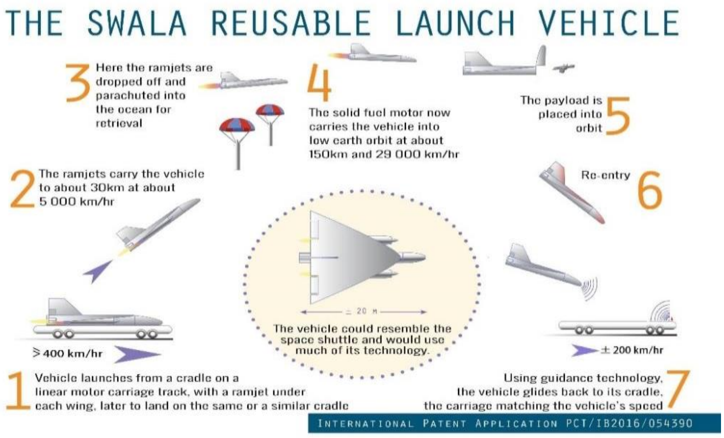
Swala Aerospace Ltd

<u>The Business Plan</u>

February 2020 B833-375

Summary



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, ramjets that are jettisoned and recoverable 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 examiners (British patent GB2555068 and 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 financing the full-scale operation (Stage 2), perhaps through the formation of a public company. This will see the creation of a spaceport for the Swala vehicle at Machrihanish Airport on the Kintyre peninsula, south west from Glasgow. Stage 2 commissioning would be less than 18 months after the start of construction.

'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). However, the rest of it would either burn up in the atmosphere or join the space junk orbiting the earth.

Two commercial launch ventures have achieved partial 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 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 up through an atmosphere that is 20% oxygen anyway. 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, because 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 Shephard and Falcon9 are very large vehicles, designed to lift the heavy payloads arising from the need to resupply 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 LEO, 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 be over $2 billion in 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 scheduling. Currently satellite owners have to wait for nine months or more for a place in a big rocket payload. Swala can provide an on-call and at-need service at a price that matches the cheapest existing launch system.

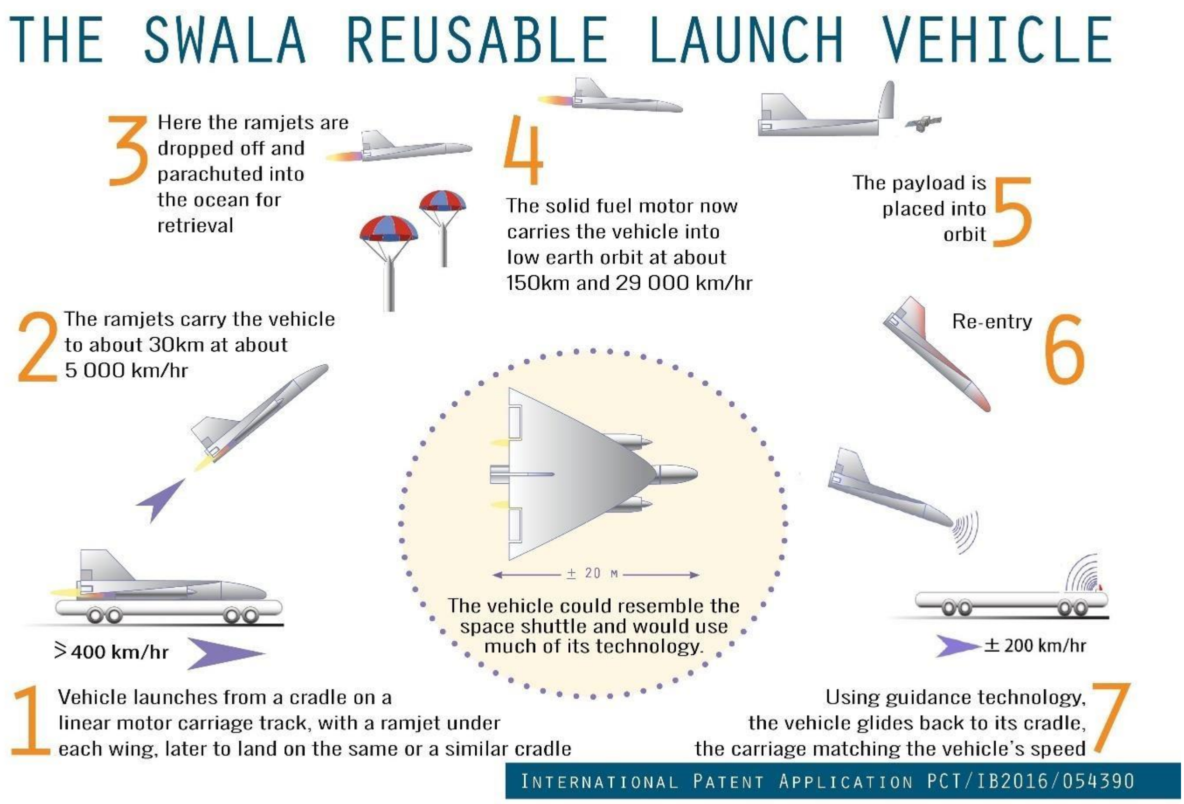
When the free world space launch industry started in 1945 it used technology which was less than optimal because it was the only sort available at the time. As we know, at a terrible cost in the lives of slave labourers (12,000 is one estimate) and to the German economy, the Nazis managed to make a liquid 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. The concept is set out diagrammatically below.

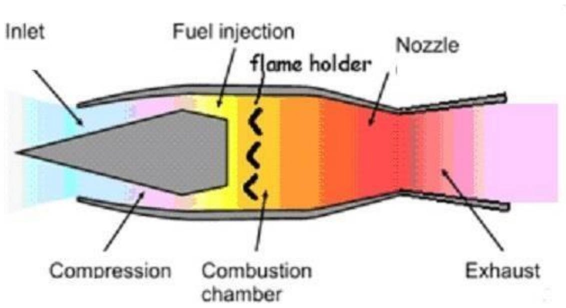
There are three stages to the launch. First the vehicle is accelerated on a carriage powered by an electric (linear motor) system down a 3km track. At about 400km/h ramjets fly it off the carriage and up to the limits of the atmosphere. Finally, after the ramjets flame out, they are parachuted back for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



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

The Swala vehicle achieves remarkable economy by using ramjets to lift it up 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 greatly and drive it onward. 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 20,000 feet when its throttle stuck. Ramjets were used almost exclusively on military hardware and little performance data is available, but there is much 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 1940s and 1950s, 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 by 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	379,890	3723	0.27
Boeing 737 300	2	CFM 563B1	89	178	59,645	584	0.30
Swala vehicle	2	RJ43-MA*	53	106	30,000	295	0.36

* Marquardt Corporation ramjet as used in the Bomarc missile Source: NASA

Using the Smithsonian data, then at 400 km/hr ramjet efficiency will be about 35% - say a total of 36kN from two RJ43 ramjets. The thrust-to-weight ratio of the Swala vehicle will then 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 8 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 (now part of Grumman) 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 using 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, an ex-RAF/USAF base, that now only serves the small town of Campbeltown on the Kintyre peninsula, about 220 km west of Glasgow. Swala has concluded a business alliance with MACC Business Park, the community 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 20 metres wide, and as such would make an almost ideal foundation for the Swala launch track. The MACC Business Park has 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 (Campeltown) 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 22 metres long from the ogive tip to the solid fuel motor nozzle, with a wingspan totalling about 21 metres and a fuselage diameter of about 1.5 metres. Its weight empty of fuel and payload but with the ramjets will be about 3t. The solid fuel motor would amount to about 24t plus another ton for the payload and control systems. The ramjet fuel will be approximately 2 tons, giving an all-up total of around 30 tons

4.1. Launch Power Requirements

If a 33-ton mass (3 tons for the carriage, 30 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 during this time. The power requirement during landing will, of course, be a fraction of the launch power. However, the power supply must be uninterruptible, 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 that a fuel mass of about 24 tons with a diameter of about 1.5m would have a length of about 12m. This will be a conventional ammonium perchlorate-based (APCP) 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 a pilot in the crew usually took the opportunity to ‘fly’ 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 gulley of greater width than the fuselage, being secured there by electromagnets 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 Stage 1 cost and scheduling data given below arise from the following sequence of events in the initial development of the Swala concept:

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.

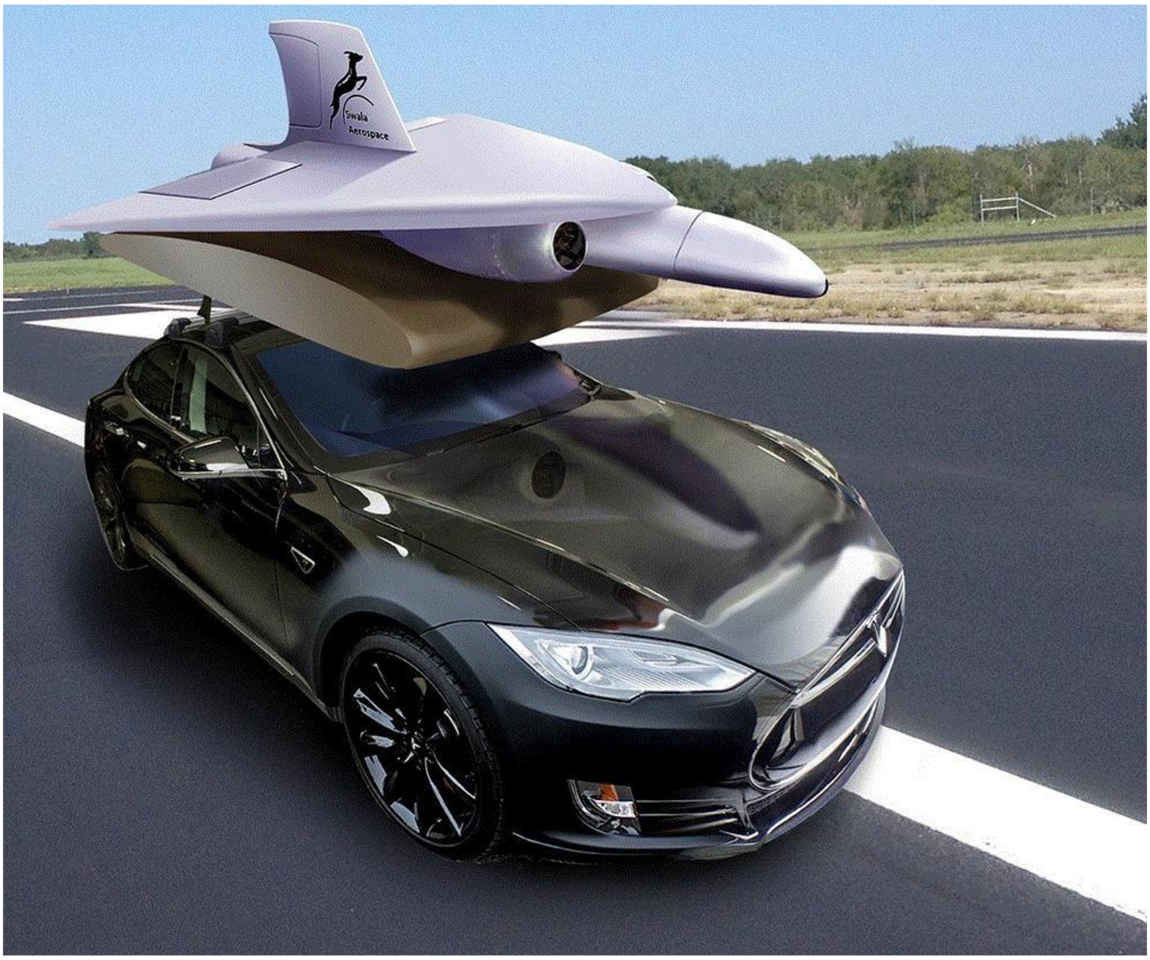
2. This initial launch and capture will first employ the modified RC units, using a roof platform on a Tesla Model S electric car equipped with a responsive guidance system and electromagnets.
3. Once the launch and capture systems have been perfected they will be transferred to the completed 1/10th 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 financing of Swala Aerospace, perhaps on the Alternate Investment Market.

Even at this scale, the UK's Civil Aviation Authority will have to be involved, and, as mentioned, an airfield approved for Unmanned Aerial Systems (UAS) will have to be used. Two are currently licenced for such activity; the Cornwall Airport at Newquay and the West Wales Airport near Aberporth. The latter is quieter and could accept the intermittent launching of the 1/10th scale vehicle down its less-used grass 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 ot include any contingency, and nor does it include any capital recovery from the sale of the assets after development is complete.

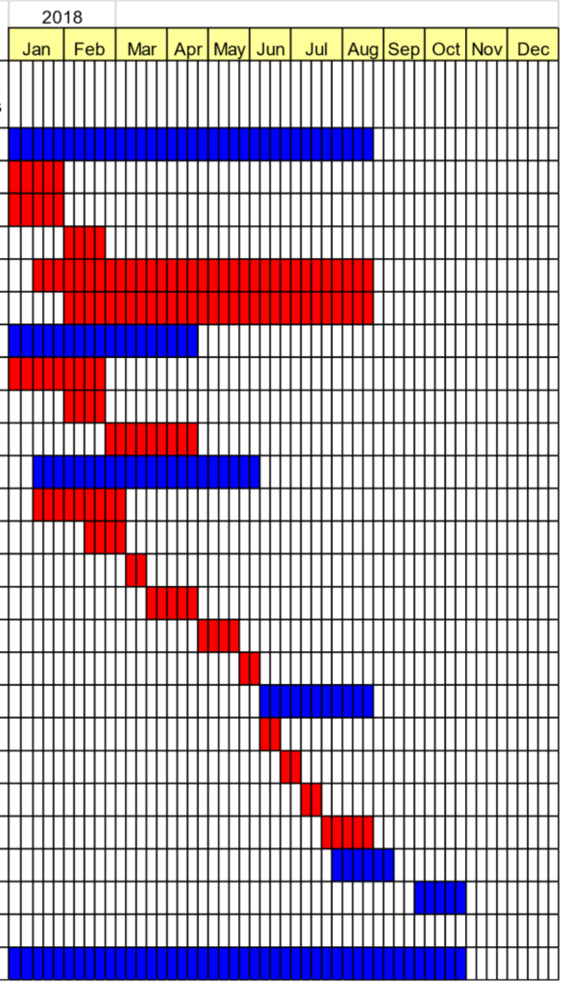


The 1/10th Scale Swala Vehicle on its launch/capture platform on a Tesla Model S

5.1. The Costing and Scheduling of the Stage 1 Programme (Nominal Dating)

375-AF - One-Tenth Scale Swala-Tesla Ensemble Development and Launch - Capex and Gantt Chart

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



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 linear motor carriage, complete with ramjets. During the ensuing pre-launch 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 focussed 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 their 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 operating altitude are encountered, probably between 35 and 40 km. Leading edge stagnation temperatures will dictate the maximum velocity; this will probably be somewhere in the range of Mach 2.5 to 3.5. 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 to 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 (token dates are used here).

This will be a major aerospace project, with appropriate international 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 required to import, rather than re-invent, them.

6.6. A Preliminary Cash Flow Projection for Swala Aerospace

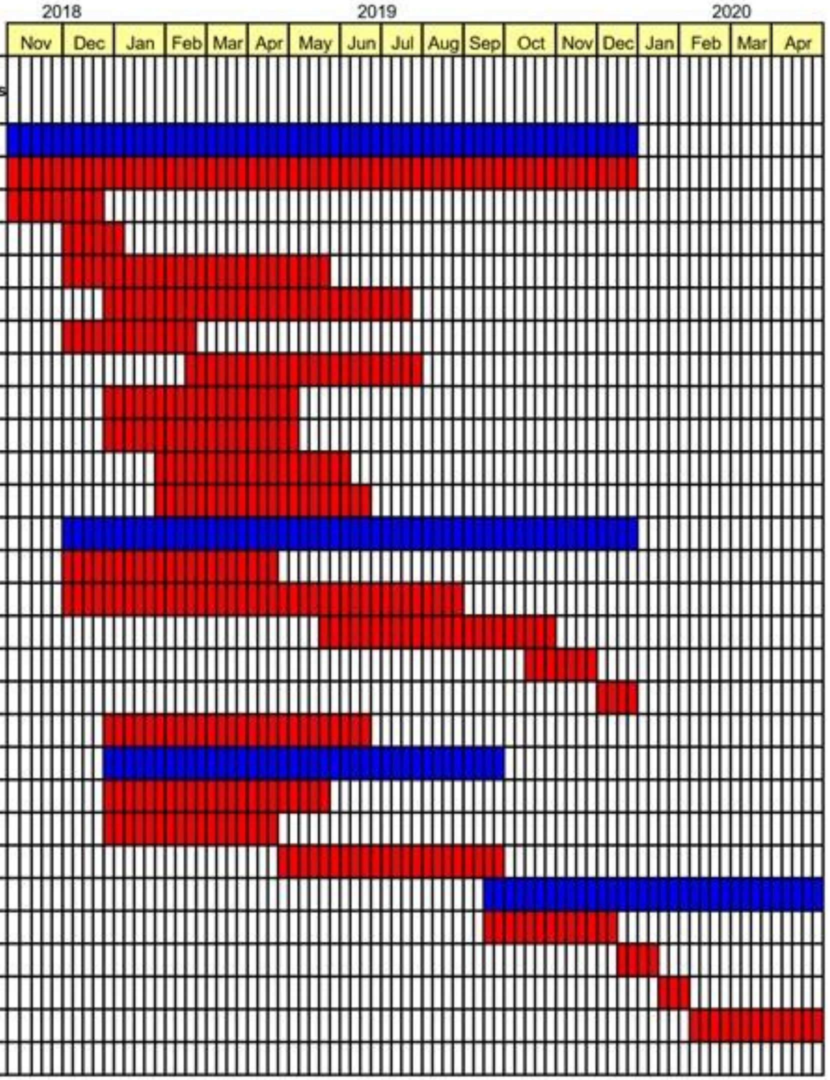
In the technical section a preliminary capital costing is provided for the prototype vehicle and its spaceport support and service facilities. This amounts to £90.5m, spent over 16 months. Operating costs will be dominated by the cost of the solid fuel used, at about £20/kg, totalling about £0.4m a launch. 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				
sNo. 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%					

Conceptual Costing and Scheduling of the Full-Scale Swala Project (Dating is Nominal)

Item	Appx. Costs £m	Tasks	Possible Start	Possible Finish	Weeks
1.0	**28.5**	**Ground Services**	**01-Nov-18**	**31-Dec-19**	61
1.1	0.0	The Acquisition of UAS status for Machrihanish (for MACC's a/c)	01-Nov-18	31-Dec-19	61
1.2	1.0	Arranging Housing & Services	01-Nov-18	01-Jan-19	9
1.3	0.5	Survey of Launch Track	01-Dec-18	15-Jan-19	6
1.4	1.0	Launch Track Design	01-Dec-18	30-May-19	26
1.5	15.0	Launch Track Contract	31-Dec-18	31-Jul-19	30
1.6	1.0	Service Area Design	01-Dec-18	28-Feb-19	13
1.7	2.0	Service Area Construction and Equipping	28-Feb-19	01-Aug-19	23
1.8	1.0	Carriage Design	01-Jan-19	15-May-19	
1.9	1.0	Carriage Power System Design	01-Jan-19	15-May-19	19
1.10	3.0	Carriage Power System Procure and Install	01-Feb-19	15-Jun-19	19
1.11	3.0	Carriage Procurement and Construction	01-Feb-19	01-Jul-19	21
2.0	**38.0**	**Swala Vehicle**	**30-Nov-18**	**01-Jan-20**	56
2.1	2.0	Vehicle Design	30-Nov-18	30-Apr-19	21
2.2	10.0	Ramjet Fabrication/Acquisition	30-Nov-18	01-Sep-19	39
2.3	15.0	Vehicle Construction and Delivery	30-May-19	31-Oct-19	23
2.4	3.0	Unfuelled Testing of Vehicle-Carriage Ensemble	15-Oct-19	30-Nov-19	7
2.5	3.0	Hot testing of Vehicle-Carriage Ensemble	01-Dec-19	01-Jan-20	4
2.6	5.0	Order and Supply of Solid Fuel Rocket Motors	01-Jan-19	01-Jul-19	26
3.0	**4.0**	**Control Systems Development and Testing**	**30-Dec-18**	**30-Sep-19**	39
3.1	2.0	Design, Procure & Install Carriage Guidance & Speed System	30-Dec-18	02-Jun-19	22
3.2	1.0	Capture System Testing/Modifying Using 1/10th Scale Vehicle	01-Jan-19	01-May-19	17
3.3	1.0	Swala Vehicle Capture Guidance System Installation	01-May-19	30-Sep-19	22
4.0	**20.0**	**Flight Testing**	**15-Sep-19**	**30-Apr-20**	33
4.1	4.0	Sub-Orbital Flight Testing of Vehicle Launch and Landing	15-Sep-19	15-Dec-19	13
4.2	1.0	Independent Review and Checks	15-Dec-19	15-Jan-20	4
4.3	5.0	First Orbital Flight	15-Jan-20	01-Feb-20	3
4.4	10.0	Orbital Flight Testing Programme	01-Feb-20	30-Apr-20	13
	90.5	**Total Cost £M Without Contingency Allowance**			



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 otherwise 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.

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

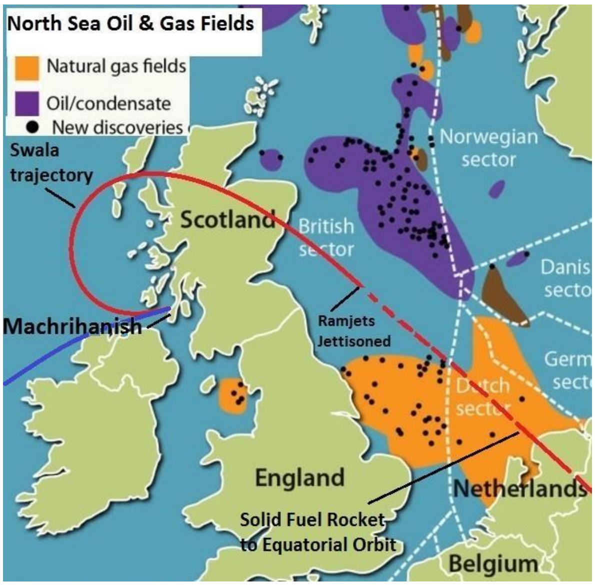
8.0. The Swala Vehicle Trajectory – Environmental and Safety Aspects

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 initial (i.e. low level) generation of its 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.



Possible Swala Flight Paths

9.0. Conclusions

According to the United Kingdom Space Agency, Britain's space industry will probably represent about 7% of the value of the global industry in the 2020s. But the Swala spaceplane will be the first all-British launch system to be created 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.

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.

Most importantly of all, SpaceX has usurped the older launch players in the United States with its reusable first stage rockets. After a rocky start (its first three attempts failed) it has become a very reliable and relatively cheap launch service, with a reputed price to low earth orbit of $3,000/kg. This, therefore, is the figure used here to assess the profitability of a Swala launch.

However, what neither the SpaceX or any other existing rocket can do is to replicate the sheer convenience of the Swala vehicle. Satellite owners typically wait for nine months or more until a launch place is available, while Swala, with an expected 24-hour turnaround, will be available at need and on-call. It fills a 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.

As the Introduction noted, 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