Assessment of Space Adventure Evolution

ASSESSMENT OF SPACE ADVENTURE EVOLUTION

ESA contract n° 17285/03/F/DC
# Summary

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Preamble

The case of space tourism has long been advertised now as the new commercial market for future space transportation. This possibility has long been seen as an abstract concept due to the relatively low reliability of the space systems and to the high costs involved.

Recently 2 paying tourists have flown on board Soyuz and ISS (Dennis Tito, April 2001, Mark Shuttleworth, May 2002) while other millionaire candidates are foreseen. The price paid to fly, in the order of 20M$ cannot allow this to be defined as “mass space tourism”. However, this has proven that even at such high prices there is a real interest for public space flights.

Other possibilities, such as sub-orbital flights are announced and commercialized (Space Adventures already proposes tickets for a ride on XCOR’s Xerus plane, X-Prize competitor that received the FAA’s second reusable launch vehicle license in May 2004). Prices are still too high to consider space tourism as mass tourism, but concrete signs of interests are being shown.

Some of the space tourism related ventures, such as parabolic flights to sense weightlessness and high altitude aircraft flights to >the edge of space< seem today commercially viable while relying on low cost means and low liability regulations of countries like Russia. These opportunities are much closer to mass tourism application due to much lower cost and risk.

Nevertheless, real space tourism, even if it may never become a real mass tourism, has the potential to exceed today’s commercial space flight market volume. But to reach an effective in-orbit space tourism accessible to a larger amount of potential customers, new transportation concepts have to be defined enhancing both safety and cost, especially when compared to the Space Shuttle.

This study aims at presenting a brief overview of the space tourism issues at short, medium and long terms. Market and technical aspects are addressed in the following chapters as well as environmental, legal and industrial matters.
1. General Aspects

1.1 “General” Tourism of Today

General tourism has become the world’s largest business enterprise, overtaking the defense, manufacturing, oil and agriculture industries, and it grows nearly twice as fast as the world GNP, generating millions of jobs.

Especially in the high end tourism, beside pleasure trips, the demand for adventure “tours” (“tour” will be used here to define a commercially organized expedition) with more and more thrills (physical and mental challenge to overcome) is steadily growing, suggesting that public space travel could become the newest segment in this industry.

A good example in this category corresponds to guided tours on the Mount Everest and in Arctic. Both locations are getting crowded these days (several travel organizations propose today such “tours” adapted for different levels of skills), despite the inherent major survival risk at least for Everest tours.

Special Everest tours face exponential growth (Fig 1.1-1) where a guided tour costs up to 60 000 $ per ticket (source : GEO magazine) despite an annual death rate still around 5%, varying between 1 out of 10 in bad years to 1 out of 40 in good years (~1 in 40 is the total rate on the Shuttle today).

The ticket cost includes national license fee's, equipment and transport cost, Sherpas, weather, communication and other logistic support as well as mission leaders with great experience in Everest trips.

The maximum number of people reaching the Everest summit per year was 182 up to now in 2001. Typically, there are much more paying applicants whose attempts are not successful and that stay below the zone of death (above 6000 m) or that stop even earlier. Others join the mission just to be a member of the team, supporting the attempt.

Taking into account only the 180 paying customers per year, the Mount Everest adventure turn-over exceeds already 10 MUSD per year despite (or thanks to…) the induced risks.

The Everest adventure tour features suborbital space tourism target cost but requires a priori far more physical engagement than suborbital flights or even short journeys to orbit:

- The Everest “tourist” must have years of training in advance
- Must have a far better than average health
- The risk of life is several times higher
- The risk of not accomplishing the target is higher
- The preparation time is longer (training)
- The mission is much longer (which might be a plus for certain people but a minus for others)

However, the exponential market growth despite extreme risk, efforts and requirements provides a hint of what can be expected for a less demanding, suborbital space tourism.
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TB6 Launchers 49/04°
Final Report 05.2004

**Rapid Growing “Market”** at up to **60 000 $** per guided Tour

**Despite extreme risk** of about 1 death out of 30/40

The same as for today’s Space Shuttle flights

- Annual death toll
- Triumphants

**Fig 1.1-1 Everest Tours**  Source: GEO magazine

**The real Space Tourism of Today is Orbital**

**Visions on the way to reality**

**Dennis Tito > first space tourist**

Interest in Space Tourism clearly demonstrated
Several requests even at ticket prices of 20 000 000 $

Russia already expects additional income from tourism space flights on Soyuz.
Two passengers per launch option reviewed (viable only once the STS is back to flight).

**Trend confirmed by the latest Futron’s launch market study**

**Fig 1.2-1 Dennis Tito – First Space**
1.2 “Space” Tourism of Today

As no one has expected, the first real space tourists Dennis Tito (Fig 1.2-1) and Mike Shuttleworth travelled not only directly into the orbit but they also visited an orbital facility - the space station. Previous thought was that Space tourism will develop step by step via suborbital flights, not only due to the higher risk of orbital flights with today's launch systems but also due to the enormous ticket cost, which was reported to be 20 MUSD in both cases.

Once the Space Station recovers from the current situation following Columbia’s tragedy (reduced ISS configuration, permanent crew reduced to 2 astronauts as long as the Space Shuttles are forced to remain on the ground), further “passenger flights” are expected. The option of launching two passengers on Soyuz flights is already in discussion as well as dedicated flights not aiming to dock to the ISS.

Notes:

If a space tourist is someone who pays for experiences and adventures in connection with space activities one can say that a space camp attendee who performs a real, partial or simplified astronaut training is also somehow a space tourist. Extending this view, a visitor of a space center or museum can be seen at least as a space related tourist providing an indication of the public interest. Several million visitors per year are expected in this branch, generating about 100 MUSD of revenue.

Other activities already including flight opportunities on aircraft for the sensation of weightlessness or flights to the edge of space that already provide much of the typical astronaut sensation. About 3000 passengers (extrapolated from Space Adventure’s figure of 2000 passengers that flew on a MiG-25) have been flown since 1994 up to now. No more than 10 to 15 MUSD of global revenue is expected to be achieved today for such flight opportunities (costs between 2000 and 10000 USD). However, these opportunities are quite recent and still in the market development phase.

Depending on how far one extends the definition of space tourism, the market today represents no more than 100 - 150 MUSD worth. If limited to flight opportunities, it remains below 25 MUSD if one Soyuz passenger flight occurs in addition to the parabolic and edge to space flights.

1.3 Space tourism flight opportunities

Since the space boundary is not really defined yet, it is not easy to say what a real space tourist is. One definition could be that it is a tourist paying for a space travel, leaving the Earth. Further features are still needed, to distinguish between space tourists and tourists performing flights on normal aircraft to experience brief moments of weightlessness or to see the curvature of the Earth. Of course, orbital flights are considered to be real space flights but what about suborbital flights? And if agreed that a suborbital flight is a real flight into space, at which minimum altitude does it become suborbital?
All flight opportunities, which provide at least a close relation to space flight, are listed hereafter.

- Subsonic parabolic flights within transport aircraft
- Supersonic parabolic and edge to space flights
- Suborbital flights
- Orbital flights
- Visit of orbital facilities

Figure 1.3-1 illustrates the typical different flight regimes of the different opportunities and Table 1.3-2 the approximate values for typical space travel primary "sensation factors" which are considered also as selling factors:

- Weightlessness
- Space view on the curvature of Earth
- Dark skies on the daytime side of the Earth
- High velocities
- Sensation of g-forces although this might not be a pleasure above a certain limit
- The experience of wearing space suits
- The possibility to share the experience of the trip with other tourists
- Duration of the flight

It is not obvious which flight opportunity will be preferred by the passengers on the basis of this sensation factors. For example, the very high g-forces experienced during re-entry might limit the number of passengers which want to go to orbit but there are other selection criteria which are considered more important.

Below are listed the most important marketing features for the different space flight opportunities which are: Ticket Cost, the time the passengers need to prepare for the flight and the risk of loss of live due to a catastrophic failure.

<table>
<thead>
<tr>
<th>Flight Opportunity</th>
<th>Ticket Cost ($)</th>
<th>Flight Preparation</th>
<th>Risk (catastrophic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbital (today)</td>
<td>20 000 000</td>
<td>6 months (Soyuz)</td>
<td>1: 1000*</td>
</tr>
<tr>
<td>Suborbital</td>
<td>100 000**</td>
<td>1 week</td>
<td>1: 2000*</td>
</tr>
<tr>
<td>Touch space/Parab.</td>
<td>10 000</td>
<td>some hours</td>
<td>1: &gt;20000*</td>
</tr>
</tbody>
</table>

* ROM estimate
** ROM target

For the touch space flights, the risk probability considered corresponds to the typical figure encountered for military jets.

The difference of one order of magnitude in cost, time and risk suggests that the three market segments can exist separately. They should not interfere but promote each other.

One Russian astronaut claimed that he was interested to fly to the edge of space, just to sense the switch from blue skies to dark skies, because he was not able to sense this moment during his rocket
launch. On the other hand tourists who initially take the lowest price and risk opportunity might want more afterwards.
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**Fig. 1.3-1 Definition of Space Tourism Flight Opportunities**

<table>
<thead>
<tr>
<th>Flight</th>
<th>Altitude Km</th>
<th>Weightlessness</th>
<th>Space View at Altitude Km</th>
<th>Velocity Mach</th>
<th>Space Suits Required</th>
<th>G Force</th>
<th>Team Experience</th>
<th>Flight Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Subsonic Parabolic Flights</strong></td>
<td>200 Km</td>
<td>1hPa &lt; 0.1%</td>
<td>No /10</td>
<td>0.7</td>
<td>No</td>
<td>2</td>
<td>20</td>
<td>&gt;1h</td>
</tr>
<tr>
<td><strong>MiG - 25</strong></td>
<td>100 Km</td>
<td>10hPa &lt; 1% of S/L pressure</td>
<td>No</td>
<td>2.8</td>
<td>Yes</td>
<td>2-4</td>
<td>No</td>
<td>&gt;1h</td>
</tr>
<tr>
<td><strong>MiGBUS</strong></td>
<td>36 Km MiG 31 dynamic ceiling</td>
<td>30 Km</td>
<td>36 Km MiG 31 static Ceiling Altitudes</td>
<td>25 Km MiG 31 static Ceiling Altitudes</td>
<td>15 Km Concorde</td>
<td>11 Km Boeing 747</td>
<td>8.8 Km Everest</td>
<td></td>
</tr>
<tr>
<td><strong>Suborbital</strong></td>
<td>200 Km</td>
<td>1hPa &lt; 0.1%</td>
<td>No</td>
<td>0.7</td>
<td>Yes</td>
<td>2-4</td>
<td>12+1</td>
<td>&gt;1h</td>
</tr>
<tr>
<td><strong>Soyuz</strong></td>
<td>Several Days</td>
<td>100%/&gt;200 Orbital v</td>
<td>Yes</td>
<td>4-6</td>
<td>3</td>
<td>Days</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ISS/Hotel</strong></td>
<td>Several Days</td>
<td>100%/&gt;200 Orbital v</td>
<td>Yes</td>
<td>4-6</td>
<td>1-TBD</td>
<td>Days</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* In case of airlaunch, due to the long climb period of the aircraft / ** MiG-31 + passengers external cabin
1.4 Customer Profiles

A very detailed analysis on space tourism market has been performed by US Futron Corporation/Zogby International for Orbital, Suborbital and edge to space flights. 450 individuals in the United States, with a net income of at least 250 000 $ or a minimum net worth of 1 MUSD have been interviewed by Zogby in 2002. Each survey interview lasted an average of 30 minutes to ensure that the survey participant understood the concepts (flight time and loads profiles, time which is needed for preparation and cost) and questions presented. The survey margin of error was calculated at +/- 4.7%.

One outcome was the typical customer profile which wants to apply for suborbital or for orbital flight.

<table>
<thead>
<tr>
<th>Potential Suborbital Customers</th>
<th>Potential Orbital Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 72% Male</td>
<td>- 89% Male</td>
</tr>
<tr>
<td>- 28% Female</td>
<td>- 11% Female</td>
</tr>
<tr>
<td>- Average age: 55</td>
<td>- Average age: 53</td>
</tr>
<tr>
<td>- 41% work full time</td>
<td>- 37% work full time</td>
</tr>
<tr>
<td>- 25% retired</td>
<td>- 14% retired</td>
</tr>
<tr>
<td>- 48% spend a month+ on annual vacations</td>
<td>- 37% spend a month+ on annual vacations</td>
</tr>
<tr>
<td>- 46% Fitness above average or better</td>
<td>- 60% Fitness above average or better</td>
</tr>
</tbody>
</table>

Futron performed a dedicated study dedicated to edge of space flights on behalf of Astrium SI (now EADS-ST) as Edge to Space Flight:
- can be considered as “more than semi space tourism” since almost all sensation factors of space flight can be experienced,
- can be used to promote suborbital and orbital space flight as a less physical demanding and very safe “taster”,
- can be used as a first “affordable” space market test.

For these edge of space flights, Futron assumed a minimum of “average” fitness for participation in the Space Coaster service (83% of the population).

32% of respondents said their primary reason for wanting to participate in suborbital flight was to do something that few others have done.

1.5 Space Tourism Market

The Futron study previously mentioned included a market development forecast (Fig. 1.5-1/-2/-3). The following assumptions were taken for the ticket costs:

- **Orbital flights** at ticket cost of 20 MUSD(*) today and 5 MUSD in 2020
- **Suborbital flights** at ticket cost of 100 000 $ in 2005 and 50 000 $ in 2020
- **Edge of space flights** at ticket cost of 10 000$ (***) constant between 2006 and 2015

(*) actual cost of a tourist seat onboard Soyuz
(**) Space Coaster service cost assumed to be US$10,000 as already sold by Space Adventure.
In this study, the market development analysis was based on Fisher-Pry S-curve to calculate the market penetration over time.

The market forecast for orbital and suborbital flights is based on the 2002 Futron study detailed in the previous paragraph.

For edge of space flights, the Futron assumptions for the Space Coaster market were based on Futron/Zogby survey of affluent individuals for space tourism services and are listed hereafter:

- Futron determined that an average of 4.5% of annual income would be spent on a SpaceCoaster type of activity (*) which means that households that earn roughly US$225,000 or more annuually could afford this service (in 2003, there were roughly 2.5 million households that earned more than US$225,000 in the United States which represents the total number of potential customers, assuming one customer per household),
- Futron assumed that the interest level would decrease over time due to the loss of interest among these “pioneers,” or those wishing to do something few others have done

(*) This 4.5% figure was calculated by Futron using the answers to survey questions that addressed past spending on leisure activities and annual vacations. These answers were analyzed with answers on household income and wealth to determine the average percentage of annual income that this population would spend on an activity such as the SpaceCoaster. This limit of 4.5% of income led to consider an income of $225,000 to afford a SpaceCoaster's price of $10,000. This income threshold was used to determine the total number of people that could afford to pay for the service.

It has to be noted that Futron did not address the issue of meeting transport costs that were envisaged during the interviews.

The following figures present the outputs of Futron’s study and especially the sensitivity of the potential space tourism market (for orbital and suborbital flights) with respect to the ticket cost.
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TB6 Launchers 49/04°
Final Report 05.2004

Business Development and Market Shares over Time

**Fig 1.5-1 Orbital Flights** at (2020 today – 52020) MUSD Ticket Price

- Annual 60 Pax / 300 MUSD revenue if ticket price can be 5 MUSD

**Fig 1.5-2 Suborbital** at (100 0002005 – 50 0002020) $ Ticket Price

- Annual 15 000 Pax / 800 MUSD revenue if ticket price can be 50 000 $

**Fig 1.5-3 Edge of Space Flights** at Ticket Price 10 000 $

- Potential Market ~70 000 Passengers 700 MUSD in 2015

Source Futron derived from US Market
According to these market study outputs, the following number of passengers and revenue can be expected:

<table>
<thead>
<tr>
<th>Passengers</th>
<th>Revenue in 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbital flights</td>
<td>60 300</td>
</tr>
<tr>
<td>Suborbital flights</td>
<td>15 000 800</td>
</tr>
<tr>
<td>Edge of space flights at ticket</td>
<td>80 000 &gt; 700</td>
</tr>
</tbody>
</table>

Together with ground based space tourism application the entire market of space tourism could approach 2 BUSD for the first 15 years, provided that space tourism means are operational.

1.6 Global Picture of Space Tourism today

The orbital space tourism today can be summed up as follows:
- 2 tourists but more than 10 non professionals onboard Soyuz and the Space Shuttle
- Total revenue today is about 20 MEURO (1 tourist)/ year
- Futron’s latest study considers only millionaire passengers on Soyuz to should lead to a turnover of 800 MUSD up to 2020

Indeed, space tourism development is hampered by the lack of launch and orbital means at medium term (at least up to 2020).

The only potential breakthrough in the meantime lies in the suborbital flights initiated by X-prize competitors but which development may also depend on certification issues.

1.7 Technological Challenge and Risk

The Challenger, Columbia disaster (Fig 1.6-1) show that orbital space flight is still very dangerous with a risk of life between 1000(Soyuz) and 10000(Shuttle) times higher than for ordinary airplanes.

The technological challenge and risk of space tourism flights increase with Mach number (Fig. 1.6-2). The higher the Mach number is, the more severe the environmental conditions and flight loads are as well as the technological means to achieve that Mach number by additional equipment e.g. reaction control systems or multiple rocket stages.

The different types of man-rated flights are addressed hereafter:

- **Subsonic parabolic flights**:
  They are considered to be very safe as after more than 120,000+ parabolas conducted by NASA and the Russian Space Agency, there has never been a crash or any sort of serious accident.

- **Flights to the edge of space**:
They are typically performed with high performance fighter aircraft as the MiG-25 in Russia. Also these flights are considered almost as safe as ordinary passenger transport flights due to the robust two engines aircraft and non military operations (of course combat training is more risky). Furthermore, and most important, the risk of life should be reduced by the availability of ejection seats but the quality of the maintenance and safety controls performed in Russia can be questionable.

- **Suborbital flights**:
  They require the use of at least one primary rocket system. Depending on the concept, reaction control and thermal protection systems could also be required. A rocket system still remains a great risk alone. Therefore, although the general complexity of a suborbital launch system is much lower than for an orbital launch system (suborbital flights induce less demanding requirements), it is not expected that, at present technology level, the risk for life can be reduced far below 1 in 2000. However, compared to the Everest example (1 in 10 to 40 risk of loss of life), such a failure probability remains a priori “acceptable”. However, the loss of a crewed suborbital vehicle would probably have a higher impact on the public opinion than an anonymous Everest climber accident. Suborbital flights have been begun in the early sixties on X-15 and Mercury (Fig 1.6-3). 2 Mercury and 199 X-15 flights have been performed where only 1 X-15 flight led to a fatal accident. The X-15 was remarkably robust and reliable, considering the experimental character of this program.
However, "...If we insist on perfect safety, we will get it... because no one will ever fly...." Jeff Greason, President XCOR Aerospace at U.S. House Committee Hearing on Commercial Human Space Flight.

<table>
<thead>
<tr>
<th>Velocity [Mach]</th>
<th>Subsonic flight</th>
<th>Supersonic flight</th>
<th>Hypersonic temperature rise</th>
<th>High performance rocket engines</th>
<th>Extreme lightweight construction</th>
<th>Low margins of safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fig 1.6-2 Technological Challenge**

<table>
<thead>
<tr>
<th>Condition Dev.</th>
<th>MiGBUS SpaceCoaster</th>
<th>X - 15 Mach</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 MUSD</td>
<td>delta development cost 50 MUSD</td>
<td></td>
</tr>
<tr>
<td>100 Km altitude = X – Prize</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fig 1.6-1 Spaceflight Safety**

Technological Challenge and Risk

**Challenger**

**Columbia**
Orbital flights:
They are considered to be the most challenging. There are three manned orbital transportation systems available today, i.e. the Space Shuttle, Soyuz and the Chinese system (Long March 3A + Shenzhu Soyuz-derived capsule). Only the Soyuz system can be considered as a fairly reliable and proven space transportation system while the Space Shuttle safety appears insufficient today, after the Columbia accident.

However, the Soyuz system is expected to lead to a risk of loss of life in the order of 1 in 1000 flights (still better than the Everest case) taking into account the additional special risk of re-entry from orbital velocity but also the crew escape system that is available to deal with mission abort cases. In contrast the expected risk on Space Shuttle is presently considered below 1 in 100 flights while the crew escape system does not cover much of the risks.

One major feature which makes Soyuz superior to the Space Shuttle is the credible safeguard system which covers the entire launch. Furthermore, after the re-entry maneuver, a passive ballistic re-entry is possible with Soyuz, in case of failure of the re-entry control subsystems (such a case occurred in 2003 leading to a landing several hundreds of kilometers away from the targeted point but without causing major injuries to the crew).

By contrast, on the Shuttle, a failure on the sensors, computers, flaps, hydraulics or reaction control could become more critical.

Of course, the integrity of the thermal protection system must be guaranteed in both cases but Space Shuttles surface area is an order of magnitude larger than the Soyuz one and the thermal protection system is more fragile and features moving parts and very critical moveable seals on the control surfaces.

A next generation reusable or semi-reusable launch system without using breakthrough technologies but which addresses all these issues by selection of the right design features, should achieve at least a 1 in 1000 risk of loss of life probability. Such a risk figure remains non negligible. However, as Jeff Greason, President of XCOR Aerospace, said:
"... If we insist on perfect safety, we will get it... because no one will ever fly...."
(U.S. House Committee Hearing on Commercial Human Space Flight)

Flights to orbital facilities
They would add risk: some specific critical risks are related to fire, longer exposure to micrometeorites, fuel transfer, docking …

However, available safe haven and crew rescue vehicles (lifeboats capable to re-enter), allow for minimizing the risk of loss of life.
Both, Single Stage Rockets and Airlaunched Rocket Planes have been successfully demonstrated for Suborbital Flights. 

**Fig 1.6-3 Suborbital flights** of the ‘60s indicate > Lower Risk < than orbital flights and Everest tours. 

199 Flights/1 fatal failure

**Fig 1.7-1 Legal structure** (e.g. liability of /against)
1.8 Legal Aspects

Legal aspects of commercial manned space flight are currently studied in a separate EADS internal study together with the Institute of Air and Space Law at the University of Cologne.

3 cases are investigated i.e.: Edge of Space /Suborbital /Orbital
International aspects and the specific case of 4 Nations i.e.: USA/ Russia /Germany /Australia are considered.

The study is still on-going but preliminary outputs have been gathered hereafter:

The open legal issues are listed below:

- Liability
- Delimitation of airspace and outer space
- Basic contractual issues
- Permissibility
- Insurance
- Safety and legal status of crew and passengers
- Criminal Jurisdiction
- Commercial entertainment
- Intellectual Property, Secrecy, Privacy

On these issues, the main questions that have to be answered are the following:

- How far is Air law or space law applicable? Where does airspace end and outer space begin?
- Can it be registered in accordance with the Registration Convention?
- Is the Liability Convention applicable?
- Does the state of registry have “jurisdiction and control”?
- Can lex loci registrations apply?
- What could be the definition of a “space object” in legal instruments?

Overview of the current situation

An international space law and several national space acts are in place or in preparation (Germany) or applicable paragraphs exist in national airspace acts. However, a more specific space law has to be developed as the use of space should become more commercial especially with tourists.

For example, today there are no or insufficient definitions on what space objects are and when air space ends and “outer space” begins. “Any object that is launched or attempted to be launched into outer space” could be proposed as a preliminary space object definition as the purpose should be decisive. A space object would not necessary reach an Earth orbit as it should cover suborbital launches.

Liability is a big issue. This is why private investors in space tourism would see a great benefit in limiting their liability as provided by the Warsaw convention.
Control and certification authorities have to be established or nominated and applicable certification rules have to be established.

The major issue for the development of space tourism transport is related to certification and liability. The following example illustrates the basic problem of obtaining permission to flight and insurance for parabolic flights on aircraft which may have normal passenger flight certification but which fly outside the certified flight envelope.

**From Stephan Hobe / Jürgen Cloppenburg, Study on Legal Aspects of Space Tourism (preliminary draft), Köln November 2003**

1. German aircraft need a “traffic certification” (Verkehrszulassung) if they are to operate within German airspace. In order to obtain this certificate, the type must be certified, and the “Halter”, that is the person making use of the aircraft in a factual and economical sense (not necessarily the owner), must have obtained third party insurance.

The “traffic certification” can either be issued in a regular or a preliminary form. When conducting parabolic flights, the aircraft will exceed the binding limits laid down in the aircraft flight manual (AFM). A violation of these limits constitutes an administrative offence.

Therefore, a preliminary certification is needed to conduct parabolic flights. However, preliminary certificate can only be issued exceptionally “especially for technical purposes, educational, demonstration or transfer flights, if insurance coverage is available and risk associated with the intended use of the aircraft is acceptable.” The non-exhaustive list shows that the preliminary certificate can only be issued for very limited purposes. It is likely that commercial purposes are excluded. This interpretation would take into account the exceptional character of the provision. A regular service seems to be well beyond the scope of the provision, though exceptional services may be acceptable. It therefore is not decisive whether the services are offered on a commercial basis or not. Therefore, a regular traffic certification is needed for regular commercial services.

2. It is important to note that insurers will usually exclude coverage for damages caused by aircraft not operated in accordance with the applicable legislation, e.g. certification. Consequently, generally there is no insurance coverage available for parabolic flights with aircraft not certified for this purpose.

3. The carrier may not limit his liability, as the liability provisions cannot be changed to the disadvantage of the passenger, Art. 23 Warsaw Convention, § 49 (1) LuftVG. However, a waiver of liability can be agreed upon in case of carriage not for remuneration and not for profit. In this case, the exclusion of liability is limited by the general provisions of the German Civil Code (e.g. no exclusion in case of intent; specific provisions apply to general terms and conditions).

---

1. §§ 1 et seq. LuftVZO.
3. § 2 (1) LuftVG.
4. §§ 6 and 12 LuftVZO.
6. § 57 Nr. 2 LuftBO.
7. § 12 LuftVZO.
8. § 12 (1) LuftVZO.
A simple but expensive fix of the problem would be to extend the certification envelope. Beside the cost for this certification there is the question if structural margins can be kept high enough to fulfill reliability requirements.

Space Adventure sells obviously commercial parabolic flights on transport aircraft as well as flights to the edge of space on high performance fighter jet aircraft. Obviously national exceptions are granted for these flights and restricted in liability by a waiver to be signed by the passenger. However, Russia remains a special case. For parabolic flights performed in France by Novespace, it seems that Novespace could still be sued in case a problem occurs, although a waiver of liability has been granted. A potential way to avoid such liability issues would be to assimilate the passengers to “test pilots” but the feasibility to do so from a legal point of view is still to be assessed.

Fig. 1.7 -1 (page 17) shows a potential legal structure for space tourism liability

Three industrial teams, competing for the X-Prize, have applied to the Federal Aviation Administration’s Office of Commercial Space Transportation for permission to perform man-rated suborbital flights (The FAA sub-orbital space flight license is required for U.S. contenders in the X-Prize competition).

It is obvious that also US government has at least morale pressure to ensure that these flights can be performed, since it greatly welcomes and officially appreciates the competition (see: 2.2.2 Suborbital flights for Space tourism - the X-Prize foundation). The recent advances of X-prize teams as Scaled Composites of national hero Burt Rutan seem to have spark the willingness to fix the problem to allow such flights as:

FAA recently issued the 1st License for Historic Sub-Orbital Manned Rocket Launch
The U.S. Department of Transportation announced it has issued the world’s first license for a sub-orbital manned rocket flight. In fact, “commercial” rocket launches already need a launch authorization, i.e. a license granted by the Transportation Department (see the details of the FAA licensing process in appendix). It must be noted “that all commercial licensees demonstrate financial responsibility to compensate for the maximum probable loss (MPL) from claims by a third party for death, bodily injury, or property damage or loss resulting from an activity carried out under the license“. The amounts of financial responsibility required of the licensee is determined by the U.S. Department of Transportation.
Finally, this license for a manned suborbital launch shows that the U.S. Department of Transportation has evaluated the respect of the safety requirements (technical review of the concept), has determined the amounts of financial responsibility and has verified that the applicant has the resource to cover his financial responsibility.
The license was issued April 1, 2004 by the Federal Aviation Administration’s Office of Commercial Space Transportation to Scaled Composites.
A 2nd license was issued in May to XCOR for its Xerus concept.

Page 20
It is proposed that a waiver policy will be accepted for these flights i.e.: crew and passenger would sign forms relieving each other and the federal government of liability in case of an accident. The crew has to meet specific training and medical requirements.

The following key information must also be added on this topic:

- The House of Representatives took up the bill in 2004
- An agreement is already in place under the National Transport Safety Board (in charge of plane crashes investigations) to cover also the “space ships/planes”
- The Transportation Department has also licensed the ~150 unmanned commercial launches in the U.S.
1.9 Environmental Impact

Environmental aspects are under growing consideration for aviation since exhaust gas in the upper atmosphere might have an impact on the climate e.g. by water vapor, contribute to the greenhouse effect or might attack the ozone layer. Ozone reducing substance produced by a reference rocket engine for different fuels is shown in Table 1.8-1 together with a comparison of space and aviation emission forecast for 2010. A Comparison of Anthropogenic and Natural Sources of Emissions is provided in Table 1.8-2.

As a further example for environmental impact one can use the ambitious market forecast shown before with about 15 000 suborbital passengers and 60 orbital passengers per year (assuming that the space access means are available and sufficiently affordable : see §1.5). This example is very optimistic but will allow evaluating an extreme case for the environmental impact.

An airlaunched rocket passenger vehicle capable to carry 3 passengers to 100 Km altitude will consume below 2 000 Kg of fuel (order of magnitude deduced from Scaled Composites SpaceShipOne GLOW which is around 3,6 t including 1 pilot and 2 passengers). 7500 flights should be performed annually to lift the 15 000 passengers thereby leading to a consumption of fuel below 15 000 Mg. If the 60 orbital passengers are launched with Soyuz which requires about 270 Mg of propellant per flight, 16 000 Mg have to be added if one considered flights with 2 “professional” astronauts and one paying passenger (or 8000 Mg for two-passenger flights). The total of roughly 31 000 Mg is below what is emitted by unmanned rocket launches today and about 10 000 times less than what is emitted global aviation.

However, suborbital and orbital space transportation will affect higher layers of the atmosphere than aviation and then might be harmful even at this low emission rate : this would require further investigations.

As supporting information a comparison of space emission with other anthropogenic sources is shown in Fig 1.8-1 and values for the production of water vapor and ozone depleting gas produced by reference rocket engines are shown in Fig 1.8-2.

Finally, environmental aspects should not be a critical issue for the growth of space tourism at least until it becomes a “mass tourism”. Nevertheless, the vehicle designs should take into account the risk of a ban or a limitation of the use of solid propellant, while a green label should anyway be an advantage.
Assessment of Space Adventure Evolution

Environmental Impacts of Engine Exhaust Gases

Important Ozone Killers
NO_x, HO_x, ClO_x, HCl, HNO_3

<table>
<thead>
<tr>
<th>PORS</th>
<th>Solid</th>
<th>LH2/LOX</th>
<th>RP-1/LOX</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCl</td>
<td>200</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Cl_y</td>
<td>750</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>NO_x</td>
<td>7.0</td>
<td>10^6</td>
<td>10^6</td>
</tr>
<tr>
<td>HO_x</td>
<td>10</td>
<td>10^3</td>
<td></td>
</tr>
<tr>
<td>H_2O</td>
<td>800</td>
<td>757</td>
<td>380</td>
</tr>
</tbody>
</table>

Comparison of Minimum Emission Forecast for Civilian Aviation (up to 25 km) and Space Activities (up to 150 km)

Emissions
Space 2010
• 45.324 t
Aviation 2010
• 389 Mt

Reference: Prof. Lo, Berlin

Potential Ozone Reducing Substance Products of a 810 klbf (3600 KN) Class Reference Engine

Reference: Lewis 1994

Fig 1.8-1 Space Emission

Comparison of Anthropogenic and Natural Sources of Emissions

<table>
<thead>
<tr>
<th></th>
<th>Anthropogenic Sources Mt/Year</th>
<th>Natural Sources Mt/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Space (maximum)</td>
<td>Aviation</td>
</tr>
<tr>
<td>H_2O</td>
<td>0.0140</td>
<td>222</td>
</tr>
<tr>
<td>CO</td>
<td>0.0140</td>
<td>0.26</td>
</tr>
<tr>
<td>CO_2</td>
<td>0.0050</td>
<td>554</td>
</tr>
<tr>
<td>N_2</td>
<td>0.0100</td>
<td></td>
</tr>
<tr>
<td>HCl</td>
<td>0.0013</td>
<td>1.98</td>
</tr>
<tr>
<td>NO_x</td>
<td>3.2</td>
<td>90</td>
</tr>
<tr>
<td>SO_2</td>
<td></td>
<td>&gt;1</td>
</tr>
</tbody>
</table>

Reference: Prof. Lo

Fig 1.8-2 Comparison of Emission Sources
2. Space Tourism Facilities

The different space tourism flight opportunities are subsequently described hereafter providing design examples, technical, and economical data as far as available. Raw assumption, or similarity analysis were used for new concepts when no data was available.

2.1 Flights to the edge of space

2.1.1 Touch Space flights with MiG 25

_Touch Space with MiG 25_ (Fig. 2.1.1-1) is an operational venture offered by Space Adventures featuring:

- Up to Mach 3 supersonic flights at altitudes above 25 Km
- Single passenger per flight
- Ticket Price: ~10 000 $
- Launch and Landing: Zhukovsky Air Base close to Moscow

Services: two nights stay with breakfast at downtown Moscow luxury hotel, genuine leather flight jacket, transfer between airport and hotel, VIP immigration and customs processing, transfer between hotel and Zhukovsky Air Base with English-speaking guide, photograph of you with your pilot and aircraft, Space Adventures Flight Certificate, display quality model of the MiG-25, flight planning, training, and medical check, flight in MiG-25 "Foxbat"

Advertised features: _Very few people have seen the Earth from a breathtaking vista of 25km, nearly three times the altitude of Everest! From the cockpit of a MiG-25, your view directly overhead fades into the darkness of space. Below you, the curvature of Earth is awesomely apparent, and the horizon is 1100km across. Flying at Mach 2.5, at almost 1 Km per second, a trip in the MiG-25 "Foxbat" is one of the most exhilarating experiences available anywhere._ (Source Space Adventures)
Edge of Space Flights- Touch Space

Fig. 2.1.1- 1 Flights to the Edge of Space with MiG-25

MIGBUS SpaceCoaster

Fig. 2.1.1- 2 Flights to the Edge of Space on MiG-31 with MiGBUS SpaceCoaster
2.1.2 Touch Space flights with MIGBUS *SpaceCoaster*

A similar concept of edge to space flights as the MiG 25 case has been envisaged by Astrium SI (now EADS-ST) but utilizing the MIG 31 Foxhound (MiG 25’s successor) by piggyback attachment of an external passenger cabin. The basic features are:

- Carrier aircraft MIG-31
- Cabin for passengers and flight attendant mounted on top of the aircraft (spacesuit required for the passengers)
- Ticket Price: < 15 000 $ (min 3000 $)
- Launch and Landing: From Germany to European destination
- Certification status - Application Letter filed to German airworthiness authorities

This MIGBUS preliminary concept (Fig 2.1.2-1) was designed by the Russian Aircraft Corporation “MIG” (a Memorandum of Understanding has been signed between MIG and EADS-ST GmbH). As the MIG-31 accurate characteristics and performances in extreme conditions are classified, the Russians only released very few technical information although they guaranteed the viability of the MIGBUS concept (in particular, they mentioned that the additional wave drag due to the adaptation of the passenger compartment was assessed by numerical as well as experimental wind tunnel investigations).

Nevertheless, a deeper evaluation of the impact on aerodynamics of a piggyback passenger cabin (MIG-31 dorsal tails to be enlarged or modified ?) and of passengers safety aspects would be required to validate and cross-check MIG’s preliminary design. Up to now, only a succinct expertise has been done by German expert Peter Sacher that identified these issues and recommended additional wind tunnels experiments (for symmetrical and unsymmetrical onset-flow conditions of the MIGBUS in sub-, trans-, and supersonic flow) and flight tests with a dummy cabin to validate the aerodynamic configuration and the feasibility of a cabin jettisoning in case of mission abort. MIG agreed on these recommendations and noted that the MIGBUS configuration had to be considered as not frozen (especially for the passenger cabin design) although no major showstopper was identified.

This project is now in stand-by as for the moment it is lacking of financial support.

2.2 Suborbital Flights

2.2.1 Historical suborbital flights

Suborbital flights have been performed in the early days of development of manned access to space in the USA.

The single seat recoverable Mercury capsule was boosted by a single stage expendable Redstone rocket to ~ 190 Km altitude in a ballistic trajectory.

In parallel the reusable X-15 rocket plane was developed. The X-15 was airlaunched by a B-52 aircraft. Within 199 flights, the three test planes (two X-15 and one X-15/A with additional droptank and ablative cover) set several speed and altitude records.
Maximum altitude: 107 Km (X-15).
Maximum speed : Mach 6.7 (X-15/A)

Three major accidents occurred during flight tests, two non fatal, where the rocket planes where severely damaged during landing (but repairable) and one fatal accident, where the structural load exceeded design limits (+7.33/-3g) in flight, due to the loss of flight control leading finally to the destructive pitch oscillation. However, for a frontier flight test vehicle the X-15 was remarkably reliable.

Note : another fatal accident occurred in the frame of the X-15 program, but during ground operations (explosion).

2.2.2 Suborbital flights for Space tourism - the X-Prize foundation

Today there are several attempts to revive suborbital flights for space tourism purposes. More than two dozen applicants are competing in the US X-Prize

In 1994, Gregg E. Maryniak gave Peter H. Diamandis a copy of the Spirit of St. Louis, written by Charles Lindbergh. Dr. Diamandis read the book and realized that aviation prizes had been one of the critical forces in opening up today's $250 Billion aviation industry.

Diamandis had the idea of creating a cash prize for space travel as a mechanism to implement his lifelong dream of traveling into space. In 1995 Diamandis established the X PRIZE Foundation with the assistance of Byron K. Lichtenberg, Colette M. Bevis and Gregg E. Maryniak.

The X- Prize Rules:
Flight vehicles will have to be privately financed and built.
The flight vehicle must be flown twice within a 14-day period. Each flight must carry at least one person, to minimum altitude of 100 km (62 miles). The flight vehicle must be built with the capacity (weight and volume) to carry a minimum of 3 adults of height 188 cm (6 feet 2 inches) and weight 90 kg (198 pounds) each. Three people of this size or larger must be able to enter, occupy, and be fastened into the flight vehicle on Earth's surface prior to take-off, and equivalent ballast must be carried in-flight if the number of persons on-board during flight is less than 3 persons.
The second flight must demonstrate economical vehicle reusability. It is the X PRIZE Rules Committee's intent that the winning flight vehicle should exhibit sufficiently low per-flight costs such that the flight vehicle will support low-cost space access. Toward this end, no more than 10% of the flight vehicle's first-flight non-propellant mass may be replaced between the two flights.

Prior to the official announcement a number of important steps needed to be taken. This included appropriate briefings to NASA, the FAA and members of the leading space and aviation organizations, as well as recruiting international support for the competition.

X PRIZE Founders travelled to Paris where the Fédération Aéronautique Internationale, the Aero-Club de France and the advising participation of Dr. Hubert Curien (past Minister of Science and Technology) were recruited. The group then traveled on to Sri Lanka where a personal message from Arthur C. Clarke was recorded to serve as a kick-off to the founding event.

On May 18th, 1996, under the Arch in St. Louis, the creation of the X PRIZE competition was announced. Participating in this event was a large number of important supporters of the Foundation. NASA Administrator Dan Goldin flew to St. Louis that morning to lend his strong support and encouragement. The Association of Space Explorers and Byron K. Lichtenberg, twenty astronauts, Erik and Morgan Lindbergh also participated in the event.
In the morning was a press conference featuring presentations by: Morgan and Erik Lindbergh, Peter H. Diamandis, Richard Flemming, Buzz Aldrin, Burt Rutan and Dan Goldin.

It was at this event that Burt Rutan, the famous aviation designer first announced his intention to compete for the X PRIZE.

2.2.3 Trajectory strategies, human limitations and launch mode

Trajectory strategies

Two different trajectory strategies have been developed with several pros and cons as shown in Fig 2.2.3-1.

The X-prize asks for an altitude of more than 100 km which has to be demonstrated. There are no further direct trajectory requirements but test people shall survive in healthy conditions which restrict the allowable g-forces to about 5 g’s for short duration, although no value is specified (see human limitation diagram 2.2.3-2)

The minimum energy approach is achieved in a vertical trajectory profile with ideally no horizontal velocity at the top. The characteristics are:

- Minimum energy required to achieve target altitude (to minimize the propulsion system)
- Low Mach number profile not exceeding Mach 4 (100 Km target) (avoiding complex Thermal Protection and larger propulsion systems)
- Deceleration by aerodynamic lift (pull out) will lead to high g-loads due to the steep trajectory
- Aerobraking by body drag (Rutan) or staged parachutes can keep deceleration in the 5 g-range.

Minimum g-load approach is achieved in a relatively flat parabolic trajectory profile with considerable horizontal velocity at the top. The characteristics are:

- High energy required to achieve target altitude, leading to a larger propulsion system
- High Mach number of more than Mach 7 leading to a more complex TPS
- Flat trajectory allowing for a relatively soft pull out of about 3.5 g’s thereby increasing passengers comfort.
Launch modes

As during the early days of suborbital flight, ground and airlaunched concepts are proposed for the X-prize. The orders of magnitude of velocity requirements for the different launch modes are provided below.

<table>
<thead>
<tr>
<th>DV required for vertical Trajectory (max. Mach &lt; 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Launch from v/h</strong></td>
</tr>
<tr>
<td>Lauch from v/h</td>
</tr>
<tr>
<td>Climb Angle</td>
</tr>
<tr>
<td>Rocket Climb Alt</td>
</tr>
<tr>
<td><strong>Dv (√2gh - Vo)</strong></td>
</tr>
<tr>
<td>Acceleration time (v/3g)</td>
</tr>
<tr>
<td>G loss (g x t)</td>
</tr>
<tr>
<td>Other losses (Drag..)</td>
</tr>
<tr>
<td><strong>Total dv required</strong></td>
</tr>
</tbody>
</table>

* Demonstrated with transport (45°) and fighter (>80°) aircraft

For a 3.5 g parabolic trajectory, an additional 750 m/s Dv is required (max. v about Mach 7)

Airlaunch can be divided into:
- subsonic airlaunch used on X-15 and also by Rutan
- supersonic airlaunch which has been demonstrated by the SR-71 with the D21 drone
- balloon launch, a method which also has been demonstrated before.

Airlaunch can reduce the rocket stage mass by several effects when compared to ground launch. i.e.:
- saved losses,
- velocity and altitude gains (which is more important for suborbital than for orbital flights),
- reduced drag profile and nozzle adaptation gains.

A further advantage of airlaunch is that the wing and landing gear size of the rocket vehicle have only to be designed for empty weight landing.
Assessment of Space Adventure Evolution

Fig 2.2.3-1 Trajectory Strategy drives Technologies

Mach < 1
Low Energy Profile
(Rutan)

Mach < 3
G-load < 3.5
Deceleration by drag only

Mach < 4
1hPa <

Mach > 7
G-load < 3.5

Mach 5

Mach 3

1hPa <

Mach < 4
G-load < 5

Fig 2.2.3-2 Human Tolerances on G-Loads

Preferable below 3 g but maximum 5g is acceptable for short duration within the launch and re-entry profile of a passenger vehicle

Source: http://www.hq.nasa.gov/office/pao/History/conghand/mannedev.htm#fig15d5
2.2.4 Suborbital Concepts for Space Tourism

As already stated, more than two dozen applicants are competing in the US-X-Prize. The following four concepts with significant differences are addressed in the following paragraphs:

- Subsonic airlaunch concept for minimum energy trajectory strategy (Rutan)
- Subsonic airlaunch concept for flat parabolic trajectory
- Supersonic airlaunch concept for flat parabolic trajectory
- Single stage vertical ground launch

2.2.4.1 Subsonic airlaunch concept for minimum energy trajectory strategy

Subsonic airlaunch has been used for the famous X-15 in the sixties but is also in use for the operational Pegasus ELV small rocket launcher (Fig. 2.2.4.1-1).

The X-15 unofficial absolute world record for its class of 354 200 ft (108 KM) was achieved by the X-15 aircraft no 3 (not by the improved no 2 aircraft).

- The X-15 can produce a total Dv of 2336 m/s
- The subsonic launch attitude was horizontal
- With Mach 5.58 maximum speed during this flight, the final trajectory was very close to vertical like in the Rutan approach.

The X-15 could then have been a good candidate for the X-prize if it was able to carry 2 additional passengers.

Hereafter, a rough evaluation of an X-15-like passengers vehicle is provided. A 20 t Take-Off Weight has been considered to be compatible with an Airbus A330. Lox/kerosene has been considered for the propellant (instead of Lox/ammonia for the X-15) which provides additional margins for the passengers accommodation.

<table>
<thead>
<tr>
<th>X-15</th>
<th>passengers vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry mass:</td>
<td>6.350 Kg</td>
</tr>
<tr>
<td>Net mass:</td>
<td>6.500 Kg</td>
</tr>
<tr>
<td>MTOW:</td>
<td>15.422 Kg</td>
</tr>
<tr>
<td>M/Mt:</td>
<td>2.37</td>
</tr>
<tr>
<td>ISPvac:</td>
<td>276 s</td>
</tr>
<tr>
<td>ISPsl:</td>
<td>239 s</td>
</tr>
<tr>
<td>Dv</td>
<td>2336 m/s</td>
</tr>
</tbody>
</table>

(*) net mass/MTOW ratio much more conservative (factor 2) than what is observed on Rutan’s SpaceShipOne (3 passengers for 3,6 t MTOW)
(**) use of Lox/kerosene
**2.2.4.1-2 Rutans Subsonic Airlaunch Concept**

**Low Energy Profile easier to obtain**
Low: dv, max Mach, heating, μ-g time, flight duration and range
Acceleration depends on braking technology but can be below 5 g’s smaller, lower technology vehicle

**Rutan tail feather technology for aerobreak**

---

**Fig 2.2.4.1-1 Pegasus Airlaunch Operational Example**

**Characteristics:**
- max. payload mass: 23580 kg
- mission radius: 1000 nm
- operating altitude: 11887 m
- max. Mach speed: 0.82
Therefore, such a X-15-like vehicle could be accommodated with several passengers (a priori 1 pilot + 4 passengers) thanks to the gains linked to the use of Lox/kerosene propellant and light weight structures (not available at the time of the X-15).

Subsonic airlaunch is proposed for at least four different X-Prize concepts namely by Pioneer Rocket Plane Inc., Kelly Space and Technology, Suborbital Cooperation and Scaled Composites. The most famous competitor is Scaled Composites headed by Burt Rutan who became a national hero by designing the first aircraft performing a non-stop trip around the Earth without refueling.

Rutan proposes an airlaunched rocket vehicle (the SpaceShipOne) which, after separation, follows the nearly vertical minimum energy trajectory profile. Aerobrake means to decelerate the vehicle is provided by a special tiltable tail feather mechanism which stabilizes the vehicle in a body forward attitude in order to provide increased drag and to reduce the loads on the tail.

The tail is repositioned into normal mode after aerobraking to support an horizontal landing.

Rutan claimed he developed the hardware for about 20 MUSD. Such a cost seems too low to be realistic as it is also supposed to include the development of the launch aircraft (White Knight).

Rutan’s objective is only to win the X-prize competition. Rutan rejects to do a commercial business due to the certification issues. His estimate is that after successful first test flights another 300 MUSD are needed for commercial certification. For him, this is a "waste of time which inherits too much lack of fun".
2.2.4.2 Flat trajectory airlaunch concept for reduced g

In order to achieve more comfortable g-loads trajectories have to be designed flatter and lift has to be used to further soften the profile. For the same ultimate altitude, more energy has to be delivered to fly the flatter trajectory leading to a maximum velocity around Mach 7. The higher required energy combined with the wings (or additional structure for lifting bodies) and TPS structures needed to handle a soft deceleration phase will lead to GLOWs quite higher than for minimum energy concepts. A typical example of such a vehicle is Dassault Aviation’s VEHRA concept which is currently presented as a potential 3-passenger suborbital vehicle in its 30 t version as shown hereunder:

![VEHRA concept](image)

2.2.4.3 Supersonic Airlaunch

Supersonic airlaunch could provide a MTOW gain above 50% with respect to subsonic airlaunch on suborbital mission (see 2.2.3). This is not only due to the induced speed which is already more than 50% of the speed required for a vertical trajectory but it is also due to an initial altitude that represents more than 20% of the aimed altitude.

The rocket part needs thereby a mass fraction of only M/Mt: 1.4

A supersonic launch raises 2 main issues:
- the first one is to find an aircraft carrier that can maintain a high Mach number at a high altitude, if possible with a high incidence with a large (with high impact on the aircraft aerodynamic behaviour and performances) and heavy payload,
- the second issue is the feasibility of a safe separation in supersonic conditions.

The main example of supersonic separation was the D-21 drone / SR-71 aircraft separation. The D-21 was mounted with a slight nose-up attitude on the SR-71 and there was no forceful separation mechanism. The launch manoeuvre was a push-over at which time the D-21 was released and expected to separate.
An unsuccessful launch attempt occurred when, after release, the drone encountered the bow shock of the SR-71, experienced a nose-down pitching moment and collided with the SR-71.
However, supersonic separation from the back is thereby not incredible as it was demonstrated by the three successful attempts achieved before. It just involves some danger which could be a priori reduced by forced separation. Solid motors or mechanical guide mechanism are typical means to secure separation.

These constraints, and especially the lack of supersonic aircraft able to fit the supersonic release conditions for a large manned vehicle, make such a solution hardly conceivable today.

2.2.4.4 Vertical Ground launch

Although airlaunch seems to be beneficial to reduce the size and propulsion demand of the rocket vehicle it is not obvious that the extra cost of the air-launch platform would lead to global cost lower than a ground launch. The comparable low Dv requirement for near vertical trajectories of about 2200 m/s can easily be achieved by single stage vertical ground launch. A Delta Clipper-like design (Fig. 2.2.4.4-1) could be used adding about 200 m/s for landing or less if parachutes are applied.

The rough characterization can be as follow:

- A mass fraction of 2.1 is sufficient at an average ISP of 320 s (Lox/Kerosene)
- The vehicle size should be almost the same as for the Delta Clipper experimental vehicle due to the higher fuel density (DC-X GLOW : 16.3 t with Lox/LH2 propellant)
- A rough assessment gives a MTOW above 20 Mg for at least 3 passengers
Potential carriers: Airbus A300, A330, A340
- Limited reduction in propulsion demand and vehicle size compared to ground launch.
- More flexible launch and landing site selection.

Accommodation example on an A330 (Pegasus-like scheme)

Delta Clipper DC-X

Fig 2.2.4.4-1 Vertical Ground Launch – Delta Clipper Design Option
2.2.4.5 Synthesis for Suborbital concepts

Operational cost comparison of airlaunch to ground launch

X-prize competitors have been first constrained by development costs, but they have a priori also look at recurring costs issues in order to propose a concept economically viable for a commercial exploitation.

One can observe that X-prize concepts have gone both towards classic ground launch (Canadian Arrow concept) and airlaunch (Rutan’s SpaceShipOne) and have even gone towards more original ways with horizontal take-off from the ground (XCOR’s Xerus concept) or release from a ballon (Neguev concept).

The fact that very different concepts have been envisaged by X-prize competitors demonstrates that there is no obvious way to reduce the launch cost for a suborbital flight.

Indeed, ground launch leads to a bigger, more costly rocket vehicle while airlaunch requires the use of a second vehicle, the carrier aircraft, which has at least to be adapted to accommodate the rocket vehicle.

Mission profile

Flat trajectories allow to reduce g-loads but with huge penalties.

Near vertical trajectories, easier to obtain, lead to the following advantages:
- Low: Dv, max Mach, heating, µ-g time, flight duration and range
- adapted to a return to launch site
- acceleration due to re-entry depends on braking technology but can be below 5 g’s
- smaller, lower technology vehicle
- less subsystems (TPS,…), vehicle mass & size reduced

Ground launch / Airlaunch trade-off

Airlaunch:
- Economically potentially attractive only if launch aircraft is available or developed at extreme low cost (Rutan)
- Smaller vehicle size / lower required Dv wrt vertical launch, especially for supersonic airlaunch
- Separation might be a safety issue, especially at supersonic velocity
- Airlaunch platform must allow to provide optimum flight path angle at separation for full benefit – this might be an additional safety issue for separation
- Launch and target airport can be the same, even at flat trajectories
- More time for fuel dump with a design consistent with flat trajectories in case of launch aborts

Ground launch:
- MTOW/propulsion system demand increased.
- Engine out critical in early flight phase but conventional safeguard systems are applicable

Finally, whatever the suborbital vehicle will look like, the following technologies and operational aspects of RLV and RLV demonstration vehicles might be applicable:
- reusability and maintenance of propulsion systems and TPS
- vehicle navigation and control
- abort modes and rescue systems
- aerothermal aspects

Note:
No direct re-use of a technology demonstrator design that would be developed in the frame of ESA’s Future Launcher Preparatory Programme could be envisaged for a manned suborbital application. Indeed, the passengers accommodation constraints lead to ballistic coefficients quite different from the ones encountered on unmanned X-vehicles.
2.3 Orbital Flights and Orbital Facilities

2.3.1 Soyuz

The Soyuz System (launch vehicle plus spacecraft vehicle) is the only operational transport system in use for orbital space tourism purposes.

A total Mission Cost of 66 Mio US$ is considered for a flight to the ISS (cost deduced from a Johnson Space Center document mentioning a 400 M$ cost for 6 Soyuz flights to the ISS). It has to be noted that what is called here cost is actually rather the price to be paid.

The announced Price per Seat for a paying Flight Participant is 20 Million US$ (Dennis Tito, Marc Shuttleworth).

Fig. 2.3.1-1 shows the Soyuz launcher together with two concepts aiming at an improved performance which are described hereafter.

2.3.1.1 "Clipper" a Russian concept for performance improvement of Soyuz

The Clipper manned spacecraft replacement for Soyuz was first mentioned at a Moscow news conference on February 17, 2004. The 14.5 tons reusable lifting body would be used as a space station ferry and lifeboat, or could operate independently to shuttle tourists to space. Assuming the Russian government provides full scale financing, Clipper and its new Onega launch vehicle, derived from the Soyuz) could fly as early as 2010.

The Clipper main characteristics are summed up hereafter:

- **Craft. Crew Size**: 6.
- **Design Life**: 10 days.
- **Total Length**: 10.00 m.
- **Total Mass**: 14,500 kg.
- **Total Payload**: 700 kg.

With this Onega/Clipper combination, a ticket price in the order of 15 MUSD is expected possible if the development must not be amortized and if the Russian living standards increase does not make the launch cost of Onega much higher than the Soyuz current launch cost.

The Onega “upgrade Soyuz” launcher requires a cryogenic upper stage as well as an upgrade of the lower blocks to achieve a 14.5 Mg performance in LEO.

Another way to enhance the Soyuz performance would be to perform a limited upgrade considering only a cryogenic upper stage. Such a Soyuz improvement, based on a cryogenic upper stage using the Vinci engine, is discussed in the following paragraph.
2.3.1-1 Soyuz and Improvement Options

SoyAR Elements
- Fairings from Ariane or Soyuz
- H 22 Cryostage
- Vinci
- Interstage
- Soyuz Core with Boosters
- Total length 44 m without VEB/fairing

2.3.1.3-1 Soyuz Spacecraft derived 6 passenger capsule
2.3.1.2 "SoyAR" a Soyuz/Ariane derived concept for performance improvement of Soyuz launcher

As a potential upgrade of the Soyuz launcher with a cryogenic upper stage derived from the Ariane 4 H 10 tank system combined with the Vinci engine has been briefly analyzed. This improved launcher could be used together with an enlarged capsule in order to increase the number of passengers for space tourism.

A mass breakdown is detailed below. It has to be noted that the figures presented correspond to optimistic assumptions which would need to be consolidated. However, through this approach, one can assess the maximum performance that could be obtained with the SoyAR concept.

### Mass Model (Kg)

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference dry mass</td>
<td>1247 (Ariane 4 H10)</td>
</tr>
<tr>
<td>VEB</td>
<td>527</td>
</tr>
<tr>
<td>Residuals</td>
<td>81</td>
</tr>
<tr>
<td>Perfo margins</td>
<td>190</td>
</tr>
<tr>
<td>Delta mass Vinci/Hm7</td>
<td>400 (550-150)</td>
</tr>
<tr>
<td>Thrust frame</td>
<td>100 (reinforcement)</td>
</tr>
<tr>
<td><strong>Burn end</strong></td>
<td><strong>2545 H10 with Vinci</strong></td>
</tr>
</tbody>
</table>

All computations have been made considering a 5.8 mixture ratio adapted to the Vinci engine. The following assumptions have been used to take into account an increase of the fuel loading:

- Delta length /1000 Kg fuel = 500 mm
- Delta mass due to fuel increase above 10000 Kg = 35 Kg per 1000 Kg fuel

These assumptions lead to the following burn end mass model for the cryogenic upper stage:

\[
m = 2545 \text{ kg} + (m_{\text{fuel}} - 10000 \text{ Kg}) \times \frac{35}{1000}
\]

The following LEO performances of the SoyAR concept have been computed:

### Performance in LEO

For missions to the space station inclination 51.6°/altitude 200 km

- Usable propellant (t)  
  - H18  
  - H20  
  - H22

- Payload in LEO (kg)  
  - 9992  
  - 10029  
  - 9949

The launch cost for the SoyAR concept has been evaluated as follows:

### Estimate of Hardware Cost (RoM figures)

<table>
<thead>
<tr>
<th>Cost</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 MEURO</td>
<td>H 22 Cryostage with Vinci engine</td>
</tr>
<tr>
<td>20-25 MEURO</td>
<td>Soyuz first stage core + 4 Boosters including Fairings, Adapter…</td>
</tr>
<tr>
<td>36-41 MEURO</td>
<td>Launcher Hardware</td>
</tr>
</tbody>
</table>
Estimate of Launch cost

50-60 MEURO
assuming that fixed costs (Kourou spaceport and facilities,...) are shared with Ariane 5 commercial
launches.

Note: this estimate of launch cost of the upgraded Soyuz launched from Kourou is in line with the
foreseen launch cost of the current version of the Soyuz launcher from Kourou (i.e. 40 MEURO).

Finally, such a SoyAR concept would be potentially compatible with a Progress with double capacity
or with an upgraded Soyuz capsule allowing to transport up to 6 astronauts. Such an upgraded Soyuz
capsule is described in the following paragraph.

2.3.1.3 Soyuz Spacecraft Performance Improvement Potential

Instead of designing a complete new spacecraft one can also keep the orbital and the resource module
of the Soyuz Spacecraft almost unchanged (Fig. 2.3.1.3) and build only a larger landing module in
order to save time and development costs.

The foreseen upgrades leads to a capsule for 5 Passengers + Pilot featuring:

- A 4 m Diameter Capsule (partially reusable)
- Soyuz-derived Orbital Module / Service Module
- Improved Boarding/Exit
- Gear Landing System

These design assumptions lead to the following mass breakdown (in kg):

<table>
<thead>
<tr>
<th>Soyuz Version</th>
<th>3 Seats</th>
<th>6 Seats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service Module</td>
<td>2950</td>
<td>3150</td>
</tr>
<tr>
<td>Orbital Module</td>
<td>1300</td>
<td>1350</td>
</tr>
<tr>
<td>Descent Module</td>
<td>3000</td>
<td>5700</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7250</strong></td>
<td><strong>10200</strong></td>
</tr>
</tbody>
</table>

The 3-seat version figures correspond to the Soyuz TMA figures published in Jane’s Space Directory.
The OM and SM mass estimates for the 6-seat version have been deduced from the 3-seat figures as-
suming minor changes as justified below. The 6-seat DM is considered to have a mass almost doubled
(because of a doubled astronauts/passengers capacity) as detailed hereafter.

Justifications of the spacecraft mass breakdown:

- Only several orbits expected for tourism flights / no ISS visit
  therefore limited impact on OM due to reduced in-orbit stay and maneuvering.
- Soft landing system provided by the use of landing gear and improved retro rocket system with
  wind compensation. Redundancy philosophy with minimum dry mass impact: if one rocket
  pair fails, the DM goes hard landing but does not lead to major injuries. No reuse foreseen for
  the retro rocket system. The gear and rockets are exposed with the separation of the base heat-
  shield (as with Soyuz).
- Delta mass 100 Kg mainly for the gear as the existing retro rockets are almost sufficient if only duplicated.
- Mass savings on the DM because several subsystems must not be duplicated e.g. flight computer to deal with extra passengers. There is also a structural mass saving compared to two DM if merged in one. The mass savings can be used to improve Dv capability on the SM and consumables on the OM.

The following cost assessment was made (rough order of magnitude):

- 66 MUSD (*) Soyuz ISS mission from Plesetsk today including 3 stage Soyuz launcher.
- 6 MEURO (**) cost decrease by 2nd Soyuz stage not needed
+16 MEURO (***) cost increase by the Vinci-based cryogenic stage
- 4 MEURO cost decrease for partially reusable passenger DM compared to Soyuz DM
+ 8 MEURO (****) cost increase if launched from Kourou

(*) cost deduced from a Johnson Space Center document mentioning a 400 M$ cost for 6 Soyuz flights to the ISS
(**) deduced from the 40 MEURO cost of the Soyuz launched from Kourou
(***) extrapolated from the ESCB production cost objective
(****) preliminary assessment as this figure would depend on general costs sharing with Ariane (circa 25 MEURO/year for CSG maintenance, AE figure) and on amortization of CSG adaptations for Soyuz. Insurance costs are not included here.

This would lead to a launch cost from Kourou of 80 MEURO (cost figure a priori optimistic as the 6-pax DM is supposed to be partially reusable and then less costly than the existing 3-pax DM), leading to approximately 16 MEURO per passenger (assuming 5 passengers).

The gain in terms of orbital ride cost is quite small with respect to the current tourist ticket price for an orbital flight to the ISS with Soyuz (20 MEURO). This makes this SoyAR/upgraded Soyuz capsule have a limited interest to reduce the cost of access to orbit for space tourists.

### 2.3.1.4 Issue of an upgraded Soyuz launcher in Kourou spaceport

A man-rated Soyuz from Kourou could be an option:
- interest for Europe to get an « independent » means of human access to space
- potential opportunity for tourists flights (but more stringent legal issues than in Russia)

The Russians have already expressed their will to use the Onega launcher not only from Plesetsk (reference launch site for Onega) or Baikonur but also from Kourou if Europe agrees.

However, such upgraded Soyuz launchers would lead to low cost launchers able to launch heavy GEO communication satellites (4 to 5 t in GTO). Such launchers would then turn into dangerous Ariane 5 competitors on the commercial market.
2.3.2 China’s ambitions & space tourism

China has acquired a man-rated flight capability since Nov. 15, 2003 but with a single passenger Shenzhou capsule (Fig. 2.3.2-1). The next Shenzhou flight is foreseen in 2005 with 2 or 3 passengers. China presently also envisions the development of a space station (to be operational in 2015).

Finally, one can say that:
- China has the potential to become a major space tourist operator in the coming years
- but the military background of the Chinese space program is for the moment a critical show-stopper

2.3.3 Ariane 5 & man-rating

Ariane 5 was initially conceived to be compatible with man-rated missions (HERMES):
- Lower composite failure probability < $10^{-2}$ also imposed by commercial need
- mixed solid/cryogenic configuration selected
- number of engines and « simple » design engines
- ground control of the cryogenic propulsion before lift-off
- redundant Electrical System
- robust algorithmic conception
- simple and qualified technologies preferred

The crew security (global risk of catastrophic consequence for the crew specified < $10^{-3}$ including $9.10^4$ due to the launcher) was to be ensured by the implementation of a Launch Escape System:
- mastering of failure divergence (delay between failure and explosion > 3s in atmospheric phase and > 30 s in exo-atmospheric phase)
- implementation of an health monitoring system to analyse the failure and decide the triggering of the Launch Escape System

A highly energetic lower composite was chosen to maximise the LEO performance (but this design with heavy solid boosters might be an issue regarding safety when regarding Challenger).

Since the HERMES program was stopped, no lower composite design evolution has a priori hampered the A5 compatibility with manned missions.

It can be noted that none of former Ariane 5 failures would have led to the loss of the crew:
- Ariane 5 explosion shortly after lift-off (501):
  - divergence delay around 4,5 s ⇒ easily detected
  - (compatible with the triggering of the Launch Escape System)
- Other failures (502, 510, 517) without explosion:
  - slow divergence failures (>30s) ⇒ easily detected
  - (compatible with the triggering of the Launch Escape System)

To minimize the development and recurring costs, a man-rated Ariane 5 should feature:
- The same lower composite (or minimum evolutions) for commercial and manned missions
- A manned vehicle to include the launcher avionics bay (HERMES-like scheme)
A manned vehicle design constrained by the launcher

However, it is still a long way to get to a man-rated A5. The following development steps would be needed:

- system loop on the launcher (aerodynamics, controllability, structural loads, …) & potential design modifications
- development of the launch escape system
- development of the manned vehicle
- specific ground infrastructures and launch pad modifications

An Ariane 5 derived Tourism Transport System could be envisaged (Fig. 2.3.3 - 1). It could accommodate approximately 10 passengers for short low altitude orbits (without space station visit). Such a man-rated Ariane 5 / passengers capsule system would lead to the following cost considerations:

- A minimum launch cost for a partially reusable capsule system should be 150 MEURO including Booster (100 MEURO A5E / 50 MEURO Capsule)
- Cost per seat 15 MEURO
- Development cost of some BEURO (launcher + capsule)

It appears that such huge development costs cannot be endorsed by private investors: such a large capsule could exist only if it was required to fulfil institutional missions and thus developed under institutional funding (at least for the major part).

2.3.4 Advanced Passenger Space Transportation

The long term vision of space tourism includes an improvement of reliability, comfort and cost aspects.

Today's orbital tourist launch option Soyuz features:

- 1 in 1000 flights expected catastrophic failure risk (risk of life)
- A ticket cost of about 20 MEURO
- A training period lasting about 6 months
- 1 tourist/year (potential for two pax per flight with 1 – 3 possible flights/year but tourists are momentarily no more tolerated since the Columbia accident due to the 2-astronaut ISS configuration constraint)
- Vertical take-off, unpleasant boarding seating, and “hard” touch down

A next generation tourist launch vehicle would ideally feature:

- A catastrophic failure risk equal or lower than Soyuz
- One order of magnitude gain on ticket cost and tourist flight opportunities
- A training period below 1 month (passengers without crew function)
- A higher flight rate compatible with an increased tourist demand
- Horizontal take-off, comfortable boarding and seating, soft landing
Assessment of Space Adventure Evolution

Soyuz is considered the most reliable and economical orbital passenger transport system of today. More reliability is of course welcome but the Everest example (see 1.1) shows that Soyuz risk might be acceptable.

A high market progress margin with respect to ticket price is predicted by Abitzsch (97): a 0.5 MEURO ticket price could mean a 1000 -10000 pax/year market (see 1.5).

The Russian Spiral concept, featuring airlaunch of an expendable rocket stage with a reusable passenger vehicle on top (Fig. 2.3.4-1) could be an example of a new generation system that might fulfill the above requirements at today's technology level. The Spiral program was an approved program beginning in the early sixties leading to some flight hardware but was ended in favor of the Buran development.

Anyway, there is no clear evidence of what an advanced passenger vehicle will look like at long term (within the coming 30 to 40 years).

Both expendable and reusable concepts could be envisaged:
- an increased reliability can be handled at production level for ELVs (well-mastered manufacturing process guaranteeing that all the units are fully identical to the validated reference configuration or with modifications clearly identified and qualified) and at maintenance level for RLVs (controls, overhaul process to avoid critical consequences of the vehicle’s ageing)
- a lower launch cost can be achieved to a certain extent for ELVs through the series effect (a large tourist market is assumed) and an “optimized” production organisation while for RLVs, the recurring cost will depend on the complexity and duration of the maintenance process.

Nevertheless, at very long term, once the maintenance and ageing issues are well mastered, the RLV seems the “natural” way for space transportation and space tourism.

2.3.5 Synthesis on future Tourists Launch Vehicles

As development costs are not affordable for private investors, a space tourism LV version shall be based on an existing LV. Current NG LV specifications lead to a performance of 23 t in LEO which is “naturally” consistent with a 10 pax capsule (or less in case of long duration on-orbit phasing) but the present European Next Generation Launcher specifications do not take into account man-rating constraints.

The necessity to ensure a minimum of commonality between a commercial LV and a space tourism LV has been clearly demonstrated. This leads to the following observations:
- a dedicated passengers vehicle seems the best solution (accommodation as a payload on the LV)
- passengers safety issues could be partially handled through the robustness of the LV design with respect to abort situations (performance margin in case of an engine failure for instance)
2.3.2-1 Chinas ambitions

2.3.3-1 Ariane 5 Man Rating

2.3.4-1 Advanced Passenger Space Transportation
2.3.6 Orbital facilities

2.3.6.1 ISS

The Space Station “Hotel” saw already two real space tourists.

Adding a tourist dedicated module (Fig 2.3.6.1-1) could be a logical step further but is unrealistic as the following constraints appear:
- ISS safety issues (maximum number of people / number of Soyuz CRVs)
- limited number of future STS missions foreseen since the Columbia accident
- limited Soyuz production rate

One can quote Bigelow Aerospace, a US company that tried for 2 years to close a deal with NASA to accommodate and operate inflatable habitation module at the ISS for space tourists. Bigelow Aerospace presently envisages to launch a one-third scale version of its planned habitation module with the Falcon 5 maiden flight (foreseen in November 2005).

2.3.6.2 Soyuz Spacecraft

The Soyuz Spacecraft could be used independently from ISS supply missions in order to reduce the political and technical issues for passenger visits to the ISS. However, sensation features would have to be improved.

Self supported very large high pressure windows are used to increase sensation on submerged tourism facilities. Even entire submarine hulls have been made from acryl for diving at up to 100 m. The orbital module of the Soyuz capsule could be accommodated with such windows as shown in Fig. 2.3.6.2-1.

2.3.6.3 Self Standing Single Module “Hotel”

An interim step toward larger space “hotels” could also be a self standing single module (Fig. 2.3.6.3-1) in order to provide more comfort and sensation for Soyuz passengers.

However, the cost increase compared to a capsule solo flight would be in the order of several MEURO per passenger (increased cost due to the orbital module maintenance, the logistics and ground support for an orbital stay of several days, and to the orbital module development and launch costs amortization).

2.3.6.4 Long Term Vision of a Space Hotel

A 115 m diameter Space Hotel to accommodate 200 guests who stay normally for 4 days has been analysed in a former EADS-ST internal study entitled Public Access to Space Study/PASS (Fig. 2.3.6.4-1).

Such a hotel would feature the following facilities:
Assessment of Space Adventure Evolution

Luxury high-tech ambient of a modern resort hotel with large windows to watch space and Earth at an altitude of ~350 km
- Rotational Simulated Gravity of
  - 0.3 g living area
  - 0.2 g common area
- Restaurants, space shopping, education, discotheques….in common area
- Large Weightlessness Sphere
- Micro Gravity Pool

Implementing such huge hotels in Earth orbit still remains a long term vision as major issues pave the way:
- The existence of an ISS successor is not guaranteed
- Heavy orbital infrastructure will require
  - heavy lift and/or improved in-orbit assembly capabilities
  - an affordable access to space
- Private investors could not afford the development costs of an on-orbit tourist facility

Therefore, such a project appears feasible only through a synergy with institutional programs (e.g. the Aurora space exploration program). Indeed, if it appears that a huge orbital facility is required, for instance to perform “rehearsals” of long duration journeys in space or to support LEO activities linked to the assembly of huge vehicles for man-rated exploration, the orbital facility could be turned into such a hotel once the institutional activities are completed. However, the need of an orbital facility for planetary exploration is still uncertain.
An interim step toward larger space hotels could also be a self standing single module in order to provide more comfort and sensation for e.g. 5 passengers of improved Soyuz.

However, cost increase compared to capsule solo flights of several MEURO per passenger.
Fig. 2.3.6.4-1 Long Term Vision of a Space Ho-

Promenade connection walks and elevators

Solar panels and radiators

Weightlessness sphere Micro gravity pool

Personnel living rooms

Rotational joints

Common area

Additional shielding for common areas

Hazardous supplies/systems Docking

No rotation for all elements on central Axis
3. Conclusion

3.1 Ascent Study, Futron - Lessons Learned

The latest Futron launch market forecast (2003) led to the following observations:

- Rising markets identified in the previous market forecasts (power from space, hazardous waste disposal …) will still not exist in the next 20 years
- Existing space markets cannot achieve a sustained growth over the next 20 years
- Existing space markets are inelastic to lowering launch prices (the satellite performance growth should balance the launch demand while the launch cost is a negligible contributor to communications cost : e.g. 0.2% for a phone call)
- The only evolving market within next 20 years that has been identified with great growth potential should be the public space travel although limited to millionaire passengers onboard Soyuz
- Public space travel is very responsive to launch price reduction
- Space tourism should have beneficial consequences on traditional and other new markets as well as governmental or science missions (allowing for safer/cheaper access to space)

Finally, space tourism could be a major player in the future of space.

Note:
A forecast does not rid you of uncertainty; it is a way to manage it. Every forecast, no matter how analytically rigorously it is performed, will have some risk. However, the Futron space tourism market survey was superior to all prior surveys conducted on this market. It was comprehensive regarding:
- the launch market (only “realistic” assumptions have been considered : no major breakthrough in the technologies or in the use of space has been envisaged for the next 20 years),
- space tourism (over 400 survey respondents), it focused only on the addressable market (only millionaires were surveyed), realistic descriptions were used for space travel (positive and negative aspects of space tourism were described to respondents), and realistic price points were used.

Also, all assumptions used by Futron in the forecast had a factual basis for their estimation.

However, major issues and showstoppers remain:

- Development costs
  Man-rating development costs are not compatible with private investors: orbital space tourism growth will be completely dependent on the launch vehicles and orbital infrastructures that will be developed in the frame of institutional programs. Presently, only suborbital projects are compatible with private funding and are about to reach the flight experiment in the frame of the X-prize competition (but mostly in the USA thanks to a fiscal advantages policy for space investments).

- Safety
  Certification and liability remain critical issues, whatever the space tourism means are.
3.2 Europe and Space Tourism

**Suborbital space tourism:**
Europe lacks of vehicles and on-going projects for this market segment: there is no existing institutional program and most promising X-prize concepts are US.

**Orbital space tourism:**
- commercial launchers available in Europe could be adapted to carry paying passengers (Soyuz within a few years provided we use the existing Soyuz capsule, A5 within several years with the development of a specific manned transfer vehicle),
- a priori Europe is not in position to fight against Russian costs with Soyuz launched from Baikonur
- European space tourism capabilities will depend on Europe’s involvement in man-rated programs such as LEO utilization or Moon/Mars exploration.

The following conclusions can be drawn from the short analysis presented in this document:

- The future of orbital space tourism lies mainly in the political will to promote manned missions for scientific, industrial and exploration goals
- Most technologies could be developed in Europe provided that institutional programs are launched, as for instance a CRV or CTV
- Although an “Office of Public Space Travel” is envisaged by the NASA for political and regulatory issues (i.e. certification, commercial space ports, commercial rocket flights, third party insurance…), there is no immediate need of an ESA counterpart: it seems a priori better to let space tourism activity mature without a too heavy legislation.
- ESA could pave the way at least taking into account man-rated requirements for the next generation launcher and supporting technically and politically industrial initiatives if arising in Europe.
EADS Space Transportation Motivation in Space Tourism

EADS-ST Bremen motivation in space tourism is clearly shown by considerable investments in space tourism evaluation and support of early steps since about 1994. I.e.:

- **Space Park Bremen studies and foundation in 94** Nowadays a 250 MEUR project almost completed
- **Foundation of Space Tours company** supported by SI
- **Foundation of the International Symposium on Space Tourism (ISST)** held 97 and 99 in Bremen. A worldwide network exists to other space tourism interested groups especially in USA/Japan.
- **Public Access to Space (PASS) study** 97 to 99. Target was to see, if there is potential for real space tourism at all and what are the potential interim steps. The Investigation lead to a closed scenario for large scale space tourism based on state of the art and near term technologies comprising ground segment, transportation, conception of a space hotel including all technological, ergonomically, entertainment aspects. A business case was established on the basis of adapted FESTIP and ISS findings.
- **TVE-Media**
- **MIGBUS SpaceCoaster concept.** Investigation and patent application in 2001.
- **Pass 2 study** Suborbital Passenger Rocket based on RLV demo vehicle, study on legal aspects
Appendix
FAA licensing process
(extract from the FAA web site)
The Federal Aviation Administration
Associate Administrator for Commercial Space Transportation
Licensing Regulations & Regulatory Activity: About the Licensing Process

The primary objective of AST's commercial space transportation licensing program, carried out by the Licensing and Safety Division, is to ensure public health and safety through the licensing of commercial space launches and reentries, and the operation of launch sites. For launches, the components of the licensing process include pre-application consultation, policy review and approval, safety review and approval, payload review and determination, financial responsibility determination, and an environmental review. For the operation of a launch site and for the reentry of a reentry vehicle, the FAA/AST evaluates an applicant's proposal on an individual basis. The FAA/AST issues a commercial space transportation license when it determines that an applicant's launch or reentry proposal or proposal to operate a launch site will not jeopardize public health and safety, safety of property, U.S. national security or foreign policy interests, or international obligations of the United States. Statutes, regulations, and advisory circulars can be found at Statute, Regs, ACs & Notices.

Applicants proposing to launch unguided suborbital launch vehicles, such as for amateur rockets, require a license unless the launch is exempt. To be exempt under the regulations (14 C.F.R. § 400.2), a launch must take place from a private site and involve a rocket that meets all three of the following conditions:

- Has a motor or combination of motors with a total impulse of 200,000 pound-seconds or less; and
- Whose motor or combination of motors have a total burning time or operating time of less than 15 seconds; and
- The rocket has a ballistic coefficient - i.e., gross weight in pounds divided by frontal area of rocket vehicle - less than 12 pounds per square inch.

Types of Licenses: AST issues two general types of commercial space transportation licenses. A launch-specific license authorizes a licensee to conduct one or more launches, having the same launch parameters, of one type of launch vehicle from one launch site. The license identifies, by name or mission, each launch authorized under the license. A licensee's authorization to launch terminates upon completion of all launches authorized by the license or the expiration date stated in the license, whichever occurs first. A launch operator license authorizes a licensee to conduct launches from one launch site, within a range of launch parameters, of launch vehicles from the same family of vehicles transporting specified classes of payloads. A launch operator license remains in effect for five years from the date of issuance.

There are several key components to the launch licensing process:

- Pre-application consultation;
- Application evaluation, comprised of
  - Policy review and approval;
Pre-application consultation is accomplished prior to the formal submittal of a license application. The policy review, safety review, payload review, financial responsibility determination, and environmental review are part of the launch license application evaluation. Compliance monitoring is performed after the license has been issued.

An applicant may submit data related to the policy review, safety review, and payload review together as a single package or separately. An applicant may also request a maximum probability of loss determination separately to determine its financial responsibility requirements early on in its launch program. Environmental information is required for evaluation if the proposed activity is not adequately addressed in AST programmatic documents.

The following is a brief description of each component of the launch licensing process:

**Pre-Application Consultation:** An applicant must consult with the FAA before submitting an application. Pre-application consultation consists of any and all meetings, communications, or draft application submittals that a potential applicant may undertake with the FAA prior to submitting a formal application. Pre-application consultation allows a prospective applicant to familiarize the FAA with its proposal and the FAA to familiarize the prospective applicant with the licensing process. It also provides a potential applicant with an opportunity to identify any unique aspects of its proposal, and develop a schedule for submitting an application.

**Policy Review and Approval:** The FAA reviews a license application to determine whether it presents any issues affecting U.S. national security or foreign policy interests, or international obligations of the United States. A major element of the policy review is the interagency review of the launch proposal. An interagency review allows government agencies to examine the proposed mission from their unique perspectives. The FAA consults with the Department of Defense, the Department of State, and other federal agencies such as the National Aeronautics and Space Administration that are authorized to address national security, foreign policy, or international obligation issues.

**Safety Review and Approval:** The purpose of the safety review is to determine whether an applicant can safely conduct the launch of the proposed launch vehicle(s) and any payload. Because the licensee is responsible for public safety, it is important that the applicant demonstrate an understanding of the hazards involved and discuss how the operations will be performed safely. There are a number of technical analyses, some quantitative and some qualitative, that the applicant may perform in order to demonstrate that their commercial launch operations will pose no unacceptable threat to the public. The quantitative analyses tend to focus on the reliability and functions of critical safety systems, and the hazards associated with the hardware, and the risk those hazards pose to public property and individuals near the launch site and along the flight path, to satellites and other on-orbit spacecraft. The qualitative analyses focus on the organizational attributes of the applicant such as launch safety policies and procedures, communications, qualifications of key individuals, and critical internal and external interfaces. For applicants proposing to launch from a federal launch range who have contracted with the federal launch range for the provision of safety-related launch services and property, the FAA issues a safety approval if the applicant satisfies the requirements of the regulations and if those launch services and the proposed use of launch property are within the federal launch range's experi-
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Payload Review and Determination: The FAA reviews a payload proposed for launch to determine whether a license applicant or payload owner or operator has obtained all required licenses, authorization, and permits, unless the payload is exempt from review. The FAA does not review payloads that are subject to regulation by the Federal Communications Commission (FCC) or the Department of Commerce, National Oceanic and Atmospheric Administration (NOAA); or owned or operated by the U.S. Government. If not otherwise exempt, the FAA reviews a payload proposed for launch to determine whether its launch would jeopardize public health and safety, safety of property, U.S. national security or foreign policy interests, or international obligations of the United States. The FAA may review and issue findings regarding a proposed class of payload, e.g., communications, remote sensing or navigation. However, each payload is subject to compliance monitoring by the FAA before launch.

Financial Responsibility Determination: Section 70112 of the Commercial Space Launch Act[1] requires that all commercial licensees demonstrate financial responsibility to compensate for the maximum probable loss (MPL) from claims by a third party for death, bodily injury, or property damage or loss resulting from an activity carried out under the license; and the U.S. Government against a person for damage or loss to government property resulting from an activity carried out under the license. Section 70112 also requires that the Department of Transportation set the amounts of financial responsibility required of the licensee. The licensee can then elect to meet this requirement by proving they have financial reserves equal to or exceeding the amount specified, or placing the required amount in escrow, or purchasing liability insurance equal to the amount specified. The most common and preferred method is via the purchase of liability insurance.

The MPL determination is based on an analysis and assessment of the maximum monetary losses likely to be incurred by government and third party personnel and property in the event of a mishap. It is calculated by assessing the dollar value of government and third party properties at risk by launch accidents likely to occur as the result of the conduct of launch activities.

Environmental Review: The environmental evaluation ensures that proposed launch activities pose no unacceptable danger to the natural environment. FAA/AST is required to consider the environmental effects of commercial space launches authorized under a license because the issuance of a license is considered to be a major federal action under the National Environmental Policy Act, 42 U.S.C. 4321 et seq. (NEPA). An applicant must provide information sufficient to enable the FAA/AST to comply with the requirements of NEPA, the Council on Environmental Quality Regulations for Implementing the Procedural Provisions of NEPA, 40 CFR Parts 1500-1508, and the FAA's Procedures for Considering Environmental Impacts, FAA Order 1050.1D.

Compliance Monitoring: The purpose of compliance monitoring is to ensure that a licensee complies with the Act, the regulations, and the terms and conditions set forth in its license. A launch licensee shall allow access by, and cooperate with, federal officers or employees or other individuals authorized by the FAA to observe any activities of the licensee, or of the licensee's contractors or subcontractors, associated with the conduct of a licensed launch. (See also, Enforcement) Specific information to be included in an application for a license is located on
the Application Information and Reports and Studies web pages.
Study Contributions

**Lead, Reusable Systems, RLV, MiGBUS, SoyAR**
Holger Stockfleth

**Ariane 5 Human Rating**
Laurent Bouaziz

**Space Hotel**
Hartmut Müller

**Market**
Hartmut Müller, Werner Inden

**In Kind Contributions**

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