



Swala Aerospace Ltd

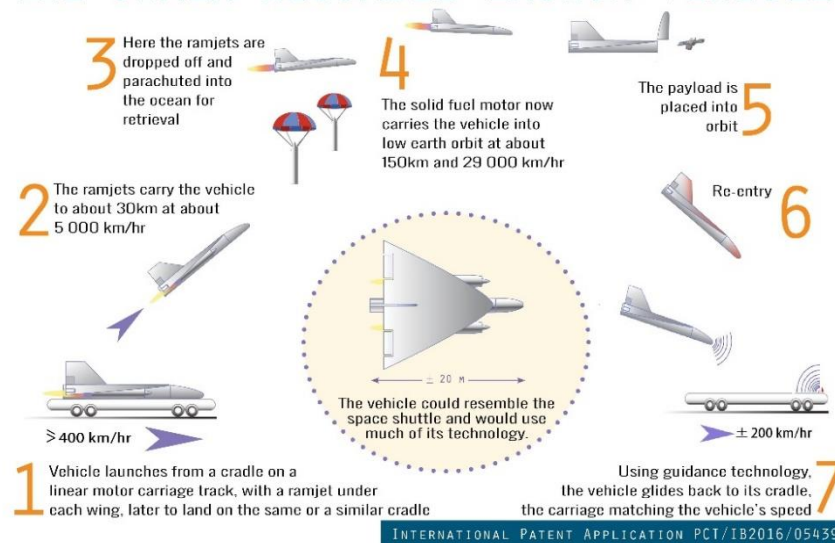
The Business Plan

7th August 2017

B650-375

Summary

THE SWALA REUSABLE LAUNCH VEHICLE



By using well-proven technology in an innovative manner, the Swala vehicle will offer the world's lowest satellite-launch cost per kilogram while still providing a generous margin to investors. Preliminary figures suggest that an IRR of over 30% can be achieved for a charge of £3,000/kg for its half-ton payload, which is a fraction of the price currently charged for non-reusable vehicles.

A combination of simple innovations – a linear motor launch track, jettisonable and recoverable ramjets and the capture of the vehicle on a carriage using the same launch track - are the heart of the Swala concept and have been accepted by the patent examiner (International Application WO 2017/029566 A1).

Initially the project will be first operated on a 1/10th scale and in the atmospheric phase (Stage 1) to perfect the software needed for the vehicle's launch and capture as shown above. This would be undertaken at the West Wales Airport near Aberporth, which has clearance for the operation of unmanned aircraft.

Detailed design work will follow, and the Proof of Concept document created will be used as the basis for the formation of a public company that will finance the full-scale operation (Stage 2). This will see the creation of a spaceport for the Swala vehicle at Machrihanish Airport on the Kintyre peninsula, south west from Glasgow. Construction could commence in late 2018, for commissioning in 2020 (Stage 2).

'**Swala**' is the Swahili word for a gazelle, and the Swala spaceplane is a small, light but fast vehicle designed to carry a payload of about 500kg of satellites into low earth orbit (LEO). It uses well-proven technology and systems to provide a profitable alternative to conventional rockets, achieving this by initially using the oxygen in the air instead of hauling up liquid oxygen. At the top of the atmosphere it then reduces its mass further by jettisoning (for recovery) the ramjets that have powered it up to that point. Thereafter it uses a conventional solid fuel motor to carry it to LEO. Apart from the vehicle carriage, the Swala project has effectively no moving parts.



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1.0. Introduction

The Holy Grail of space launches is the reusable launch vehicle (RLV), because until 2015, once a rocket had been used, that was it. Valuable bits containing people and the like might be flown back to earth (the space shuttle) or parachuted down (the Soyuz spacecraft) but the rest of it was allowed to burn up in the atmosphere or to join the space junk orbiting the earth or to drift off into the universe.

Now, suddenly, two separate commercial ventures have apparently achieved this reusability. On November 23rd 2015 Blue Origin, owned by Jeff Bezos (of Amazon) managed to get its New Shepard space craft back to earth and also the rocket booster that put it up there. Then on the 21st of December Elon Musk's SpaceX did much the same with its Falcon9 rocket.

There are three points here. The first two are minor - the same result could have been achieved by using specialised parachutes and currently the period between the use of the vehicles is months rather than days because of the need to check and replace items

The third point is fundamental. In the 1930s Robert Goddard in the US and Herman Oberth in Germany first demonstrated that liquid oxygen and hydrocarbon fuels used in conjunction with constricting nozzles gave exceptional rocket thrust from a standing start. Then in late 1944 the German V2 rocket showed that with stabilising and guidance systems this combination could be transformed into extraordinary effective missiles that soared beyond the reach of all countermeasures.

After the war America and Russia seized the technology - and the rocket scientists who invented it – and from this came the ultimate weapon, the ICBM, armed with an atomic bomb. Thereafter the same technology was employed more constructively for Sputnik, Yuri Gagarin, Mercury, Gemini, Apollo and so forth. To this day the only sure way to get things off the planet is to use liquid oxygen and a fuel and go straight up.

It works but it is flawed, because all rockets still carry their oxygen up with them, just like the German ones. Every ton of liquid fuel burnt will require about 2.4 tons of liquid oxygen, most being used in the first 50 miles or so – that is while the vehicle is climbing through an atmosphere that is 20% oxygen anyway. Indeed, if you replace the liquid fuel with hydrogen, which gives a very high thrust, then over eight tons of oxygen are needed per ton of hydrogen. Again, all this oxygen has to be hauled up in the rocket, which in turn has to use more fuel to do so. In present-day terms, conventional rockets have a very big carbon footprint; by not using the oxygen in the air they are extremely inefficient. The reusable rockets of Elon Musk and Jeff Bezos have an even larger footprint than normal because they have to haul up all the fuel and oxygen that will allow the first stage to land slowly and safely back to earth in an upright position, reducing their payloads – and income – by about a third.

There is also an important non-technical problem. Both New Shepard and Falcon9 are very large vehicles, designed to lift the heavy payloads arising from the need to



re-supply the International Space Station and to place large communications satellites in distant geostationary orbits. Yet the main market for space launches now is for inserting large numbers of relatively small satellites into low earth orbit (LOE), arising from the expanding markets for the services they can provide and the miniaturization of their components. The nanosatellite and microsatellite market size has been estimated to grow from USD 889.8 Million in 2015 to USD 2.52 Billion by 2020.*

The Swala 'space launch lite' concept is for a small and light vehicle that uses the atmosphere both for its initial source of oxygen and to provide lift for its wings. It has a payload of about half a ton and is truly reusable, with a turn-around time of a day or so. This will have a dramatic effect on space launch prices. Currently it costs about \$15,000 to put a kilogram into LOE; the Swala vehicle should be able to achieve this for well under a third of the price.

When the space industry started in 1945 it used technology which was less than optimal because it was the only sort available at the time. As we know, at a terrible cost in the lives of slave labourers (12,000 is one estimate) and to the German economy, the Nazis managed to make a liquid fuel and liquid oxygen combination send bomb-carrying rockets up to the edge of space. Since for the victors this technology presented an opportunity to deliver atomic bombs on to an enemy a very long way away, both West and East seized on it, along with its creators, and built vehicles that would achieve this aim.

In those circumstances, the technology quickly became sophisticated, reasonably reliable and institutionalised. The essential contradiction of hauling oxygen up through the atmosphere was ignored. So were the benefits that this atmosphere bestows in the form of providing lift to aerofoils.

2.0. The Swala Reusable Launch Vehicle Concept

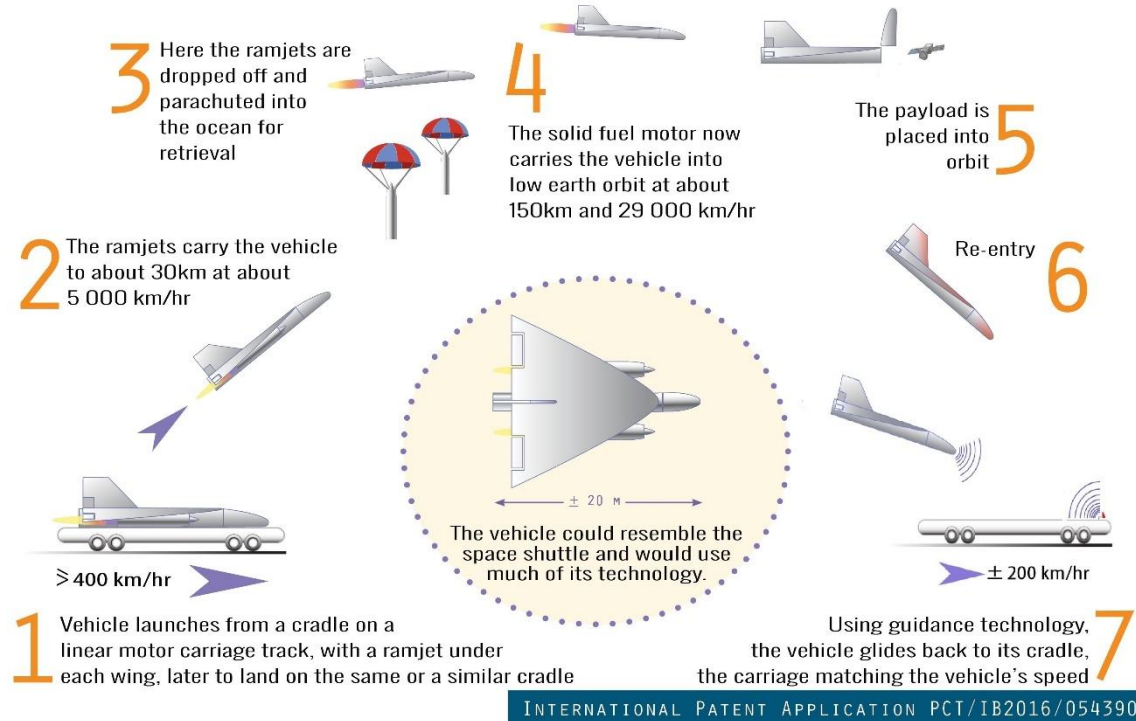
The Swala reusable launch vehicle concept takes several well-established technologies and combines them in a manner never considered before, to create a seven-step system, whose key patent claims have been accepted by the patent examiner (International Patent Application PCT/IB2016/054390). The concept is set out diagrammatically below.

There are three stages of acceleration. First the vehicle is accelerated on a carriage powered by an electric (linear motor) system down a 3km launch track. At about 400km/h ramjets fly it off the carriage and up to the limits of the atmosphere. Finally, after the ramjets flame out, they are parachuted back for reuse and a solid fuel motor carries the vehicle to LEO at orbital speed, where the payload – usually satellites – is inserted into orbit. When the Swala vehicle re-enters the atmosphere, it descends back on to the launch track, the carriage there capturing it on electromagnets by

*See marketsandmarkets.com. Publishing Date: November 2015. Report Code: TC 2267

matching its own speed with that of the vehicle as it glides in.

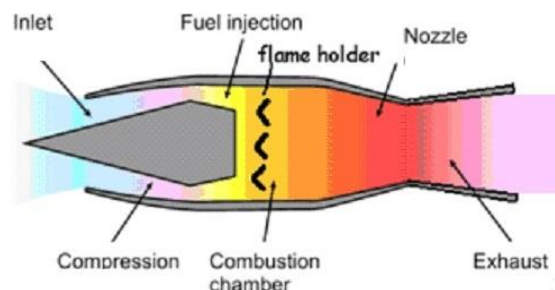
THE SWALA REUSABLE LAUNCH VEHICLE



2.1. Steps 1 and 2. Lift-Off and Climb

The Swala vehicle achieves remarkable economy by using an air-breathing ramjet to lift the vehicle through the atmosphere. This is a propulsion device that is essentially a tube – a 'flying stovepipe' is one description - with a constriction near the front and fuel burners behind it. It has no moving parts except for a fuel pump, and relies on its forward velocity to compress air at the constriction so that the heat from the burners causes it to expand and drive it forward. The flames are stopped from blowing out by a flameholder – a screen of white-hot bars in the combustion chamber.

Diagram of a Ramjet (Wikipedia)



It can achieve very high speeds – Lockheed Martin's (then Martin Marietta's) prototype ASALM missile inadvertently achieved Mach 5.5 in 1980 at 40,000 feet when its throttle stuck. Ramjets were used almost exclusively on military hardware



and little performance data is available, but It seems probable from circumstantial evidence that a ramjet will still be delivering thrust at over 100,000 feet (30km).

Hence a ramjet would be ideal for carrying a rocket up to the limits of the atmosphere. However, it cannot start working until it is thrusting through the air at a high enough speed to achieve sufficient compression. Thereafter it accelerates to a speed dictated almost entirely by the rate at which its fuel is supplied. But first it must get to a velocity at which the thrust-to-weight ratio allows take-off, which in the case of the Swala vehicle is probably about 400 km/hr. The following suggests that this will be sufficient:

- The French Leduc 0.10 ramjet aircraft of 1947 was launched from an aircraft flying at 200m/h (320km/h) and thereafter broke a number of speed and altitude records.
- The Marquardt Corporation, America's principal maker of ramjets in the 40s and 50s, built a ramjet specifically designed to operate at sub-sonic speeds (designated the XRJ-31-A1).
- The NHI H-3 Kolibrie (Dutch for "Hummingbird") was a small helicopter developed in the Netherlands in the 1950s. Its rotors were ramjet tipped and were self-propelling at a tip speed of 132km/hr.
- 1950s graphs for sub-sonic ramjet operation obtained from the Smithsonian Air and Space Museum showed that a thrust (Isp) value of about 150 could be expected at 400km/h.
- Thrust-to-weight ratios can be used to judge whether a ramjet could generate enough power at +/- 400km/hr to drive the Swala vehicle forwards. (The wing aerofoil would, of course, ensure that it would lift off if so driven). This table compares values.

| Name of Aircraft | No. of Engines | Engine Type | Thrust per Engine in kN | Thrust per engine x number of engines kN | Airplane Mass in kg | Mass x 9.8m/s ² kN | Thrust-to-weight ratio |
|------------------|----------------|-------------|-------------------------|--|---------------------|-------------------------------|------------------------|
| Boeing 747 – 400 | 4 | GE CF680C1 | 252 | 1008 | 379890 | 3722.9 | 0.27 |
| Boeing 737 - 300 | 2 | CFM 563B1 | 88.9 | 177.8 | 59645 | 584.5 | 0.30 |
| Swala vehicle | 2 | RJ43-MA* | 53 | 106 | 30000 | 295.0 | 0.36 |

* Marquardt Corporation ramjet as used in the Bomarc missile

Source: NASA

Assuming that at 400 km/hr ramjet efficiency will be about 35% - say a total of 36kN from two RJ43 ramjets - then the thrust-to-weight ratio of the Swala vehicle will be about 0.12, or about 45% of a 747's take-off thrust-to-weight value. Provided that this thrust is enough to keep the vehicle moving forward against drag, the steep upward curve of the efficiency graph will ensure that it will accelerate rapidly away.



The ability of a linear motor to accelerate the Swala vehicle to the required launch speed has been demonstrated by the Electromagnetic Launch System (EMALS) of the US Navy. This is in place of steam-driven catapults to launch planes from aircraft carriers, and they can accelerate a 45-ton aircraft to 240 km/hr in 90 metres.

2.2. Step 3. The Ramjets Discarded

Once the ramjets flame out they are dropped off and parachuted back into the sea, as was done with the solid fuel rocket stages on the space shuttle. As the ramjets are very strong and simple they can be recovered and re-used (one of the shuttle solid fuel motors was reused 29 times). Section 2.13.1. sets out a likely trajectory.

2.3. Steps 4 and 5. Into Orbit and Insert Satellite(s)

Now the solid fuel motor that takes up most of the body of the rocket ignites and accelerates the rocket to LEO altitude, over 150km above the earth at a speed of 28,000 to 30,000 kilometres/hour (17,500 to 18,500 mph). This replicates the system used by the Pegasus rocket of Orbital ATK in the USA, which uses solid fuel stages after launching at 45,000 feet from an aircraft, but is not reusable.

Once the Swala vehicle has reached roughly the right height and speed, hydrazine or cold gas thrusters on the rocket are used to position the vehicle at the point where the payload can be placed in its correct orbit. The nose swings open, the satellite(s) are ejected and it closes again. The technology of placing satellites in their required orbit is well established, and the Swala vehicle will make use of this experience.

2.4. Step 6. Re-entry

The thrusters operate again to direct the vehicle back down and to slow it. It will draw on the technology and experience of the space shuttle, but perhaps not with its spectacular glowing re-entry. What is likely is that the very low ballistic coefficient (i.e. mass to volume ratio) of the vehicle at this stage – just a shell with wings and a stabiliser – could enable it to employ a heat resistant titanium alloy alone for its surfaces, without an insulating coating. With no deadlines to meet, the Swala vehicle can take its time to return to earth, losing momentum much more slowly than any of its predecessors and so heating to a far lesser extent.

2.5. Step 7. Landing on to a 'Capture Carriage'

The capture carriage could perform the cushioning function of landing gear on conventional aircraft, and so its receiving tray might be supported on oleo struts. Landing will be at perhaps 200 km/h and the US Navy is already landing drones on its aircraft carriers using a variant of the aircraft instrument landing systems (ILS) that have been in service since the 1960s.

The key difference is that the Swala capture carriage adjusts its speed precisely to the arriving vehicle due to the variable frequency linear motor driving it. The homing beam sent out by the carriage guides the vehicle down, while a transmission from the vehicle causes the carriage to match its speed. As soon as it touches down, electromagnets will lock the vehicle in place.

Unlike normal aircraft landings, the Swala vehicle can time its arrival for a period of calm weather. Alternatively, landings can be scheduled for dawn, when, as balloonists know, winds are normally absent.

3.0. The Swala Spaceport

In July 2014, the British Civil Aviation Authority undertook a review of spaceplane certification and operational requirements, including possible launch sites in the UK. The Technical Report identified 46 airfields that might be used, but only one of these had the necessary qualifications –

- Long existing runway (3,000m at least) with a potential for extension
- Low population density under flight paths
- Over-ocean launch and retrieval potential

This is the Machrihanish airport, serving the small town of Campbeltown on the Kintyre peninsula, about 220 km west of Glasgow, and a business alliance has been made with MACC Business Park, the firm that now owns the site and its extensive infrastructure.

Amongst the latter is the taxiway, which is on the left of the main runway in the photo, and is unused. This is also 3 km long and is about 20m wide, and as such would make an almost ideal foundation for the Swala launch track. The General Manager of the business park saw no objection to it being leased for this purpose. Other assets that might be of value include hangars and workshops, a control tower, jet fuel storage facilities and accommodation for about 100 personnel.



The Machrihanish (Campbeltown) Airport showing the Taxiway

As it happens the airspace above Machrihanish is very busy, being on the great circle route to North America. Permission to launch Swala here will require Unmanned Aerial Systems (UAS) approval for the Machrihanish spaceport, which could take two years. In the meantime, the initial flight testing of the 1/10th scale Swala vehicle will be undertaken at the West Wales Airfield, Aberporth, which has the necessary UAS approval.

4.0. The Swala Vehicle

As currently envisaged, the approximate size of the vehicle would be about 20m long from the ogive tip to the solid fuel motor nozzle, with a wing span totalling about 15m and a fuselage diameter of about 1.5m. Its weight empty of fuel and payload will be about 3t. The solid fuel motor would amount to about 22t plus another ton for the payload and control systems. The ramjet fuel will be 1 to 2 tons, giving an all-up total of around 28 tons

4.1. Launch Power Requirements

If a 33-ton mass (5 tons for the carriage, 28 tons for the fuelled-up vehicle) is to be accelerated to 400km/hr over a 30 second period, then the total energy requirement will be about 100kWh, giving a power requirement of the order of 10MW this time. The power requirement during landing will, of course, be a fraction of the launch power. However, the power supply must be uninterrupted, and £4m has been allocated to ensure this with some combination of capacitors and batteries. As a matter of interest, the proposed site – the Kintyre peninsula – is a major wind-farm area and it may be possible to get electric power at favourable rates by charging the batteries at night-time.

4.2. The Solid Fuel Motor

Preliminary estimates for the solid fuel motor indicate a fuel mass of about 22 tons, a diameter of about 1.5m and a length of about 12m. This will be a conventional motor encased in graphite fibre that is slid into the Swala body. The nozzle is bolted on afterwards, and may be vectorable – i.e. can be moved to alter the direction of travel.

4.3. The Vehicle Capture System

The landing of the Swala vehicle on to a ‘Capture Carriage’ that has matched its incoming speed may seem remarkable but there are antecedents. Autonomous landing has been practised for many years, and almost the entire space shuttle re-entry procedure (apart from lowering the landing gear) could be performed under computer control, although the crew often ‘flew’ the vehicle for the last 150 miles of its glide.

The US Navy has been landing aircraft autonomously on carriers since 2013. The Northrop-Grumman X47-B fighter was specifically designed for such operations, and photographs show that it lands aligned precisely with the centre line marking of the carrier flight deck. Similarly, drones are now routinely operated autonomously from carriers and they too land on the centre line.

The Swala vehicle will have some lateral latitude in the sense that it will be guided down into a gully of greater width than the fuselage, being secured there by electro-magnets at its base.

5.0. The Stage 1 (1/10th Scale) Development Programme

The principal concern for the Swala rlv will be the evolution of its control and guidance systems, and these will be developed from the earlier (Stage 1) experience at the West Wales Airport using a 1/10 scale version of the vehicle.

The assumptions underlying the Stage 1 cost figures given below arise from the following sequence of events in the initial development of the Swala concept, using small scale vehicles:

1. The acquisition of two pulse jet radio controlled (RC) model aircraft, one as a spare in case of loss. These have a 1.2m wingspan and can travel at over 200km/h; an example is shown below. They will be used to develop the launching and capture software and hardware for the 1/10th scale Swala vehicle.



2. This initial launch and capture will first employ the modified RC units, using a roof platform on a Tesla Model S electric car equipped with responsive guidance system and electromagnets.
3. Once the launch and capture systems have been perfected they will be transferred to the completed 1/10th scale Swala vehicle, and the testing of the launch and capture systems will be followed by flight testing to maximum altitude and speed, again using the Tesla vehicle, as shown.
4. The creation of the Proof of Concept Document, with input from a number of experts, will then be undertaken. This will be a detailed document which will take the design work on the vehicle and the necessary infrastructure to an advanced stage

5. This document will then become the basis of a prospectus for the flotation of Swala Aerospace plc on the Alternate Investment Market.

Even at this scale, the UK's Civil Aviation Authority will have to be involved, and an airfield approved for Unmanned Aerial Systems (UAS) used. Two are currently licenced for such activity; the Cornwall Airport at Newquay and the West Wales Airport near Aberporth. The latter is less used and could accept the intermittent launching of the 1/10th scale vehicle down its runway.

A detailed schedule of the possible costing and scheduling of Stage 1 is given on the next page. The Stage 2 projections are given in the following Technical Section.

In summary, a total capital requirement for Stage 1 will be about £474,000. This does not include any contingency, and nor does it include any capital recovery from the sale of the assets after development is complete.



The 1/10th Scale Swala Vehicle on its launch/capture platform on a Tesla Model S



5.1. The Costing and Scheduling of the Stage 1 Programme

| | | | | | | 2018 | | | | | | | | | | | |
|--|----------------------|--|----------------|-----------------|-------------|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 375-AF - One-Tenth Scale Swala-Tesla Ensemble Development and Launch - Capex and Gantt Chart | | | | | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Item | Possible Costs \$000 | Tasks | Possible Start | Possible Finish | Apprx Weeks | | | | | | | | | | | | |
| 1.0 | 119 | Ground Services | 01-Jan-18 | 01-Sep-18 | 35 | [Gantt bars for Ground Services] | | | | | | | | | | | |
| 1.1 | 4 | Acquisition of Pulse-Jet RC Models for Control Systems Development | 01-Jan-18 | 31-Jan-18 | 5 | [Gantt bar for 1.1] | | | | | | | | | | | |
| 1.2 | 45 | Tesla Model S Purchase (second-hand) | 01-Jan-18 | 31-Jan-18 | 5 | [Gantt bar for 1.2] | | | | | | | | | | | |
| 1.3 | 10 | Modifications to the Tesla vehicle | 31-Jan-18 | 28-Feb-18 | 4 | [Gantt bar for 1.3] | | | | | | | | | | | |
| 1.4 | 50 | Support staff (2) costs plus travel and subsistence | 15-Jan-18 | 01-Sep-18 | 33 | [Gantt bar for 1.4] | | | | | | | | | | | |
| 1.5 | 10 | Pulse-Jet - Swala - Tesla Ensemble operating incidentals | 01-Feb-18 | 01-Sep-18 | 30 | [Gantt bar for 1.5] | | | | | | | | | | | |
| 2.0 | 130 | Swala 1/10th Scale Vehicle | 01-Jan-18 | 01-May-18 | 18 | [Gantt bars for Swala 1/10th Scale Vehicle] | | | | | | | | | | | |
| 2.1 | 30 | Vehicle Design | 01-Jan-18 | 28-Feb-18 | 9 | [Gantt bar for 2.1] | | | | | | | | | | | |
| 2.2 | 20 | Hiller Ramjet Acquisition and Delivery | 31-Jan-18 | 28-Feb-18 | 4 | [Gantt bar for 2.2] | | | | | | | | | | | |
| 2.3 | 80 | Vehicle Construction and Delivery | 01-Mar-18 | 01-May-18 | 9 | [Gantt bar for 2.3] | | | | | | | | | | | |
| 3.0 | 40 | Control Systems | 15-Jan-18 | 15-Jun-18 | 22 | [Gantt bars for Control Systems] | | | | | | | | | | | |
| 3.1 | 10 | Design, Procurement and Installation of Speed-Guidance System on Tesla Vehicle | 15-Jan-18 | 15-Mar-18 | 9 | [Gantt bar for 3.1] | | | | | | | | | | | |
| 3.2 | 10 | Design, Procurement and Installation of Guidance Receiver-Controller System on Pulse-Jet | 15-Feb-18 | 15-Mar-18 | 4 | [Gantt bar for 3.2] | | | | | | | | | | | |
| 3.3 | 5 | Commissioning of Command and Control Systems on Pulse-Jet-Tesla Ensemble | 15-Mar-18 | 31-Mar-18 | 2 | [Gantt bar for 3.3] | | | | | | | | | | | |
| 3.4 | 5 | Debugging of Command and Control Systems on Pulse-Jet-Tesla Ensemble | 01-Apr-18 | 01-May-18 | 5 | [Gantt bar for 3.4] | | | | | | | | | | | |
| 3.5 | 5 | Transfer to and Commissioning of Command and Control Systems on Swala-Tesla Ensemble | 01-May-18 | 01-Jun-18 | 4 | [Gantt bar for 3.5] | | | | | | | | | | | |
| 3.6 | 5 | Fuelled Ground Testing of Swala-Tesla Ensemble | 01-Jun-18 | 15-Jun-18 | 2 | [Gantt bar for 3.6] | | | | | | | | | | | |
| 4.0 | 65 | Flight Testing | 15-Jun-18 | 31-Aug-18 | 11 | [Gantt bars for Flight Testing] | | | | | | | | | | | |
| 4.1 | 20 | Initial Flight Testing of Swala -Tesla Ensemble Launch and Landing | 15-Jun-18 | 01-Jul-18 | 2 | [Gantt bar for 4.1] | | | | | | | | | | | |
| 4.2 | 20 | Independent Review and Checks on the Programme | 01-Jul-18 | 15-Jul-18 | 2 | [Gantt bar for 4.2] | | | | | | | | | | | |
| 4.3 | 10 | First Extended (Trans-Sonic) Flight | 15-Jul-18 | 24-Jul-18 | 2 | [Gantt bar for 4.3] | | | | | | | | | | | |
| 4.4 | 15 | Swala Vehicle Flight Testing Programme | 25-Jul-18 | 31-Aug-18 | 5 | [Gantt bar for 4.4] | | | | | | | | | | | |
| 5.0 | 80 | Creation of Proof of Concept Document | 01-Aug-18 | 15-Sep-18 | 6 | [Gantt bar for 5.0] | | | | | | | | | | | |
| 6.0 | 40 | Flotation of Swala Aerospace plc | 01-Oct-18 | 01-Nov-18 | 5 | [Gantt bar for 6.0] | | | | | | | | | | | |
| | | Note - no contingency allowance | | | | | | | | | | | | | | | |
| 474 | | Total Possible Cost, \$M, and Duration, Weeks. | 01-Jan-18 | 01-Nov-18 | 44 | [Total Gantt bar] | | | | | | | | | | | |

6.0. The Stage 2 (Full Scale) Development Programme

A major attraction of the Swala project is that most of the development will be incremental, with relatively small, low-risk steps at each stage. Consequently, it will be possible to adjust and correct design elements and operating procedures without incurring major cost and time penalties. However, there are two major uncertainties in the project that the development programme must answer:

1. The speed at which the thrust from the ramjets (coupled with the lift from the aerofoil) enables the vehicle to launch.
2. The height and speed that can be attained by the vehicle before the ramjets cease to provide thrust and are separated from it. This will dictate the solid fuel rocket capacity required.

These are not expected to be insurmountable challenges, but it will be necessary to resolve them for the project to achieve success.

Finally, there are two steps in the Stage 2 Swala development programme which are of an all-or-nothing nature:

1. The first lift-off and retrieval
2. The first full orbital flight and retrieval.

These mark the major hurdles of the concept, and will not be undertaken until every aspect has been fully explored and tested and contingency procedures established.

6.1. Pre-Flight Testing

With the take-off and landing systems now proven, they can be installed in the full-scale Swala vehicle, which will now be placed on the carriage, complete with ramjets. During the ensuing pre-flight tests, it will be modified to carry water instead of liquid and solid fuels, and water will also be used to simulate the payload in the nose cone. The initial launch testing will be on the ability of the carriage and power supply to undertake the functions required of them in terms of acceleration and braking. The stability of the vehicle on the carriage when subject to cross-winds will also be checked.

The next stage will be to commission the ramjets. The ensemble, with the vehicle clamped by the electromagnets, will then be accelerated down the track and the behaviour of the ramjets monitored through strain gauges placed in front of the ramjet mountings (for thrust) and under the prototype body (for lift). This will be repeated several times until the speed at which lift-off will occur has been well established. If necessary, the launch track will be extended at this point.

6.2. The First Swala Vehicle Lift-Off and Retrieval

The first flight will be a short one, with sufficient fuel to last for perhaps 10 minutes. The vehicle will be allowed to fly straight ahead to a height of several thousand feet, at which point it will discharge its load of water and parachute the ramjets back into

the sea. It will then be guided back to the launch site until it is able to receive the glide path signals needed to align it for landing.

If no major problems are encountered, then this procedure will be repeated a number of times, on each occasion going higher and faster until the limits of ramjet speed and height are encountered. This will probably be somewhere in the range of Mach 5 to 7 and at 25 to 35 km altitude. Once this is known the solid fuel rocket requirement can be established and hence the final vehicle design.

6.3. The First Orbital Flight and Retrieval

This step will be preceded by an independent review of all activities and results to date, to ensure that no detail that might affect the safety of the personnel and the success of the project is overlooked.

The first orbital flight will test the following features:

- The behaviour of the solid fuel rocket motor, from ignition to burn-out
- The in-orbit thrusters which will position the vehicle for the insertion of the payload into the correct orbit and for its re-entry
- The payload deployment mechanism
- The maximum re-entry temperature and the behaviour of any refractory coatings on the vehicle in those circumstances.
- The vehicle alignment and landing system for re-entry from orbit.

The first successful launch, orbital flight and landing will be followed by others to establish the reusable characteristics of the vehicle and develop the turn-around procedures and precautions. During this period, the commercial insertion of payloads can commence.

6.4. Stage 2 Programme - Administrative Structure

Effective control of the project will be in the hands of a Project Manager, with four principal departmental heads reporting him or her:

1. The Ground Services Manager, responsible for all aspects of the interim launch/landing site, including the control room, the launch/landing carriage(s), the launch/landing track, the service area(s) and the power supply
2. The Vehicle Manager, responsible for the design and construction of the Swala vehicle, including the propulsion systems
3. The Control Systems Manager, responsible for all aspects of the project where the remote control of the vehicle(s) is involved.
4. The Administration Manager, responsible for all aspects of the project administration, including personnel, services, security and financial control.

6.5. Costing and Scheduling of the Stage 2 Programme

The chart below gives a preliminary capital costing together with the activities and time scales involved. The ground services are estimated at £28.5m, the vehicle at

£38m, control and communication systems at £4m and the test programme at £20m, totalling £90.5m without a contingency provision. It envisages an 18-month construction period. If construction commences in November 2018, then the first orbital flight could be in March of 2020.

This will be a major aerospace project, with appropriate standards of design, construction and operation. Consequently, quality compliance will be as set out in AS9100 Revision D (2016) - Quality Management Systems Requirements for Aviation, Space and Defense Organizations.

An area that might need a non-UK governmental approval is the acquisition of ramjets from the United States. These fall under the US International Traffic in Arms Regulations (ITAR) and UK Space Agency assistance might be needed to import, rather than re-invent, them.

6.6. A Preliminary Cash Flow Projection for Swala Aerospace plc

In the technical section a preliminary capital costing is provided for the prototype vehicle and its spaceport support and service facilities. This amounts to £90.5m, spent over the period December 2018 to April 2020. Operating costs will be dominated by the cost of the solid fuel used, at about £20/kg, totalling about £0.4m a launch. Other operating costs, including site lease, are assumed to amount to about £0.2m a launch.

These assumptions give rise to the following simple cash flow projection, taking the capital cost as £100m and with a cautious build-up of launches:

| Year | 1 | 2 | 3 | 4 | 5 | 6-10 |
|--------------------------------------|-------------|-------------|------------|------------|------------|-------------|
| Capital Expenditure £ | -67,000,000 | -33,000,000 | | | | |
| No. Launches | | 3 | 10 | 20 | 50 | 100 |
| Tot payload mass, t (0.5t/launch) | - | 1.5 | 5 | 10 | 25 | 50 |
| Payload charge/kg, £ | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 |
| Gross Revenue, £ | - | 4,500,000 | 15,000,000 | 30,000,000 | 75,000,000 | 150,000,000 |
| Operating cost/launch, £ | 600,000 | 600,000 | 600,000 | 600,000 | 600,000 | 600,000 |
| Operating cost/annum, £ | - | 1,800,000 | 6,000,000 | 12,000,000 | 30,000,000 | 60,000,000 |
| Net Cash Flow/annum, £ | -67,000,000 | -33,000,000 | 9,000,000 | 18,000,000 | 45,000,000 | 90,000,000 |
| IRR | 33% | | | | | |

7.0. Environmental Considerations

The environmental impact of both Stage 1 and Stage 2 will not be significantly greater than that arising from normal aviation activity, apart from one aspect. This is the noise from the ramjets on take-off. One of the reasons that ramjet-powered helicopters, such as the Hiller Hornet, did not succeed commercially was the noise they made. At about 160dB a ramjet of the type to be used in Stage 2 of the Swala Project will make more noise than a similarly-sized jet engine with afterburner.

However, the launch site at Machrihanish is remote and unpopulated, although staff in the proximity will need ear protection during take-off.

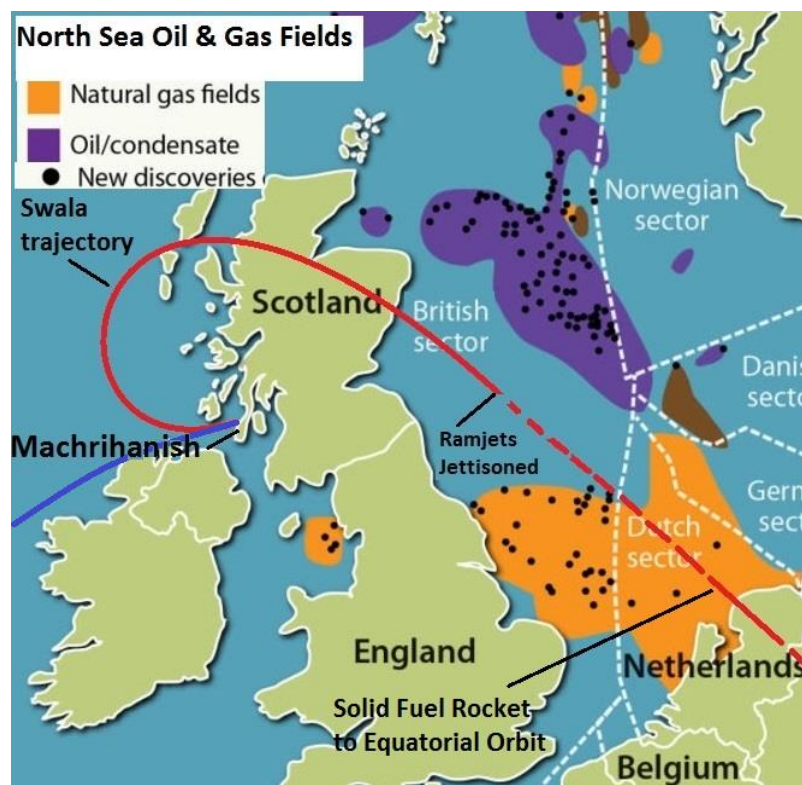
The Swala concept is noteworthy for its low environmental impact. It is not only reusable, so minimising the amount of raw material used for its manufacture, but it has a carbon footprint of less than two thirds of conventional rockets, which carry up all their oxygen. Because of this it is likely that the Swala project would qualify for assistance under the Clean Sky programme of the European Commission,

Only existing facilities are used for developing the Swala concept and for the spaceport it will use. Consequently, there should be no significant impact on fauna and flora.

8.0. The Swala Vehicle Trajectory – Environmental and Safety

For safety reasons, and to minimise the impact of its sonic boom, the Swala vehicle will launch seawards. At the Machrihanish spaceport this means that the take-off will be from east to west, so that the advantage conferred by the earth's rotation (about 800km/h at that latitude) when taking off from west to east is replaced by a negative velocity of the same speed. However, the very high velocities expected from ramjet propulsion reduce the importance of this aspect.

For satellites required to travel in an equatorial orbit a typical trajectory for the Swala vehicle could be as shown in red below. This would ensure that the generation of its



Possible Swala Flight Paths



sonic boom will be over sea, and when the vehicle does return over land on its way south-eastward it will be at an altitude (perhaps +50,000 ft) for the boom to be acceptable.

The map shows that the parachuting down of the ramjets, in this case about 80 nautical miles (150km) off the English coast, approximately opposite Newcastle, will not present a hazard to existing and future oil and gas operations in the North Sea. This location is also away from ferry routes, and the windfarms along the east coast of England are too far south and too close inshore to be a concern.

A possible return trajectory is indicated in blue; the navigation and control systems used for this could be similar to those developed for the return of the space shuttle.

9.0. Conclusions

According to the United Kingdom Space Agency, Britain's space industry had a turnover of nearly £14 billion in 2014/15 and will this year probably represent about 7% of the value of the global industry. But there are no British rockets to launch the satellites and satellite equipment made here.

This is remarkable, for the first British rocket to reach space was in 1957. This was the Skylark, a sounding (i.e. straight up and down) rocket. Then in April 1962 Britain became the third nation, after Russia and the United States, to launch a satellite—Ariel 1. However, it was constructed in the United States by NASA's Goddard Space Flight Centre and launched aboard an American Thor-Delta rocket. And, fifty-five years on, that's it.

In the meantime, China, Japan, India, Israel, Iran and Brazil have been launching their own rockets, while the French created a spaceport at Kourou in French Guiana in 1964 that is now shared with the European Space Agency.

The Swala vehicle fills this yawning gap in the space industry of the United Kingdom, and does so in a manner that not only meets local requirements but will no doubt launch satellites from other countries.

In the longer term, such cheap and relatively safe access to space will raise two questions –

- Can it be scaled up, and to what size?
- Can it provide a shuttle service to astronauts to the International Space Station?

The answers to both these questions are likely to be positive, for reasons which can be deduced from the following figures:

- The current cost of sending a 0.5 ton payload into orbit using Swala's most direct competitor, the expendable Pegasus rockets of Orbital ATK, is over \$50m
- The return ticket cost to place an astronaut in the International Space Station is over \$70m

The concept of the reusable single stage to orbit vehicle has been the Holy Grail of space launch for a hundred years. It is now within our grasp.



The Swala vehicle just prior to jettisoning its ramjets