7th International Symposium on Launcher Technologies
Barcelona, Spain
April 2-5, 2007
Session: Transportation Systems

Introducing the SpaceLiner Vision

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The paper describes the vision of an ultrafast intercontinental passenger transport based on a rocket powered two-stage reusable vehicle. Today's situation in space launcher operations and development is analyzed and options for the relief of its critical state are discussed. An assessment of the necessary investment and potential ultrafast transport market is followed by a development roadmap. A brief overview on the latest technical lay-out of a generic vehicle and its flight performance are provided.

1. Introduction

A strategic vision has been recently proposed by DLR which ultimately has the potential to enable sustainable low-cost space transportation to orbit. The baseline idea is simple and quite conventional: Strongly surging the number of launches per year and hence dramatically shrinking manufacturing and operating cost of launcher hardware.

The obvious challenge of the vision is to identify the very application creating this new, large-size market. All recent assessments of the launch business are sobering. The required new market must be significantly different from today's orbiting of communication or earth observation satellites because almost no growth is to be expected in these areas. As has been demonstrated by the ASCENT study for NASA MSFC, "most of today's markets, both commercial and governmental, are virtually unaffected by even massive reductions in launch prices." The ASCENT study prognosis of an almost flat launch demand in the next 15 to 20 years contains already some optimism of new emerging applications. Without the launch demand generated by new businesses, (notably public space travel), there would be a rather rapid decline of the launch industry during the forecast period.

Nevertheless a market, well beyond the recent assessment, could be created if the conventional thinking of what rocket propelled vehicles are to be used for is exceeded.

Figure 1: The SpaceLiner vision of a rocket-propelled intercontinental passenger transport, shown here in an artist's impression, could push spaceflight further than any other credible scenario

Ultra fast transportation, much faster than supersonic and even potential hypersonic airplanes, is definitely a fundamental new application for launch vehicles. Even in the case that only a very small portion of the upper business travel segment could be tapped by a rocket-propelled intercontinental passenger transport, the resulting launch rates per year would be far in excess of any other credible scenario. By no more than partially tapping the huge intercontinental travel and tourist market, production rates of RLVs and their rocket engines could increase hundredfold which is out of reach for all other known earth-orbit space transportation applications. The fast intercontinental travel form of space tourism, not only attracting the leisure market, would, as a byproduct, enable to also considerably reduce the cost of space transportation to orbit.

2. Background and Analysis of Current Situation

Currently, the worldwide launcher sector including research and industry is running into a deep crisis.

A recent assessment of the launch business already including some kind of optimism is sobering. The Futron *Analysis of Space Concepts Enabled by New Transportation* (ASCENT) Study [2] was a major undertaking on the part of NASA Marshall Space Flight Center (MSFC) and Futron Corporation designed to provide the best possible estimates of global launch vehicle demand for the next twenty years via the research, analysis and forecasting of current and future space markets and applications. The ASCENT study prognosis of an almost flat launch demand in the next 15 to 20 years (Figure 2) contains already new emerging applications. Without the launch demand generated by these new businesses, (notably public space travel), there would be a rather rapid decline of the launch industry during the forecast period.

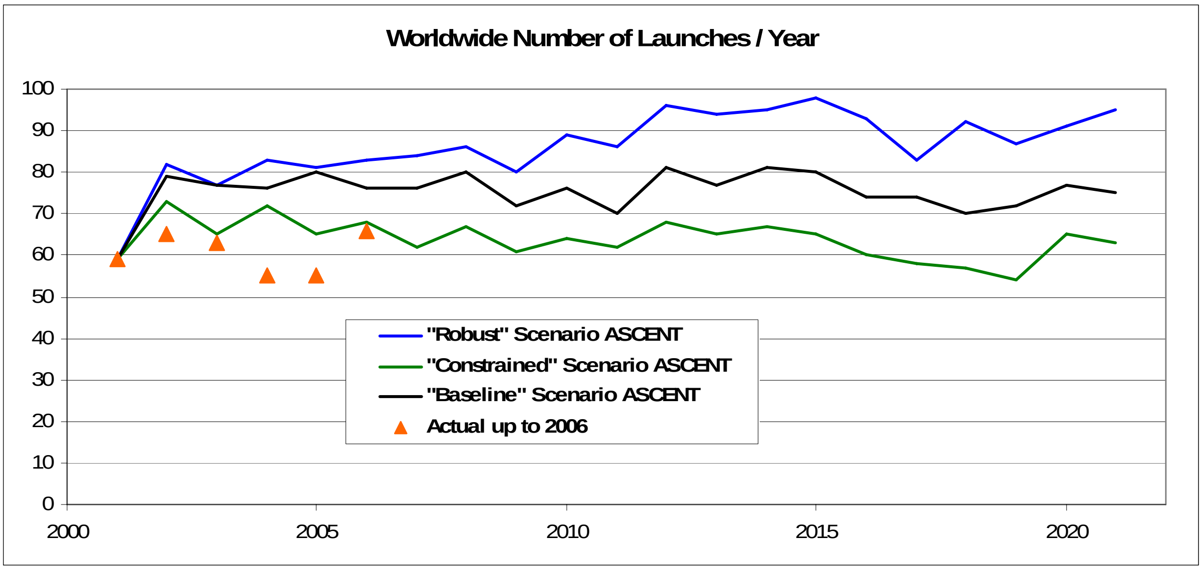

Figure 2: Baseline, Robust and Constrained Forecasts of worldwide number of launches per year for different ASCENT study [2] scenarios compared with actual number of launches

Figure 2 shows that even the most optimistic “Robust” scenario would only see a slight increase in the number of launches until 2021. The recent history of the past few years sadly demonstrated that the "Constrained" lower end of the prognosis was still too optimistic. The actual number of launch attempts to orbit in *every year* up to 2006 remained *beneath* even the most pessimistic prognosis as shown in Figure 2.

The consequences for the development and operation for all kinds of launchers are catastrophic. The ruinous competition on the shrinking commercial telecommunication market requires heavy subsidies only for continuing the operation of existing launchers. On the launcher development side the situation is even worse: The very small market volume and the underutilization of existing infrastructure do not require any new large development project. Everything needed could be served by the available, sometimes 50 years old rocket designs. Technological progress is slowing or stopping because of the decline in development budgets. Without fascinating and challenging tasks a 'brain-drain' of the best and brightest engineers and scientists seems to be inevitable in the near future.

If one postulates that a surge in launches requires a dramatic reduction in launch prices and vice versa, the perspective is quite desperate. The required new market must be significantly different from today’s orbiting of communication or earth observation satellites because almost no growth is to be expected in these areas. As has been demonstrated by the ASCENT study, “most of today’s markets, both commercial and governmental, are virtually unaffected by even massive reductions in launch prices.” [2]

Fortunately, the idea for a new application of spaceflight is gaining momentum: **The space tourism market.**

A number of initiatives on commercial space flight have been recently started with companies developing privately-funded crew vehicles and launchers. For human space flight, this phenomenon was initially triggered by the Ansari X Prize, a contest focused on sub-orbital crew vehicles for space tourism. The Ansari X Prize was won in October 2004 when a privately funded crew vehicle, SpaceShipOne developed by Scaled Composites, reached an altitude of 111 km. It was the first time in history that humans flew to space not using an institutional space vehicle. Undoubtedly, an impressing achievement based on an only moderate investment.

Figure 3: SpaceShipOne potentially initiated a new era in space flight by winning the X-Prize on October 4, 2004

Presently, a number of privately-funded companies are completing the development of suborbital vehicles, claiming to begin commercial operations as early as 2008. Also, corresponding space ports are being planned at several locations.

One of the most serious and credible of such approaches is by Scaled Composites/Virgin Galactic, for which British entrepreneur Richard Branson already unveiled a concept interior of its SpaceShipTwo in September 2006 in New York City (see Figure 4). Virgin Galactic's spaceliners will be specially-outfitted SpaceShipTwo vehicles built by Mojave, California-based Scaled Composites and veteran aerospace designer Burt Rutan. The new spacecraft, designed specifically for space tourism, will be three times the size of Rutan's SpaceShipOne [6].

The air-launched SpaceShipTwo is designed to seat eight people – six passengers and two pilots – and be hauled into launch position by WhiteKnightTwo, a massive carrier craft currently under construction by Scaled Composites [6]. For an initial ticket price of $200000, Virgin Galactic passengers will buy a 2.5-hour flight aboard SpaceShipTwo and launch from an altitude of about 18.3 km, while reaching an apogee of at least 110 kilometers [6].

Branson's Virgin Galactic spaceliners are slated to roll out and begin test flights by early 2008 in Mojave, California, with future operational spaceflights to be staged from New Mexico's Spaceport America beginning in 2009, probably followed by Kiruna, north Sweden in 2012.

Figure 4: Mock-up interior of SpaceShipTwo Credit: Michael Soluri, for SPACE.com [6]

Although, what is called "suborbital space travel" is assessed as an additional promising market, Futron's forecast for suborbital space travel outside of the ASCENT analysis is relatively limited. This study projects that by 2021, 15000 passengers could be flying annually, representing revenues in excess of US$700 million [1]. See also section 4 on page 7.

However, despite all achievements and promising developments, one has to realize that the overall impact of all recent developments in space travel on the launch industry and its technology is limited at best. The 'low-tech'-approach seems to be the only affordable one for small and medium private companies in the near-term. As a result, it is unlikely that the necessary advancement in launch vehicle technology is notably assisted. Further, the overall emerging market volume is insufficient to significantly support the classical rocket launch business. The question comes up if a business could be conceived which significantly raises the number of launches exceeding all current prognoses and hence reduces costs.

A market, well beyond the recent assessment, could be created if the conventional thinking of what rocket propelled vehicles are to be used for is exceeded.

Ultra long distance travel from one major business center of the world to another major agglomeration on earth is a huge and mature market. Since the termination of Concorde operation, intercontinental travel is restricted to low-speed, subsonic, elongated multi-hour flight. An interesting alternative to air-breathing hypersonic passenger airliners in the field of future high-speed intercontinental passenger transport vehicles might be a rocket-propelled, suborbital craft. Such a new kind of 'space tourism' based on a two stage RLV has been proposed by DLR under the name **SpaceLiner** [4]. Ultra long-haul distances like Europe – Australia could be flown in less than 90 minutes. Travel times between other interesting intercontinental destinations are even shorter.

Ultra fast transportation far in excess of supersonic and even potential hypersonic airplanes is definitely a fundamental new application for launch vehicles. Even in the case that only a very small portion of the upper business travel segment could be tapped by a rocket-propelled intercontinental passenger transport, the resulting launch rates per year would be far in excess of any other credible scenario. By no more than partially tapping the huge intercontinental travel and tourist market, production rates of RLVs and their rocket engines could increase hundredfold which is out of reach for all other known earth-orbit space transportation. The fast intercontinental travel space tourism, not only attracting the leisure market, would, as a byproduct, also enable to considerably reduce the cost of space transportation to orbit.

3. Mission and Operational Scenario of the SpaceLiner

Since the demise of Concorde operation, intercontinental travel is restricted to low-speed, subsonic, elongated multi-hour flight. The reasons for the commercial failures of Concorde (Figure 5) and its Soviet counterpart Tu-144 (Figure 6) can be seen in their relatively high cost but severely restricted range offering only a limited benefit for travellers. However, the scientific and political interest in hypersonic passenger airliners is still alive, as has been recently demonstrated by an ongoing European Union (EU) research project. This study called LAPCAT addresses advanced high-speed air-breathing propulsion concepts: a Turbine or Rocket Based Combined Cycle (TBCC/RBCC) capable of achieving the ultimate goal to reduce long-distance flights, e.g. from Brussels to Sydney, to less than 2 to 4 hours [7].

Figure 5: The last supersonic intercontinental airliner Concorde terminated its operation in October 2003

Figure 6: The soviet supersonic transport Tu-144 ceased airliner operation already much earlier in 1978

Conventional wisdom always assumes to operate these transport craft, depending on the flight Mach-number, by combined airbreathing turbo-jet-RAM-, or SCRAM-engines. Although these propulsion systems seem to be feasible in principle, their utilization is still quite far away in the future due to technical challenges, development-, and operational cost. The technical demonstration of SCRAM has reached the subscale level at best. The airbreathing vehicles are very sensitive to their achievable range and to environmental issues. Therefore, they might be severely restricted in the destinations they are able to actually serve. The potential RBCC / SCRAM propulsion of hypersonic aircraft has a low technology readiness level and the technical feasibility of such a large-scale propulsion system raises tremendous design challenges and is yet to be demonstrated [7].

An interesting alternative in the field of high-speed intercontinental passenger transport vehicles might be a rocket-propelled, suborbital craft. The functionality of rocket propulsion is a proven technology since decades and their performance characteristics are well known. Furthermore, a rocket powered RLV-concept like the SpaceLiner is more attractive because the flight durations are two to three times lower than those of even the most advanced airbreathing systems. Such a rocket engine powered vehicle would rapidly climb out of atmosphere, accelerate to about 6.6 km/s, and be able to reach its destination 10000 to 18000 km downrange in slightly more than 1 hour. In contrast to the first generation of SST, a substantial advantage in travel times and hence improved business case can be expected.

The negative environmental impact of the LOX-LH2 propelled SpaceLiner seems to be much less critical than for airbreathing concepts. The engines do not pollute the atmosphere with nitrogen oxides because they do not use the air. Most of the flight trajectory is at a much higher altitude than for the airbreathing vehicles considerably reducing the noise impact on ground. Nevertheless, the launch has to most likely be performed off-shore because usually no remote, unpopulated areas are found close to the business centers of the world. Consequently decoupling of the launch and landing site will create some logistical challenges.

Interesting intercontinental flight routes from one major business center of the world to another major agglomeration are shown in Figure 7. Note that the shown destinations and tracks are neither fixed nor exhaustive. Changes or additional sites on other continents could be considered.

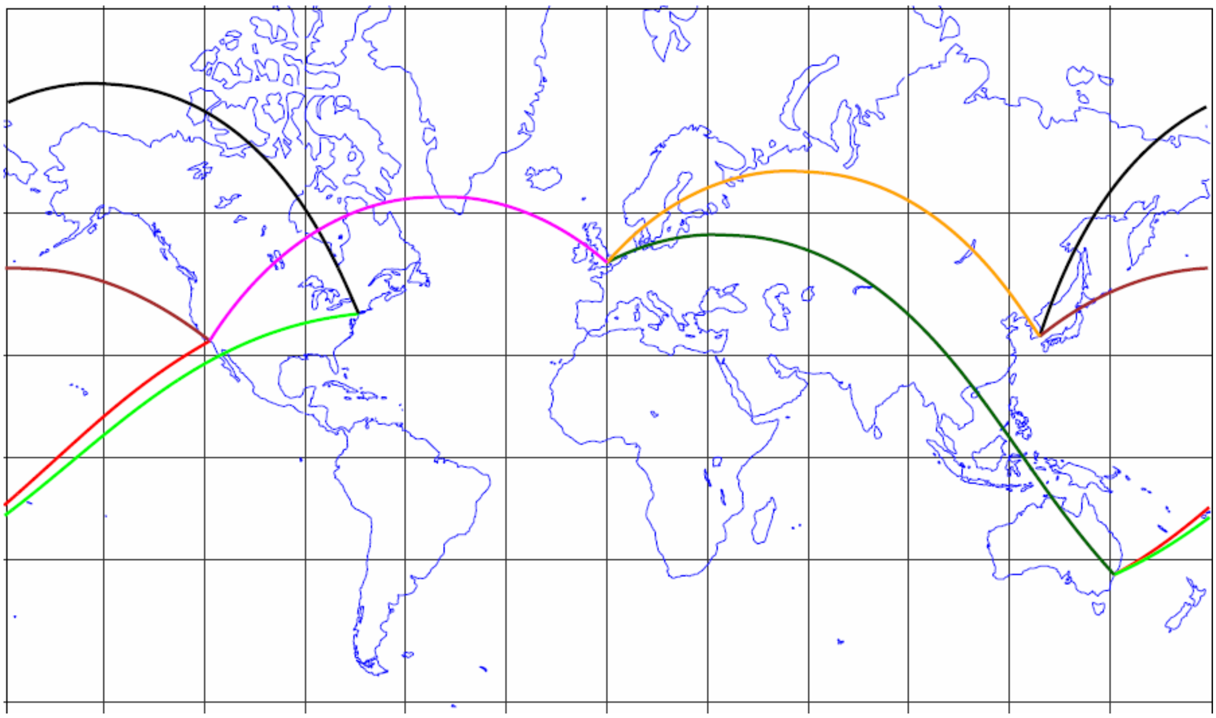

Figure 7: An intercontinental ultrafast travel network could be established by the SpaceLiner concept connecting some of the main population and business areas

The largest benefits of the SpaceLiner ultra-fast transport could be gained on the ultra long-haul routes. Thus, a transatlantic flight has not been considered in the preliminary mission definition. Potentially interesting destinations and their respective flight distances following the orthodrome are listed in Table 1. The baseline mission scenario assumes over-flying populated areas at high altitudes by the RLV during the ascent phase. Restrictions in the flight azimuth could force other routes which will be investigated in the future. This might include more polar flights and utilization of the passenger stage's cross-range capability.

Another major benefit of the SpaceLiner beyond the faster travel option compared to supersonic airliners is the fact that each passenger will reach the edge of space and will become an "Astronaut". According to [1] this is the main motivation for most potential space travelers: "Of all the attractive features associated with a flight into space, viewing the Earth from space rated highest, with 63% of respondents indicating that the opportunity to do so was ‘very important’ as an aspect of suborbital flight."

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 1: Characteristic distances of some potential SpaceLiner missions

4. Cost and Market Scenario

A major shortcoming of Futron's early forecast for suborbital space travel [1] is its limitation on the fun side of the market and restriction of looking at private discretionary income spending habits. Obviously, this approach is justified if one looks at the current endeavors like SpaceShipTwo. Assuming then a suborbital trip ticket priced at US$100000, the minimum net worth required for a potential customer is nearly US$7 million [1]. Therefore, the potential market of suborbital travelers is the proportion of the global population with a net worth in excess of US$7 million. Futron further narrowed the potential market to a target market for suborbital space travel by applying limiting factors, such as interest in suborbital travel, willingness to pay current prices, reasons for interest in space flight, and physical fitness. Specifically, Futron gauged interest based on individuals who responded “definitely likely" and “very likely" to questions pertaining to participation in suborbital space travel, after having been presented with both the positive and less attractive aspects of suborbital flight [1]. The Futron study then projects that by 2021, 15000 passengers could be flying annually, representing revenues in excess of US$700 million [1].

Despite the deserving analysis of Futron, its results are not easily transferable to a different, more expansive operational scenario as for the SpaceLiner. The fundamental difference is found in the fact that the ultrafast long-haul travel option is able to tap the business travel segment. Therefore, the potential market is no longer solely dependent on personal net worth and spending habits. Thus, in a first assessment a simple independent analysis has been started by DLR, which is to be refined based on more detailed long-haul travel data in the near future.

The major interest in all high-speed intercontinental passenger transports is a significant reduction in flight duration. Travel times of up to more than 25 hours are not unusual for long haul distances like Europe - Australia or East Asia - North East America. In sharp contrast, the flight times from take-off to landing of the rocket powered SpaceLiner is less than 1.5 hours. Additional check-in and commuter times are to be added as with today's subsonic airliners. The latter might increase because fewer launch and landing facilities will most likely be available for the high-speed craft than with the current subsonic infrastructure. Nevertheless, a reduction in total travel time of up to 80 % seems to be achievable which would be sufficiently attractive for the increased ticket price.

The very high-speed travel option of the SpaceLiner is most attractive on ultra-long haul distances between the main population and business centers of the world. These can be identified at least in Australia, East Asia, Europe, and the Atlantic and Pacific coast of North America (compare Figure 7). Obviously, more destinations might be of interest but the current study is based on seven flight routes and a daily two way service on each of them.

Thus, a total of 14 launches would be performed each day and 5110 every year. This very number demonstrates that today's launch rate might increase by two orders of magnitude. Taking into account the passenger capacity of 50 for each SpaceLiner voyage, a total of 255000 people might be able to reach space per year. If an ambitious two day turn around time should be achievable and assuming ten vehicles permanently in heavy maintenance or overhaul, a minimum fleet size of 38 vehicles would be required.

The lifetime of the reusable stages and the engines is an important parameter for the assessment of the operation costs. The Space Shuttle orbiter and more recent studies on RLV are based on a design lifetime of slightly above 100 missions. Engine life should reach between 20 and 50 reuses, although not demonstrated up to now. These lifetime data have been parametrically changed to obtain the average annual production numbers. In a scenario with a moderate reusability requirement of 150 flights for the vehicles and 25 for the engines, an average *yearly* production rate of 34 orbiters and boosters and about 2000 engines will be needed. Obviously, this would be a ‘mass production’ never seen before in spaceflight but still quite modest compared to large airliners. A sharp increase in the production rate allows, following a standard learning curve approach, a dramatic reduction in unit cost. The complexity of a reusable rocket powered stage and of the rocket engines is not principally higher than that of large airplanes like Airbus A-380 or Boeing B-747 and their respective high bypass turbofans. Thus, also production cost per item should reach a similar cost level.

The total development cost and investment into the infrastructure will be huge. Development and qualification cost of the passenger SpaceLiner might well reach 30 B€. An additional 30 B€ is roughly estimated for the necessary infrastructure and the initial fleet. Despite this significant investment a business case might exist. Table 2 gives the estimated operation costs of SpaceLiner with 14 flights a day and based on the reusability scenario as mentioned above.

average vehicle replacement cost	/ M€	8857
average engine replacement cost	/ M€	3066
total production cost	/ M€	11923
total maintenance cost	/ M€	4000
total direct operation cost	/ M€	10220
total operation cost per year	**/ M€**	**26143**

Table 2: Operation cost of SpaceLiner per year

One sees that engine and vehicle replacement accounts for a large part of the operation costs due to the limited life time of the components. Maintenance and direct operation costs (including also the necessary commuter transfer of the passengers to the launch site) are to be verified in more detailed analyses in the future. However, these cost data are sufficiently reliable to check under which circumstances and ticket prices a business case might come up. It seems unlikely that the up front investment in development and infrastructure of the private venture for intercontinental high speed passenger travel will be publicly funded. Therefore, it seems necessary to foresee an amortization on the investment which is preliminarily assumed here with 6 B€ per year. Assuming now an average load factor of 90 % and a ticket price for one way travel of 150000 €, the SpaceLiner will be able to generate more than 34 billion € per year (Table 3).

total cost per year	**/ M€**	**26143**
yearly amortization of investment	**/ M€**	**6000**
total revenues per year	**/ M€**	**34492**
profit per year	**/ M€**	**2349**

Table 3: Revenue balance of SpaceLiner per year

Thus, the passenger spaceflight business might be able to have a yearly profit of 2.3 billion €. Surely it is to be acknowledged that these are preliminary estimations with a lot of uncertainties. One of the main reservation is if there will be sufficiently enough people willing to pay the fee of 150000 € per flight. This question might be answered with increased confidence if a commercial space flight venture like Burt Rutan's SpaceShipTwo in cooperation with Virgin Galactic or other endeavors will become reality. Such a precursor application allows testing the market and gaining operational experience. The big difference between the SpaceShip approach and the SpaceLiner concept described in this paper is that the latter not only reaches the edges of space but also offers an attractive extremely fast transportation option.

The recent surge in private business jets operated on a wet-lease basis gives some confidence in the existence of a sufficient high-value travel market. A “jet card” membership scheme starting at 155000 $ for 25 hours of private jet flying time has found a significant number of customers [3]. Even in the case that only a very small portion of the upper business travel segment could be tapped by a rocket-propelled intercontinental passenger transport, the resulting launch rates per year would be far in excess of any other credible future launcher scenario. This form of space tourism, not only attracting the leisure market, would, as a byproduct, enable to considerably reduce the cost of space transportation to orbit.

The specific space transportation cost to orbit improvement in a SpaceLiner environment can be quantified assuming the usage of then existing infrastructure and a high commonality in flight hardware. However, a dedicated upper stage or at least the integration of a large cargo bay in the orbiter will be required. Considering payload preparation and check-out which is cautiously assumed more costly then the transport of people on their sub-orbital trajectory, specific costs between 500 and 1000 €/kg to LEO seem to be realistically achievable. At such orbital transportation price levels a new on orbit market might be generated, further increasing launch rates and hence reducing overall cost.

5. Technical Development Status and Outlook

First proposed in 2005 [4], the SpaceLiner is under constant development and a first major update has been recently published [8]. The latest design includes a first mass estimation of the advanced transpiration cooling subsystem together with an updated estimation of wing structure mass. Tank volume in the orbiter has been decreased, whereas tank volume of the booster has been increased. This was done to achieve more optimal staging. Aerodynamic performance of the orbiter is improved by changing the geometry of the fin (higher sweep angle) and making the wing somewhat thinner [8]. Finally, nozzle expansion ratios of the staged combustion cycle engines are optimized for both the booster and the orbiter.

All engines should work from lift-off until MECO. A propellant crossfeed from the booster to the orbiter is foreseen up to separation to reduce the overall size of the orbiter stage. Fuel rich staged combustion cycle engines with a moderate 16 MPa chamber pressure, 437.6 kg/s mass flow, and 437.6 (booster) / 448 s (orbiter) I_{sp} in vacuum are assumed for the propulsion system. These engine performance data are not overly ambitious and have already been exceeded by existing engines like SSME or RD-0120. However, the ambitious goal of a passenger rocket is to considerably enhance reliability and reusability of the engines beyond the current state of the art.

The total take-off mass of the SpaceLiner configuration in the version 2 reference lay-out is 1094 Mg [8]. This value is in the same class as for other proposed reusable TSTO. The total lift-off mass of the Space Shuttle is much higher in contrast; but the Space Shuttle is designed for increased payload capability to higher circular orbits and has a lower average specific impulse due to its solid motors. The structural index of the passenger stage is at 62 %, thus conservative for a relatively large cryogenic RLV. However, it has to be considered that the vehicle has to include a passenger cabin and safety features.

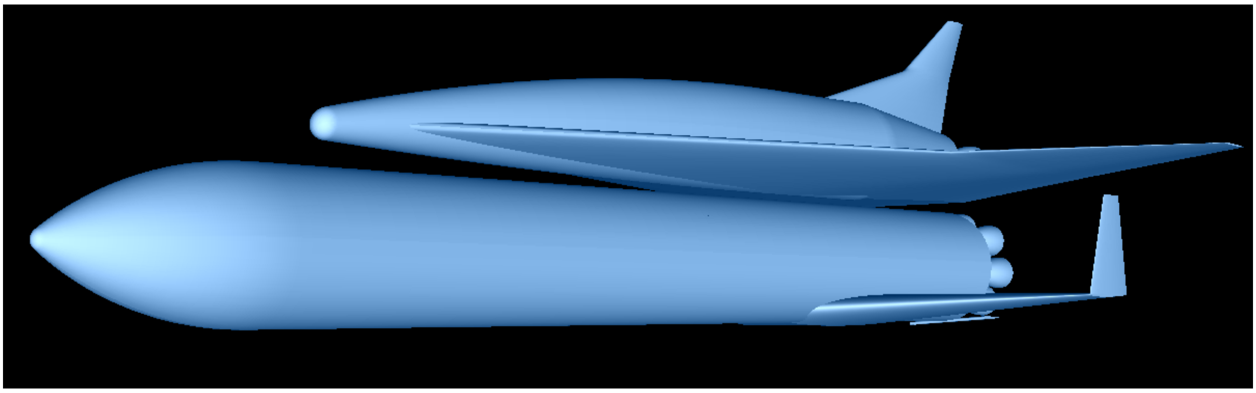

Figure 8: Latest geometry of generic rocket powered intercontinental passenger spaceplane SpaceLiner (top) with reusable booster (bottom)

Ongoing technical feasibility analyses indicate that a vertically launched rocket powered two-stage space vehicle is able to transport about 50 passengers over distances of up to 17000 km in less than 1.5 hours.

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

Increasing the TRL of advanced technologies like transpiration cooling, reusable cryogenic thermal insulation or advanced GNC is indispensable for any realization of the SpaceLiner vision. A preliminary roadmap has been established by DLR to guide further development and to identify potential synergies with other future launch vehicle developments. Figure 9 depicts this roadmap over a span of more than 25 years. Intensive technology development has to start soon for enabling the introduction of high speed freight and passenger service before 2030. These technologies would also support a potential semi-reusable unmanned European Next Generation launcher and the experience gained with such an RLV would benefit the operational introduction of the SpaceLiner. Nevertheless, the introduction of the ultrafast transportation option is not dependent on previous RLV operation.

The operations of suborbital Space Tourism like SpaceShipTwo play an important role in developing the market of passenger flight through space. The required technologies for these kinds of endeavors, however, can support only on a strictly limited basis the much more ambitious and sophisticated skills necessary for the SpaceLiner.

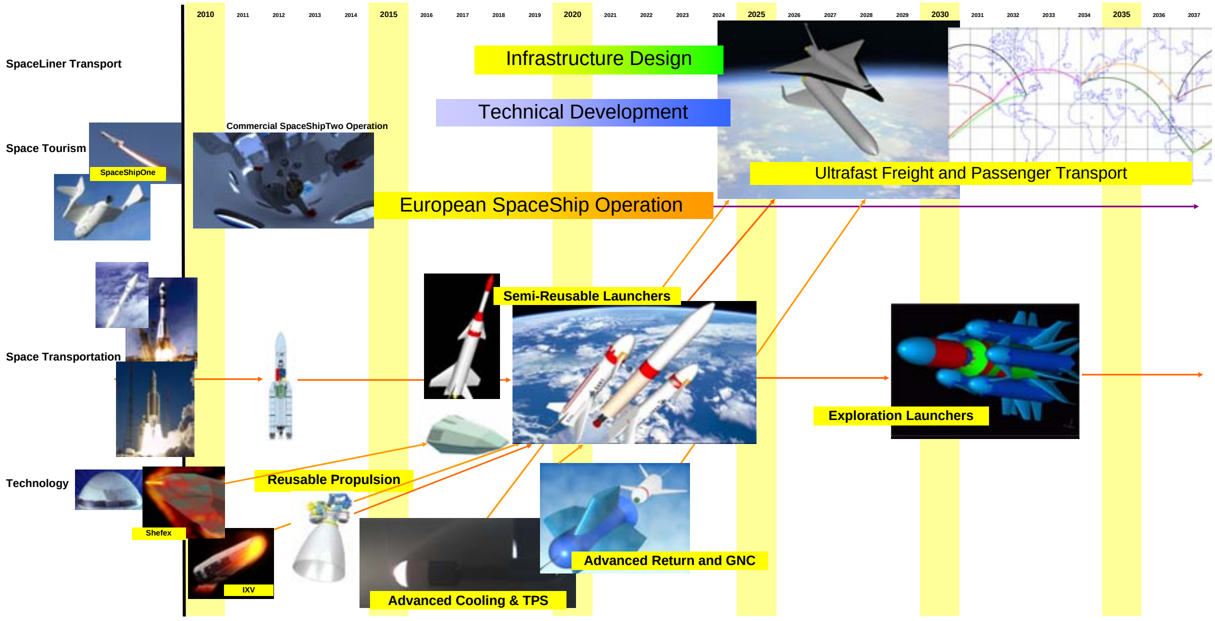

Figure 9: Proposed roadmap of SpaceLiner development and operation with required core technologies

DLR's intention is to initiate soon an international cooperative study on the technical, medical, and socio-economical aspects and challenges of future ultrafast passenger transportation. If the vision behind the SpaceLiner concept should prove its viability, not only a major step forward in transportation technology could be achieved, but also a real breakthrough for enabling low-cost space transportation to orbit.

6. References

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