Project no.: **30712**

FLACON

Future High-Altitude Flight - an Attractive Commercial Niche?

Specific Support Action (SSA)

Priority 4 – Aeronautics and Space

Deliverable D.1.3 - 1
Publishable Final Activity Report

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Project coordinator organisation name: ESA/ESTEC

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PUBLISHABLE FINAL ACTIVITY REPORT "FLACON"
(Future high-altitude flight- an attractive commercial niche?)
EC SSA Study contract 30712 of FP6

1. Project Execution

The participants are:

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Project objectives

The objective of the study is to identify and assess the long-term potential of commercial high-altitude flight in Europe for selected mission requirements, in view of the activities in the USA following the successful SpaceShipOne (SS1) demonstration and the efforts performed to arrive at the next generation space ship 2 as well as aspirations by other companies. Furthermore, it is proposed to identify for Europe missing developments in technology and address safety measures as well as needed steps to satisfy legislation. A corresponding research and development strategy to enable commercial high-altitude flights will be worked out in order to secure the international competitiveness of European industries.

While the common understanding of the European community is that the sub-orbital high-altitude flight is technically feasible within a few years, building on the available knowledge in aviation, it has never been proven experimentally. The USA have achieved with SS1 an air-launched X-vehicle, which, however, requires significant effort before becoming a commercial, routinely used transport vehicle such as SS2. Such sub-orbital flight is also understood to be on the borderline to space, since the transport of people is approaching the orbital environment without really entering it fully in the sense of having to master the harsh environment of hypersonic re-entry into the atmosphere. According to reports the interest in the USA and elsewhere in high-altitude flying is very large in spite of the high price, suggesting a profitable niche for commercial flight and triggering innovation in small industries to satisfy such demand.

Key objectives are hence
1. assess worldwide activities and define reasonable mission requirements
2. identify potential show stoppers, technical but in particular non-technical ones, and missing elements for carrying out commercial high-altitude flight
3. propose a way forward to achieve commercial sub-orbital flight, including potential self-sustained development steps leading to human hypersonic flight, and a funding scenario for a first experimental flight

Major achievements

In the achievements obtained all partners of the FLACON consortium have been involved, as is required and suitable according to the proposed work plan.

Mission Opportunities

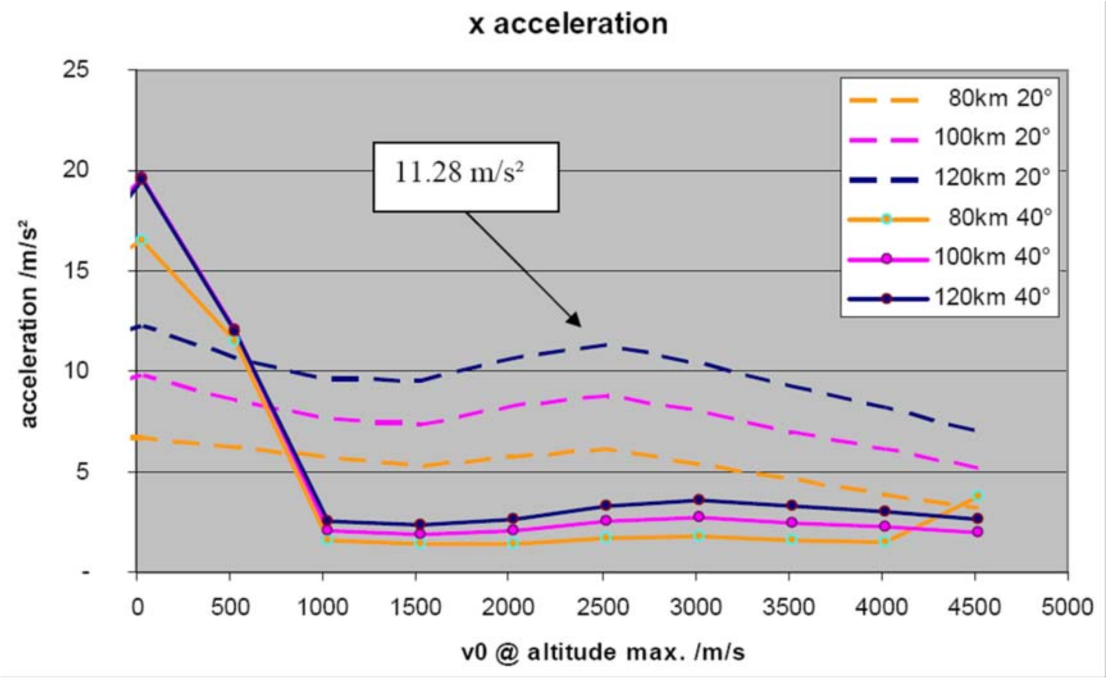
Mission opportunities for commercial suborbital flight have been investigated early in the project. For this purpose available studies, publications and announcements on the subject have been screened, and in-house inquiries have been carried out.

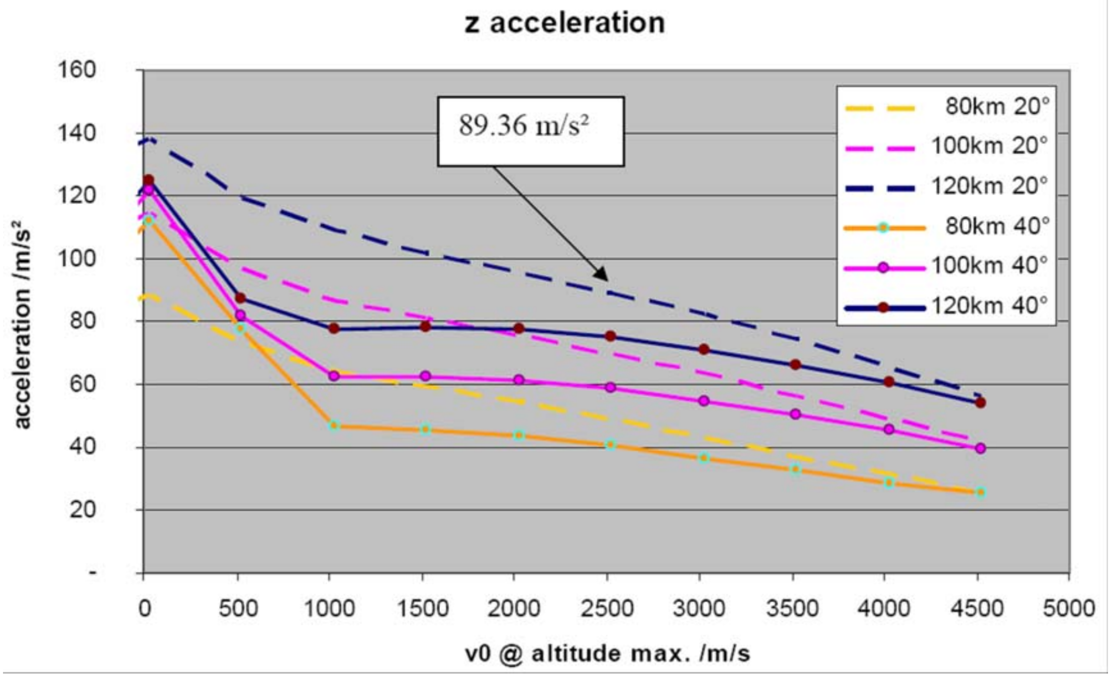
Hence, the published suborbital projects and project plans including results of available polling surveys for space tourism have been assessed, and combined with in-house knowledge, where available (in particular Astrium, Dassault). In addition, the potential of commercial suborbital flight for purposes other than space tourism has been evaluated (Astrium, and in particular ONERA). The main result was that there are hardly any other potential purposes such as micro-gravity research, earth observation, military observation, space environment characterisation, astronomical research or biological research, etc., unless the suborbital flight operations are much less expensive compared with the presently employed means for achieving the desired goals of e.g. earth or military observation. This requirement varies with the purpose.

In summary when considering the development of suborbital transport capabilities for space tourism the assessments resulted in the formulation of the following human user requirements:

• **Demanded altitude / trajectory**	**> 100 km**
• **Low g phase duration**	**few min**
• **Acceptable G-Loads**	**< 4-5 g**
• **Number of passengers**	**< 10**
• **Piloted vehicle**	**yes**
• **Safety**	**high**
• **Visibility of space and earth**	**necessary**
• **Short maintenance duration**	**>1 flight / week**
• **Long range**	**> 100 km ?**
• **Ticket price**	**< 200 k$ (TBC)**
– **requires low operational costs**	
• **Time to market**	**< 2009 ?**

Concerning the possible horizontal or vertical launch possibilities, it is remarkable to see that current space travel agencies have selected only horizontally starting vehicles in their commercial offers for suborbital missions. The reason for this choice is not entirely clear, since e.g. the US Shuttle is launched in vertical direction. However, there the passengers are hand-picked and heavily trained people. The offered suborbital vehicles which are launched from ground or in the air in horizontal direction, do land horizontally. Although credible concepts exist also for single vehicle concepts based on a combination of aircraft engine and rocket propulsion, the current study emphasizes the two-vehicle air-launch concept based on an aircraft carrier and the space vehicle (see e.g. SS2 below the carrier aircraft White Knight 2 and the Russian Explorer concept with the space vehicle on top of the carrier). This has a number of benefits, where one major advantage concerns legal considerations, namely that a clear distinction is possible between aircraft and space vehicle. The list of advantages is briefly given below in form of bullets:





Figures: Sensitivity of the acceleration loads on horizontal speeds at maximum altitude during re-entry for a given vehicle for different maximum altitudes and angles of attack. (The numbers in the frames address reference values for accuracy control.)

- performance of space vehicle easier to obtain
- no need to develop the carrier aircraft if an available one can be adapted (note that Burt Rutan for SS2/WK2 cites the advantage of having a new design for the carrier that with that aircraft the performance of SS2 can be simulated and pilots as well as passengers can be trained with respect to g loads and micro gravity; this includes also the qualification of material and components used for SS2 as well)
- high level of safety by using an available carrier, including certification (with possible need of extension of certification)
- existing airfields may be used
- low cost of operations (potential multiple use of the carrier as long as the suborbital flights are not too many)
- separation manoeuvre already demonstrated (if mastered again this would provide spin-off advantages for future space transportation project in Europe in terms of advanced flight testing capabilities)
- allows to separate aircraft regulations from space vehicle regulations

The acceptance and thus the success of future business will depend on the requirements with respect to the training and the health of the passengers, i.e. essentially on the loads experienced during flight. Note that just increasing the maximum altitude of ballistic flights by introducing more propulsion energy will lead to higher g loads. The pilot of SS1 underwent loads of about 5 to 6 g. DLR performed simulations to investigate the sensitivity of the level of g loads encountered on trajectories with respect to space flight parameters, based on an experimental vehicle from former FESTIP and DLR studies, see e.g. the two pictures showing the accelerations during re-entry in x (normal to the body axis) and z (in body axis, i.e. towards the head or away from it) directions. The resulting figures show that the g loads can be reduced most if one equips the vehicle with sufficient energy to reach 1000 m/s horizontal speed at maximum altitude, while increasing further the speed is not such beneficial. The figures also indicate the beneficial influence of increasing the angle of attack during re-entry. However, one has to keep in mind that the dynamic pressure during the re-entry flight increases possibly to values which are detrimental to the aircraft. A similar situation arises for thermal loads. Hence, some optimisation will be required to arrive at the best and safest operational solution. The FLACON low acceleration reference trajectory for descent as elaborated by DLR (and IRS) has thus to be seen as an attempt to arrive at a trajectory with very low prescribed g loads (< roughly 2 in body-axis direction) regardless of the consequences with respect to associated mechanical and thermal loads.

It is worthwhile to mention these investigations indicate that ballistic suborbital flight can be considered as an entry point towards long-distance suborbital transportation. In addition to the above-mentioned load drawbacks one then has to keep in mind of course environmental issues, including noise.

Some elements of high-altitude flight in Europe

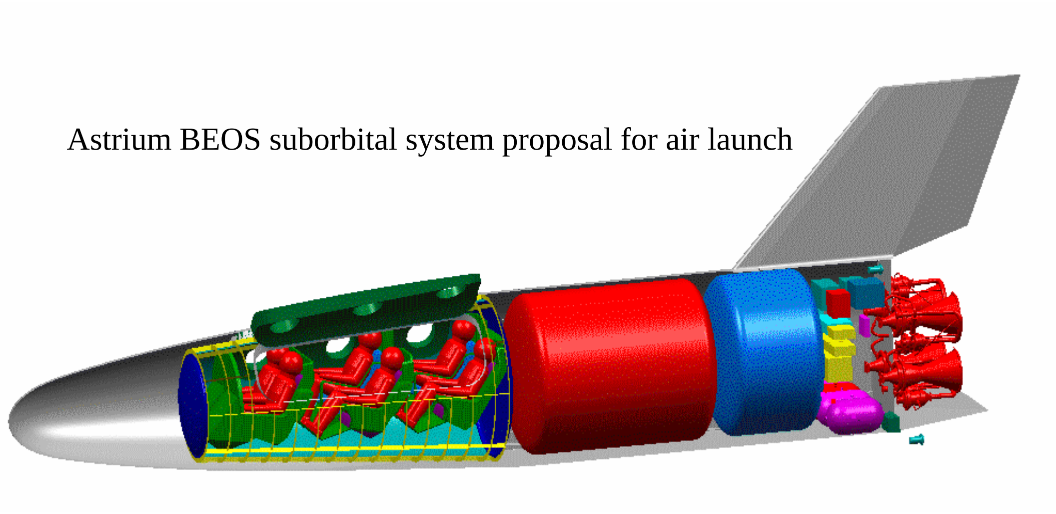
Astrium asked Prof. Hobe, a renown air and space law expert from the University of Cologne, to provide his view on the legal situation in Europe with respect to air-launch suborbital flights in Europe and elsewhere. The results indicate essentially that Europe is a zone where considerations concerning suborbital flight legislation and other consequences wrt liability, insurance, licensing, jurisdiction on board of the vehicles, etc. are missing. Note however that ESRANGE in Sweden is making arrangements to serve as first European spaceport for suborbital flights with SS2 when being organised by Virgin Galactic in Europe. In the USA it is fairly easy to obtain permission to fly passengers suborbital provided the passengers have put in writing that they are aware of the total risks of such flight, and provided that the operator can make clear that people on ground are not endangered by the operations. All these regulations and rules remain to be discussed with authorities in Europe.

A particular question is when air law and when space law applies. Only Australia has defined that space starts when the altitude of 100 Km is exceeded. For air-launched suborbital flight the situation is comparatively simple: air law applies to the aircraft carrier and to the combination of carrier and space vehicle. After separation, the space vehicle is governed by space law. While the national and international air law is clearly defined, and the aircraft is defined by its characteristics, this is not the case for the national and international space law. The latter is under development, and the definition of the space vehicle/object is e.g. derived from the intended mission altitude of the trajectory. The delimitation is under discussion in Europe. The international outer space treaty says that the state has to authorize and supervise the space operations of private entities. The US FAA already defined regulations in the commercial space launch amendment act (valid since the beginning of 2007 until around 2012).

In general the jurisdiction of the state of registration has to be applied. The rights of the crew and the passengers will be defined by the state of registration. In the case of the ISS one distinguishes between professional astronauts and the space flight participants. Insurances will have to be negotiated on the basis of the certifications. The launching state will not be liable for accidents occurring with private missions, while this is the case for national missions. Concerning the medical risks which passengers run, the operator has to make sure that all participants have been checked with respect to the medical requirements. Virgin Galactic requires e.g. that all passengers pass a 2-day check-up course using e.g. a centrifuge to mimic the loads encountered during flight (up to 6 g during the re-entry phase of SS2).

Astrium also presented a comparison of risks anticipated for orbital, suborbital, and high-altitude fighter flight and Mount Everest climbing. In fact, the risks of suborbital flight are just twice those for military flights and much lower than for the guided mountain climbing adventure tour. Concerning the environmental pollution due to the combustion products of the proposed LOX/Kerosene engine an earlier study suggests that 50 BEOS (the Astrium space vehicle based on the German HOPPER concept) flights just contribute 0.2 % to the air traffic environmental pollution. However, this needs to be confirmed, and the fact needs to be considered that the products are present in other altitudes than for conventional air traffic.

Based on the 20-tons air-launched BEOS concept for 7 passengers and 1 pilot Astrium has previously shown that medium range distances can be covered, say of the order of 800 Km, by means of suborbital flight up to the altitude of 95 Km and horizontal speed exceeding 2000 m/s. The penalty is high dynamic pressure of about 50 kPa and a maximum heat flux of 450 kW/m**2 for a short period of time.



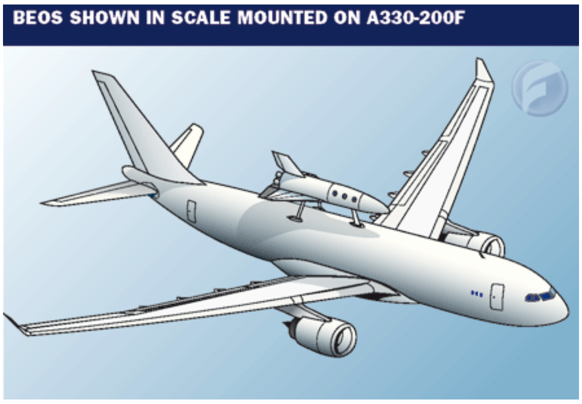
Astrium BEOS suborbital system proposal for air launch

Inquiries within Onera’s departments for the air-launched transport suggest that the integration of suborbital transportation activities into the European air traffic regulation should be possible, provided the airports used are not heavily frequented by normal air traffic. The combined starting phase and the – in this case gliding – entry phase are comparable to regular air traffic. The rocket propelled phase is very short and in near vertical direction so that the regular air traffic should not be disturbed. Of course, one has also to consider certification or rather demonstration of sufficient safety for the vehicle, passengers, and the environment which was not treated in this study. It is assumed that negotiations with the national/international authorities have to be performed to arrive at flight permission. Certainly negotiations will also be required with insurance companies to determine and limit the magnitude of insurance premiums to an affordable level.

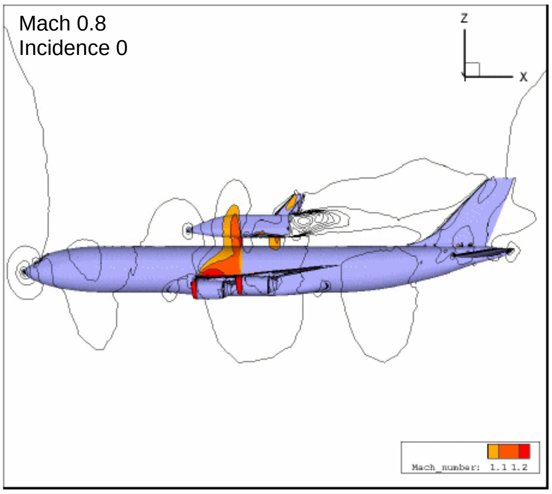
Onera considered the impact of the space environment for suborbital human transport. Vacuum effects do not represent a concern. The impact of debris and meteorites seems to be low for altitudes between 100 and 150 Km, although this would need further investigations. Radiation issues, on the other hand, could become of larger concern, considering electromagnetic radiations (UV, X and gamma rays), charged particles (protons, ions and electrons), and neutrons. One origin of radiation is cosmic radiation from outside the solar system. The second one is the sun, in particular due to solar activity and especially through solar flares. The third origin is caused by the Van Allen belts resulting from the earth magnetic field that trap charged particles around the earth at latitudes below 50 to 60 degrees. In these latitudes the earth is generally shielded which is not the case for larger latitudes (note that the position of ESRANGE is at larger latitudes). For suborbital flights the solar activity/flares based radiation poses, in general, the largest danger, less on the vehicle components and not on the tourists flying at most once a year but for the crew of suborbital transport accumulating larger doses. Flights at high latitudes should definitely be avoided during solar flare periods, which may last up to five days. The environment topic requires further investigations.

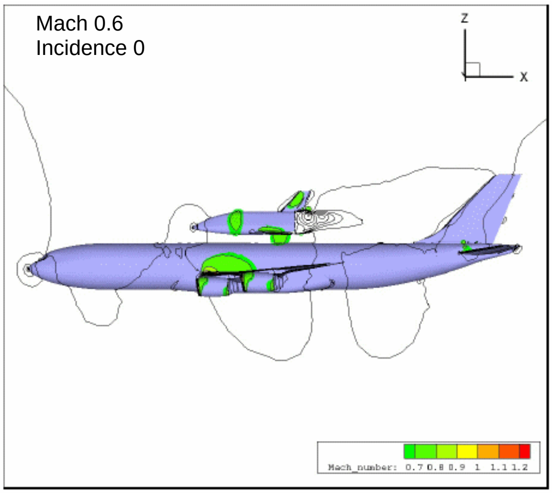
Air-launch for high altitude flight in Europe

The advantages associated with an air-launched suborbital flight have been provided above.



Previously, Dassault had considered the A300-B2 aircraft as carrier for their investigated VEHRA vehicle. An Airbus carrier vehicle is the natural choice in Europe. The VEHRA vehicle of interest here out of en entire family of space vehicles has a mass of about 12 tons. Further potential air-launch opportunities have been considered by Astrium with the help of Airbus. Here the A330-200F freighter version is preferred due to its capabilities to fly high at high velocity and carry heavy loads with large margins. Astrium used the form of the subscale version Phoenix of the FESTIP derived vehicle HOPPER, called BEOS as a result of an earlier regional programme. Including fuel and oxidiser the full-scale BEOS would weigh about 20 tons. The initial requirement was to separate and launch this space vehicle at an altitude of about 10 Km and a speed corresponding to M = 0.8, restricting considerably the choice of carrier aircraft. The position of the space object was chosen to be on top of the aircraft, since it would fit underneath neither under the fuselage nor under the wings. In addition, Dassault demonstrated such a separation condition is not trivial. Based on its rich experience as a producer of fighters, Dassault discussed the separation issue in detail, and developed a separation strategy. To support this, engineering (inviscid) computations in three dimensions by DLR showed that the requirement in terms of M=0.8 was too high, causing strong interactions between carrier and space vehicle, and leading to unfavourable separation conditions. From the DLR results Dassault derived conditions for the angle of attack for the combined configuration to counteract the loss of lift due to the interaction. In addition, Dassault suggested a rationale to derive practical requirements for the carrier aircraft with respect to the performance and flying quality. This rationale is based rather on

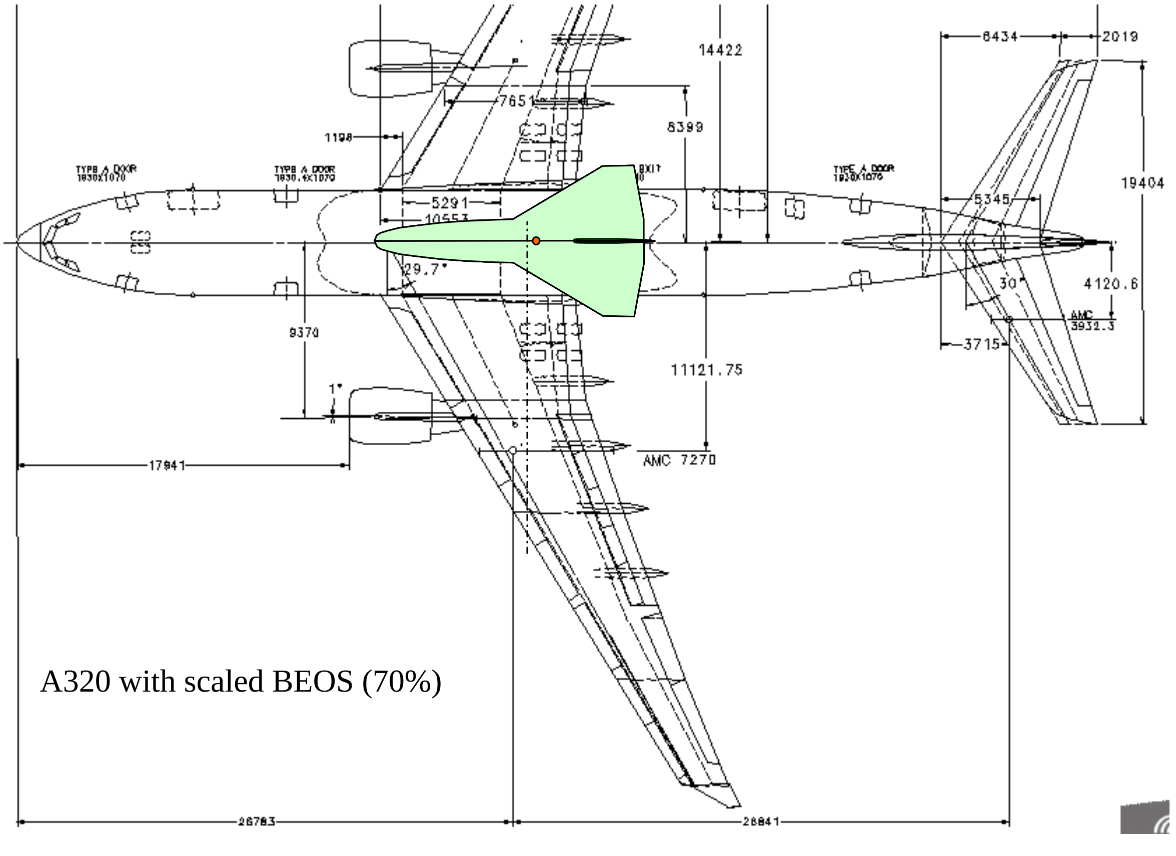




maximising the ratio energy over weight (=equivalent altitude) than on prescribing both Mach number and altitude. Such analysis in the case of the A300-B2 carrier was leading to a separation Mach number of about 0.68 at an altitude of roughly 9 Km resulting in a realistic equivalent air speed of about 240 knots at separation.

It has been mentioned earlier that the separation process has been carried out decades ago in Europe, but needs to be mastered again.

A cost estimate of adapting the carrier aircrafts A300-B2 and A330-200F have been carried out by Dassault and Astrium/Airbus. This includes the truss needed to hold the space vehicle with a kind of separation mechanism (Dassault has a patent on its system of separation) and the required re-enforcements of the fuselage of the aircrafts to carry the 11 tons of VEHRA and the 20 tons of BEOS. Furthermore, included are the development steps and wind tunnel investigations needed to arrive at a safe combination of carrier and space vehicle, as well as a safe separation. The resulting amount is between 10 and 15 M€. For the development and manufacturing of a subscale version of BEOS (70 %) for an unmanned automatic flight Astrium came up with a total cost of about 170 M€, a number which seems to be too large to attract funding to perform a first experimental flight. It is believed that a different approach needs to be taken to arrive at more reasonable numbers for a first flight experiment, much in the spirit of Boeing’s skunk work approach which aims at arriving at a given goal at minimum cost. Since for a first experimental flight it may not be feasible to obtain an A330 freighter, it was considered useful to possibly approach a research organisation using routinely an A320 aircraft as research aircraft. Below is the scaled down BEOS sketched on top of an A320 to provide an impression of the length scales involved.



A320 with scaled BEOS (70%)

Synthesis and potential way forward

The work performed for FLACON has shown that there is no technical show stopper as was already anticipated. The propulsion system required to achieve space-like altitudes has not been considered here. In BEOS a suitable Russian liquid propulsion engine was assumed available off-the-shelf. Preliminary investigations for a proposal for FP7 indicated that a hybrid propulsion system could be made available in West Europe, if needed, similar to the one of SS1, but not with corresponding validation history. The air launch approach was followed since in the USA this approach to suborbital flight was shown to be very successful leading to a follow-up version which will be operated commercially within the next two years. In fact, several decades ago also West Europe had some experience with this approach, however, the corresponding know how needs to be gained again.

A suitable air field for experimental flights can certainly be found – the future space port ESRANGE could be a candidate in any case. However, the negotiations with the national/international authorities remain to be made with respect to flight permission and legislation as well as liability issues, including last not least discussions with insurance companies. Insurance companies need to be convinced that the design of the air launch is safe and robust.

An experimental unmanned automatic flight with a subscale space vehicle piggy-back on an aircraft is deemed to be the first step to verify the approach taken and the involved design methodology. To demonstrate mastering the technologies by in flight experimentation is most probably too risky for an established aircraft manufacturer. Hence some funding support from third parties' side would be needed to perform this first step. And since in West Europe venture capital is less easy to obtain than elsewhere recourse will have to be taken to governmental institutions such as the EC. Unfortunately, a private foundation to support research in this field is not available, such as the Guggenheim fund in the USA in the early 20th century helping to substantially advance aviation research, innovation and development. On the other hand, the numbers obtained from Astrium for developing and manufacturing the subscale BEOS indicate that a new, more dedicated organisation needs to be found to carry out the air-launched orbital flight experiment. It is obvious that once the funding is available the advancements have to be taken step by step, as was the case when SS1 was developed.

The required time frame is not easy to estimate, because it depends on the experience and dedication of the engineers involved as well as on the available funding level, but a good guess would be four to five years. One has to keep in mind that Burt Rutan, the father of SS1, owned a research outlet since 1982, producing and flying novel aircraft every year for about the first 12 years. Hence his research factory had a lot of experience in building innovative aircraft before embarking into the X-Prize competition based on the funding of a billionaire (Paul Allen).

2. Dissemination and use

A web site "FLACON" has been opened by ESA/ESTEC which contains all presentations during the six progress meetings as well as the kick-off and close-out meetings, including the corresponding minutes as prepared by the coordinator and agreed by the participants.

The site can be reached by searching for FLACON on the ESA portal page. The more specific and detailed information is pass word protected for use by the consortium.

After the acceptance of the publishable report this will appear also on the portal of ESA/ESTEC (www.esa.int/ESTEC), available for everybody.

Results of the study were presented at the occasion of the first CEAS European Air and Space Conference taking place in Berlin from 10 to 13 September 2007 (www.ceas2007.org). The presentation had the title “FLACON, Summary of an EU FP6 Study” and was presented by the coordinator as last author due to special circumstances.

In addition, a contribution has been made to an EU synopsis book on running projects in 2007, probably to appear in 2008.

The final presentation of the results took place at ESTEC where other potentially interested parties were invited to attend and fuel the discussion. The invited people included in particular also participants of a related proposal FAST20XX, “Future high-altitude high-speed transport 20XX”, submitted in the first call of EC’s FP7.

An abstract “Some Considerations on Suborbital Flight in Europe – Results of a study funded by the European Community (EC)” was submitted to and accepted by the 15th AIAA International Space Planes and Hypersonic Systems and Technologies Conference, 28 April – 1 May, 2008, Dayton, Ohio, USA.

A further abstract “Reflections on Conditions for Commercial Suborbital Flight in Europe” is planned for the 1st Symposium on Private Human Spaceflight, May 28 – 30, Arcachon, France.

Using the obtained indications of how to arrive at long-distance suborbital flight, some of the partners consider how to come up with a modified proposal FAST20XX for the next call of FP7.