The 20th Annual Meeting of the China Association of Science and Technology

Symposium on Reusable Aerospace Transportation System

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System Design of the SpaceLiner Project and Its Latest Technical Progress

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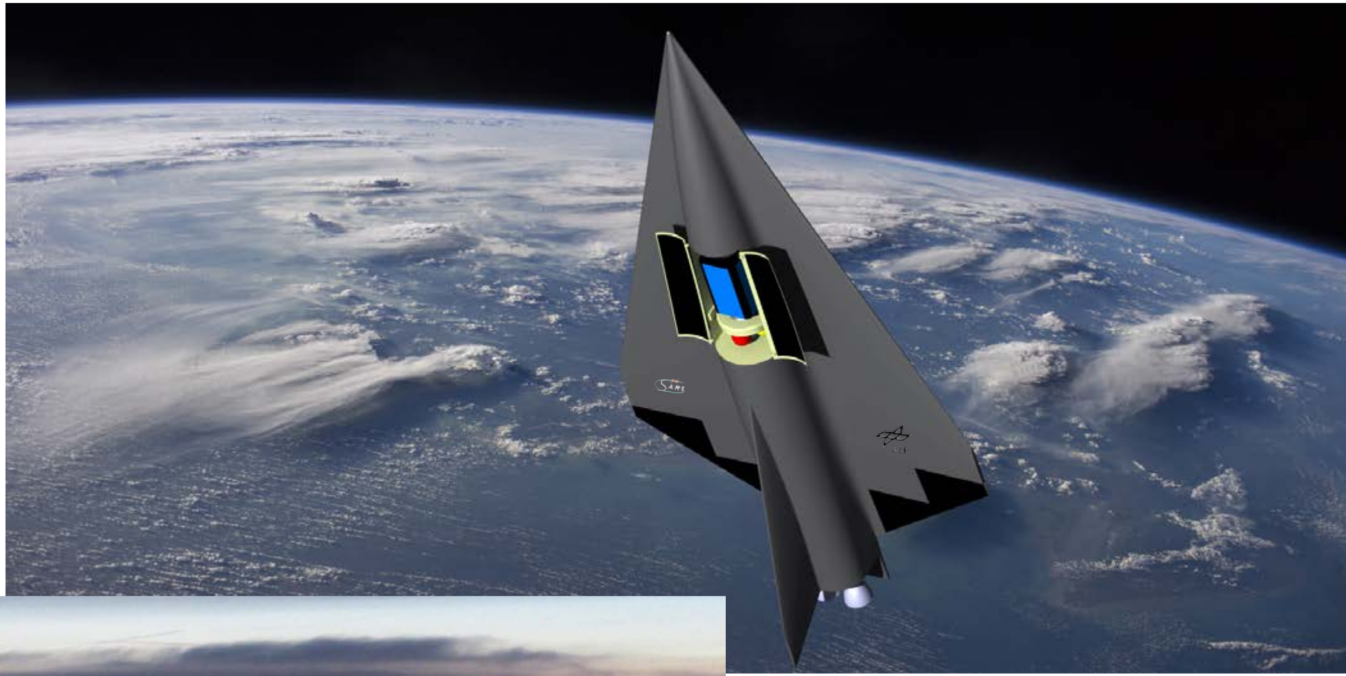
Outline

- The idea of SpaceLiner
- Configuration architecture and masses of the SpaceLiner
- SpaceLiner 7-3 technical status:
  - Propulsion System
  - Structural design simulation
  - Aerodynamics and CFD-simulations of SpaceLiner
  - SpaceLiner cabin / capsule
  - Hypersonic trajectories and ascent control
- Development Roadmap
- Conclusion

Multi-mission Reusable Transport: SpaceLiner

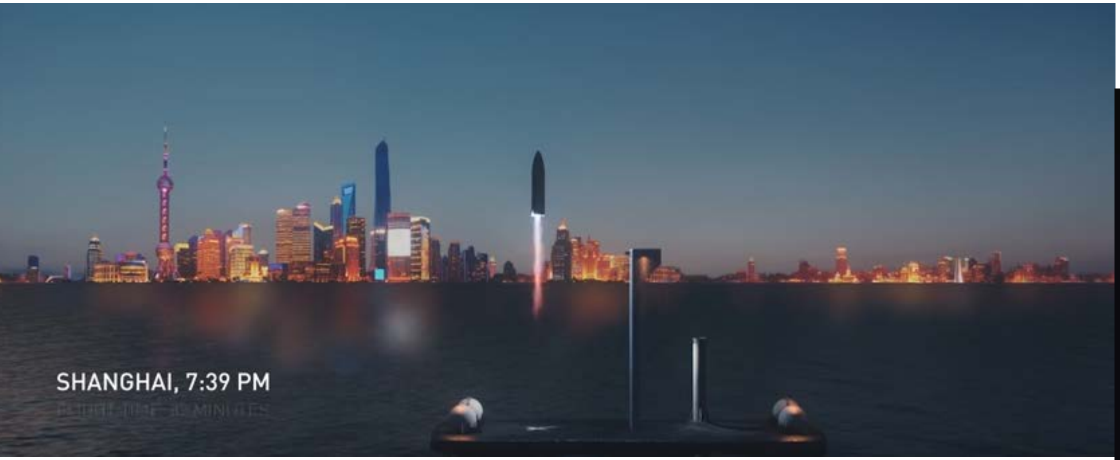
- 2-stage rocket-propelled fully reusable vehicle (VTHL)
- Serving 2 missions: unmanned satellite launcher and ultrafast intercontinental passenger transport (e.g. Australia – Europe in 90 minutes).
- After completion of MRR in Phase A development

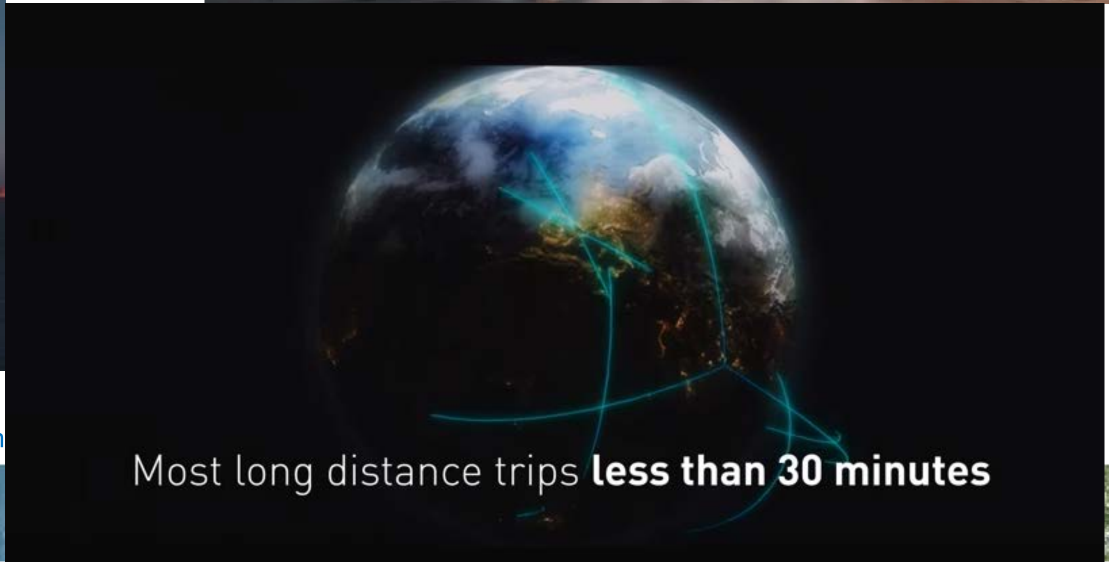


Elon Musk announcement 29.9.2017: "BFR" as ultrafast rocket-based passenger transport

https://www.youtube.com/watch?v=zqE-ultsWt0

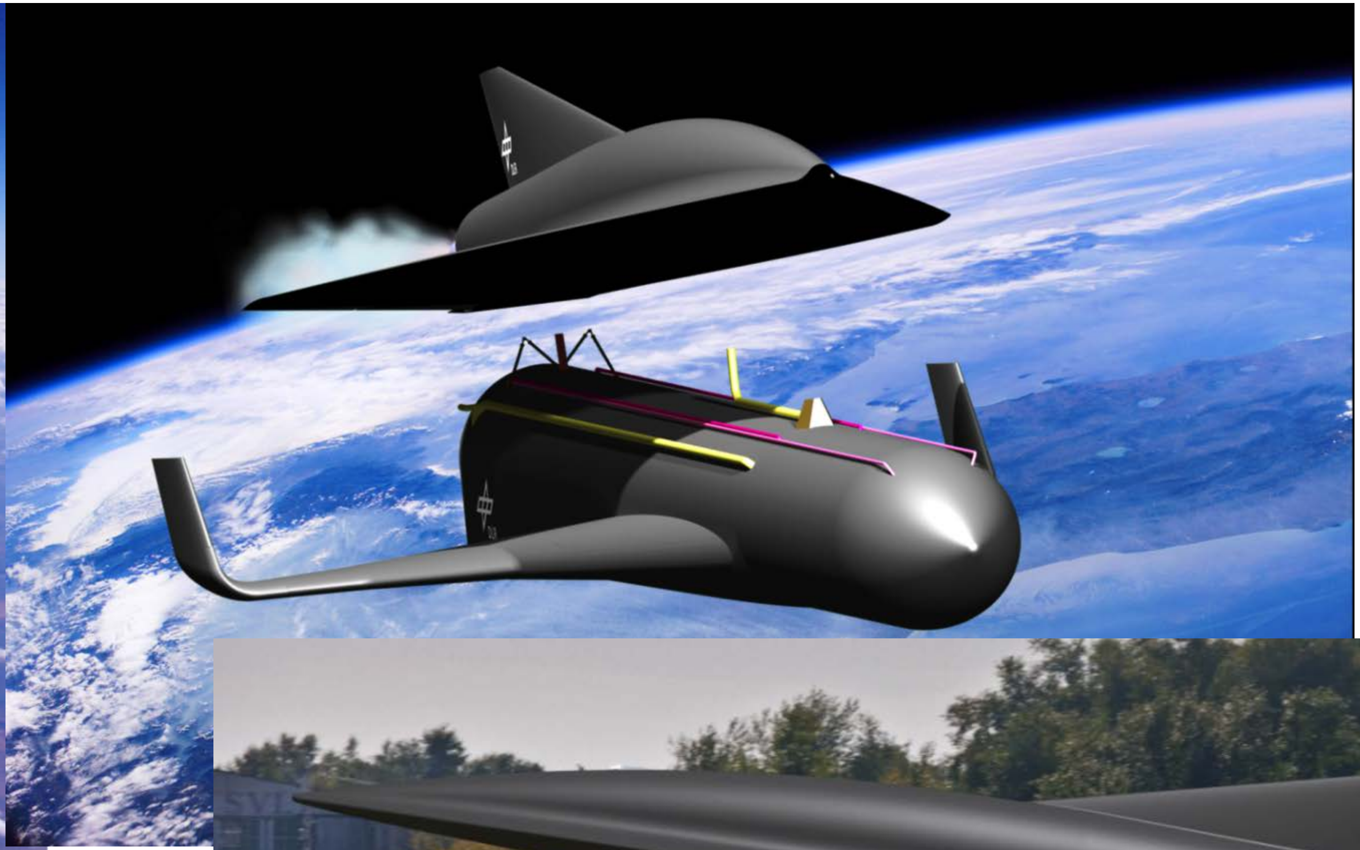
vertical take-off – vertical landing



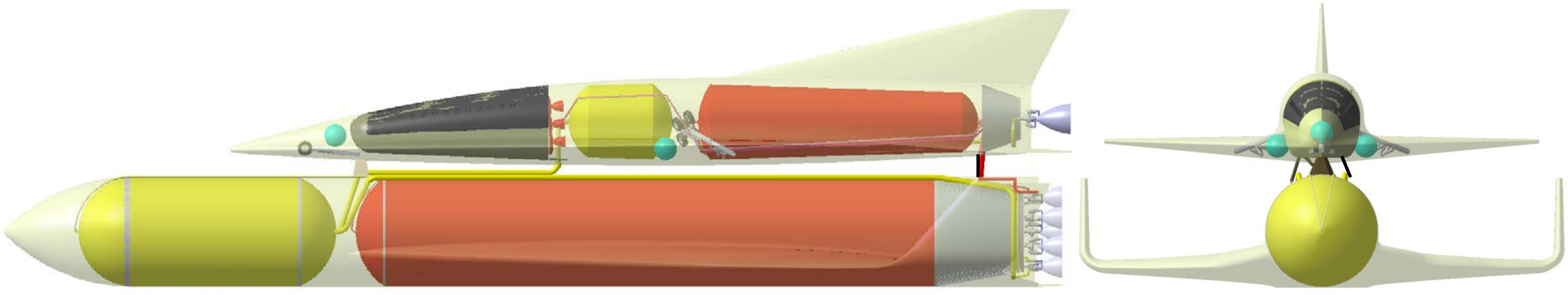


Visionary Ultra-fast Passenger Transport: SpaceLiner

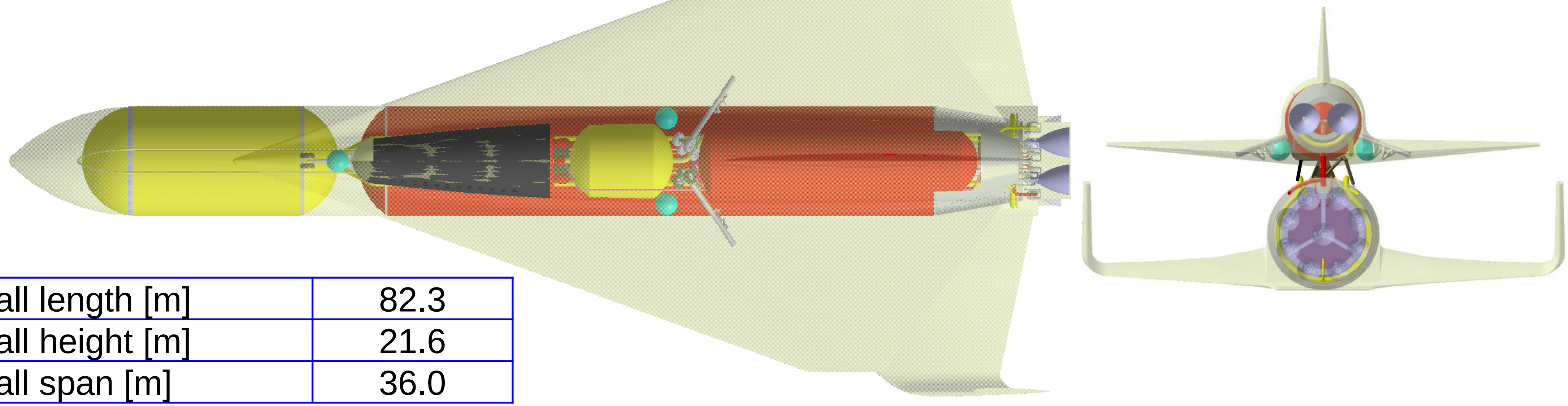
- Flying e.g. Australia – Europe in 90 minutes (or China – America / Europe in 60 minutes) in a 2-stage rocket-propelled fully reusable vehicle
- Investigated by DLR internal and EU 7th - FRP funding



SpaceLiner 7 Configuration Overview (Passenger version)

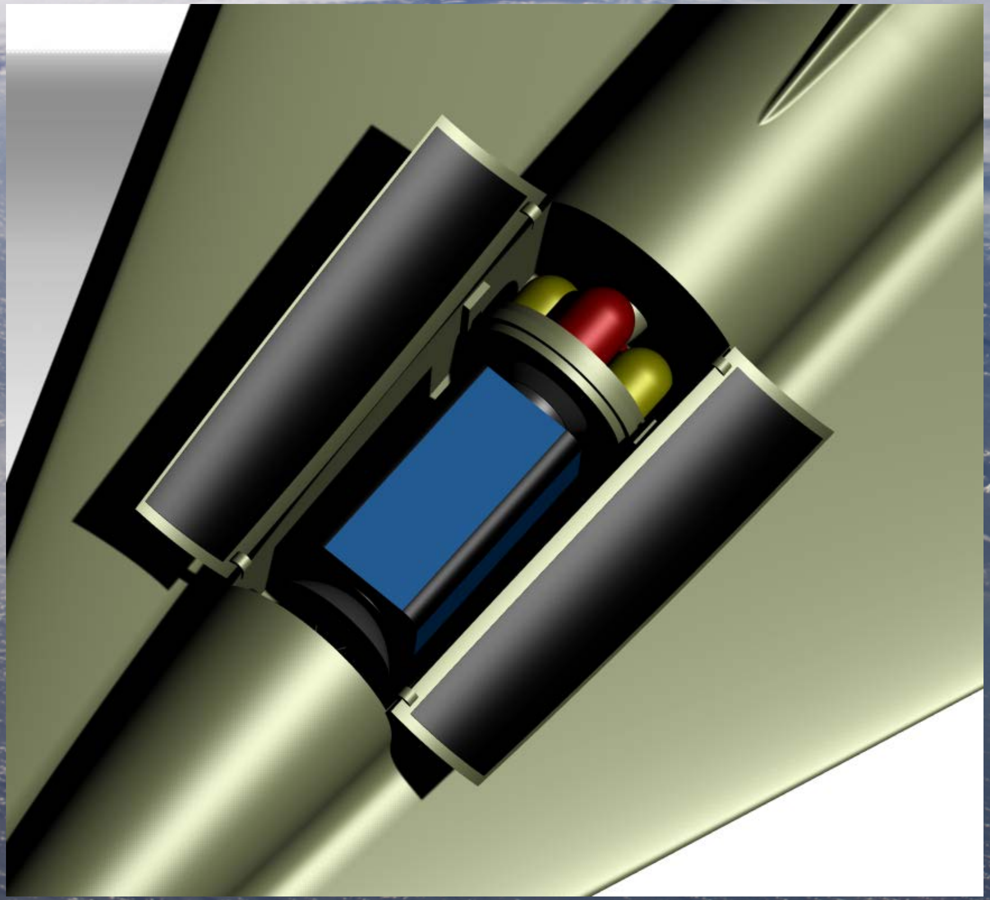


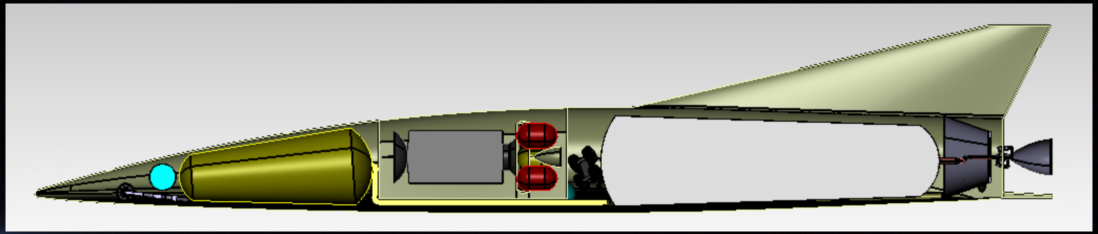
- Parallel arrangement of 2 stages with LOX-LH2 propellants
- Both stages with wings

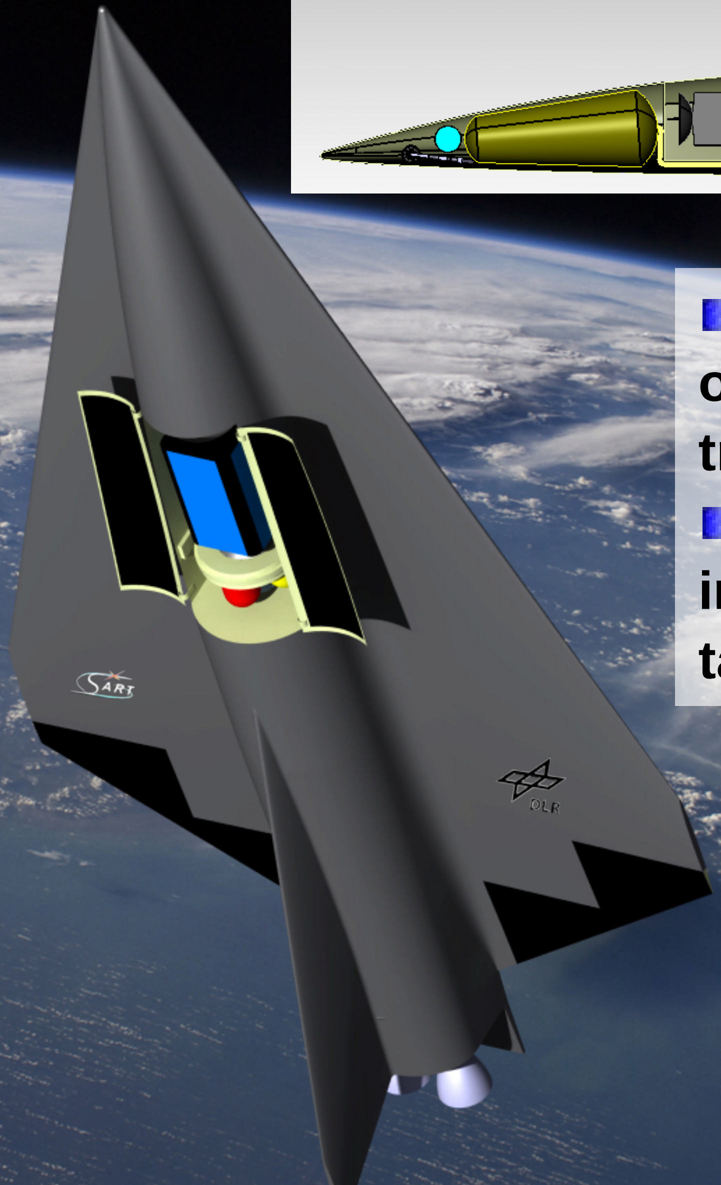


overall length [m]	82.3
overall height [m]	21.6
overall span [m]	36.0

SpaceLiner as Fully Reusable TSTO to LEO



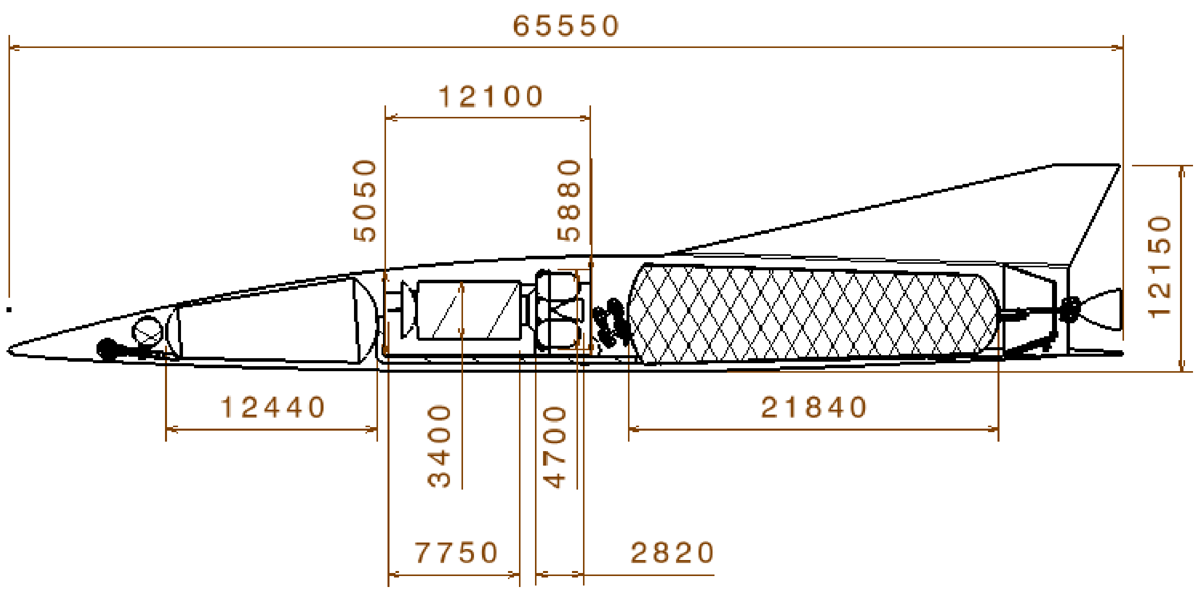


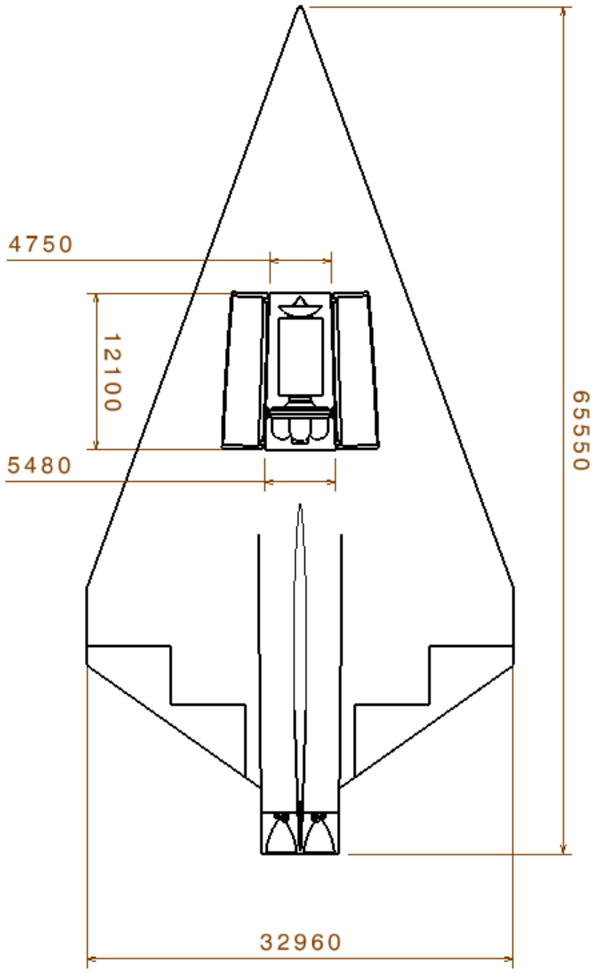


- Similar external shape of cargo and passenger transport
- However, adapted internal arrangement of tanks, structure feedlines

Geometry SL7 TSTO

- Major constraint is available length of payload bay.
- Propellant loading is reduced by 24 Mg to 190 Mg with smaller LOX-tank to allow for 12.1 m payload bay.
- Super-heavy GTO satellites of 8+ m and storable upper stage seem to be feasible payloads.



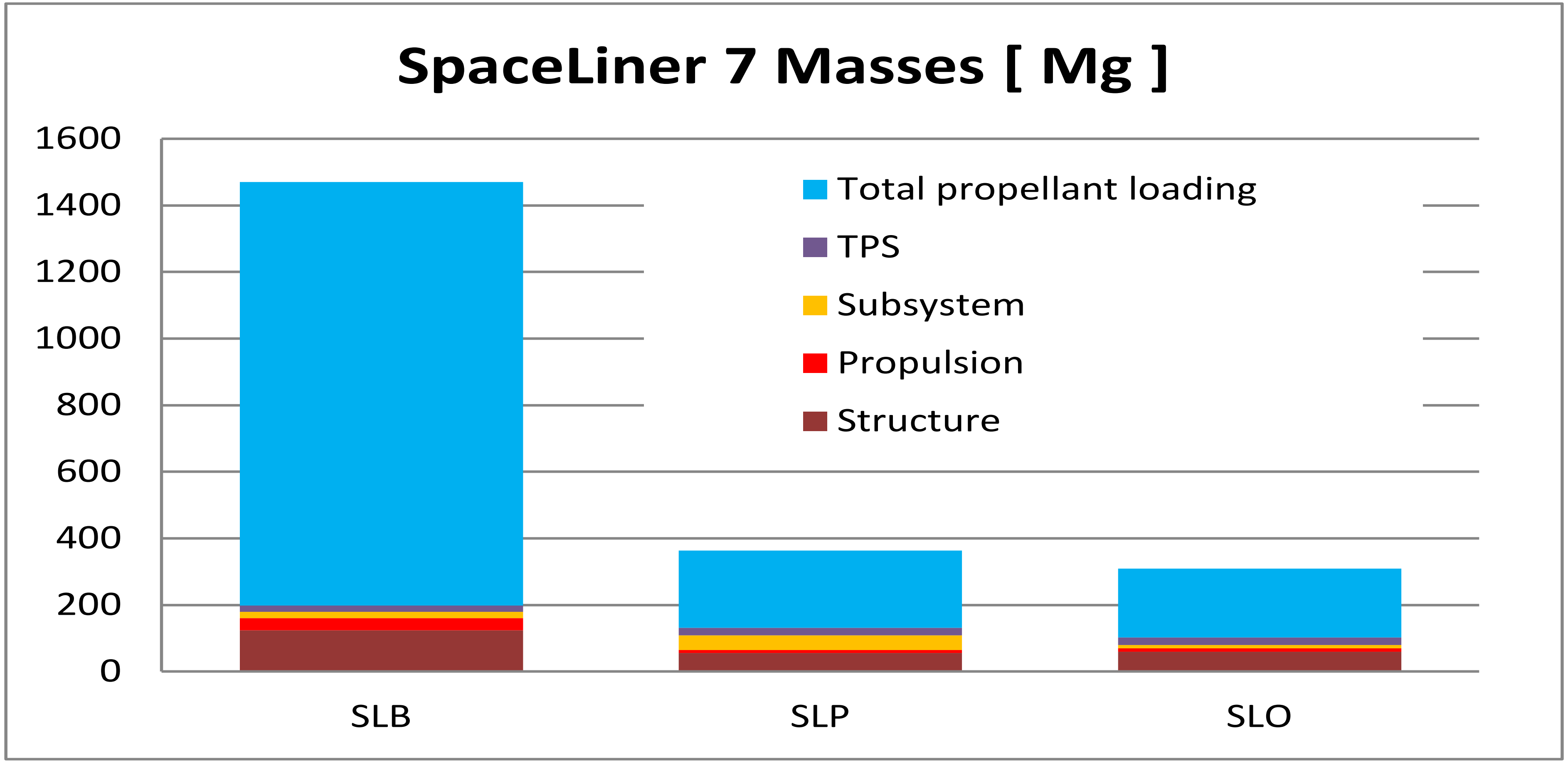


SL7 TSTO Payload Performance & Cost

- **For equatorial target orbit of 30 km × 250 km a P/L of 26.2 t is achievable**
- **Different options exist for satellite delivery in stable transfer orbit**
- **To date delivery in 250 km × 35786 km GTO by conventional storable upper stage was analyzed**
- **Achieved GTO-payload performance: 8250 kg**
- **Trajectory simulations of all RLV-stages for ascent and return performed and feasibility & robustness of concept proven.**

- **Manufacturing of orbiter on same line as passenger stage allows dramatic cost reduction in satellite transport:**
  - **<1000 €/kg to LEO**
  - **<2000 €/kg to GTO**

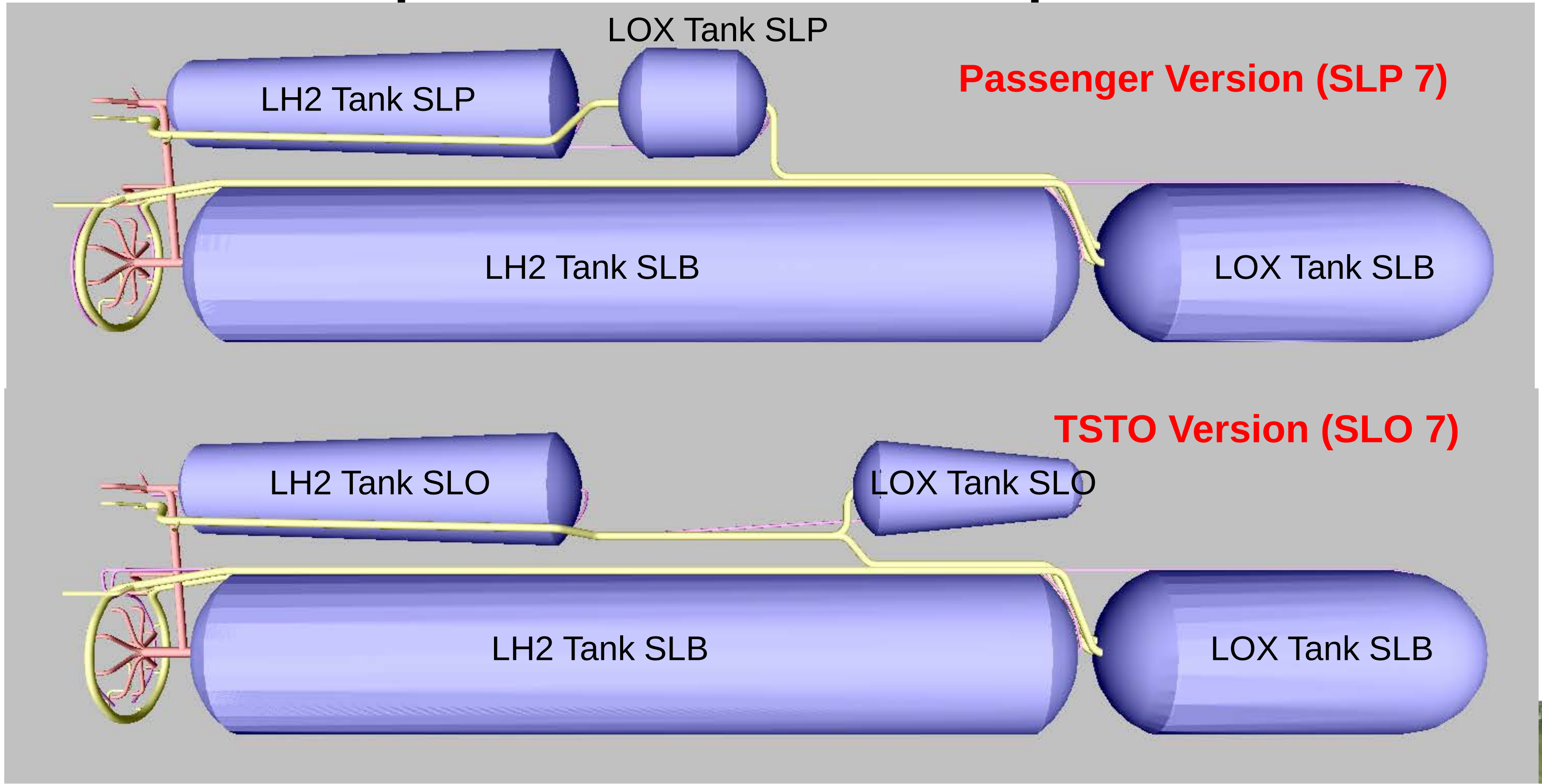
SpaceLiner 7 Configuration Overview



- Total GLOW of 1832 Mg (PAX-version) and 1807 Mg (Orbital version) still considerably below Space Shuttle (2050 Mg)

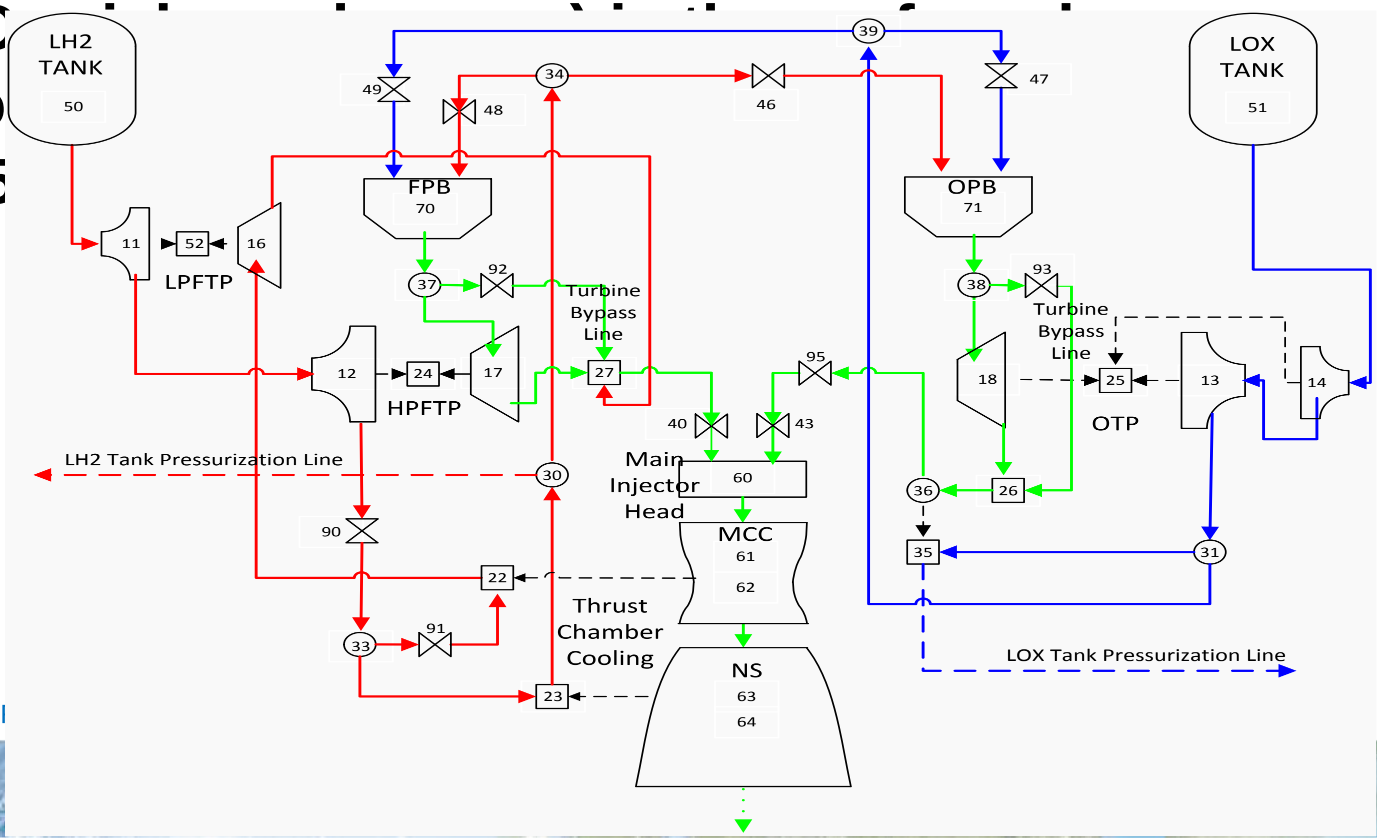
Subsystem: Feed- and Pressurization System

- Crossfeed of LOX and LH2 foreseen during Booster + Orbiter mated ascent. Preliminary design in CHATT FP7-project.
- SpaceLiner should be He-free system with GOX used for pressurization in LOX-tank and GH2 in LH2 tank.
- Design refined and updated for satellite transport version



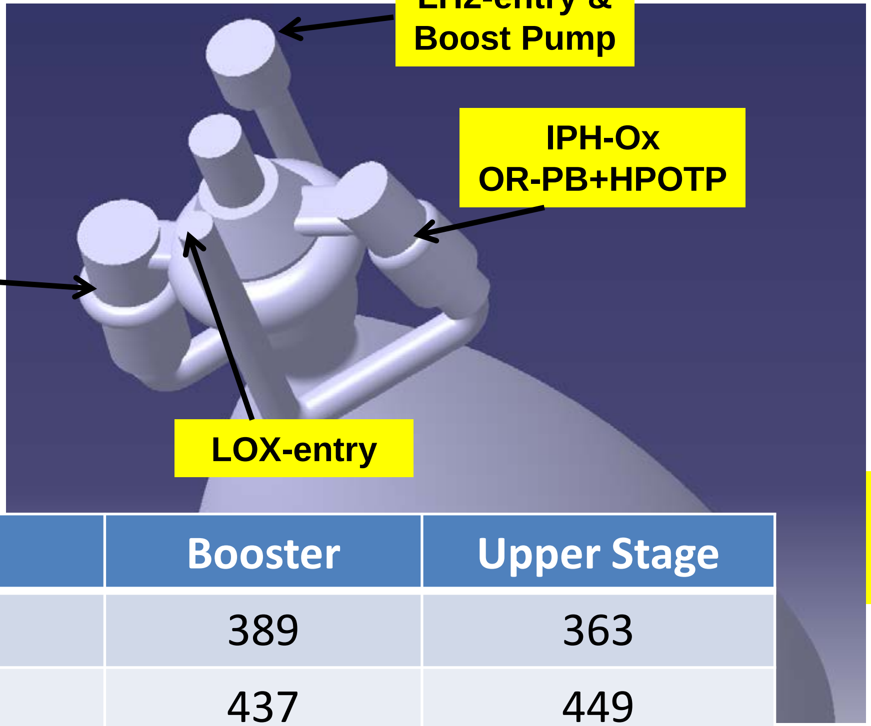
SpaceLiner Main Engine (SLME): Requirements and Functional Architecture

- Baseline are similar LOX-LH2 rocket engines in booster and upper stages; however with adapted nozzle expansion ratios.
- Engine cycle is Staged Combustion type in order to achieve compact engines and good performance.
- Full-flow SC cycle (fuel-rich and O
option for operational and safety co
- Nominal MR-operational range 6.5
- 25 reuses:
  - SLB engine accumulated operational time 6100 s (1.7 h)
  - Upper stage engine accumulated operational time almost 11600 s (3.2 h); 2h 20 minutes at demanding MR 6.5



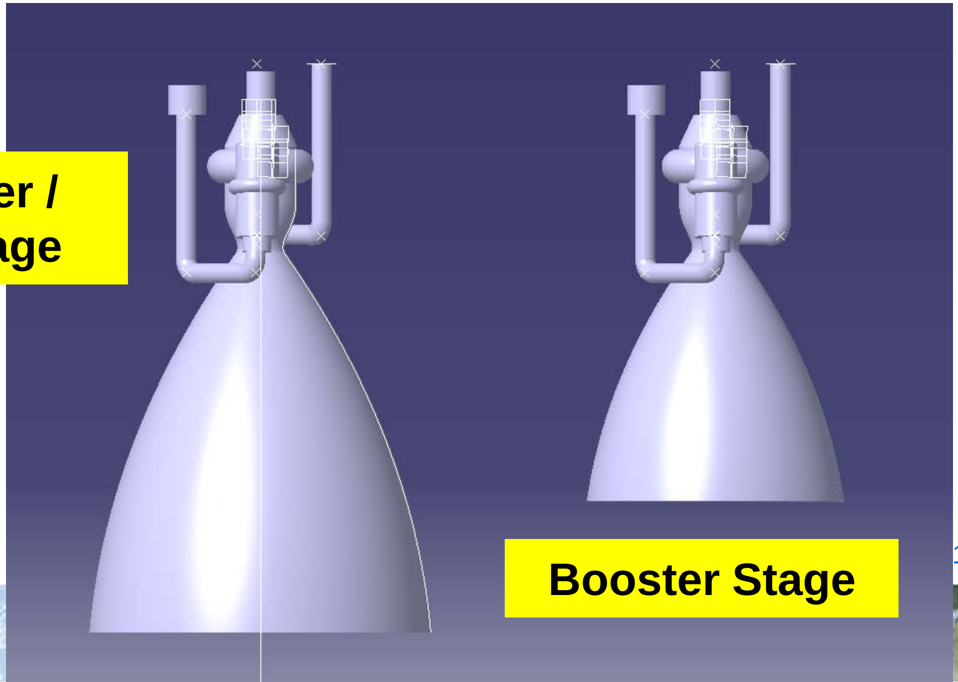
Subsystem Definition: SLME / turbomachinery

- Turbomachinery pre-sizing performed.
- Integrated Power Head (Pre-burner + Turbine + Impeller pump) as on SSME is preferred design solution for mass saving and compact lay-out.



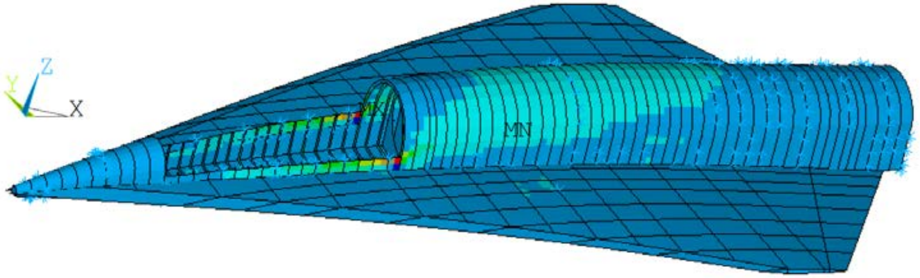
	Booster	Upper Stage
Isp (s/l) [s]	389	363
Isp (vac) [s]	437	449
Thrust (s/l) [kN]	1961	1830
Thrust (vac) [kN]	2206	2268

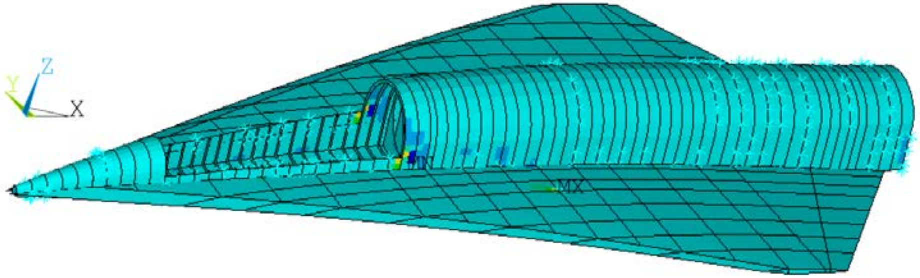
- FTP: Boost-pump + 2st. Impeller
- OTP: Inducer + Impeller



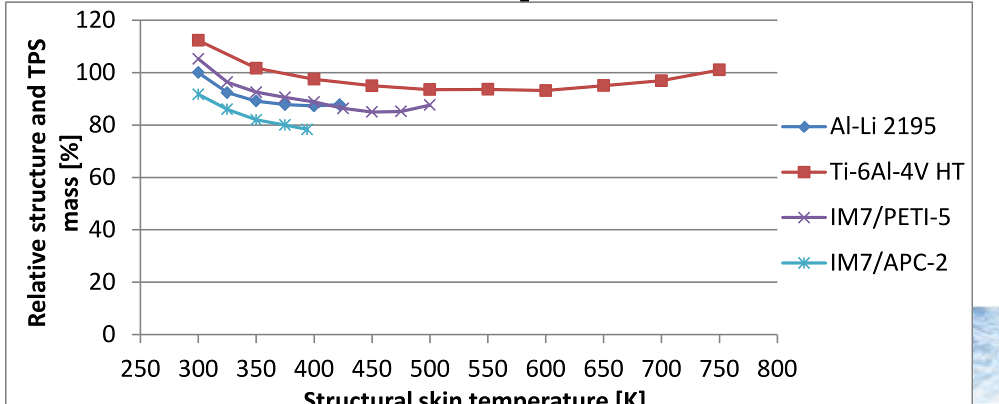
Structural Design and Analyses

- Structural pre-designs of the Passenger Stage and capsule run at DLR and Orbspace for non-integral tank lay-out.
- Passenger stage is all honeycomb-sandwich design.
- Cut-out in fuselage for passenger cabin integration included in vehicle's FE-model:



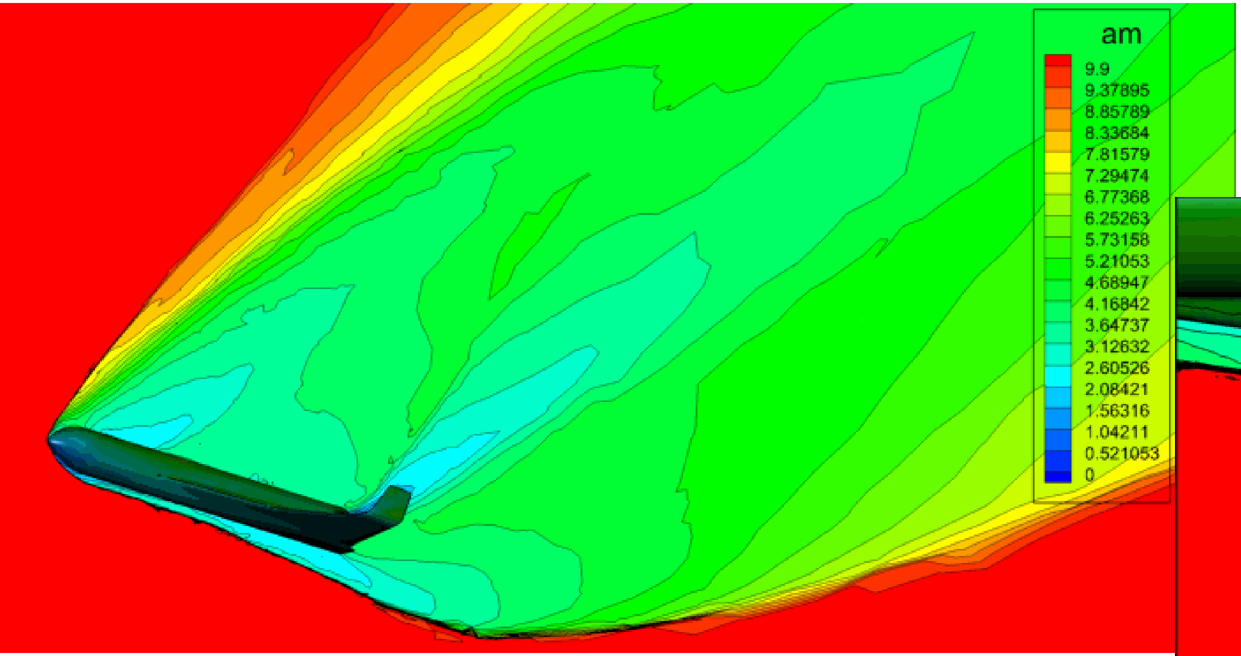


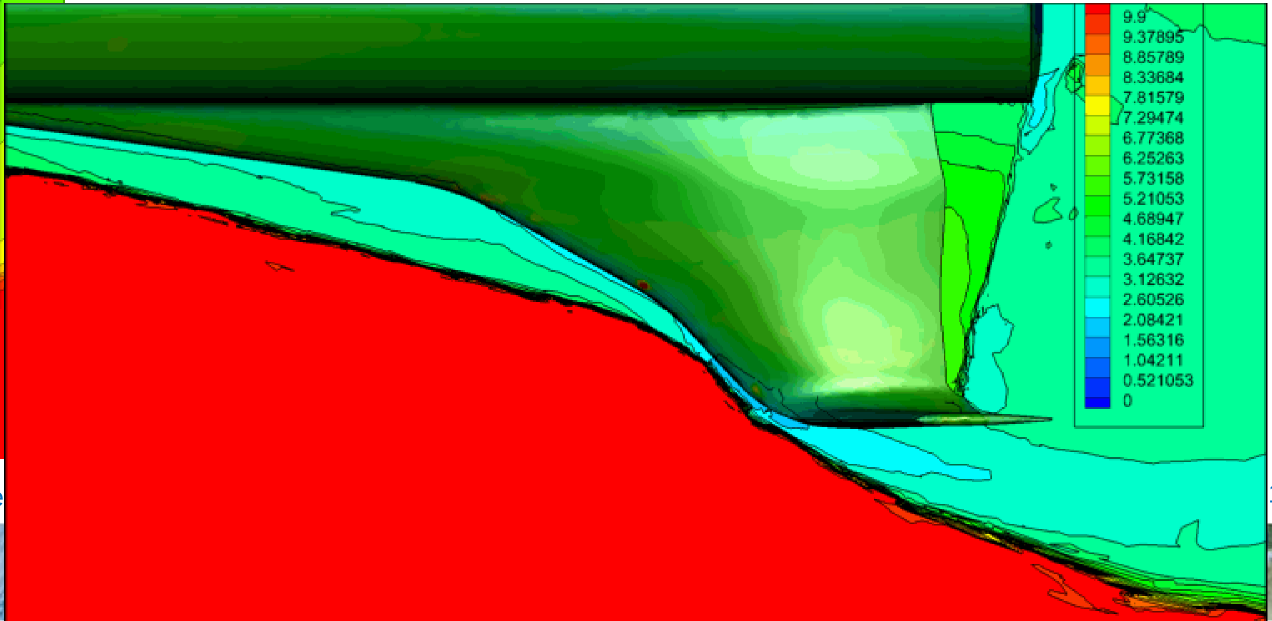
- Parametric analyses of materials and maximum acceptable structural temperatures.
- Combined structure and passive TPS mass show minimum in range 400 K to 500 K:



Aerodynamics and CFD-simulations of SpaceLiner

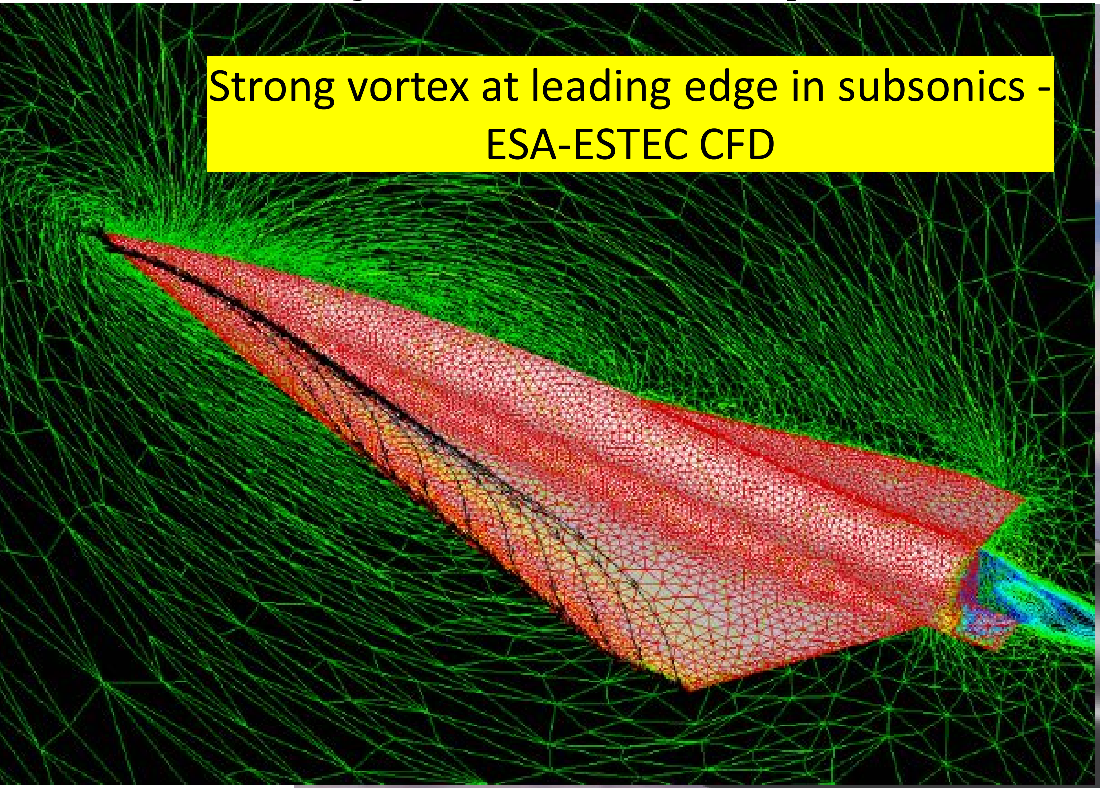
- Booster stage with double delta wing and large outboard fins
- Wing airfoils modified NPL-EC/ECH 4.5 cut at finite trailing edge thickness
- CFD performed at ESA-ESTEC for critical flight condition with maximum reentry heat flux at Mach 10
- Shock-shock interaction at outboard leading edge revealed. Situation needs improved design in future variants.

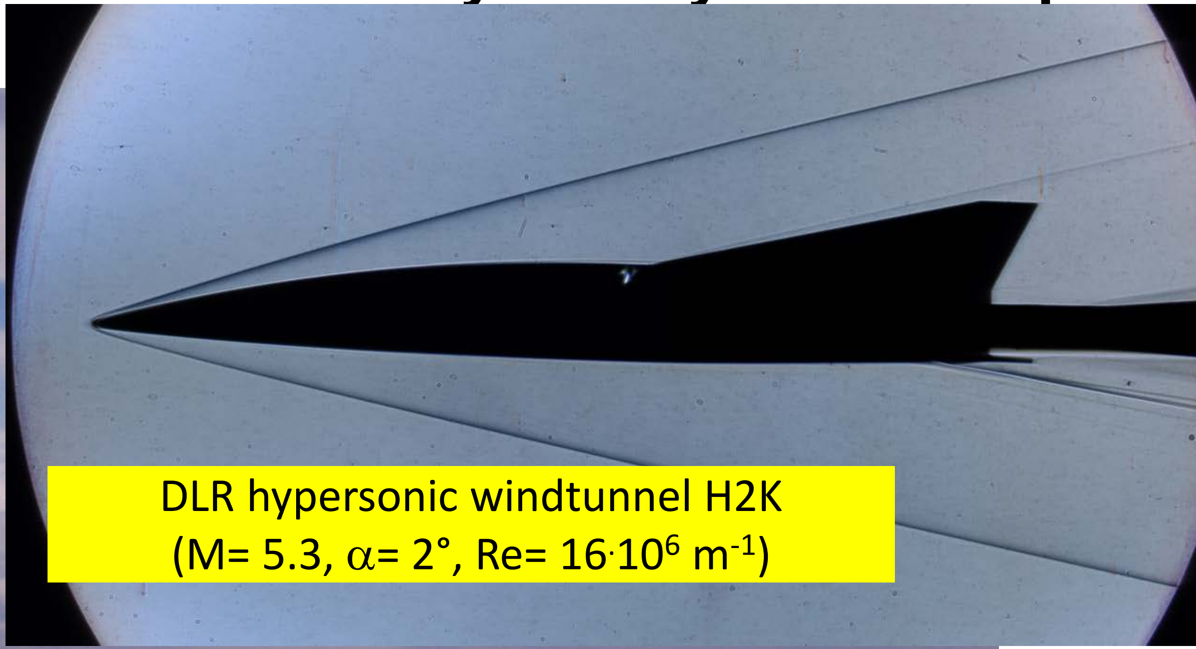




Aerodynamics and CFD-simulations of SpaceLiner

- **Objective: Very good hypersonic L/D with minimum flap deflection in nominal gliding.**
- **SpaceLiner7 was first SL configuration characterized by aerodynamic shape from fully automated optimization.**



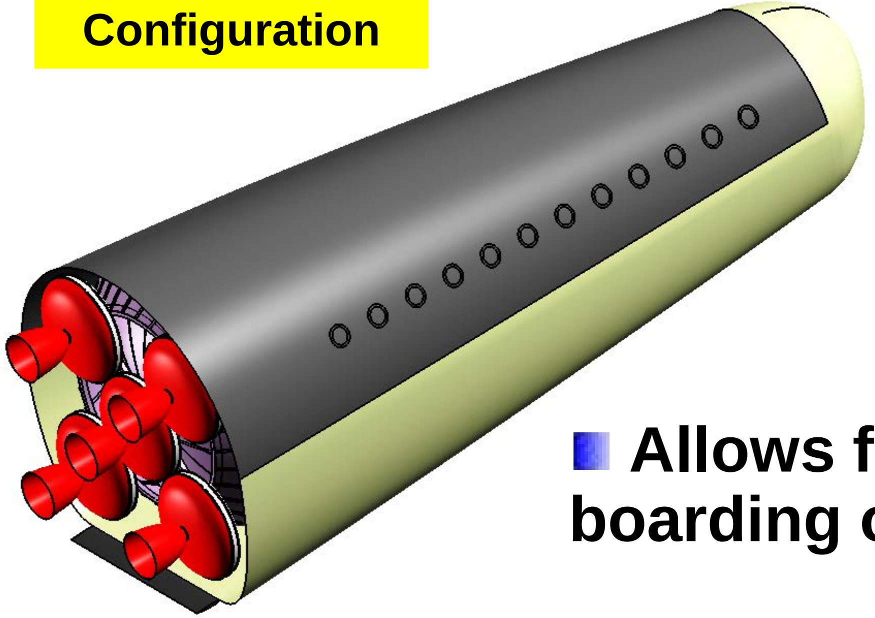


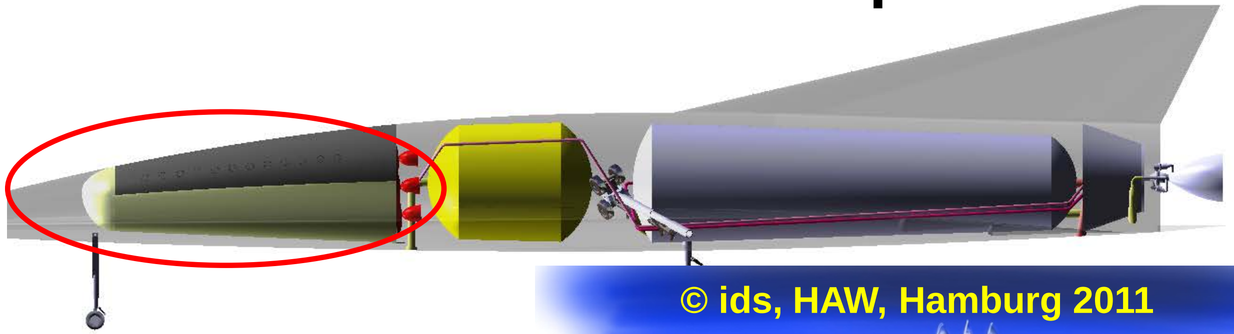
DLR

Subsystem: Passenger Cabin/Capsule

- Separable passenger capsule with 50 seats is essential part of safety concept:

Reference Configuration



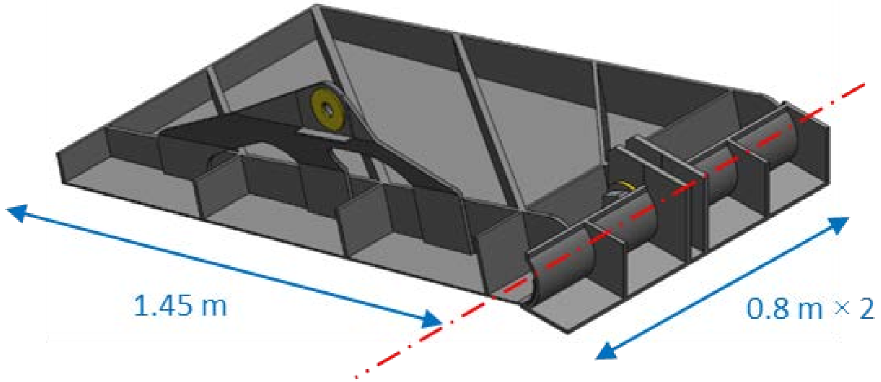


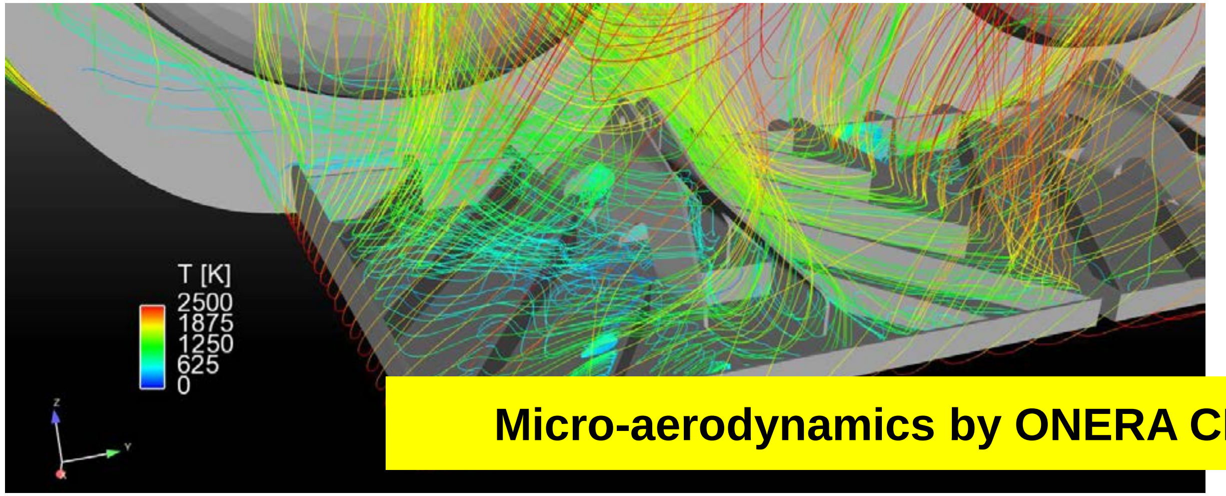
- Allows for horizontal boarding of passengers

- Requirement of feasible capsule separation at any flight condition and attitude highly challenging – ongoing work

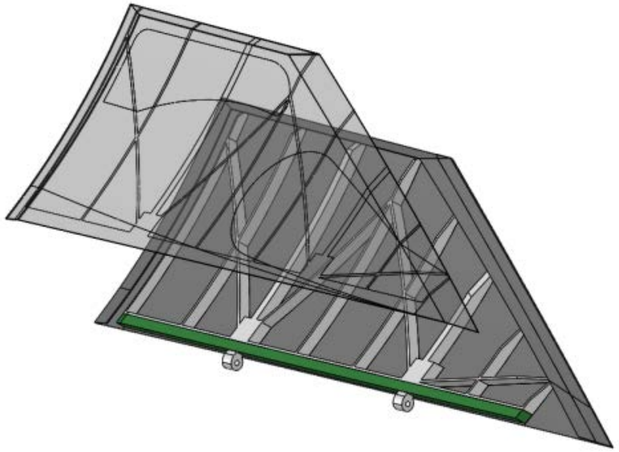
Subsystem: Passenger Cabin/Capsule

- **Aerodynamic control subsystems refined in HYPMOCES-project:**
  - **Previously single bodyflap replaced by double flaps; design Aviospace derived of IXV as open box with C/C-C-SiC ribs**





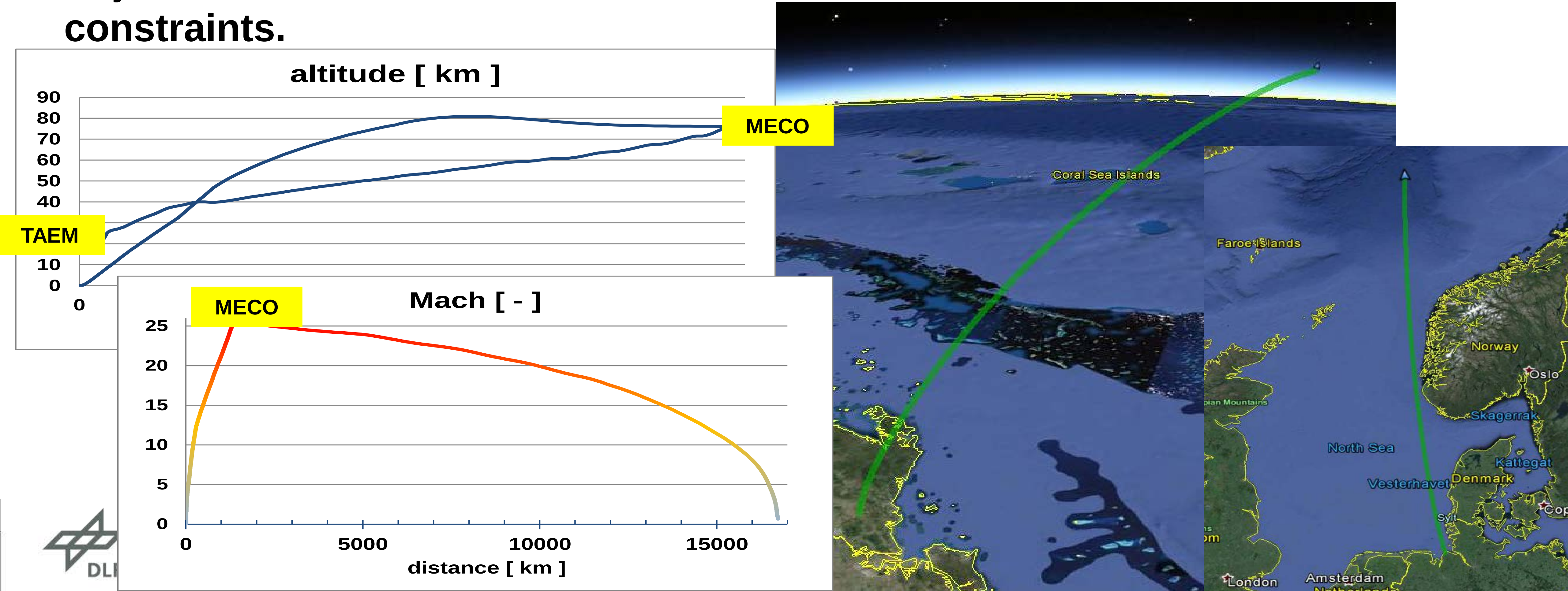
  - **Two deployable control fins added on the upper surface; design Aviospace (I) skeleton and panels made out of C/C-SiC**



- **RCS defined with 2 clusters in rear part**

SpaceLiner 7: Feasible Trajectories

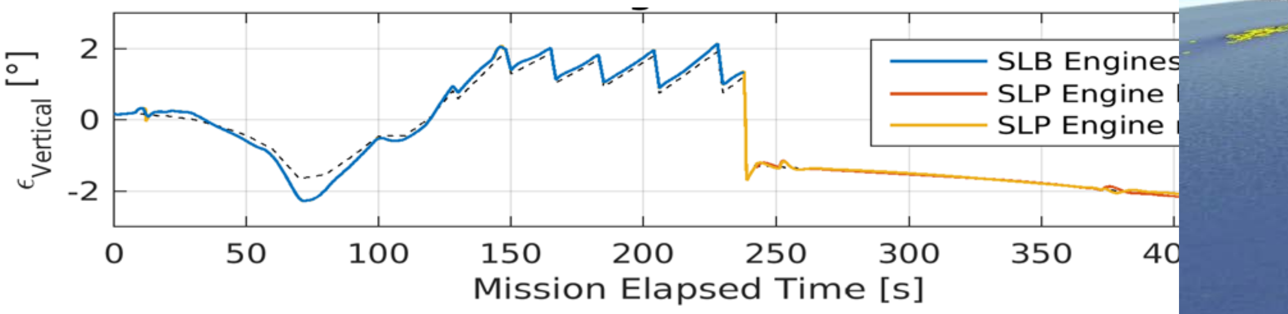
- Standard launch vehicle vertical ascent, hypersonic gliding after MECO, horizontal landing on runway.
- For Australia – Europe reference mission and other inter-continental trajectories realistic tracks considered under ascent noise and sonic boom constraints.

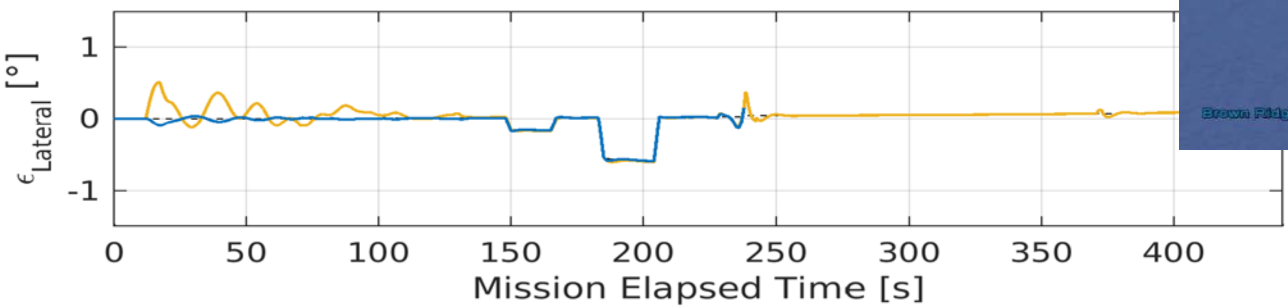


SpaceLiner 7: Feasible Trajectories

- Launch-sites need to be located close to sea or on off-shore platforms
- Trajectories to be selected that ascent noise is not interfering with inhabited areas.

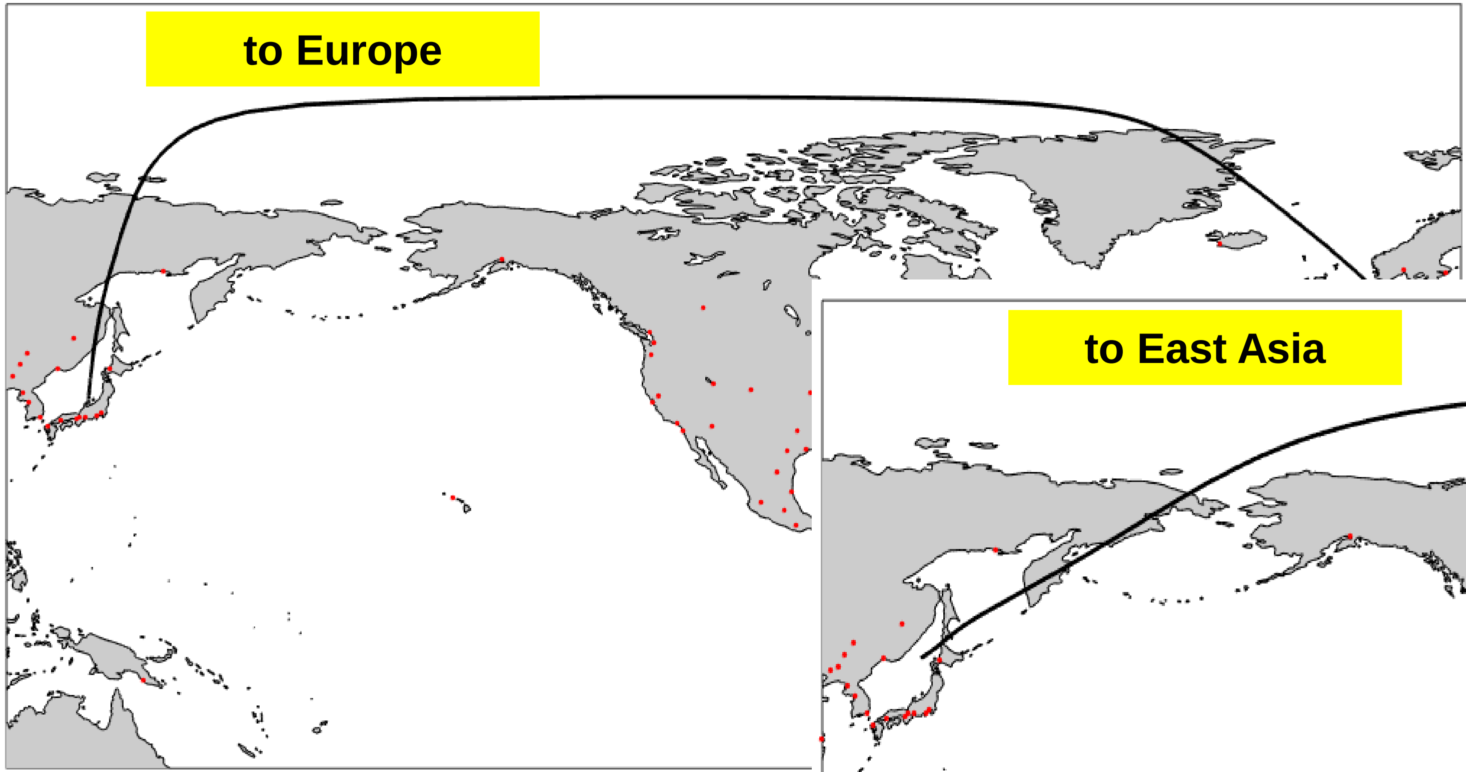
- Ascent flight control by TVC of asymmetric SpaceLiner 7 launcher in 6DOF simulated – static and dynamic trimmability assured.
- Integration of the SpaceLiner (or other RLV) into Air Traffic Management (ATM) assessed.

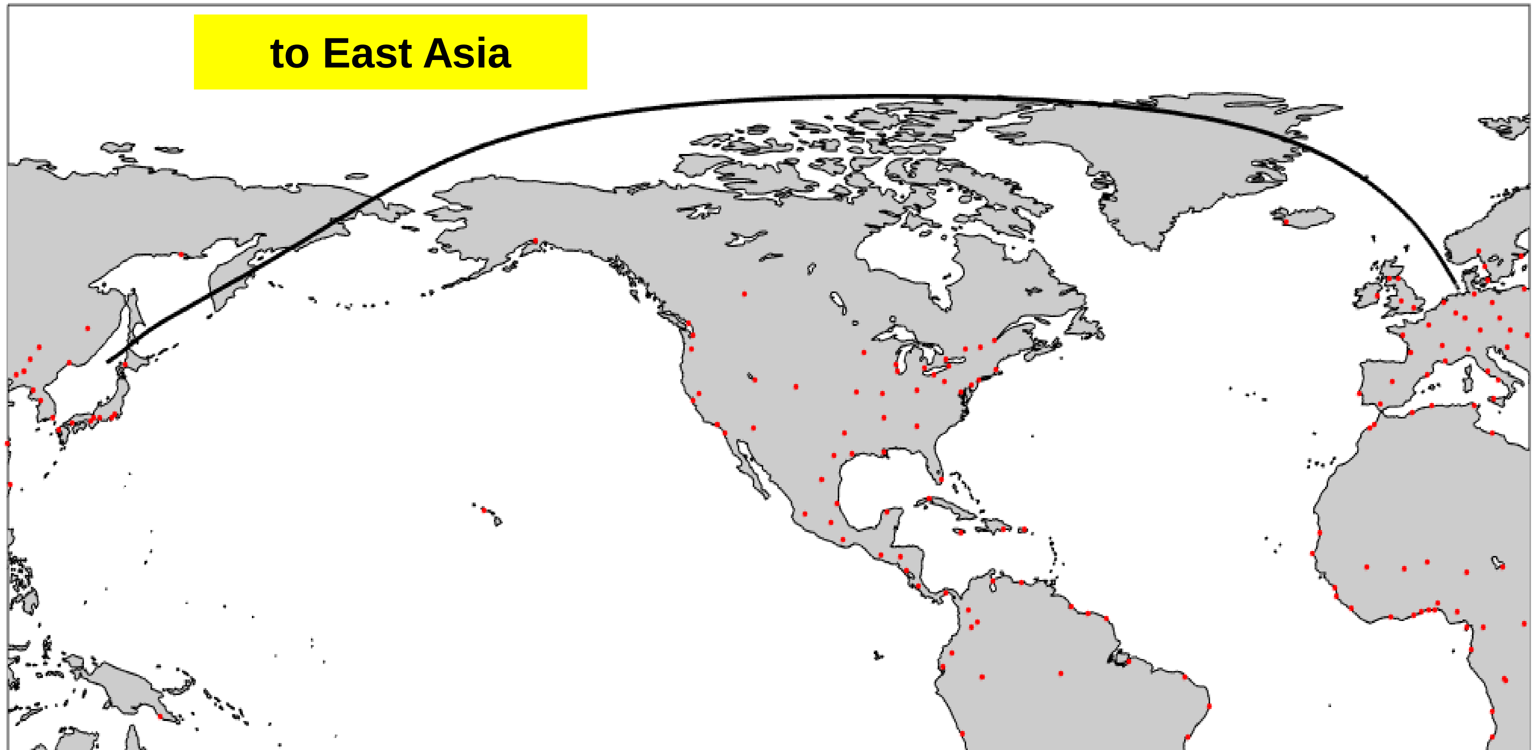




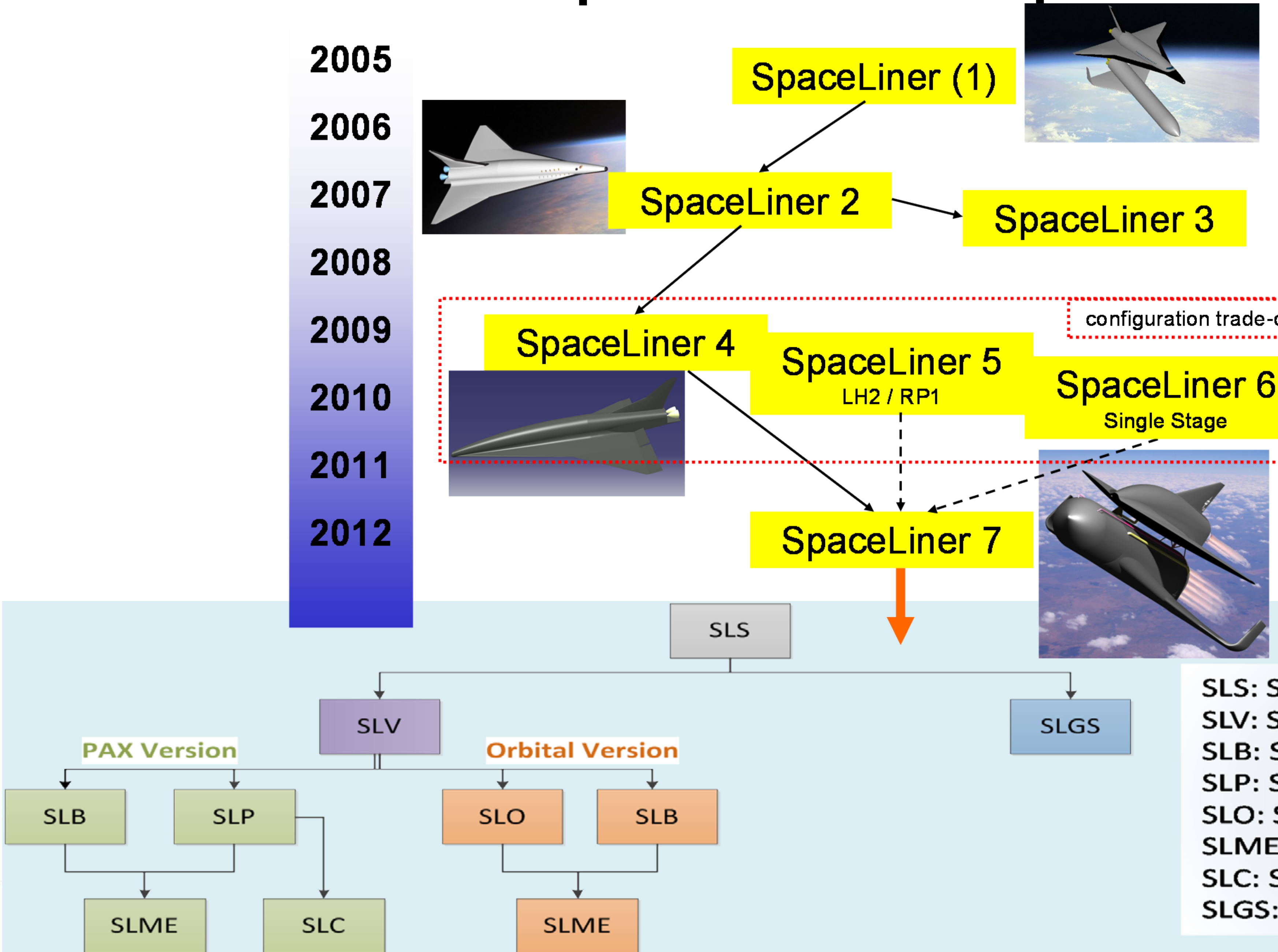
SpaceLiner 7: Feasible Trajectories

- Mission East Asia – Europe:
- Challenge of finding trajectories for which ascent noise is not interfering with inhabited areas.





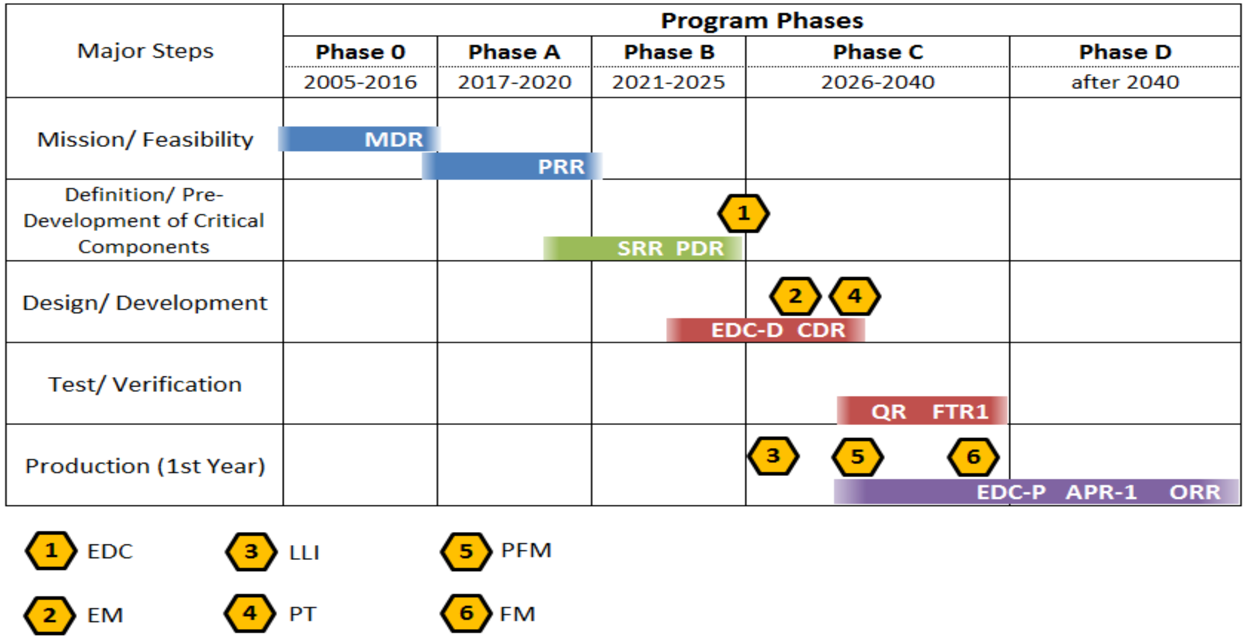
Evolution of the SpaceLiner Concept and Elements



SLS: SpaceLiner System
SLV: SpaceLiner Vehicle
SLB: SpaceLiner Booster stage
SLP: SpaceLiner Passenger stage
SLO: SpaceLiner Orbiter stage
SLME: SpaceLiner Main Engine
SLC: SpaceLiner passenger Cabin
SLGS: SpaceLiner Ground System

SpaceLiner MRR & Development Roadmap

- Structured pre-development:
  - MRR successfully completed in 2016
  - MRD is available to all project partners
- Afterwards – depending on available funding – technical development of SpaceLiner in rough estimation:
  - PRR, SRR in 2020 +
  - PDR in 2025
  - CDR in 2030



- First Flight SpaceLiner ca. 2035 and subsequently extensive flight testing and certification
- Operational passenger transport system 2040+, TSTO earlier

Intermediate Semi-RLV Option

- Displayed for first time at ILA
- Currently under investigation at DLR

Conclusion and Outlook

- DLR proposed reusable winged rocket SpaceLiner is constantly maturing in its conceptual design as multi-mission transport.
- Research on the vehicle performed with support from EU projects FAST20XX, CHATT, HIKARI and HYPMOCES in cooperation with European partners.

- SpaceLiner fully reusable TSTO satellite launcher designed with > 8000 kg GTO performance.
- Attractive satellite launch costs of less than 1000 €/kg (LEO) and less than 2000 €/kg (GTO) in reach in full SpaceLiner operational scenario.
- That’s exactly the promise of rocket-based multi-mission transport!

Conclusion and Outlook

- Consolidated SpaceLiner 7-3 configuration has generous performance margins.
- Launch-sites need to be located close to the sea and passenger route trajectories are to be selected that ascent noise or sonic boom are not interfering with inhabited areas.
- Potential worldwide flight routes with realistic constraints under investigation considering advanced 6DOF control simulations.

- MRR of SpaceLiner successfully concluded in 2016.
- Work on visionary SpaceLiner reached new milestone and project is open to industrial participation in Phase A.
- Operational passenger transport targeted for 2040s.

谢谢！

Thank you!

Merci beaucoup !

Vielen Dank!

Большо́е спаси́бо!