Some Considerations on Suborbital Flight in Europe

- Results of a Study Funded by the European Community (EC)

J. Starke.[1]
Astrium Space Transportation, Airbus Allee 1, 28199 Bremen, Germany

J.-P. Belmont[2]
DASSAULT Aviation, 78, Quai Marcel Dassault, 92552 St. Cloud Cedex 300, France

J. Longo[3]
DLR, Lilienthalplatz 7, 38108 Braunschweig, Germany

Ph. Novelli[4]
ONERA, BP 72, 92322 Châtillon Cedex, France

and

W. Kordulla[5]
ESA/ESTEC, Keplerlaan 1, 2201 AZ Noordwijk, Netherlands

Sparked by the achievements of Scaled Composites with their SpaceShipOne flights in 2004, a study was proposed to the EC to look into corresponding capabilities and opportunities for suborbital flight in Europe. This study confirmed that space tourism is the major commercial driver for suborbital ballistic flight, unless the corresponding costs can be reduced substantially. The study considered a variety of issues to conclude that technical show stoppers to achieve suborbital flight in Europe do not exist, assuming the composite configuration of an Airbus as carrier plane and a winged space plane as suborbital vehicle. A major stumbling block, except for the funding issues, remains to achieve permission to fly such vehicles in Europe.

Nomenclature

AoA = Angle of attack, ALPHA
CL, CD = Coefficient of Lift, Drag
CoG = Center of gravity
DARPA = US Defense Advanced Research Projects Agency
EC = European Commission
FFA = US Federal Aviation Administration
FLACON = Future High-Altitude Flight – An Attractive Commercial Niche?
FPx = Framework Program x of the European Commission (EC) (x = 6 or 7 here)
L/D = Ratio Lift over Drag
M = Mach number
SSi = Space Ship i (i = 1 or 2)
UAV = Uninhabited Aerial Vehicles
WKi = Carrier plane White Knight i (i = 1 or 2)

---

[1] Study Manager & Senior System Engineer, Advanced Projects TOB 1.
[2] Space Activity Coordinator, Prospective Department, DGT/DPR.
[3] Branch Head, Space Vehicles, DLR AS-RF; AIAA Senior Member.
[4] Space Transportation R&T program manager, Fundamental and Applied Energetics Department.
[5] DLR seconded Agent, Mechanical Engineering Department, TEC-MZ; AIAA Senior Member

I. Introduction

THE winning of Ansari's X-Prize competition by Scaled Composites in 2004 showed the public that going to space would be possible without the enormous cost typical for institutional access to space which, however, can not prevent accidents to happen from time to time. Of course, the suborbital ballistic flights of SpaceShipOne can not be compared with those of e.g. the Space Shuttle since the harsh environment of atmospheric re-entry from low-earth orbit is not encountered. However, for a short period of time, the passenger obtains a comparable sensational feeling being at an altitude of around hundred kilometers. In the wake of these events a proposal for a small study was made to the European Commission to assess the situation in Europe to some extent. The title of the study is "Future High-Altitude Flight – An Attractive Commercial Niche?" abbreviated as FLACON. The study started finally in September of 2006 and ended by the end of October 2007.

The objective of the study was 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 Space Ship One (SS1) demonstration and the efforts performed to arrive at the next generation space ship 2 as an operational vehicle as well as aspirations by other companies. Furthermore, an aim was to identify for Europe missing developments in technology and address safety measures as well as needed steps to satisfy legislation. 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 in Europe. 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.

The typical vehicle design in the context of human space flight is viewed as oriented towards two major directions as a kind of road map for future applications. The first is oriented towards the **orbital transport** taking into account the space station and space hotel development and further steps to the Moon. The other line is oriented towards the **fast suborbital transportation around the earth**. Generally, it is assumed that such human hypersonic suborbital transport would be preceded by developments triggered through military demands and corresponding developments[10]. Suborbital ballistic flight is considered a first step in that direction, and is in the focus of the FLACON study and also of world wide attempts to achieve suborbital flight. This "simplest" suborbital flight is that one e.g. carried out with SS1.

The various vehicle concepts proposed worldwide are exhibiting major differences with respect to the vertical or horizontal launch principle, with respect to the staging concept with one or two stages and finally with respect to the vertical or horizontal landing approach. The reusability of the modules is one of the key commonalities of all concepts.

In the following, first the legal situation of suborbital flight is briefly being discussed. Then the situation of the suborbital market and potential mission opportunities other than space tourism, the latter being the main reason for current commercial developments, are evaluated. Further, published concepts are assessed, user requirements resulting from surveys are given, and design parameters are discussed. Furthermore, the possible suborbital mission scenarios are described with respect to the energy which needs to be put into the system, including the corresponding performance consequences in particular for the passenger. Then a potential European reference mission based on Airbus launch capabilities is considered, including a demonstration potential. Also, environmental issues are briefly discussed, in particular the effect of radiation on humans while flying suborbital.

II. Legal Aspects for Suborbital Air-Launched Flights

Astrium asked Prof. Hobe, a well-known 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[3]. The results indicate essentially that Europe is a zone where considerations concerning suborbital flight legislation and other consequences with respect to 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 organized 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. Note that these agreements will certainly not protect airline operators to be sued in case of mishaps, but it helps. All these regulations and rules remain to be discussed with authorities in Europe.

A particular question is when air law applies, 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 corresponding 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).

A comparison of risks anticipated for orbital, suborbital, and high-altitude fighter flight and Mount Everest climbing was found in literature. In fact, the risks of suborbital flight are estimated just twice those for military flights and much lower than for the guided mountain climbing adventure tour.

III. Suborbital Flight Market Analysis

The first market analysis for human space flights is published in the 1990s emphasizing orbital space flight for space tourism purposes. A new basis for the market assessment in particular for suborbital space flight has been established by FUTRON in 2002, and complemented in 2006 for passenger transport[1,2,5]. In addition to the space tourism aspect it is interesting to investigate which other markets could be served by suborbital flight. The other applications which have been taken into account are e.g. missions for scientific payload as complement or alternative to sounding rocket systems or the application for earth observation and last not least military applications.

Only a few space tourism market studies exist. Indeed, before 2000, the studies are related exclusively to orbital tourism. Most of the authors recognize the high level of uncertainty of demand surveys. It remains difficult to know what people will do when the possibility to fly would become reality. It is also not clear that interviewed people have a sufficient knowledge of real flight conditions. The people's capability to save the required money is also a factor that is not taken into account in many studies. On this point, the Futron study is considered the most credible one because of the selection of interviewed people from high income households. It is also noted that in the reviewed papers, the transition from survey to market prediction is generally not explained properly.

Beyond these remarks, we should nevertheless underline the good convergence between all the studies with respect to a number of aspects. The most striking one is the agreement between all the surveys concerning the main motivation for people to go to space, namely to see the earth from space. This expectation is much stronger than the desire to experience weightlessness, which is nevertheless considered important. We also note that a quite important number of people say to be ready to pay quite a large amount of their income for their travel. This is confirmed by the reports of Virgin Galactic on performed down payments for the anticipated WK2/SS2 flights.

As a conclusion, Futron appears to be the most credible study and, in fact, is the basis for most of the presently running or planned space tourism projects. Among other studies its results are the most pessimistic ones concerning the interest for space tourism but are obtained with the most credible potential customers. The next step is to evaluate the space tourism business viability for such a market prediction.

In order to increase the field of application of suborbital flight to enhance the commercial motivation to have such transportation capability, some surveys on competing existing technologies and interviews with specialists led to the following conclusions based on the assumptions that suborbital flight allows for a microgravity duration of < 4 minutes with a level of < 10**(-4) g, an altitude < 130 Km, cost per flight ~ 1 M€, and a flight frequency > once per week. Expected particular advantages of suborbital vehicles are re-usability, on demand availability and fast return to flight for carrying out a new experiment, and the possibility of human action.

From the inquiries it is concluded that a sub-orbital vehicle doesn't bring a real technical advantage in comparison with competing means, mainly sounding rockets, except for research on human biology. Its potential interest will strongly depend on the price for a flight together with the offer of a higher flight frequency than with sounding rockets. It's however difficult to estimate to what extent an attractive price could boost the scientific applications that represent today a very limited market. As a conclusion, it is today doubtful that scientific applications could constitute a substantial additional market that helps to foster the development of sub-orbital vehicles. It will probably rather be a side use of these vehicles, when existing, with a limited number of flights in comparison with Futron like market predictions for space tourism.

The major share of the sub-orbital market is clearly associated with the space tourism with more than 80 % and the residual section is divided by the scientific and the military applications, where the latter part is almost covered by vehicles being developed under military control (e.g. UAV). As long as point-to-point transportation is not combined with the suborbital flight the separate development will be pursued.

A fast long-distance sub-orbital transportation demand is not yet observed. A few ideas about fast transportation as point to point service over the earth (half around the world within 2 hours) are appearing, and a few transportation vehicle concepts are studied and proposed, but that may become the next generation of sub-orbital vehicles. Such vehicles will probably first materialize in the military field[10]. First, however, demand seems to be for vehicles designed for atmospheric flight (see e.g. the recent request of the US agency DARPA for an experimental plane “Blackswift”, http://www.darpa.mil/tto/solicit/PS08-02.pdf).

IV. Concept Review

Quite a few suborbital flight vehicle proposals have surfaced worldwide, a few of which are briefly mentioned below. This dawn of a new entrepreneurial space age has been triggered by the 10-million-$-X-Prize of the Ansari family and, in particular, by the winner Scaled Composites backed financially by Paul Allen, the co-founder of Microsoft, and by the positive commercial space tourism outlook owing to the Futron studies.

The below table provides an overview over selected concepts:

Company	**Vehicle**	**# Crew + Passengers**	**First Flights**
Benson Space Company - *Dream Chaser*	VT, HL	~6	2009
Blue Origin - *New Shepard*	VT, VL	3 or more	2010
Canadian Arrow / PlanetSpace	VT + parafoil landing	1+2	TBA
Mojave Aerospace Ventures - (Scaled Composites + Virgin Galactic) - *SpaceShipTwo* -	Air launch + glide landing	2+6	2009
Rocketplane Ltd. - *Rocketplane XP*	HTHL	1+3	2008
Space Adventures, Prodea, RSA - *Explorer*	Air launch + glide landing	1+5	TBA
Starchaser - *Thunderstar*	VT + Capsule parafoil landing	3	2009
XCOR - *Xerus* http://xcor.com/ Lynx Mark I	HTHL	1+1	TBA 2010

VT - vertical takeoff. VL - vertical landing
HT - horizontal takeoff, HL - Horizontal landing.
* Date of the Canadian Arrow / PlanetSpace news conference.

The original table (dating back to 2006) has been complemented by the recently announced rocket propelled Lynx which in a first step climbs up to about 60 Kilometers using kerosene based propulsion[9]. In summer 2007, an announcement has been made by EADS to launch a plane - similar to Rocketplane XP’s concept - propelled by air-breathing engines to start and to land, and methan based rockets to climb up to space[13, 14]. The corresponding development will start if sufficient investors can be convinced.

The table is dominated by US based developments. European developments are Starchaser with hardware (Starchaser Industries, United Kingdom), VEHRA (Dassault Aviation, France) [6, 11, 15], BEOS[7] (Astrium ST, Germany) and others, including from Romania with participation in the X-Prize contest.

It is of interest to note that the known space travel agencies advertise exclusively horizontally starting and landing systems, vertical launch systems are not part of their offers. This includes the three concepts identified as credible: WK2/SS2, Rocketplance XP and RSA-Explorer.

In parallel to the vehicle concepts, space ports are being generated worldwide. The most known one is Spaceport America in New Mexico owing to the high-level public relation activities of Virgin Galactic which will market SS2 flights, having New Mexico's one as main port. In Europe ESRANGE made a contract with Virgin Galactic to serve as first European location once Virgin Galactic organizes flights in Europe. However, even some small group in the Netherlands considers plans for a space port on the Dutch Antilles.

FLACON concentrates on air-launch concepts because SS1 is the reference concept, and because of the following advantages

- Performance is easier to obtain with a two-stage approach
- No need to develop a carrier if an existing plane is being used (Airbus e.g.), original use still possible; could be used as tanker for the space plane to be fuelled just before separation…..
- High level of safety
- Carrier vehicle already certified (extension may be needed)
- Existing airfields may be used
- Lower cost of operations
- Separation maneuver already demonstrated (not recently in Europe)
- Allows to separate aircraft regulations from space vehicle regulations

V. Identified Transportation Requirements

EC's (European Commission) aeronautic goals for future technology developments – included in the work program for FP7 and also expressed in discussions with the last author - include very fast point-to-point transportation including suborbital flight as possible target for the farther future. Specific requirements for the transportation of cargo to different locations in the world are not yet defined. The fast transportation of goods over a long distance (e.g. New York - Tokyo within 2 h) is related to the desire to react in a fast and flexible way[10]. What is clear for Europe, however, is that any means of transportation must respect the existing and anticipated future environmental conditions. Different design goals are mentioned in publications which could determine the transportation scenario, e.g.

- non stop flight / mission to each point of the world which means: ~ 20000 km within an acceptable time < 4 h.
- transportation mass dependent on the purpose of transportation: - civil / medical (a few 100 kg) and
  - military (a few tons)

with acceptable mechanical loads, low cost and operations from and to classical airports.

The Concorde as first regular supersonic passenger aeroplane in the world has shown the available market but also the hurdles for this kind of passenger transportation device. The EC supports technology developments aiming at very fast atmospheric transportation by funding the FP6/7 Collaboration Projects LAPCAT I and II as well as ATLLAS which look at advanced propulsion and light-weight materials for airplanes flying at Mach number 5 and 8. Leaving the atmosphere for most of the transportation time with higher velocities < Mach 10 - as is the case in suborbital transport - is another way to reduce some of the negative effects (e.g. acoustic noise) with the penalty of re-entry conditions with higher mechanical and thermal load effects and with their impacts on the reusability and maintainability of this type of vehicles, and with the need of a safe re-entry.

The identified requirements for the present ballistic suborbital space tourism are converging against a set of key requirements taking into account the potential group of passengers and their characteristics. The FUTRON study has summarized the major features of the potential passengers particularly with respect to the commercial issues and to the biological loads. The personal comfort and the exclusivity aspects are dominant concerning the size / volume of the cabin and their equipment. The aspects of training cycles and the related required time intervals have been shown as additional drivers for the acceptance of the overall product. And last not least the safety of the passenger and the crew are of importance which is almost in contradiction to the commercial factors as ticket price derived in the market study. The following list indicates some requirements for the manned suborbital missions and their preliminary justifications.

- Altitude should be at least 100 Km (because of the astronautic-like view)
- Duration of low g phase > 2 minutes (much larger than for parabolic flights)
- Acceptable g loads for passengers: < 4 – 5 g over a short time (see also the famous and often shown acceptable acceleration vs duration plot)

- Number of passengers < 10 (to guarantee the exclusivity as long as possible)
- Piloted : yes
- Safety : high
- Visibility of space and earth: definitely necessary
- Short maintenance duration: > 1 flight per week (XCOR claims several flights per day for its planned 2-seated Lynx concept[9])
- Ticket price : probably lower than 200 K$, initially well accepted as the booking for SS2 flights and others suggest, but requires low operational costs

One of the major driving requirements of the above list is the acceptable g-load. The acceptable acceleration level is known to be a strong function of the duration of the g load as is manifested in the mentioned well-known diagram. The acceleration level Gz in body axis is the most sensitive value (< 4-5 g), while the value Gx along the transverse axis can reach higher values (> 10 g), and be still tolerable for trained persons.

For ballistic (vertical) descent phases or missions with very low horizontal velocity the maximum deceleration level is almost dependent on the peak altitude only. More generally, the parametric study to investigate load factors may involve the L/D and horizontal velocity effects, see also reference 8. For given culmination altitude and wing loading, and assuming a realistic relationship of L/D and drag coefficient, such an analysis shows that the effect of L/D and horizontal velocity are drastically different in the range of low M (velocity) and high M. Especially one observes that the optimal solution in terms of minimal load factor is in the low M range at the origin with vanishing L/D and horizontal velocity (i.e. vertical fall of a zero-lift vehicle). For a vehicle with L/D = 1, it would be necessary to increase the horizontal velocity above M = 17 to improve this local optimum to a load factor of about 4, which is out of the scope of the study. For controllable vehicles a way of reducing the maximum load factor is to control the angle of attack during the high-g phase. But the price to pay is a strong increase in dynamic pressure which quickly limits the efficiency of the technique. A reasonable objective is to limit the maximum dynamic pressure e.g. to around 30 000 Pa in order to avoid strengthening the structure. As reference, the maximum dynamic pressure is estimated to about 10 000 Pa for SS1, and bout 100 000 Pa for strongest supersonic fighter aircraft.

Complementing the above analysis, the influence of non-zero velocities on the g loads was investigated computationally for a given vehicle should one want to introduce this feature to advance towards longer distance flight. For this study maximum altitudes between 80 and 120 Km and AoAs (kept constant during the descent) of 20 and 40 degrees were assumed. Increasing the horizontal velocity to 1 000 m/s gives the largest benefit while the further increase is less beneficial for the g load. The DLR computational study suggests that it would be possible to design an entry mission by modulating AoA and bank angle, satisfying an upper limit for g loads around 2.5 without resulting in large penalties on heat loads (< 210 KW/m) and dynamic pressure (here < 50 000 Pa, somewhat higher than the above recommendation).

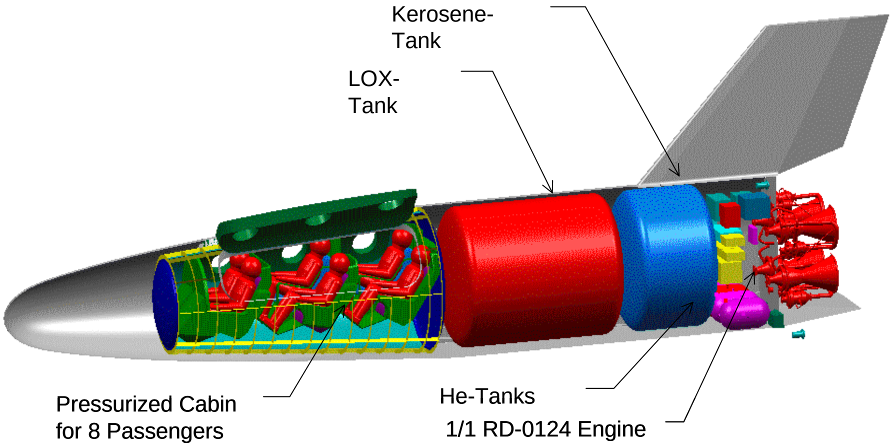
VI. Air Launch Conditions

In Europe it is quite natural that an Airbus plane is considered as carrier vehicle. Astrium involved Airbus for the choice of the vehicle and the feasibility investigation associated with the choice of BEOS as a winged space plane. Its shape corresponds to that one of Phoenix (a scaled-down version of the Hopper concept which was developed in the European Program FESTIP in the mid-nineties, and which was further developed in a German national program as well as in a regionally funded program). Note that previously Dassault had considered their VEHRA concept as being launched by the Airbus 300-B2. Here it was suggested to launch the 20 ton plane at an altitude of 10 Km at a speed corresponding to Mach 0.8.

As mentioned, separation maneuvers of lifting vehicles have been performed for many years, at least for flight test purpose. The best position is not evident. It mainly depends on the wing loading of the test vehicle. The lower position is generally preferable for heavy wing loading, and the upper position is better for lower wing loading. Of course, the dimension constraints may also be a critical criterion: a large vehicle cannot be fitted in the lower position.

The largest experience of separation refers to unwinged vehicles released downwards (tanks, military stores, etc.). But it does not mean that this kind of separation is without danger since any external shape is capable to generate lift even without wings, and many accidents already occurred in case of release at high dynamic pressure. However, methodologies have been developed e.g. by Dassault to guarantee safe separations of such bodies. In the case of upward separations (better adapted to lifting vehicles), the same methodologies apply. In addition, separation is generally easier to manage since lifting vehicles have most of the time a capacity of control. As mentioned above, the experience is more limited for this kind of separation, but it is a fact that we do not know any accident caused by them in their history.

Considering the larger Airbus aircraft Airbus found that the freighter version A330-200F was most suitable requiring the least modifications and offering a large potential for possible increase of mass of the space plane. In addition the freight doors are large enough to stow away the cone fairing needed to reduce the drag and unwanted vortices while ferrying occasionally the space plane BEOS from one location to another. Furthermore, for dimensional reasons the positioning underneath the carrier fuselage or its wing was not found an option. Hence, the piggy-back position was suggested, and estimations for the cost for needed structural changes were performed, where the exact design of the plane carrying truss was left open. Note that Dassault owns a patent for such a structure and separation mechanism which also measures the forces between carrier and space planes.



Sketch of the BEOS vehicle (max. length 14.2 m, CoG at 65%, max. height 4.3 m, span 7.4 m, 20 to)

The main guidelines for separation conditions from the top of the carrier may be summarized as follows: At separation, the AoA of the airborne vehicle has to be such as its load factor is greater than the carrier's one. Its resulting drag has to be such that the angle of separation is not too backwards, to avoid any risk of interference with the carrier's fin. These 2 constraints are only relating to respective lifts and drags, and do not depend on the flight path angle.

Using inviscid flow simulations DLR showed that the aerodynamic interaction at the wanted separation speed, corresponding to M = 0.8 at an altitude of 10 Km, could be rather severe, and therefore lead to a significant loss of lift, and with a possible decrease of the drag. In fact, a preliminary analysis of Dassault showed that for M = 0.8 the loss of lift compared with the free stream conditions is equivalent to an AoA decrease of the same order of magnitude as the Airbus AoA (5 degree loss for a 4 degree AoA) which means that the equivalent AoA is close to the incidence with respect to the Airbus (wedging angle). Therefore, to obtain the separation properly, it is necessary to increase significantly the incidence, compared with what would be necessary without interaction. It was shown that for M = 0.6 the gas dynamic interaction is less severe than is predicted for M = 0.8. The aerodynamic analysis indicates that is wise to reduce the requirements of release Mach number and altitude to lower values.

In addition, the carrier aircraft has to provide the capability to increase the drag (spoilers, flaps, etc.) as needed, such that the desired angle of separation can be achieved. Regarding the flying qualities a potential problem is the masking of the carrier’s fin by the vehicle. Potential loss of lateral stability has to be assessed, and modifications may have to be implemented.

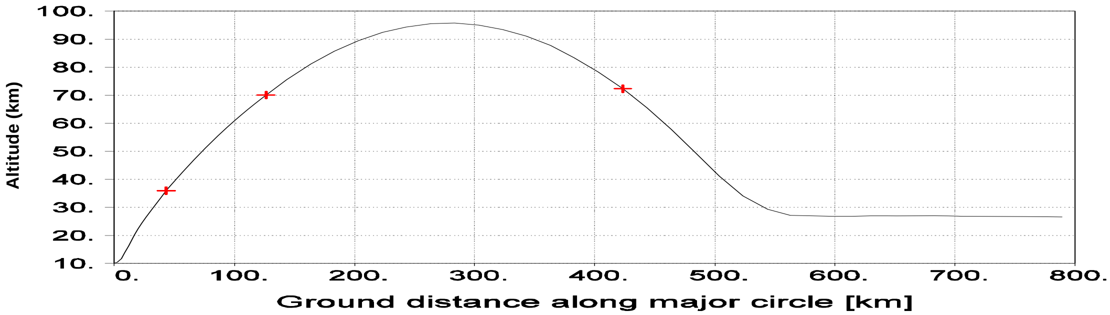
Concerning the operational use of the carrier aircraft, it is worthwhile to mention that at least in a first step into the market, the rate of suborbital flights has to be expected as low compared to the use of the carrier in its original purpose. Consequently, if the carrier is only dedicated to the suborbital missions, its maintenance cost will be likely unacceptable. Therefore, one has to consider the hypothesis that the carrier modifications will be limited enough to allow another use of it. The expected benefits are the suppression or a decrease of the acquisition cost, and a limitation of the recurrent costs (maintenance, training). Other uses could be freight, special activities (e.g. zero gravity) or flight refuelling.

VII. Low, Medium and High Energy Missions

In principle, suborbital missions can be classified into different classes of missions, depending on the amount of energy put into the system as specific parameter to distinguish between the missions. Here the consequence of increased energy input is understood as increase in horizontal speed, and not as increase in altitude. This translates into an attempt to achieve more and more point-to-point transportation by means of suborbital super/hypersonic flight, i.e. an ultra-fast commercial transport as vision. To reach this goal requires obviously a long way to go, last not least due to increased mechanical/thermal loads for the vehicle, due to highest requirements for safety, and large associated expenses for commercial entrepreneurs and operators. Ballistic suborbital flight is considered a first step to reach the goal some time in the future. Usually the airborne vehicle carries out an un-powered glide back to the earth.

The low energy system, the focus of the study FLACON, is defined by the energy necessary to achieve the peak altitude, in most of the cases ~100 Km. The trajectory is nearly vertical for the ascent and shows only a low horizontal velocity at the peak altitude and therefore exhibits also near-vertical re-entry conditions. The rocket phase of such a vehicle is achieving a final velocity of about Mach 3,5 at engine cut off in order to keep the mechanical loads during the ascent phase within an acceptable range e.g. ~ 4 g. Also the maximum return velocity is in this range below Mach 4 which means low heat load and acceptable dynamic pressure situation, if the trajectory is controlled and the angle of attack selected in the corresponding way. Note that safe re-entry is achieved for SS1/SS2 by means of the patented “feathering” invented by Burt Rutan. Alternatively small thrusters are needed to control re-entry in the transitional regime and perhaps even in denser regions of the atmosphere. In the case of ballistic suborbital space tourism flights the vehicle returns to the space port, assuming that the carrier vehicle does not have to fly far before the separation takes place, because usually the longitudinal distance covered by the flight is not more than 100 Km. The vehicle frame can be that of a classical small passenger plane without the need of real heat protection at leading edges and stagnation points.

The latter situation changes in the case of medium energy missions, where the higher energy input results in a higher velocity at the cut-off altitude of the rocket engine. If used to arrive at a higher horizontal component of the velocity vector a longer range capability can be achieved, and the separation can take place farther away from the location of landing, or one may really perform some sort of travel. Typically, moderate energy missions would result in a horizontal velocity range of about 1 to 2 Km/s for a peak altitude of 100 Km as a first guess. For such conditions also the re-entry velocity increases to values around 2 Km/s which causes higher thermal/mechanical loads, but the increased maximum horizontal velocity component in combination with a controlled angle of attack and suitable drag control can be used to keep the loads in the low range with acceptable dynamic pressure values. The typical long range capability results is about 1000 km as a first estimate which can be seen as an entrance into the fast transportation scenario. The TAEM (Terminal Altitude and Energy Management) can be expanded due to the high horizontal velocity component. The typical thermal load for this type of vehicle is estimated in the range below 500 kW/m² heat flux as reference value which would need already some thermal protection on the vehicle surface, or the use of some light-weight hot structures.



Typical trajectory for a moderate energy vehicle (BEOS)

The start conditions for the above system are derived from an air launch system taking into account an aircraft carrier with 10 km altitude and Mach 0.8 release velocity. Another example for a moderate energy vehicle is the South Korean concept proposal called PROTEUS. This vehicle is launched vertically and shall land horizontally in a gliding phase. The overall distance between the launch site and the different landing sites is in the range between 600 and 800 km. The target altitude is more than 100 km and the maximum acceleration during the return phase is about 4 g. Due to the required long range capability for the two different landing sites in South Korea the horizontal velocities at the peak altitude are different, and are defined as 1.4 and 1.9 km/s. These so called Space Tourism trajectories show the market-oriented tendency to operate over the home territories and to be able to see the country from a new perspective.

The high energy missions are characterized by a high horizontal velocity in the range corresponding to Mach numbers > 12. A few of the principal vehicle ideas take into account a long range capability of about 20000 km or in other words to reach any point on the Earth non-stop within ~ 2 h (this idea is essentially being put forward by military authorities in the US, leading probably to first realization of such vehicles, if at all being done.). The high horizontal velocity component (~ 1/2 orbital velocity) allows to use the bouncing effect at the earth atmosphere to extend the long range capability as is the case in the two-stage all rocket SpaceLiner vision of Sippel (DLR), starting vertically and landing horizontally in a gliding fashion[4]. The step to orbital transportation is closest for this type of suborbital flight and becomes more realistic. The peak altitude can vary according to the envisaged long range and landing site. The specific re-entry conditions are determined by the high thermal loads and require a specific thermal protection system to survive the high heat flux and specifically the high integral heat load. Alternatively light-weight hot structures could be developed. The mechanical loads will be larger as well. The g loads can be kept in the range below 3 g with an adequate control of the angle of attack. The duration of the micro - g phase is dependent on the achieved peak altitude and long range, and can achieve more than 20 min. A clear market situation is however not yet visible for this kind of transportation unless military authorities decide to want it, and such a vehicle remains to materialize.

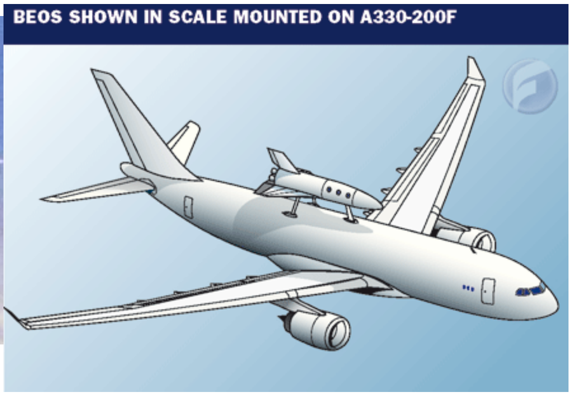
VIII. Some Environmental Issues

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.

Noise issues have not been considered in the study. The integration in the air traffic management has been considered feasible due to the short times for ballistic flight vehicles in the aviation traffic area.

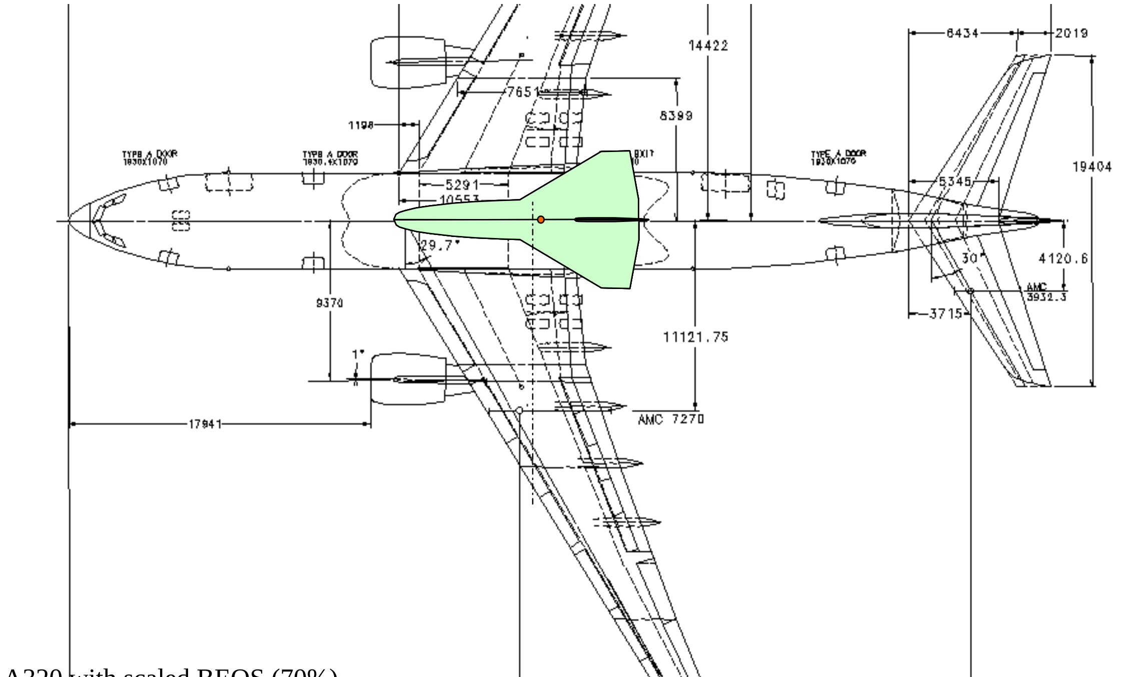
Environmental issues due to combustion products would need to be investigated in some detail for potential suborbital flights, since environmental aspects play an important role in the FP7, and certainly also in the farther future.

IX. Demonstration Potential in Europe



The left figure shows the concept devised previously by Dassault and combining the VEHRA vehicle with an Airbus 300-B2, the right figure indicates the composite configuration considered by Astrium and Airbus for FLACON using an Airbus 330-200F to carry the BEOS vehicle. Cost estimates of adapting the carrier aircrafts A300-B2 and A330-200F have been carried out by Dassault (previously) 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. Included in the rough estimates 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 estimated between roughly 10 and 15 M€. In order to reduce the cost for a first experimental flight, Astrium/Airbus proposed a reduced BEOS, combined with a correspondingly less performing Airbus. For the development and manufacturing of a subscale version of BEOS (70 %) for an unmanned automatic demonstration flight Astrium came up with a total cost of about 170 M€ as a first rough estimate, a number which seems to be too large to attract funding for a first experimental flight. It is believed that a different approach needs to be taken to arrive at more reasonable cost for a first flight experiment, much in the spirit of Lockheed'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 organization using routinely an A320 aircraft as research aircraft. Below the scaled down BEOS is sketched on top of an A320 to provide an impression of the length scales involved. The usefulness of such a subscale demonstration flight remains to be confirmed.

Of course, as a prerequisite, the close contact with European authorities would be necessary to achieve permission to use the adapted A320 as well as to fly the composite configuration, perform the separation and launch the space vehicle. It is preferred that the first flight occurs unmanned. Note, however, that rescue out of dangerous situations with the winged vehicle may not be easily possible from ground. Remember that the pilot of SS1 saved the missions during the first experimental flights by using his experience when that was needed.



Potential combination for an air separation demonstration using an A320 and a subscale BEOS (70%)

X. Concluding Remarks

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. For BEOS suitable Russian liquid propulsion engines were assumed available off-the-shelf[7]. Preliminary investigations for a proposal for FP7, called future high-altitude high-speed transport 20XX, 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[15].

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 potential 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[16]. On the other hand, the cost estimated by Astrium for developing and manufacturing the subscale BEOS indicate that a new, more dedicated organization 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).

Last not least: it is true that the investigation of additional mission opportunities was not encouraging unless the cost of suborbital flight is substantially lower than that one with presently used flight opportunities, e.g. sounding rockets. However, more recently intentions are published, e.g. by Virgin Galactic, to use either the carrier aircraft or the space vehicle as rocket base to launch small payloads into orbit. This is done hoping that the new approach turns out to be much cheaper than the classical approach with rockets fired from the ground. This requires not only a reliable design, but also high re-usability of all elements used.

Acknowledgments

Part of the reported work has been supported by the European Commission in the frame of FP6 as Specific Support Action Study 30712 (Technical Officer: Mr. J. Martinez-Hernandez). The support of Mr. H. Schnieder from Airbus, Hamburg, for the composite configuration analysis, and Professor Hobe from the University of Cologne for the legal aspects, as well as Dr. M. Grässlin from the Institute of Space Systems from the University of Stuttgart for flight mechanics analysis in support of DLR is highly appreciated.

References

[1] "Space Tourism: From lofty dreams to commercial reality", Proceedings of a Symposium organized by the RAeS, London, June 7, 2006, CD, ISBN 1 85768220 3.

[2] Starzyk, J., "A fresh look at space tourism demand" in: "*Space Tourism: From lofty dreams to commercial reality*", CD proceedings of a Symposium organized by the RAeS, London, 7 June 2006, ISBN 1 85768220 3.

[3] Hobe, S., Mick, S., and Neumann, J., "Expert Opinion: Scenario 2 – Air Launch – (airport to rocket range)", Internal Report of the Institute of Air and Space Law, University of Cologne, Köln, Germany, March 2007.

[4] Sippel, M., "Introducing the SpaceLiner Vision", 7th International Symposium on Launcher Technologies, Session: Transportation Systems, Barcelona. Spain, April 2-5, 2007.

[5] "Suborbital Space Tourism Demand Revisited", Futron Corporation, 7315 Wisconsin Avenue, Suite 900W, Bethesda, MD, USA, August 24, 2006, see www.futron.com (also Starzyk, J., A survey of surveys: a look at research on space tourism, May 19, 2005, also: Beard, S. S., and Starzyk, J. (primary authors), "Space tourism market study", October 2002).

[6] Haigneré, J.-P., Gathier, L., Coué, Ph., "Vehra-SH Suborbital Manned Vehicle", Paper IAC 06-E3.4.07, 2006.

[7] Grallert, H., Starke, J., Hobe, S., and Cloppenburg, J., "Conceptual approach to a space tourism vehicle with respect to technical, commercial and legal aspects", Paper IAC-04-U.1.05, 2004.

[8] Filatyev, A. S., Golikov, A. A., Yanova, O. V., and Petrokovsky, S. A., "Physical frameworks of safe vehicles for space tourism", Paper IAC-06-E3.4.03, 2006.

[9] Norris, G., "Space Hopper", Aviation Week & Space Technology, March 31, 2008, p.24-25.

[10] Dinerman, T., "Point-to-point suborbital spaceflight and military logistics", http://www.thespacereview.com/article/1103/1, (cited April 14, 2008).

[11] Gathier, L., and Coué, Ph., “The VSH Project”, Paper, 7th International Symposium on Launcher Technologies, Barcelona, Spain, 2-4 April, 2007.

[12] Sippel, M., and van Foreest, A., “Latest progress in research on the SpaceLiner high-speed passenger transportation concept”, IAC-07-D2.7.07, 2007.

[13] Chavagnac, C., “The EADS Astrium Space Tourism Poject”, presentation, IAC, Hyderabad, India, 28 September, 2007.

[14] Butterworth-Hayes, P., “Space tourism race speeds up”, Aerospace America, August 2007, p.4-6.

[15] Gathier, L., Coué, Ph., and Bouaziz, L., “Les systèmes de lancement aéroportés”, La Lettre, AAAF, Novembre-Décembre 2004, p. 12-16.

[16] Bahn, P., “A Guggenheim Fund for spaceflight”, http://www.thespacereview.com/article/986/1, (cited October 22, 2007).