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3nd International Symposium: "Hypersonic Flight: from 100.000 to 400.000 ft"
Accademia Aeronautica (Air Force Academy)
Pozzuoli (Naples), Italy, 30 – 31 May 2019

Overview of research activities on Hypersonic Vehicles at the Department of Engineering of the University of Campania "L. Vanvitelli"

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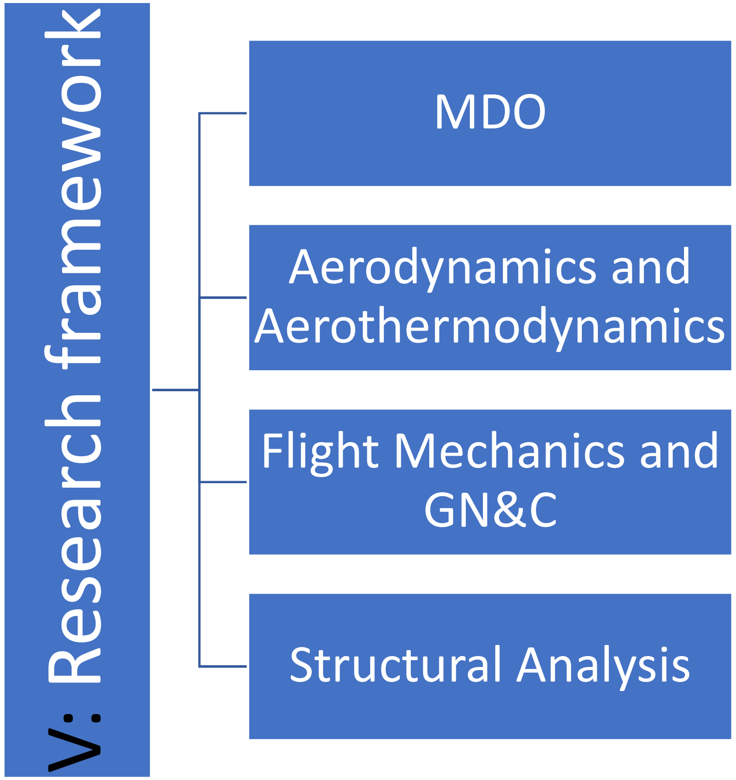
Outline



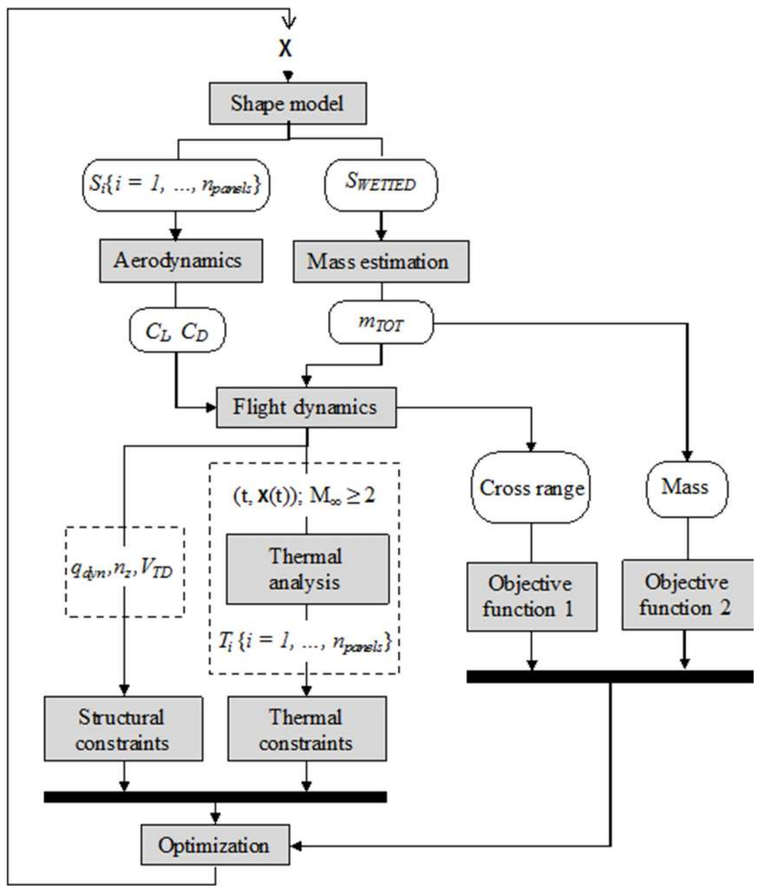
- Hypersonic Vehicles Research Framework

- **MDO** of vehicle shape related to mission objectives;
  - Typical mission profile of an RLV;
  - Design criteria adopted;
  - Thermal heating problems;

- **Soft objects modelling** of Thermal Protection System;
  - Basic idea of soft objects;
  - Two-dimensional Integral Soft Objects for TPS modelling;
  - TPS modelling procedure on conceptual RLV shape;

- **TPS sizing** for conceptual vehicle configurations
  - Applications of modelling procedure over conceptual RLV shapes;
  - Thickness distribution and coating material distribution;
  - Results of applications for a conceptual design cycle;

Overview



- Study Subject: investigation for Minimum Weight Configurations for hypersonic/supersonic/subsonic Vehicles.
- Shape Parametric Model.
- Parametric Model Thermal Protection System.
- Trajectory Model.
- TPS Thermal State Model.
- Multi-objective optimization for Minimum Weight and Maximum Cross-Range performance.

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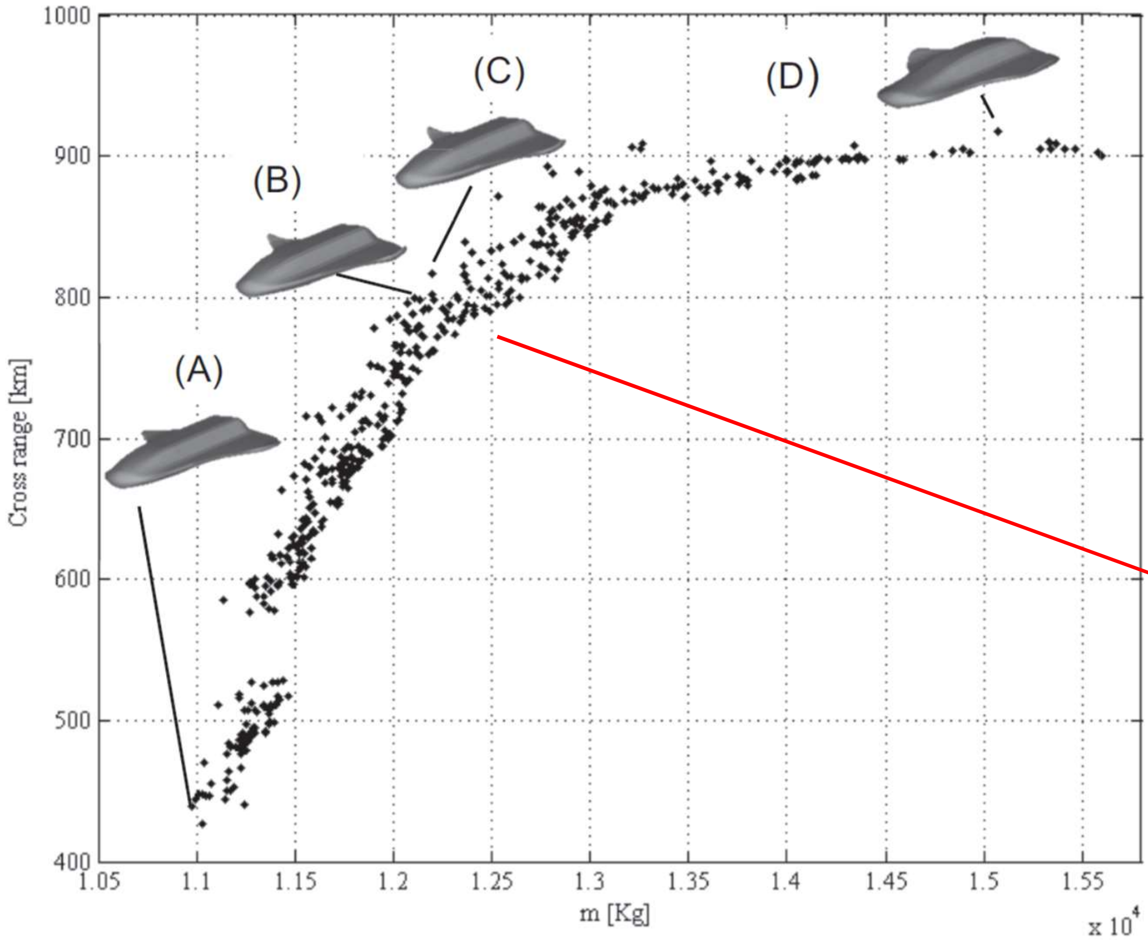
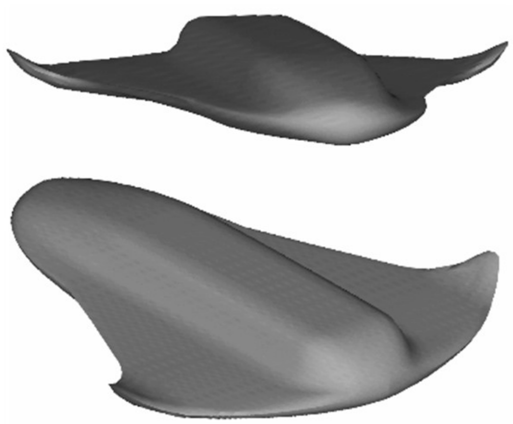
Pareto front obtained by MDO procedure

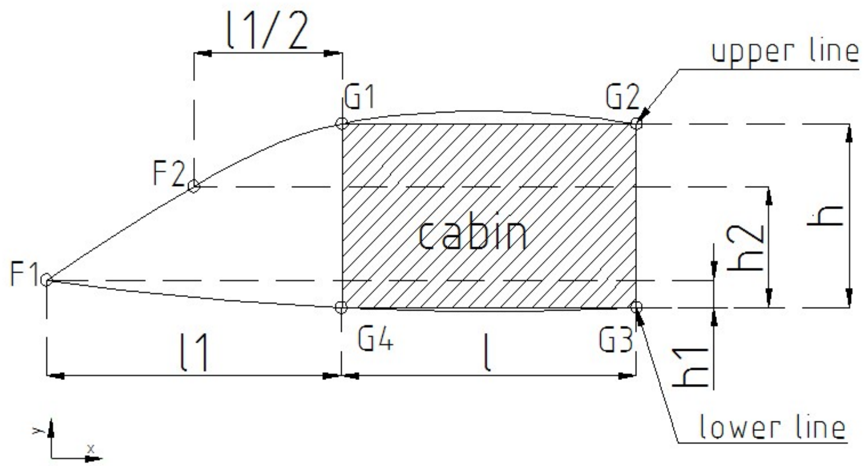


Objective functions:
Mass and Cross-range

Conceptual RLV shape for LEO re-entry
(**Viviani et al. Aero. Sci. & Techn. Vol. 71, 2017**)



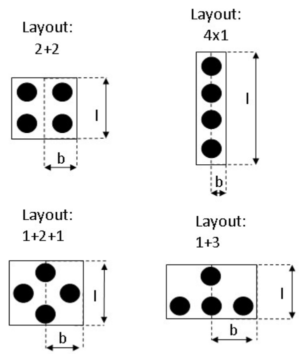
Geometric Model: Symmetry Plane



The outline in the symmetry plane is designed using:

- an upper and a lower parametric b-spline for the windward and leeward side.
- the nose fillet.

Parametric layout for Crew Accommodation



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Soft Objects Modelling

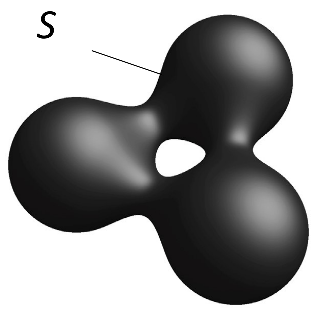
- Geometric modelling with basic primitives (lines, planes, etc.) in some cases **inefficiently** represents **smooth blending** (RLV wing/fuselage lofting; blunt nose/fuselage integration)
- Parametric variation of shape (commonly adopted in optimizations) drastically increases control parameters;

Soft Objects (metaballs, blobs) represents an object by a scalar potential field *F*

- Object instances can be modelled tracking an isosurface of *F* **specified by the threshold *T***
- (*S* implicit surface of equation *F(x)-T=0* : potential field *F* created by three coplanar blobs) :

$$S = \left\{ \mathbf{x} \in R^3 \,\middle|\, F(\mathbf{x}) = T \right\}$$

$$F(d) = \sum_{i=1}^{n_{blob}} f_i(d_i) \qquad d_i = \frac{\left\| \mathrm{x} - \mathrm{x}_i \right\|_k}{r_i}$$



field functions f_i and distance metric , determine the shape of the object

- Advantages:
  - Self & smooth blending among different objects (seamless blend);
  - Complex shapes obtainable simply with potential field superposition;
  - Self-blending property holds in two dimension;

TPS modelling procedure

Rationale

(1) A 2d-grid (equal nr. panels, connectivity) emulates the topological map;

Each centroid of panel on topological map has same neighboring point either on the topological or morphological map.

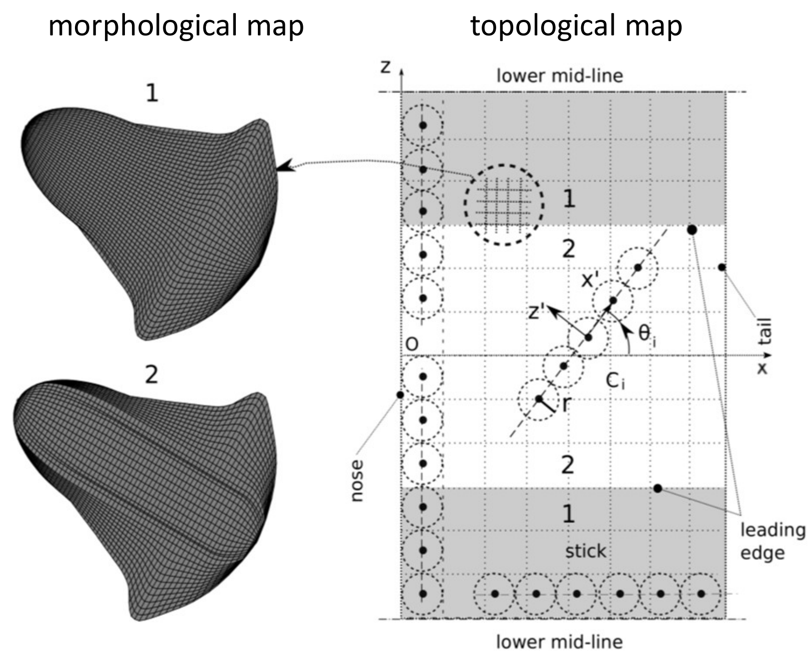
(2) Sticks are defined over a topological map associated to object morphology

- Sticks positions & orientation

1. *Coordinates of centroids;*
2. *Orientation of axis* $\boldsymbol{\theta}_i$;
3. *Strength and radius of sticks;*

(3) *The full integral field created by sticks is mapped on morphological (panelled surface) and modulates TPS thickness;*

(4) *Similar but completely independent field modulates a dynamical distribution of insulating material;*



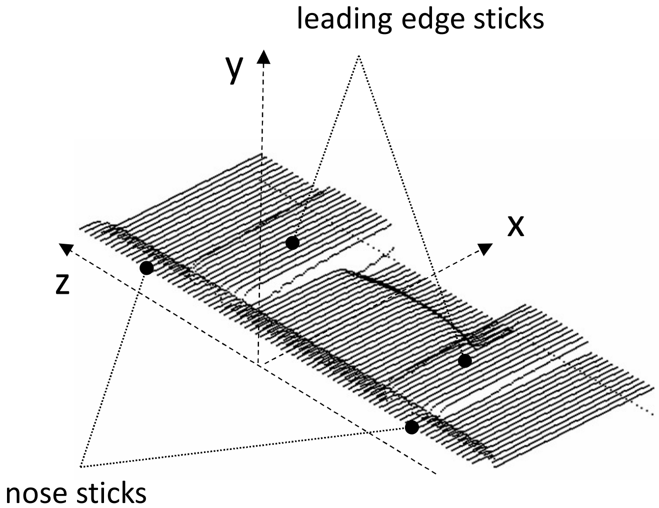
TPS modelling

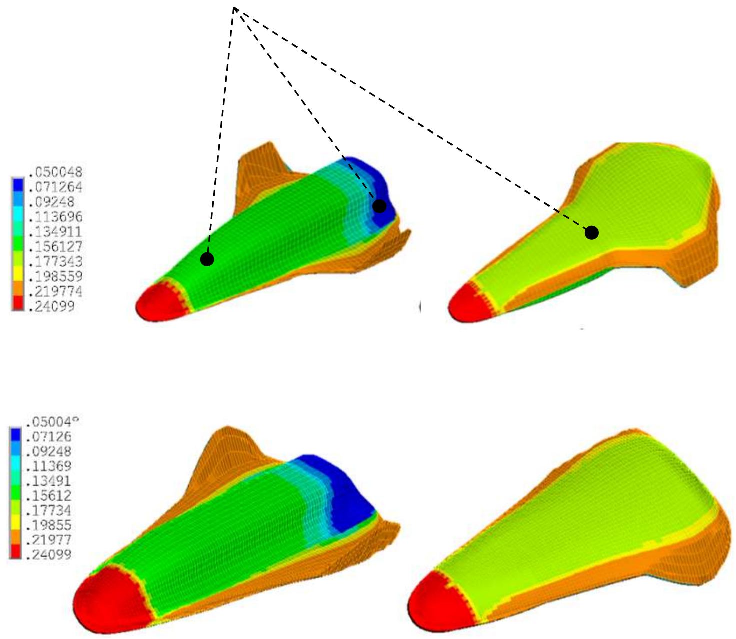
Sticks positions assigned accordingly an (arbitrary) covering in regions of expected heating:

- Sticks are placed on vehicle nose; leading edge; leeward
- Thickness is assigned manually tuned accordingly:

Topology map projected on panel surface;

a) Freedom to choose the thickness distribution;
b) Same TPS mapping is preserved on different RLV;



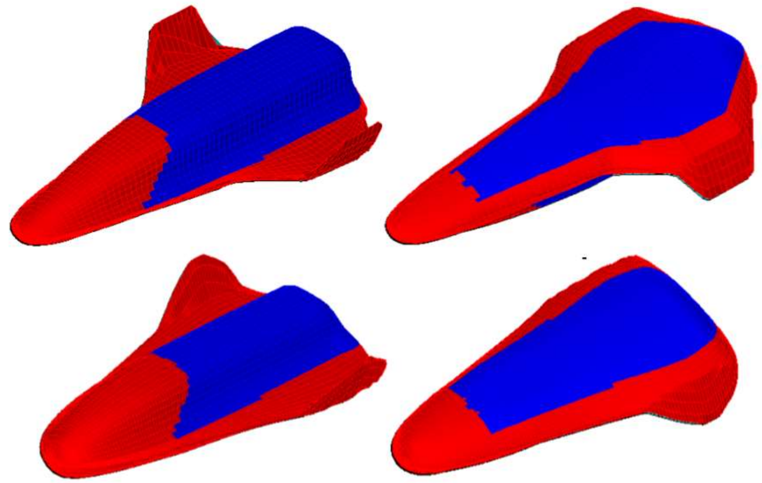


Material modelling distribution

A completely independent stick-based parameterization models material distribution;

Test case: we assume a generic material 1 (red) to outperform material (2)

- Material 1: adopted on nose, leading edge and trailing edge
- Material 2: other regions of vehicle surface



Material modelling distribution

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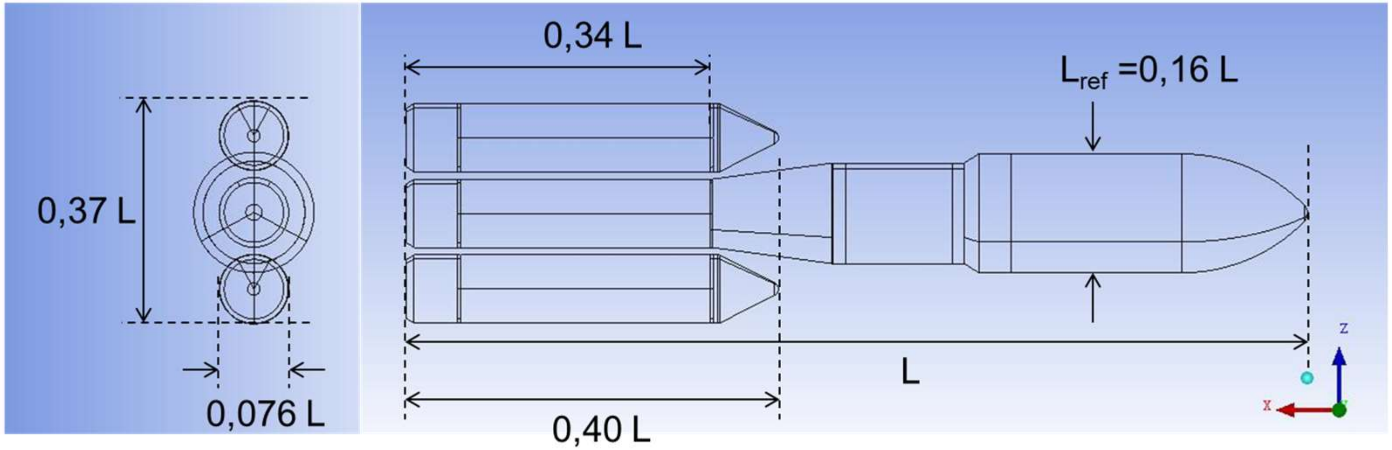
Launcher configuration under investigation



The aeroshape under investigation features two boosters and a central core stage with hammerhead fairings

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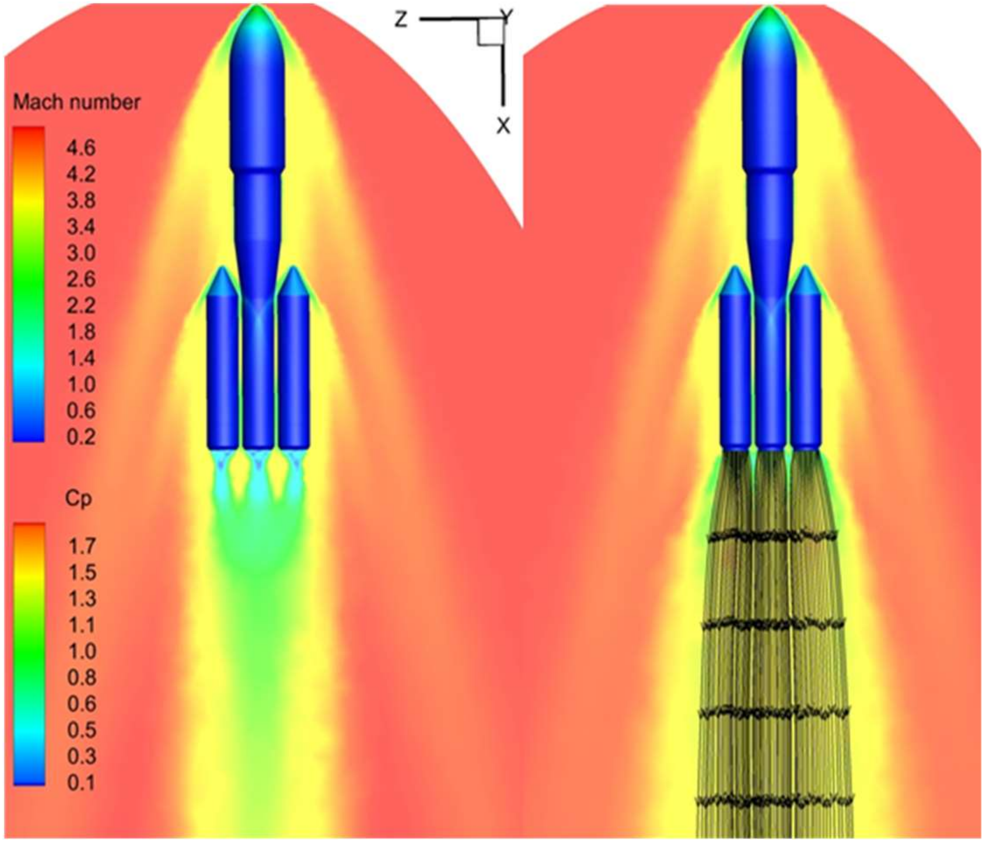
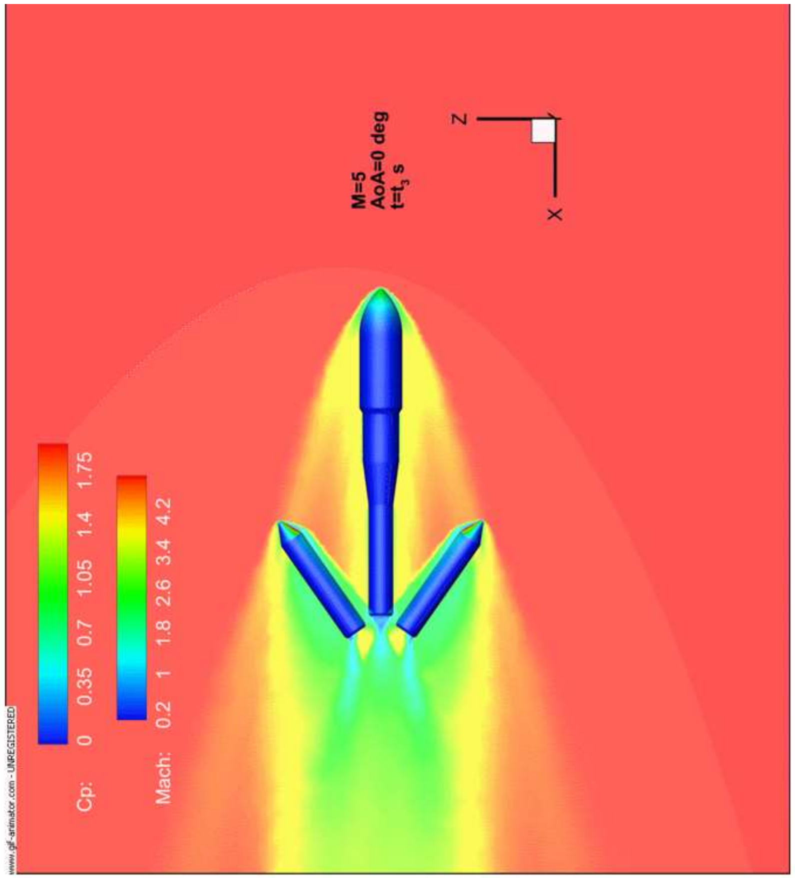
Launcher configuration under investigation



Mach contours at $M_{\infty}=5$ and $\alpha=0$ deg with pressure distribution on the surface. Comparison between Motor-off and Motor-on conditions.



Boosters' separation dynamics

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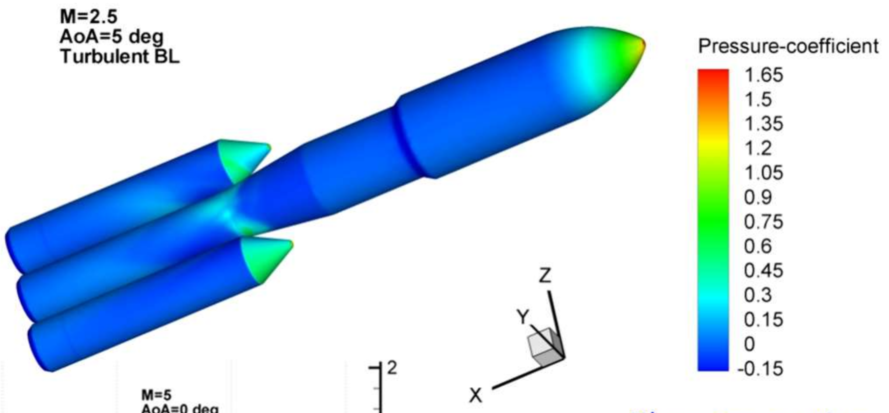
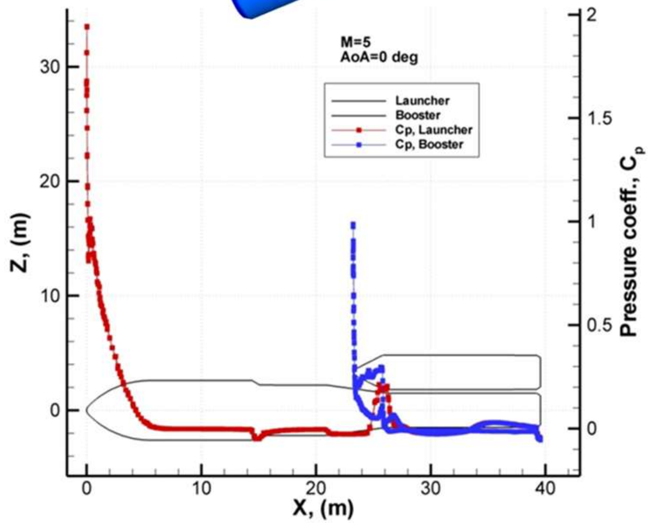
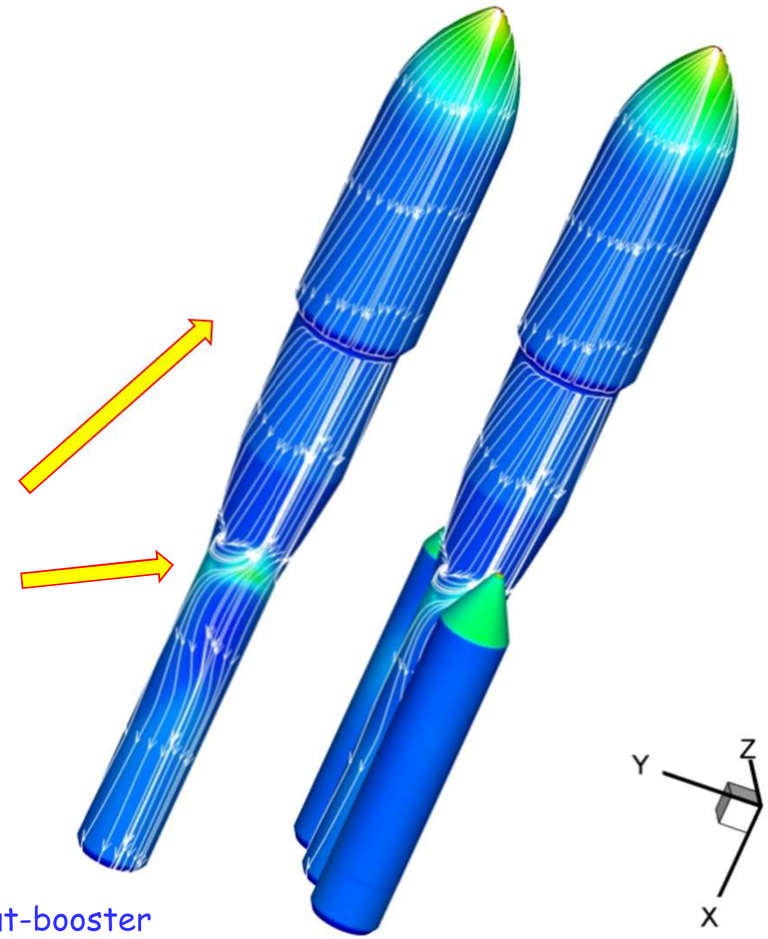
CFD Analysis

Overview of pressure field on launcher surface at M=2,5 and α=5 deg with skin frictions





Flow separation bubble at fairing boat-tail and effect of fuselage-booster shock-shock interaction



without-booster

with-booster

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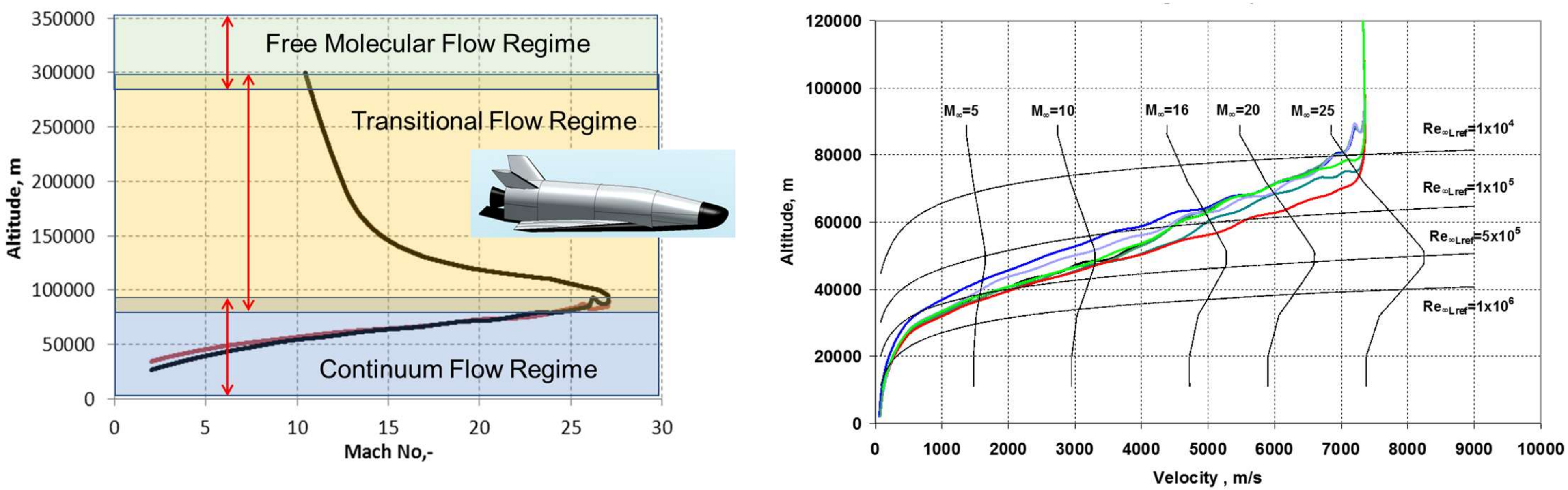
Flight Regimes Assessment



Flight scenario in the Velocity/Mach-Altitude map.

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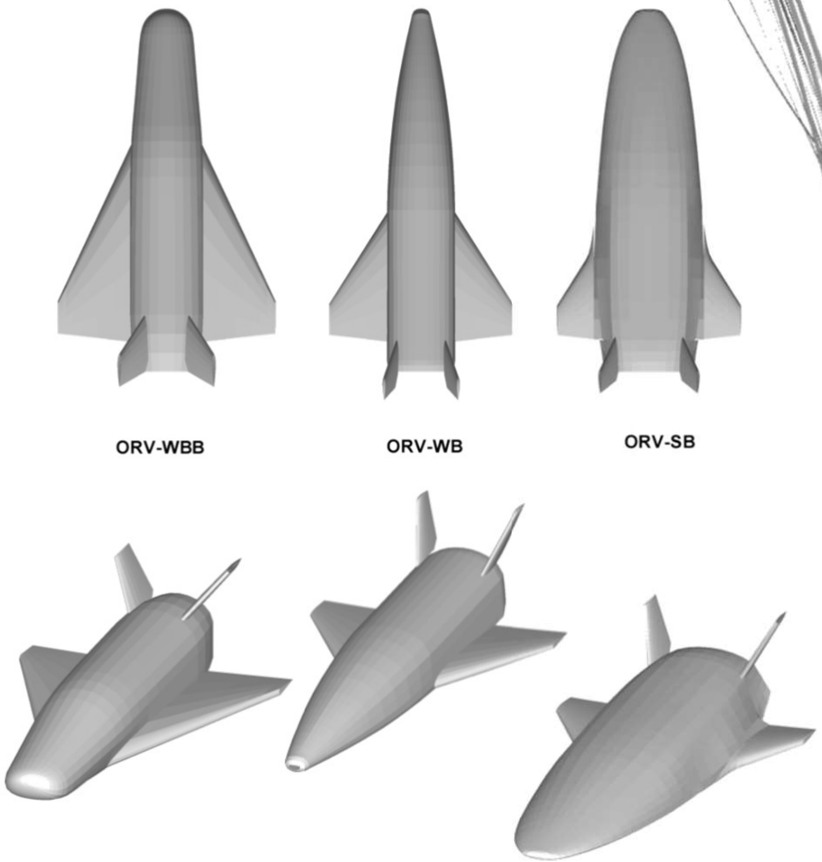
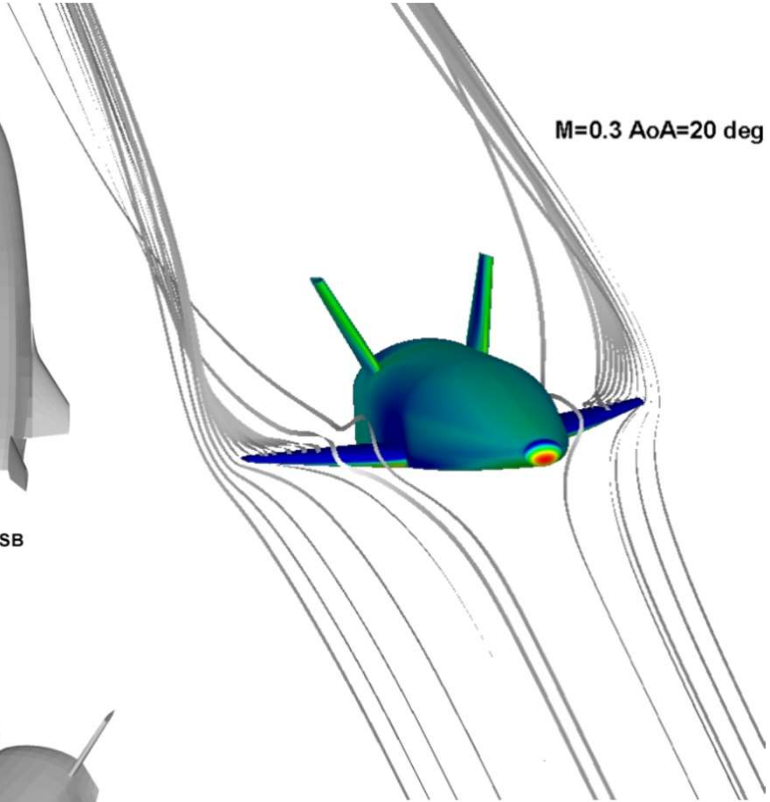
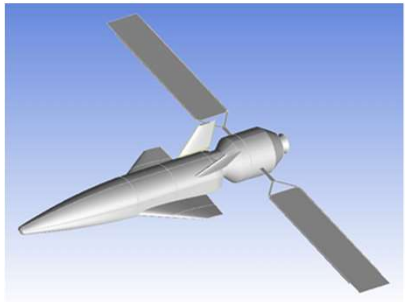
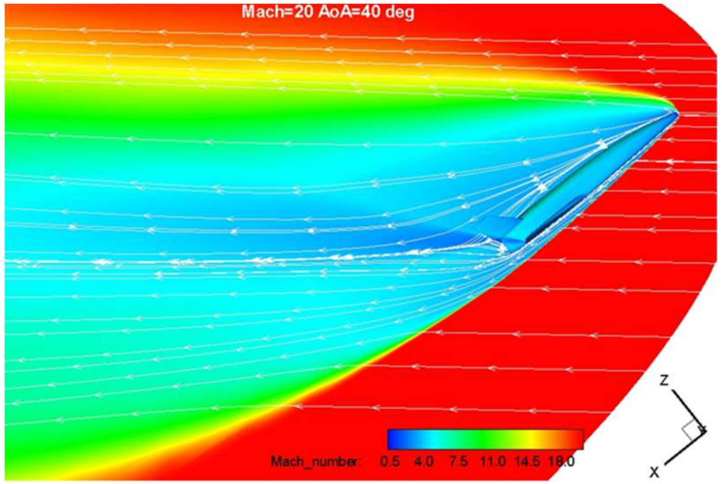
Winged configurations under investigation









WBB: winged bluff body
WB: winged body
SB: spatuled body

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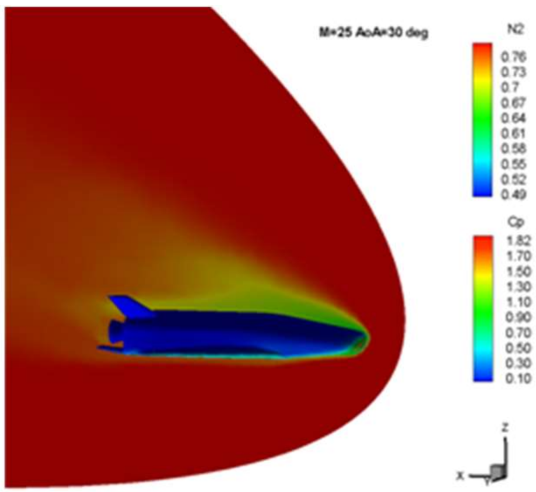
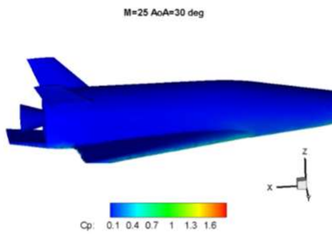
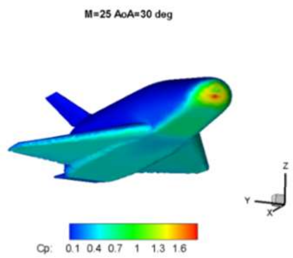
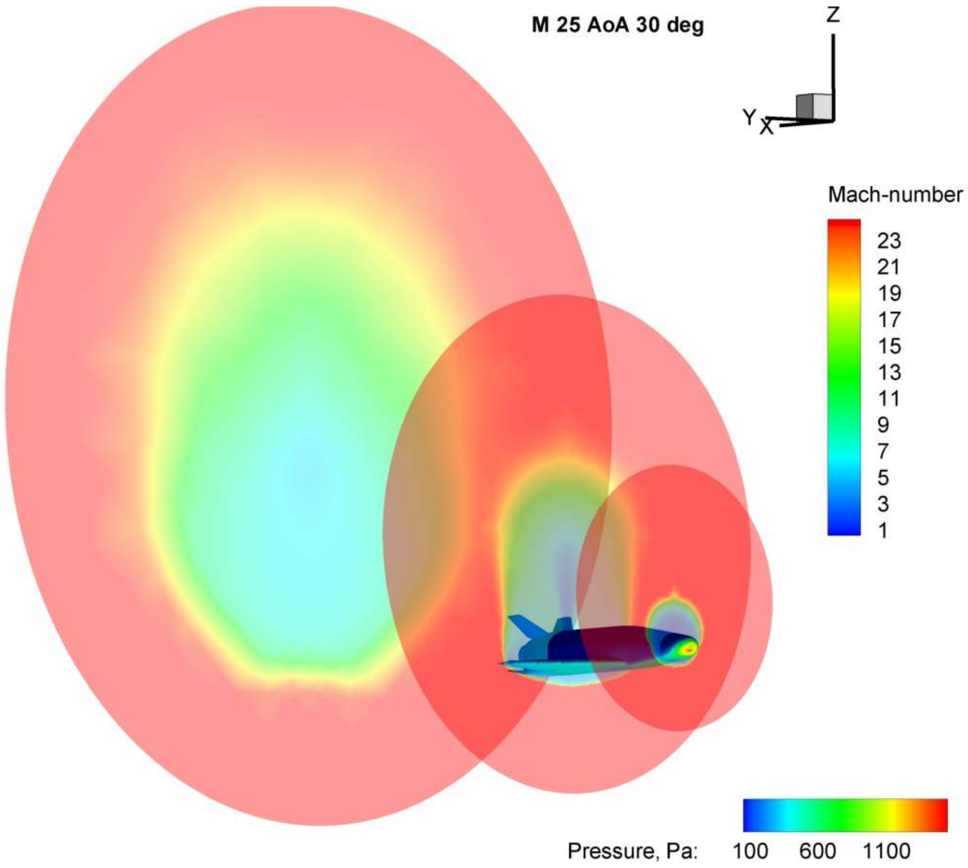
Design results









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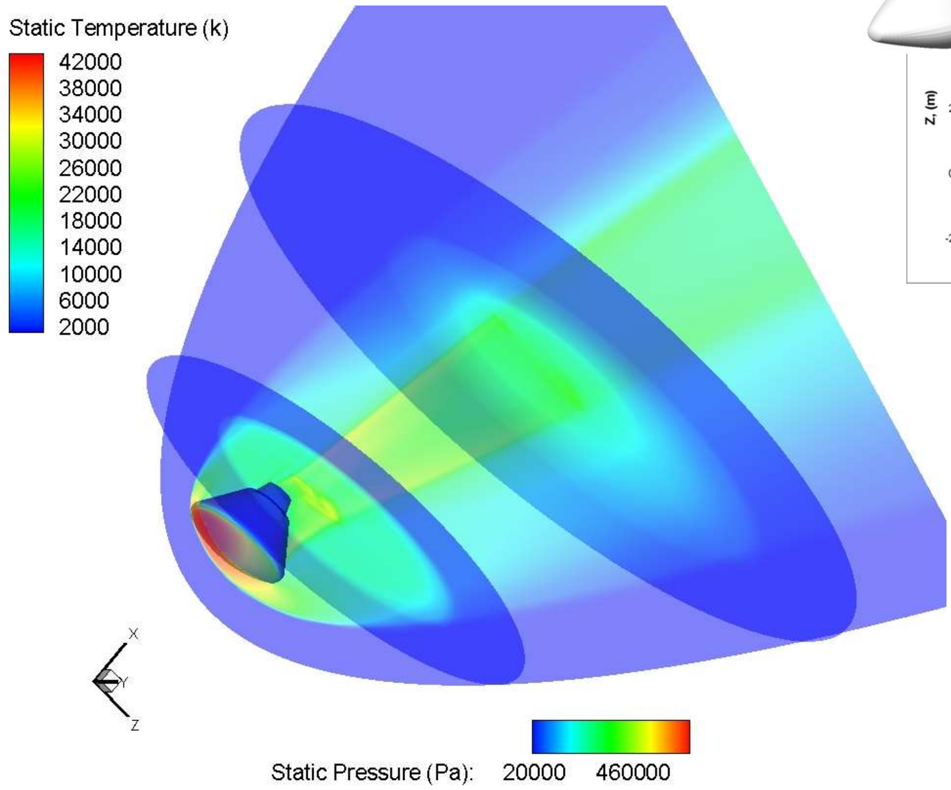
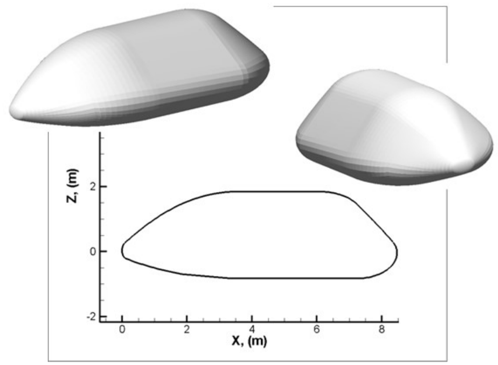
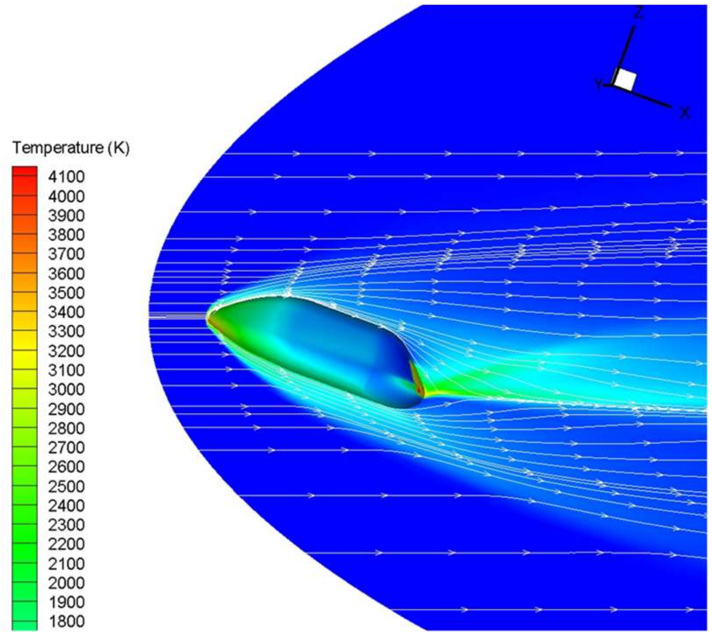
Lifting Body configurations under investigation



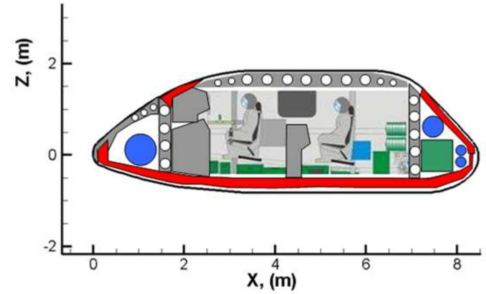
M_∞=20 AoA=20 deg





Static Temperature contours @ M_∞=9 AoA=20 deg

Crew Accommodation



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