# Evaluation of Future Ariane Reusable VTOL Booster stages

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# Introduction

**The launcher market is changing quickly, many new launchers will enter on the market in the coming years:**

- **Ariane 6, H3, Falcon Heavy, Vulcan, New Glenn, GSLV Mk. III, …**

**New solutions have to be implemented to guarantee competitiveness: reusability or new propellant could be some of them**

**DLR is performing a systematic analysis of different first stage return systems:**

- **Fly Back**
- **In Air capturing**
- **Return to Launch Site**
- **Down-range Landing**

Fly Back, In Air capturing: winged

Return to Launch Site, Down-range Landing: ballistic

**Propellant combinations considered: LOx/LH2, LOx/LCH4, LOx/LC3H8 and sub-cooling**



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# Overview

- **Assumptions**
- **Trajectory overview**
- **Validation**
- **Preliminary design (iterations 1 and 2)**
- **Aerothermal analysis and structure temperature evaluation**
- **Conclusions**



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# Assumptions

- **Launch from CSG**
- **Sizing mission: 7 tons into GTO (+ 500 kg project margins)**
- **TSTO architecture (generic launcher)**
- **Same engine in both stages (longer nozzle for the upper stage)**
- **Three stagings determined by fixed ΔV (6.6 km/s, 7.0 km/s and 7.6 km/s) of the upper stage**
- **Return to launch site (RTLS) and down range landing (DRL) considered**
- **Dry mass:**
  - **1st iteration pre-assumed structural index**
  - **2nd iteration structural preliminary sizing + margins**

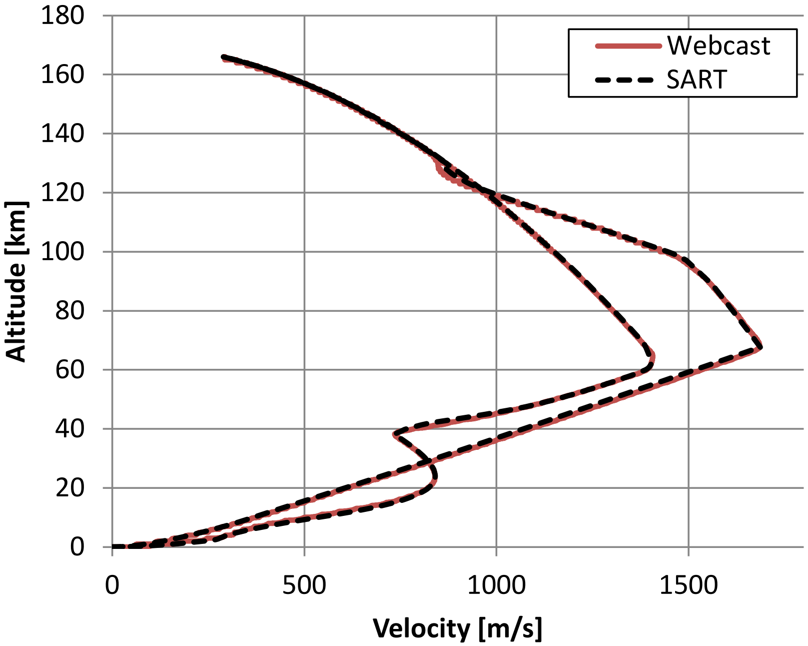
# RTLS and DRL



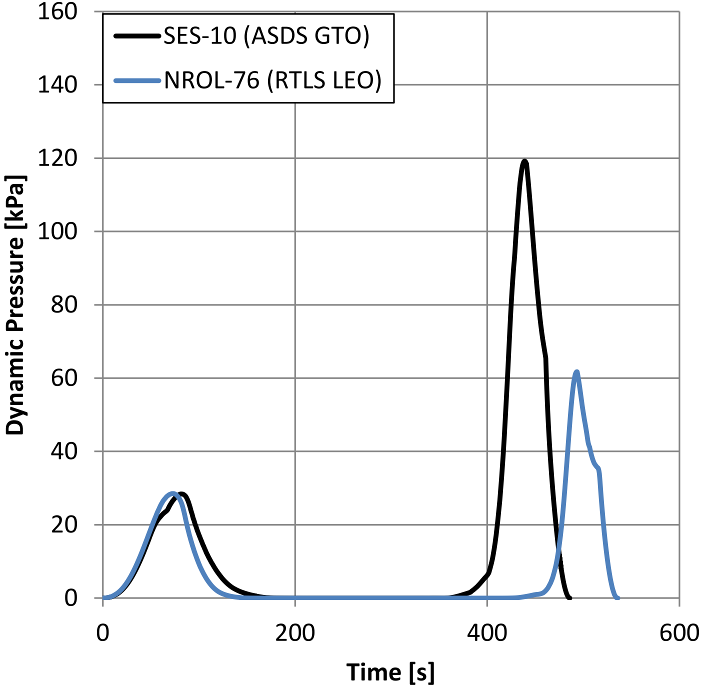

Examples of RTLS (return to launch site) and DRL (down range landing) trajectories

# Validation: Falcon 9 flight simulations

- **Example of the SES-10 and the NROL-76 flights**

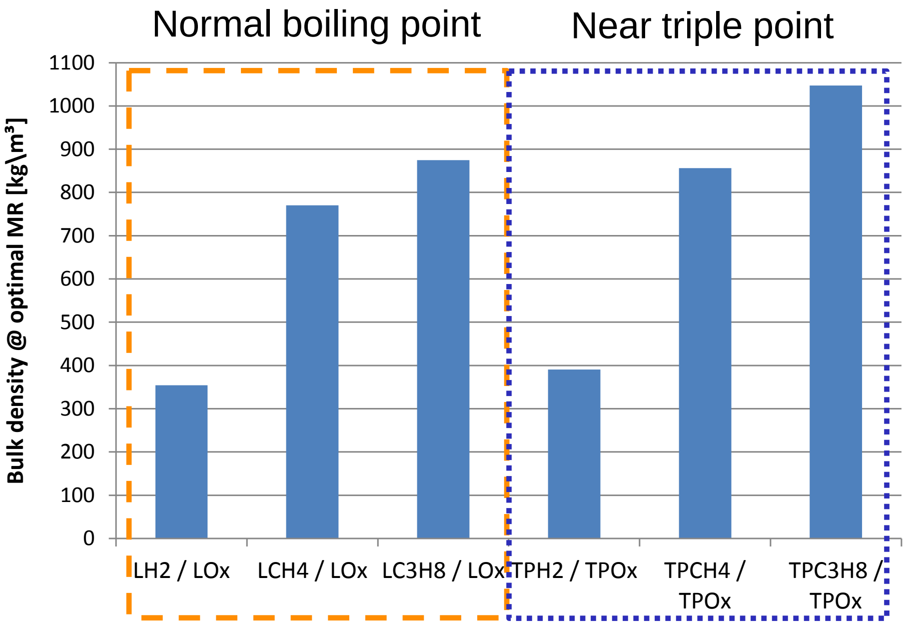



NROL-76 first stage

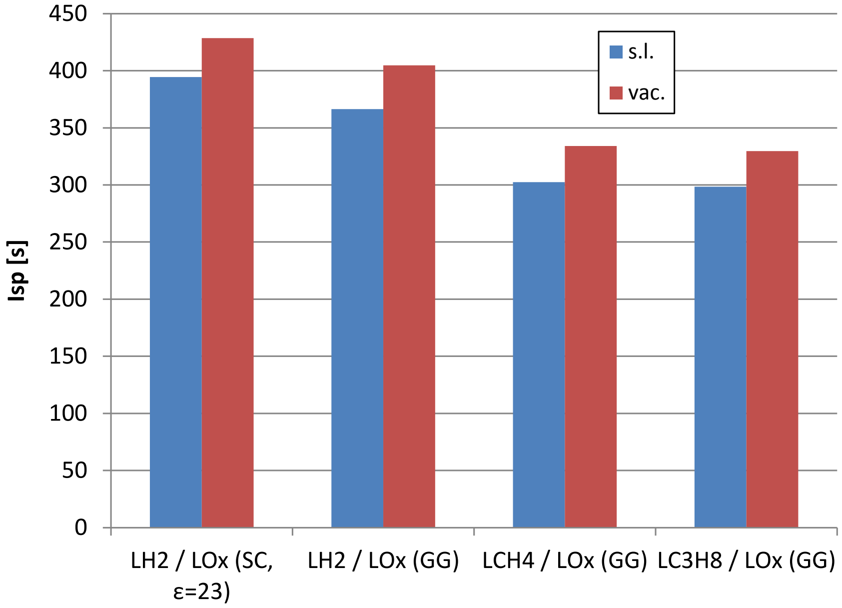


# Preliminary design

- **Propellants**
  - LC3H8 has a large densification potential

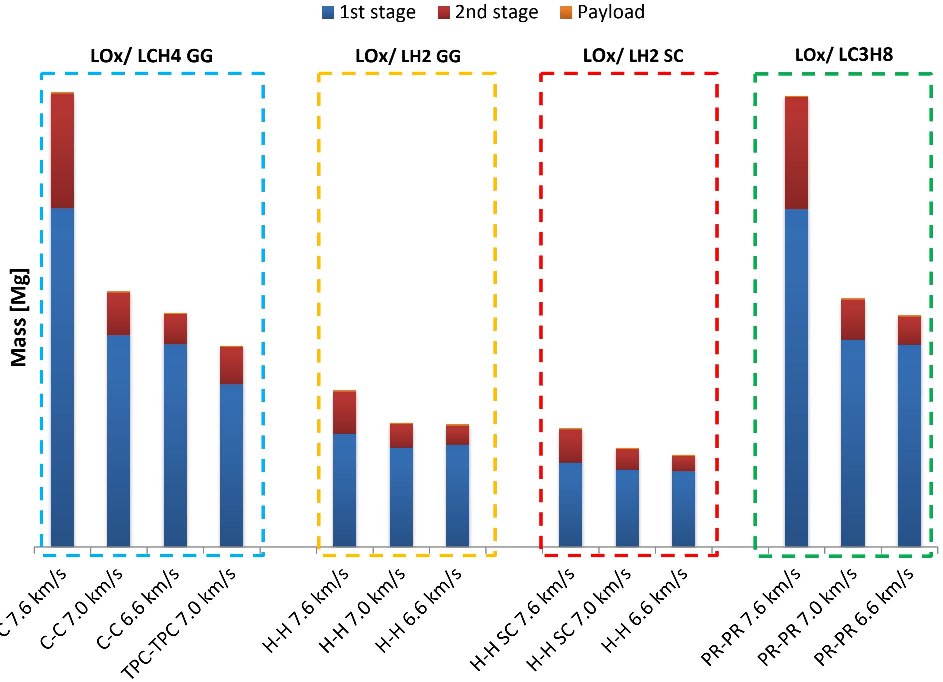


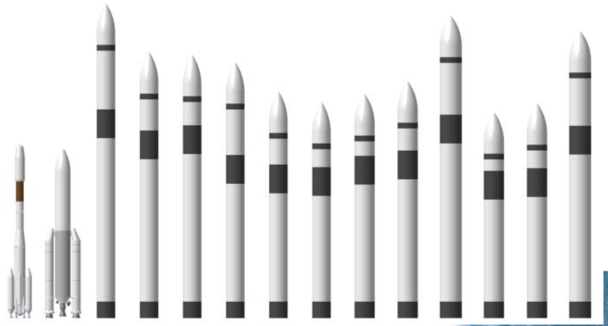

- **Engines**
  - 1st stage nozzle extension chosen to avoid flow separation at landing at low thrust level



# Preliminary design: 1st iteration

- **Main results**
  - RTLS: all solutions require very large stages, not very interesting for TSTO flying into GTO
  - DRL: optimum engine number strongly dependent on propellant
  - DRL: lower stage size is not decreasing with increasing upper stage $\Delta V$
  - DRL: LC3H8 launchers have some advantages over LCH4





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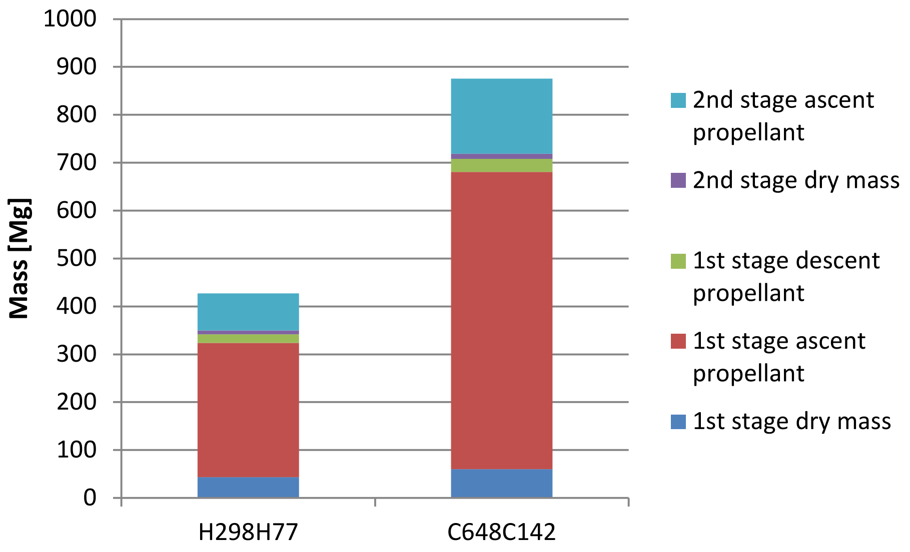
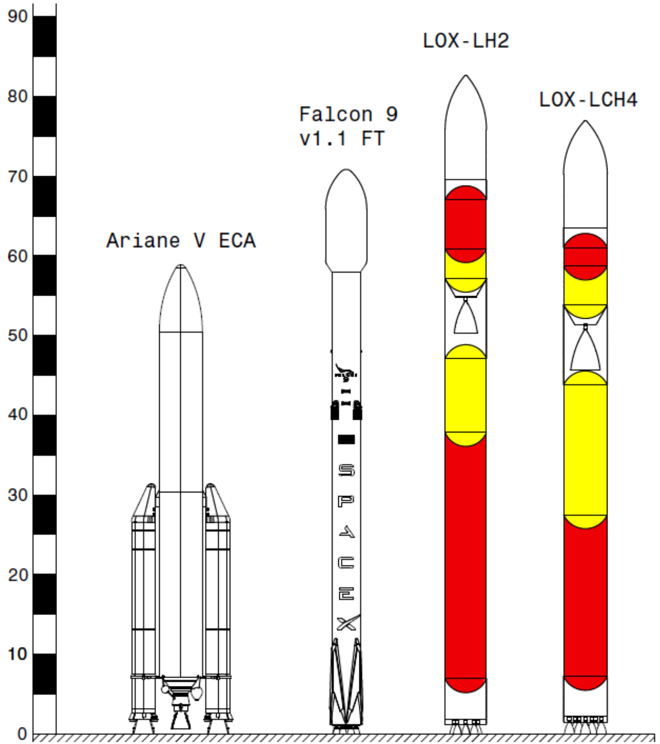
# Preliminary design: 2nd iteration (DRL)

- **Main results**
  - Strong mass decrease due to light upper stage
  - LCH4 configuration slightly larger than the LH2 one in volume and double in mass

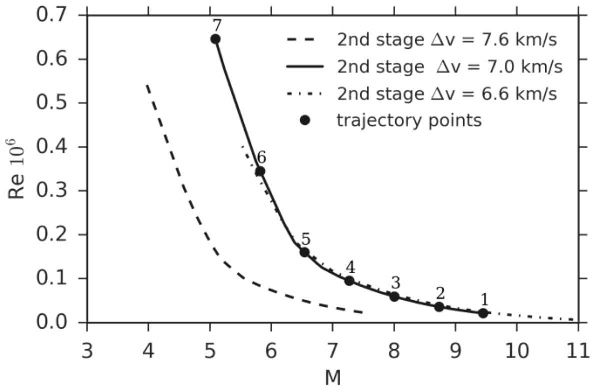


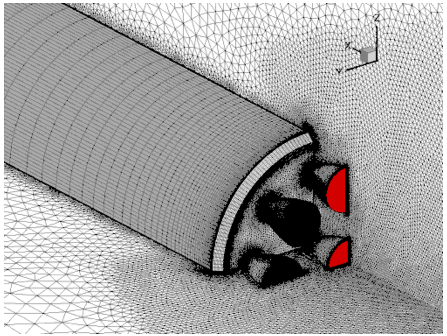



# Aerothermal analysis

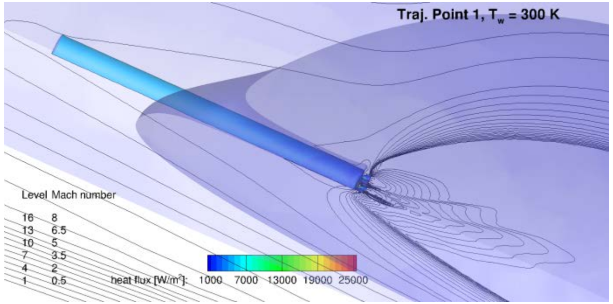
- **Aerothermal database**
  - Several RANS calculations at different trajectory points and fixed uniform wall temperatures were performed.

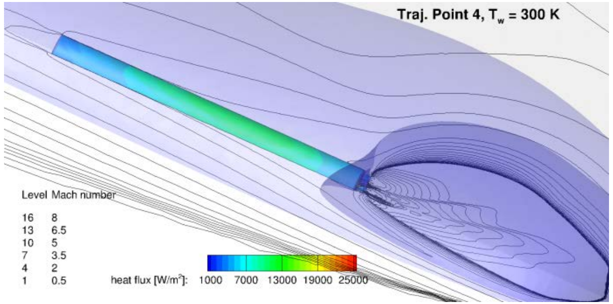
- **Numerical domain and boundary conditions**
  - Exhaust gas composition was determined from equilibrium and held frozen.
  - Zero angle of attack
  - Uniform wall temperatures (300 and 400 K)
  - Internal nozzle wall temperature set to 1000 K

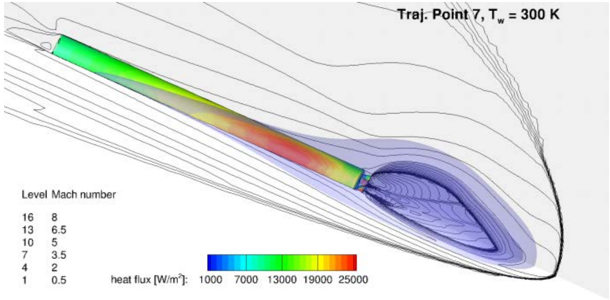


# Aerothermal database

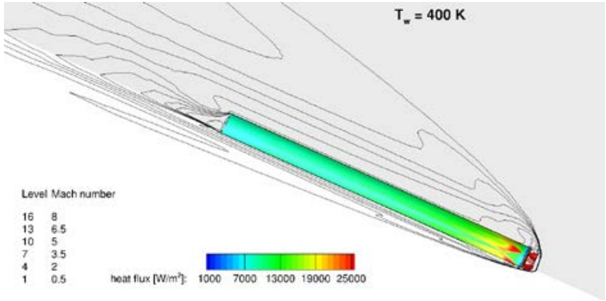



**End of retro-propulsion**

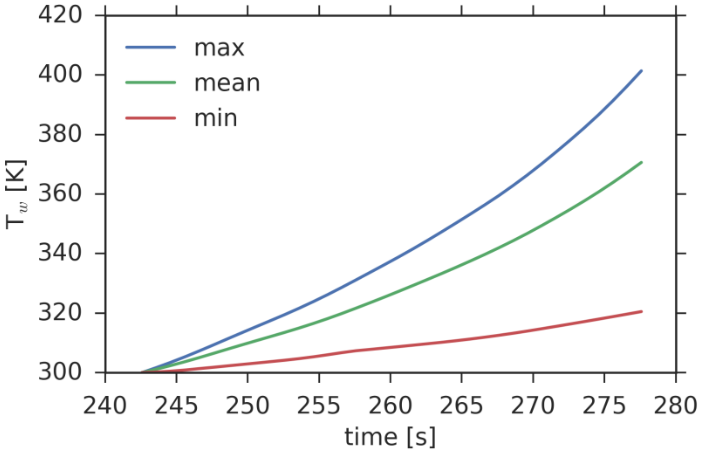
- **Plume flow development**
  - Plume extension is strongly dependent on altitude.
  - Full immersion of vehicle at the beginning of retro-propulsion. Partial immersion at the end of the maneuver.
  - After retro-propulsion heat flux peaks on lower skirt and nozzle region.

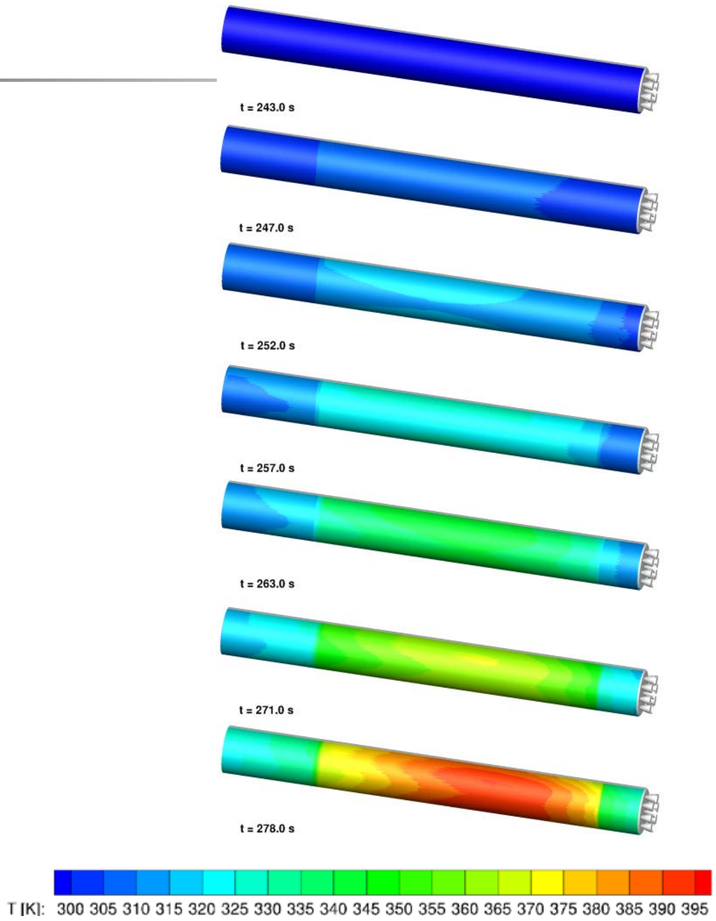



**After retro-propulsion**

# Surface temperature evolution

- **Aerothermal database and wall temperature estimation:**
  - Wall temperature at t = 0 s is estimated at 300 K
  - Lumped mass, 0D heat transfer model (wall thickness non uniform along the streamwise axis)



# Conclusions

- **RTLS**
  - TSTO vehicles able to launch 7 tons to GTO have a low economic relevance

- **DRL**
  - TSTO performing GTO missions have reasonable sizes and masses
  - LOx/LH2 versions are twice as light as LOx/hydrocarbon versions
  - The LOx/LCH4 versions are the bulkiest of all, the LOx/LC3H8 is the less bulky
  - Densification has a large potential for improvement, especially for propane
  - Larger upper stage $\Delta V$ leads to larger lower stage
  - Most heat loads on the sidewall are taking place during the retro-propulsion, the temperature increase can get high in low thickness structures place in the bottom of the vehicle

  - Main goal is to compare costs but it is tricky due to a lack of knowledge of the operational costs.
    - Demonstrators are required