RETALT
RETro propulsion Assisted Landing Technologies

AERODYNAMIC PHENOMENA OF RETRO PROPULSION DESCENT AND LANDING CONFIGURATIONS

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HORIZON 2020
European Union funding for Research & Innovation

Overview

- Wind Tunnels at DLR in Cologne
- Configurations
- Trajectories and test conditions
- Wind Tunnel Test results:
  - Aerodynamic phase – TMK – RETALT1
  - Re-entry burn – H2K
  - Landing burn – VMK
  - Aerodynamic phase – TMK – RETALT2
- Conclusion and Outlook

Overview Wind Tunnels at DLR in Cologne

H2K
(Hypersonic Wind Tunnel Cologne)

- Mach: 4.8 - 11.2
- Blow down facility (pressure-vacuum)

TMK
(Trisonic Wind Tunnel Cologne)

- Mach: 0.5 – 4.5 (w/o ejector)
- Continuously adjustable Laval nozzle and diffuser

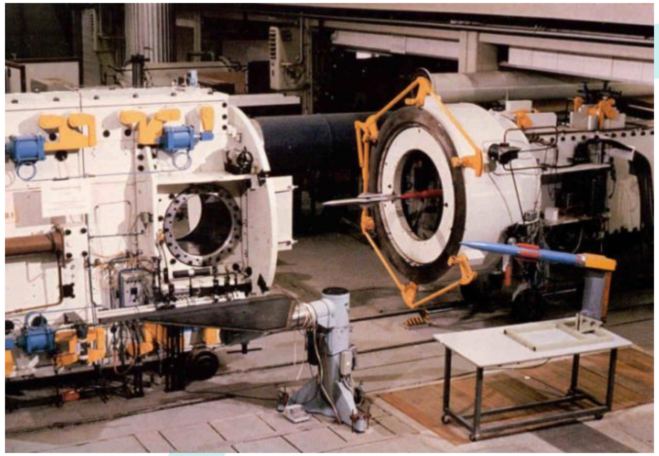
VMK
(Vertical Free Jet Facility Cologne)

- Atmospheric free-jet facility
- Ma = [0.4, 0.95], [1.5, 3.2]

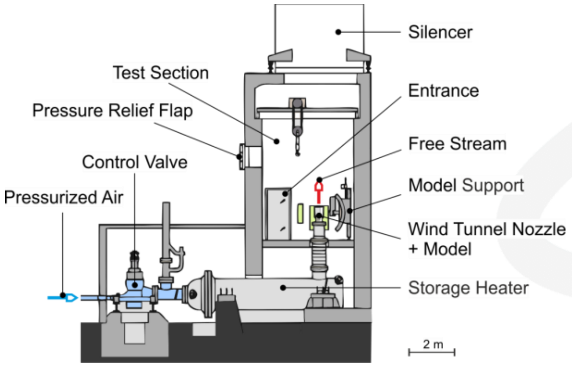
VMK – GOX/GH2 Test Stand Infrastructure

- Add-on to our Vertical Wind Tunnel (VMK)
- Plume of up to 115 bar and 3600 K stagnation conditions

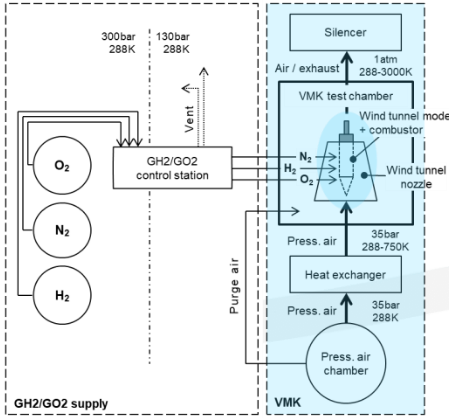
H2K – Test section



TMK – Test section



Schematic of VMK



Schematic GOX/GH2 Test Stand

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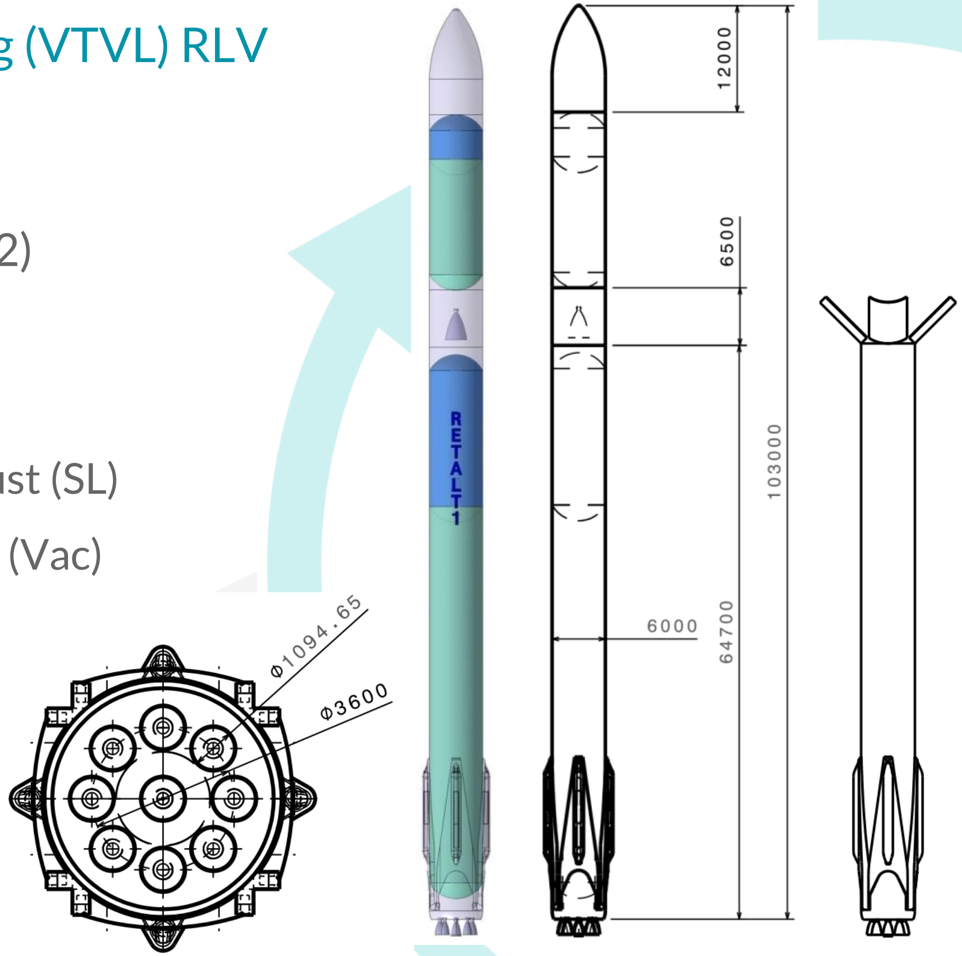
RETALT1

- Two Stage To Orbit (TSTO) Vertical Take-off Vertical Landing (VTVL) RLV
- Payload capacity: 14t to Geostationary Transfer Orbit (GTO)

  - LOX/LH2 Gas Generator (GG) engines (similar to the Vulcain 2)
  - Stage 1: 9 engines
  - Stage 2: 1 engine (similar to first stage engine)
  - Stage 1 engines adapted to sea level conditions - 1179 kN Thrust (SL)
  - Stage 2 engine adapted to vacuum conditions - 1364 kN thrust (Vac)
  - Height: 103 m
  - Diameter: 6 m
  - Take-off Mass: 899 t
  - Retro propulsion and the novel aerodynamic control surfaces (interstage segment)



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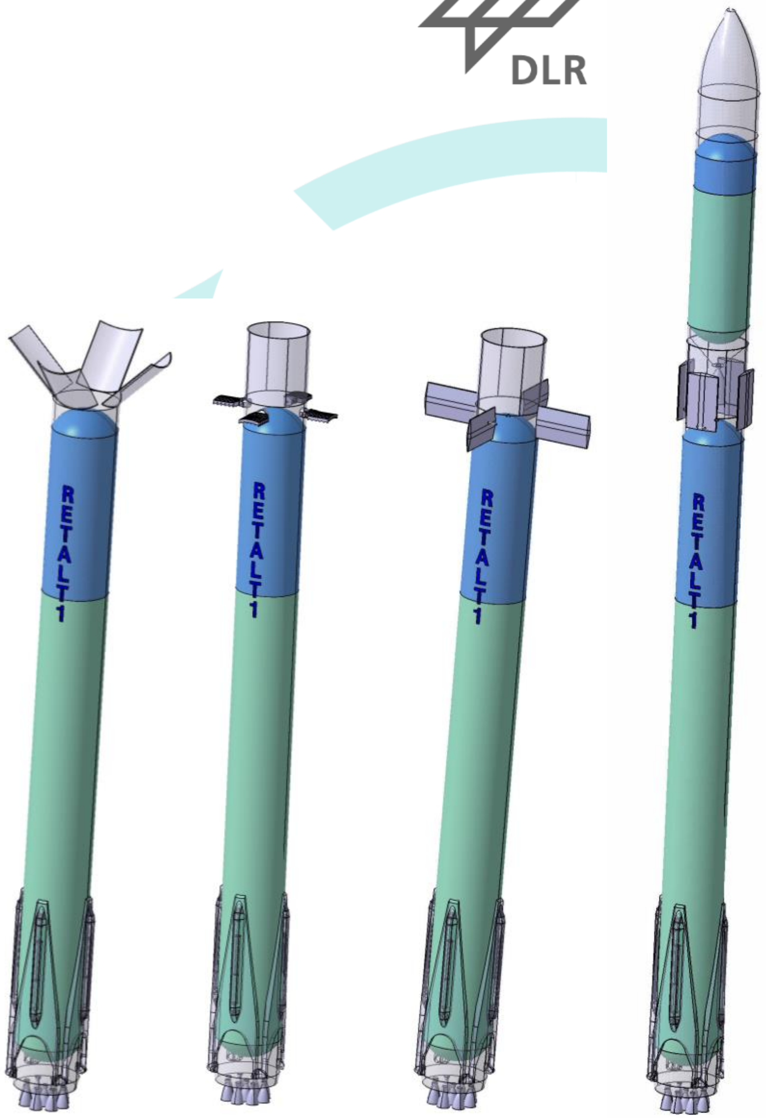
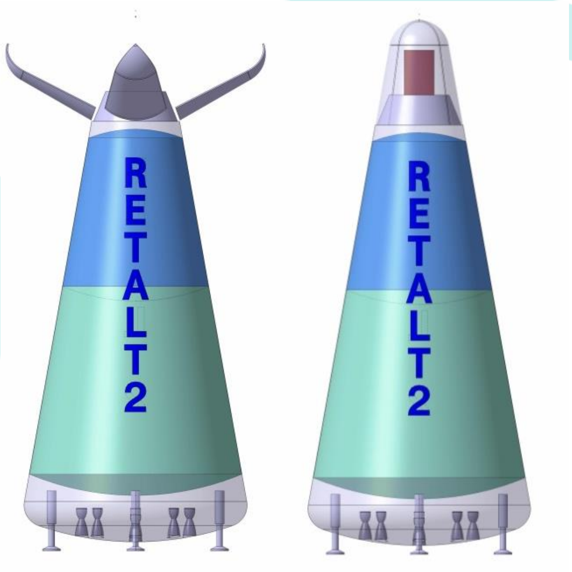
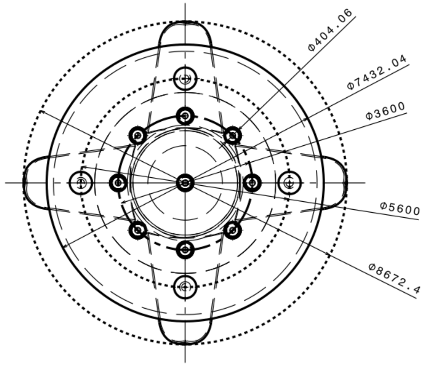


RETALT2

- Single Stage to Orbit (SSTO) Vertical Take-off Vertical Landing (VTVL) RLV
- Payload capacity: 0.5t to Low Earth Orbit (LEO)
  - LOX/LH2 engine (similar to Vinci) adapted to sea level conditions
  - 9 identical engines - 370 kN thrust (Vac)
  - More academically: „technology test bed“
  - Retro propulsion + novel aerodynamic control surfaces (fairing section)
  - Aerodynamic braking: capsule-like shape + fairing segments
  - Nozzle exits flush with base plane of the vehicle
  - Heigth: 17.6 m
  - Diameter: 7.4 m
  - Take-off Mass: 79.4 t





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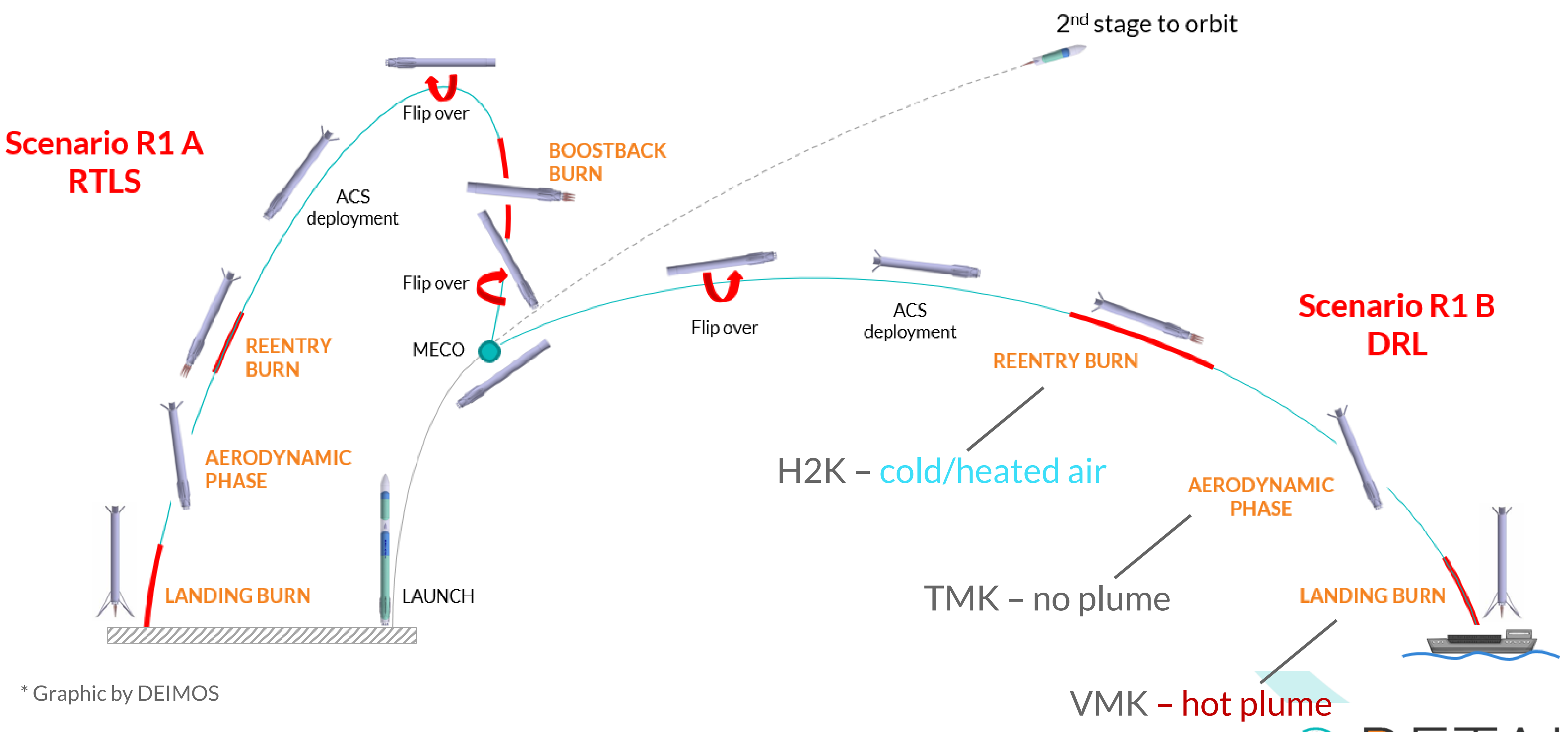
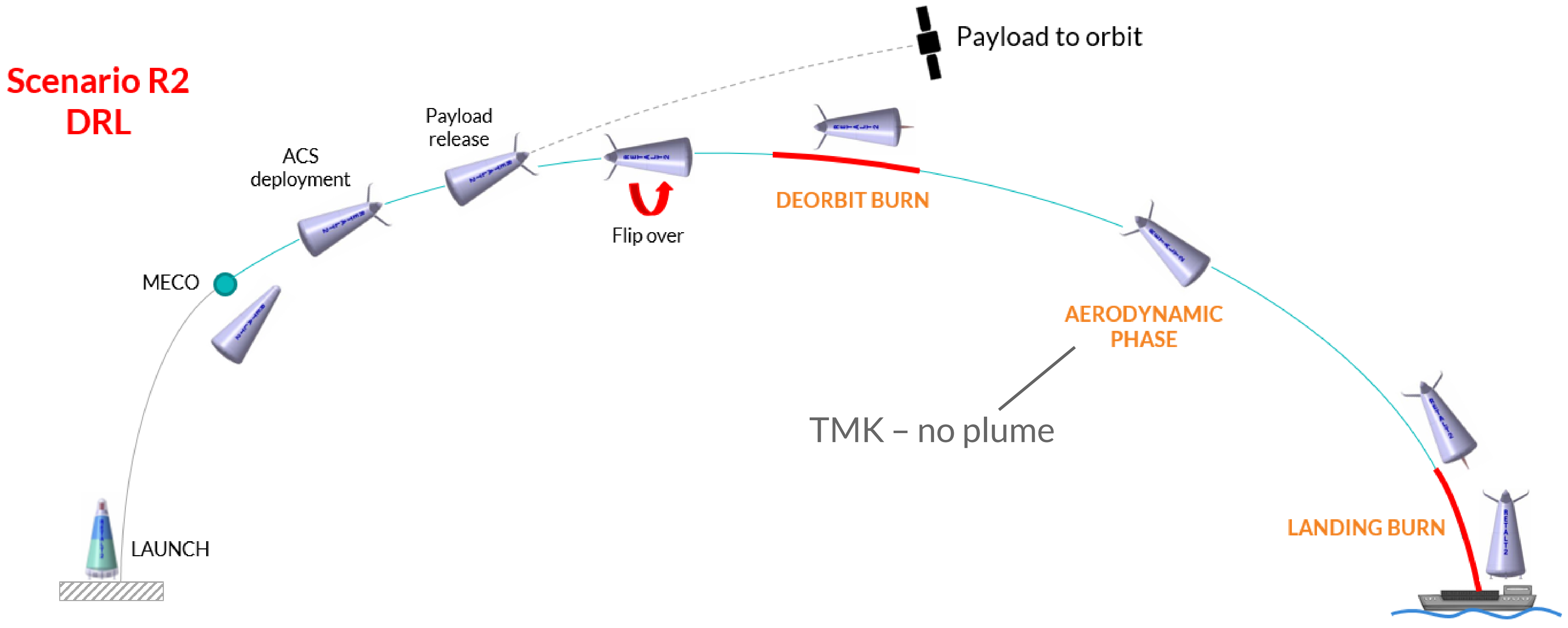
RETALT1 return mission concept



* Graphic by DEIMOS

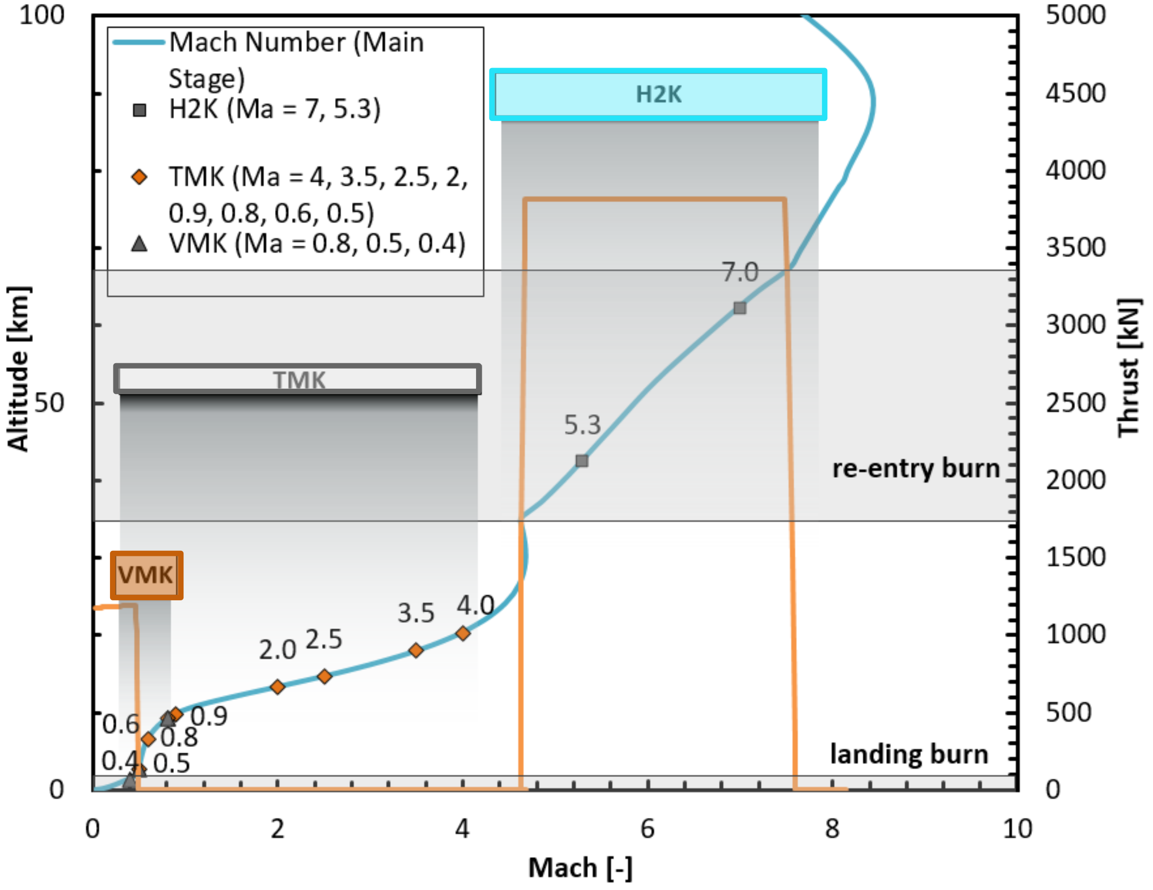
RETALT2 return mission concept



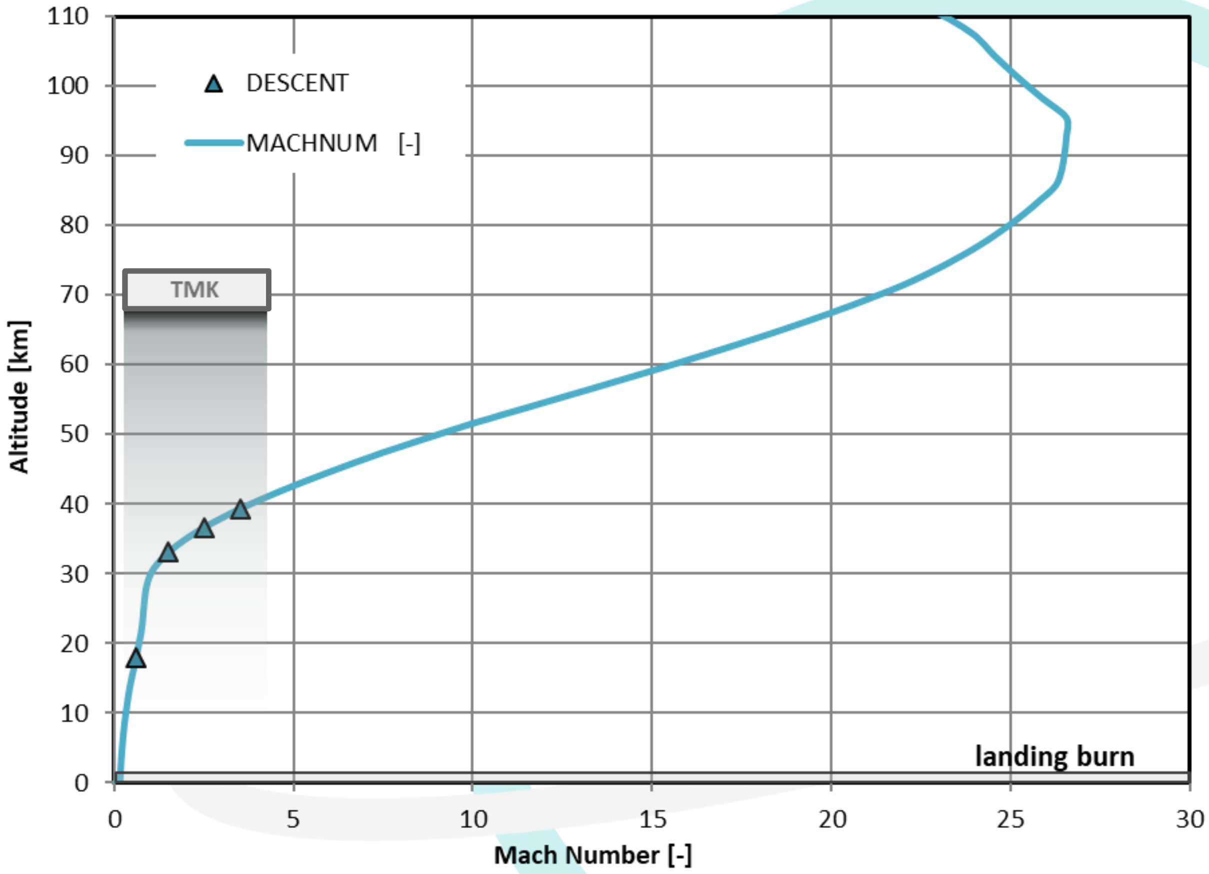
* Graphic by DEIMOS

Trajectories and Test Conditions

Cold plume
No plume
Hot plume



RETALT1



RETALT2

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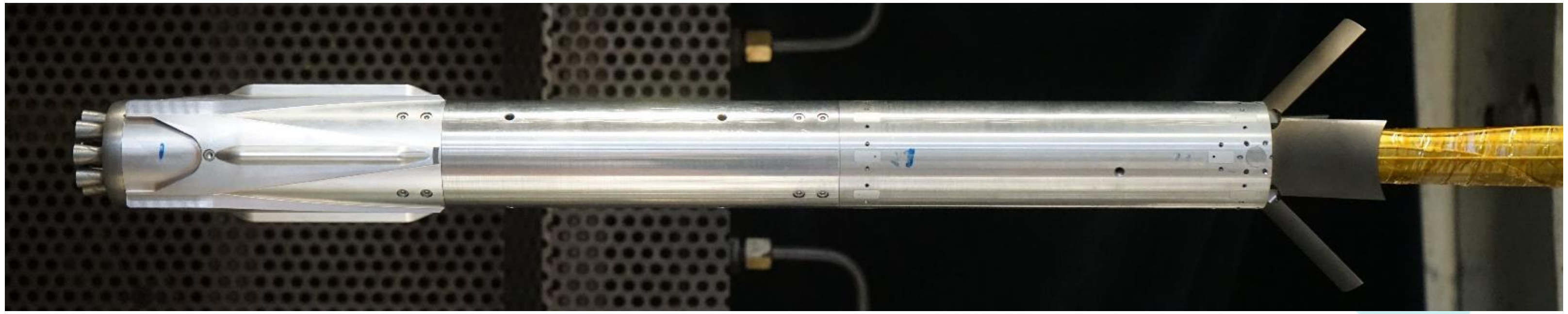
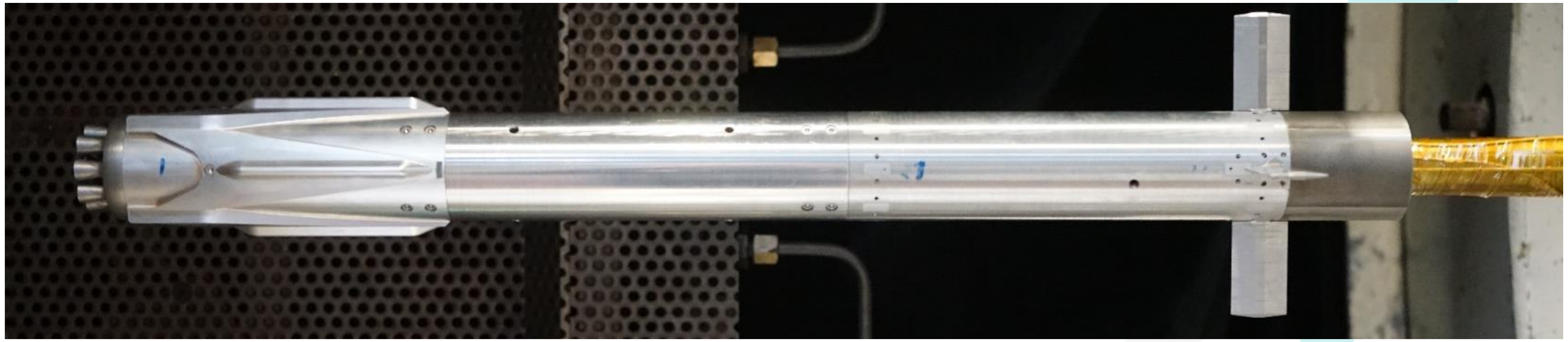
RETALT1 Wind Tunnel Model
in TMK

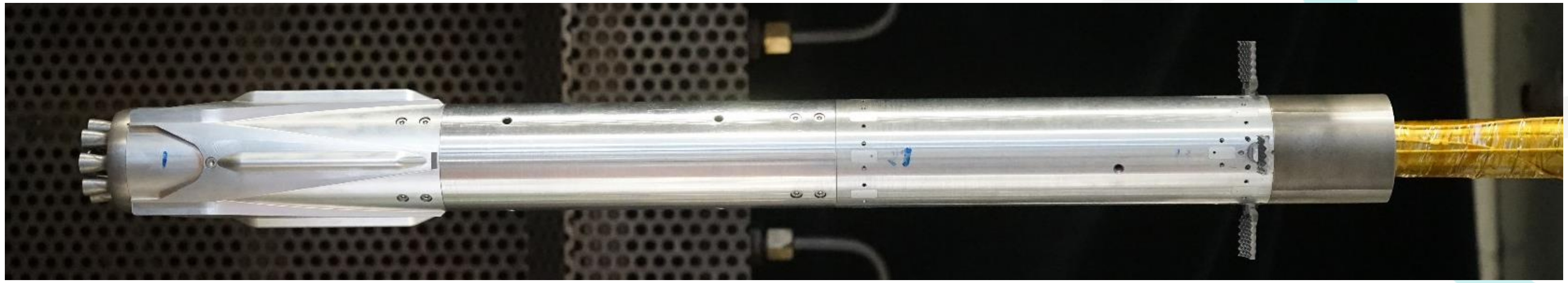
Petals



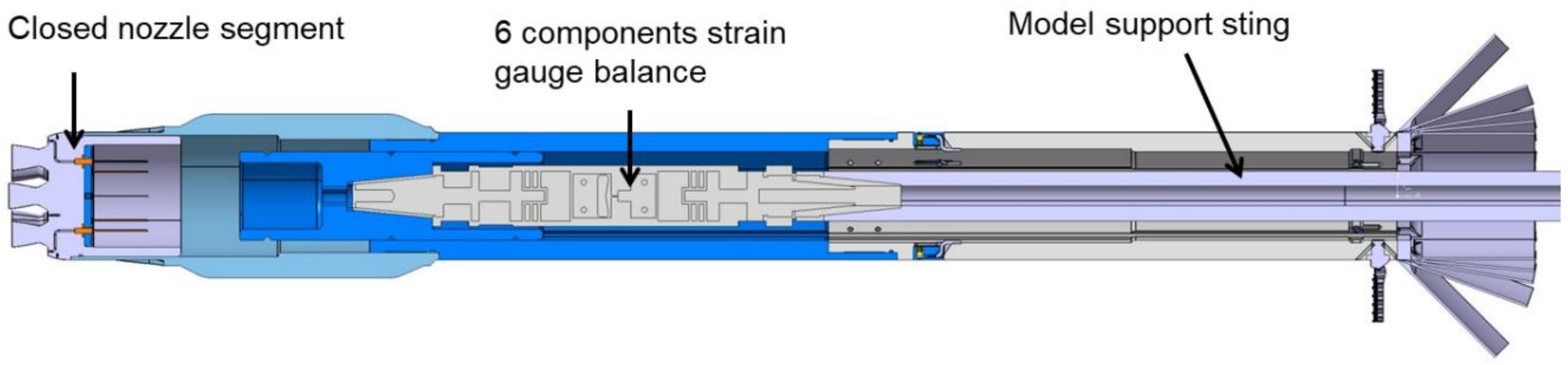
Planar Fins



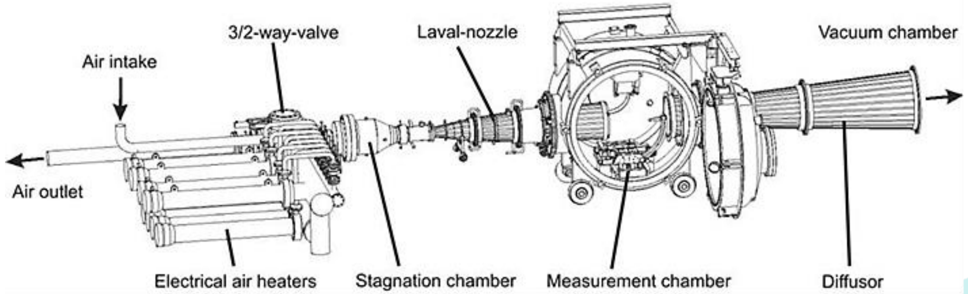
Grid Fins

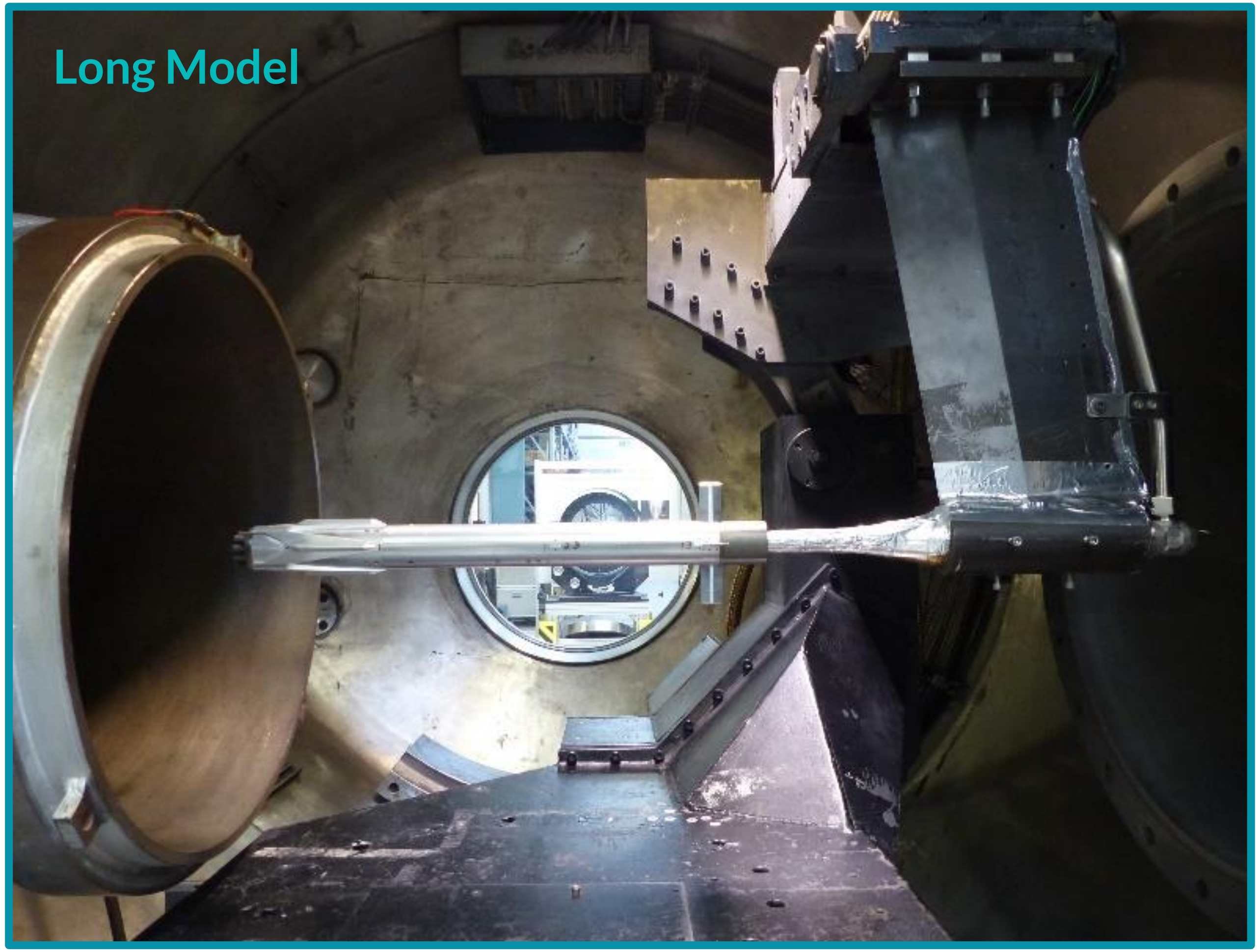


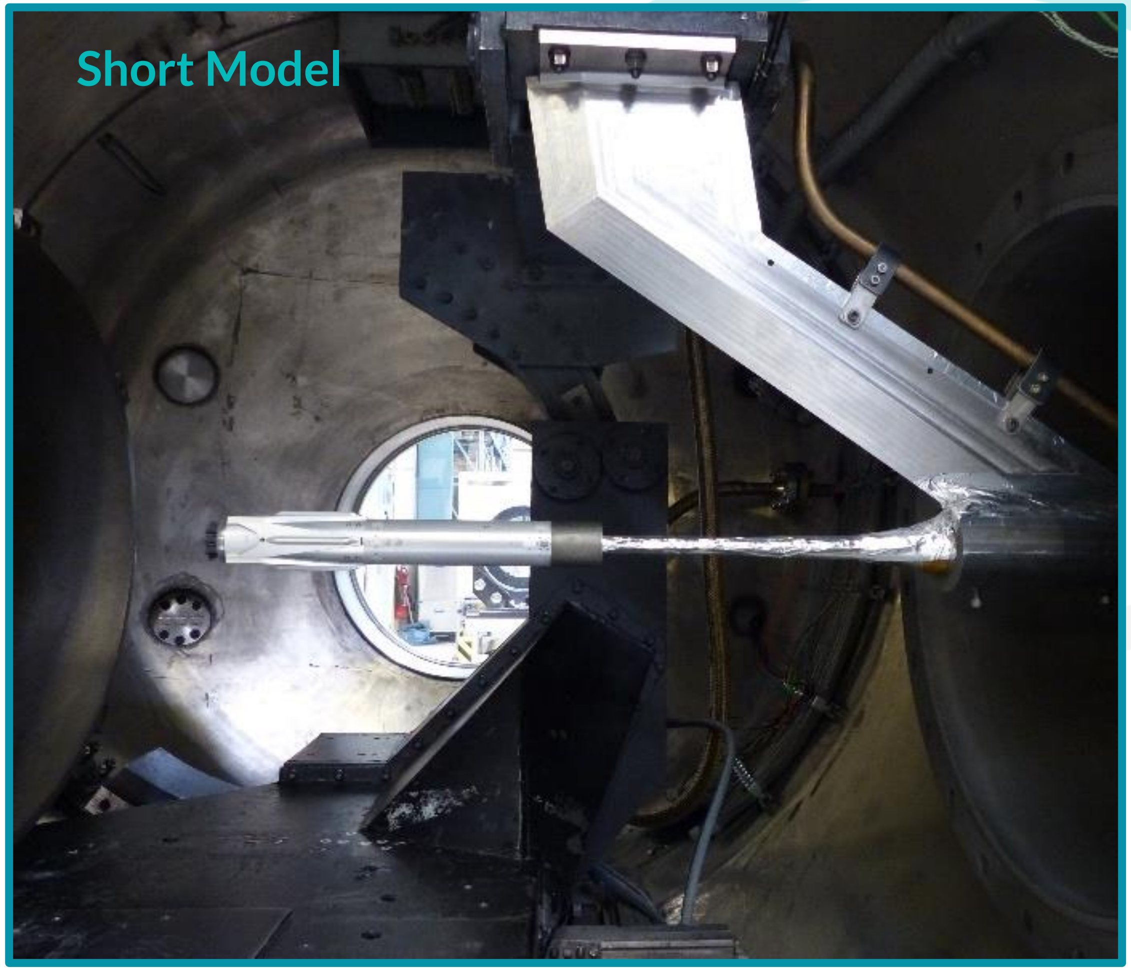
RETALT1 Wind Tunnel Model
in TMK



RETALT1 Wind Tunnel Model
in H2K

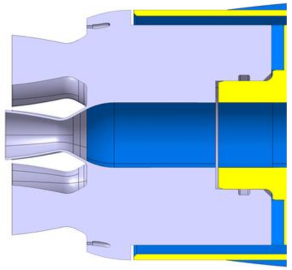




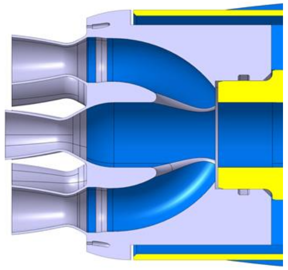


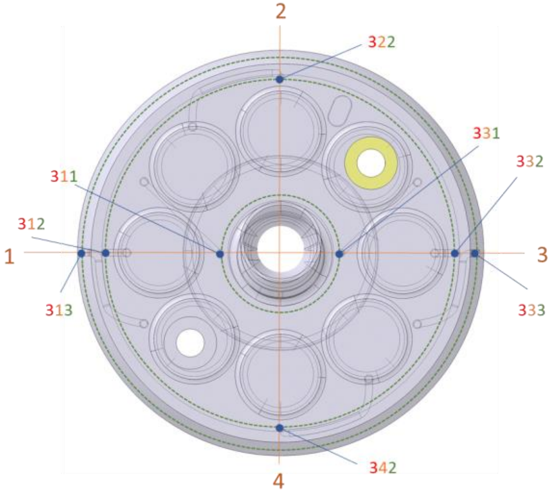
RETALT1 Wind Tunnel Model

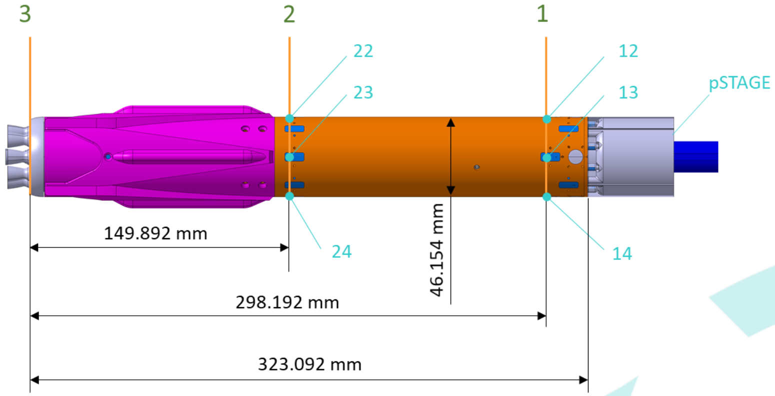
1 active engine
0° deflection



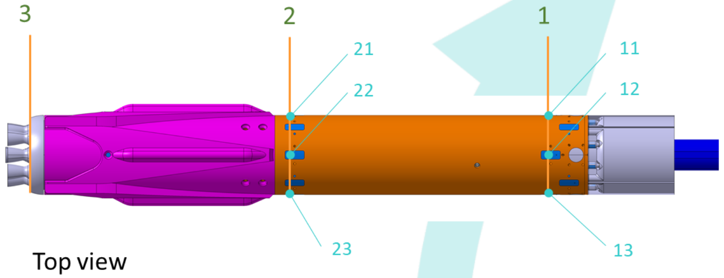
3 active engines
0° deflection



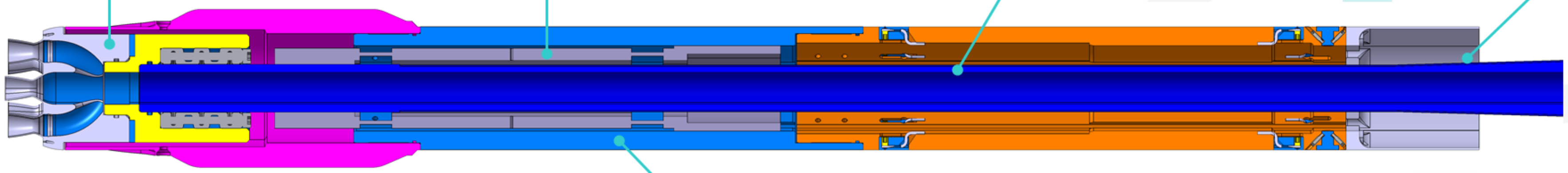




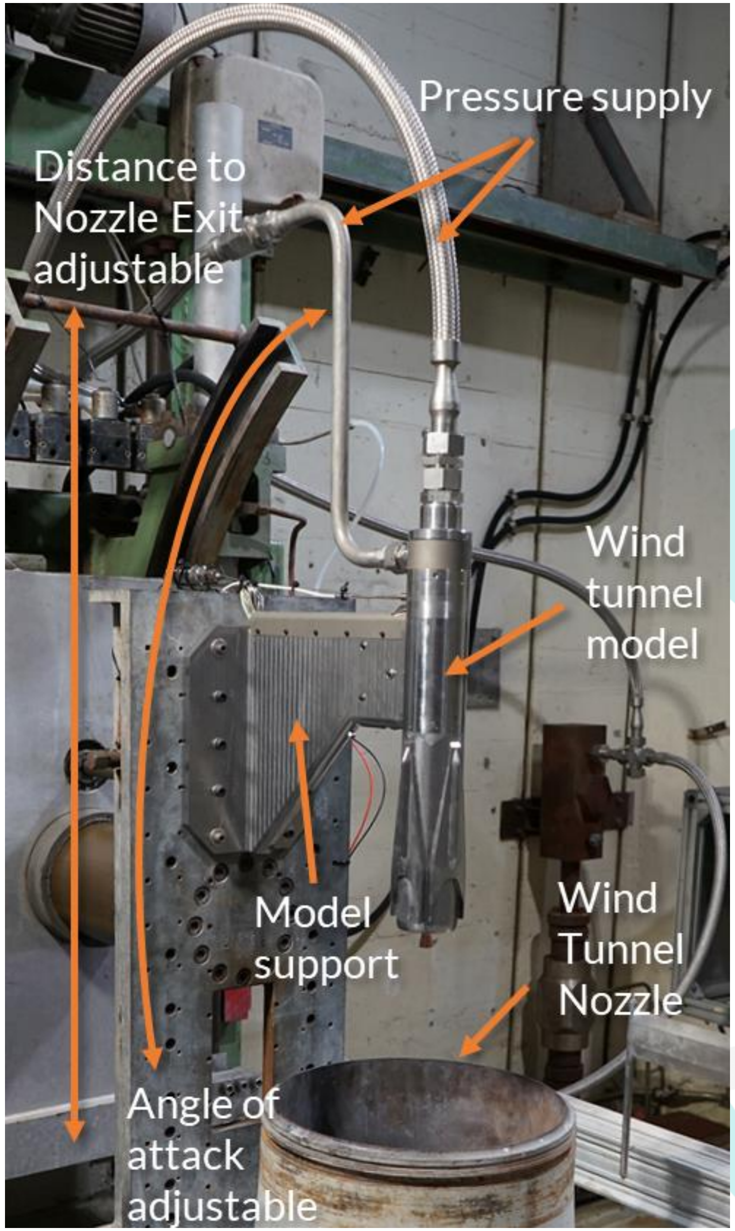
Side view



Top view



RETALT1 Wind Tunnel Model
in VMK



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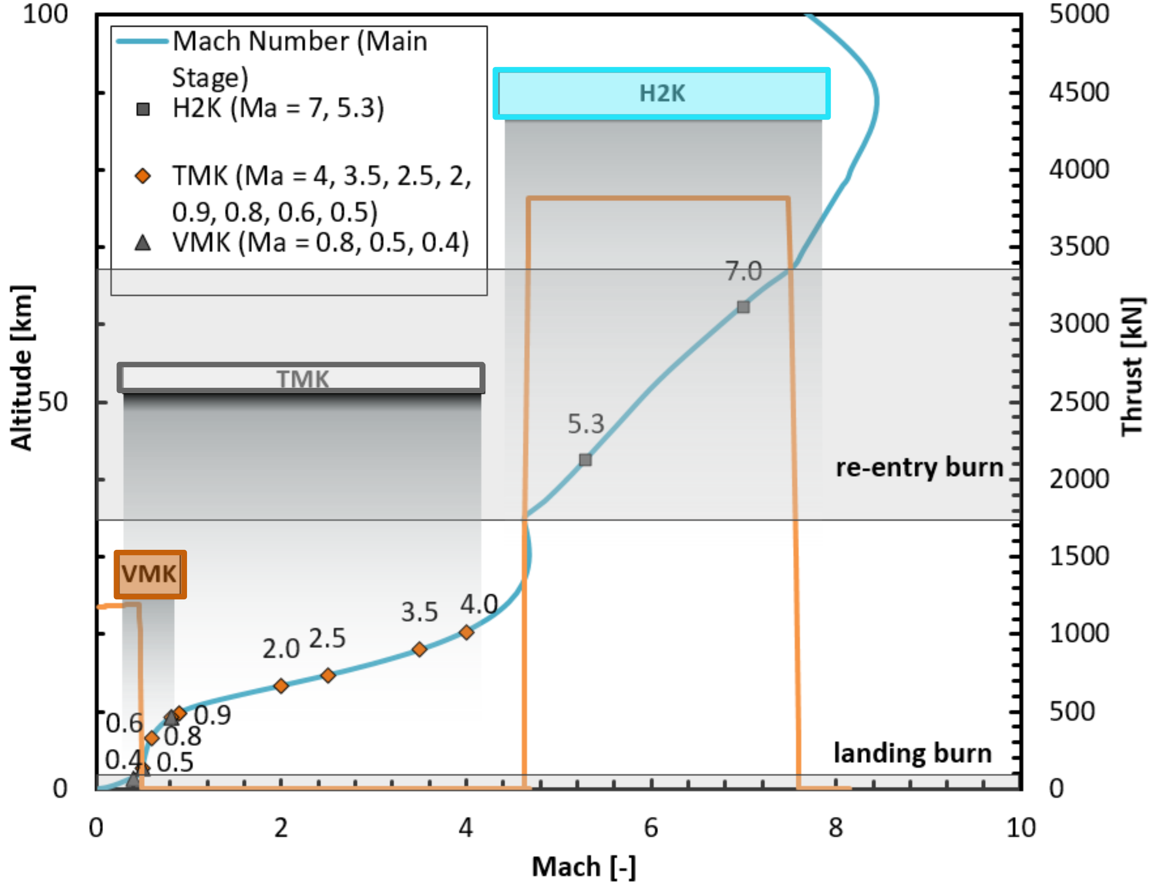


RETALT1

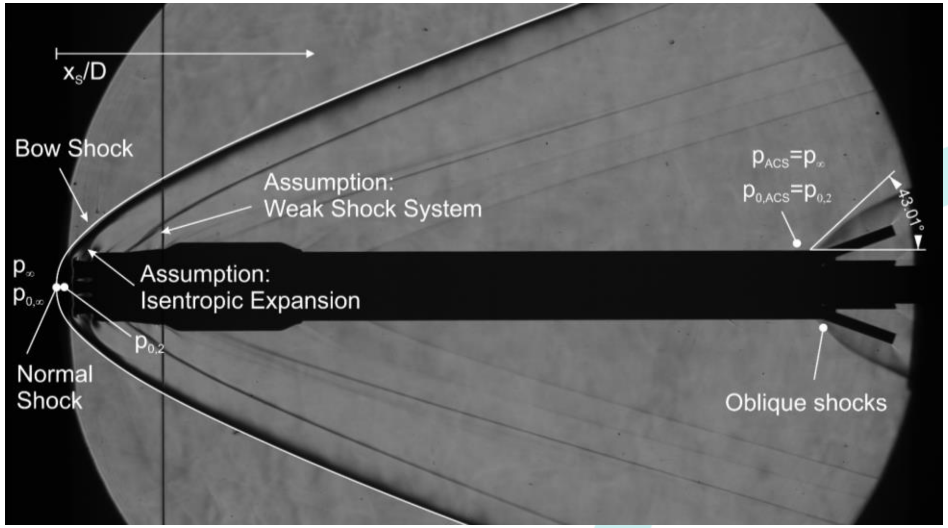
Flow conditions at aerodynamic control surfaces*

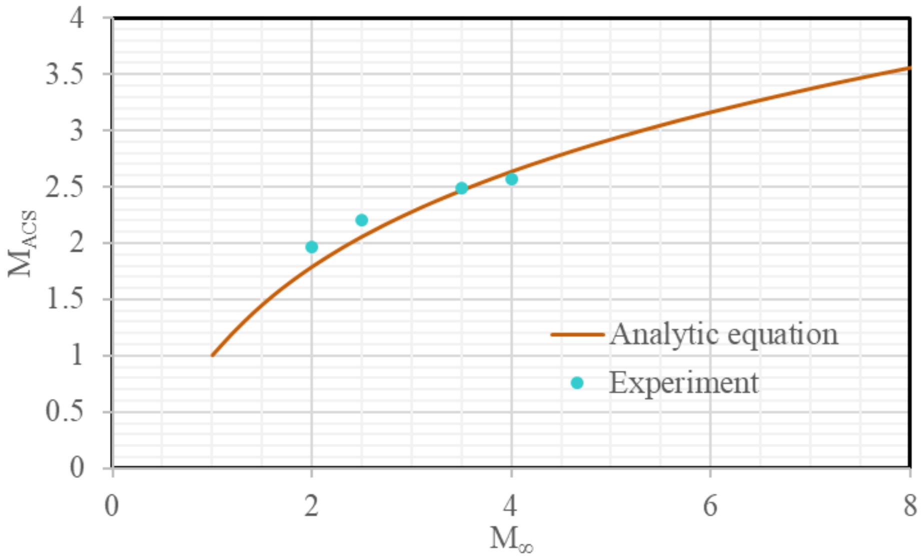
- Assumptions:
  - from blast wave analogy: $p_{ACS} = p_\infty$
  - Isentropic expansion
  - Weak shock system

  → $p_{0,ACS} = p_{0,2}$

- Mach number at ACS:
  - $M_{ACS} = \sqrt{\left(\frac{\left(1+\frac{\gamma-1}{2}M_\infty^2\right)(\gamma+1)M_\infty^2}{\left(1+\frac{2\gamma}{\gamma+1}(M_\infty^2-1)\right)^{\frac{1}{\gamma}}\left(2+(\gamma-1)M_\infty^2\right)}-1\right)\frac{2}{\gamma-1}}$

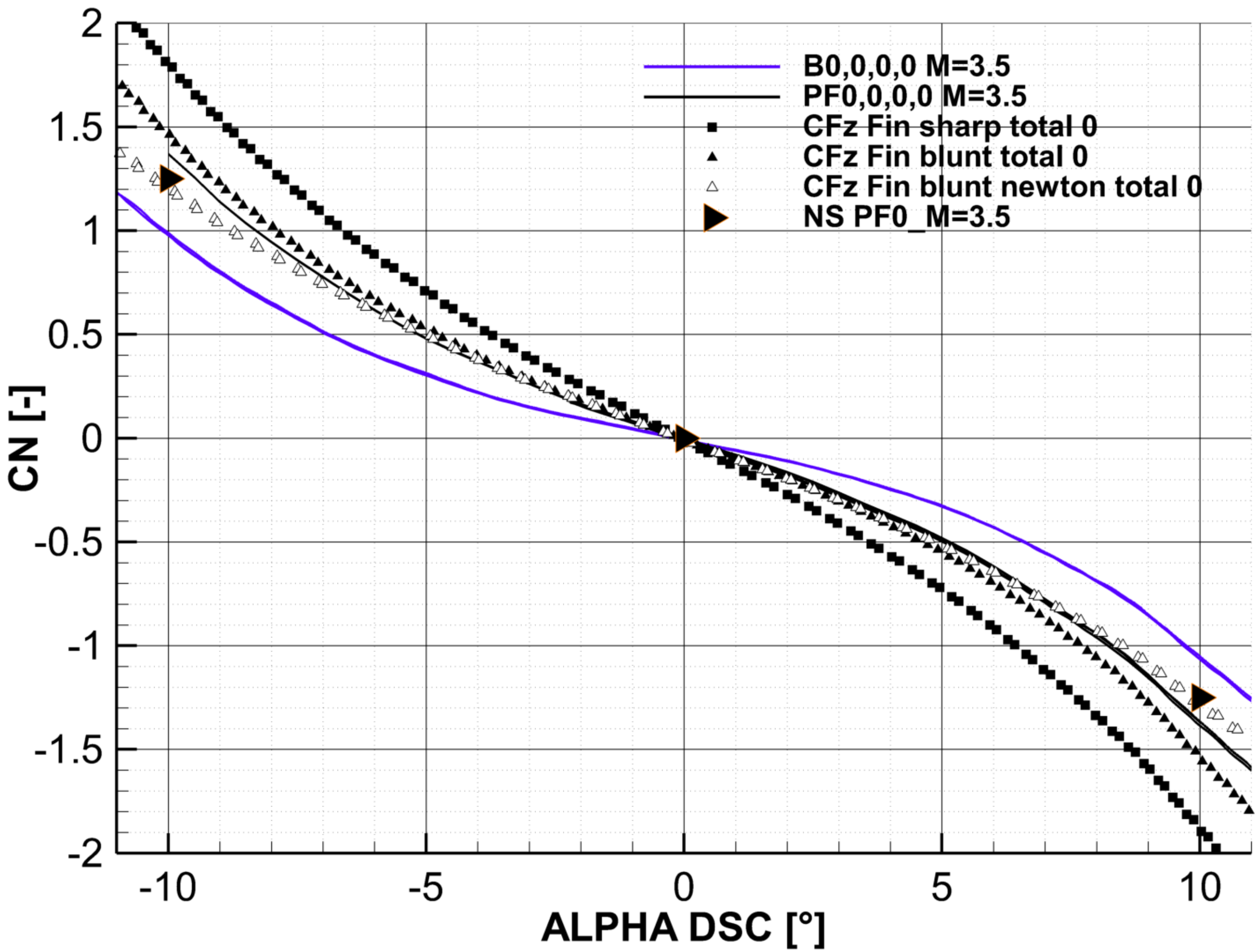
- Static pressure in dependence of angle of attack:
  - Modified Newtonian law
  - $C_p = C_{p_{max}} \sin^2 \alpha \, ; C_{p_{max}} = \frac{p_{0,2}-p_\infty}{q_\infty}$

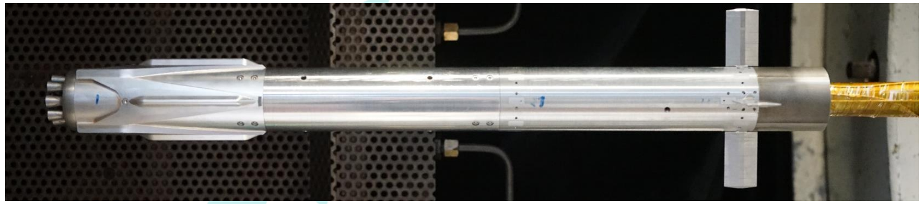


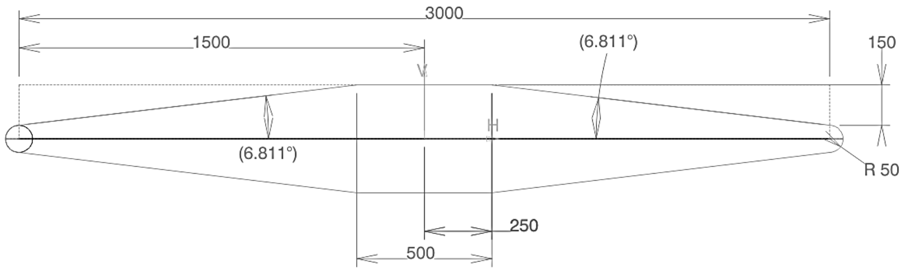


*Marwege, A. et al. : "Wind Tunnel Experiments of Interstage Segments used for Aerodynamic Control of Retro-Propulsion Assisted Landing Vehicles", CEAS Space J (2022).

Forces and Moments
measured vs analytical







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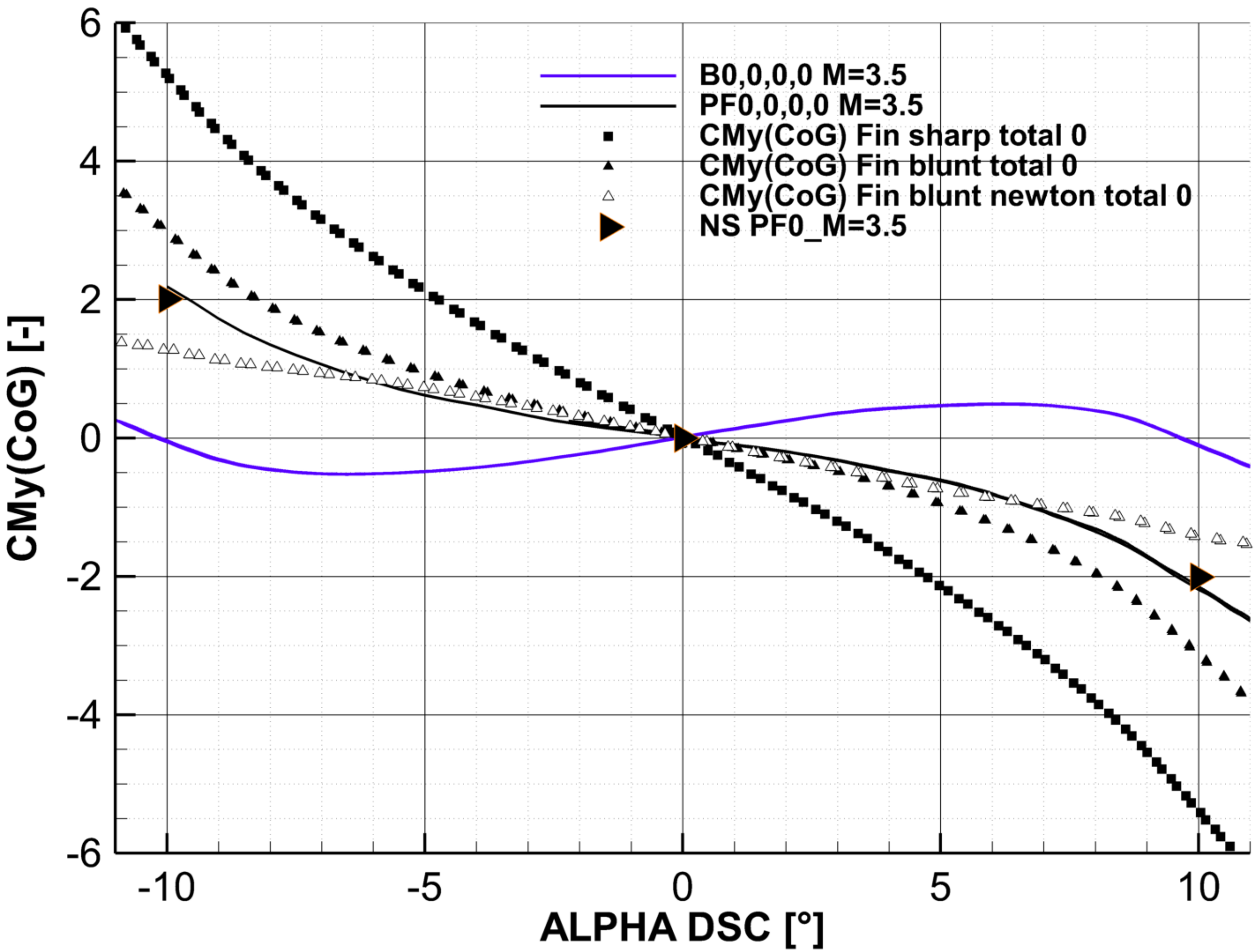

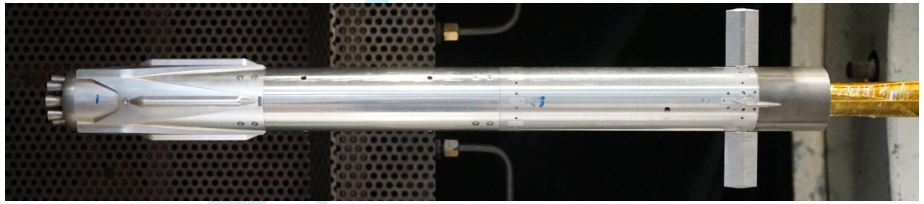

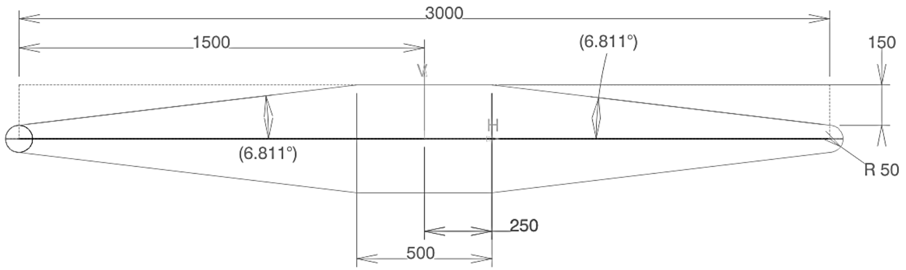

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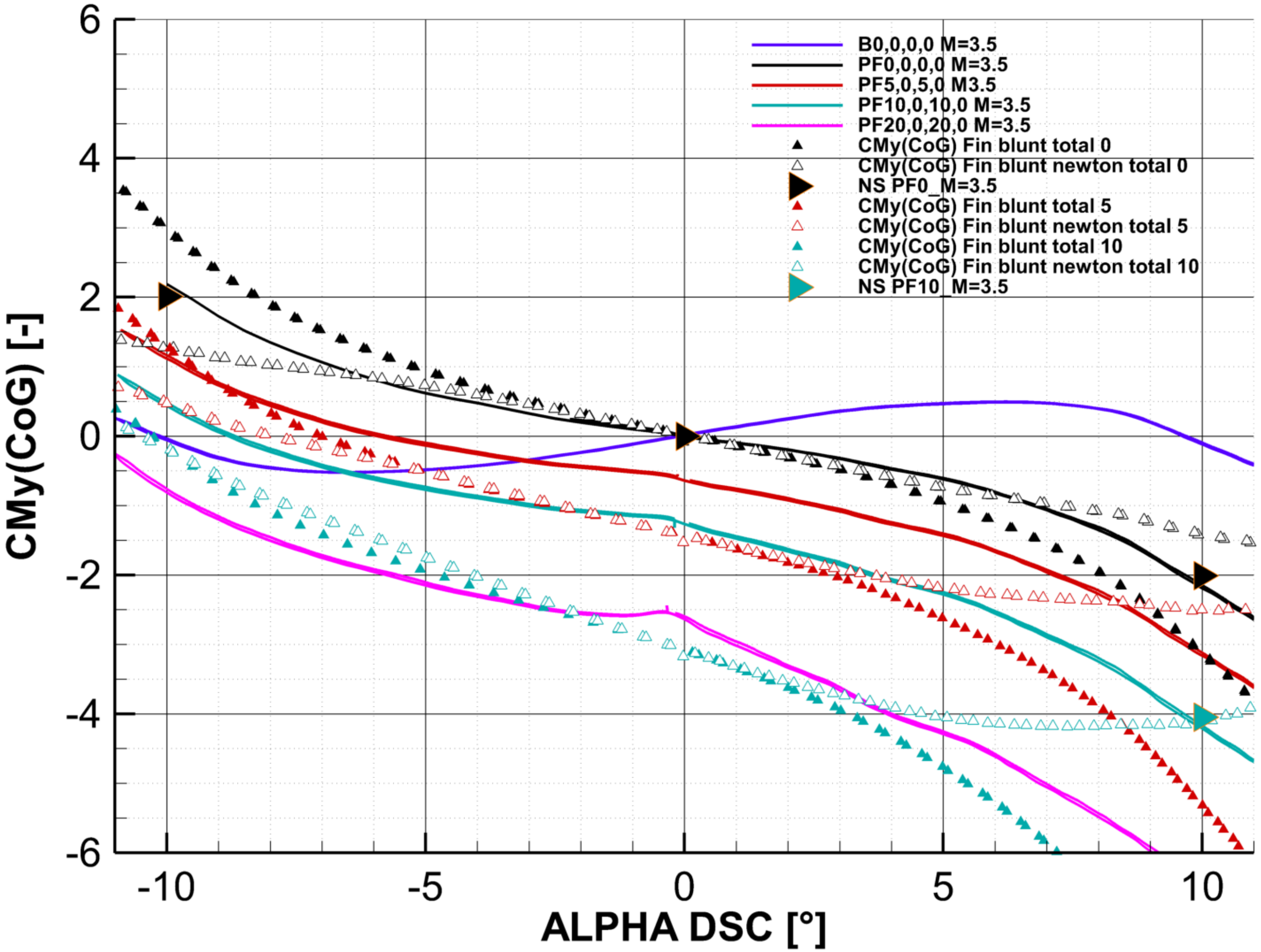

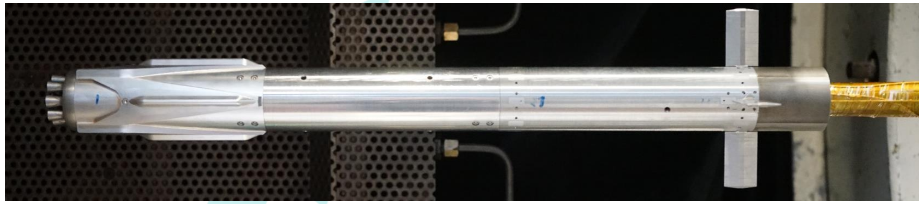

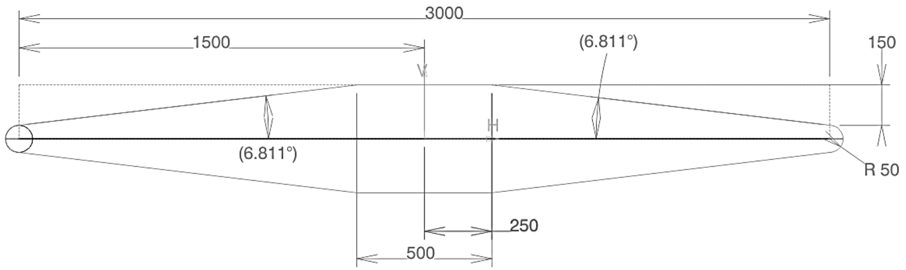

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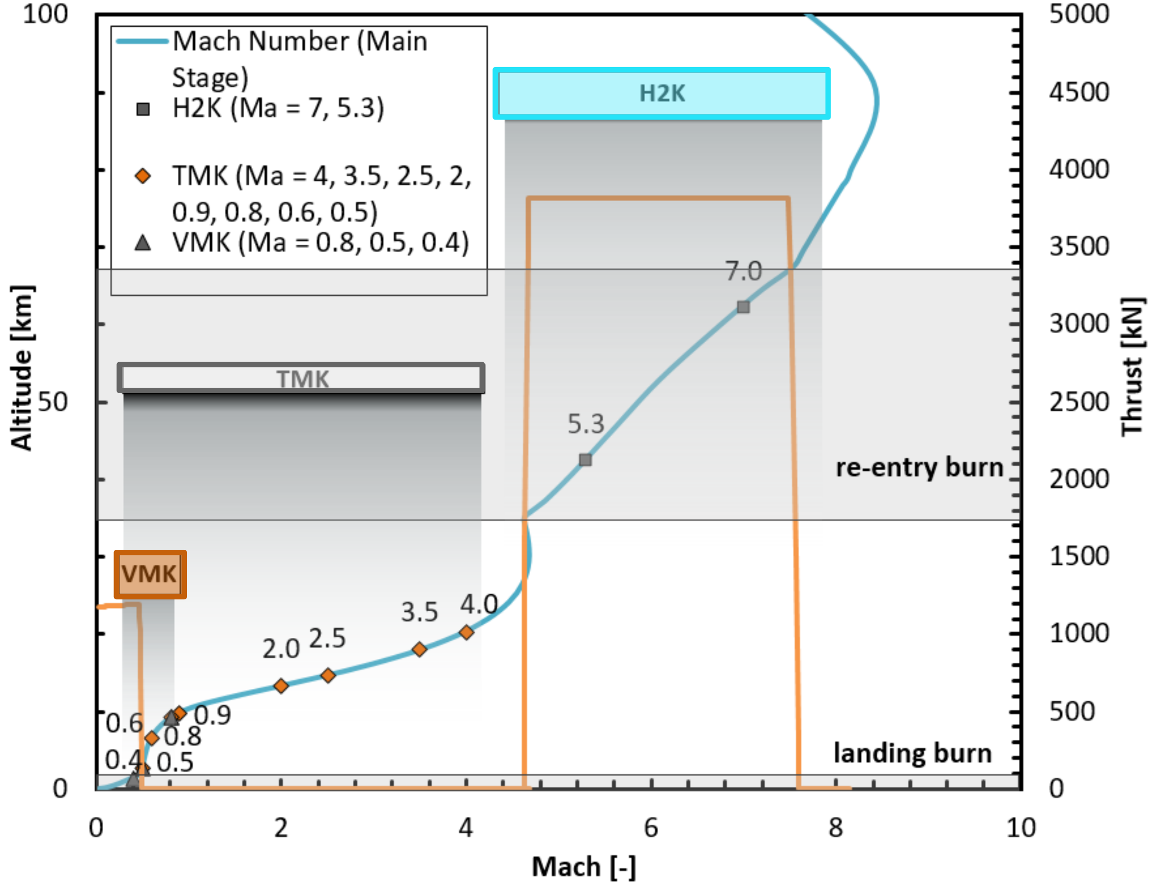
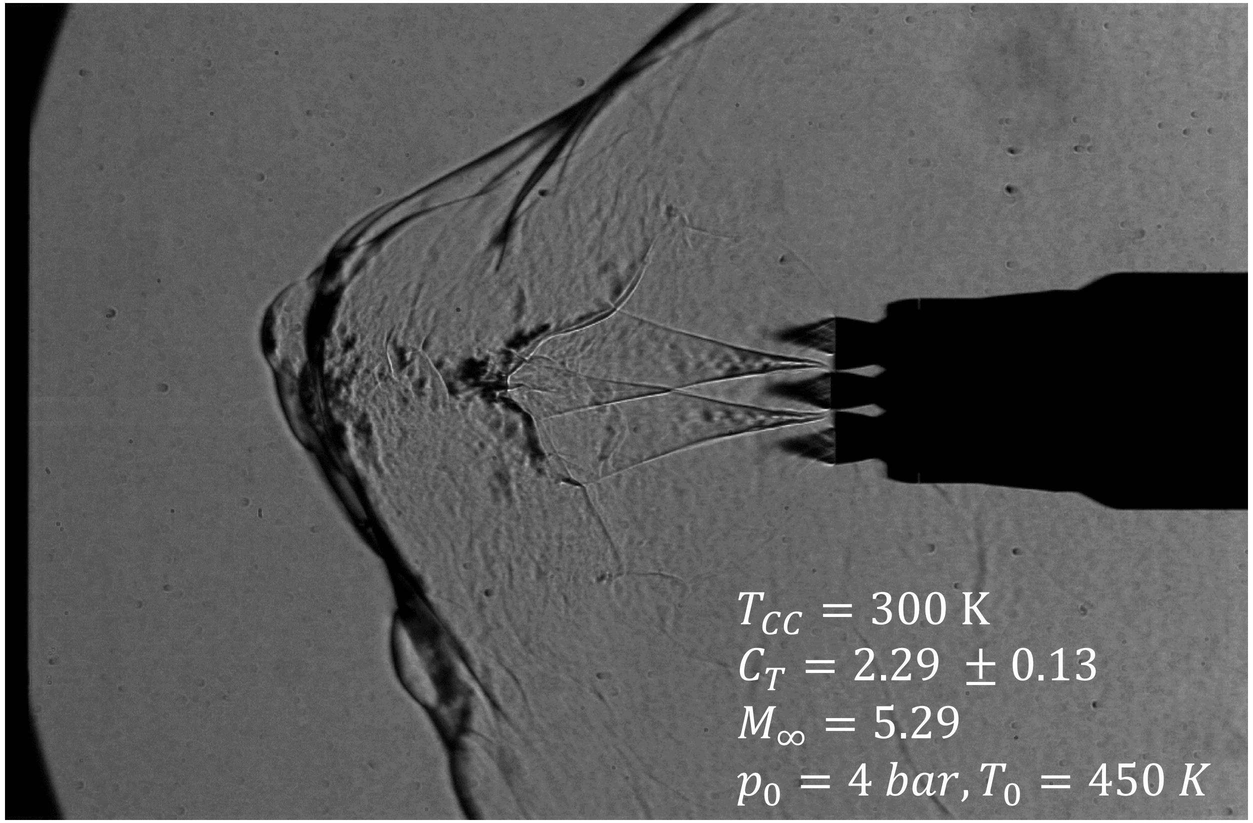
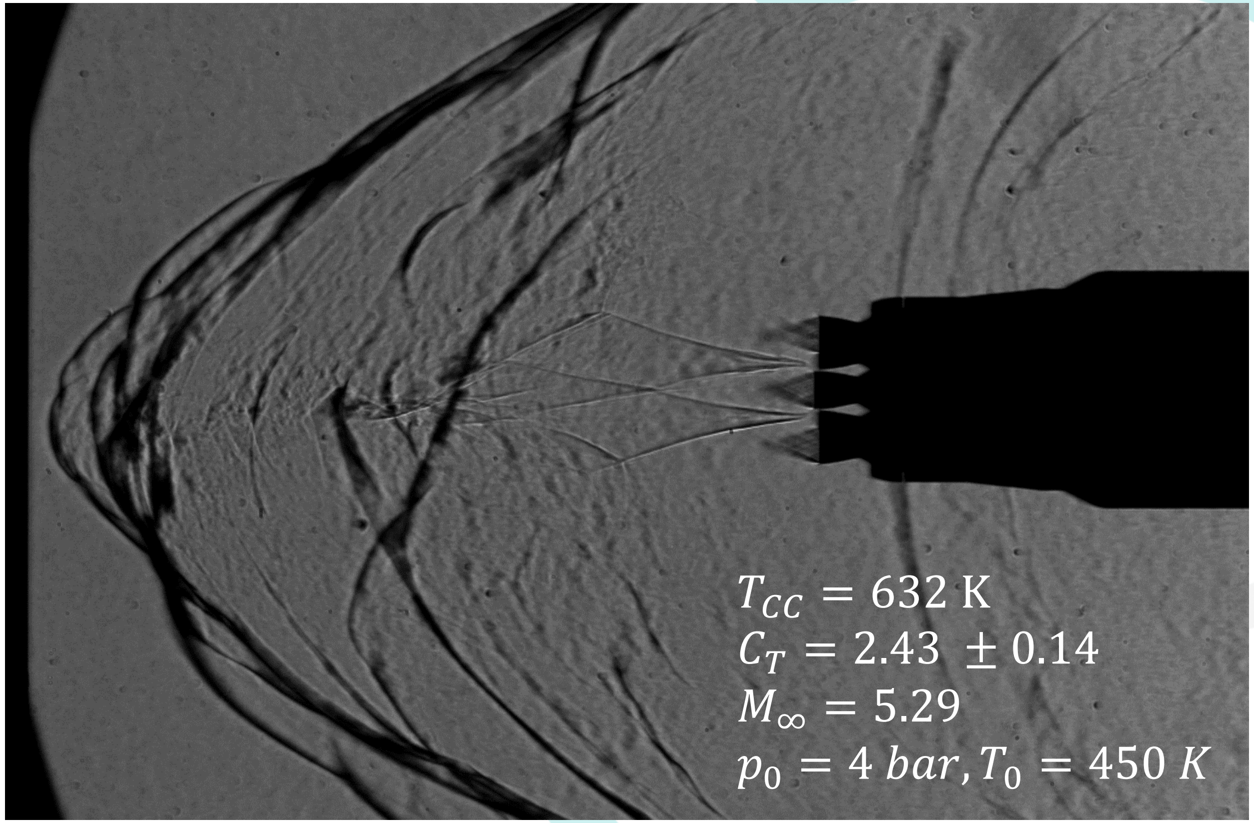


RETALT1

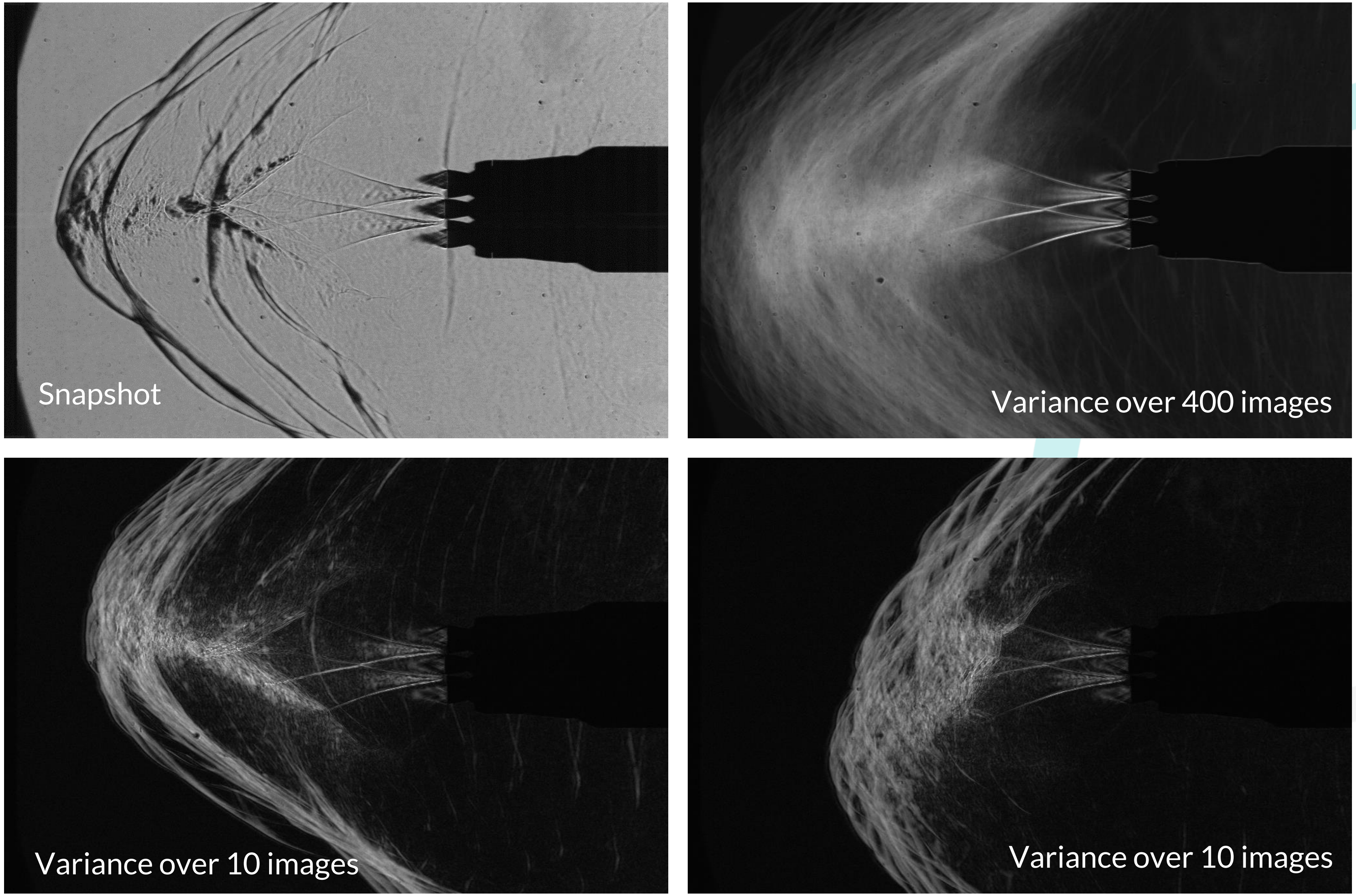
RETALT1 Re-entry burn – 3 active engines
H2K





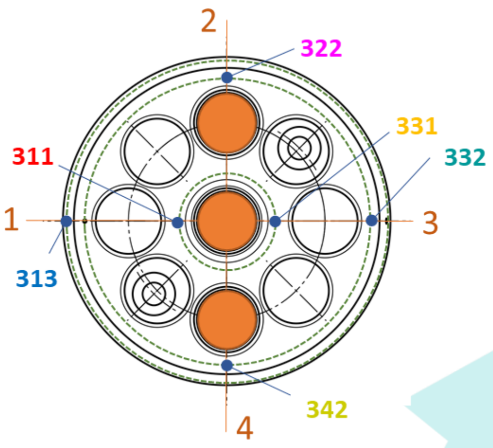
RETALT1 Re-entry burn – 3 active engines
H2K

$T_{CC} = 300$ K
$C_T = 2.29 \pm 0.13$
$M_\infty = 5.29$
$p_0 = 4\ bar, T_0 = 450\ K$



RETALT1 Re-entry burn – 3 active engines
H2K
Spectrograms of pressure sensors

- Dominant frequencies:
  22.6 kHz, 21.9 kHz, 21.1 kHz, 2.5 kHz



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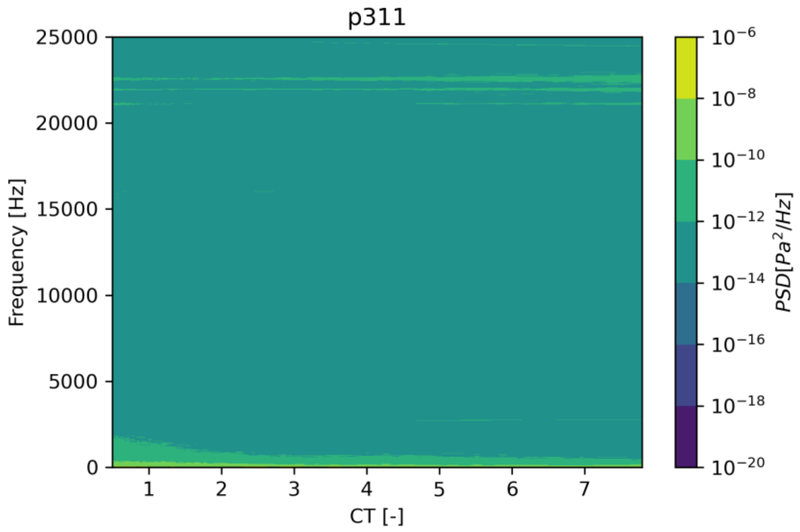

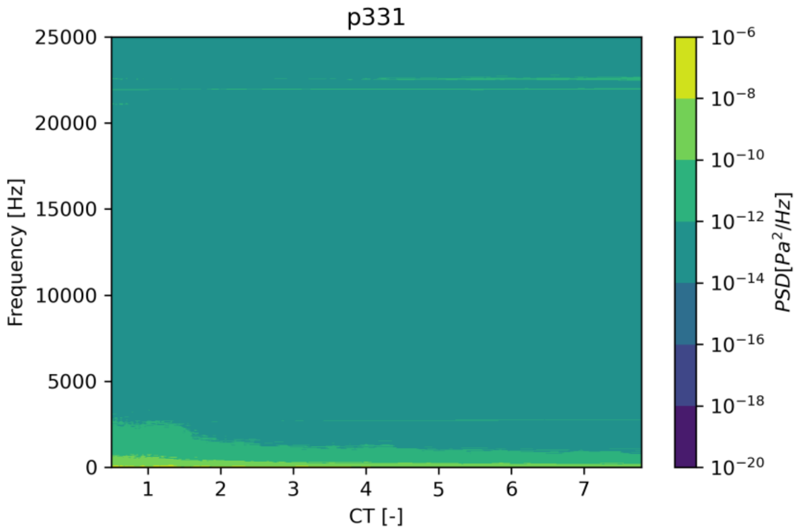

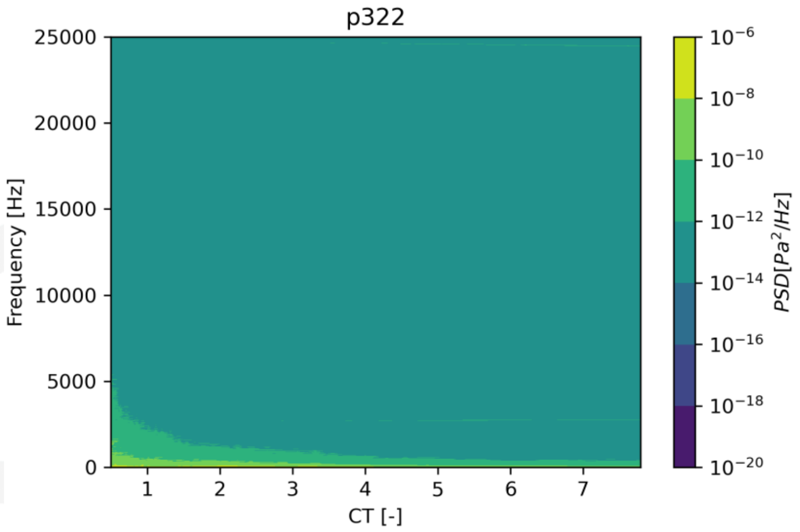

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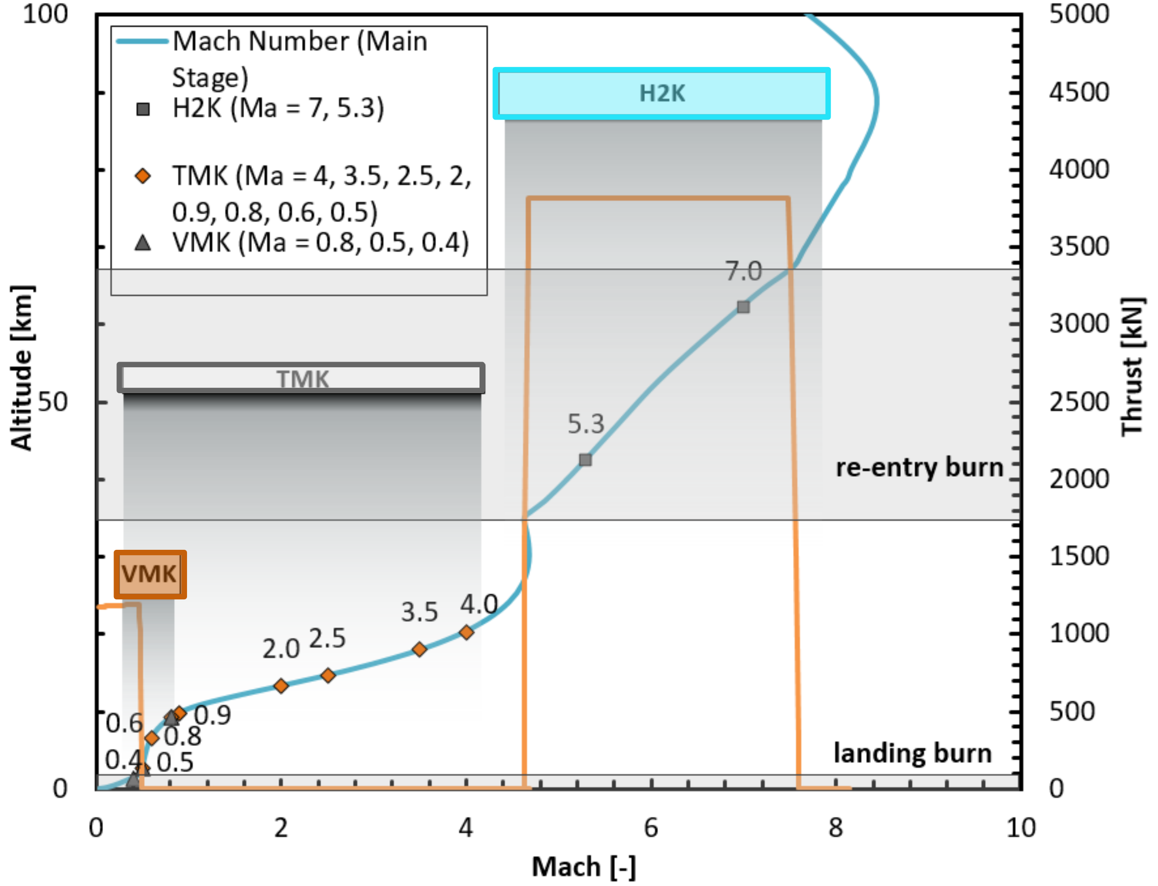
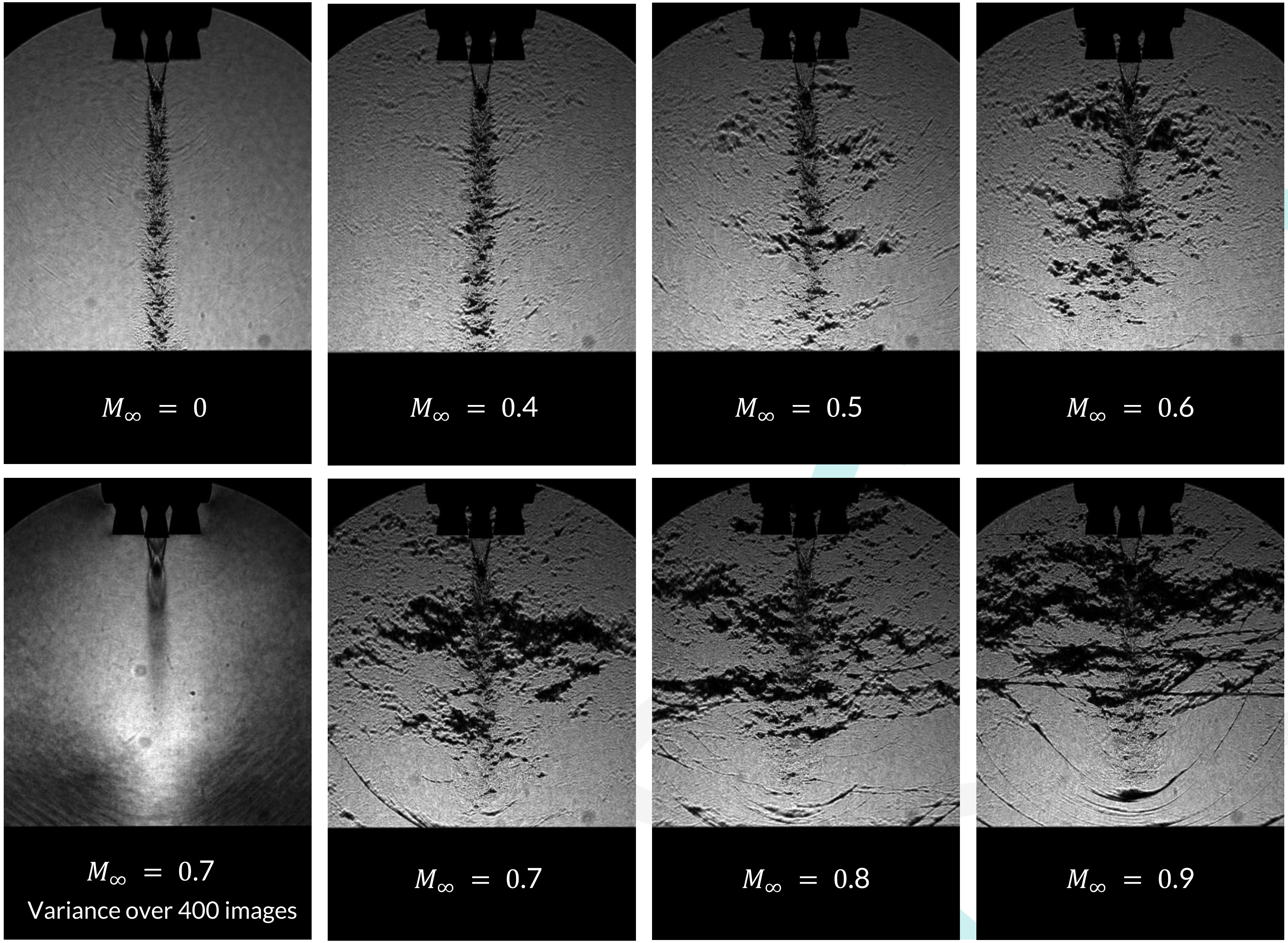


RETALT1

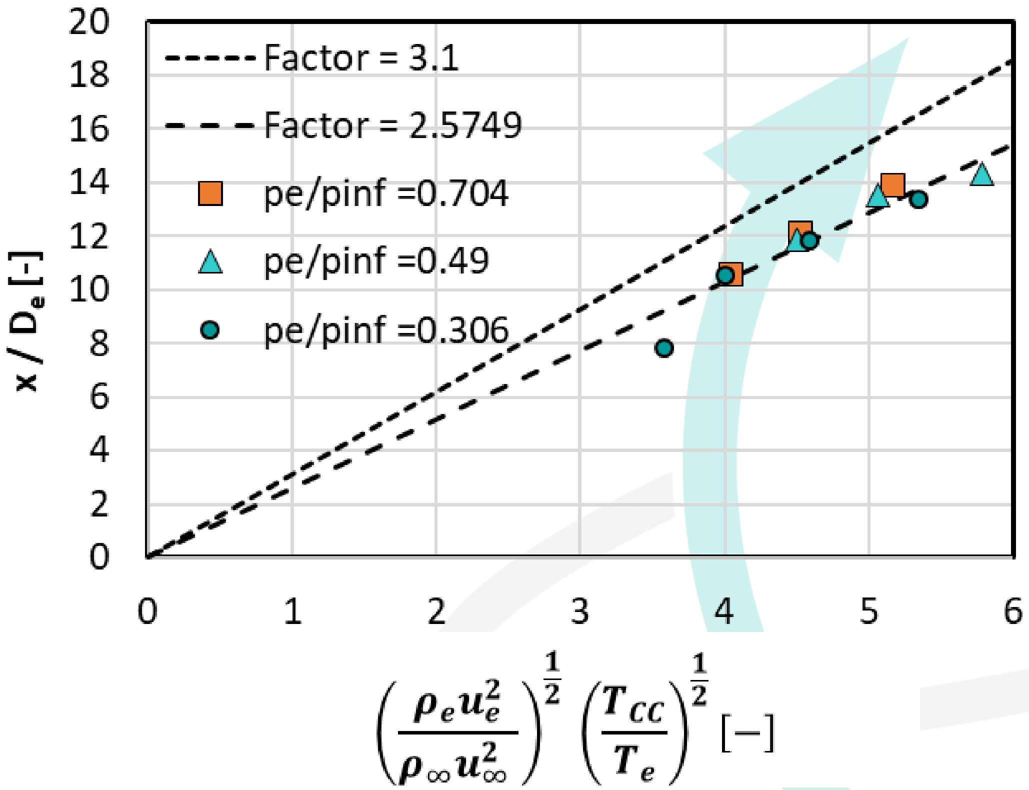
RETALT1 - Landing Burn
VMK

- Example:
  - Run 28
  - $p_{CC} = 28\ bar$
  - $\frac{p_e}{p_\infty} = 0.49$
- fluctuations increase with increasing Mach numbers
- Largest fluctuations in stagnation region



RETALT1 - Landing Burn
VMK

- Plume length linear dependent on momentum flux ratio and temperature ratio*:
- $\frac{x}{D_e} = 3.1 \left(\frac{\rho_e u_e^2}{\rho_\infty u_\infty^2}\right)^{\frac{1}{2}} \left(\frac{T_{CC}}{T_e}\right)^{\frac{1}{2}}$
- Factor 2.57 gives better fit for experiments



*Jarvinen, P. O.; Hill, A. F.: "Penetration of Retrorocket Exhausts into Subsonic Counterflows", Journal of Spacecraft and Rockets, Vol 10, 1973

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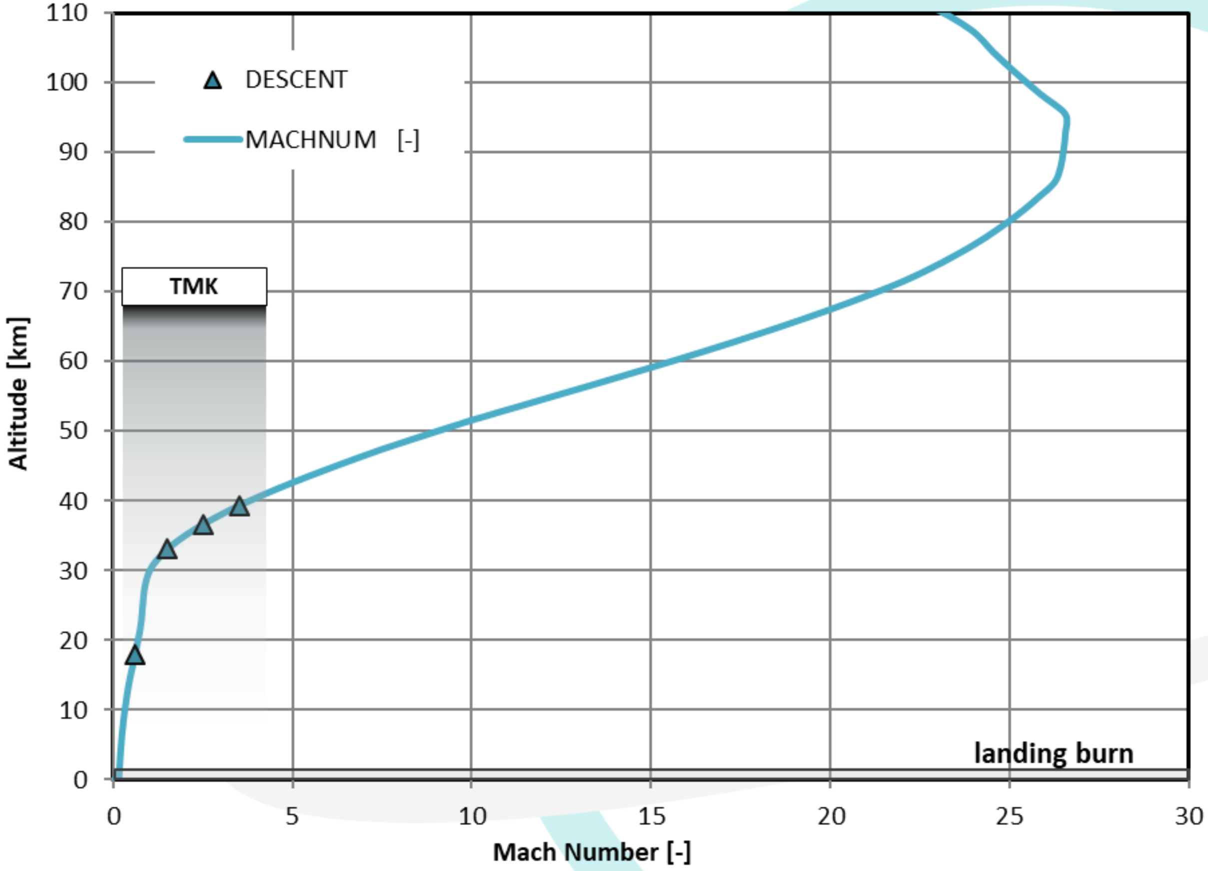
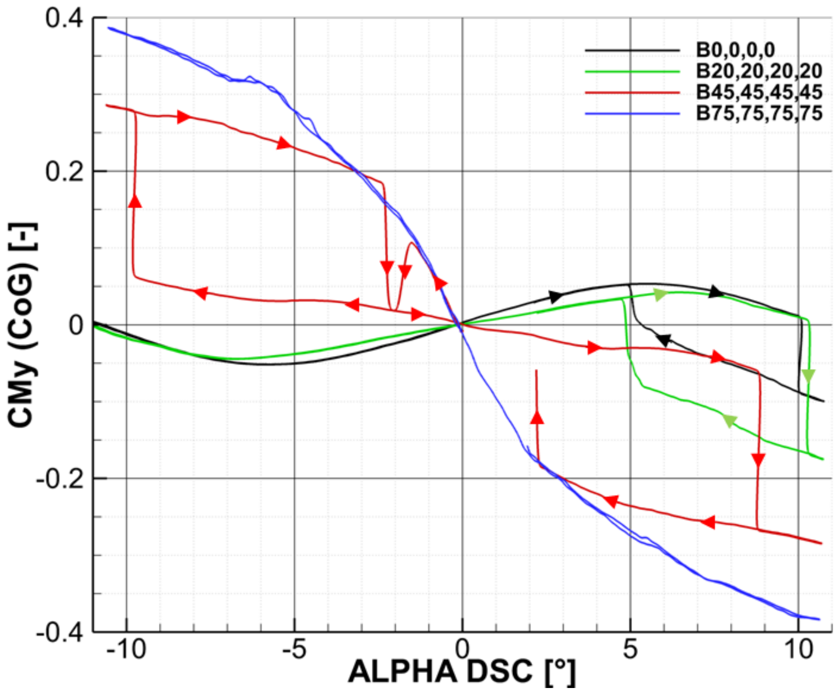


RETALT2 – Aerodynamic Phase
TMK



RETALT2 in TMK at Mach 1.5, Petal deflection 45°

Conclusion

- Analytical approach for the design of aerodynamic control surfaces proposed
- Highly unsteady flow fields observed for retro propulsion environments for re-entry burn with 3 active engines and landing burn
- Dominant frequencies can be found in pressure measurements
- Plume length of landing burn follows analytical relation
- Aerodynamic Data Base (AEDB2.0) for RETALT1 and RETALT2 published on Zenodo (aerodynamic coefficients)

Outlook

- Further modal analyses planned for further understanding of unsteady phenomena and resulting loads
- Hot plume test being performed at the VMK at the moment
- CEAS Space Journal Special Issue will be published (a lot of papers already available online)

Deutsches Zentrum für Luft- und Raumfahrt

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AMORIM CORK COMPOSITES

CFS Engineering
Computational Fluids & Structures Engineering

deimos elecnor group

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