EXPERT Aerothermodynamic Flight Instrumentation and Integration

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ESA ESTEC

Objectives of EXPERT

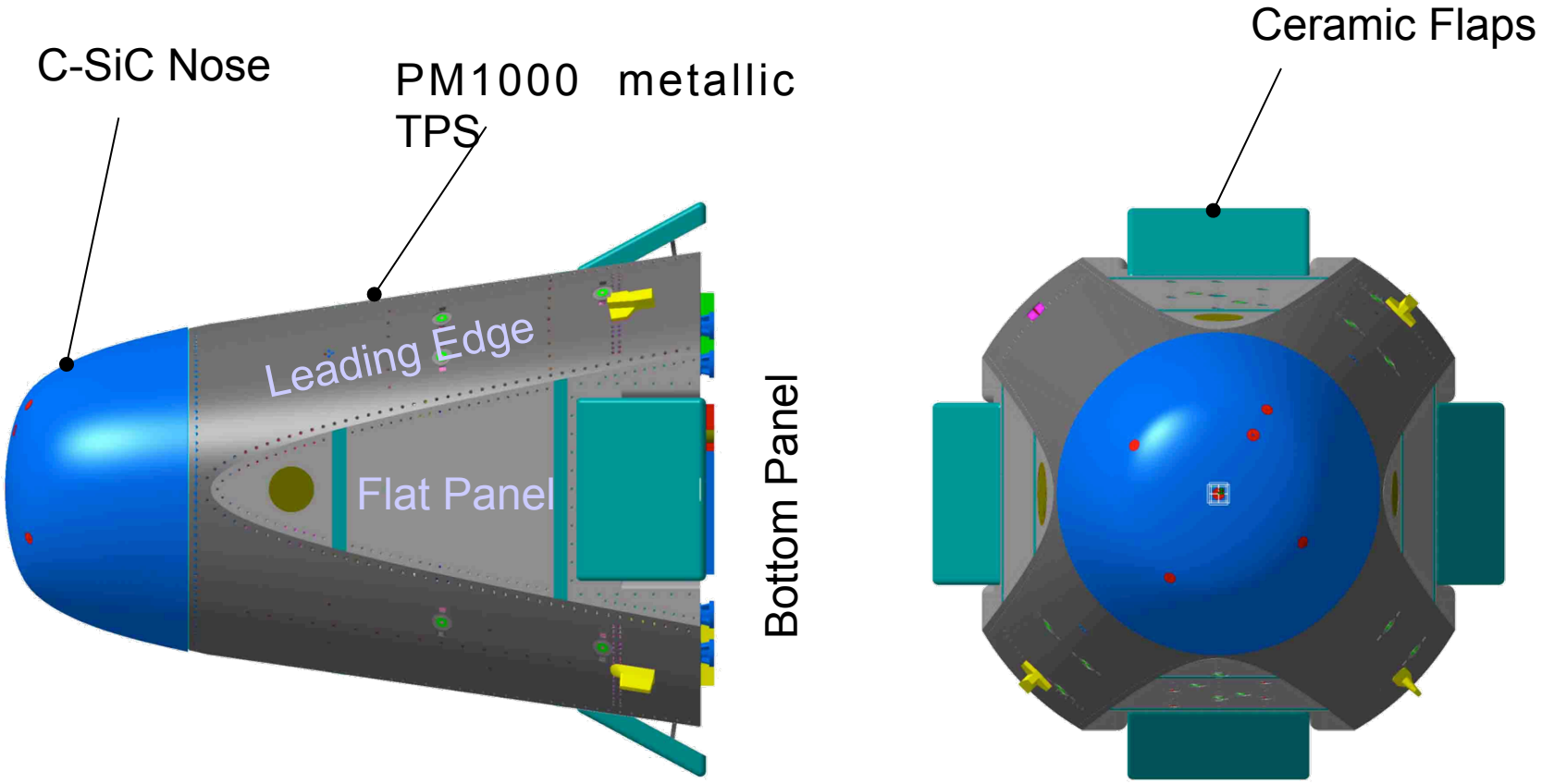
- Get flight data on critical ATD and TPS phenomena to improve the tools for re-entry vehicle design.

- In flight research on :
  - Transition , catalysis
  - Real gas effects on SWBLI
  - Shock layer chemistry
  - Skin friction and base flows

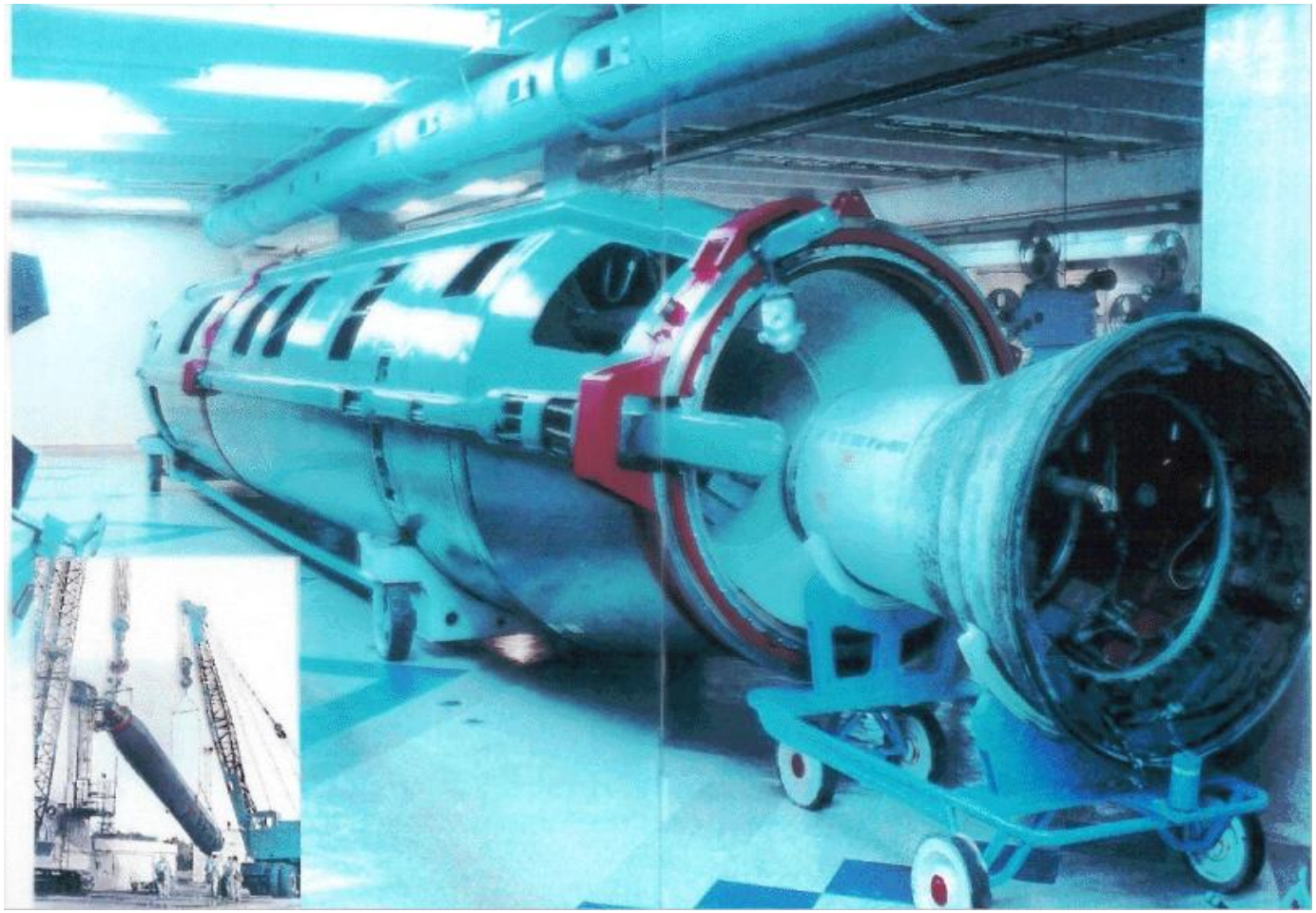
- Focus on wind tunnel to flight extrapolation and scaling.

- Special attention to flight instrumentation development, qualification and integration into TPS.

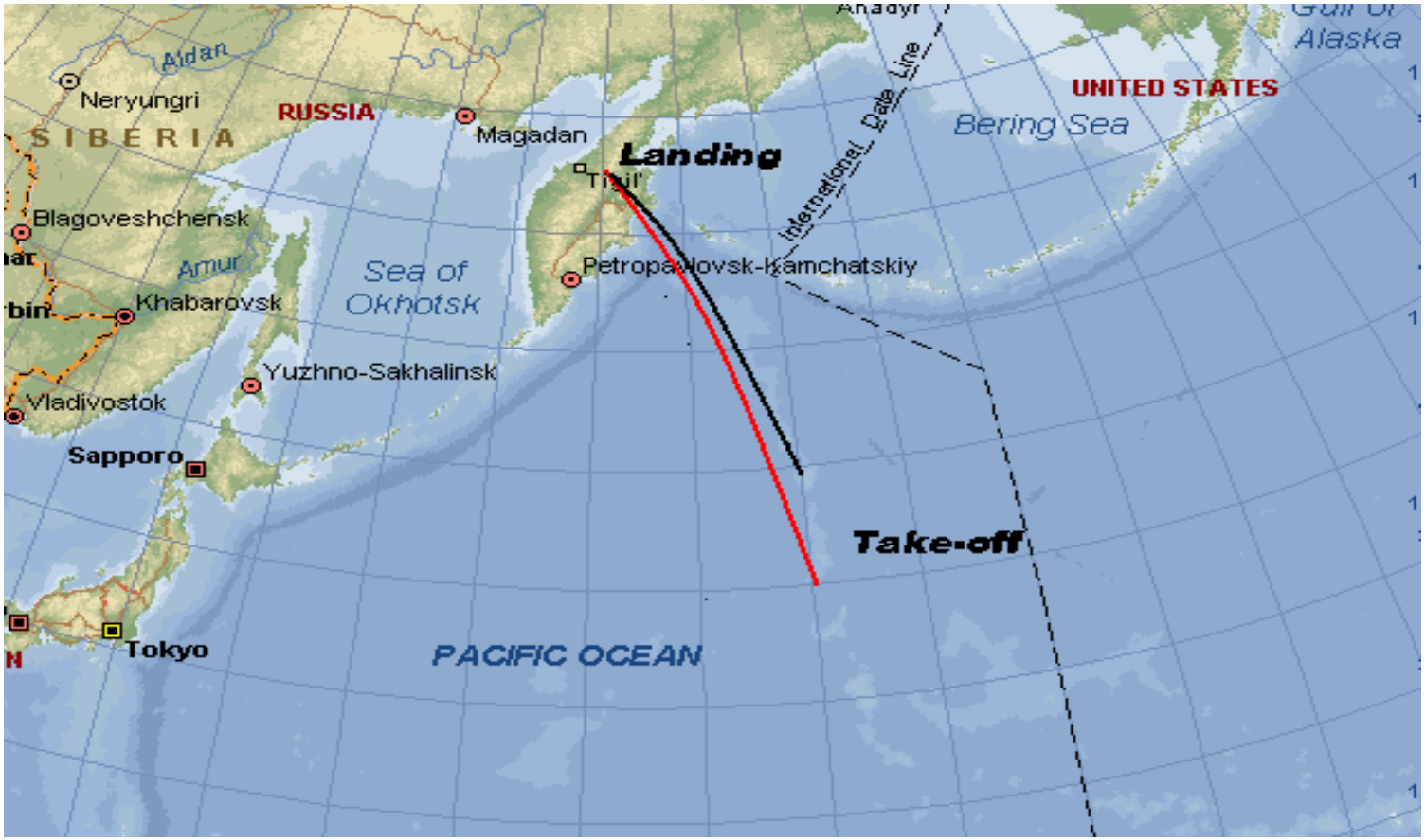
EXPERT configuration overview



Volan in Volna launcher

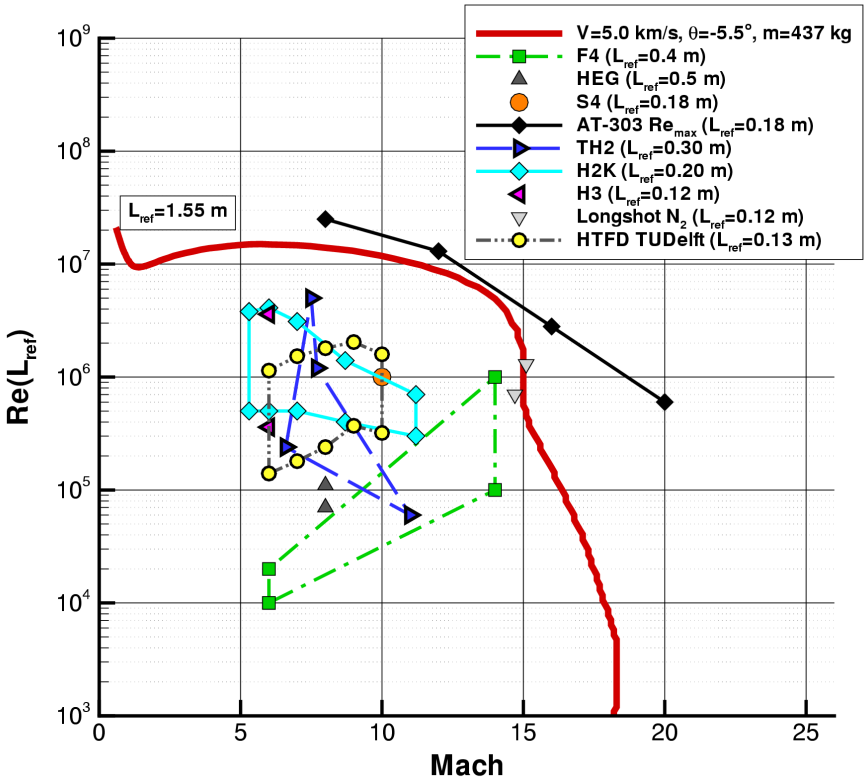


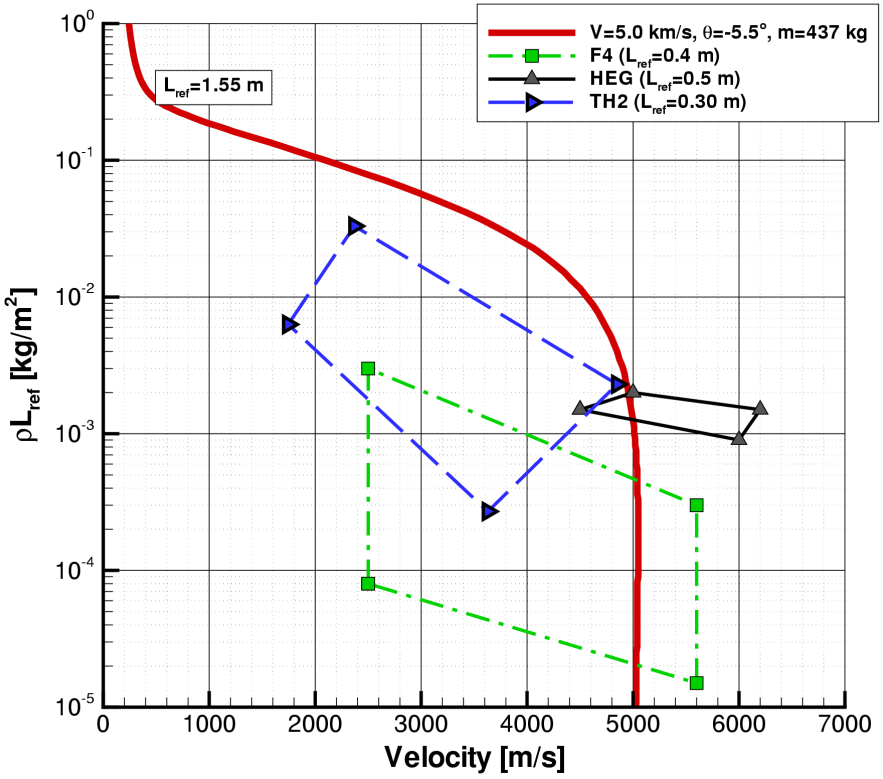
EXPERT mission ground tracks



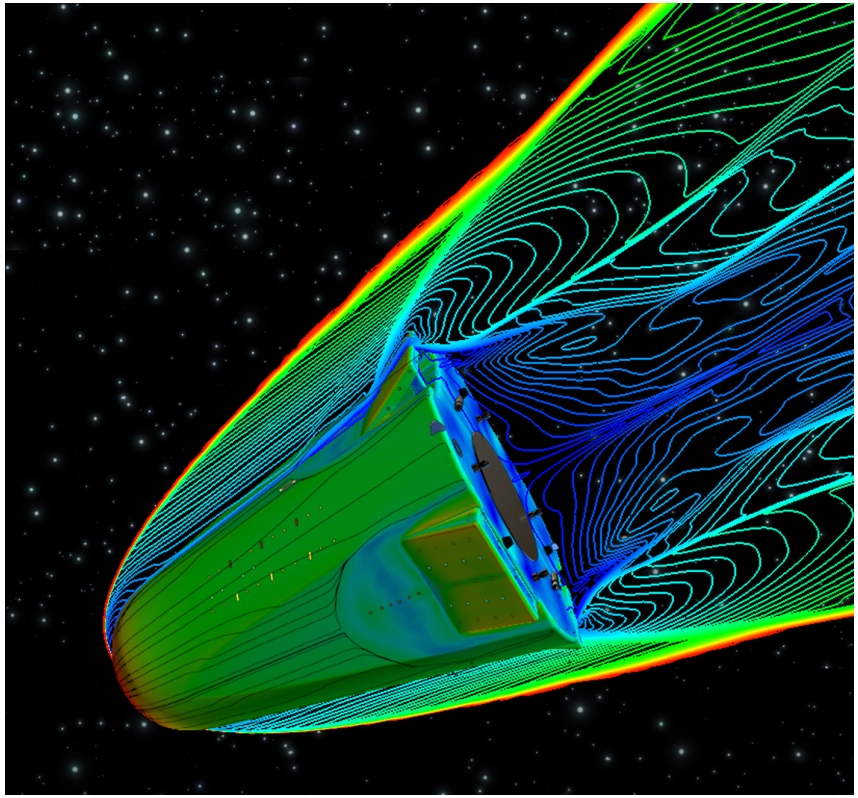
V_e=5.0 and 6.0 km/s , presently only 5 km/sec funded

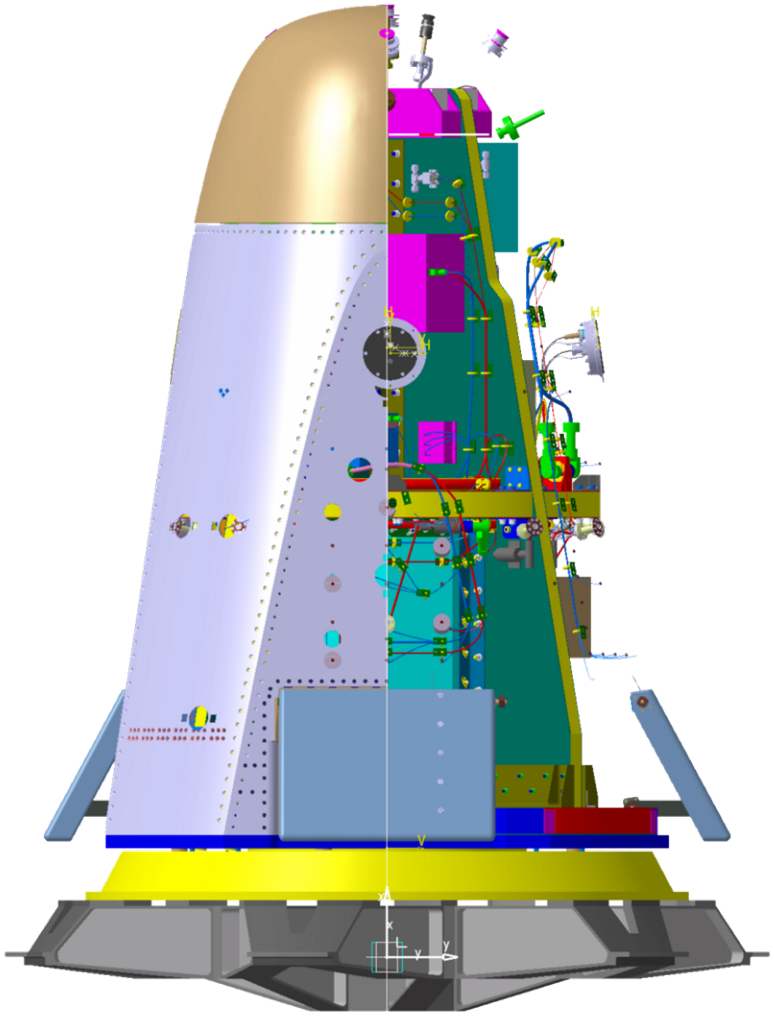
Hypersonic Wind tunnel coverage EXPERT





EXPERT is a test-bed for "In flight ATD research "

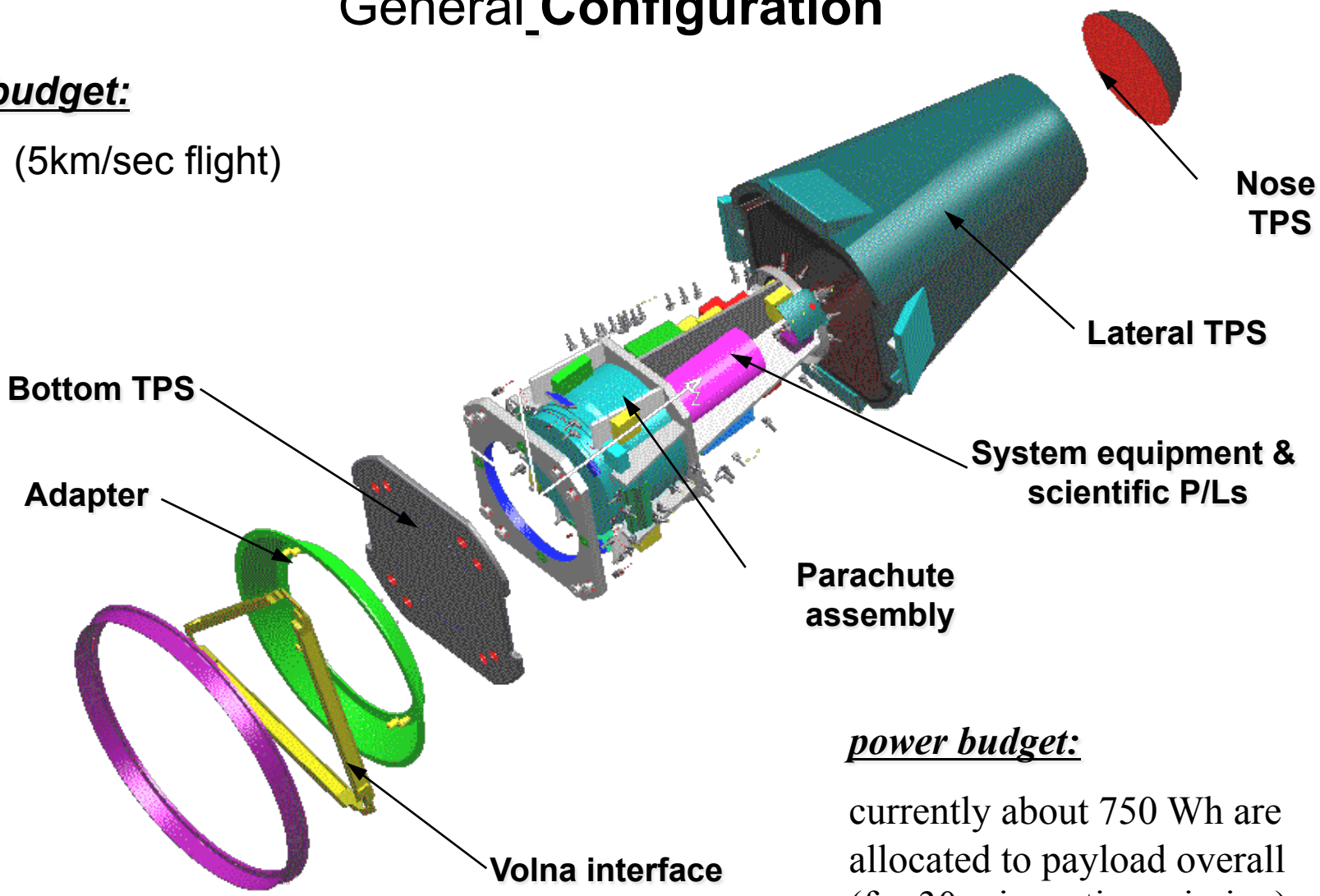




General Configuration

mass budget:

437 kg (5km/sec flight)

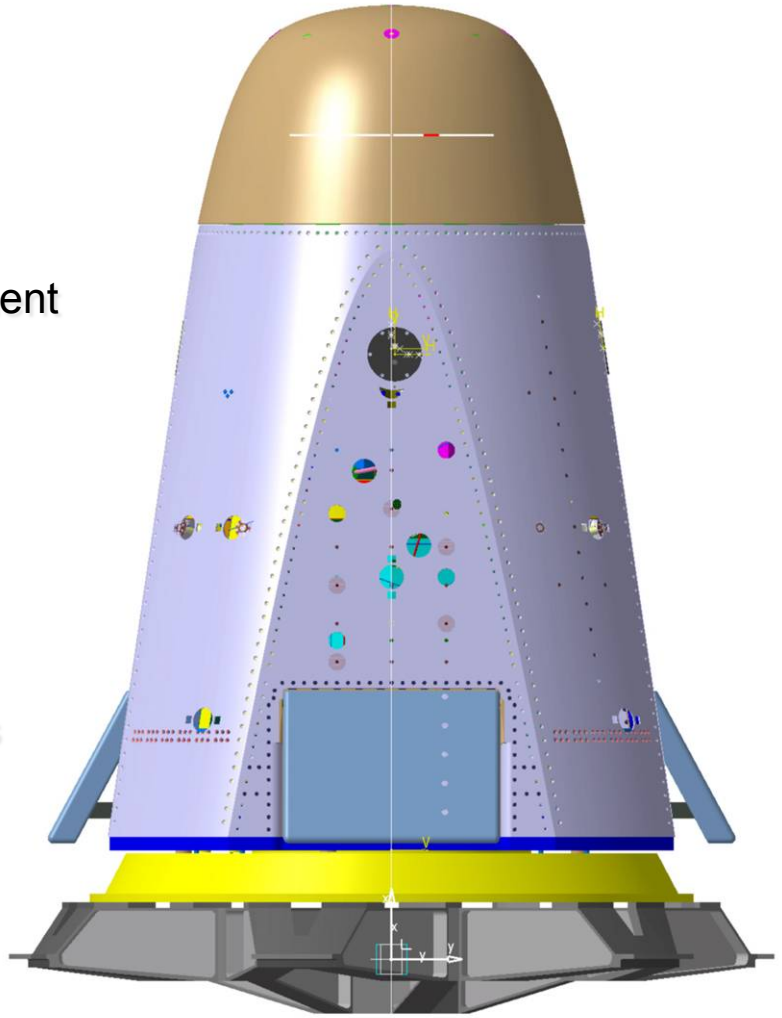


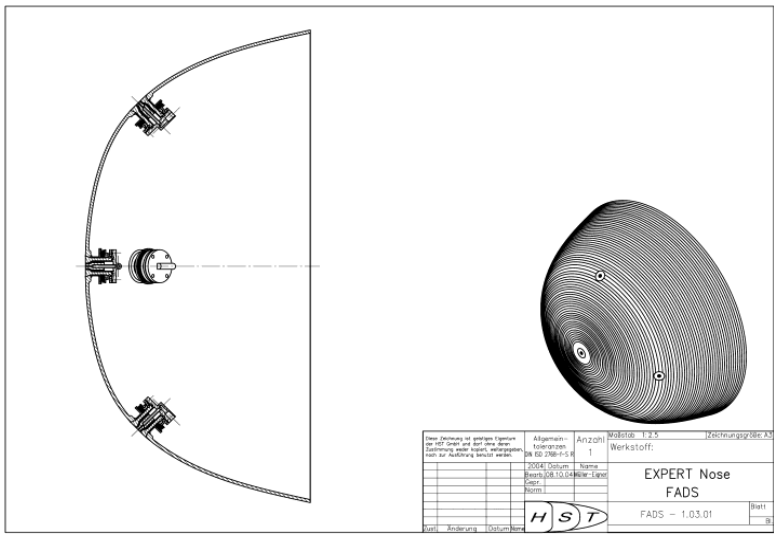
power budget:

currently about 750 Wh are allocated to payload overall (for 30 min. active mission)

Scientific Payloads

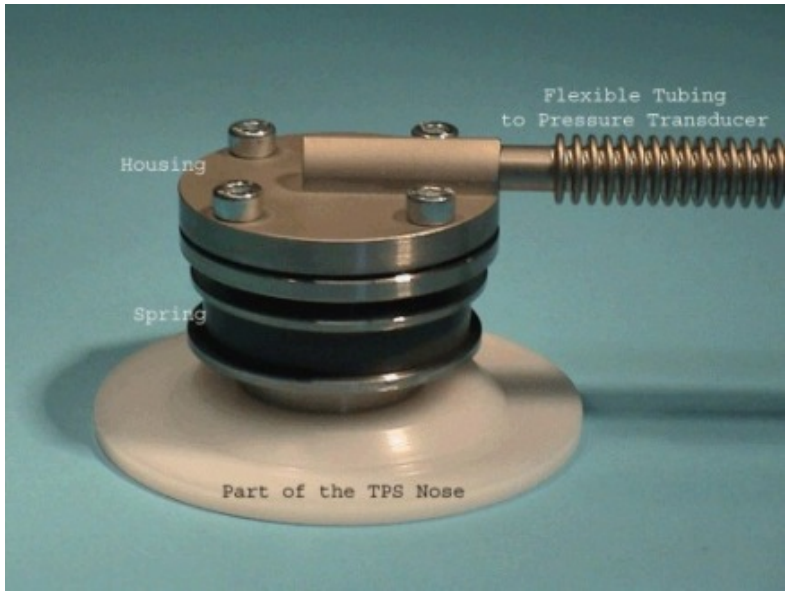
- **Payload 1** – FADS Flush Air Data System
- **Payload 2** – PYREX Nose Heating Experiment
- **Payload 3** – Catalicity Experiment
- **Payload 4** – Natural Transition Experiment
- **Payload 5** – Roughness Induced Transition Experiment
- **Payload 6** – SWBLI onto EXPERT Open Flaps
- **Payload 7** – SWBLI ahead of EXPERT Open Flaps
- **Payload 8** – IR Thermography
- **Payload 11** – Junction Experiment
- **Payload 10** – Re-entry Spectrometry (RESPECT)
- **Payload 12** – Base Pressure and Heat Flux Sensors
- **Payload 13** – Skin Friction Sensors
- **Payload 15** - Sharp Hot Structures
- **Payload 16** - Actively Cooled Sample
- **Payload 18** - Intermetallic Matrix Composite Tile





RAFLEX FADS

- Two Thermocouples
- One Pressure Sensor



PYREX Nose heating Experiment

Scientific Goals:

Temperature and heat flux measurement inside nose cone

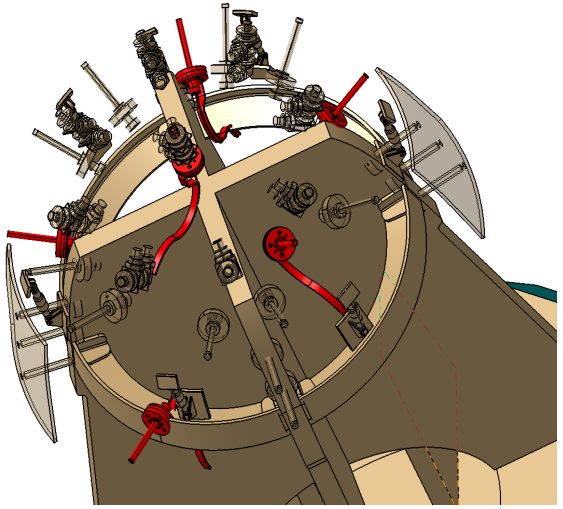
⇒ **Validation of numerical models / codes**

System consists of:

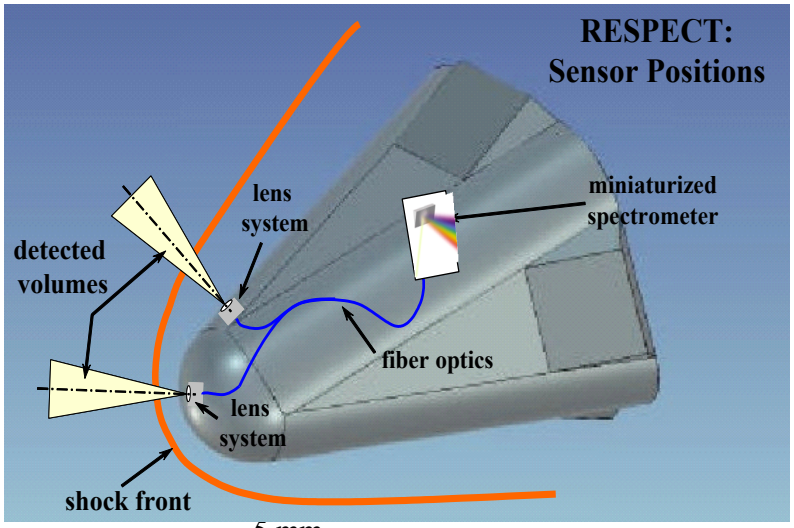
- **6 PYREX Sensors (SH 1-6)**
- **Mounting on cold structure**
- **Fiber Optics and holding Brackets**
- **Sensor Unit (SU)**
- **Interface to OBDH**

PYREX:

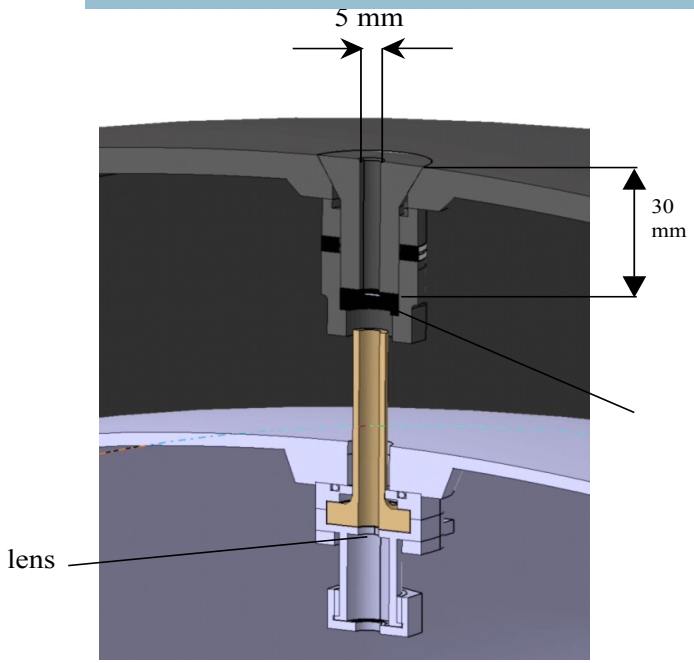
Measurement in six locations



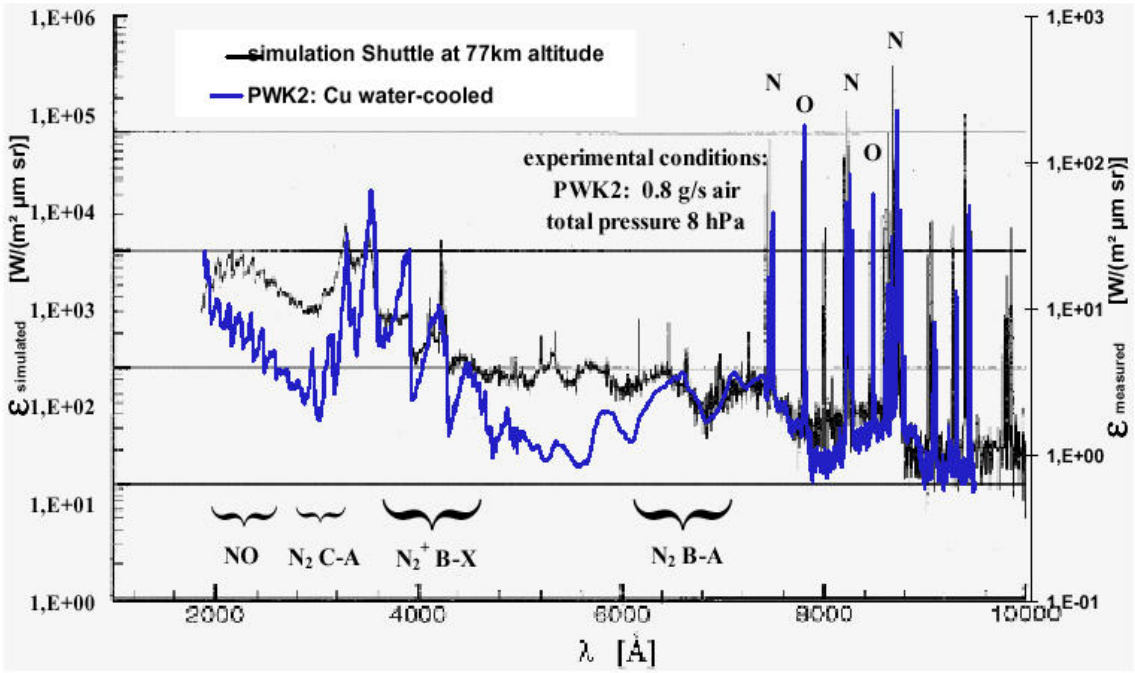
Prelim Positions of PYREX



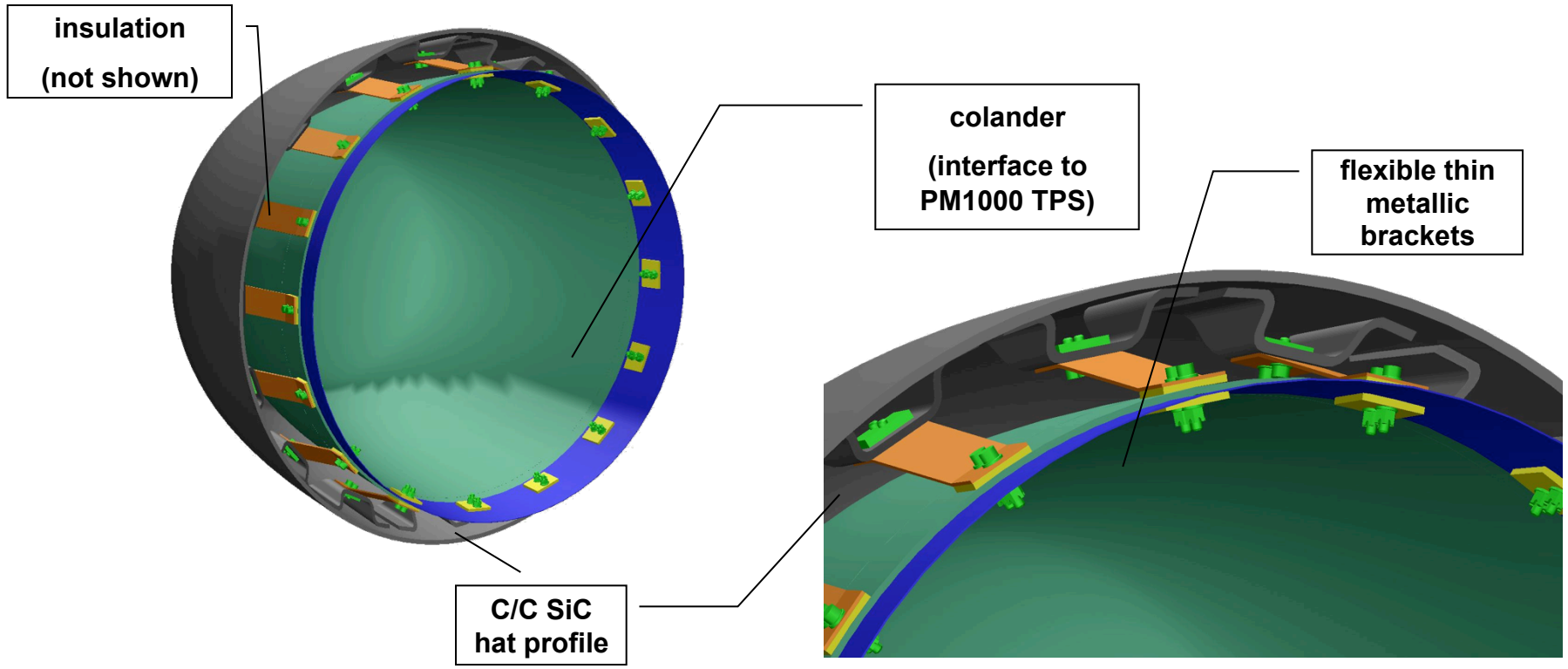
RESPECT Emission



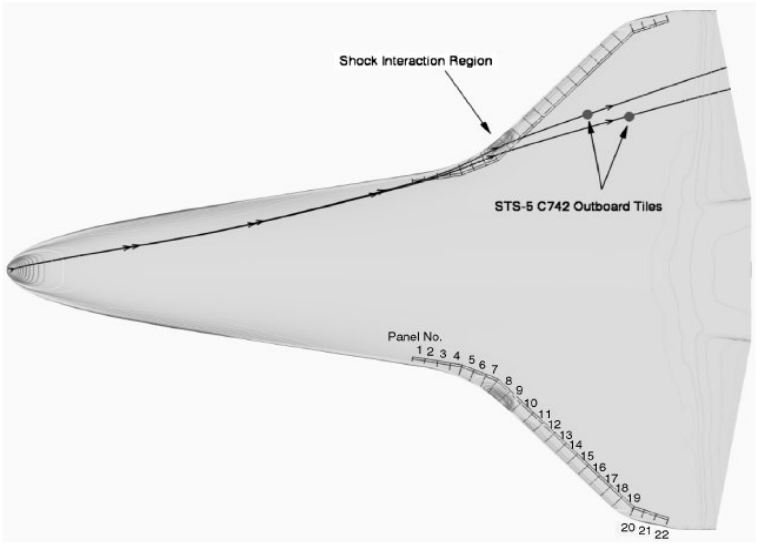
saphire window: thickness 3 mm, diameter 14 mm

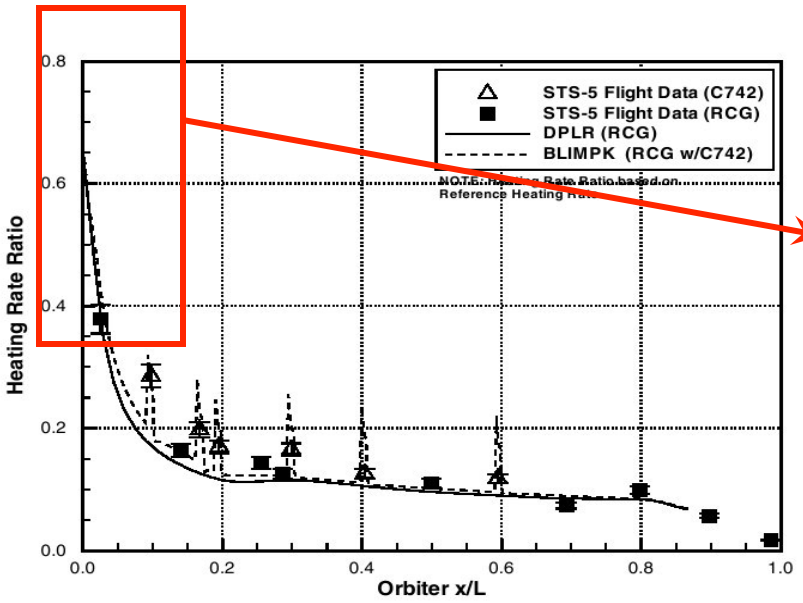


Nose cone interface

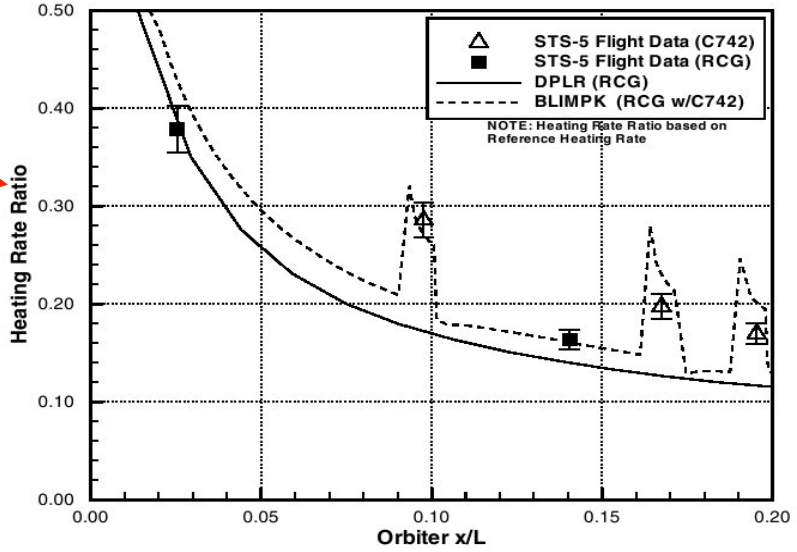


CFD compared to OEX flight data for M=18 STS-5 @ Centerline



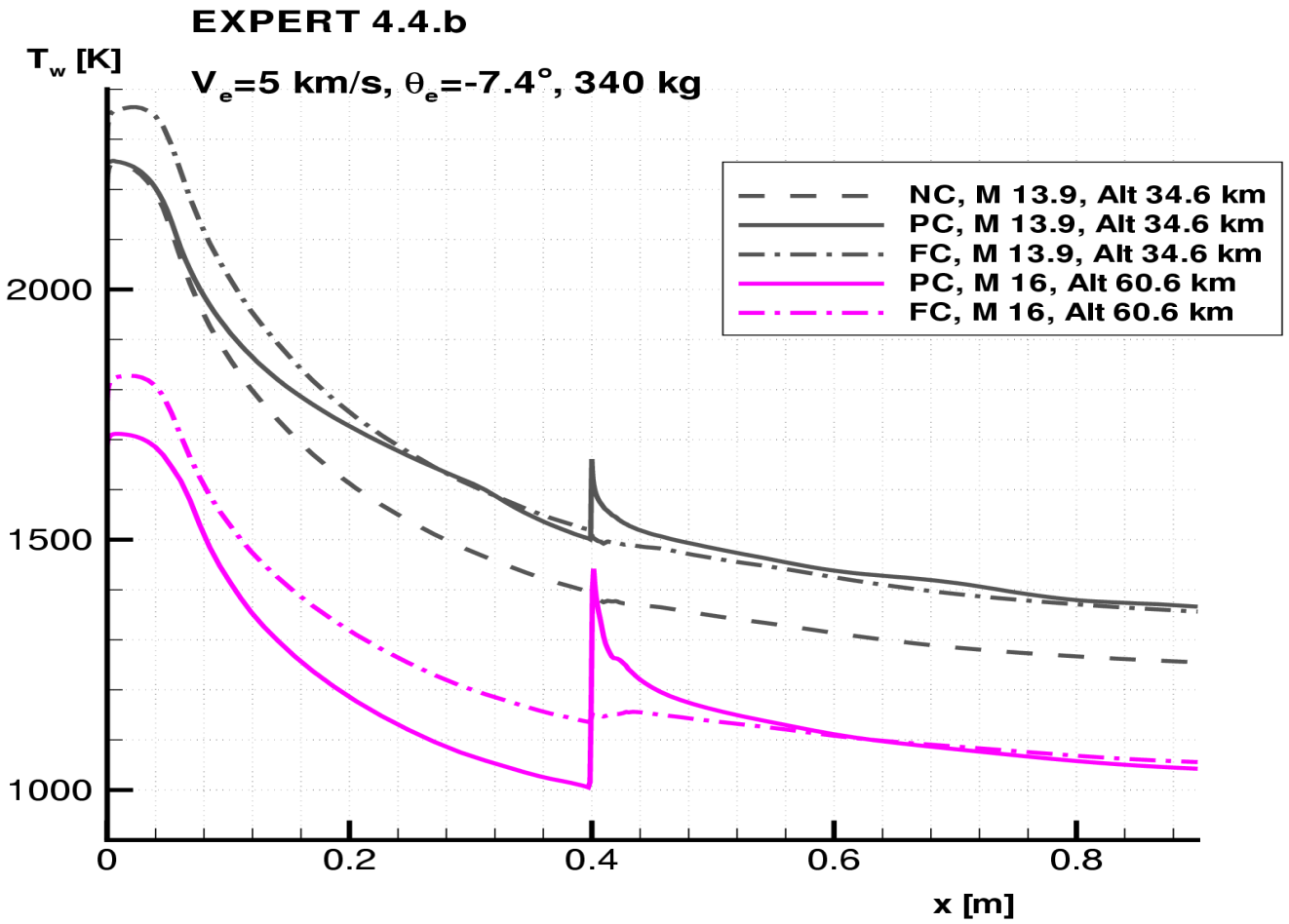


a) Heating rate ratio for Orbiter centerline

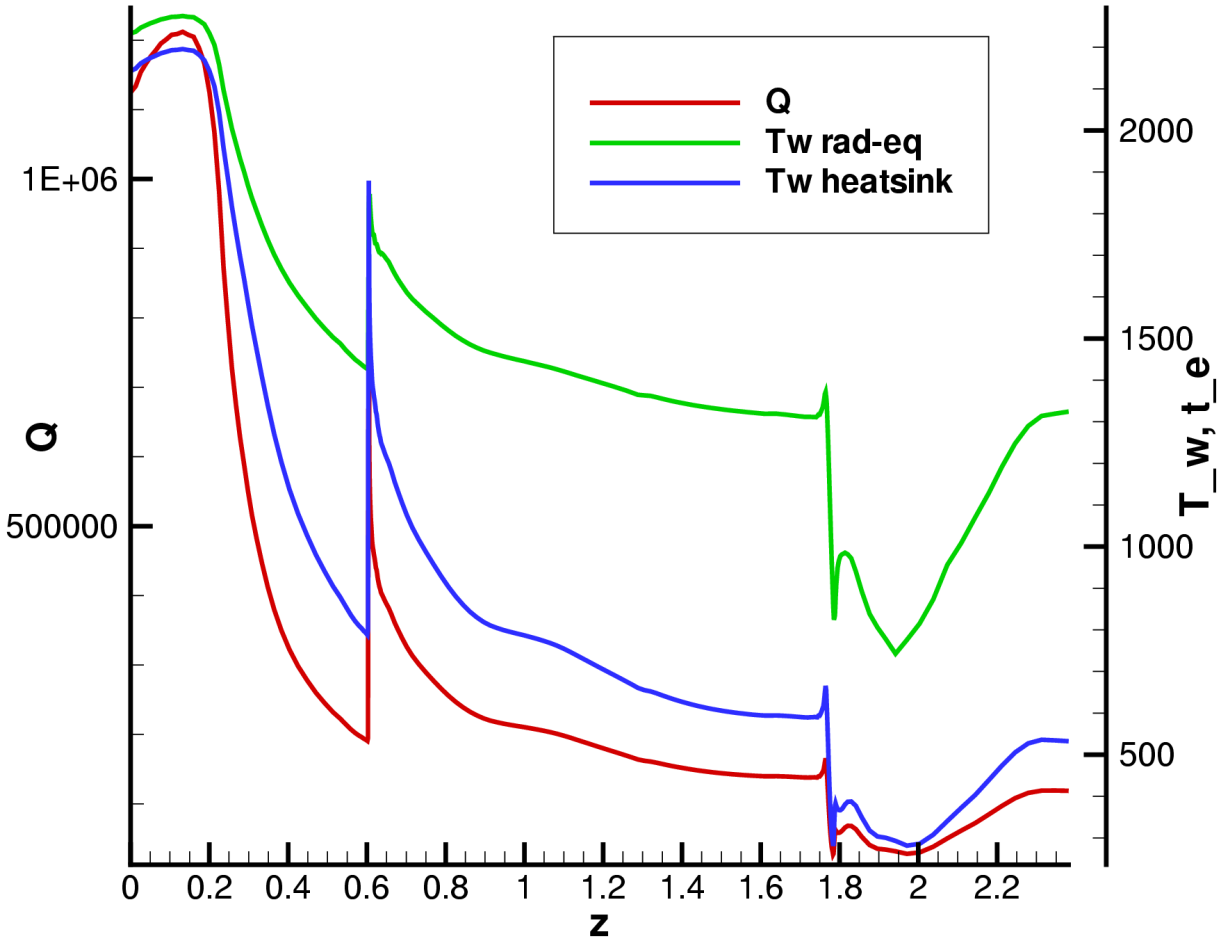


b) Magnification

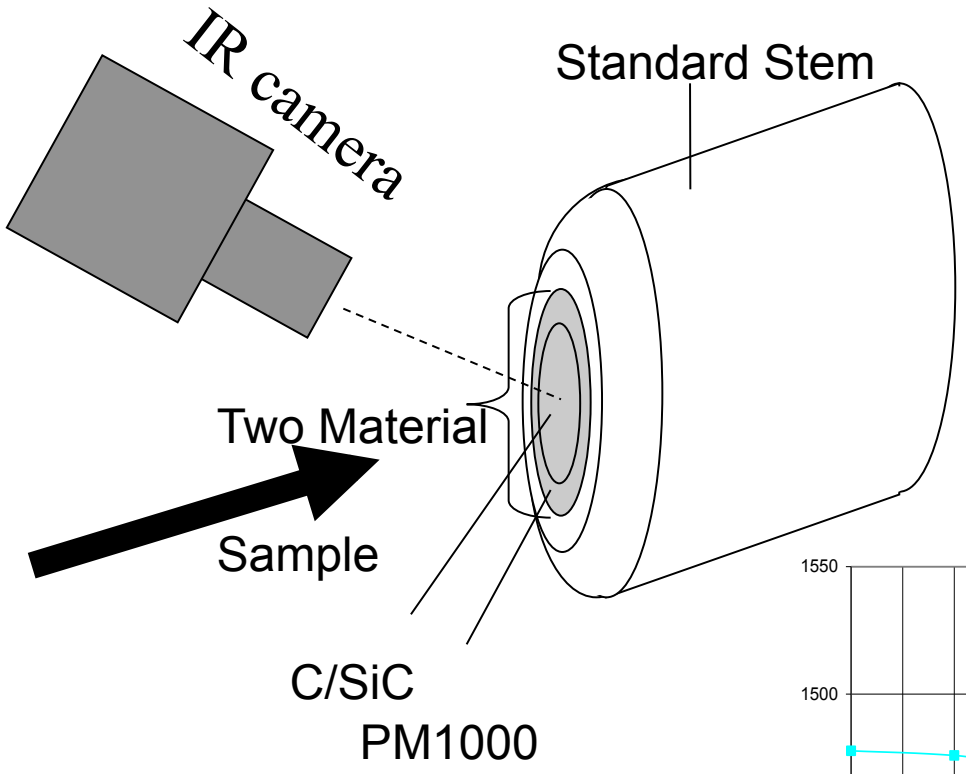
Temperature jump at nose C-SiC/PM1000 junction

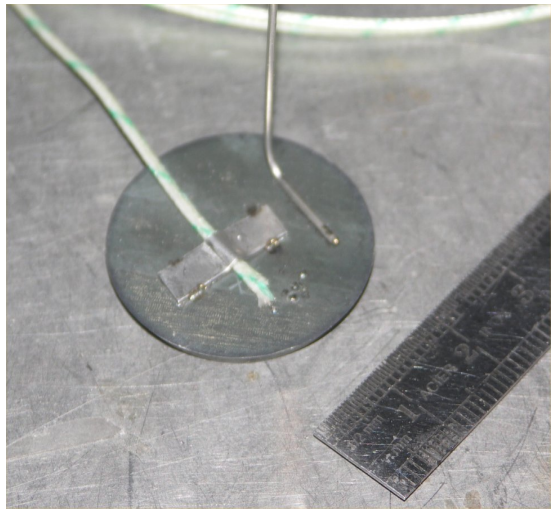


Temperature jump at nose
C-SiC/PM1000 junction with effect of heatsink

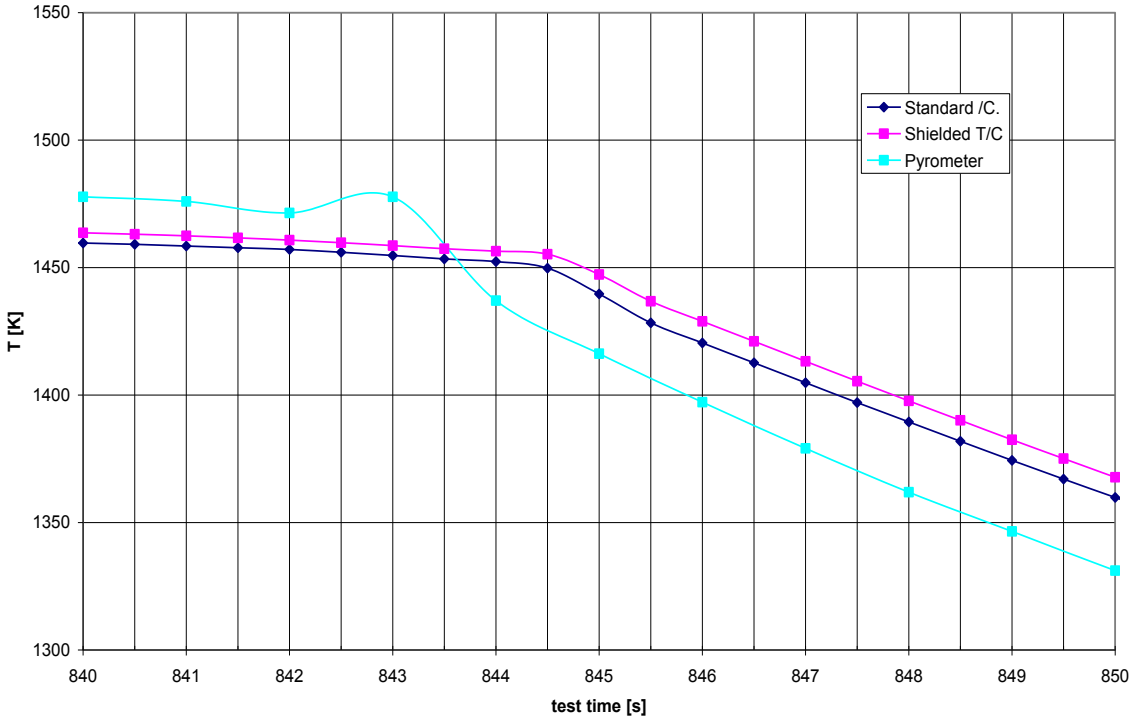


EXPERT: EUROPEAN EXPERIMENTAL REENTRY TESTBED

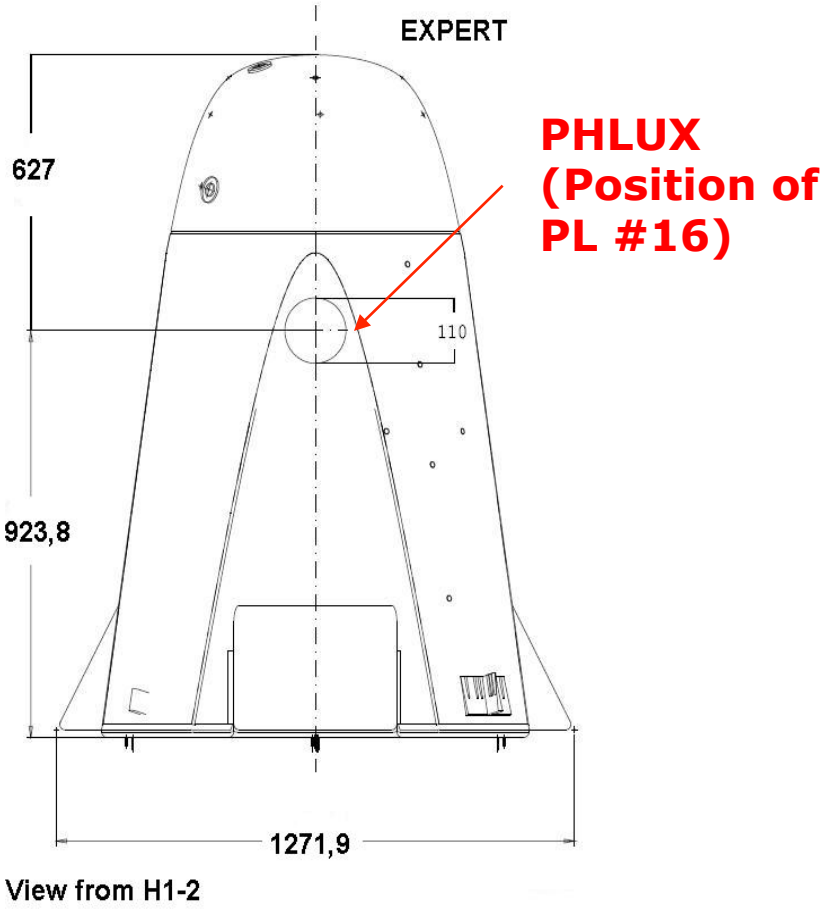


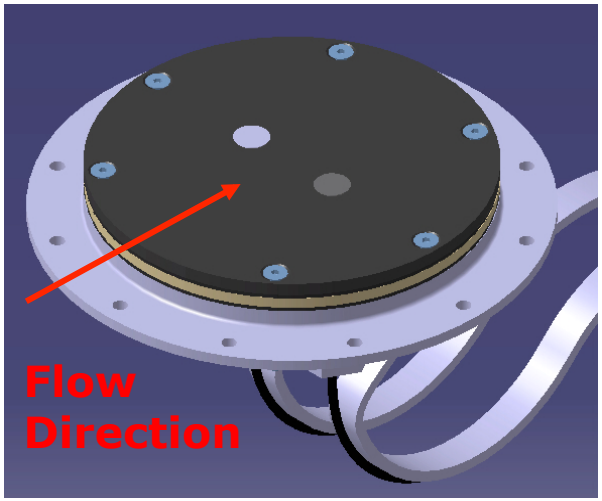


Spotwelding qualification Plasmatron

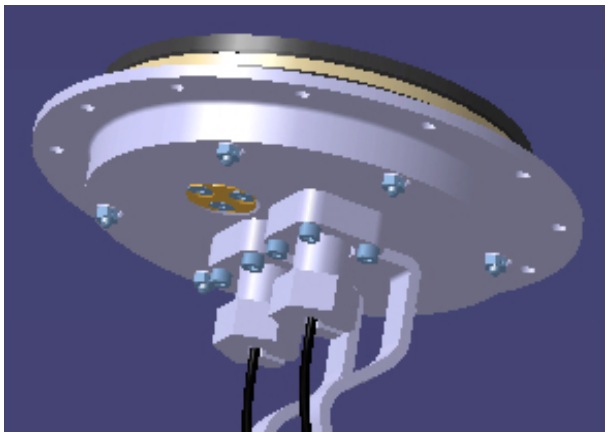


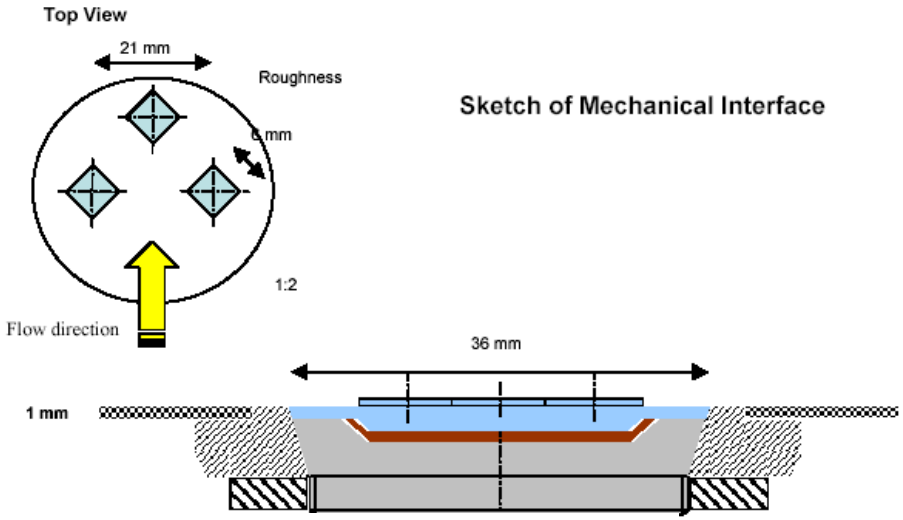
Catalysis with PHLUX and imbedded Thermocouples



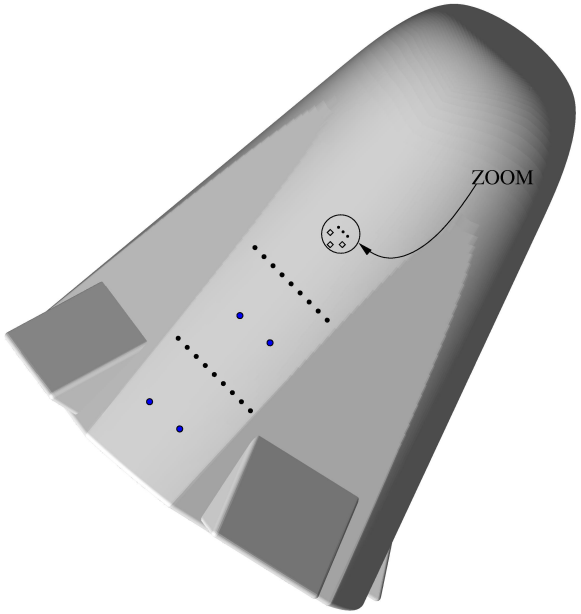


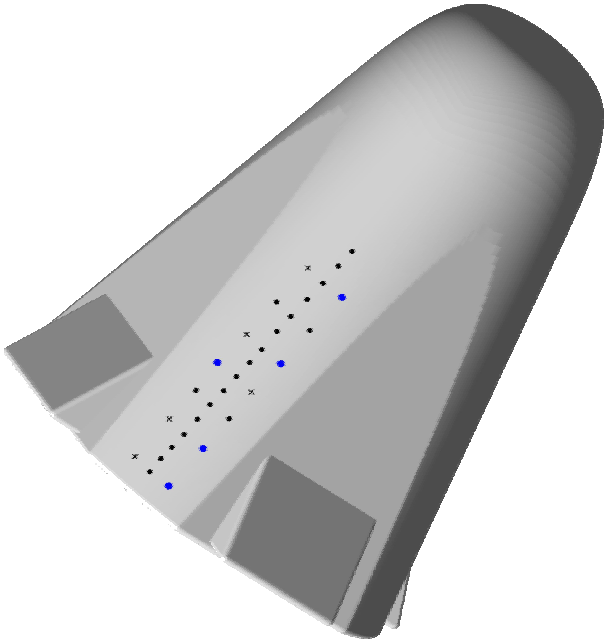
PHLUX Sensor pair



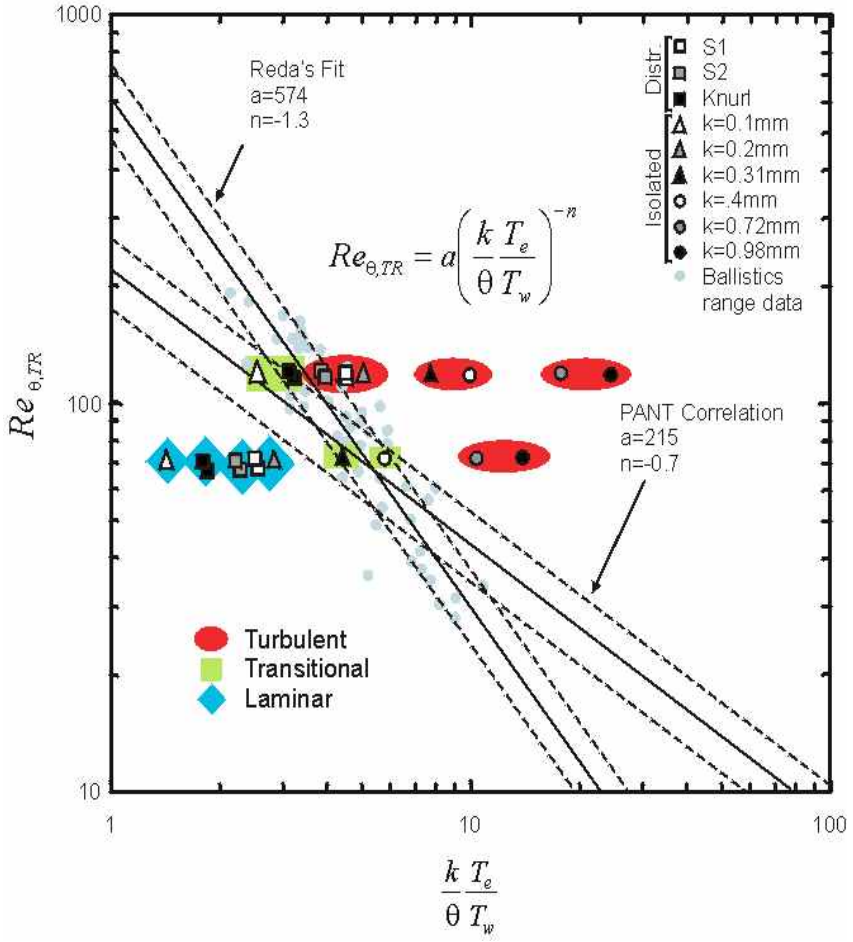


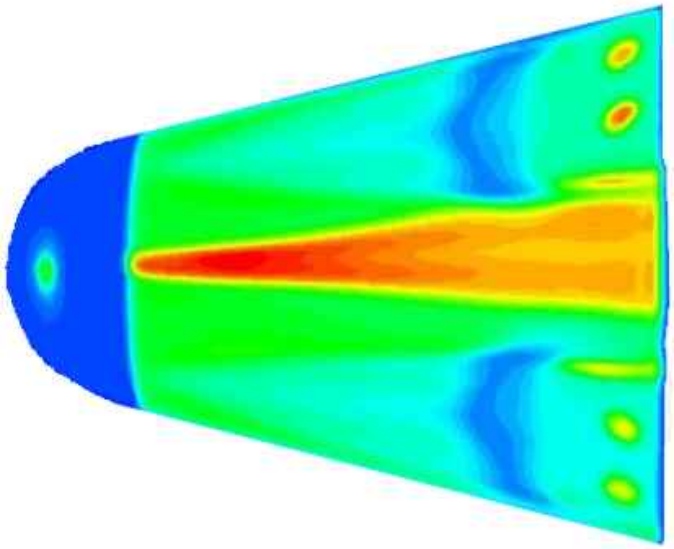
Roughness induced transition





Roughness **induced** Transition VKI-H3



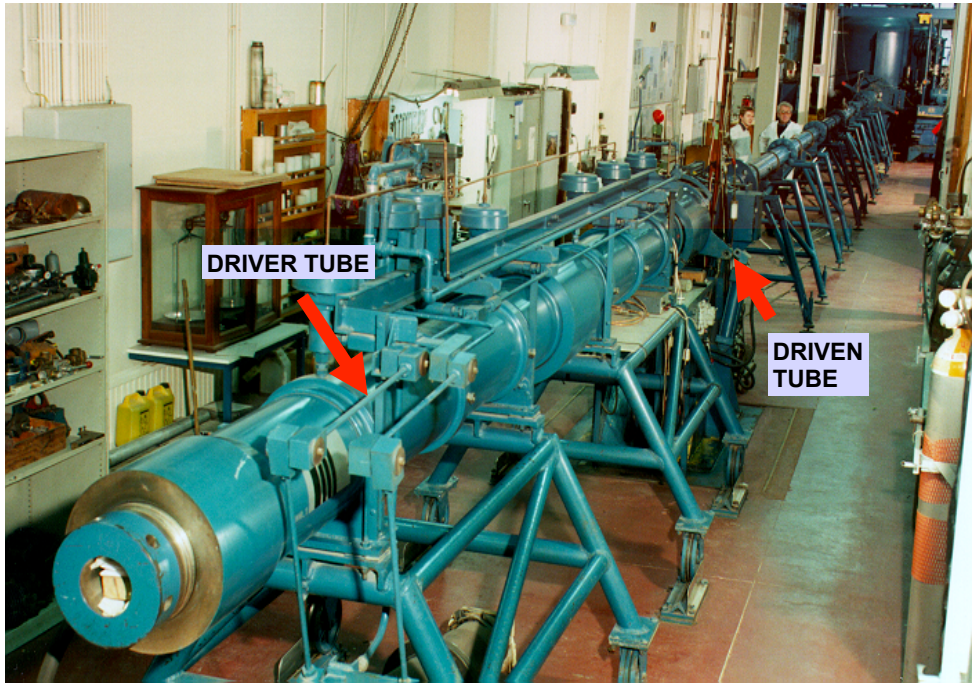


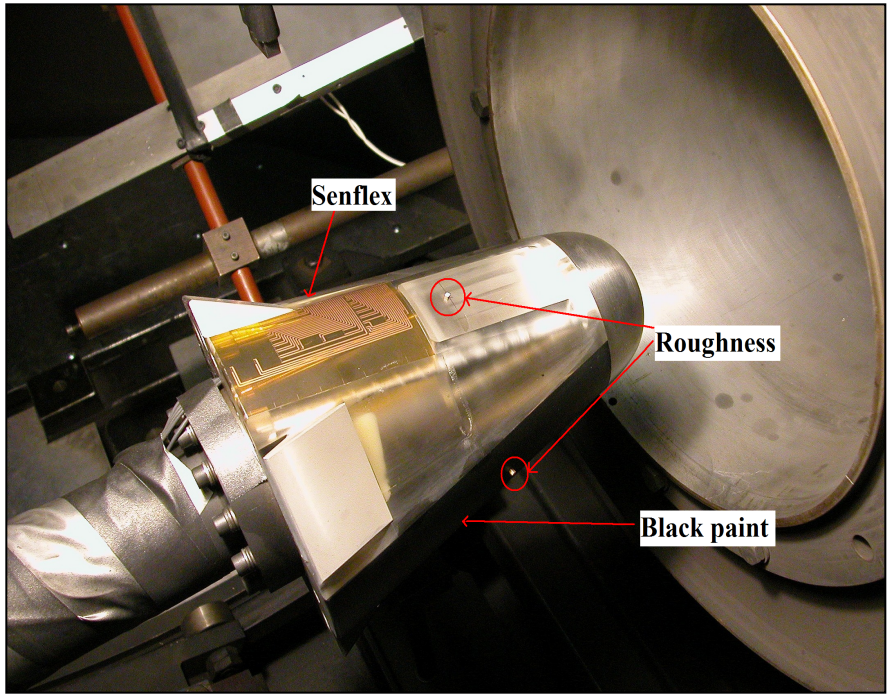
Re=2.5x10^7/m

k=0.200mm

Roughness Induced Transition

Tests in VKI-Longshot





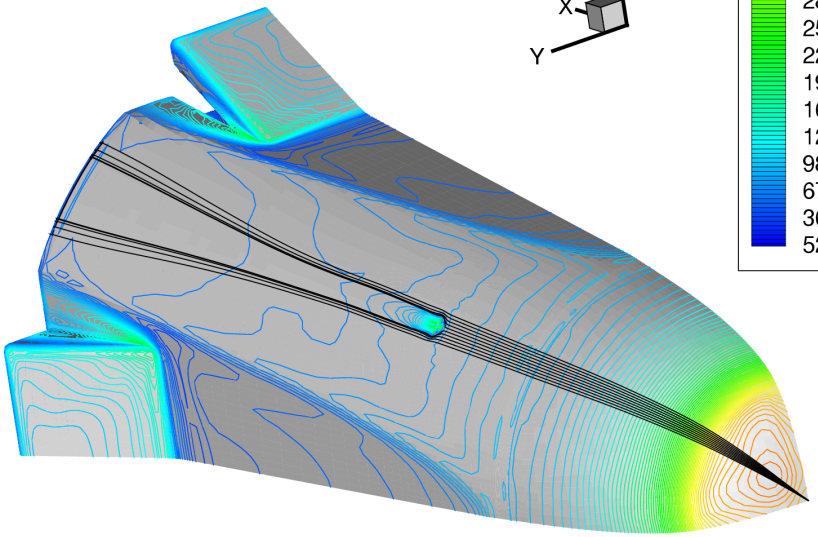
- FLIR SC3000 Thermocam for one corner, thin film sensors
- High speed Schlieren movies to verify boundary layer condition

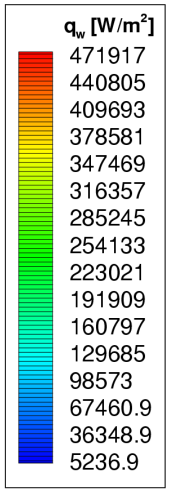
Roughness Induced Transition

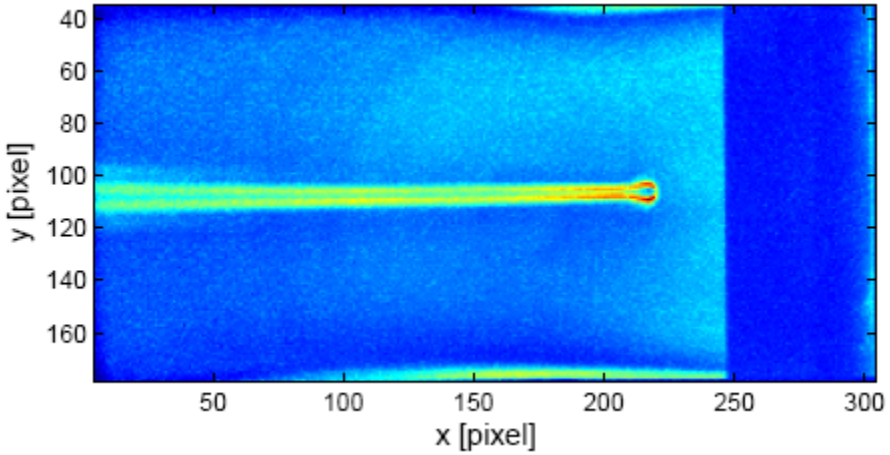
EXPERT 4.4.b with Roughness Elements VKI

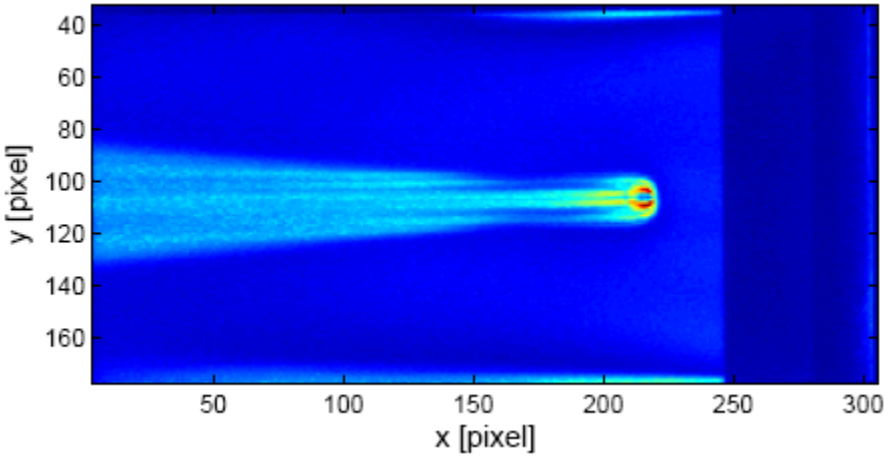
M=8.0, Laminar computation

Boundary conditions: Radiative equilibrium
Nose: NC
PM1000: FC







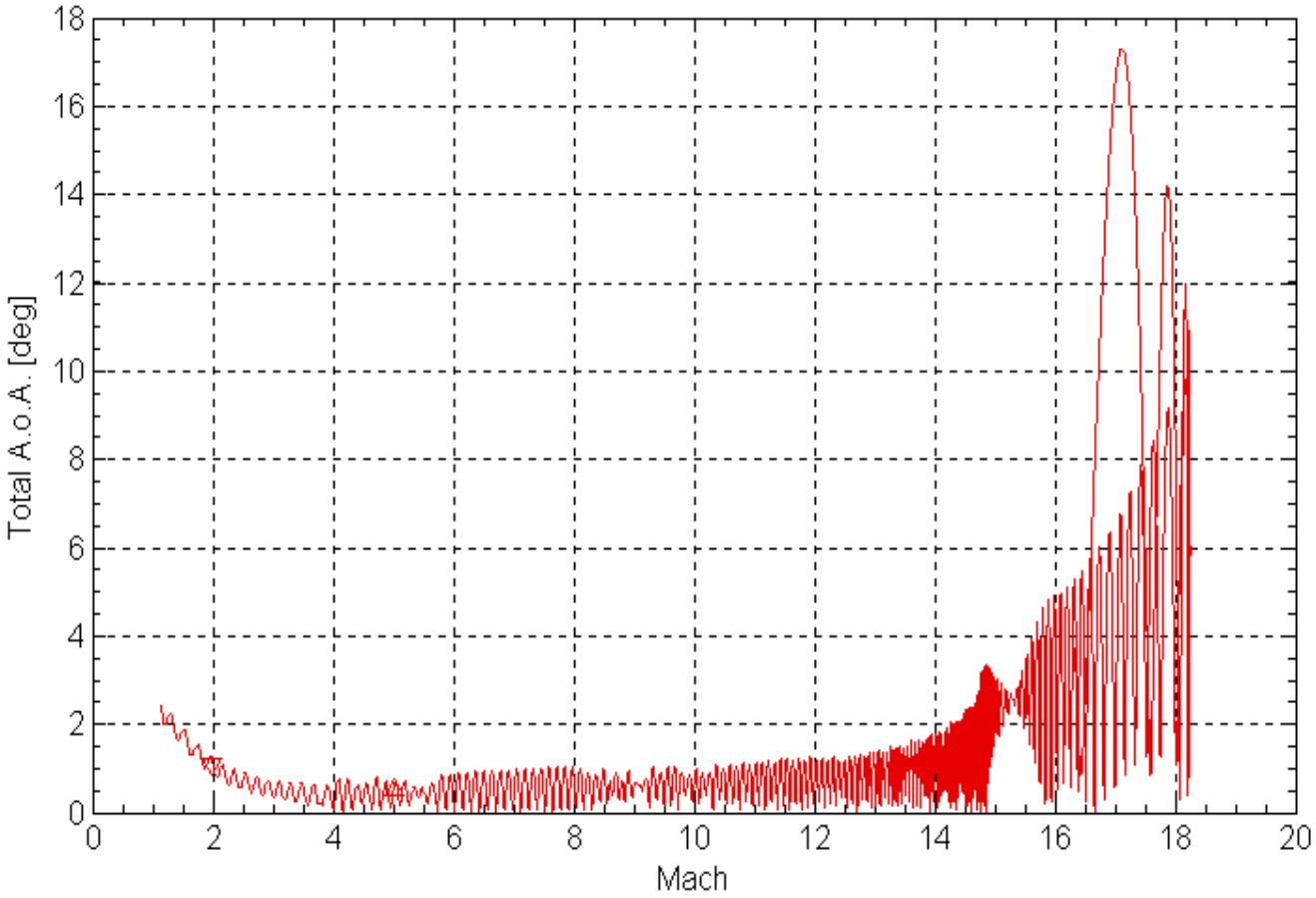


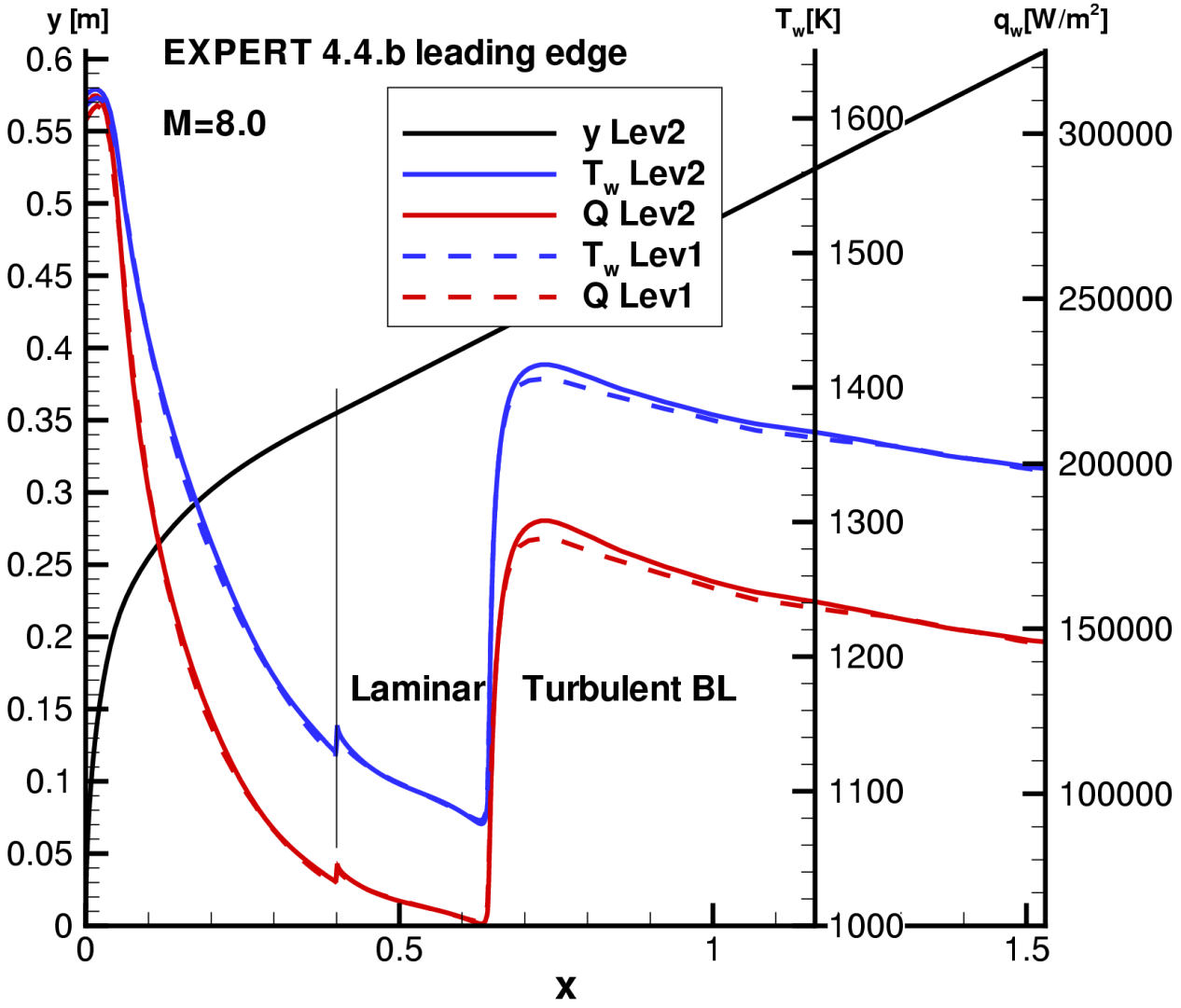
ion

Mission 1.2 Cases - Time from separation

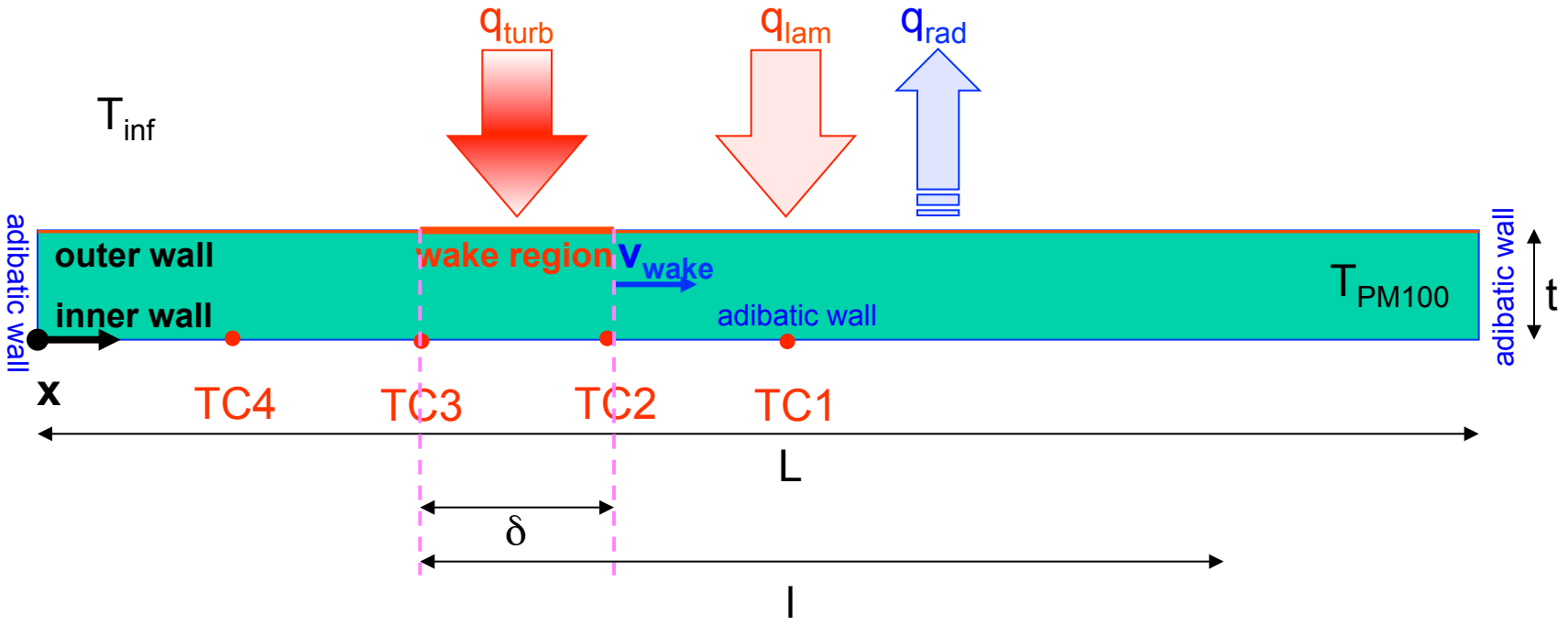
BASELINE : PDR - Mission 1.2 - 5.0 km/s γ_e = 5.5°, 330 kg

Δ Mach 5
V Mach 2




y [m]
T_w[K]
q_w[W/m^2]
EXPERT 4.4.b leading edge
M=8.0
y Lev2
T_w Lev2
Q Lev2
T_w Lev1
Q Lev1
Laminar
Turbulent BL
x
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
1600
1500
1400
1300
1200
1100
1000
300000
250000
200000
150000
100000

Unsteady 2-D heat transfer simulations: Oscillating Wave

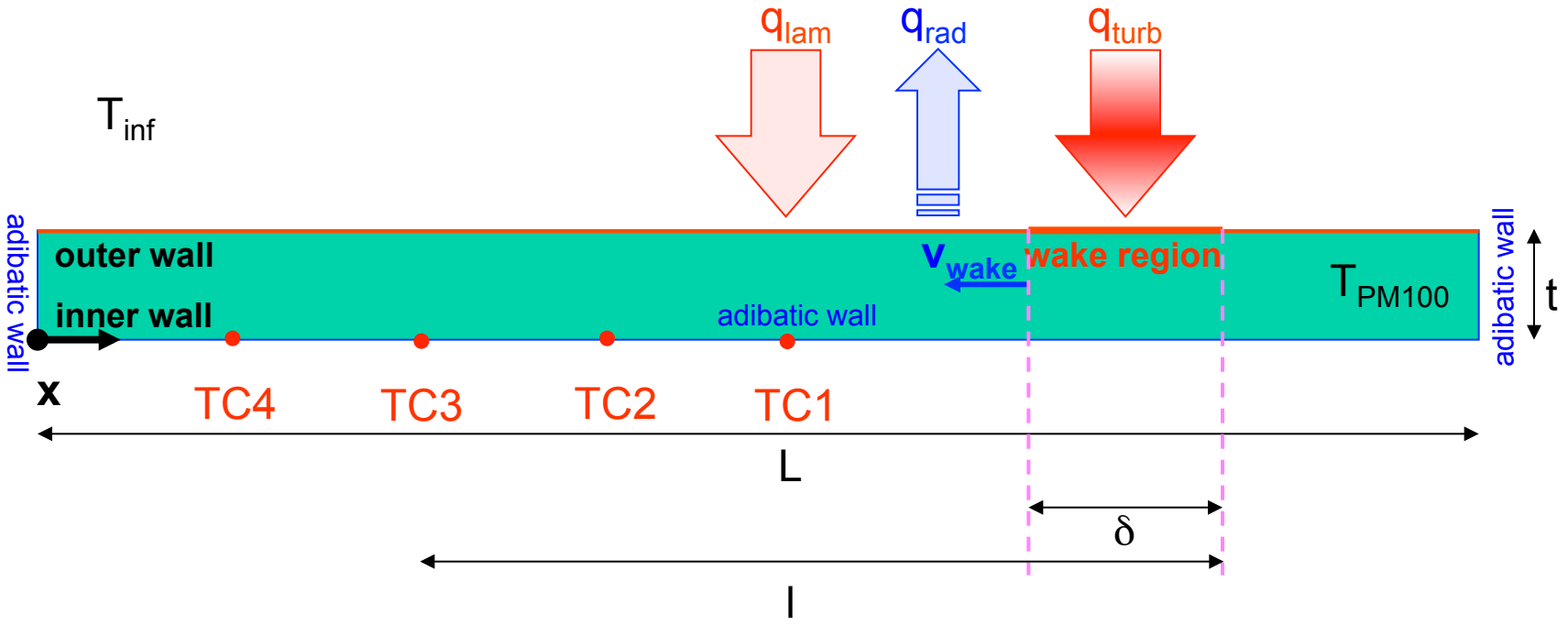


$T_{PM100}(t=0) = 800$ K
$T_{inf} = 300$ K
$q_{lam} = 100{,}000$ W/m^2
$q_{turb} = 300{,}000$ W/m^2

t = 2,5 mm
L = 10 cm
l = 4 cm
δ = 1 cm

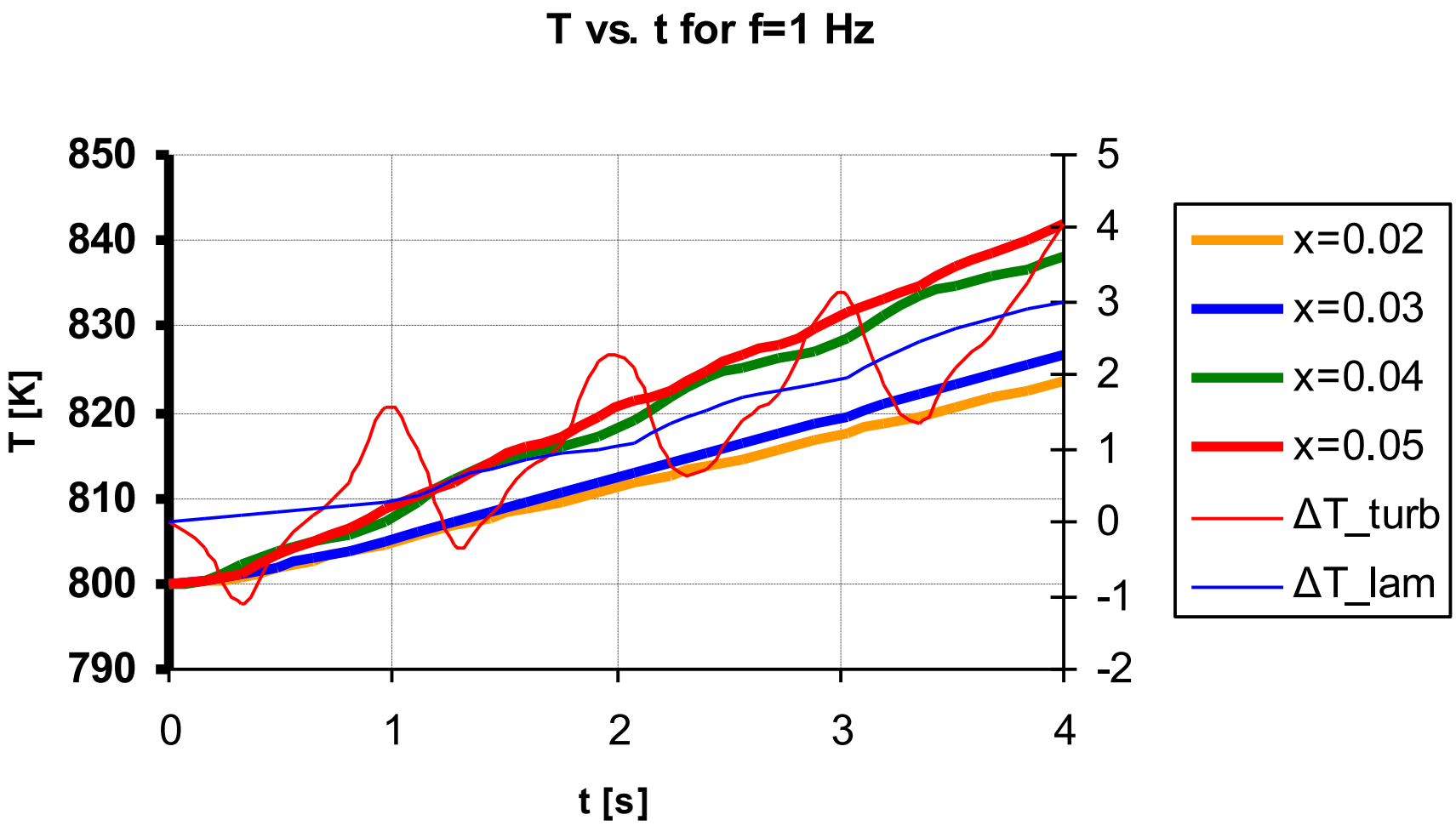
x(TC1) = 50 mm
x(TC2) = 40 mm
x(TC3) = 30 mm
x(TC4) = 20 mm

Unsteady 2-D heat transfer simulations: Oscillating Wave



$T_{PM100}(t=0) = 800$ K	t = 2,5 mm	x(TC1) = 50 mm
$T_{inf} = 300$ K	L = 10 cm	x(TC2) = 40 mm
$q_{lam} = 100{,}000$ W/m^2	l = 4 cm	x(TC3) = 30 mm
$q_{turb} = 300{,}000$ W/m^2	δ = 1 cm	x(TC4) = 20 mm

Unsteady 2-D heat transfer simulations: Oscillating Wave



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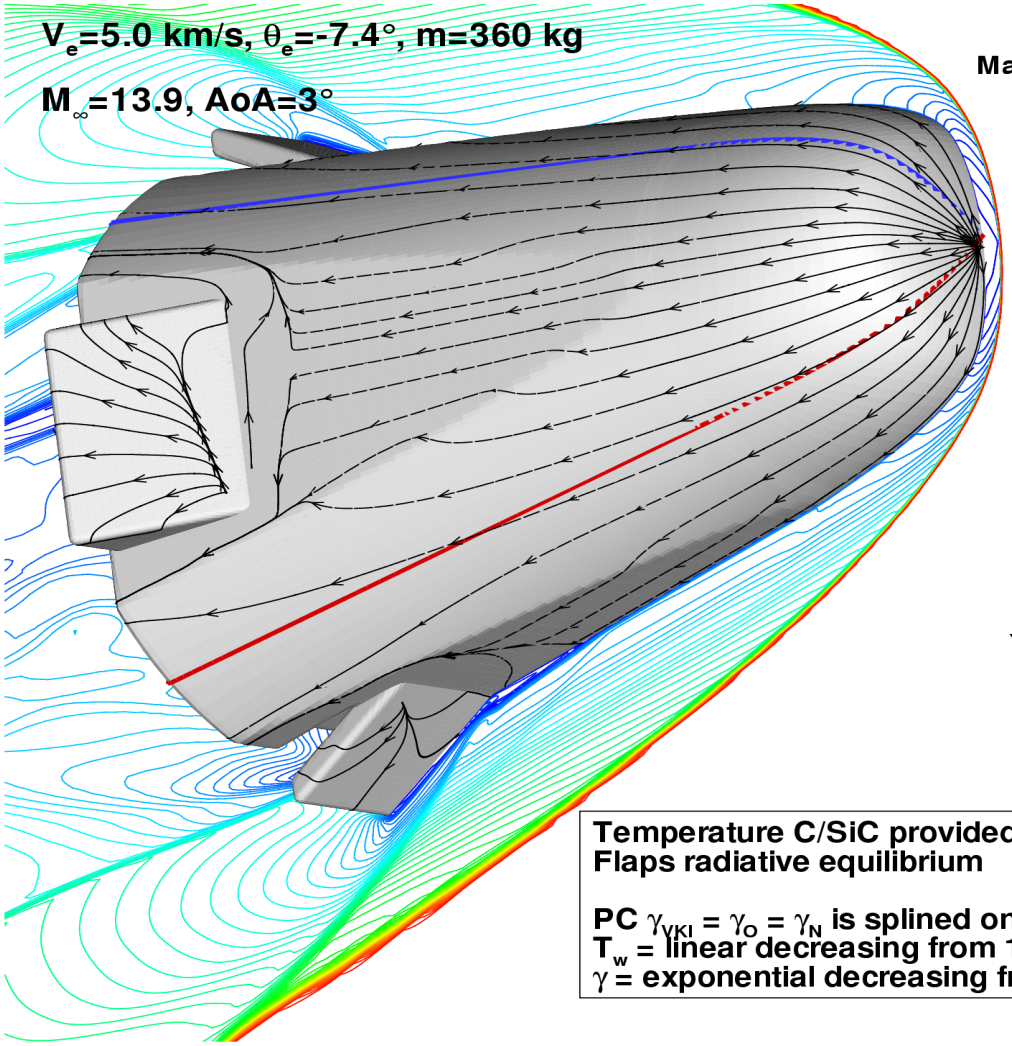
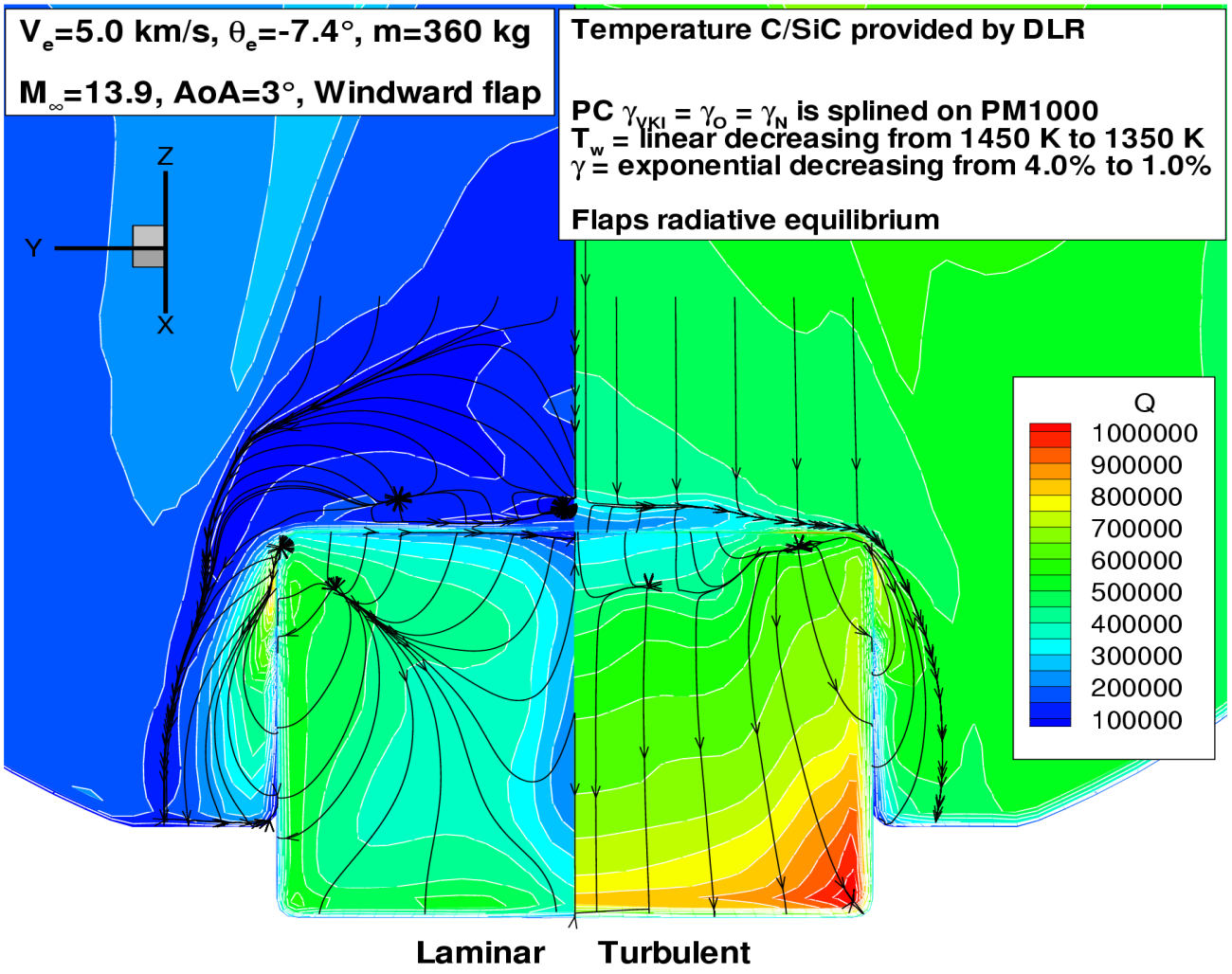


Temperature C/SiC provided by DLR
Flaps radiative equilibrium

PC $\gamma_{VKI} = \gamma_O = \gamma_N$ is splined on PM1000
T_w = linear decreasing from 1450 K to 1350 K
γ = exponential decreasing from 4.0% to 1.0%

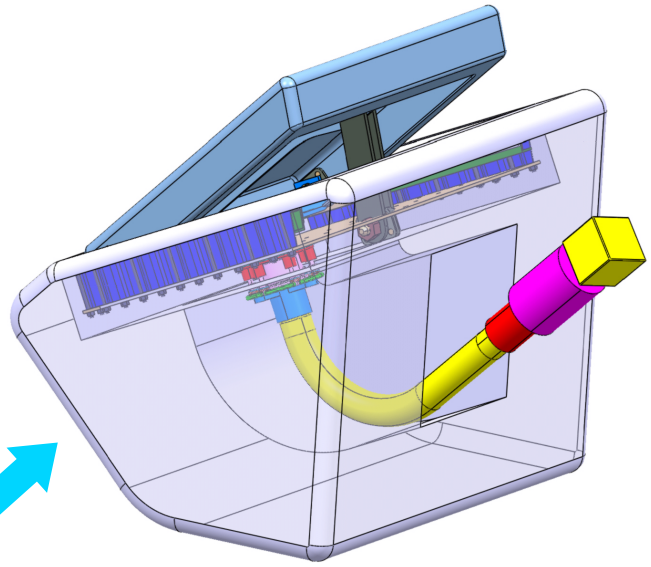
Shear-layer transition

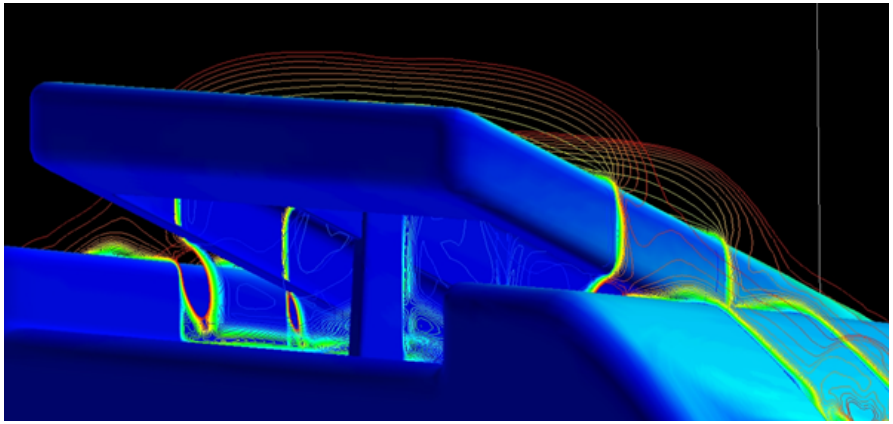


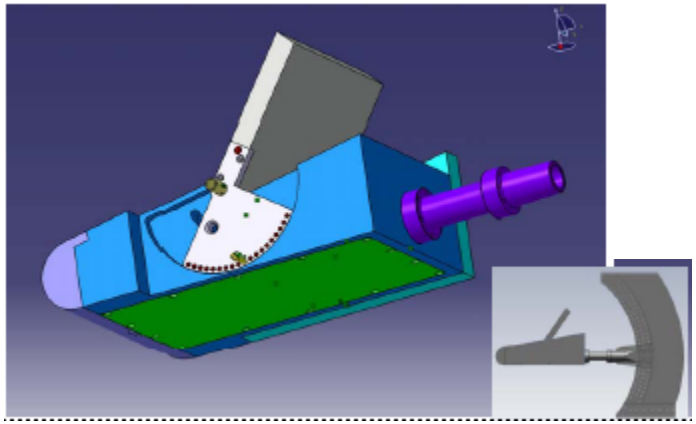
EXPERT: EUROPEAN EXPERIMENTAL REENTRY TESTBED

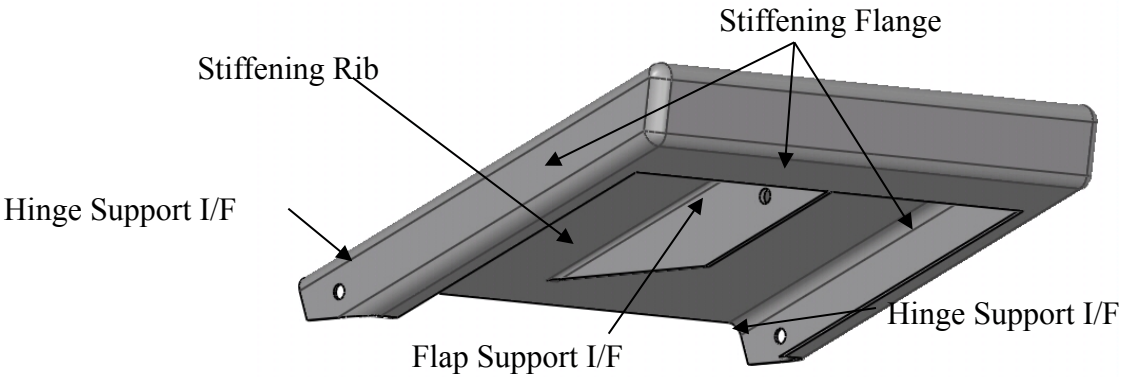
Flap
SWBLI

IR Camera

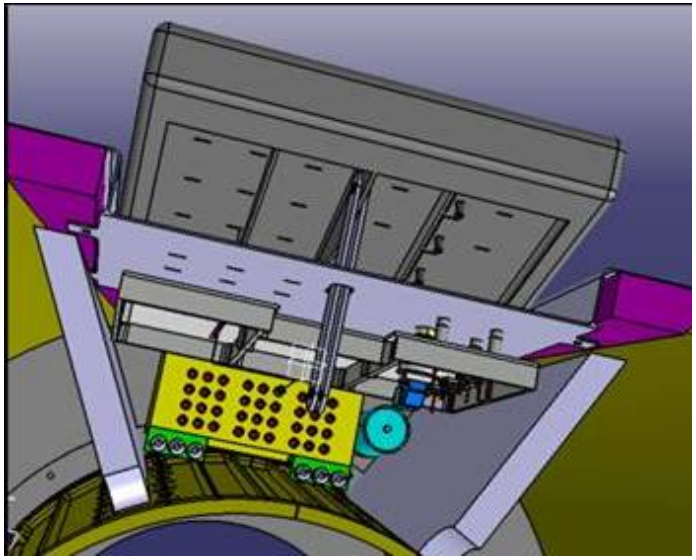


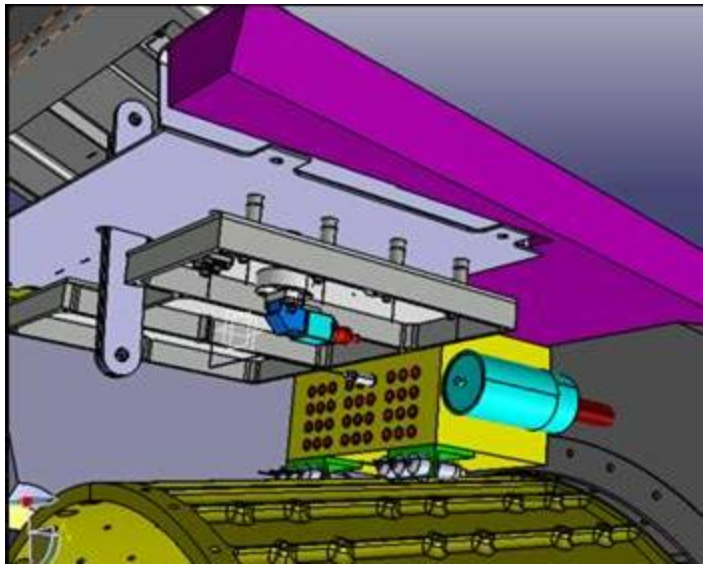




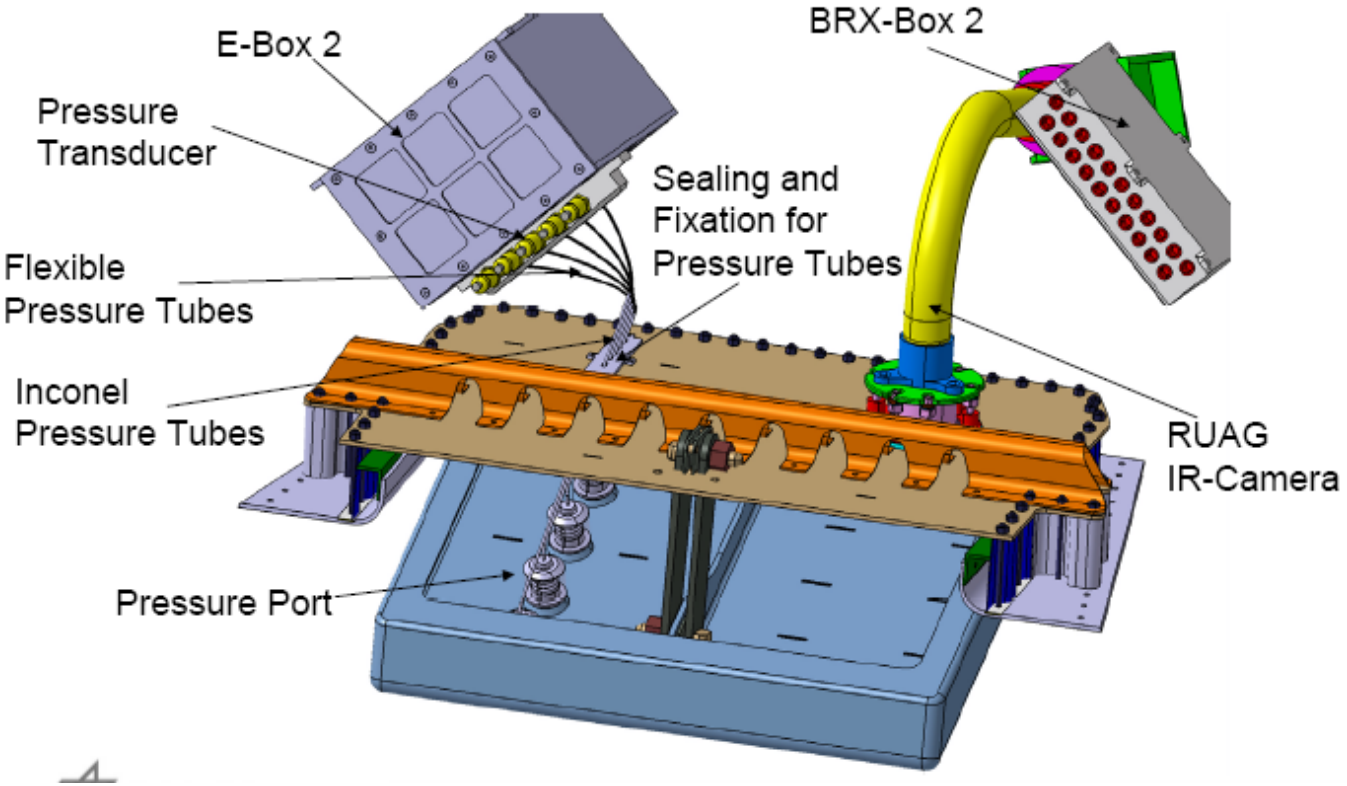

Stiffening Flange
Stiffening Rib
Hinge Support I/F
Hinge Support I/F
Flap Support I/F

Flap SWBLI





Flap SWBLI



- Qualification test :
  - Pressure sensor, Heat Flux sensor, Pyrometer, PCBs and DC/DC Converters:
    - Thermal, Vacuum, Electrical, Aero Thermal,Structural
  - Aero Thermal tests at HEG DLR and SCIROCCO CIRA

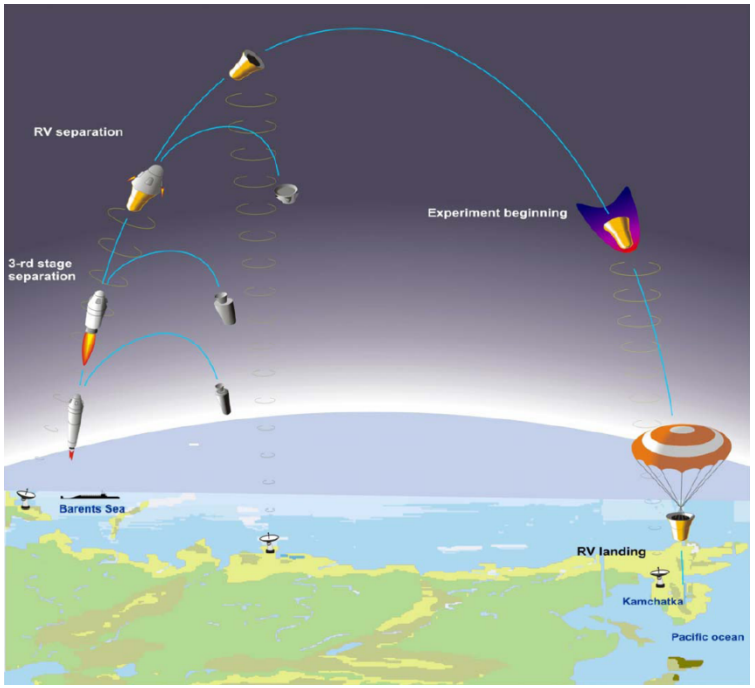
Summary

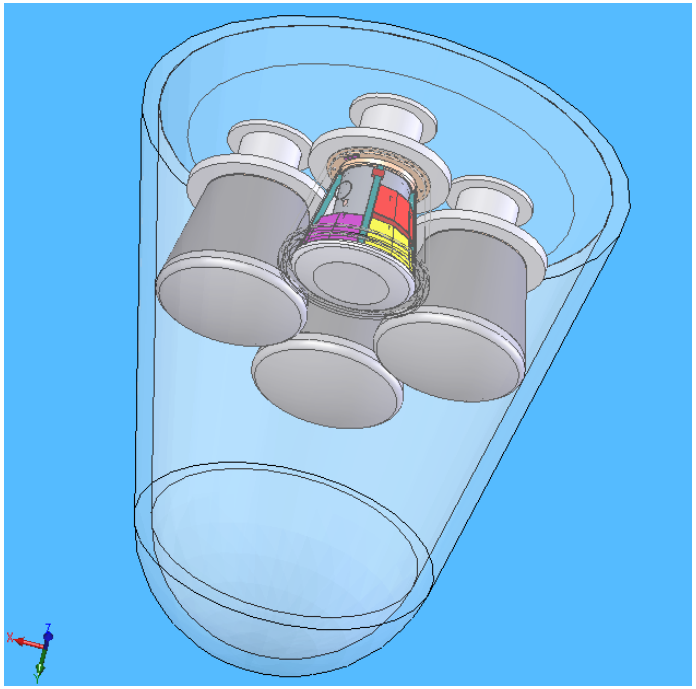
- EXPERT IS A FULLY FUNDED "in flight research project " PROVIDING ATD AND TPS DATA TO REDUCE UNCERTAITIES IN DESIGN PROCESS.
- UNCERTAITIES ASSOCIATED WITH VALIDATION OF PHYSICAL MODELLING INCLUDING WINDTUNNEL TO FLIGHT EXTRAPOLATION AND SCALING .
- UNCERTAITIES ASSOCIATED WITH FLIGHT INSTRUMENTATION INTEGRATION.
- 5 KM/SEC SUBORBITAL FLIGHT SCHEDULED FOR AUTUMN 2009.

Future plans

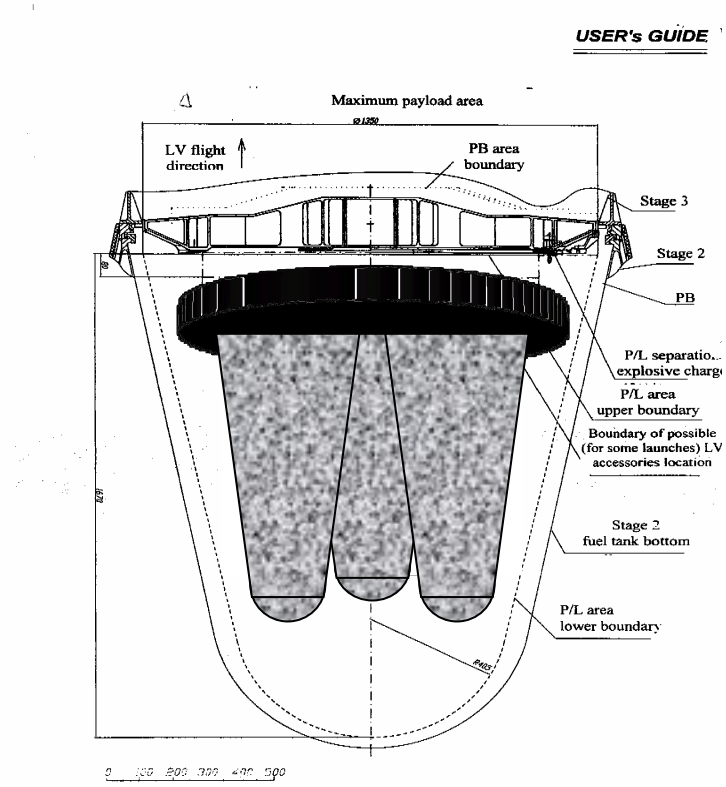
- **PROCEED WITH HYPERSONIC INFLIGHT RESEARCH ACTIVITIES TO AUGMENT TECHNOLOGY BASE AND REDUCE UNCERTAITIES IN DESIGN PROCESS ASSOCIATED WITH :**
  - **CRITICAL ATD and TPS DATA BASE SUCH AS ABLATION RADIATION COUPLING, TRANSITION, TURBULENCE, WAKE CLOSURE…**
  - **FLIGHT MEASUREMENT TECHNIQUES QUALIFICATION NOT POSSIBLE IN GROUND BASED FACILITIES**
  - **NEW STRATEGIES SUCH AS AEROBRAKING OR AEROASSIST**
  - **NEW CONCEPTS SUCH AS INFLATABLE SYSTEMS, BALLUTES,**
- **How ?**

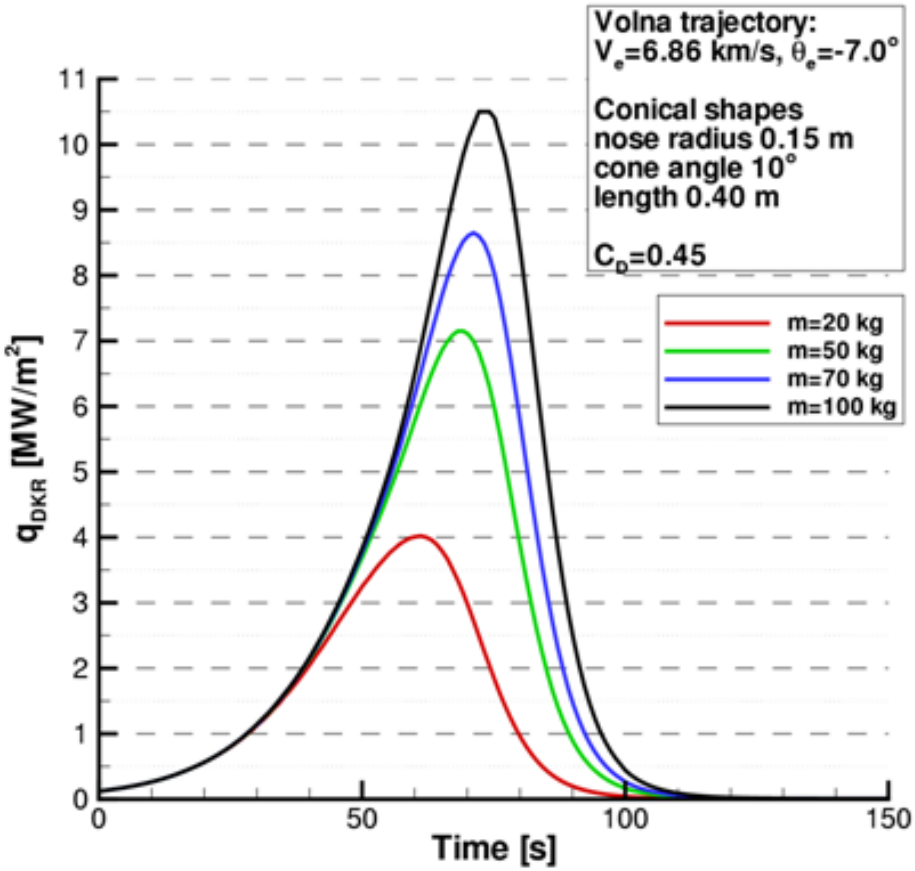
Re-entry inflight research on ATD on ATD and TPS using multiple capsules



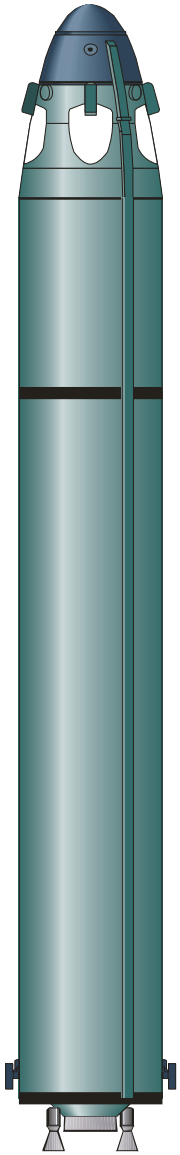


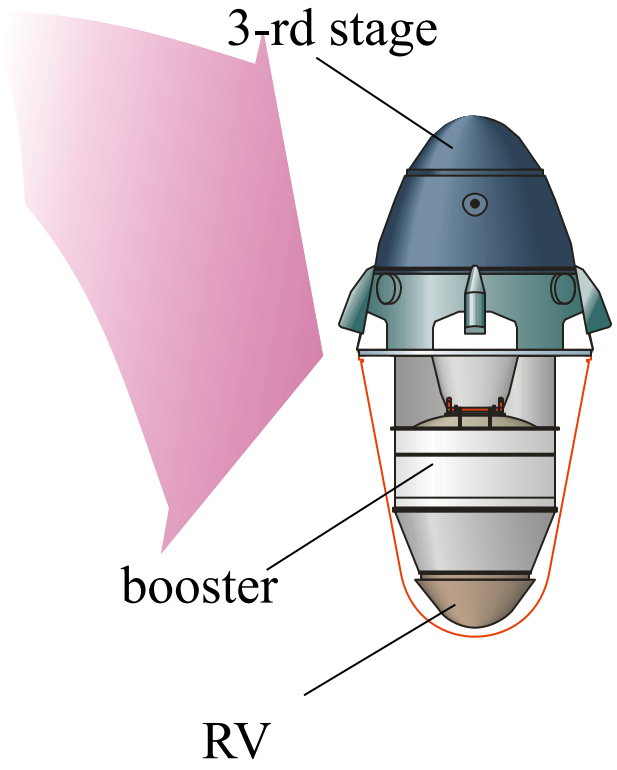
Ablation In-flight research





Boosted Radiation Flight

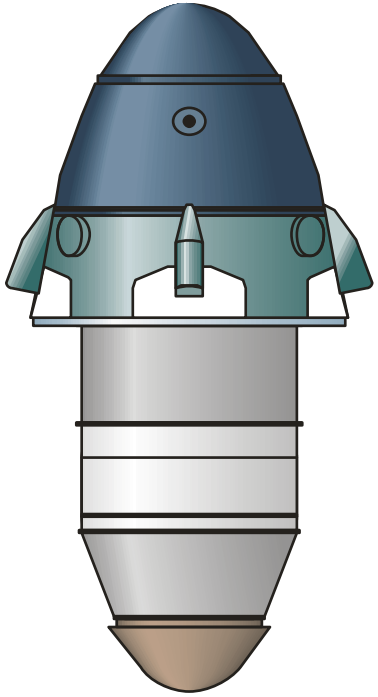




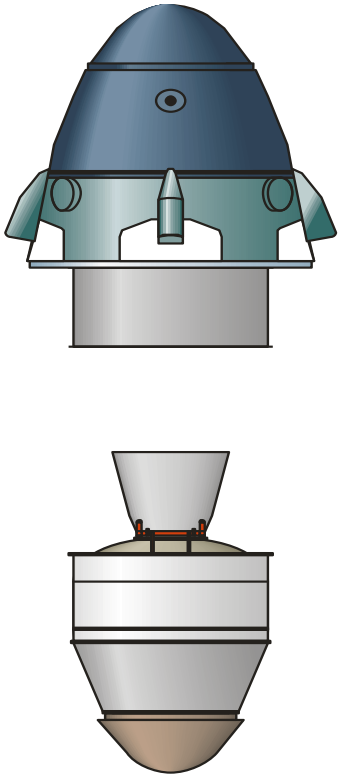
Basic characteristics

Mass of fuelled booster РБ - 963 kg;
Type of fuel – solid;
Number of motors – 1;
Motor thrust -3700 kgf;
Specific thrust impulse of motor in vacuum – 275 s;
Time of operation – 60 s.

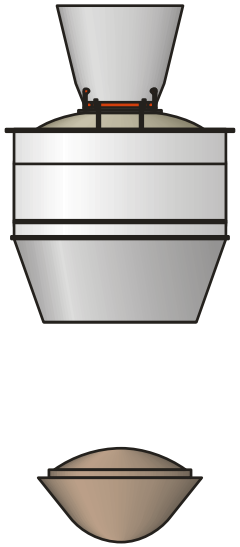
Flight phases



3-rd stage with booster

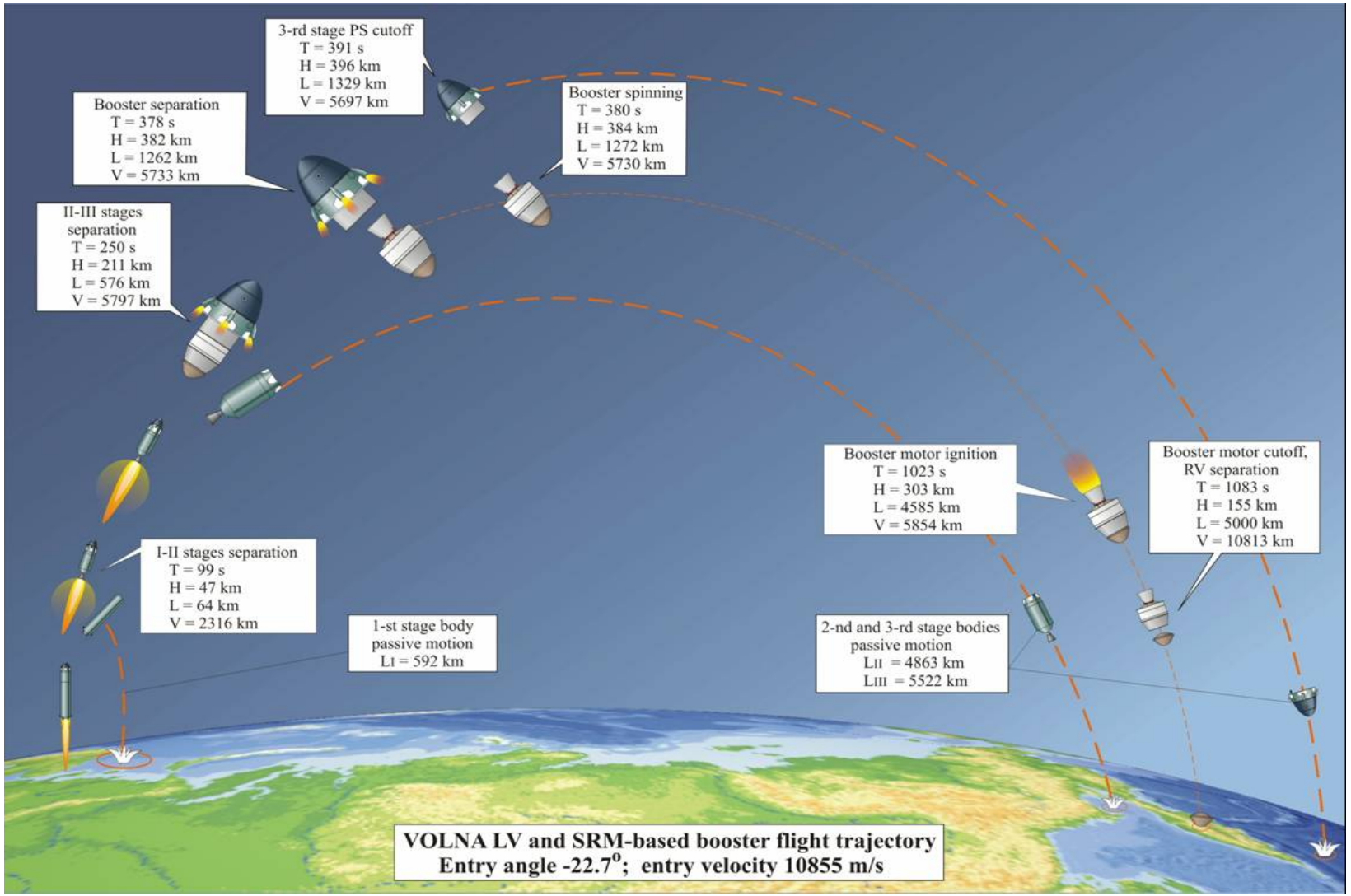


Booster separation



RV separation

Radiation In-flight research



Summary of entry flights with usable aeroheating data

Flight	Entry Date	Geometry	Destination	V (km/s)	α (deg)	γ (deg)	Utility	Recent Analysis?
Big-Joe	Sep. 9, 1959	Truncated Sphere	Earth	6.3	4	-0.9	Low	No
MA-2	Feb. 21, 1961	Truncated Sphere	Earth	5.5	13		Med.	No
MA-5	Nov. 29, 1961	Truncated Sphere	Earth	7.4	0	-1	Med.	No
MA-7	May 24, 1962	Truncated Sphere	Earth	7.4	0	-1	Med.	No
MA-8	Oct. 3, 1962	Truncated Sphere	Earth	7.4	0	-1	Med.	No
Fire-I	Apr. 14, 1964	Truncated Sphere	Earth	11.5	0	-15	Low	No
GT-2	Jan. 19, 1965	Truncated Sphere	Earth	7.4	18	-3	Med.	No
GT-3	Mar. 23, 1965	Truncated Sphere	Earth	7.4	10	-1	Med.	No
Fire-II	May 22, 1965	Truncated Sphere	Earth	11.3	0	-15	High	Yes
GT-4	Jun. 03, 1965	Truncated Sphere	Earth	7.4	12	-1	Med.	No
AS-201	Feb. 26, 1966	Truncated Sphere	Earth	7.7	20	-9	High	No
AS-202	Aug. 25, 1966	Truncated Sphere	Earth	8.3	18	-3.5	High	Yes
Apollo 4	Nov. 9, 1967	Truncated Sphere	Earth	10.7	25	-7	High	No
Apollo 6	Apr. 4, 1968	Truncated Sphere	Earth	9.6	25	-6	High	No
Reentry F	Apr. 22, 1968	Slender Cone	Earth	6	0	-20	High	No
Viking I	Jul. 20, 1976	70° Sphere Cone	Mars	4.5	11	-17	Med.	No
Viking II	Sep. 3, 1976	70° Sphere Cone	Mars	4.5	11	-17	Med.	No
Galileo	Dec. 7, 1995	45° Sphere Cone	Jupiter	47.4	0	-8.5	Low	Yes
Pathfinder	Jul. 4, 1997	70° Sphere Cone	Mars	7.5	0	-14	Med.	Yes
MIRKA	Oct. 23, 1997	Flat-Based Sphere	Earth	7.6	0	-2.5	Low	No
ARD	Oct. 12, 1998	Truncated Sphere	Earth	7.5	21	-2.6	High	Yes