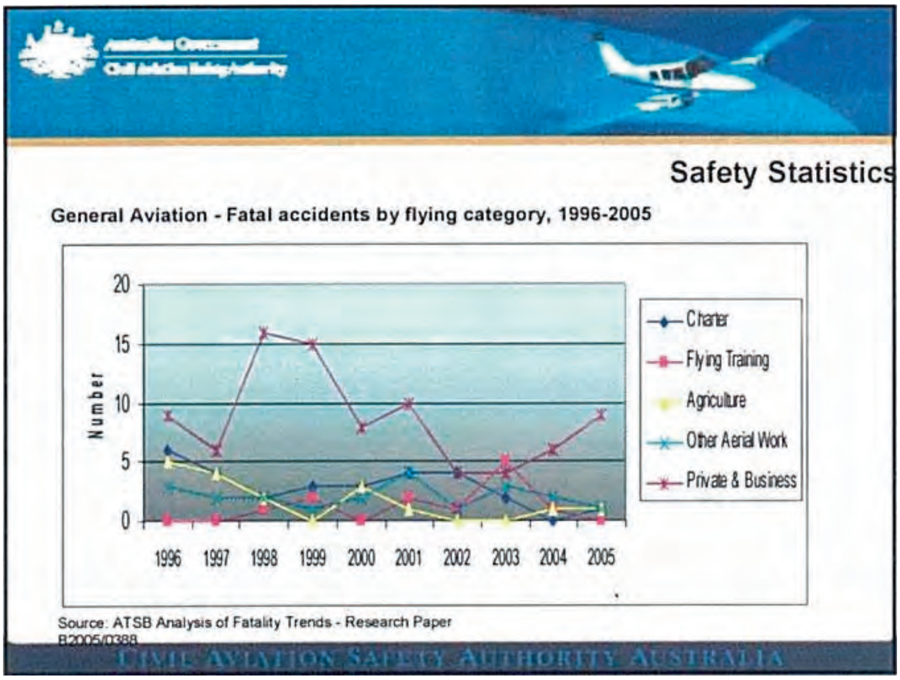
First, one had to differentiate all available accident data into the different aviation activities of Commercial (Airlines), Business, Corporate, State, Military and General Aviation. There are in some cases some major differences between countries in how certain aerial activities are summarised under which category: some countries, in their statistics, further differentiate Commercial activities in Airline, Commuter and Air Taxi, others put all activities below the commercial world under General Aviation, and others again differentiate the General aviation domain quite extensively into Training, Leisure flying, and Aerial Work.

In other words, a comprehensive, worldwide database with accident data splitted as per category of aerial activity does not exist.

To give us a first feeling as to where the aerial work community – of which flight inspection is a part of – stands, it helps to look at the statistics of two countries, which respective regulator took some effort to further differentiate accident data and break it down into the different categories of aerial activities.

The Civil Aviation safety Authority of Australia took some effort in differentiating Australian data: they splitted General Aviation into Charter, Flight Training, Agricultural Flying, Aerial Work and Private and Business Flying. For the purpose of accident analysis it appears to be fair to combine both Agricultural Flying and Aerial Work under one category of Aerial Work.

Figure 3 below gives us tha fatal accident rate by flying category in Australia from 1996 to 2005:



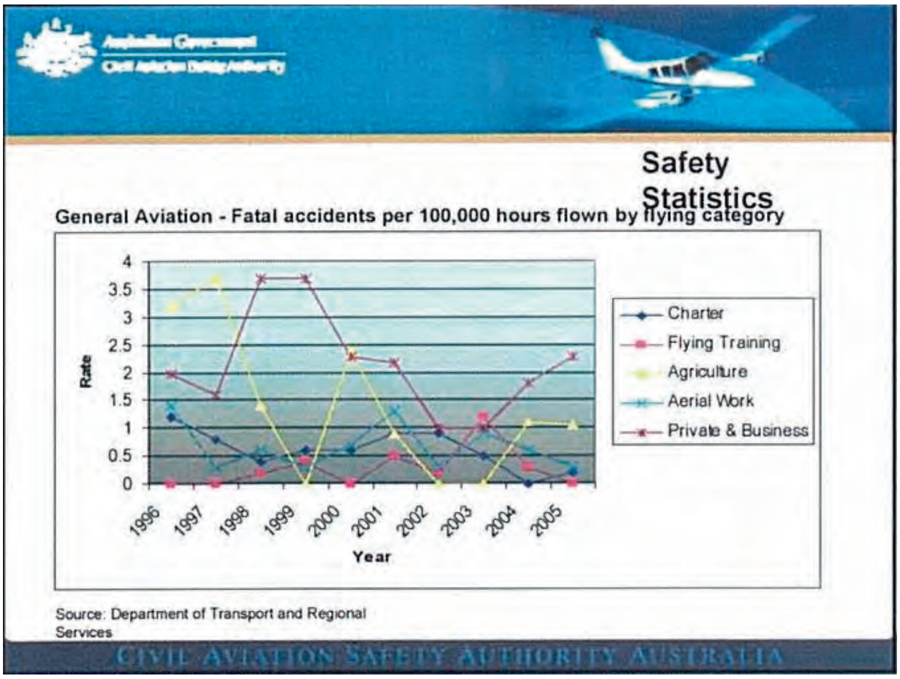
Safety Statistics

General Aviation - Fatal accidents by flying category, 1996-2005

Source: ATSB Analysis of Fatality Trends - Research Paper B2005/0388

CIVIL AVIATION SAFETY AUTHORITY AUSTRALIA

Figure 3. Fatal Accidents Australia by Flying Category.



Safety Statistics

General Aviation - Fatal accidents per 100,000 hours flown by flying category

Source: Department of Transport and Regional Services

CIVIL AVIATION SAFETY AUTHORITY AUSTRALIA

Figure 4. Fatal Accidents Australia by Flying Category.

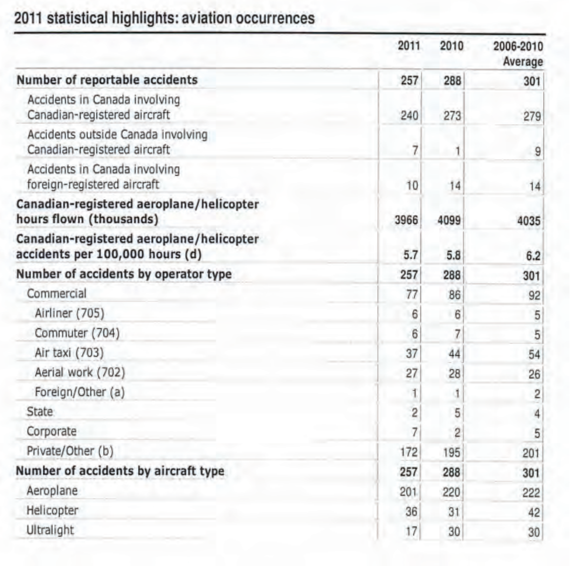
According to Figure 3, Australia suffered 2 fatal accidents in 2005 in the aerial Work domain, for stance (1 in Agriculture, 1 in other aerial Work).

According to Figure 4, in 2005 there were 1,3 accidents per 100.000 flying hours in Australia in the Aerial Work domain.

This gives us a first, rough comparison to the data of the airline sector given above: 0,4 fatal accidents per 1 million flight hours stand against a statistical value of 13 accidents per 1 million hours flown in the Aerial Work sector in Australia – roughly 33 times the number of the airline sector.

Of course this number has to be treated with caution: Australia has a very active aerial work community (thus increasing the chances of a mishap statistically), on the other hand it has a well established infrastructure around this sector, with good training being available, and a comprehensive and competent oversight by the regulator being exercised. So in the absence of world wide statistics being available, it might be fair to take the Australian data as a first proximation and indication were the Aerial Work Community in general might stand in terms of safety.

The Transportation Safety Board of Canada's statistics below support this proximation in a way; unfortunately it does not differentiate the number of hours flown by the operator type. Canada suffered 257 accidents across the whole spectrum of the industry, of which Aerial Work contributed 27 (roughly 10%). As this can not be broken down to the number of hours being flown in the individual sector, direct comparisons are somewhat hampered, furthered by the fact that the Australian data refer to fatal accidents only, the Canadian data to reportable accidents.



2011 statistical highlights: aviation occurrences

	2011	2010	2006-2010 Average
Number of reportable accidents	257	288	301
Accidents in Canada involving Canadian-registered aircraft	240	273	279
Accidents outside Canada involving Canadian-registered aircraft	7	1	9
Accidents in Canada involving foreign-registered aircraft	10	14	14
Canadian-registered aeroplane/helicopter hours flown (thousands)	3966	4099	4035
Canadian-registered aeroplane/helicopter accidents per 100,000 hours (d)	5.7	5.8	6.2
Number of accidents by operator type	257	288	301
Commercial	77	86	92
Airliner (705)	6	6	5
Commuter (704)	6	7	5
Air taxi (703)	37	44	54
Aerial work (702)	27	28	26
Foreign/Other (a)	1	1	2
State	2	5	4
Corporate	7	2	5
Private/Other (b)	172	195	201
Number of accidents by aircraft type	257	288	301
Aeroplane	201	220	222
Helicopter	36	31	42
Ultralight	17	30	30

Figure 5: Canadian Accidents Data 2011

Flight Inspection specific Statistics

As indicated above, there is no country-specific, let alone world-wide statistic data available for accidents and incidents in the flight inspection community. It is even impossible to quantify the share of flight inspection activities within the Aerial Work sector.

All that notwithstanding, our industry did suffer some accidents and incidents in the past, which will be described in more detail below. The listing starts in 1993; there is anecdotal evidence that there were accidents and incidents before that date (there is anecdotal evidence that the German Airforce lost a Flight Inspection Douglas C-47 on take off in the sixties, for instance), but these data are hard to verify. As both the technical as well as the operational environment of our sector has changed considerably over the past 20 years, the question arises as to how relevant these pre-1993 incidents – as tragic as they might have been – are for conclusions to be drawn from them to today's flight inspection environment. It was therefor decided to concentrate on the last 20 years.

Accidents and incidents of the flight inpection community have been identified as follows:

1. On October 26, 1993, the FAA's flight Inspection Area Office of Atlantic City, NJ, lost a Beech B300 near Front Royal, Virginia, on a transit flight after a calibration mission
   The primary cause has been identified as being a controlled-flight-into-terrain (CFIT) accident; the flight was continued under VFR in IMC, the aircraft subsequently hit terrain. 3 fatalities

2. On October 24, 2000, the German Flight Inspection International FII GmbH lost a Beech B300 near Donaueschingen, southern Germany, after the aircraft completed a commisioning flight check for a new NDB and tried to land back at the airfield. Again, primary factor was a CFIT accident (here as well the flight was continued under VFR in IMC). 4 fatalities

3. On June 23, 2004, an Indian Airports Authority Dornier Do228 landed gear up inadvertently at Pune Airport, India. No fatalities, no injuries

4. On November 26, 2006, a Pakistan CAA Beech B200 skidded of the runway at Sharjah, United Arab Emirates, after a main gear tyre burst on landing. No

fatalities, no injuries
There are news reports that report the same aircraft to belly land again at Sharjah on July 26, 2007; however, these reports could not be verified, it rather appears the aircraft had an “Gear Unsafe” indication and made a precautionary diversion, and subsequent safe landing, at Minhad Airbase, UAE.

5. On August 17, 2008, a Cessna 402C of Reconnaissance Ventures, had a mid-air collision with a Rand KR-2 single engine aircraft at Coventry airport, UK. The Cessna was on a flight calibration training flight, flying an ILS approach to runway 23. ATC error as well as ambigeous procedures for mixing IFR and VFR traffic in Class G uncontrolled airspace played a part in this accident. 4 fatalities in the Cessna, 1 fatality in the KR-2.

All causes and explanations were derived by the author from the relevant accident investigation reports.

Table 1. Accidents and Incidents Flight Inspection Aircraft 1993 - 2011

Date	Aircraft	Operator	Accident, Location	Primary Cause	Fatalities
26 Oct, 1993	Beech B300	FAA; USA	CFIT, Fort Royal, Virginia, USA	Continued VFR flight in IMC	3
24 Oct, 2000	Beech B300	FII GmbH, Germany	CFIT, Donaueschingen, Germany	Continued VFR flight in IMC	4
23 Jun, 2003	Dornier Do228	Indian Airport Authority	Gear-up landing	Cause not known	nil
27 Nov, 2006	Beech B200	CAA Pakistan	Gear failure on landing	Cause not known	nil
17 Aug, 2008	Cessna 402C	Reconnaissance Ventures, UK	Mid-air collision, Coventry, UK	ATC error / airspace and ATC-set-up ambigiuities	5

The primary cause for the belly landing of the Do228 is not known; inadvertent gear-up landings, by experience, though, do indicate an unresolved Crew Resource Management (CRM) issue within the crew and / or its organisation at that time.

Neither is the cause of the gear failure on landing of the Beech B200 known. This might be indicative of a maintenance issue, however, this would be purely speculative.

It should be noted though, that from a more generic view, and expressively irrespective of that specific incident, maintenance issue very often do have broader implications towards the organisational set-up of a flight organisation, were insufficient oversight is given to issues like maintenance intervals and quality, obsolescense issues with aircraft, systems and equipment, training, etc.

The term of organisational environment or set-up or processes has been named several times in this paper so far. By that it is meant that over the last odd 25 years the focus of any accident analysis has shifted from purely concentrating on the crew actions and failings (which still form a vital part of any accident investigation) to looking into the broader concept in which the ill-fated flight took place. How was the flight organisation set up at the time of accident? Did the crew receive the amount of support required for that specific mission to be flown? Was a coherent strategy in place in that particular organisation, starting from top manangement down, to ensure a safe flight operation?

That approach was a simple necessity to further bring down accident statistics; up to that point, in the vast majority of cases, an accident investigation closed with the verdict: crew error. And in the broader sense of that term, 70% of all aviation accidents still fall under that category. However, in order to faster safety that verdict left stand alone proved to be useless and had to be scrutinized much further: why did the crew react the way it did? What was the organisational environment it was operating in? Was a coherent strategy in place how to operate the aircraft, including SOPs, checklists, CRM and CRM training? What was the safety culture of that flight organisation at the time of accident?

It is interesting to note that most Accident Investigation Reports, like those of the US NTSB, now start by looking into these organisational issues first prior turning to the individual crew action in question.

In the light of these organisational environment issues the two CFIT accidents warrant a closer look.

Although both accidents were, at first glance, a straightforward CFIT, and thus a classic pilot or crew error, accident investigation unearthed a number of deficiencies in both organisation that were at least contributing factors.

In both cases it was fairly quickly established that a number of organisational prerequisites were overlooked: CRM and SOPs were either non-existent or not enforced by the respective organisation; in both cases a very steep hierarchy gradient between the cockpit crew existed, with an overbearing commander not seeking feedback and advise from his fellow crew member – a known fact within the respective flight departments for quite a while without being addressed. Further training issues, like training on the job / supervision time, or the lack of, were discovered.

It is comforting to know that both organisations involved successfully took all steps necessary to tackle the deficiencies identified by the respective accident investigation reports. To that end both cases could be viewed as text book examples of challenges our industry does face, and that it is possible to address them.

The Coventry mid-air collision does feature several contributing factors; some are related to the specific UK airspace and ATC structure (the ILS training approach was flown in class G uncontrolled airspace, were responsibilty for separation between traffic lies with the respective pilots, yet both aircraft were in contact with ATC, maybe erroneously believing to be under "positive" control by ATC); other contributing factors were the late handover of the Cessna from the approach controller to the local tower controller. The geometry of both targets approaching each other in the traffic pattern, according to the accident investiigation report, positively prevented both crews from seeing each other.

So, although a single, primary cause may not be derived from that accident, it serves as a grim reminder that most of our work is done in rather densely populated airspace, and that a properly arranged and trained ATC environment, clear communications between all parties involved and a constant, vigilant look out is absolutely paramaount for the safety of our mission. In this particular case, although purely speculative, appropriate technical equipment (in this case TCAS) might have helped to mitigate the situation. More to that in the latter chapter of this paper.

SPECIFIC RISKS OF FLIGHT INSPECTION MISSIONS

We now have looked at some safety statistics of aviation in general and aerial work / flight inspection statistics in particular. What are the specific risks now involved in doing flight inspection?

Before we address that question, we quickly look at risk definition in aviation in general.

Aviation Risk Models in General

Numerous risk models do exist in the aviation industry and research community, like Fault Tree Analysis (FTA), Probabilistic Risk Analysis (PRA) or Aviation System Risk Model (ASRM).

They all share the approach to modell as closely as possible the rather complex factors influencing flight operations and their respective inter-dependencies.

It is worth to note that according to the standards of risk research, all aviation accidents fall under the category of the so-called low probability / high consequence events (lp/hc), were
"The lp/hc problem domains are inherently ill-structured, multi-layered, and characterized by consequences with low likelihoods, high severities and numerous, pervasive uncertainties. Decision making is typically complex, multitiered and non-transparent with conflicting objectives and multiple perspectives" (Clement 1996)

Translated into a much more simplified formular, it might be fair to say that risk is the product of probability times severity

$$\mathbf{R_{isk} = P_{robability} * S_{everity}}$$

One has to note though that this approach contains a fairly subjective element, in how to judge severity: if we categorize the consequences or severity of an event as being absolutely unbearable, severity in our formular will be indefinite. Even with our probability being very small, the product of anything times indefinite will be indefinite as well – in this case, our risk would be indefinite as well. In other words, first, a general consensus within the industry and / or society has to be reached as to what severity is still acceptable.

If we label a single aircraft loss as being totally unbearable, in the light of our formular above flying has to stop, as the risk would be indefinite. Obviously, society informally agreed on the current level of safety in aviation (at least within a certain margin) of being acceptable.

As the risk cannot be brought down to zero, the challenge is to minimise probability as much as possible.

To further refine our formular above we might break down probability into number of (flight) events times interfering factors – and these are all things that might go wrong, like weather, ATC, crew performance, technical issues with airframe and systems, operational environment and circumstences, etc.

$$\mathbf{R_{isk} = P_{robability} * S_{everity}}$$

With $\mathbf{P = (E_{vents} * I_{nterfering}\ F_{actors}),}$

= $\mathbf{R = (E * IF) * S}$

According to that approach, the airline industry has been very successful in bringing down the interfering factors, as the number of events (= flight) per day is very high, yet the risk(= number of accidents) is exceptionally low.

On the other, although the aerial work community has worked hard to bring down the interfering factors over the last years, our operational environment still remains challenging; the fact that accident numbers did not roared sky-high is probably due to the fact the number of events is just a fraction of those of the airline industry.

So the sheer quantity of our activity plays in our favour, statistically, it also indicates that the aerial work industry might be able to take on more challenging environments (= accepting specific interfering factors) without our accident rate (= risk) reaching unacceptable levels.

In order to substantiate the claim of being able to accept more specific interfering factors, we might have to brake down these interfering factors into mission-specific factors that can not be changed (we have to fly low, in densely populated airspace; a rescue helicopter has to land in tight spots, maybe in marginal weather, etc.), and operational factors, which encompass all aspects like aircraft, equipment, weather, ATC, operational environment, etc.

$$\mathbf{R_{isk} = P_{robability} * S_{everity}}$$

With $\mathbf{P = (E_{vents} * I_{nterfering}\ F_{actors}),}$

= $\mathbf{R = (E * IF) * S}$

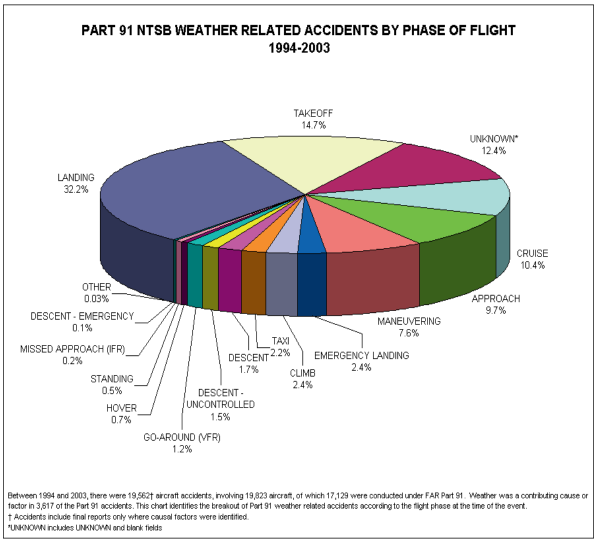
With $\mathbf{IF = (M_{ission}\ S_{pecific} * O_{perational})}$

= $\mathbf{R = (E * (MS * O)) * S}$

With all this said, it is quite obvious that the flight inspection has to focus on the operational aspects (O) of our working environement, as we cannot bring lower some mission-inherent factors, to keep the current level of safety, or better, to improve that level. More to that in the following chapter.

Flight Inspection specific Risks

Flight inspection mission do pose certain challenges. To illustrate one of them, a quick step back to a more fundamental aviation accident statistics:



Between 1994 and 2003, there were 19,562† aircraft accidents, involving 19,823 aircraft, of which 17,129 were conducted under FAR Part 91. Weather was a contributing cause or factor in 3,617 of the Part 91 accidents. This chart identifies the breakout of Part 91 weather related accidents according to the flight phase at the time of the event.

† Accidents include final reports only where causal factors were identified.

*UNKNOWN includes UNKNOWN and blank fields

Figure 6: US Accidents per Flight Phase

Figure 6 depicts the relative percentage of accidents per phase of flight. These are US data, they are consistent with data from other coutries as well, though. They show that a combined 56,6% of all accidents happen either on take off, approach or landing - in this segment of the we spent between 70 to 80% of all our flight time, this being the first challenge.

We fly low, sometimes very low.

We fly in densely populated airspace, seeing and avoiding other traffic is absolutely paramount.

We fly demanding mssions with at times high crew workload, neccessitating to liase with ATC, ground engineers and the NavAid Inspector on board simultaneously..

We might find ourselves in operatinally harsh environments, both with regard to climate / weather, as well as infrastructure, ATC, etc.

Even if we are not working for a private service provider, we face a certain commercial pressure most of the times, as flight inspection does tend to interrupt the usual routine at any airport, which might cause delays to (and in turn: generates pressure from) the airlines.

On commissioning flight checks, unknown terrain and obstacle data might pose a challenge.

Working internationally, language barriers might hamper communications, both on the ground as in the air.

Flying demanding missions, maybe on deployment for several days or even weeks in a row, ever poses the danger of crew fatigue.

To keep the aircraft being used for flight inspection and their respective systems technically up to date with current requirements at times poses a challenge, again in the light of ever present commercial pressure.

Finding the right staff with the right skill set and the right attitude commensurate with the flight inspection mission is a challenge, retaining them through the cyclic ups and downs of the industry even more so!

How to address these challenges will be covered in the following chapter.

MITIGATING TOOLS AND STRATEGIES

To start with, as indicated in the statistics part of this paper, there are some mission specific external factors we simply cannot avoid, like the neccessity to fly low.

This requirements (i.e. on coverage / clearance flights for both localizer and glideslope) do not only stem from the appropriate ICAO Doc8071, they are a bare neccessity in order to ensure proper signal coverage for those, who on a dark, stormy night, tired after a long flight, stray off course and find themselves off centerline and glideslope – in other words, increasing our safety margins in terms of terrain clearance considerably would definitely help us, but not the others, who we vowed to serve.

For this dilemma, we may draw comfort from the statistics discussed above: let us assume we look at an airport with 10.000 landings per year, and maybe a challenging terrain in the approach sector. Chances are that of these 10.000 arrivals 10 (= 0,1%) over the year get it wrong and end up off localizer, below glideslope, yet still in ICAO-defined coverage limits of 1.500ft above station level,.and not 1.000 ft above highest obstacle in the arc area.

No problem in this case, as the flight inspection organisation tasked with checking this approach selected to fly the coverage at the basic ICAO requirements, making sure that signal coverage is given even at that lower altitude. The arriving traffic, even off-course, does have signal reception, and is thus able to recover and land safely.

To achieve this signal reception guaranty, a well trained, well equipped flight inspection crew has to fly the coverage twice a year at that level – compairing the numbers (2 flights of a well prepared crew vs. 10 flights of crews that for a moment lost situational awareness), it is fairly obvious what statistically is overall the more safe solution.

A similar thought process applies to the densely populated airspace dilemma: although some mitigation strategies might apply, like looking for low times in traffic flow, this might collide with other requirements and will not solve the problem 100%.

It remains a fact that in our walk of life certain challenges cannot be avoided, they have to be tackled. How this might be achieved will be broken down in 4 areas:

1. Equipment
2. Operational Environmen, internally
3. Operational Enviroenment, externally
4. Training

Equipment:

In an ideal world, our flight inspection aircraft is 3 years old, has the transit speed of a fast business jet, the slow flying qualities of a Piper Cub, a visibility from the cockpit like a F-16, a stand-up cabin with separate toilet and suffcient baggage space, an effective air conditioning system even in hot climates, and all that of course for the operating economics of a light piston twin – obviously, such an aircraft does not exist.

What is achievable and desirable, though, is to fly, maintain and upgrade the flight inspection aircraft in use as best as possible to the current, mission-specific requirements.

Proper maintenance by qualified staff, at the right intervals, should go without saying.

Providing a cockpit environment that offers a good support to achieve situational awareness is highly desirable. Today, this almost automatically translates into a glass cockpit with a suitable Flight Management System FMS, and moving map displays that goes with it.

Being able to depict the calibration mission (desired tracks, tracks to starting point of a run) as well in one way or the other to the cockpit crew is highly recommended as well , either by interfacing the Flight Inspection System FIS with the existing avionics (preferred option), or by providing an additional display.

It cannot be stressed enough that keeping situational awareness is absolutely paramount on flight inspection missions, any piece of equipment supporting that goal, therefor, is highly desirable.

When flying Procedure Validation missions, a FMS commensurate with the task is a must – the FMS must be capable of processing the ARINC424 formats used by the procdedure designer / coder, for instance, and depicting them properly.

A Traffic Collision Avoiding System TCAS is a highly desirable piece of equipment to have on board, especially when flying in densely populated airspace. As TCAS is not really cheap (USD 250.00 – 500.000,- per aircraft), this might easily collide with the commercial pressures mentioned above. Nevertheless, as this is a very effective tool to enhance safety, it should be installed whenever possible. To benefit from it, proper training should be supplied; part of that taining should be to raise awareness that TCAS might not be able to "see" all traffic, as some other targets might have switched off their transponders or do not have on to start with – like gliders, a major challenge in Germany at times, for instance. So the requirement for constant airspace surveillance remains.

There are other, low-cost TCAS-Look-alike solutions out there on the market. When installed, great care must be taken that the installation was done properly, otherwise false / nuisance indications might result, which effectively do more harm then good, as they distract the crew and undermine the confidence in the system.

Enhanced Ground Proximity Warning Systems EGPWS are another valuable safety feature. It might have saved both the US as well as the German B300.
On flight inspection missions it does have its limitations, though, as it will cause false alarms when flying low approaches with gear / flaps up. As repetitive false alarms must be avoided, when EGPWS is installed on flight inspection aircraft, having a switch available to turn the system off and back on, when required, is paramount. For turning the EGPWS off and later back on after mission, an appriate SOP has to be devised by the respective flight operation, and that SOP has to be reflected by the Normal Checklist in use.

In order to reduce stress for the crew as much as possible, all systems that provide cabin comfort should be operational and effective (heating in cold climate, air conditioning in hot climate). Notably an effective air conditioning is paramount in hot climates, as heat tends to foster the onset of fatigue considerably.

In the near future, Enhanced Vision Systems EVS might bring great benefits to safety, as these system swill dramatically enhance situational awareness in marginal weather and /or at night. Up to this point, these systems habve been fairly expensive, as some high tech is involved to cool the required infrared sensors down. At present, there are a number of low cost systems at the doorstep of being introduced into the aviation world; it remains to be seen how good and thus, how cost effective the systems are. First results by the manufacturers look promising.

At last, the type of aircraft picked to fly the mission is a very important issue. In general, the aircraft type should be able to fly the mission required without too many restrictions (i.e. fuel load, payload), in order not to pressure crews too much into accepting risks, just to get the mission done.

Under normal circumstances, the size of the equipment required to fulfill the role more or less dictates the size of the aircraft in use. With the advent of very small, low cost Flight Inspection Systems, using fairy small twin engined piston aircraft became a viable option in the flight inspection world. A prominent example of this new breed is the Diamond DA42 Twinstar. Under defined circumstances (limited amount of flying required per year, moderate climate, no high top speed required at busy airports) it is already clear that the combination of low cost FIS and low cost aircraft do work; it remains to be seen over the next years though, how well this combination fares when pushed harder, both in terms of flying hours required and harsher external environments encountered.

Operational Environment, internally

Here the internal organisation of the flight operation is addressed. It starts with the safety culture of that organisation, and it is absolutely paramount that this safety culture is a top priority from top management down – beyond pure lip service. Safety often does has cost implications (i.e. if equipment has to be replaced, systems to be upgraded or training to be initiated), always a tough proposition in times of commercial pressure, as mentioned before. The right balance has to be struck regardless, taking the requirements of both positions into account.

At the core of any safe and successful flight operation is a set of operating rules, workable SOPs Crew Coordination Concept and CRM and checklists that do reflect all this, with everything combined preferably in one comprehensive Operations Manual OM.

When setting up an OM and designing SOPs and Checklists that go with them, great care should be taken not to overload the sytem with complexity. It is with a certain degree of scepticism that this author watches the advent of ever new safety systems being introduced into the aviation industry: Flight Safety Systems, Risk Management Systems, Fatigue Risk Management Systems, not to mention an exhaustive Quality Assurance System that today is part of the legal requirements as per EU OPS, for instance, they all add to complexity, creating different reporting paths within an organisation, resulting in ambiguity or even friction. One has to bear in mind that most flight inspection organisation, compared to airlines, are fairly small. One should further bear in mind that flight inspection is a fairly demanding mission, requiring a considerable amount of mental capacity of the crews that fly it – one should avoid to overload them.

KISS – keep it simple and stupid, should be the way forward. This is not to say that issues like risk, fatigue, etc, should not be taken into account, far from it. The ensuing procedures dealing with these issues should be set up in way though, that is manageable and workable in an every day environment, especially in the field when away from homebase.

Normal checklists for operating the aircraft are another good example for the KISS approach: it is a well known fact that the manufacturer's checklists, especially when the aircraft in question is certified for single pilot operations, are often useless in a normal aviation environment for reasons of overcomplexiity and length. These checklists reflect legal and liability issues, which might be well required to keep the manufacturer from harm in legal terms, however, focussing on these legal aspects unfortunately renders these checklists almost useless.

So every operator is called upon to design checklists that do reflect its individual needs. Depending on the regulatory environment it might be necessary to get the altered checklist approved by the respective regulator.

In the arena of internal operational environment falls the issue of flight time limitations. What are the regulatory guidelines, and what does the flight inspection organisation expect from its crews to achieve? An internal survey of ICASC members brought to light a wide variety of operational flight and rest time regimes; it was impossible to draw a common line.
What all flight and rest time regimes should have in common is to combat fatigue, or even the onset of it.

At what point fatigue hits will very much depend on the type of mission flown (ILS low level work, in general, being more stressful then airway work high up), the aircraft being used (Cockpit equipment being available, space available on board, susceptibilty to turbulence, temperature control) and the environment operated in (poor ATC? Poor infrastructure,i.e. refueling a major undertaking? Night flying involved?). A very important consideration also is accomodation and transportation for crews, notably when away from base. It must be established that a good rest and a good night sleep can be accomplished at the accomodation picked.

So, in essence, again each operator will have to come up with its individual flight and rest time regulations, of course always in line with the respective regulatory environment of the country of registration, that take into account the individual environmental circumstances.

Operational Environment, externally

Here the external circumstances of the operation are addressed: were do we operate, doing what with whom? How is the terrain, how is the infrastructure (fuel / de-icing / hangar available)? How well is ATC organised, is radar coverage given? Who on a specific mission will be point of contact for the company? Who for the crew?

Giving all this a thorough consideration is even more important when doing commissioning flight checks at new airports.

Dealing with these questions effectively constitutes some sort of risk assessment prior embarking on the mission, something that is highly desirable. Whenever possible, these data should be collated prior bidding for a tender; marketing or management should try to find out as much information as possible prior committing to a task, in order to reduce pressure and stress to the crew on site later.

Training:

The training aspect of flight inspection flying cannot be overestimated.

It starts with the challenge to pick the right crews for the job. Every operator will have his individual selection and hiring process. Great care should be spent on finding pilots that have an professional attitude towards special mission flying – not too many as per class that annually leave flight school, as per own experience, as the vast majority a striving for a job with the big airlines.

Once the right set of people has been found, training them initially poses its next challenge. The initial training on the type of aircraft to be flown should be a chalennge that is fairly easily to be accomplished; in an ideal world the initial training on type already reflects the special requirements of the mission, the company's own SOPs, checklists, etc. Emphasis should be put on adjusting the candidates focus on the aircraft being merely a tool for a bigger purpose; when in commercial flying the task is to fly safely from A to B, in our world the real job only starts at B.

Whenever possible, and a suitable simulator does exist for the type of aircraft flown, a simulator should be used for initial and recurrent training, again according to a syllabus that already reflects the individuals company SOPs, checklists and tasks (“ train as you fly, fly as you train”).

Training a new entry on the mission specifics is much harder to achieve, as it inevitably involves a lot of in-house training (normally no commercial, off-the-shelf training solutions available for the flight inspection world). ICAO recently published a new document, Doc 9906 Volume 6 “ Flight Validation Pilot Training and Evaluation”, that provides valuable input to flight inspection pilot training in general and procedure validation training in particular.

It cannot be overstressed that a well trained crew is the most potent mitigation strategy to deal with the specific risks attached to flight inspection flying, as identified in the former chapters. Investment in training is also always a good indicator as to how seriously the whole company, from top management down, stands to its safety commitment, as described above.

THE LOOK BEYOND ONE’S OWN NOSE – HOW THE OTHERS FARE

Inevitably, other sectors of the aviation industry have tackled the issue of safety as well, coming up with tools and strategies to mitigate risks and dangers.

A good example for this is the International Standard for Business Aircraft Operations IS-BAO, published by theInternational Business Aviation Council IBAC.

IS-BAO is an industry standard, written by the industry for the industry. It gives guidelines how to organise a business aviation flight department and provides structures and recommendations, which closely resemble regulatory docuemnts like EU-OPS and others.

The interesting point of IS-BAO is that any flight department inplementing IS-BAO can register with IBAC to monitor, and later on audit the implementation, with the goal of receiving a seal of approval as being a IS-BAO registered and conformal organisation, a fact that then might be brought to the market as a quality attribute, to differentiate one self from the rest of the competition.

That might be an interesting approach for our industry as well, more to that further below.

Similar guidelines for the aerial work community have been issued by the International Airborne Geophysics Safety Association IAGSA.

IAGSA’s Safety Policy Manual describes a set of issues and factors that have to be observed and addressed on survey flights, like Job Safety Analysis (basically a risk assessment of the impending survey to be flown), survey heights and procedures, speeds, flight following and survival provisions, flight and duty times, night flying, and many more.

This manual is already fairly close to our kind of operations in flight inspection and thus warrants further consideration for our line of work.

A very smart approach IAGSA brought to the fore was to condense the essence of its Safety Policy Manual into an Annex that should then be attached to potential survey contracts (Recommendation to Include Specific Safety Requirements in Geophysical Survey Contracts). This Annex has been distributed to all potential parties contracting airborne geophysical surveys, thus raising awareness within the industry, and providing a level playing field for all in the process. A very promising approach that warrants further discussions within our industry.

CONCLUSIONS

Although hard statistical data is hard to come by, some exemplary evidence provided by selected authorities indicate that safety in the aerial work domain, of which the flight inspection community is part of, remains at an acceptable level, given the challenges this demanding role poses.

As shown, not all factors contributing to the risks of our industry can or should be avoided, however, there are tools and strategies at hand to reduce or even mitigate the specific risks associated with our line of work.

FUTURE WORK

One of the purposes this paper should serve was to open the discussion within our industry on the topic of introducing similar standards and best practises, as other sectors of the aviation industry have done, to foster safety. To that end, in the view of the author, the work of both IBAC as well as IAGSA show great potential, and their adaption to our specific needs should warrant further discussions.

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Elegant Stealth Solution for Buildings to Prevent ILS Disturbance

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ABSTRACT

The performances of the Instrument Landing System (ILS) can be degraded by interference caused by nearby scattering objects such as aircraft, cranes and buildings.

The collaboration of AIRBUS, EADS Innovation Works and ENAC has permitted to develop an elegant stealth solution for future building C65 to prevent the building from causing the loss of Category III (CAT III) operations at Toulouse Blagnac airport. The solution is based on diffraction gratings that redirect the incident wave back to its source rather than the specular direction. Diffraction gratings have been extensively studied in the 1980s but have never been applied to buildings for the ILS problem. The shape of the diffraction grating on C65 facade was optimized for the specific position and orientation of C65 regarding ILS sitting.

The construction of the building has begun (mid december 2011) and the diffraction gratings will be installed in summer 2012.

By using this stealth technology on buildings located within previously forbidden areas, land-constrained airports are now in a position to significantly increase their land income.

INTRODUCTION

The Instrument Landing System (ILS) allows aircraft to land in low visibility conditions. It provides guidance in the vertical and horizontal planes by emitting a signal with a spatially varying modulation. Nearby scattering objects such as aircraft, cranes and buildings can produce perturbations, degrading the performance of the ILS. The quality of the ILS is characterized by measurements of the difference of depth of modulation (DDM) along the runway axis and is classed on a scale of CAT I to CAT III (the strictest CAT III being required for zero visibility landings).

The ICAO European guidelines for managing Building Restricted Areas (BRA) [1] define a volume where buildings have the potential to cause unacceptable interference to the ILS signal. Within the BRA, it is necessary to demonstrate (using simulation or other means) that the building will not cause disturbances in excess of predefined limits.

DESIGNING OF THE STEALTH SOLUTION

Initial Situation

The Airbus A350 program requires the construction of several new buildings on the Airbus Blagnac site, near Toulouse in the South of France. A hangar will be constructed close to Runway 14R/32L of Toulouse-Blagnac Airport. We see in the top view (see Figure 1) that the building must be oblique to the runway to be consistent with the surrounding architecture. This complicates matters in that two facades are identified as being potential sources of disturbances. The north facade receives a signal from the LOC 32L antenna at 44.8° to normal and the east facade, which contains a large door (see Figure 2), receives a signal from the LOC 14R antenna at 25° to normal.

Figure 1. The implementation of the proposed hangar C65

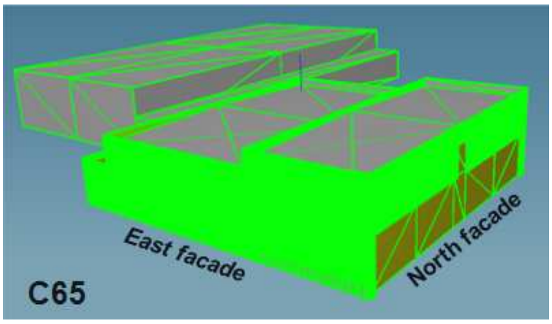

Figure 2. 3D model of the C65 buiding

Initial simulations performed using ELISE indicate that the disturbance of the DDM generated by the East Facade (if left untreated) can amount to 14.7µA (see Figure 3), which is far in excess of the CAT III limit at this position of 7.2 µA. The disturbance generated by the North facade is smaller (see Figure 4), but it is still potentially problematic, coinciding with the ICAO limit for CAT III landings of 7.9 µA. We conclude that it is necessary to apply a treatment to the building facades to reduce the generated disturbance.

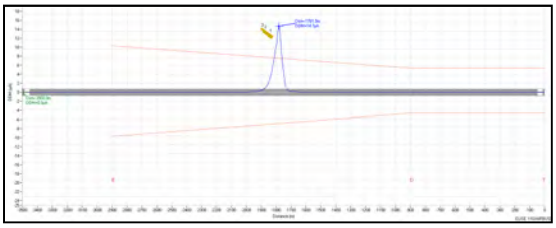

Figure 3. Simulated DDM for the LOC 14R antenna (disturbance due to East Facade)

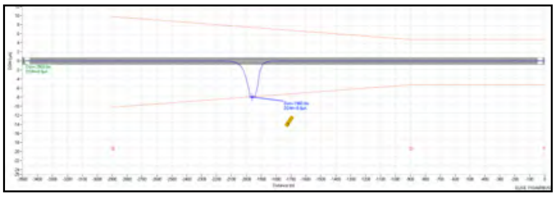

Figure 4. Simulated DDM for LOC 32L antenna (disturbance due to North Facade)

Diffraction Gratings for Building Disturbances

Several solutions have been proposed to solve the problem of ILS disturbance from buildings [2] but they often suffer from the problem of the relatively long wavelength in the ILS band (2.7 m). Consequently, diffractive effects can become important if the structures employed are not significantly larger than the wavelength. An elegant solution has been proposed and extensively studied by Jull et al. [3-6], who propose a diffraction grating that redirects the incident wave back to its source rather than the specular direction.

For each of the two facades we perform a preliminary study using CST Microwave Studio to find the optimal crenellation shape. The crenellation spacing is given by the classic Bragg diffraction condition $d = \lambda/(2\sin\theta)$, where d is the periodicity of the grating.

Simulations are performed varying crenellation depths for a selection of different crenellation widths. The amplitude of the specular reflection is plotted, and the optimal depth is calculated as the minimum of this curve. The optimal depths are displayed in Figure 5 for the north facade. We also display the ratio of the specular reflected field before and after application of the diffraction grating (Figure 6).

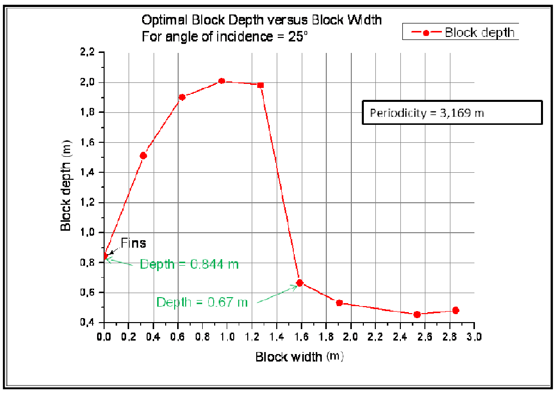

Figure 5. Optimal crenellation dimensions for the north facade

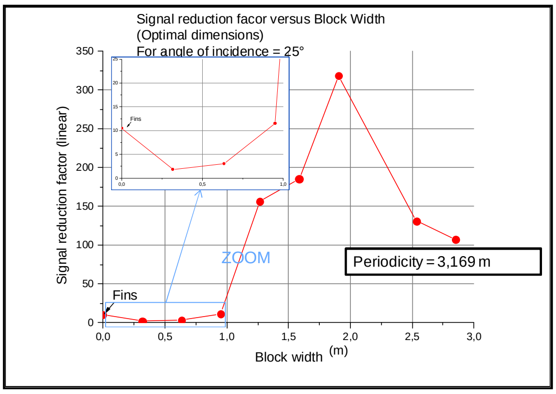

Figure 6. Signal reduction for the optimal dimensions displayed in Figure 5

The final decision for the dimensions chosen depends upon both electromagnetic and architectural considerations. For the north facade, we clearly see that a block width of 1 m or less provides insufficient signal reduction. For installation purposes it is desirable to minimise the quantity of additional metal plates employed, but it is also important not to overhang the building by much more than 60 cm. As a compromise of all these constraints we choose a block with dimensions of 158.4 by 66.9 cm (see Figure 7 for mechanical implementation).

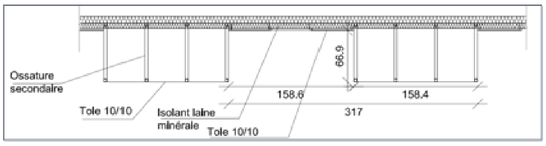

Figure 7. Mechanical construction of the north facade crenellations

STEALTH SOLUTION IMPLEMENTATION

Operational Constraints

Once an optimal grating shape has been found, we can evaluate its effectiveness for realistic building geometries using the ELISE simulation tool [7]. In this step we can also perform an analysis to minimize the surfaces of the building to be treated. The reasons for this being:

1. The surface treatment implies a financial overhead that should be minimized

2. The crenellations can act as obstacles for ground operations.

3. The disturbances are often much reduced for the lower half of the building since the horizontally polarized wave employed by the ILS system is attenuated by the ground plane.

4. The north facade contains a large door to allow aircraft to enter, upon which the diffraction grating cannot be applied.

In Figure 8 we see the treatment applied the north facade. The notch, visible in the figure, is an extension of the door allowing the aircraft vertical tail to enter the building.

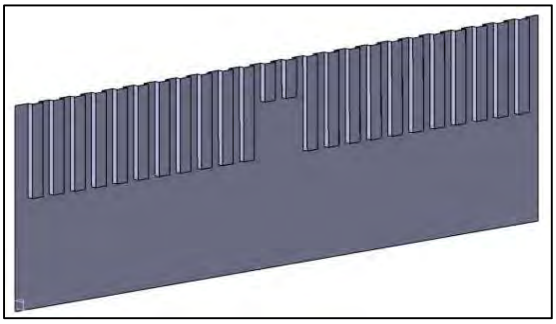

Figure 8. The diffraction grating applied to the north facade

In Figure 9 we display the variation of the residual DDM for different heights of application of the diffraction grating (measured from the top of the building). The red lines represent a goal of 3 µA that we set ourselves (far inferior to the 7.9 µA limit specified by the ICAO). To leave a large error margin and also for aesthetic reasons we choose a height of 11.5 m.

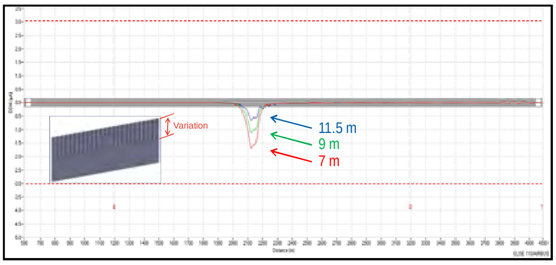

Figure 9. Variation of the DDM for different applied heights

Modeling of the Construction Site

The above simulations demonstrate that the final building does not disturb the CAT III classification of the airport, but it is also necessary to confirm that airport operations are not disturbed during the construction of the building. We have already seen (Figure 3 and Figure 4) that the naked facades do exceed the specified limits but this phase of construction is relatively short and will occur in 'good visibility' period of summer. Of greater concern is the installation of the steel framework of the building, erected in the winter months. ELISE simulations were performed to establish that this structure does not cause an out-of-tolerance disturbance. The architectural model of the building was in the AutoCAD 3D format, which cannot be meshed directly for simulation using ELISE. Furthermore, the model was highly complex and included several interpenetrating beams. In order to simplify this model, a routine developed by EADS-IW was employed to convert the geometry into a mesh consisting of wire elements (see Figure 10).

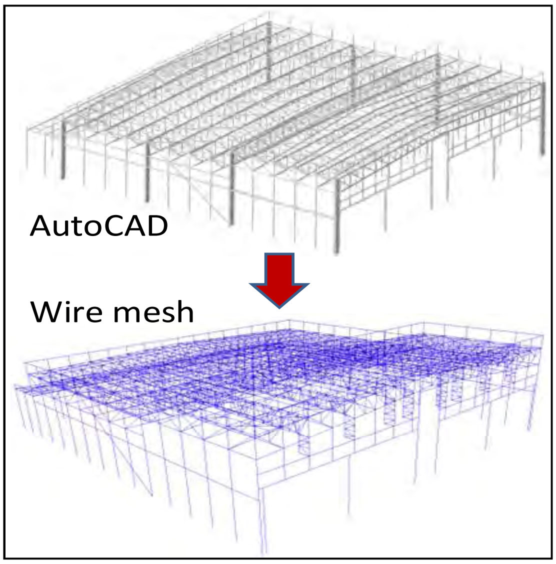

Figure 10. The conversion of the AutoCAD architectural drawing to a wire mesh

The ELISE simulation, was performed using an analytical thick wire model (diameter 10cm) and showed that disturbances for the two localiser antennas that were less than 50% of the limit. See **Erreur ! Source du renvoi introuvable.** for the case of the LOC 14R antenna.

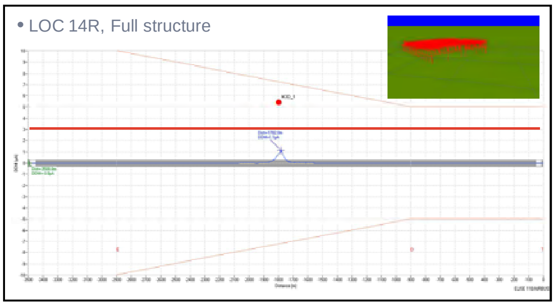

Figure 11. Simulated DDM for the steel building framework

Construction Site Follow-up

The building foundations were laid in december 2011. End of construction is planned for september 2012. Measurements are being performed on a regular basis since the beginning of the construction, and are compared with simulations. Erection of the steel framework was completed end of april 2012. Until then, measurements did not revealed any major alteration of the LOC 14R signal compared to what the signal was before, as anticipated by ELISE simulations.

Installation of the first skin of the building facades started in early may 2012 (start of ‘good visibility’ period), as shown in Figure 12 (approximately 1/3rd of east facade covered). This was an intermediate step before diffraction gratings implementation. LOC 14R signal alterations were anticipated during this construction phase, which was confirmed by mid-way measurements (see Figure 13). Indeed, these measurements showed the emergence of a new DDM static bend, although the coverage of the facade was not finished yet. LOC 14R signal is expected to be declassified from CAT III to CAT II during this construction phase until installation of the diffraction gratings, which will permit to get the signal back into CAT III tolerances.

Figure 12. Start of first skin erection of east facade

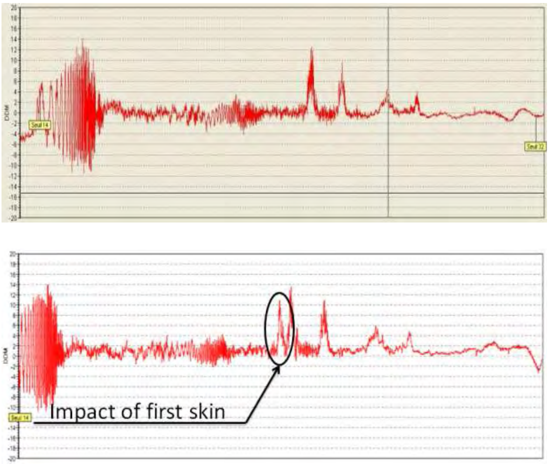

Figure 13. LOC 14 DDM measurements before (up) and after (down) start of first skin erection

An artist’s impression of the completed building is displayed in **Figure 14**.

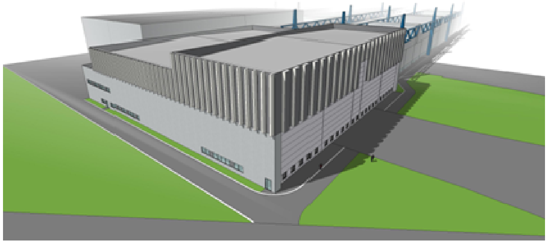

Figure 14. Final form of the building

FUTURE WORK

We have already alluded to the financial considerations of introducing large crenellations on the building surface. We have filed patents presenting a method of employing a smaller structure. These results will be presented in a near future.

This work opens up the exciting prospect of exploiting more efficiently the land located close to runways, particularly as these zones are of great interest for property developers, for the implantation of high buildings such as car parks, conference centres, aircraft terminals and maintenance hangars.

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Roll	Aurélia	Sagem	France
Ronold	Kai-Tore	Norwegian Special Mission AS	Norway
Rosten	Bjørn		Norway
Ruud	Oivind	Norwegian Special Mission AS	Norway
Sandwel	Jay	FAA	USA
Sarver	Scott	Cessna Aircraft Company	USA
Sawatpanich	Thongchai	Department of Civil Aviation Thailand	Thailand
Scaramuzza	Maurizio	skyguide swiss air navigation services ltd	Switzerland
Schinköthe	Jens	Aerodata AG	Germany
Schmidt	Rüdiger	FCS Flight Calilbration Services GmbH	Germany
Schmidt	Christian	DFS Deutsche Flugsicherung GmbH	Germany

Last Name	First Name	Organization	Country
Schrader	Thorsten	Physikalisch-Technische Bundesanstalt	Germany
Schweifer	Martin	Austro Control GmbH	Austria
Schwendener	Markus	FCS Flight Calibration Services GmbH	Germany
Sdunnus	Holger	etamax space GmbH	Germany
Seeger	Jörg	DFS Deutsche Flugsicherung GmbH	Germany
Seide	Rolf	Aerodata AG	Germany
Shi	Xiaofeng	Beihang University	China
Sileno	Godicke	ENAV	Italy
Sitton	Jim	Airfield Technology, Inc.	USA
Slobodan	Tešanović	Serbia and Montenegro Air Traffic Services Agency	Serbia
Snelling	Brad	FAA	USA
Sorland	John	Norwegian Special Mission AS	Norway
Sortland	Oyvind	Norwegian Special Mission AS	Norway
Sousa	Alexander	Brazilian Air Force	Brazil
Spanner	Michael	AeroPearl Pty Ltd	Australia
Spetsas	Konstantinos	Hellenic Civil Aviation Authority	Greece
Spitz	Bertrand	ENAC	France
Stahl	Hans	Aerodata AG	Germany
Steffens	Knuth	Aerodata AG	Germany
Steinau	Wolfram	DFS Deutsche Flugsicherung GmbH	Germany
Storli	Martin	Norwegian Special Mission AS	Norway
Stupperich	Christoph	Serco GmbH	Germany
Sulc	Jaroslav	Civil Aviation Authority of the Slovak Republic	Slovac Republic
Suter	Roger	skyguide swiss air navigation services ltd	Switzerland
Sverstad	Tom	Norwegian Special Mission AS	Norway
Swendrak	Björn	FCS Flight Calilbration Services GmbH	Germany
Szpakowski	Pawel	Polish Air Navigation Services Agency	Poland
Tambychik	Jamaluddin	Department of Civil Aviation Malaysia	Malaysia
Teichert	Klaus	FCS Flight Calilbration Services GmbH	Germany
Theissen	Klaus	Rohde & Schwarz GmbH & Co. KG	Germany
Thirkettle	Peter	UK CAA	England
Thomas	Josef	VDI Braunschweiger Bezirksverein e.V.	Germany
Thompson	Carole	Radiola Aerospace NZ Ltd	New Zealand
Thompson	Richard	Radiola Aerospace NZ Ltd	New Zealand
Thörnell	Fredrik	LFV - Swedish CAA	Sweden
Tietze	Tom	Airfield Technology, Inc.	USA
Tietze	Brenda	Airfield Technology, Inc.	USA
Togersen	Erik	Norwegian Special Mission AS	Norway
Tomajer	David	ANS CR	Czech Republic
Torun	Abdulkadir	State Airports Authority (DHMI)	Turkey
Trones	Jostein	Norwegian Special Mission AS	Norway
Udoh	Nnamdi	Nigerian Airspace Management Agency	Nigeria
Van Straaten	Annelise		South Africa
Vanness	Dave	FAA	USA
Vaz	Doug	FAA	USA
Viel	Alain	École Nationale Aviation Civile	France
Vitan	Valeriu	EUROCONTROL	Belgium

Last Name	First Name	Organization	Country
Voje Blindheim	Eirik	Norwegian Special Mission AS	Norway
Vollestad	Ola	Norwegian Special Mission AS	Norway
Wang	Yongchao	Aviation Data Communication Corporation	China
Wang	Pengfei	Aviation Data Communication Corporation	China
Wang	Chenglin	Beihang University	China
Wasner	Uwe	DFS Deutsche Flugsicherung GmbH	Germany
Watier	Stephane	DTI	France
Weber	Dietmar	Rohde & Schwarz GmbH & Co. KG	Germany
Webers	Manfred	FCS Flight Calilbration Services GmbH	Germany
Wede	Tom	Cobham Flight Inspection Limited	Germany
Wilkens	Claus	Aerodata AG	Germany
Wills	Martyn	Cyrrus Ltd	United Kingdom
Wilmes	Ivo	National Aerospace Laboratory	Netherlands
Witanowski	Artur	Polish Air Navigation Services Agency	Poland
Witeska	Pawel	Polish Air Navigation Services Agency	Poland
Yglesias	José	Aerodata AG	Germany
Zehnder	Christoph	skyguide swiss air navigation services ltd	Switzerland
Zhang	Jun	Beihang University	China
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Zumkeller	Christian	Universal Avionics Systems Corporation	Switzerland
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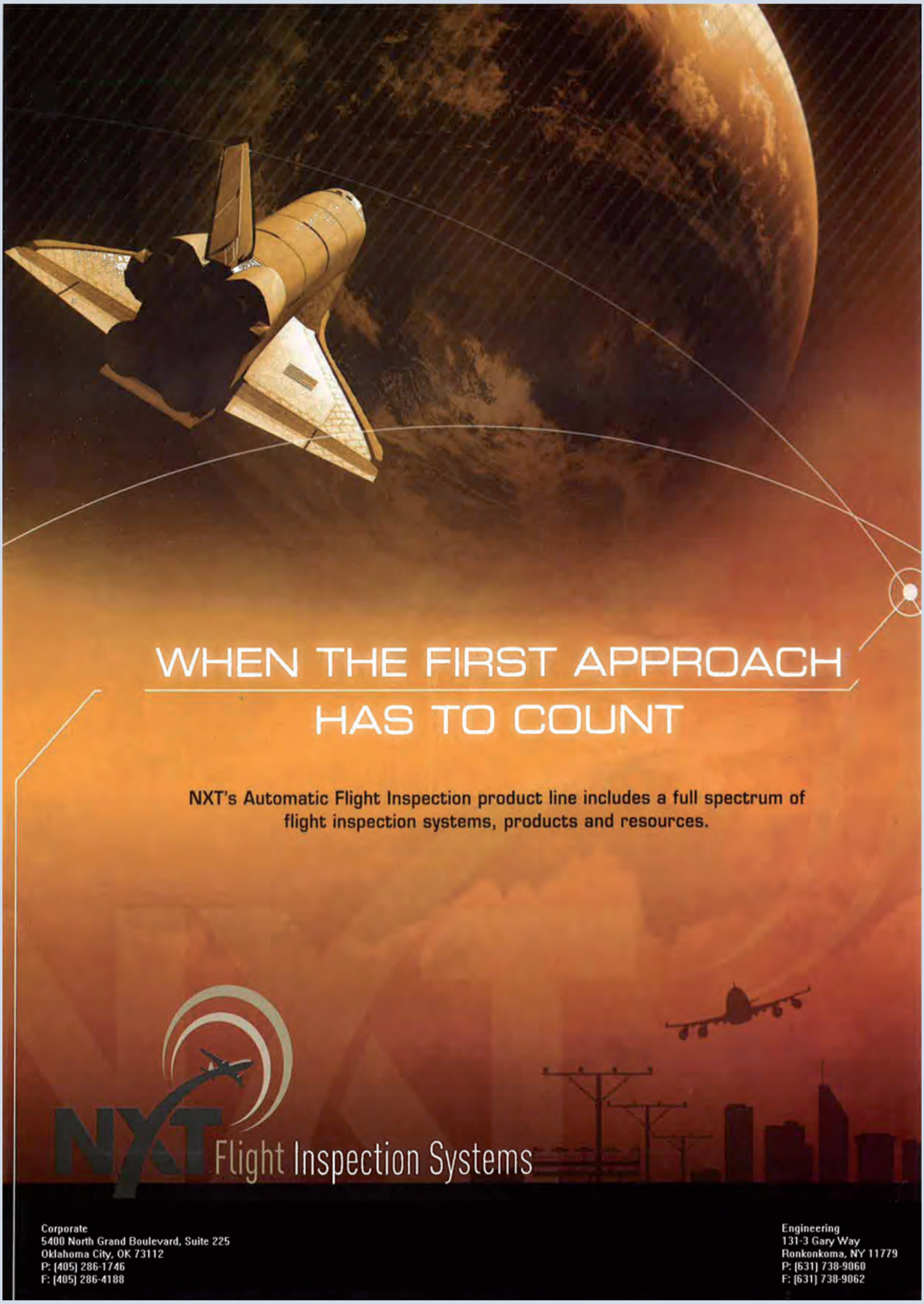
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