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Marco Polo ERC Dynamic Stability Characterization

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IPPW#12 - Cologne

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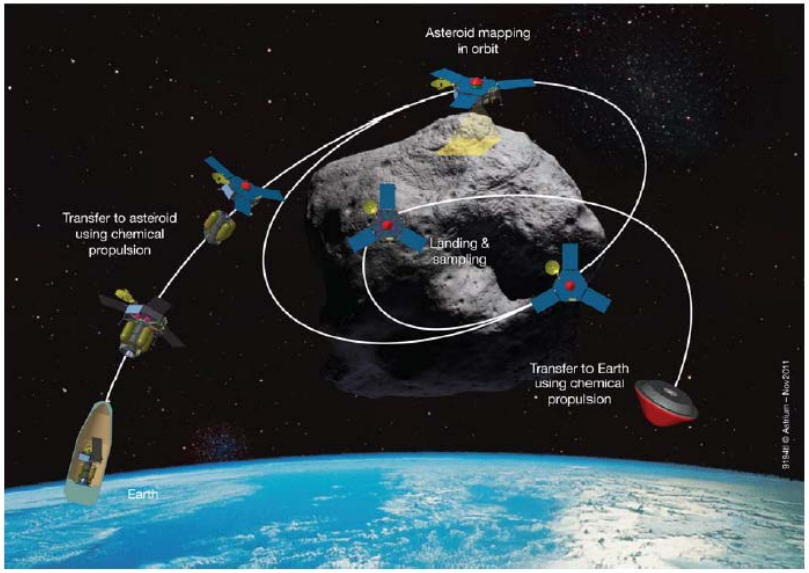
Introduction

- ESA MarcoPolo-R mission:
  - MP-R was one of the candidate for the ESA's Cosmic Vision programme,
  - Sample return mission from a primitive near-Earth asteroid,
  - A totally passive Earth re-entry capsule for cost and risk of failure minimization
    - Crushable material is used to limit the shock loads at impact
    - Attitude of ERC at impact shall be within acceptable limit



- Motivation of the Study:
  - Blunt bodies are generally dealing with dynamic instability in transonic regime that could result in undesirable tumbling motion if no parachute is deployed.
  - Passive ERC → no parachute → stability must be warranted also in transonic and subsonic regimes

- This study funded by ESA aims at selecting and characterizing an ERC meeting system and stability requirements with good margins

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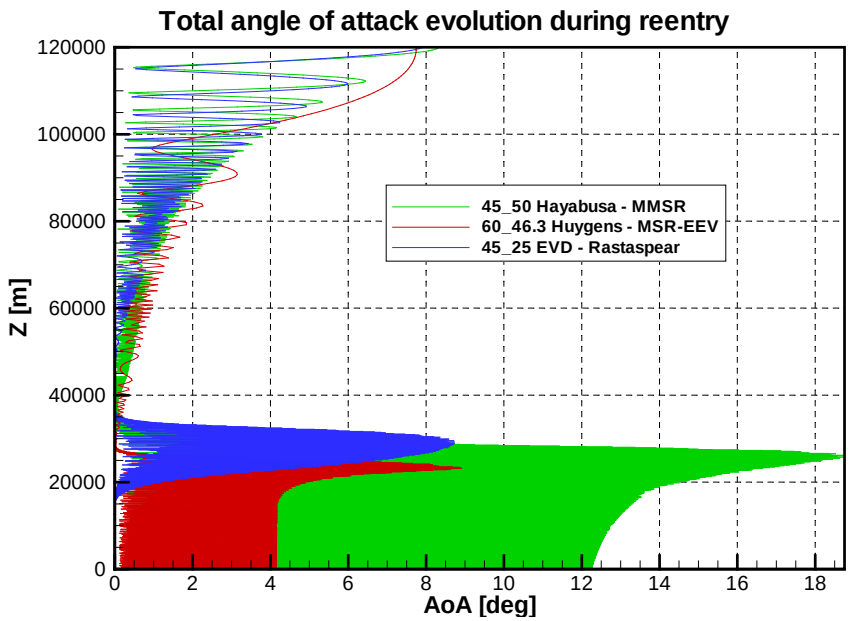
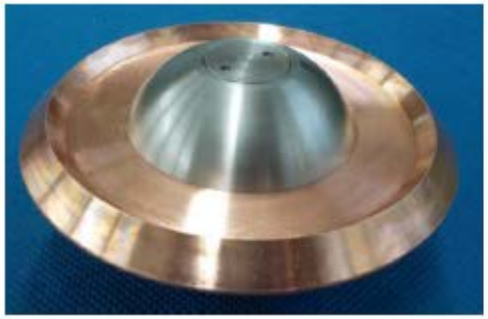
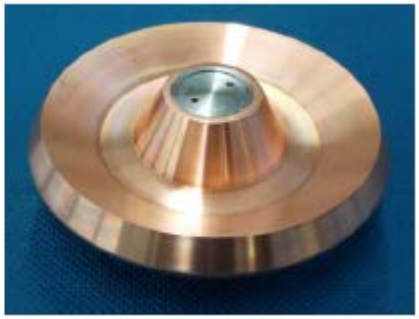
Aeroshape Trade-off & Selection



- A system trade-off is performed to select some candidates. Main requirements are:
  - Totally passive capsule (no parachute)
  - Entry velocity = 12 km/s
  - Maximum heat flux (15MW/m²)
  - Maximum shock load at ground impact of 800g
  - Maximum angle of attack at impact of 20°
  - Landing ellipse compatible w/ Woomera landing site
- Four pre-selected aeroshapes (literature & Airbus DS databases sources)
  - Dynamic stability prior ground impact is a key driver. General lack of data for dynamic stability in subsonic regime → Subsonic test campaign used for aeroshapes discrimination

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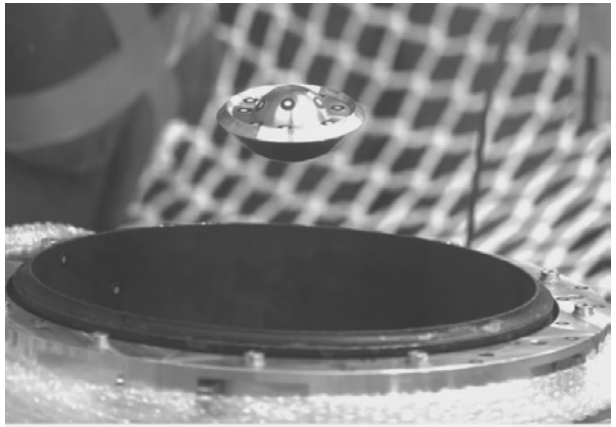
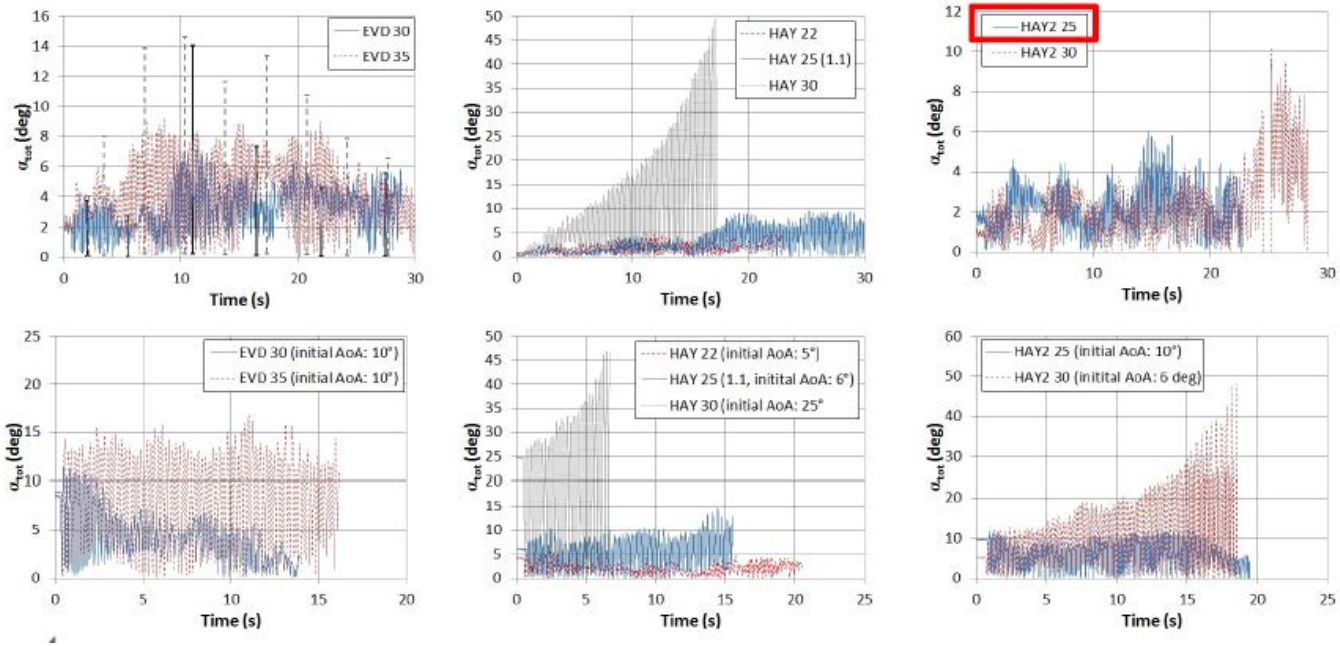
Subsonic Free-Flight Test Campaign



- Vertical wind tunnel facility of DLR (VMK)
- Objective: trade dynamic behaviour of selected aeroshapes in subsonic regime
  - Free flight in condition of the final vertical descent
  - Main technical challenge: to have enough flight time to achieve limit cycle, if any



- Tests shown an unstable behaviour of Hayabusa & ERC with Xcog=30%
- Other configurations were stable at VMK with limit cycle lower than 20°

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Aeroshape Selection

- EVD (up to 35% centring) and ERC (at 25%) are eligible
- The ERC is selected for its flexibility to mission changes and centring capabilities

	Hayabusa			ERC		EVD		Huygens	
Selection step	22%	25%	30%	25%	30%	30%	35%	17%	20%
Limit Cycle	α_{limit}=5°	α_{limit}=9°	diverging	α_{limit}=12°	diverging	α_{limit}=11°	α_{limit}=13°	α_{limit}=12°	α_{limit}=18°
CoG position	Not workable	Ballast required		25% achieved				Not workable within max. diameter requirements	Not workable within max. diameter requirements
Entry corridor width				$\Delta\gamma$ < +/- 0.2° - γ_{nom}=-11°		$\Delta\gamma$ < +/- 0.1° - γ_{nom}=-9°			
Configuration				Φ>780 mm - m>40 kg		Φ>840 mm - m>42 kg			

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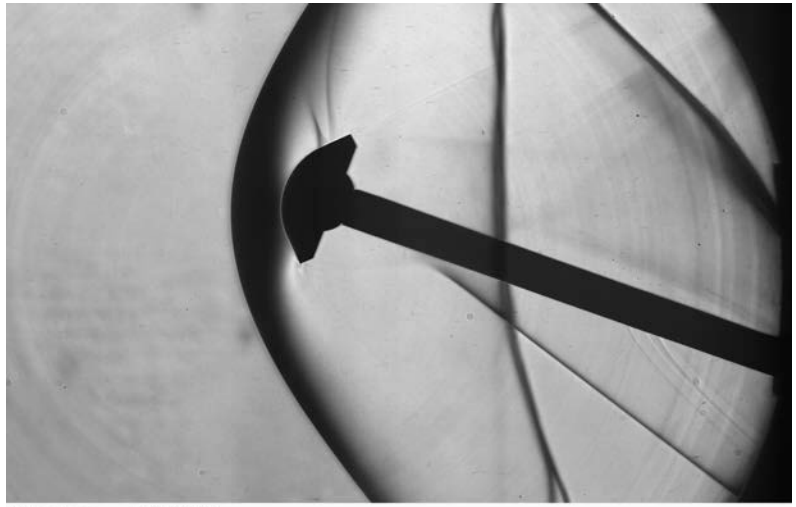
Aerodynamic Characterization

- Two experimental test campaigns are dedicated to the AEDB population
  - Static forces/moments WT campaign at TMK: determination of the static aerodynamic coefficients below Mach 3.5 down to subsonic regime (Mach = 0.5) within 0° to 25° AoA,
  - Free-flight test campaign at ISL's open range facility: Aerodynamic Damping Coefficients in low supersonic and transonic regime (0,8 < Mach < 3)



Alpha = 20.3° Mach = 1.5

- Unstationnary CFD campaign
  - Extrapolation to flight of VMK results
  - Flight prediction in subsonic regime and low transonic up to Mach 0.9

- RANS CFD campaign
  - Static aerodynamic characterization in low subsonic (Mach < 0.5)
  - Aerodynamic characterization in hypersonic regime

	susonic	transonic	supersonic	hypersonic
Static				
NSMB (CFSE)	Mach < 0.5			X
TMK (DLR)	Mach > 0.5	X	Mach < 3.5	
dynamic				
VMK	Mach 0.2			
NSMB (CFSE)	X	Mach < 0.9		
free flight (ISL)	Mach > 0.5	X	Mach < 3.5	

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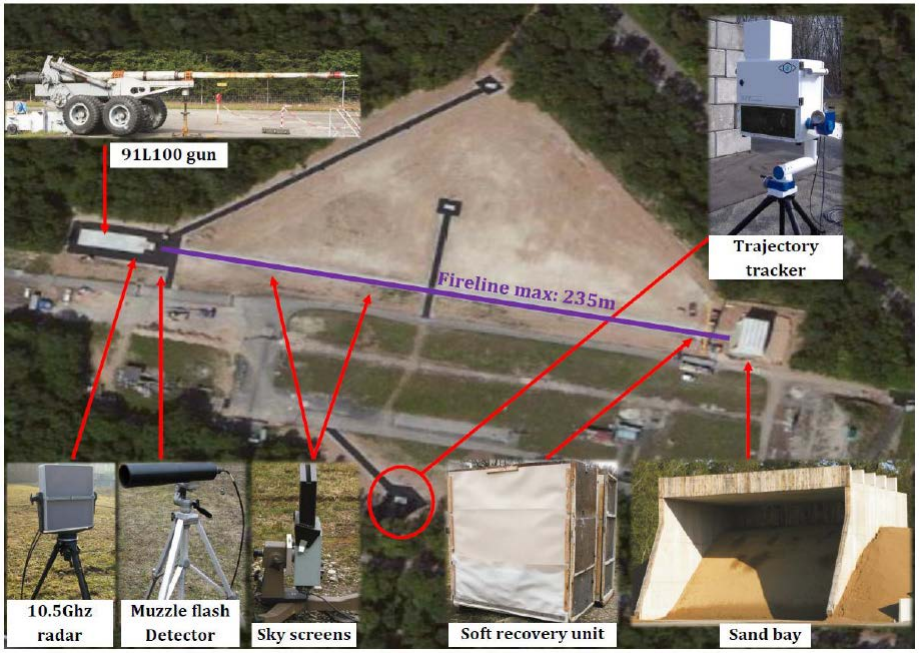
Open Range Free-Flight Test Campaign

- ISL open range facility
  - Free flight avoiding sting effect
  - 0.5 < Mach < 3.
  - Two model designs for dynamic scaling optimization purposes

- Dynamic scaling parameters:
  - Mach number,
  - Reynolds number,
  - Reduced frequency,
  - Relative density,
  - Relative inertia.

$$\omega = \sqrt{\frac{-qSDCm_{\alpha}}{It}}\frac{D}{V}$$



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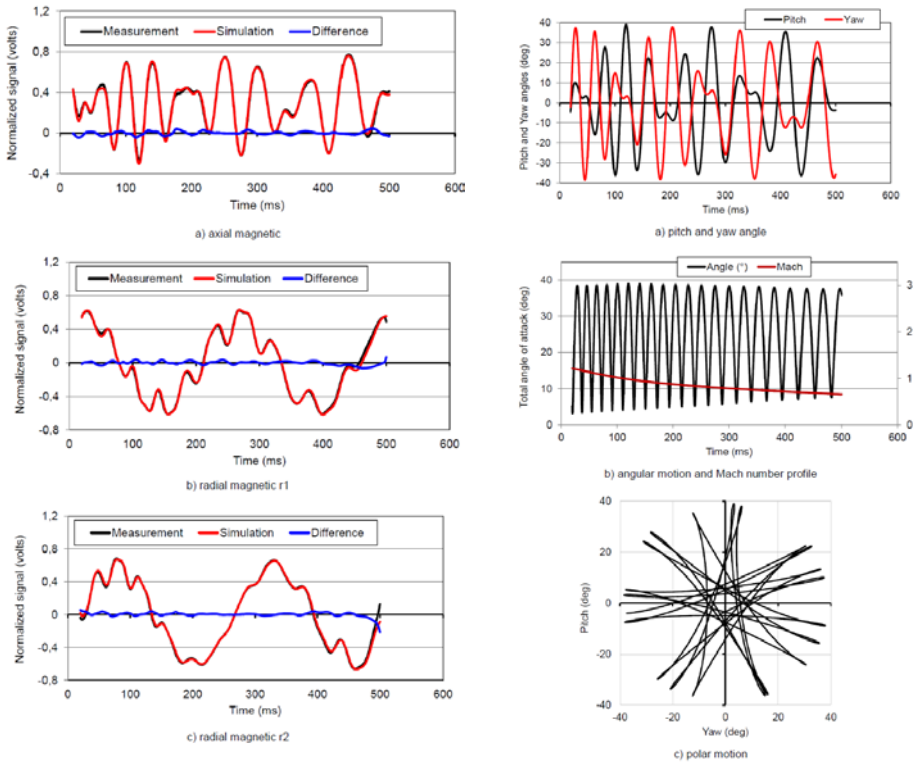
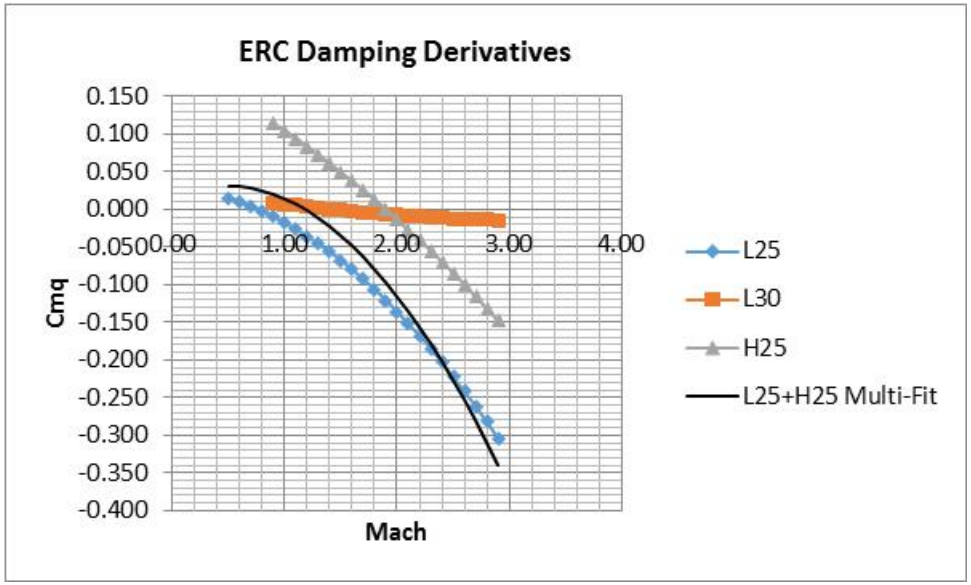
Open Range Free-Flight Test Campaign

- Test matrix has been designed to cover angles of attack range as well as possible,
  - Initial angles of attack of 0, 6 and 10°
  - Initial Mach number of 3, 1.8, 1.2 and 0.8
- Multi-fit data reduction is used to increase Cmq consistency and usability in AEDB population,

	centring at 25%		centring at 30%
	Heavy model	Light model	
Mass (kg)	1.15	0.57	0.54
diameter (m)	0.08	0.08	0.08

Ratio flight over test				
Mach number	1.5	0.5	1.5	0.5
Reynolds	7.9	1.3	7.9	1.3
reduced frequency	1.6	0.9	2.7	1.1
m/(rho*D**3)	0.4	1.2	0.2	1.1
m*D**2/It	0.9	0.9	1.3	1.3





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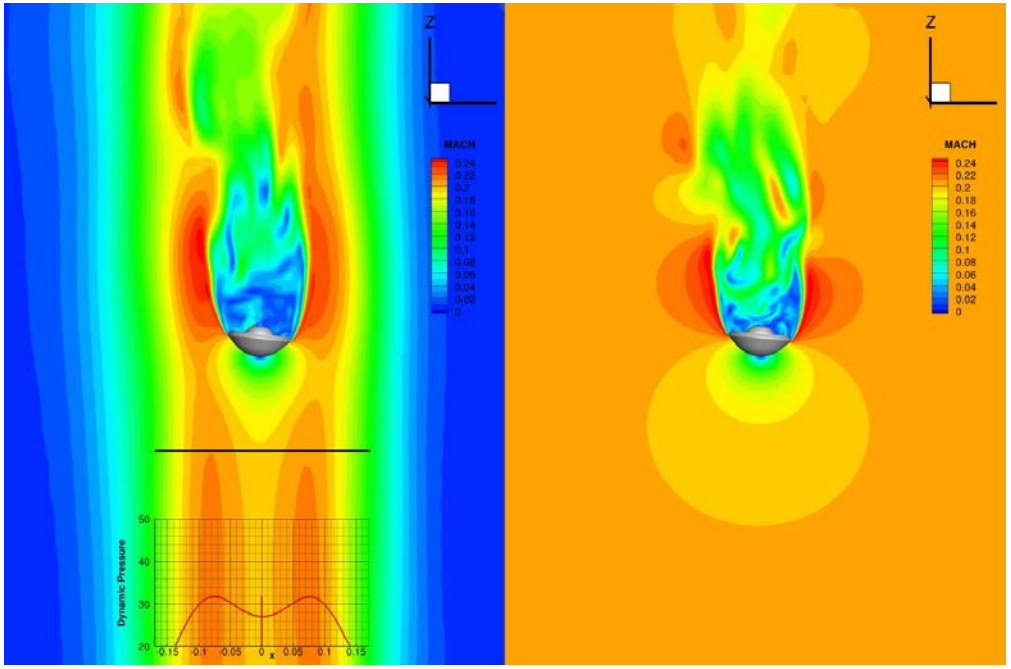
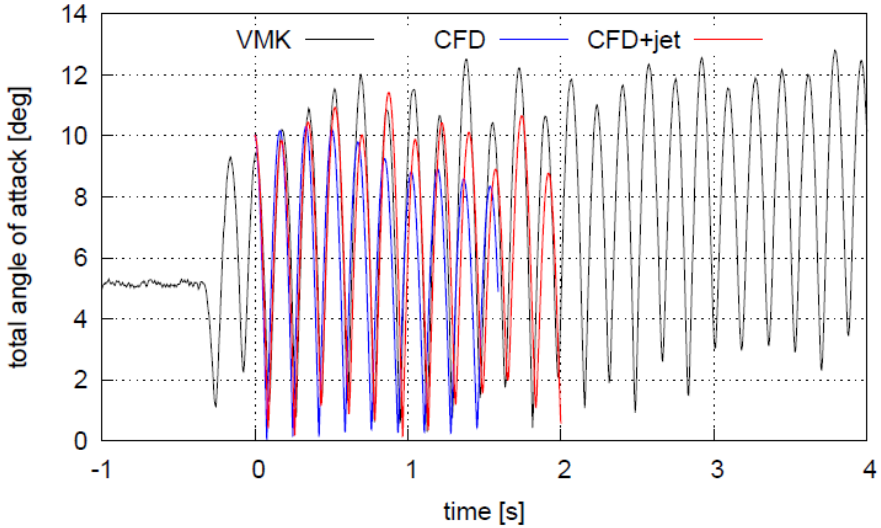
CFD Campaign

- NSMB code is used by CFS Engineering w/ a ALE/DDES approach
- Dynamic damping derivatives evaluation by CFD is still a challenging task,
- Validation of computation against unstable test at VMK
  - Main conclusion is that facility setup must be reproduced in CFD computation for reproducing the flight motion observed during test
  - Jet confinement effects leads to less damped motion





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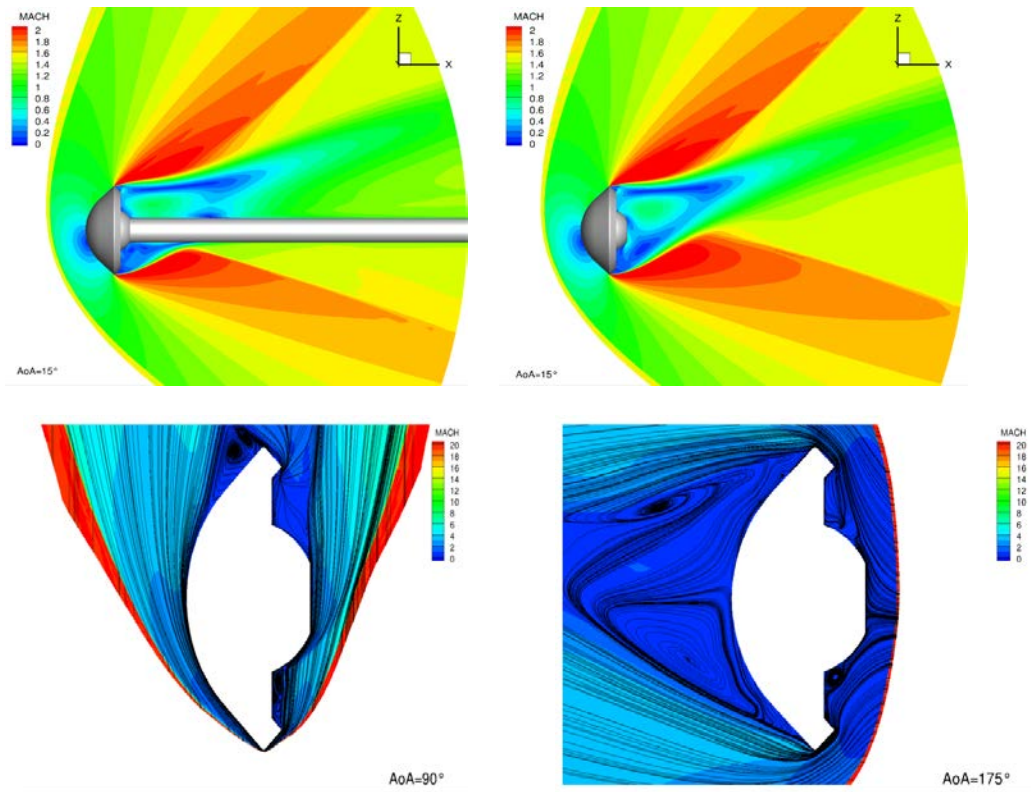
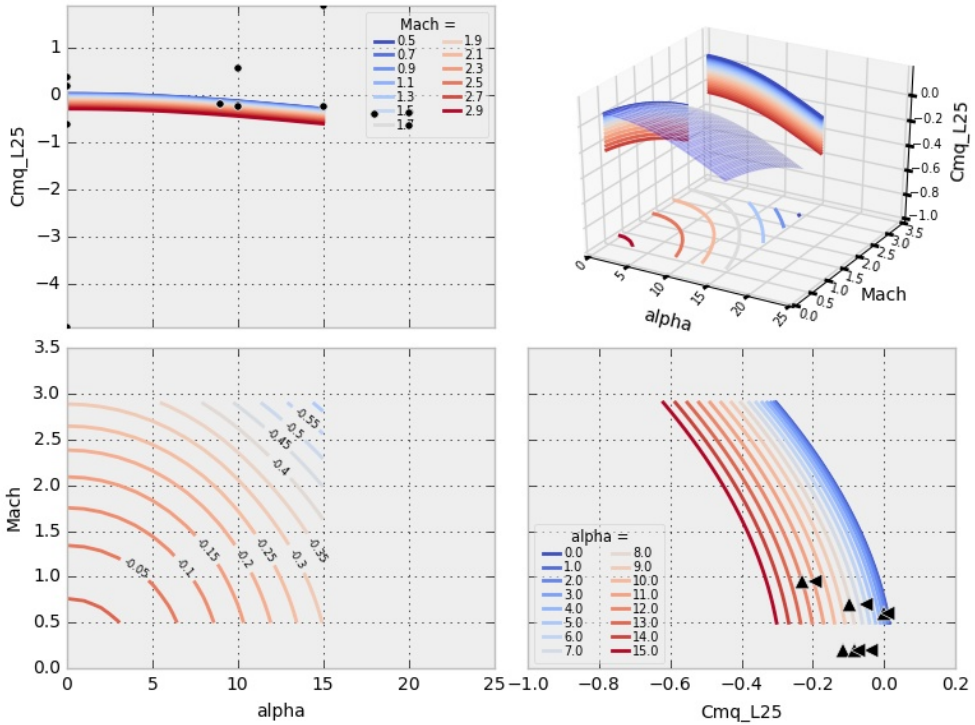
CFD Campaign

- Extrapolation of VMK tests conditions to flight,
- Sting effects analysis in TMK,
- Flight prediction in low transonic and subsonic,
- Critical points verification (conditions of mono-stability),
- AEDB missing points population





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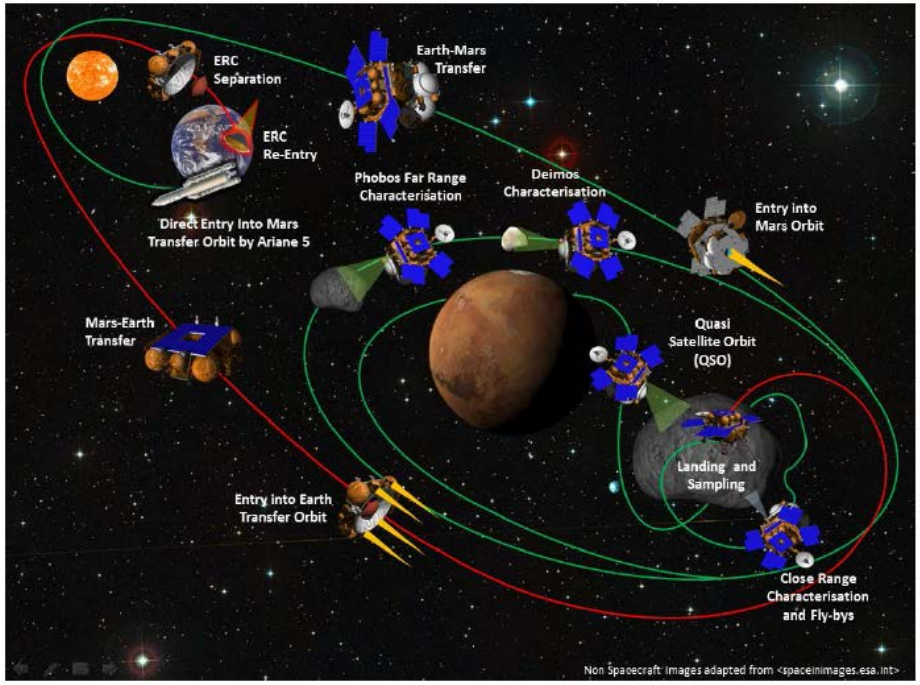
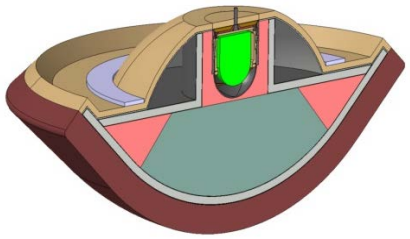
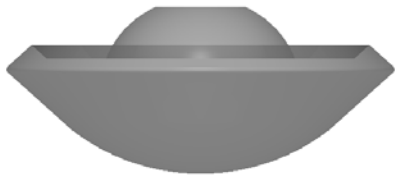
Conclusions

- ERC Aeroshape traded-off resulting in a blunt capsule Rn/D=0,5 – Θc=45° - centered at 25% of D,
- Full Passive ERC AEDB population is now completed
- Three challenging campaigns have been successfully performed, giving useful data for aeroshape selection and AEDB population
  - Subsonic free flight test in VMK
  - Transonic free flight at ISL open range
  - Dynamic computational campaign with NSMB
- Balloon Drop Tests are currently running at Kiruna (Sweden)
- Marco Polo-R has not been retained by ESA, but the Aerodynamic data could be used for any other Sample Return missions. Currently ESA is studying 2 of that kind:
  - LPSR - Lunar Polar Sample Return
  - Phobos Sample Return