Flight inspection of GNSS-based precision approaches to regional airports in Norway.

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ABSTRACT:

This paper covers the background, efforts and results in the implementation and government approval of GNSS – based precision approaches to a network of 24 regional airports in Norway.
The approval process includes the flight inspection issues of confirming procedure design, final segment alignment, GNSS signal reception and data link reception within the coverage volume.
Some of the issues presented include:

- The need for precision approaches to regional airports in difficult terrain
- The development process for Ground Stations and interoperable avionics (GLS/FMS)
- The airline stakeholder and other industrial actors in the program
- The approval process – system wise and for each individual ground station
- Flight Inspection: airborne equipment, position fixing system, inspection issues, data logging and presentation

The first section of the presentation gives an overview of the development and approval program for the SCAT-I concept as implemented in a coordinated effort between:

- American, Canadian and Norwegian industrial participants,
- Regulatory authorities including FAA, Transport Canada, N-CAA and EASA
- Widerøe Airlines
- Avinor – the Norwegian Service Provider (owner of 46 airports / ATM / CNS)

The second section deals with flight inspection issues – development – aircraft implementation and testing and the equipments role in the approval process for avionics (TIA / STC) and operating approval for the SCAT-I Ground Station.

The official inauguration of the concept and commercial SCAT-I based precision approaches took place on the 29th of October 2007.

INTRODUCTION

This paper covers a 12 year history from its inception in 1996 through development and certification stages to inauguration of the worlds 1st ground station for SCAT-I based commercial line flying in 2007 and into the present ongoing process of roll-out to 24 STOL-ports in Norway.

ACCIDENTS ON APPROACH TO 2 STOL-PORTS RAISED DEMAND FOR GLIDE SLOPE INSTRUMENTATION

In May 1988 a Widerøes Dash-7 aircraft while making its descent to Brønnøysund Airport crashed into the Torghatten mountain and all 36 passengers and crew were killed. Six years later a Widerøes DCH-6 had a CFIT accident while approaching Namsos airport. Investigations concluded that the cause of these accidents was lack of vertical approach guidance.
Following the reports from these accidents, a Parliamentary Commission proposed that implementing glide slope approaches to the STOL-ports be required. The implementation of this requirement has been closely monitored by the Parliament Transport Committee to this day.

ILS DEEMED INADEQUATE DUE TO TERRAIN/TOPOGRAPHY.

Most STOL-ports in Norway have unique geographic features which make conventional ILS equipment difficult or impossible to install and operate.
The parliamentary mandate to install electronic glide slopes ignored such issues as technical limitations.

THE NATURE OF THE STOL-PORTS AND THE UNIQUE STOL OPERATION IN NORWAY

The network of airports in Norway, owned and operated by Avinor, consists of 46 airports, of which 24 are STOL-ports with 800-1000m runways. These airports are characterized by precipitous terrain, frequent inclement weather and long periods of winter darkness, precisely the conditions that make the availability of precision approaches critical to safety and airline schedule reliability.
The passenger flow to the individual STOL-ports range from 5000 to 120000 per year, totalling 1.2 mill last year. Widerøes is the major operator on the STOL-ports and presently operate a fleet of 17 Dash-8 100-series, about half the fleet of Widerøes aircraft, and executes about 85000 STOL-ports cycles per year; one landing every 4th minute.

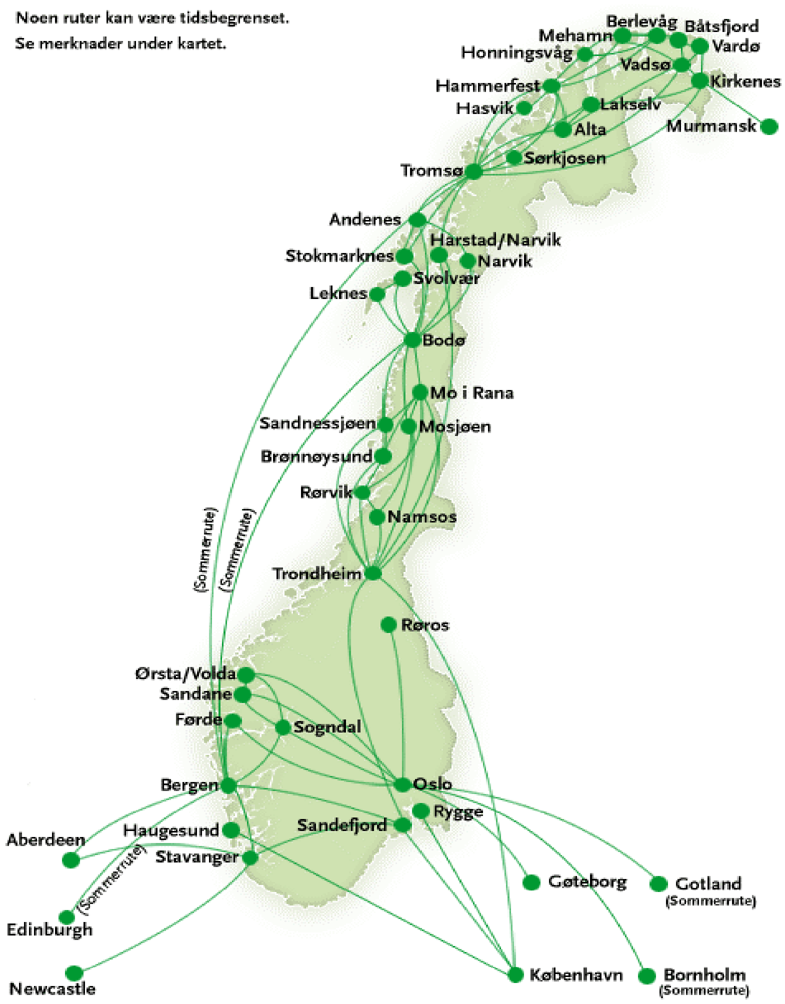

Fig. 1 Widerøes network

BOLD DECISION TO GO FOR SATELLITE BASED PRECISION LANDING SYSTEM.

Specifications for SCAT-I became published in 1993 [see References]. Subsequently, a task force within the then NCAA was formed in order to determine whether the demand for glide slope approaches to the STOL-ports could be accomplished through implementation of the SCAT-I concept.
The conclusion was positive indeed.

PROMISING TRIALS WITH PROTOTYPE AVIONICS AND GROUND EQUIPMENT.

In order to gain hands-on experience with DGPS approaches, a team was formed in 1996 comprising NCAA (then consisting of service provider and regulatory unit), Widerøes, Universal Avionics Systems Corporation (UASC) and Raytheon Systems Company. Proof-of- Concept trials were conducted at Bodø Airport with prototype avionics and ground station. The system worked remarkably well and the potential benefits of DGPS approaches were clearly demonstrated to airline operational personnel and regulators.

Early prototypes did not meet the requirements for software at appropriate safety levels and the earlier version of DO-217 was somewhat incomplete with respect to air/ground allocation of certain requirements, thus raising interoperability issues.
In the late ‘90s such interoperability issues were being addressed in the LAAS definitions and the SCAT-I Manufacturers Interoperability Group [3] agreed to additional specifications; such as ground/air integrity allocations.

Following these additional specifications, airborne and ground based equipments were redesigned.
New tests were conducted at Torp Airport, this time with the UASC avionics installed in the NCAA Dash-8-103 Flight Inspection Aircraft.
Test flights with continuous monitoring by the Flight Inspection Equipment demonstrated a very small navigation sensor error (NSE) and substantially higher noise level on the parallel ILS-recordings.
Several test pilots commented on the stability of the DGPS guidance compared to a typical ILS and stated that they occasionally made some intentional deviations to verify that the indicator was not frozen.

UPS AND DOWNS AS INDUSTRIAL PARTICIPANTS AND GOVERNMENTAL AGENCIES CAME AND WENT.

Prior to the 2nd round of testing in 1999 at least 8 manufacturers were developing SCAT-I ground stations and others were developing airborne equipment. These were the days when the Local Area Augmentation System (LAAS) concept became published.
Manufacturers started to see greener grass on the LAAS side of the fence, and one after the other dropped out of the SCAT-race.

PROGRAM HALT

The program came close to termination when FAA no longer saw fit to proceed with the certification of the ground based and airborne segments of the SCAT-I concept. As a consequence its Integrity Panel (LIP) also discontinued the work on SCAT-I.

At this point in time Park Air System (PAS) of Oslo had joined the group of manufacturers developing SCAT-I ground stations, and was encouraged by the then N-CAA to continue the process.
N-CAA became split into CAA (regulator) and Avinor (service provider) in 2000.
Somewhat later, CAA took on the task of certifying the PAS ground station and established a SCAT-I Integrity Panel (SIP) consisting of well reputed professors from European universities.

RESURRECTION OF THE PROGRAM

High level meetings between FAA and Norwegian authorities late 2003 saw FAA return to the task of certifying the airborne equipment; type approval (TSO) and Supplementary Technical Certification (STC) of the equipment in a Dash-8-100 aircraft fitted with UNS-1D Flight Management System (FMS).
The resurrection of the program saw 4 industrial participants, one airline and one service provider enter into a Memorandum of Understanding (MoU) to join efforts with the objective of having the system certified, STOL-ports fitted with SCAT-I ground stations and aircraft fitted with SCAT-I airborne equipment. This MoU was entered into with the consent of the regulators and included the definitions of the certification tasks to be undertaken in the continued process.

Industrial participants
Park Air Systems AS, Oslo to complete development and have the Ground Station Normarc 8005 certified.
Universal Avionics Systems Corporation, Tucson, AZ, USA to complete development and have SCAT-I software for FMS and GLS-1250 **G**NSS **L**andings**S**ystem certified.
Field Aviation East Ltd, Toronto, Canada to do engineering, modification of aircraft and installation of FMS and GLS-1250 **G**NSS **L**andings**S**ystem in the testbed aircraft LN-ILS, in Widerøes fleet of Dash-8-100 series aircraft (17), and in the Flight Inspection Aircraft (Beechcraft King Air 200) LN-SUZ
Normarc Flight Inspection System AS, Oslo to develop new software and upgrade existeing Avinor equipment with features for flight inspection and certification of SCAT-I.

Airline:
Widerøes Flyveselskap ASA to upgrade 17 Dash-8-100 series aircraft for the STOL-ports.
Pilots (350) to embark on training program and simulator flight training at the SAS Flight Academy.

Regulators:
FAA, Los Angeles ACU, USA, to issue type approval (TIA) and Supplementary Technical Certification (STC) for the FMS and GLS-1250 **G**NSS **L**andings**S**ystem in the testbed aircraft LN-ILS.
Transport Canada, Canada, (TC) to issue STC for the specific avionics-configuration (double FMS-configuration) for the Widerøes aircraft.
EASA (European Aviation Safety Agency) to issue ESTC’s based on FAA og Transport Canada STCs.

CAA to:

- Issue type approval for the PAS ground station NM8005
- Issue operating approval for the SCAT-I ground station at Brønnøysund Airport
- Issue operating approval (Special Category Authorization) for Widerøes and other operators to fly SCAT-I precision approach operations
- Approve criteria for design of SCAT-I IFR precision approach procedures
- Issue operating approval for the 20 odd STOL-ports and their SCAT-I IFR

All in all, it turned out that the SCAT-I program needed 23 regulator approvals before the inauguration flight took place on the 29^{th} of October 2007 – the worlds first satellite based ground augmented precision approach system to be put in commercial operation for scheduled passenger flights.

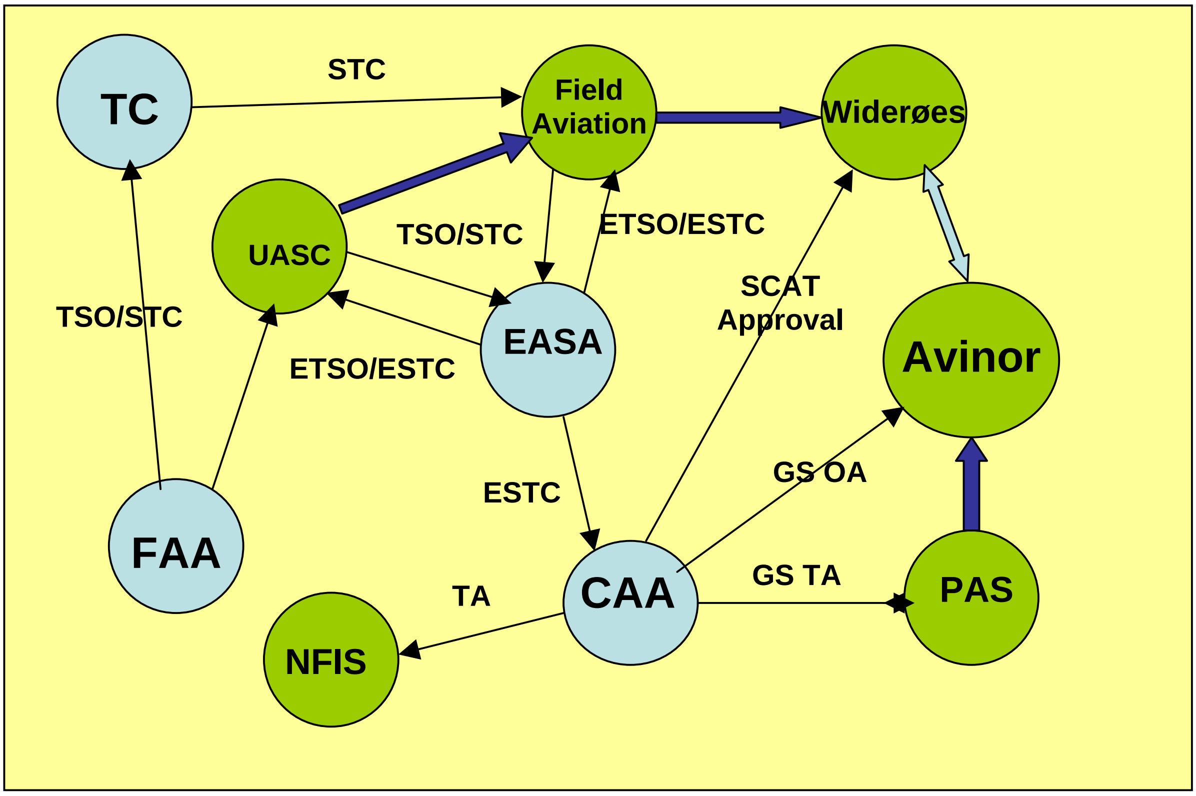

Fig 2
Illustration of industrial and regulator participants in the SCAT-I certification processes.

OFFICIAL TEST FLYING AND CERTIFICATION OF EQUIPMENT.

Certification tests with two aircrafts fitted with SCAT-I FMS software and GLS-1250 landing sensors, and test pilots from FAA and Transport Canada respectively, took place during the spring of 2005. Accuracy and stability proved unprecedented and the aircraft autopilots handled glide slopes of 3^o – 6^o effortlessly even with strong cross- and tailwinds. A total number of 150 approaches were flown, and the system was tested in every conceivable way.
The initial certification (TSO) were cleared rather quickly due to the investments made in flight inspection equipment and data analysis tools which enabled us to demonstrate and document system performance and test results at a high level.
Table 1 (next page) shows typical post-processed values of data logged by the flight inspection equipment during a certification test approach:
The lower line shows:

Distance to threshold:	0.3 nm
Height:	200 ft
Deviation EL	3.42 ft
Deviation AZ	0.95 ft

FAA type approval (TSO) was issued rather quickly as were FAA and Transport Canada STCs following a favourable ruling by SIP on the integrity issue. However, it took another 2 years before the certification obstacle race passed the target line and we were ready for inauguration.

Table 1

Typical Final Approach Segment (FAS) data derived from the Flight Inspection Equipment

UTC HH: MM SS	REF DIST NM	REF ALT FT	AZ REF DEG	EL REF DEG	AZ DEV FT	EL DEV FT	AZ Tunnel FT	EL Tunnel FT	AZ PEN %	EL PEN %
08:42:21	3,4	1500	0,05	0,08	17,57	29,75	525	172	3	17
08:42:21	3,4	1498	0,05	0,08	17,56	29,74	524	172	3	17
08:42:21	3,4	1497	0,05	0,08	17,54	29,71	524	172	3	17
08:42:21	3,4	1496	0,05	0,08	17,88	29,68	524	172	3	17
08:42:21	3,4	1491	0,05	0,08	17,83	29,59	522	171	3	17
08:42:56	2,2	1000	0,04	0,02	9,77	5,00	358	117	3	4
08:42:56	2,2	999	0,04	0,02	9,75	5,23	358	117	3	4
08:42:56	2,2	998	0,04	0,02	9,74	5,22	358	117	3	4
08:42:57	2,2	996	0,04	0,02	9,72	5,45	357	117	3	5
08:42:57	2,2	995	0,04	0,02	9,71	5,68	357	116	3	5
08:44:01	0,4	205	0,02	-0,08	0,83	3,13	111	32	1	10
08:44:01	0,4	204	0,02	-0,09	0,86	3,17	111	32	1	10
08:44:01	0,3	203	0,02	-0,09	0,89	3,30	111	32	1	10
08:44:01	0,3	201	0,03	-0,09	0,92	3,34	110	32	1	10
08:44:01	0,3	200	0,03	-0,09	0,95	3,42	110	32	1	11

PRINCIPLES OF OPERATION

So what is this SCAT-I that we have pursued so stubbornly for all of 12 years?
In the aircraft, twin Universal Avionics GLS-1250 GPS-landing sensors linked with the FMS are responsible for keeping the aircraft on a designated trajectory, within a virtual tunnel, that avoids high terrain and other obstacles in the airport vicinity. The pilots fly as if doing an ILS approach, using similar guiding cues from the flight deck instrumentation. A ground based augmentation system (the PAS NM8005 ground station) uplinks differential corrections via a VHF data link to the airborne dual GLSes, thus bringing the required accuracy to the system.
SCAT-I is capable of guiding aircraft down to Category I decision height on a defined trajectory that may start as far out as 20 NM from the runway threshold and subsequently follows a 3° – 4.5° glide slope through the typical 5 NM tunnel to touchdown (see tunnel illustration below). The system can be used day and night and in restricted visibility, but requires visual conditions from decision height (DH) to touchdown.

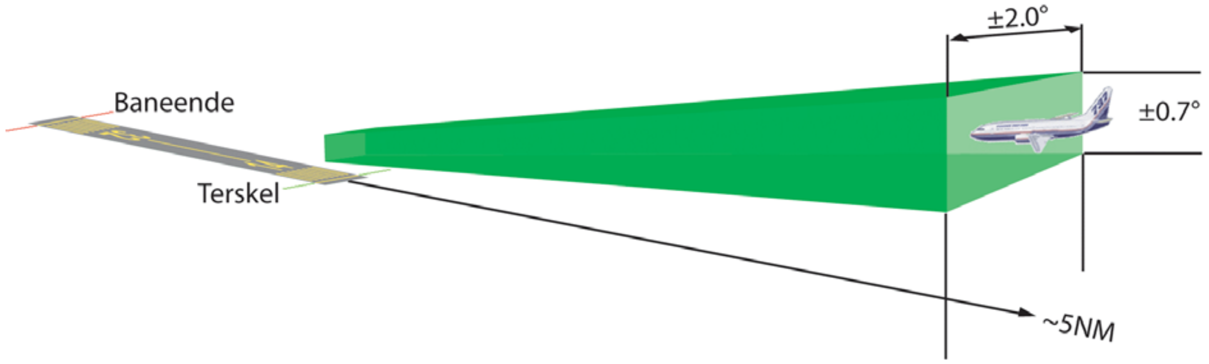

Fig 3

Final Approach Segment Tunnel

FLIGHT INSPECTION AIRCRAFT AND INSTRUMENTATION

Avinor's flight inspection aircraft Dash-8 LN-ILS, equipped with a Normarc Flight Inspection System, had been used for the 1999 and 2001 flight trials with prototype truth functions for SCAT-I.
The NFIS had seen a substantial upgrade in 2002/-03 in order to fit in a Beechcraft King Air 200. As decisions were made to use LN-ILS as baseline certification testbed for the SCAT-I GLS-1250 landing sensors, the NFIS system would again be refitted in LN-ILS and be subject to an upgrade to meet the requirements for the SCAT-I certification test flights, and future commissioning and recurring flight inspection of IFR-procedures and ground facilities.

REQUIREMENTS:

Requirements were derived from FAA Order 8200.41 And Doc 8071 Vol. 2.

FAA Order 8200.41: [5]

General.

Manufacturer or user/sponsor shall provide the airborne and independent truth system equipment required for initial and recurring flight inspection evaluation. This equipment shall be capable of providing corrected aircraft position as a real-time or post-processed data to an accuracy level necessary to satisfy all requirements established in this order.

Maintenance Procedures that require a Confirming Flight Inspection.

A confirming flight inspection shall be required whenever the location of the DGNSS antenna phase center is changed, the location of the datalink transmit antenna is changed, or the system database has been changed and corrupted. The extent of the evaluation shall depend on the changes made.

Commissioning Flight Inspection Evaluation.

The special instrument approach procedure DGNSS guidance parameters and datalink coverage shall be evaluated during initial flight inspection. Observation of ILS/MLS coincidence shall also be required for approaches that are collocated with existing ILS/MLS procedures. Data gathered during Type Certification (TC) or Supplemental Type Certification (STC) flight may satisfy many of the flight inspection requirements.

VHF Data Link (VDL).

The minimum usable VDL signal shall be available throughout the operational coverage volume as defined for SCAT-I. The minimum RF field strength shall be measured during normal data transmission, not averaged over the time intervals between signal transmissions. Initial VDL coverage shall be verified by flying a +/- 10^o arc at 20 nm from the runway threshold. The arc altitude shall correspond to 0.5 times the glidepath angle or at the Minimum Vectoring Altitude (MVA) whichever is lowest. Coverage shall also be verified on and below the approach course and glidepath.

Initial and intermediate approach segments.

Fly the entire procedure from the IAF to the PFAF maintaining procedural altitudes. Evaluation to include procedural design and VDL coverage.

Final approach segment.

Fly the final segment at procedural altitudes until intercepting the glidepath, then descend on the glidepath to the TCWP. Evaluation shall include procedural design, horizontal alignment, glidepath angle, and VDL coverage. Corrected aircraft position data shall be provided by independent real-time or post-processed data.

Missed approach segment.

Fly the missed approach segment from the MAP using the procedural design and transition to the missed approach.

Special Instrument Approach Procedure.

The special instrument approach procedure shall be evaluated to ensure flyability and safety.

Periodic evaluation.
Newly commissioned facilities shall be inspected on a progressive interval. First periodic inspection 6 months after commissioning, then continuing at 360 +/- 60 days intervals.
Requirements shall consist of the special instrument approach procedure verification and observation of the VDL performance throughout the final segment. Corrected aircraft position data shall be provided by independent real-time or post-processed data.

Doc 8071 Volume 2: [7]
For inspection of Category I GBAS procedure, a positioning system is not required, but may be used, depending upon regulatory requirements of individual States. Although no accuracy tolerances are defined, if a GNSS-based positioning system is used, its independence should be demonstrated; i.e. there must be no common-mode errors between the GBAS and positioning system. For example, for code based GBAS, a carrier-based position fixing system may be used. Alternatively, a non-GNSS based position-fixing system may be used.

Table 2
Specific Parameter Tolerances

Parameter	Tolerances
VHF Data Link Field Strength	275 μv/m (-97 dBW/m^2)
Initial / Intermediate Approach Segment Procedure Design Bearing to next WP Distance to next WP	 +/- 1.0^o +/- 0.10 nm
Zone 1 Deviations (Glidepath) Zone 1 Deviations (Horizontal)	+/- 0.14^o +/- 0.14^o
Final Approach Segment Procedure Design Bearing to TCWP Distance to TCWP	 +/- 0.10^o +/- 0.10 nm
Glidepath Angle Horizontal Alignment Zone 2 Deviations (Glidepath) Zone 2 Deviations (Horizontal) Zone 3 Deviations (Glidepath) Zone 3 Deviations (Horizontal)	+ 0.30^o / - 0.225^o +/- 0.20^o +/- 0.14^o +/- 0.40^o at Pt. A; linear decrease to +/- 0.20^o at Pt. B +/- 0.14^o +/- 0.20^o

NFIS IMPLEMENTATION

The requirements outlined in the above formed the basis for the SCAT-I upgrading of our NFIS as well as FI programs and procedures. A block diagram of the NFIS is shown in fig. 4 below.

Hardware wise a SCAT-I VDL receiver was fitted. The receiver is synchronised by the GPS PPS-signal and starts outputting VDL field strength data to the main processor when a SCAT-I type modulated signal is present.
Also, the NFIS is connected to the AIRINC-429 FMS data bus (parallel port) and receives Localizer and Glideslope Deviation signals from there.

Software wise, the upgrade constituted data acquisition and real-time processing and comparison between reference system signals (AZ/EL) and FMS Localizer and Glideslope Deviation signals and the presentation of the Localizer and Glideslope deviations in real-time on the NFIS display screen and continuous printouts per run. Data are displayed as a function of distance from threshold.
The VDL field strength is presented in an additional curve on the display.
All data gathered in the process are continuously time stamped and logged for post processing and may be presented as shown in Table 1 above.

The positioning fixing system is a carrier based GNSS unit with an UHF uplink of correction signals to the NFIS position processor. The total system accuracy of the NFIS including the position fixing and FMS accuracies when used in the Dash-8 aircraft, angle and arm corrections imbedded, is certified at 0.75m. (2 ½ ft).

The implementation, test and approval took place in the spring of 2005, just in time for the certification test flights, for which samples of post-processed data are shown in Table 1.

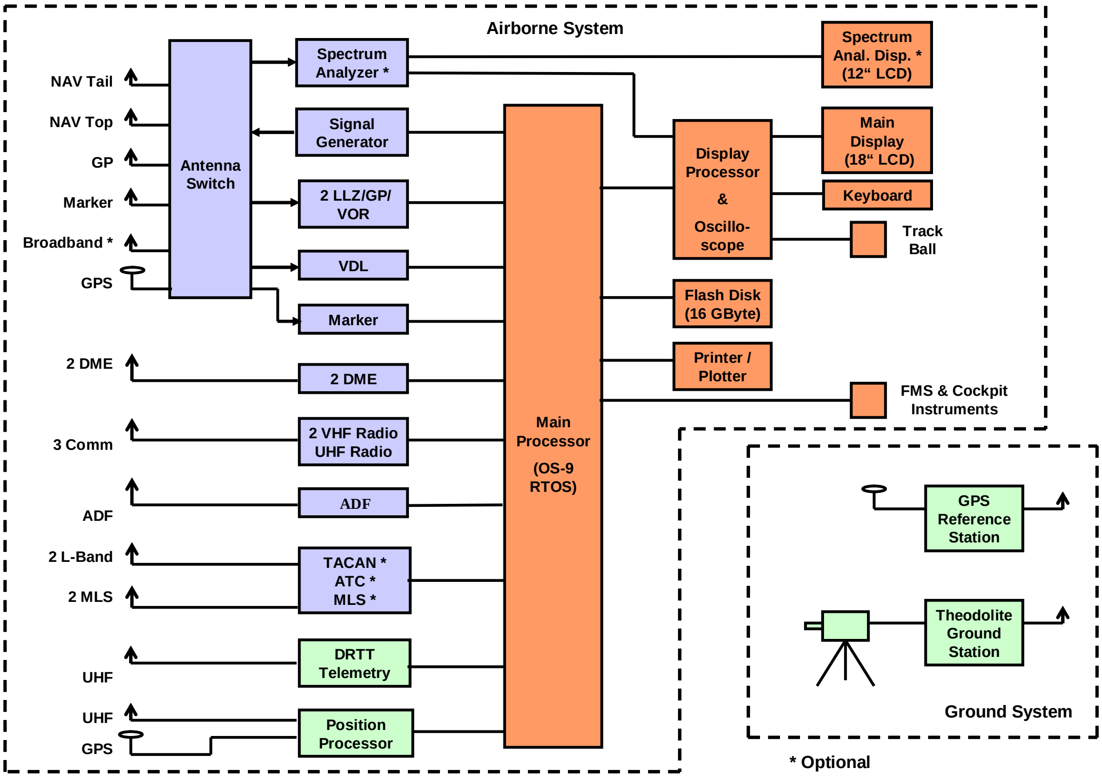

FIG 4
BLOCK DIGRAM OF NORMARC FLIGHT INSPECTION SYSTEM - NFIS

Program for commissioning flight inspection for a SCAT-I Ground Station and associated IFR GLS Procedure.

1. VDL. Field strength to be verified and logged along a 20nm orbit around THR of relevant Rwy.
   Verification of field strength in coverage volume of +/- 10^{o} of published approach course. Height can be nominal Glidepath angle or MSA.
2. Verification of VDL with reduced VDL power output (-1dB). Fly and log data as in 1).
3. Random approaches from > 30nm at different directions to verify automatic arming of SCAT-I approach function in the FMS.
4. Fly procedure according to IAC GLS RWY xx.
   a. The GLS procedure to be flown via all IAFs for establishing approach at specified glidepath angle (normally 3.9^{o}) and all the way to MAPt including the missed approach procedure.
   b. Check of potential shadowing of GPS antennas. Fly over all IAFs and complete a full circle with 35^{o} bank.
   c. Fly via all IAFs and complete procedure down to minima w/ missed approach
   d. Fly via specific IAFs normally approached via standard routes
   e. Intercept glidepath from above at +0.5^{o}.
   f. Charted heights and speeds to be adhered to, weather permitting, for correct execution of the SCAT-I procedure
5. Tunnel concept. Verify that the aircraft maintains its position within the tunnel boundaries. Verify flag warnings with respect to penetration / no penetration of boundaries in AZ and EL.
6. Flyability. Subject to items 1-5 being evaluated as acceptable all these procedures be evaluated for flyability by verification that the procedure guides the aircraft all the way to minima through missed approach and entering of charted holding.
7. Form for flight inspection of SCAT-I procedures to be filled in with all required data.

The execution of an Approach Procedure Run.

Setup

To make sure the performance of the SCAT-I mission is performed successfully, a step-by-step description is followed. To select any programmed procedure run, the GPS Reference Source and the selected Ground Facility data are verified.

Start and termination of the measurement procedure is initiated by the NFIS Operator, and calculations will start automatically as soon as the processing requirements are satisfied; i.e. continuous tracking with RVAL (Reference Valid), and absence of automatically flagged anomalies, if e.g. numbers of satellites, PDOP or other parameters are inadequate. Ordinary ILS points A, B, C and T (Zone markers) will be triggered automatically and in that sequence as the measurement procedure is commencing. The measurement procedure can be terminated any time after passing threshold.

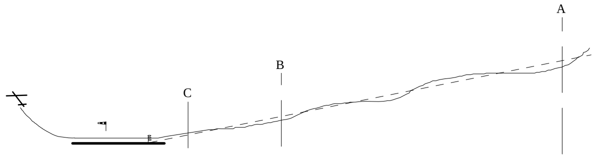

FIG 5

SCAT-I Approach

Flight Inspection Run

During the inspection; records, calculated results and system states are carefully monitored. Additional events with comments can be triggered from operator or pilots.

FIG 6

AZ AND EL COMPARE CURVES AND VDL FIELD STRENGTH FOR ON RUN

Essentials from the NFIS screen display are:

EL Deviation (in red) i.e. the difference between the reference elevation (true) and Glideslope deviation (FMS output)

AZ deviation CMP (green) i.e. the difference between the reference azimuth (true) and Localizer deviation (FMS output).

VDL field strength (yellow).

From a window with calculated values figures are:

Course alignment: the calculated average AZ deviation between points B and C (MAPt) = - 0.031°

Elevation glidepath angle: the calculated average EL deviation between points A and B = - 0.033°

All values versus reference distance to THR (true).

NFIS and its significant role in the certification of SCAT-I in Norway.

The NFIS did play a significant role in the process of certifying SCAT-I avionics and ground facilities in Norway.
A weeklong test program was carried out in the forefront of the official FAA / TC certification flights. The accuracy of the NFIS position fixing and AZ and EL deviations recorded during this test period proved without doubt that the official test program would indeed succeed.

THE ROLL-OUT OF GROUND STATIONS

Avinor has embarked on a roll-out program that will see 24 STOL-ports equipped with SCAT-I ground stations. Five airports will have operational SCAT-I approaches before the end of 2008.
The roll-out program comprises the publishing of IFR-procedures for a range of straight in and offset approaches (mostly to both runways) as well as approaches to fictitious runways (where mother nature allows no other options), all to be completed by the end of 2010, at an investment cost of US $ 30 mill.

APPROACH SAFETY IMPROVEMENT

Analysis performed by the Flight Safety Foundation shows a five fold improvement in approach safety for precision approaches compared to non precision approaches.
Further evaluation of the criteria indicates a 10 fold improvement when moving from the step-down approaches typical for our STOL-ports to precision approaches.
An in-house analysis performed by Avinor in 2000 concluded that implementation of SCAT-I is by far the best conceivable flight safety improvement effort for the STOL-ports.
Avinor strongly believes that the persistent pursuit of implementing SCAT-I continuously over a period of 12 years will finally pay off in significantly improved safety for the STOL-ports – **and the pilots love to fly it.**

References:
[1] DO-217, Minimum Aviation System Performance Standards, DGNSS Instrument Approach Systems, Special Category I (SCAT-I), RTCA Inc., Washington D.C., August, 1993
[2] DO-178B, Software Considerations in Airborne Systems and Equipment Certification, RTCA Inc., Washington D.C., 1993
[3] Specification for DO-217 Interoperability, SCAT-I Manufacturer's Interoperability Group, Salt Lake City, Utah, April 1998.
[4] DO-245, Minimum Aviation System Performance Standards for the Local Area Augmentation System (LAAS), RTCA Inc., Washington D.C., September, 1998.
[5] FAA Order 8200.41, Flight Inspection Evaluation of Differential Global Positioning System (DGNSS) Special Category I (SCAT-I) Instrument Approaches Using Private Ground Facilities, Federal Aviation Administration, AVN-230, November 1998.
[6] FAA Order 8400.11, IFR Approval for Differential Global Positioning System (DGNSS) Special Category I Instrument Approaches Using Private Ground Facilities, Federal Aviation Administration, AVN-230, November 1994.
[7] Doc 8071 Manual on Testing of radio Navigation Aids. Volume II Testing of Satellite-based Radio Navigation Systems

Biography

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The author graduated from Trondheim Faculty of Engineering, Electronics in 1965.
Positions include:

- 1966-69 SINTEF (Researcher),
- 1969-80 Teleplan AS/Norconsult AS (Consultant – posting in Sudan 1977-99),
- 1981-87 Systek AS (CEO),
- 1987-91 LCD Vision (CTO),
- Promacon AS 1991-2002 (CEO),
- NSB Gardermobanen 1993-99 (Director of Construction),
- Norway Register Development 1999-2000, (Project Director – posting in Macedonia),
- Avinor AS 2002- (Head of CNS/ATM Technical Center / SCAT-I Program Manager).