# Preparing for Atmospheric Reentry with EXPERT's Help

## - An Aerothermodynamic In-Flight Research Programme

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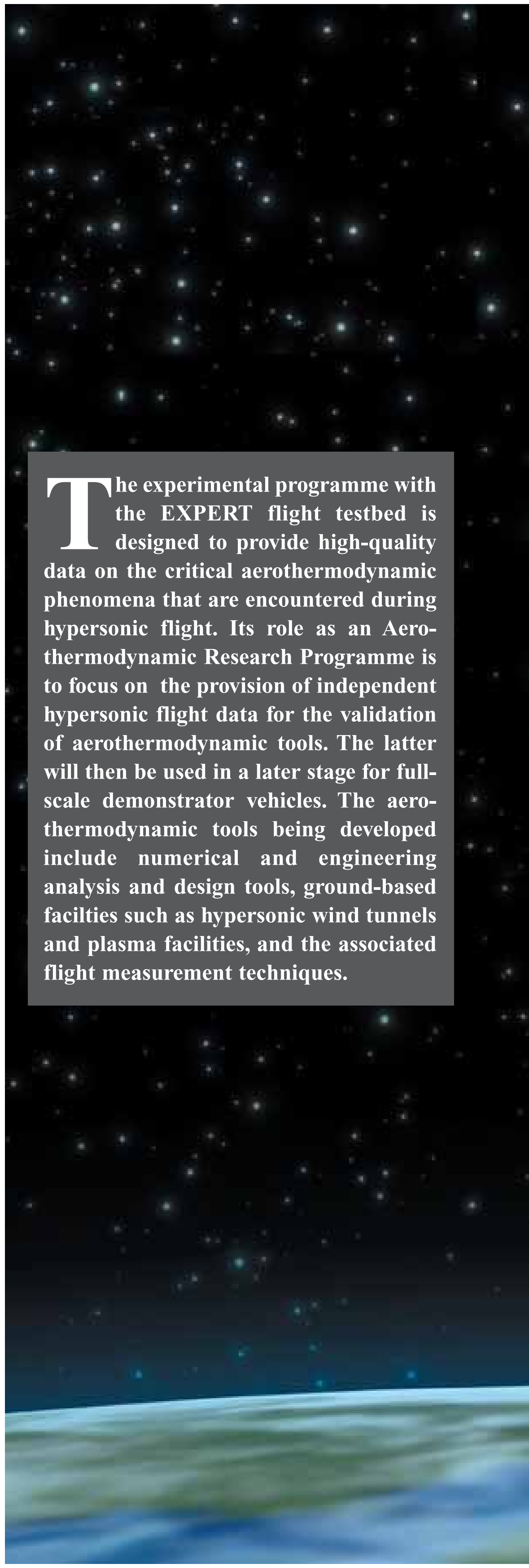
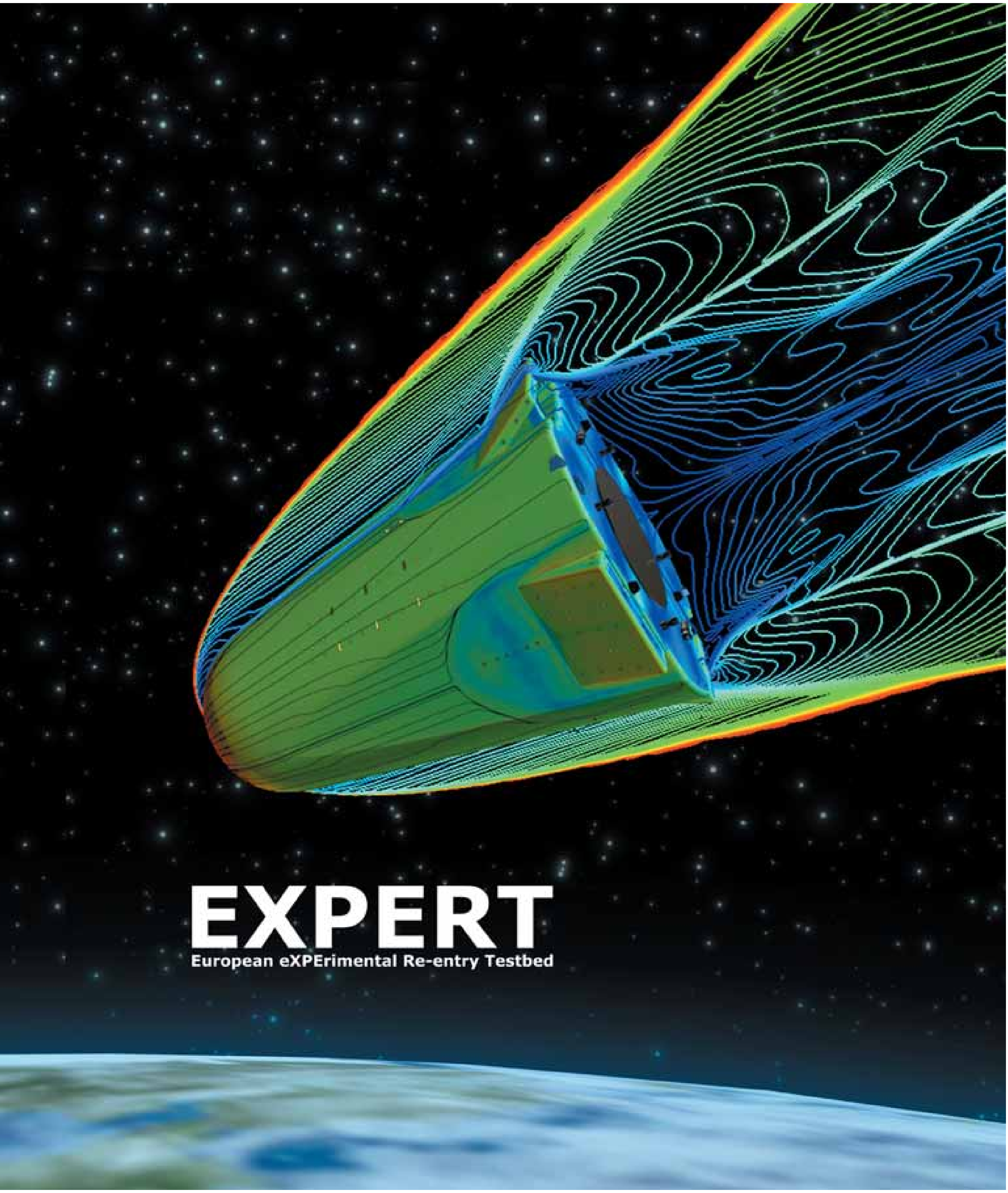


**The experimental programme with the EXPERT flight testbed is designed to provide high-quality data on the critical aerothermodynamic phenomena that are encountered during hypersonic flight. Its role as an Aerothermodynamic Research Programme is to focus on the provision of independent hypersonic flight data for the validation of aerothermodynamic tools. The latter will then be used in a later stage for full-scale demonstrator vehicles. The aerothermodynamic tools being developed include numerical and engineering analysis and design tools, ground-based facilties such as hypersonic wind tunnels and plasma facilities, and the associated flight measurement techniques.**


EXPERT
European eXPErimental Re-entry Testbed

## The Rationale for Advancing Europe's Aero-thermodynamic Knowhow

The aerodynamic knowhow needed to design and safely fly future hypersonic space vehicles is generally obtained via ground-based experimental simulations, computational predictions and ground-to-flight extrapolation methodologies. However, unless these tools have been validated by comparison with relevant wind-tunnel and flight data, they lack the verification needed to ensure optimal engineering margins. The best approach for establishing that confidence in the aerothermodynamic design tools is therefore to validate both the tools and the design approaches against flight experiments. In the past, however, such attempts have often been hampered by serious deficiencies such as poor measurement accuracy and resolution, flow contamination, limited/isolated single-point measurements and, last but not least, the high costs and risks associated with achieving a successful flight.

Lessons learned from past European flight-test programmes, such as ESA's Atmospheric Reentry Demonstrator (ARD), and development work on lifting-body vehicles such as the X38 crew-return-vehicle prototype, have underlined the need for more accurate hypersonic flight data to benchmark the quality of today's computational tools and design approaches. This is particularly the case for the most challenging problems of hypersonic flight, such as flap efficiency and heating, boundary-layer transition, high-temperature or chemistry effects, and gas-surface interaction effects such as catalysis and oxidation.

The EXPERT flight test programme addresses the current shortage of hypersonic flight data and at the same time will provide the data needed to improve wind-tunnel to flight extrapolation, by flying at speeds ranging from 5 km/sec, corresponding to today's ground-based hypersonic testing capabilities, up to 7 km/sec, which is approaching the reentry flight conditions of interest for future space transportation system design. This provides a unique opportunity in that the hypersonic facilities can partly duplicate

### IN-FLIGHT EXPERIMENTATION STRATEGY – CLASSES 1-3

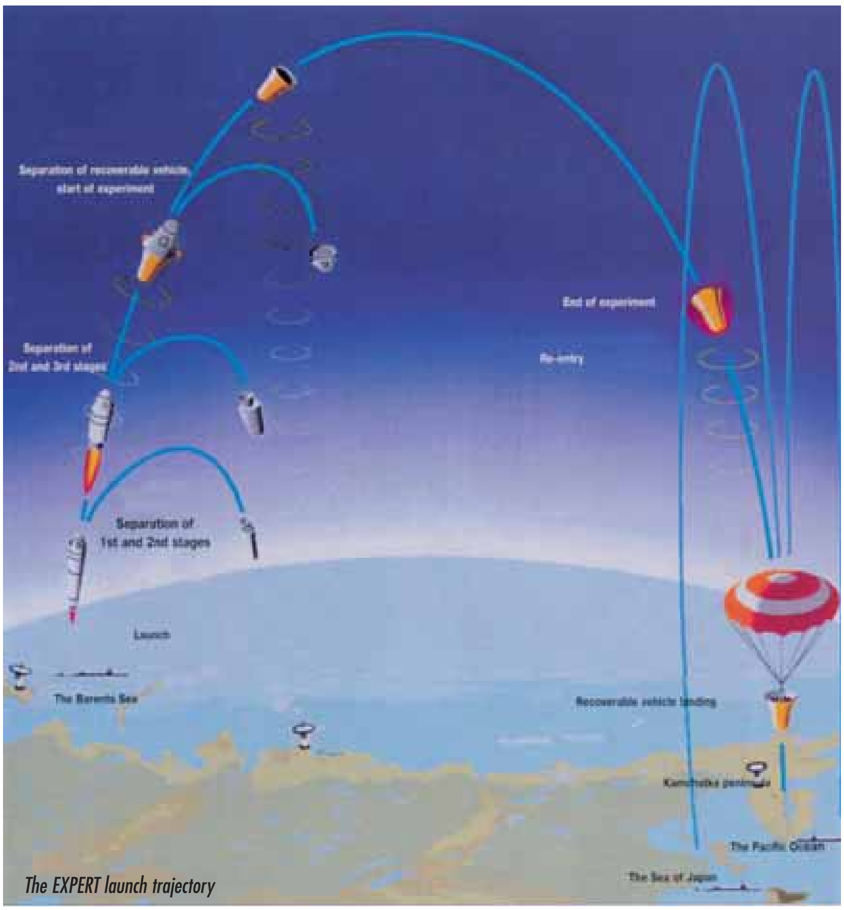
PROGRAMME

**CLASS 1.** FULL-SCALE DEMONSTRATION AND QUALIFICATION, WHEREBY PERFORMANCE ENVELOPES ARE GRADUALLY EXTENDED:
e.g. – SHUTTLE, BURAN, APOLLO, ARD, ARIANE-5
– X38, HOPE, HERMES, OSP
– HERCULES, SOCRATES

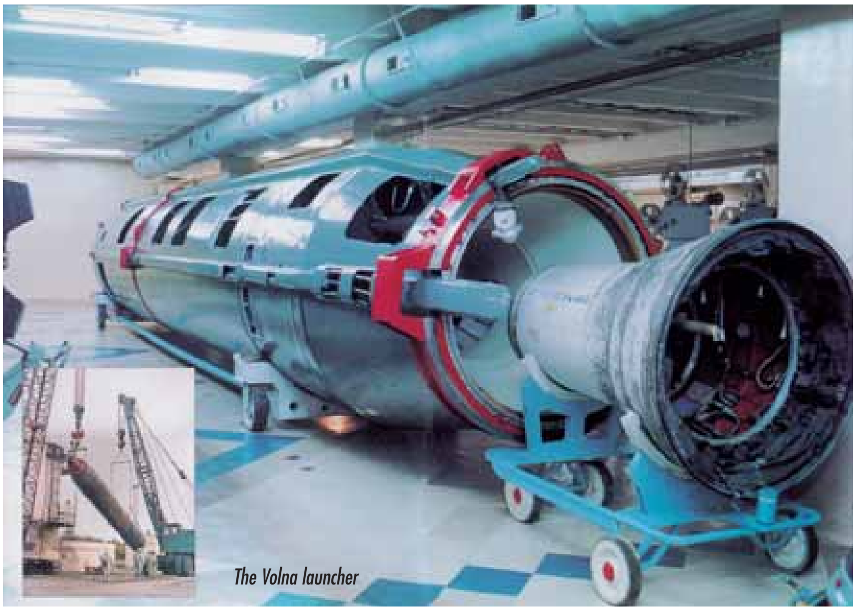
**CLASS 2.** EXPERIMENTAL VEHICLES FOR IN-FLIGHT QUALIFICATION OF SYSTEM/SUBSYSTEMS:
e.g. – BOR4 for TPS ; BOR5 for GNC;
– HYFLEX for TPS; ALFEX for GNC
– IRDT for INFLATION SYSTEM
– PHOENIX 1 and 2 for GNC
– IXV (SPHYNX – PRE-X – USV)

R&D

**CLASS 3.** IN-FLIGHT RESEARCH FOR DESIGN TOOL/PHYSICAL MODEL VALIDATION IMPROVEMENTS:
e.g. – SHARP B1, B2 FLIGHTS, HYSHOT,
– MIRKA, EXPRESS
– EXPERT multiple flights for aerothermodynamic research




*The EXPERT launch trajectory*


The Volna launcher

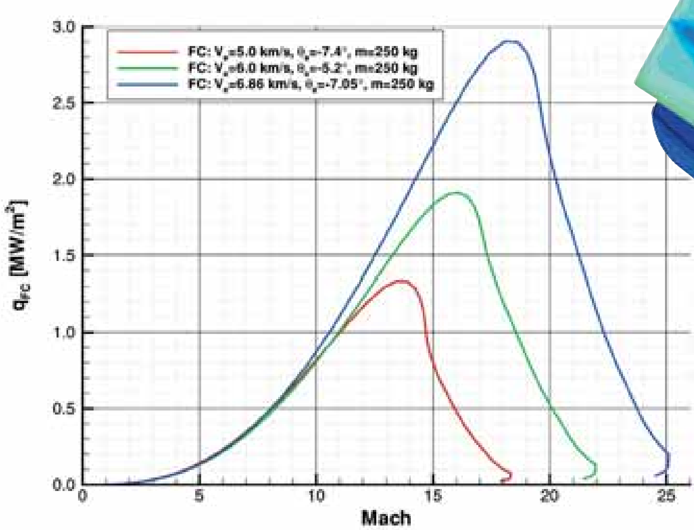
scaling parameters such as Mach number (compressibility), Reynolds number (viscosity) and high-temperature effects (real gas effects).

Thanks to the launch flexibility of the Russian Volna rocket selected, the EXPERT test vehicle will be able to make controlled ballistic suborbital flights to study all of the most critical aerothermodynamic phenomena and then be recovered for detailed post-flight inspection.

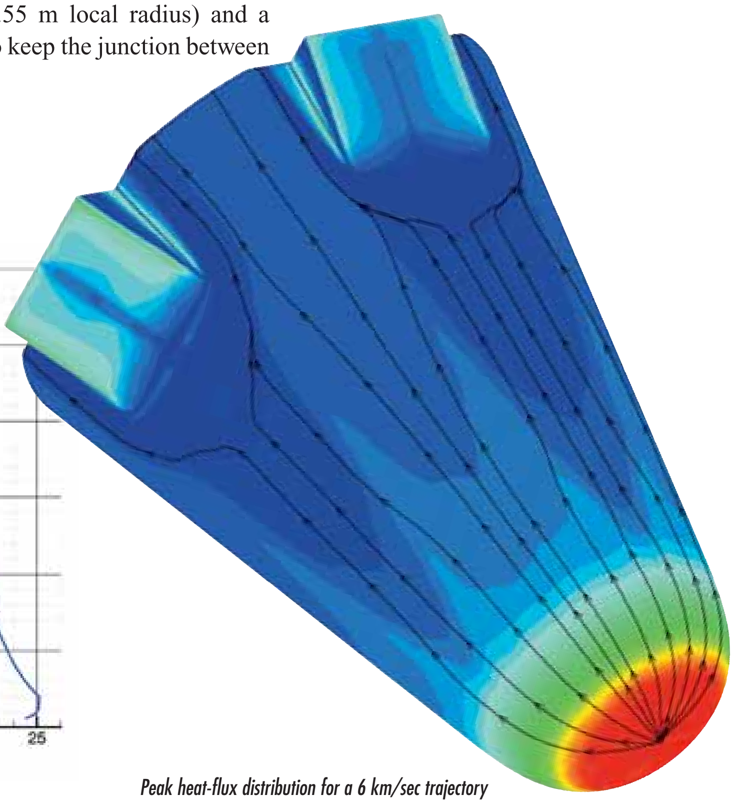
## EXPERT – A Ballistic Vehicle

The configuration finally chosen for the EXPERT vehicle is the result of a feasibility study performed under ESA contract, taking into account the payload mass and volume capabilities of the Volna launcher as well as the need to provide appropriate resolution for the aerothermodynamic phenomena of interest. It is basically a 'blunt cone' with four flaps and flat surfaces ahead of them. It is 1.6 m long and 1.1 m in diameter. It has an elliptically shaped nose (0.55 m local radius) and a smooth spline to keep the junction between the nose and conical parts continuous. The 12.5-deg conical leading edges generate axisymmetric flows, enabling two-dimensional sensitivity computations. Two diametrically opposite flaps, presently at fixed angles of 20 deg, will be open to study 3D micro-aerothermodynamic effects at the corners, base flow re-circulation, and non-convex re-radiating wall effects. Two other diametrically opposite flaps will be closed to protect sensitive instrumentation such as an infrared camera or pyrometer equipment. A Reaction Control System (RCS) for attitude and spin control will keep the flight angle of attack as close as possible to the optimum (zero-trimmed incidence).

The overall shape of the EXPERT vehicle has been dictated by the maximum allowable heat flux in order to avoid possible degradation of the nose's surface material due to active oxidation, and by the need to have clean laminar attached flow over the majority of the flight path in order to study gas/surface interaction (catalytic and boundary-layer transition phenomena) in sufficient detail.



Heat flux versus Mach Number for different trajectories – 5, 6 and 7 km/sec


Peak heat-flux distribution for a 6 km/sec trajectory

## The Scientific Payload

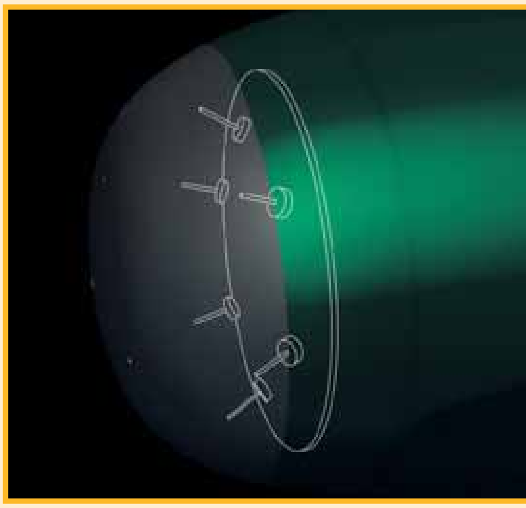
The EXPERT vehicle will carry state-of-the-art instrumentation for in-flight measurement of the critical aerothermodynamic phenomena: transition, catalysis, real gas effects on shock interaction, as well as shock-layer species partial densities and temperatures. Special attention will be paid to the design of measurement sensors, as well as to measurement of the free-stream parameters during re-entry (i.e. the design of the ADS).

### *Payload 1*
### *Free-stream tracking*

A pressure-based Air Data System (ADS) mounted on EXPERT's nose cone will be calibrated so that it can track the free air stream throughout the atmospheric portion of the flight. Lessons learned from past flight programmes have shown the importance of knowledge of this stream's density for the improved interpretation of onboard measurements.


*Positions of Payload Elements*

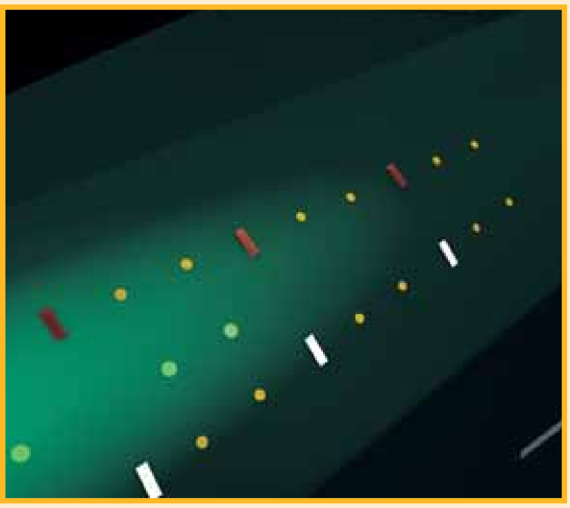
### *Payload 2*
### *Nose heating measurements*



EXPERT will take advantage of instrumentation originally developed for the X38 experimental vehicle (the forerunner of the originally planned Crew Rescue Vehicle for the ISS) to measure temperatures in the nose region. PYREX and possibly Raflex gauges will be mounted inside the nose.

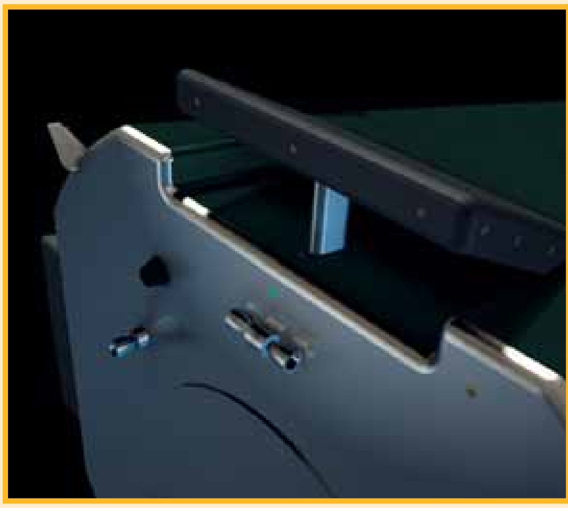
### *Payload 3*
### *Catalysis measurements*

The assessment of the catalytic gas-surface interaction is a major concern when designing a thermal-protection system. The degree of catalicity of a material affects the heating of the surface (the higher the degree of catalicity, the higher the wall heat flux), and thus the design of the protection needed. Understanding this phenomenon calls for very complex modelling at the molecular level, which can be only partly validated in ground-based plasmatron facilities. A series of temperature gauges, each covered with coatings with different degrees of catalicity, are foreseen to be flown on two diametrically opposite leading edges of EXPERT to study the phenomenon.



## Payload 4
### Roughness-induced transitions

Laminar to turbulent boundary-layer transition is considered one of the most critical aerothermodynamic phenomena due to the associated local temperature peaks. Most of the data obtained in ground-based hypersonic test facilities are contaminated by acoustic effects emanating from the wind tunnel itself. Roughness-inducing boundary-layer transition elements will be mounted on the leading edges of EXPERT in diametrically opposite locations. Their position, size and number will be chosen such that transition occurs in the lower altitude, higher Reynolds number part of the flight.

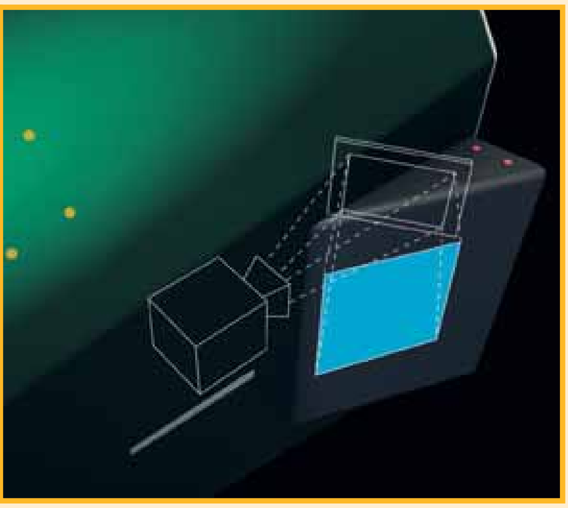


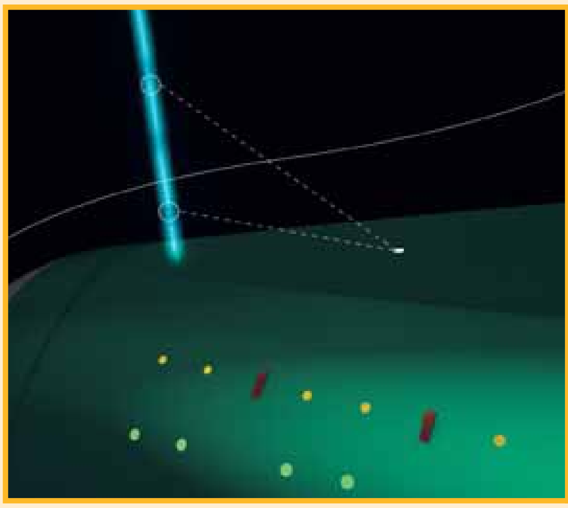
## Payload 5
### Shock interactions around open flaps

Boundary-layer separation effects in front of a deflected flap affect not only the efficiency of the flap for control purposes, but also the heating associated with shear-layer reattachment. Three-dimensional effects, corner and gap heating, base-flow circulation and wall cooling are all critical issues that need to be addressed in the design of control flaps. Specific pressure, heat-flux and force (moment) measurements will be performed using EXPERT's fixed open flaps to investigate these effects.

## Payload 6
### Heat fluxes inside closed flaps

Taking advantage of today's capabilities for measuring time-dependant 3D phenomena using non-intrusive techniques, an infrared camera will be mounted inside the closed flaps. Inverse methods will be applied to the data measured beneath the flaps in order to 'reconstruct' the external 3D heat flux during re-entry. As the deflection of all four flaps is identical, the flow results can be cross-checked with those predicted using the more classical methods.





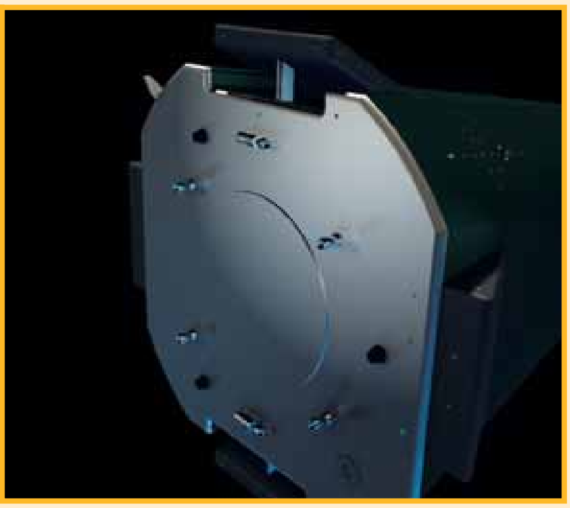
## Payload 7
### Shock-layer chemistry

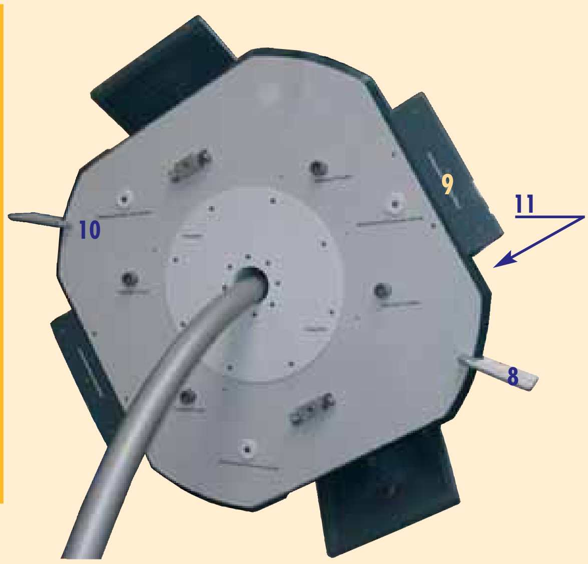
When computing a hypersonic flow field, the thermo-chemical model used plays a dominant role because it strongly affects the results of the numerical simulations. Unfortunately, those applicable to hypersonic flight could not yet be fully validated and hence there is an acute need for a reliable set of thermo-chemical measurements, particularly within the shock layer, which EXPERT can provide.

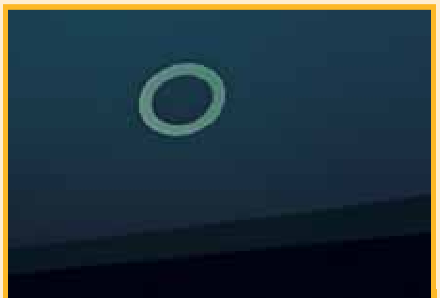
An instrument based on the electron-beam fluorescence technique will measure the concentrations of nitrogen and nitrous oxide, providing very valuable data for the validation of the thermo-chemical models and complementing the data obtained from ground-based facilities. The technique currently works only at high altitude, and so more work is required to improve the system.

***Payload 8***
***Boundary-layer measurements***
At the trailing edge, EXPERT will be equipped with a Pitot static pressure rake and a Langmuir probe in order to measure, respectively, the boun-dary-layer characteristics and the electron-density profiles close to the wall. The resulting characterisation of the boundary layer at the trailing edge of the vehicle will further contribute to our understanding of boundary-layer transition phenomena.

***Payload 9***
***Base- and slip-flow measurements***
Pressure and heat-flux measurements will be made at selected points on EXPERT's base. Some slip-flow gauges are to be installed at specific points on the vehicle's leading edges to provide data with which to validate the current Monte Carlo numerical simulation tools.





***Payload 11***
***Thermal protection***
It is planned to fly a small innovative water-cooled thermal-protection system as a passenger. Based on an idea emanating from the Technical University of Delft (NL), it uses the concept of forced convection through a water evaporation process.

***Payload 10***
***Black-out measurements***
EXPERT will carry some reflectometers, similar to those flown on ESA's Atmospheric Reentry Demonstrator (ARD), which combined with the Langmuir probes will deliver a good data-set for the validation of the attenuation codes describing the blackout phenomena.

## Conclusion

As an in-flight research programme, the prime objective of the EXPERT testbed is to improve our understanding of such critical aerothermo-dynamics phenomena as transition, catalysis, blackout, real gas effects and shock-wave boundary-layer interactions associated with flap efficiency and heating. Multiple flights using the Volna launcher are foreseen, focusing on wind-tunnel to flight extrapolation as well as on the use of modern in-flight measurement techniques. At present, two ballistic flights are planned, at 5 and 6 km/sec. If successful, further flights at higher speed (7 km/sec) will follow for the study of aero-braking and jet interaction, and flights to study advanced materials associated with high-speed re-entry may also be anticipated. esa

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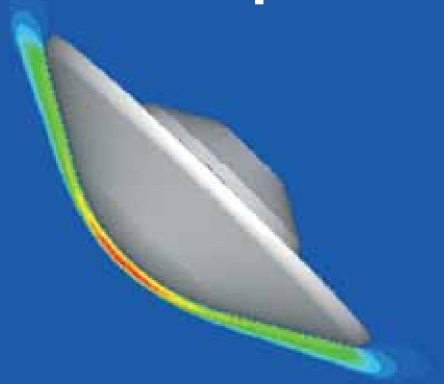
# 1ST Announcement and Call for Abstracts

# International Workshop on Radiation of High Temperature Gases in Atmospheric Entry



**8-10 October 2003**
**Instituto Superior Técnico, Lisbon, Portugal**

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esa Aurora Programme

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In the framework of ESA's Aurora programme and with the support of CNES, the Working Group "Radiation of High Temperature Gases" (WG RHTG) is organizing a workshop on Radiation of High Temperature Gases in Atmospheric Entry. Topics of interest include:

- Non Equilibrium Chemical Kinetics
- Hypersonic Flow
- Plasma Emission and Absorption
- Computational Fluid Dynamics
- Instruments and Facilities
- Flight Experiments
- Radiation Transfer
- Radiation emission & transfer database and models
- Re-building of selected radiative emission and absorption experiments
- Numerical axially-symmetric test-cases for flow and radiation emission and absorption calculations

For further information see the Workshop website at:

www.estec.esa.nl/conferences/

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