The Logistical Challenges of the SpaceLiner Concept

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The SpaceLiner concept developed at DLR combines extremely fast transport (90 minutes from Europe to Australia) with the experience of Space flight. As such it is different from the spaceflight which focuses exclusively on space tourism but it combines space tourism with for example business travel. The SpaceLiner is designed to carry 50 passengers in suborbital flight. The conceptual technical design presents some challenges which have already been partially investigated at DLR [1]. However, the overall commercial concept presents a number of different challenges. This paper will identify and describe the logistical challenges involved.

1. Introduction

The SpaceLiner combines extremely fast transport (90 minutes from Europe to Australia) with the experience of Space flight. As such it is different from the spaceflight which focuses exclusively on space tourism but it combines space tourism with for example business travel. The conceptual technical design of the SpaceLiner, summarised below, is not the main purpose of this article but intended to show that the SpaceLiner is technically feasible in principle.
The total commercial SpaceLiner concept, however, presents a number of commercial and logistical challenges which have so far not been investigated. The main challenges are:

- Identification of target groups interested in this concept of fast travel combined with the spaceflight experience;
- Launch location considerations including commercial, business and environmental aspects;
- Launch site amenities required to make the SpaceLiner concept attractive and safe;
- Travel considerations to and from the launch site and place of departure/destination;
- Operational and maintenance considerations.

For each of these topics the main items that need to be considered when addressing these challenges are identified and discussed. It is not the intention of this article to provide concrete solutions but hopefully the exiting concept of combined extremely fast travel and space flight experience will be a stimulation to take the SpaceLiner concept a step further to commercial realisation.

2. SpaceLiner Conceptual Technical Design

The SpaceLiner concept, as currently defined, requires challenging technology but avoids any exotic equipment. Its size and performance are intentionally less demanding than well known Space Shuttle technology which is now more than 25 years old. However, some key technologies have to be improved, to make the SpaceLiner vision viable. The most important are:

- High reliability and safety
- Long life staged combustion cycle rocket engines
- Transpiration cooling to safely withstand a challenging aerothermal environment
- Fast turn-around times currently unknown in the launcher business

Furthermore, the design was based on the requirement that the vehicle should be completely reusable, and that it is able to fly the distance from Sydney to Western Europe carrying 50 passengers.

A picture of the SpaceLiner is given in Figure 1. It consists of two stages, a winged booster stage and a second stage, called the orbiter. The SpaceLiner uses LOX/LH2 powered rocket engines and is designed for vertical take off, much like the Space Shuttle does. There are no solid boosters present, the booster stage and orbiter both use LH2-LOX powered engines The SpaceLiner weighs about 1152 tonnes at lift off, with a total fuel mass of 909 tonnes (Table 1). After take-off, the combined launcher

accelerates for 215 s up to 3.2 km/s (beyond Mach 11) when the booster separates. The booster main engines are throttled or are subsequently cut-off when the axial acceleration reaches 2.6 g. After its MECO the booster performs a ballistic re-entry and should be transferred back to its launch site. A classical technical solution is the powered fly-back by turbojet engines because the distance is by far too large for a simple glide-back. An innovative alternative is the capturing of the reusable stage in the air by a large subsonic airplane and subsequent tow-back.
The orbiter then accelerates further to about 6.7 km/s and an altitude of up to 100km. After this velocity is reached, all the fuel has been used and the remaining part of the flight is powerless.
By using a so called 'skip' trajectory, the range covered by powerless flight is greatly improved as compared to a ballistic trajectory. During a skip trajectory the vehicle enters the atmosphere, creates lift and leaves the atmosphere again. This is followed by a ballistic arc where after the vehicle enters the atmosphere again. The process is repeated until the trajectory converges to a gliding flight
The downside of such a trajectory is the high heat load. The stagnation point heat flux might exceed 4 MW/m^2 (2.1 MW/m^2 in nose region) for a short time [1, 2] because the orbiter has to fly with a Mach number of almost 20 at altitudes below 50 km. According to a preliminary estimation the adiabatic equilibrium temperature might exceed 3000 K in the nose and leading edge regions. New approaches for the structural materials and thermal protection including advanced active cooling have to be implemented. Some promising design options are outlined in [1, 2].

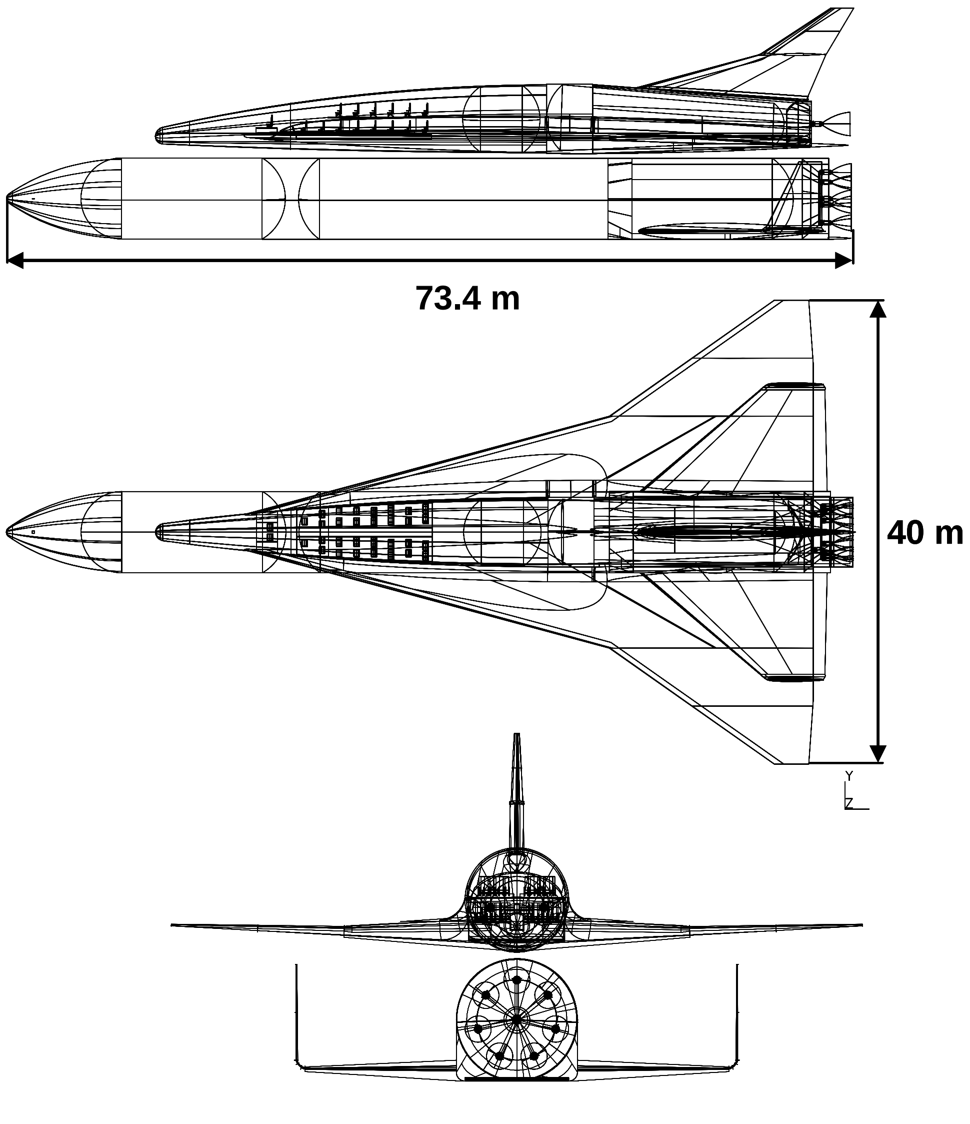

Figure 1. SpaceLiner Geometry

	GLOW Mass [kg]	Mass at burnout [kg]	Propellant mass [kg]	LOX mass [kg]	LH2 mass [kg]	Fuselage length [m]	Max. fuselage diameter [m]	Wing span [m]
Orbiter	277,934	122,934	155,000	132,857	22,143	57	6	40
Booster	873,800	119,800	754,000	646,286	107,714	71.4	7	25.5
Total	1151734	242734	909000	779,143	129,857	-	-	-

Table 1. SpaceLiner Masses and Dimensions

3. Target groups

Investigations from other initiatives indicate that there is a market for pure space tourism (i.e. without the inclusion of travel from A to B). Market researchers have indicated a demand ranging from 10,000 up to 25,000 passengers per year in the year 2021, depending on business model [3]. The SpaceLiner concept however introduces a new aspect to space travel namely the extremely fast travel between continents. This should lead to a significant increase in the number of customers as compared to pure space tourism. Target groups are likely to be extended to captains of industry, top government officials and the extremely rich and famous. Including point to point travel to the space tourism concept leads to the possibility of tapping into the huge market of intercontinental passenger transportation.

Currently, about 2 billion passengers are transported by air every year. About 9.2% of these passengers fly on intercontinental routes, see Figure 2. This results in more than 180 million passengers per year of which the SpaceLiner could tap into. The current business plan [4] assumes 14 SpaceLiner launches per day (7 routes, both directions), with 5 launch sites located in North America, Western Europe, Australia and Asia. Assuming 50 passengers on each flight, this results in a total of 255,000 passengers per year.
If the decision is made to further develop and build the SpaceLiner, it could probably fly in 20 years or so. Assuming current air traffic growth rates of about 5%, about 478 million passengers will fly on intercontinental routes. This means that only 1 in every 1900 airline passengers would than have to travel by SpaceLiner to make the current business plan feasible. The required size of the SpaceLiner market as compared to the commercial airline business is relatively modest, and indicates an opportunity to create a commercially viable, ultrafast, intercontinental infrastructure.

By tapping into both the space tourism market and the intercontinental passenger transportation market, the SpaceLiner concept has an even stronger potential to develop into a successful commercial concept. A successful concept however does not only depend on sufficiently large target groups alone, but also on practical feasibility. To this end, some logistical challenges will be discussed in the remaining part of the paper.

Figure 2. World Air Traffic in Percentage, Year 2000

4. Launch sites, Routes and Destinations

The feasibility of the SpaceLiner Concept greatly depends on the routes and launch site locations chosen. For closer examination of the launch sites and routes, the following factors were taken into account:

- Commercial factors
- Efficiency factors
- Existing infrastructure

Commercial considerations
It is important to provide a service connecting the world's areas of main commercial and political activity. These are in general USA, APAC and Europe. Seven main routes are identified, with the longest and most demanding one being the westbound flight from Sydney to Western Europe. The precise location of the launch and landing sites remains to be determined and will be discussed below.

Efficiency considerations
The SpaceLiner concept is especially interesting on long-haul flight routes, where the flight duration will be much smaller than for conventional or even most hypersonic scram-jet airplane concepts. The longest and most demanding route is the westbound flight from Sydney to Western Europe. The route is about 17000 km long. Off course, the SpaceLiner would not be limited to this route only. Other interesting routes are for example flights from Tokyo to Western Europe, Western Europe to West Coast USA, West Coast USA to Tokyo. Other routes like Western Europe to East Coast USA are possible too, but because of the much shorter distance the SpaceLiner is likely to lose some of the time advantage it has for the longer routes.
Seven routes using five launch sites are defined in Figure 3. The distances of these routes can be found in Table 2.

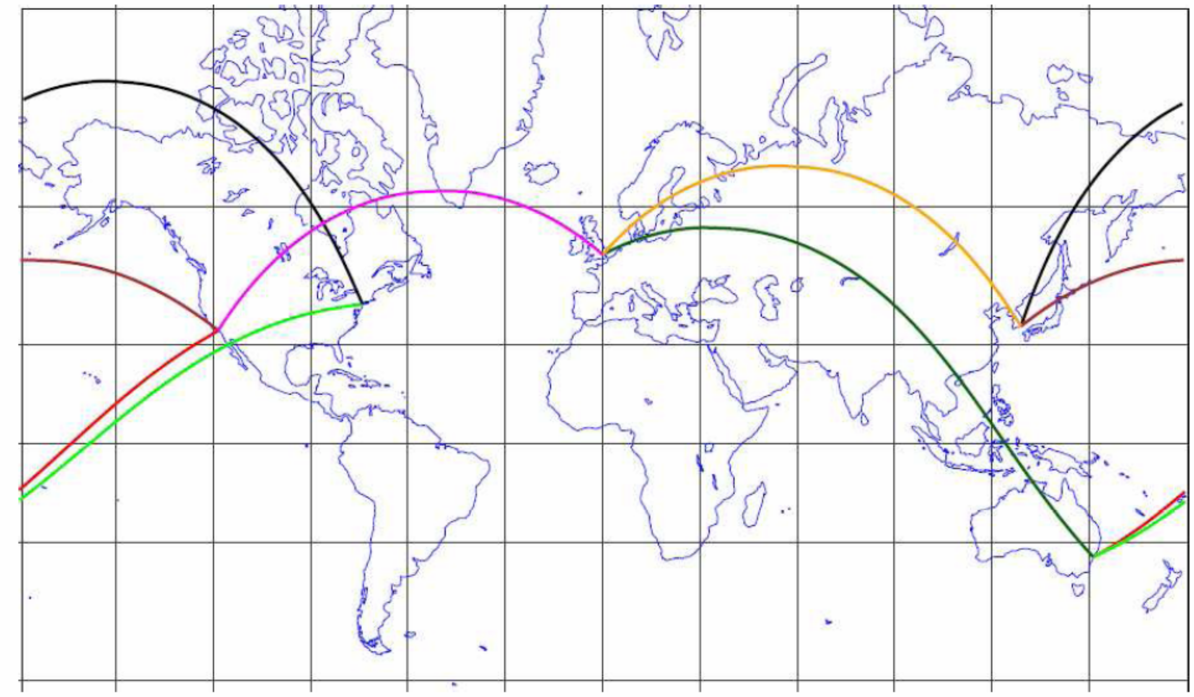

Figure 3. SpaceLiner Routes

Route	approx. Distance [km]
Western Europe – South-East Australia	17000
Western Europe – South-East Asia	9200
Western Europe – North-West America	8800
South-East Australia – North-East America	16100
South-East Australia – North-West America	12100
South-East Asia – North-East America	11300
South-East Asia – North-West America	9600

Table 2. Distances

Existing airports

Ten big staged combustion cycle rocket engines firing simultaneously during takeoff are expected to make some noise. Launching from currently existing airports is therefore probably not an option. Also, fuelling of a LOX/LH2 powered rocket is considered a fairly risky process and will therefore probably not be allowed at a conventional, currently existing airport. Launch sites will probably have to be located in more remote areas. These remote areas should still be as close as possible to the main business centres of the world to ensure quick and easy transportation of the passengers to and from the launch/landing sites. In case of a launch from Sydney, this could be the Australian outback to the west of Sydney. In case of a launch from Western Europe, remote areas are not so abundant. An option would be an offshore launch from the North Sea which would cover the densely populated West side of the Netherlands. Also an offshore launch site near Hamburg could be constructed. If southern Europe is preferred, the Atlantic Sea or Mediterranean Sea are options. Offshore launch sites are probably more complex to build and to maintain, but the Sea Launch Company proves that the basic idea is feasible (Figure 4).

Figure 4. Sea Launch

5. Getting to and from Launch sites

It is clear from the above brief discussion on launch site position considerations that potential customers will have to travel a considerable distance to get to and from the launch site to their place of departure or destination. This commuting should be organised in a way which is compatible with the exclusivity of the SpaceLiner travel concept. A private service to get from the place of departure to the launch site and from launch site to place of destination seems the only attractive option. This service must be included in the SpaceLiner travel concept and can possibly be realised with limousine service companies and private jet or helicopter companies.

The big advantage of the SpaceLiner over normal, subsonic passenger flight is the huge time saving potential. This should be a central aspect when analysing the logistics. Launch sites will not be as common as normal airfields, therefore an efficient way has to be found to get the passengers to the launch site as fast as possible. Waiting time at the launch site should be minimal, off course.
A ticket for the SpaceLiner will probably only be affordable for a very small portion of the current airline passengers. For such high ticket prices passengers should get excellent service. This means that transportation of the passenger from home to launch site will be arranged for and included in the ticket price. Passengers will for example be picked up by taxi, driven to the nearest airfield for transportation to the launch site by business jet.

Launch site services and amenities should also be compatible to the concept of luxury travel It requires all the amenities normally found at large international airports, such as shops and restaurants. Although the overall transportation concept is based on minimal waiting times to maximize the time savings, delays can never be ruled out. In such cases the passengers would expect the best with respect to the service and the facilities.
The need of such amenities leads to certain other requirements such as (un)loading facilities, roads and personnel.

6. SpaceLiner Operation considerations

A concept like the SpaceLiner introduces some restrictions and conditions on operation. These can be identified in the following fields:

- Landing and ground handling
- Emergency landings
- Vehicle transport
- Booster recovery
- LH2 production

Landing and ground handling
Landing could theoretically take place at conventional airports. The big advantage of this scenario is that the passengers can make use of existing facilities and infrastructure at these airports. On the downside, some major disadvantages can be identified. The SpaceLiner would for example need landing priority over all other airplanes because of the simple fact that it is unpowered and therefore needs to land immediately. When landed, the SpaceLiner has used up all its fuel and therefore has no power source left. Ground handling must be done by towing or pushing. Getting the SpaceLiner off the runway to the gates would take more time and effort than is the case for normal airplanes. Finally, the proposed scenario implicates that the SpaceLiner must be transported to its launch site, which has some major logistical and practical implications. These disadvantages could potentially be ATC incompatible and ban the SpaceLiner from landing at conventional airports.

Vehicle transport
If launch and landing sites are located apart from each other, the SpaceLiner must be transported from the landing to the launch site. Transportation over normal roads is impractical, if not impossible. It is not the weight that causes the problem (the empty mass of the orbiter is about 122 tonnes, which can be transported by heavy trucks), but rather the dimensions. With a span of 40 meters and a length of almost 60 meters it simply is too big to be transported over normal roads. To avoid disassembling and reassembling the SpaceLiner, additional, extra large roads or railways would have to be constructed just to get the SpaceLiner to the launch site. The easiest solution therefore may be the construction of a landing site next to the launch site.

In the event of an offshore launch, the landing site should be as near to the coast as possible. This would then minimize the distance the SpaceLiner must be transported by road to the harbour. The SpaceLiner is subsequentially loaded on a specially designed boat and then brought to the launch site. Preparing the SpaceLiner for launch at sea will probably be more difficult than in case of a land launch. Getting the vehicle of the boat, erecting it and fuelling it will require a lot of effort so from this point of view a land launch seems to be the more attractive option
A recent example of transporting a space plane is the journey of the Russian Buran to its new destination in a museum in Speyer, Germany. The journey mainly took place over waterways (see Figure 5), but some parts took place over roads. To this end, the wings of the Buran had to be detached and roads had to be blocked for other traffic. The example shows the principle feasibility of transporting large and complex machines. However, for the SpaceLiner, which should fly on daily basis and has extremely fast turnaround times, such an endeavour is to be avoided when possible.

Figure 5. Transportation of the Buran

Emergency landings

Safety and reliability are the two most important design drivers of the whole SpaceLiner concept. The chance of failures can be minimized but never excluded. If something goes wrong during flight, the SpaceLiner should be able to land as fast as possible on the nearest available airport. This location is most likely unsuitable for a relaunch because of lacking infrastructure. In such a case a way must be found to transport the SpaceLiner to a launch site. If the hassle of disassembling reassembling and blocking roads is to be avoided, the only other way is transportation by air. The SpaceLiner would have to be mounted on an aircraft, like the Space Shuttle is mounted on a Boeing 747. Figure 7 shows that from a dimensions point of view, this may be possible. The empty weight of the SpaceLiner orbiter is 122 tons, 22 tons more than the Shuttle. If a 747 can lift this extra weight must be determined. Also, the aerodynamics of the combined system 747/orbiter must be investigated. Off course, also other aircraft types could be chosen as a carrier. For something the size of the SpaceLiner, an Airbus A380 could be the better option.
Mounting the SpaceLiner on the carrier requires a specially designed crane, just as the Space Shuttle does (Figure 6). This Mate-Demate Device (MDD) must be easy to disassemble to make sure the crane can be transported over road to the landing site in an efficient way. Cranes should be available at multiple locations along the flight routes.
A detachable crew and passenger cabin is foreseen as a last resort in case of extremely serious failures during flight. This measure is thought to save the crew and passengers in case of losing structural integrity of the vehicle. Controllability of the cabin will probably be limited, in which case the landing zone is undetermined. Crew and passengers will have to be picked up by helicopter. To this end, existing infrastructure could be used but the infrastructure may not be sufficient. Rescue stations would have to be located along the route to allow for quick rescue, also in remote areas. Examination of the current infrastructure and possible improvement of the infrastructure is therefore required. Quick

rescue also means that the location of the capsule must be determined. Full trajectory tracking would be necessary. Data relay satellites, optical communication by laser and/or a powerful radio beacon in the capsule could ensure fast location of the capsule.

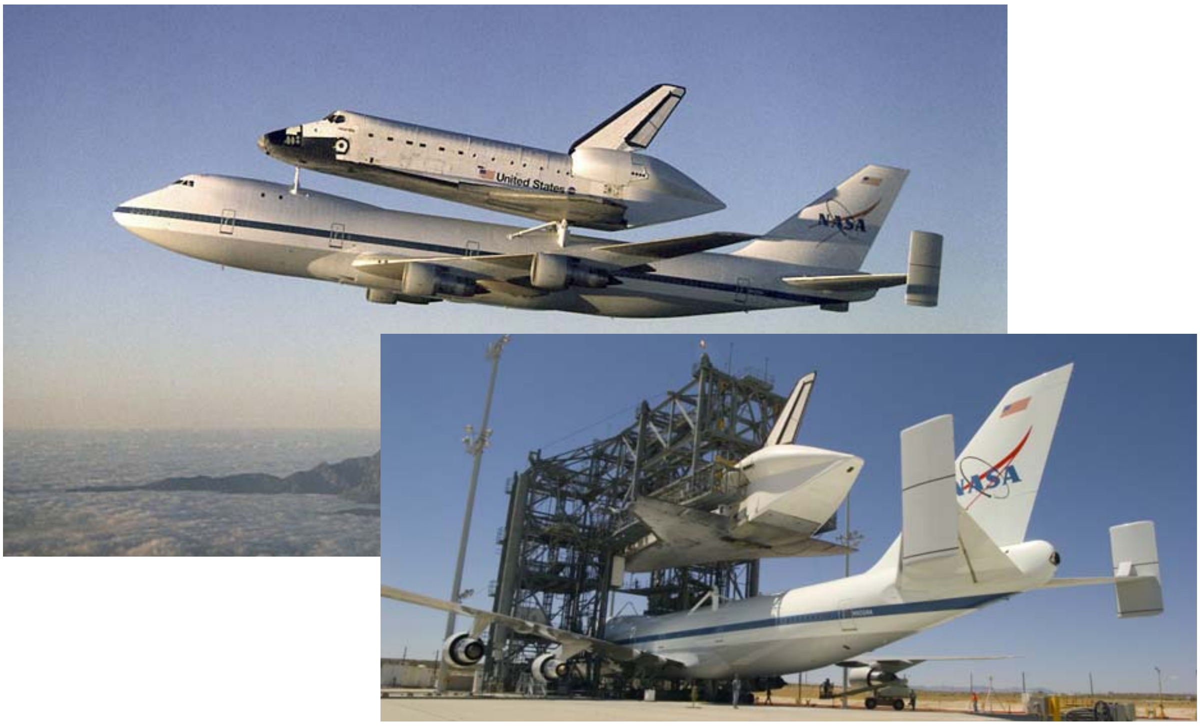

Figure 6. Mounting of Space Shutlle on 747

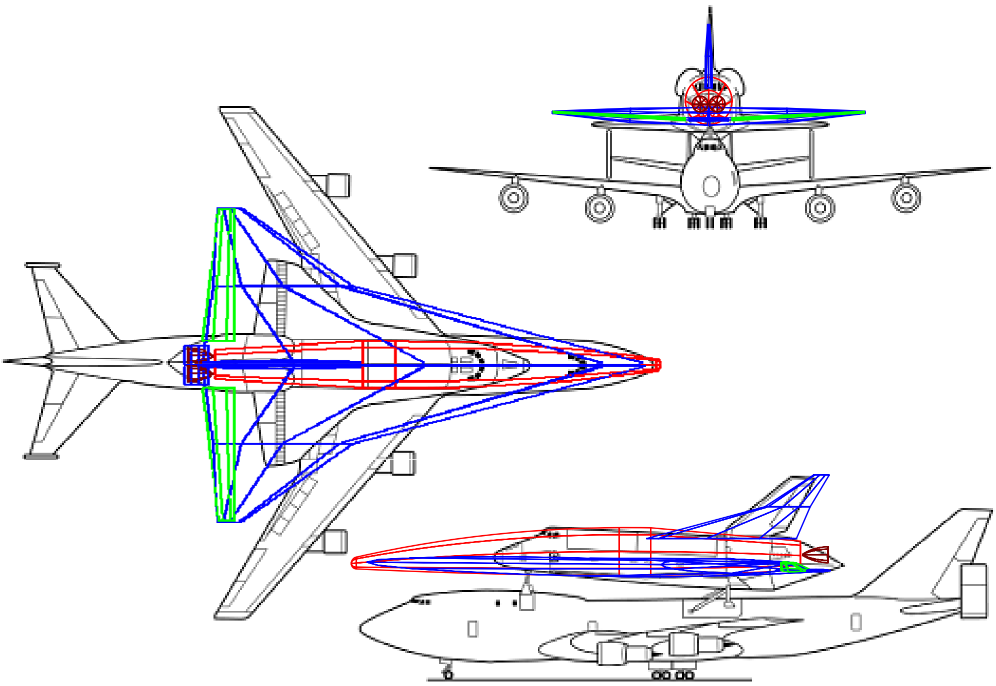

Figure 7. SpaceLiner and Space Shuttle mounted to 747

Booster recovery

After its MECO the booster performs a ballistic reentry and should be transferred back to its launch site. A classical technical solution is the powered fly-back by turbojet engines because the distance is by far too large for a simple glide-back. An innovative alternative is the capturing of the reusable stage in the air by a large subsonic airplane and subsequent tow-back.

This patented method dubbed 'in-air-capturing' has been investigated by DLR in simulations and has proven its principle feasibility [7, 8]. The massive advantage of this approach is the fact that a booster stage caught in the air does not need any fly-back propellant and turbo-engine propulsion system. The innovative capturing has been selected as the baseline technology for the booster retrieval, enabling a total lift-off mass reduction of at least 150 Mg. Conventional turbojet fly-back or a downrange landing site, if available, are the backup options, if 'in-air-capturing' would be deemed as unfeasible or as too risky [9].

Ideally, the airplane needed for in air capturing is the same airplane as needed to transport the SpaceLiner by air, as proposed in case of emergencies. After capturing the booster, it ill be towed back to the SpaceLiner landing site, and (if needed) subsequentially transported to the launch site as previously described.

LH2 production

Fourteen SpaceLiner flights per day require a liquid hydrogen production rate of about 1800 tonnes per day, divided over five launch locations. This is a major increase compared to current production rates for space transportation. Several options for obtaining LH2 exist.

The currently preferred technique is to produce it by letting methane and water vapour react at high temperatures. The downside of this production technique is the formation of carbon monoxide and carbon dioxide.

From an environmental point of view, splitting water in hydrogen and oxygen by the use of solar energy is a better option. This way, the SpaceLiner would have an extremely low environmental impact. The solar energy technique requires solar panels near the launch site to avoid transportation of liquid hydrogen over large distances. In some regions this could lead to unreliable production due to the dependency on sunny weather.

Finally, splitting water by using another power source is possible, for example the use of nuclear power. This option immediately raises the debate concerning the use of nuclear power.

In any case, a big water supply is needed at the launch site. For an offshore launch the seawater may be used, although this has to be purified to remove the salt. For a launch from for example the Australian outback, water needs to be supplied by either trucks or pipelines.

7. Conclusions

Although some tough logistical challenges are involved, they seem to be manageable. Examples of current events such as launches at sea and the transportation of the Buran to its new location prove that great logistical challenges can be overcome. The greatest challenge is not to just overcome the difficulties, but to tackle them in a sufficiently effective way, ensuring the SpaceLiner will be a commercial success.

The most important aspects which could be identified so far are:

- A land launch is preferred, but could not be possible for every location
- Transportation over road should be minimized
- Passenger transportation to and from launch sites must be quick, waiting times minimal
- Transportation of the orbiter by airplane seems to be an important asset
- Fast rescue capabilities in case of emergency capsule release
- Launch and landing sites will probably have to be constructed in more remote areas; current airfields can probably not be used.
- LH2 production options should be investigated

8. References

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