Reflections on Conditions for Commercial Air-launched Suborbital Flight in Europe

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

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Abstract

The achievements of Scaled Composites with their SpaceShipOne (SS1) flights in 2004 in the frame of the Ansari X-Prize competition led the authors to propose an EC study 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, as long as the corresponding costs cannot 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, in addition to the funding issues, remains with legal issues and to achieve permission to fly such vehicles in Europe.

Introduction

The success story of Scaled Composites' spaceships suggested that going to space would be possible without the enormous cost typical for institutional access to space although the high cost of governmental missions can not prevent accidents to happen from time to time. Of course, the mentioned suborbital ballistic flights of SpaceShipOne type 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 when 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 in September 2006 and ended by the end of October 2007. A general overview on the results of the study is presented in [17].

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 SS1 demonstration, and of 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 Xvehicle, which, however, requires significant effort before becoming a commercial, routinely used transport vehicle such as SS2 launched from White Knight 2 (WK2). 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. The other line is oriented towards the *fast suborbital transportation around the Earth*. Suborbital 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 suborbital 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, 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 briefly discussed [17]. 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. Legal and environmental issues are briefly presented in [17]. Here, the emphasis is on the technical discussion of launch issues.

Suborbital Flight Market Analysis

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. It remains difficult to know what people will do when the possibility to fly would become reality. It is also not clear whether 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. In fact, it is the basis for most of the presently running or planned space tourism projects.

The most striking agreement between all the surveys concerns 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. Quite an important number of people are ready to pay a large amount for the travel, as is suggested by the reports of Virgin Galactic on performed down payments for the anticipated WK2/SS2 flights.

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).

A fast long-distance sub-orbital transportation demand is not yet observed. Ideas about fast transportation as point to point service over the Earth are appearing, and a few transportation vehicle concepts are studied and proposed, but that may become only the next generation of sub-orbital vehicles. Such vehicles will probably first materialize in the military field [10]. First, however, demand is voiced for very fast vehicles designed for atmospheric flight (see e.g. the recent request of the US agency DARPA for an experimental plane "Blackswift" [18]).

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, 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 is planned to climb up to about 60 Kilometers using kerosene based propulsion [9]. In summer 2007, an announcement has been made by EADS to launch a plane propelled by air-breathing engines to start and to land, and methane 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), VSH (Dassault Aviation, France)[6, 11, 15], BEOS (Astrium ST, Germany) [7], 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 markets 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 in the Dutch Caribbean.

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

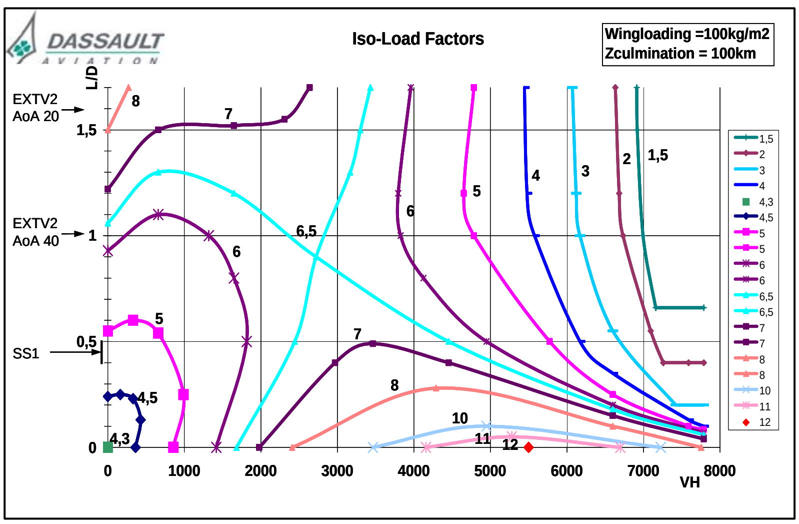
- Performance is easier to obtain with a two-stage approach
- No need to develop a carrier if an existing plane is being used (Airbus e.g.), original use still possible; could be used as tanker for the space plane to be fuelled just before separation…..
- High level of safety
- Carrier vehicle already 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

Identified Suborbital Flight Requirements

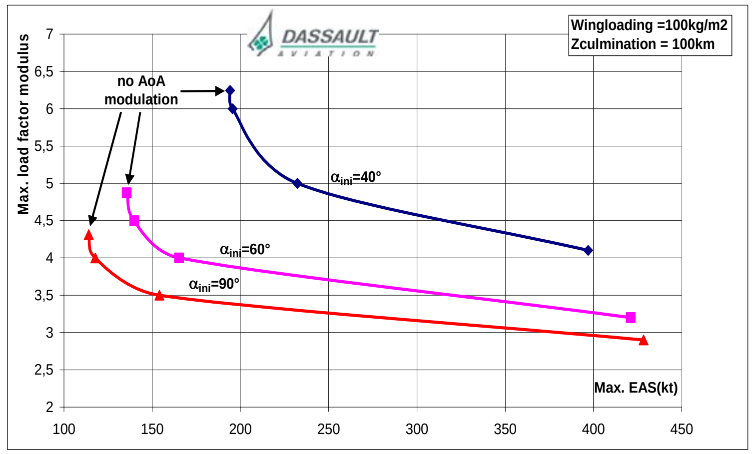
From the list of identified requirements, see [17], safety is certainly the most important topic in view of creating new commercial business cases. One other major driving requirement for successful business is to provide acceptable biological loads. The acceptable acceleration level is known to be a strong function of the duration of the g load as is manifested in the famous and often shown acceptable acceleration vs duration plot. 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 phases 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 Mach number 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 limit structural concerns, flutter problems, acoustic level, …). As references, the maximum dynamic pressure is estimated to about 10 000 Pa for SS1, and about 100 000 Pa for strongest supersonic fighter aircraft.



More precisely, decreasing the AoA to compensate for the increase of dynamic pressure enables to a certain extent to limit the maximum load factor. But in such a maneuver, the dynamic pressure increases more than in case of a constant AoA, reaching a larger maximum value.



The opposite figure shows that for a SS1-like vehicle (pink curve, with an AoA supposed to be controllable), the load factor could be reduced roughly by 1 for a maximum EAS (equivalent airspeed) of 250kt (which is the value of its VNE=Velocity Not to Exceed), and 1.5 up to 400kt. The curves actually display an asymptote which shows that it would be useless to consider EAS above 400 kt (30000 Pa dynamic pressure).

Moreover, for higher wingloadings, the maximum dynamic pressure increases, leading to a stronger limitation of the technique efficiency.

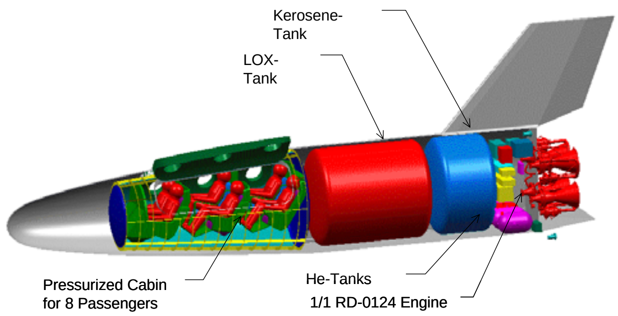
Air Launch Conditions

In Europe it is quite natural that an Airbus plane is considered as carrier vehicle. Astrium involved Airbus for the choice of the carrier and the feasibility investigation was performed on the basis 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 mid-nineties, and which was further developed in a German national program). Note that previously Dassault Aviation had considered their VEHRA concept as being launched by the Airbus 300-B2. Here it was suggested to launch the BEOS 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 Aviation 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 Aviation owns a patent for such a structure and separation mechanism which also measures the forces between carrier and spaceplane.



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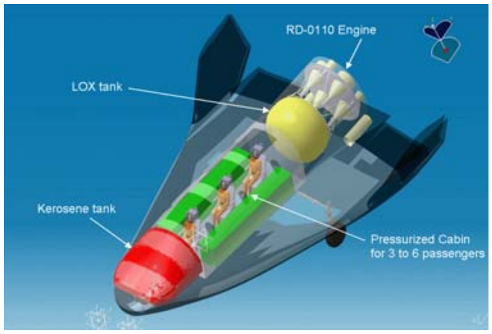

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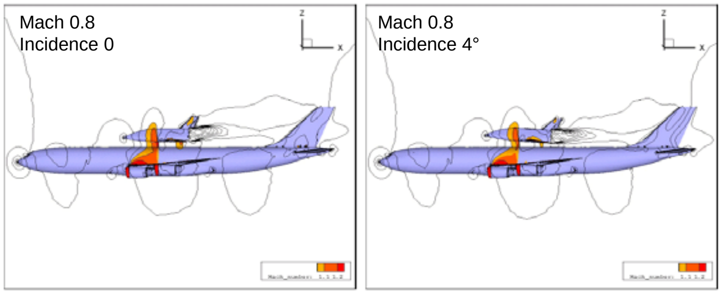
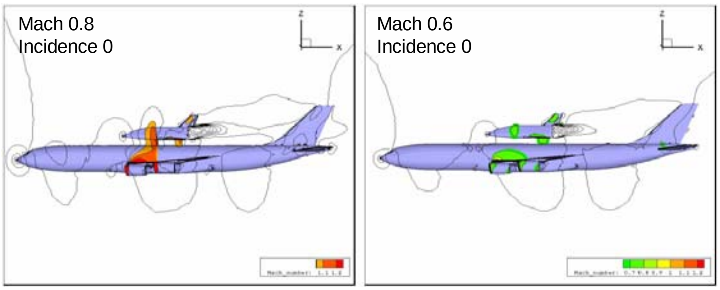
Sketches of the BEOS and VSH suborbital vehicles

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, but with a possible decrease of the drag. In fact, a preliminary analysis of Dassault Aviation 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.

Demonstration Potential in Europe

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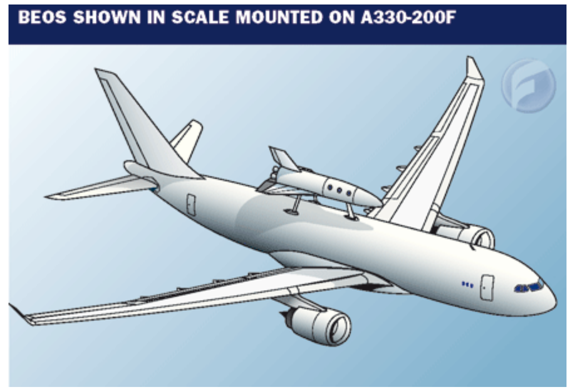

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The left figure shows the concept devised previously by Dassault Aviation and combining the VEHRA vehicle with an Airbus 300-B2, the right figure indicates the composite configuration considered by Astrium and Airbus for FLACON using an Airbus 330-200F to carry the BEOS vehicle. Cost estimates of adapting the carrier aircrafts A300-B2 and A330-200F have been carried out by Dassault and Astrium/Airbus. This includes the truss needed to hold the space vehicle with a kind of separation mechanism and the required reinforcements of the fuselage of the aircraft to carry the 11 tons of VSH 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€. 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.

Concluding Remarks

The FLACON study 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 and VSH, 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, but also several European flight test centers such as Istres. 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.

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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).

[17] Starke, J., Belmont, J.-P., Longo, J., Novelli, Ph., Kordulla, W., “Some Considerations on Suborbital Flight in Europe”, AIAA Paper 2008-2525.

[18] “Blackswift – Program Solicitation 08-02”, Defense Advanced Research Projects Agency DARPA/TTO, Arlington, VA 22203-1714, http://www.darpa.mil/tto/solicit/PS08-02.pdf.