Measurement Systems for Atmospheric Entry Missions at IRS

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Abstract
The development of flight instrumentations requires experience, knowledge and ability for the development of both analytical tools and testing facilities that allow the determination of overall information on the properties of the system and the design steps needed for the successful experiment. As a result of the experience within the plasma diagnostic tool development and the plasma wind tunnel data base acquired during the last 20 years at IRS, flight experiments such as the PYrometric Entry EXperiment PYREX (capsules EXPRESS, MIRKA and EXPERT) and HEATIN (HEATshield INstrumentation) on MIRKA were developed, qualified and successfully flown. Flight measurement techniques like the catalysis based experiment PHLUX and the miniaturized spectrometer system RESPECT (RE-entry SPECTrometer) are being developed for the ESA's capsule EXPERT. A combination of different sensors is represented by COMPARE which is originally designed for the Archimedes Mars Balloon mission and that is now being transferred to SHEFEX 2.
Both the flight missions and the experimental activities were accompanied by extensive model development activities that led to powerful numerical tools to simulate non-equilibrium entries including thermo-chemical interactions between plasma and heat shield material. The facilities and the measurements during flight in turn allow for validation and substantial improvements of the models. One example is the measurement campaign for STARDUST re-entry in which IRS participated.

1. Introduction

The need for aerothermodynamic related in-flight data is doubtless [1-4]. Technically speaking two different assessments for such measurement techniques can be made. The first approach would be to equip the spacecraft with appropriate sensor systems measuring the parameters of need. This scenario is the usual point of departure. In the second scenario measurements from outside can be taken i.e. the observer follows the re-entering spacecraft with an adequate optical system from outside. Actually, this happened e.g. with the Stardust re-entry[5].
The reason for the aforementioned need for in-flight data is evident: Both ground tests and computer simulations cannot replace space flights completely. Particularly, entry mission phases encounter challenging problems, e.g. in the field of hypersonic aerothermodynamics. Concerning the TPS, radiation-cooled materials used for re-useable spacecrafts and ablator technologies are of importance. The both experience an interaction with non-equilibrium entry plasma, a situation that leads to a significant difficulty for both understanding and modeling. For both types e.g. it is reported that the improvement of understanding of the plasma wall interaction is accompanied by a potential to optimize the TPS mass and, hence, to increase the mass of the scientific payload or to just save money [6, 7, 8].
In the field of radiation-cooled heat shield materials the knowledge on their thermo-chemical behaviour increased during the past years thanks to both extensive experimental investigations and modeling. Here, extensive investigations in the field of thermo-chemistry led to an improved understanding of the behaviour of typical thermal protection materials under representative conditions [6, 9-11].
For ablation materials the situation is more complex and, in addition, less developed. Here, the complex behaviour of the material in combination with plasma interaction makes the problem more difficult. In addition, the most efficient materials in the US are more than 20 years old and their procurement is partially doubtful. Here, adequate facilities, models and, in particular, in-flight experiments are needed to improve the understanding about such materials [7].
Besides the mentioned technologies, there is the goal to manage guidance, navigation, control, landing technology and inflatable technologies such as ballutes that aim to keep vehicles in the atmosphere without landing. The requirement to save mass and energy for planned interplanetary missions such as Mars Society Balloon Mission, Mars Sample Return Mission and Venus Sample Return mission led to the need for maneuvers like aerocapture, aero-breaking and hyperbolic entries. All three are characterized by very high kinetic vehicle energies to be

dissipated by the maneuver. In this flight regime data is rare. The importance of these maneuvers and the need to increase the knowledge of required TPS designs and behavior during such mission phases require flight experiments.

2. In-flight Measurement Systems

Historically, the development of plasma wind tunnel measurement systems motivated for the design of in-flight measurement systems as the laboratory systems have already been able to withstand the harsh environment of an atmospheric entry. Figure 1 summarizes entry projects in which the division space transportation has been involved.

Figure 1: Atmospheric entry projects with IRS participation

In principle, two groups of projects have to be distinguished in figure 1. The first group is related to complex interdisciplinary concepts of space transportation systems such as Sänger and Hermes where interdisciplinary approaches with many partners aiming for both system technology and sub system related activities were investigated over many years. The second group is often related to sub system activities as the development roadmap is often more concrete. For Titan Huygens the qualification of the heat shield material AQ60 and extensive activities related to the characterization of the Nitrogen/Methane entry plasma were performed using the magnetoplasmadynamically driven PWK2 [12]. For HOPE-X a concept for a multi-channel temperature measurement system was developed within a cooperation with NASDA (now JAXA) and Kawasaki Heavy Industries [13]. As result of the experience within the plasma diagnostic tool development and the plasma wind tunnel data base at IRS, flight experiments like the PYrometric RE-entry EXperiment PYREX were designed, developed, fully qualified and successfully flown. The capsules EXPRESS, MIRKA and IRDT and the lifting body X38 were equipped with measurement systems fully developed and qualified by IRS [2]. These activities were, of course, ongoing with extensive scientific investigations as e.g. in the field of thermo-chemistry of heat shield material. Corresponding national space programs such as TETRA and the later ASTRA accompanied these activities [2, 9, 14, 15]. The space projects themselves were international and the system aspects were within the cooperation and partnerships which also led to the usual extensive management and documentation activities. Here, PA and QA tools, documentation tools and system aspect related tools were developed. For X38 e.g. about 40 international partners were collaborating to develop, qualify and fly the vehicle which was planned as a technology demonstrator for the Crew Return Vehicle (CRV) of the International Space Station (ISS). About 1000 sensors were intended to obtain an aerothermodynamic data base. Despite the cancellation of the X-38 program the fully developed technologies are being used for the European EXPERT capsule program where three sub-orbital capsule flights using Russian Volna launchers are planned. The first flight is issued for 2008. Here, IRS is developing three different instrumentations. One is a pyrometric heat flux sensor system for the nose structure (PYREX) and the second is a catalysis based heat flux system aiming for the determination of the plasma composition and catalysis related material properties (PHLUX). The third is a miniaturized spectrometer of which the data will give important information on the plasma radiation (RESPECT) [16]. The data will also serve as a basis to improve the existing numerical models. Most of the projects were accompanied by mission analysis such as e.g. HOPPER and COLIBRI (not shown) [17]. For SHEFEX 2 the combined sensor system COMPARE is in the conceptual phase where data from mission analysis will be used for the assessment of the measurement system design [18].

Due to the system technology aspects and the internationality of all of the aforementioned projects efficient and operating expert networks developed. This heritage together with the gathered scientific and technological competences will enter the planned special cooperative center “Interplanetary Missions”. Additionally, the capabilities of all partners in the cooperative center and the space application capabilities of IRS will place the team in a position to develop and/or apply scientific payloads and satellite technologies respectively [19].

In the following sub-sections and sections exemplary results for MIRKA and STARDUST are shown. However, within the STARDUST mission spectral data were measured during an airborne observation mission. This means that the measurement system does not belong to the group of in-flight measurement systems which are understood as systems that are flown aboard the entry vehicle.

3 Results of the MIRKA Flight

The MIRKA re-entry capsule was an experimental program to investigate the thermal and erosive behavior for a so-called surface protected ablator (SPA) and to investigate the aerothermodynamic environment conditions by measurement systems. MIRKA was launched in October 1997 with the Russian FOTON-11 capsule. After several days in Orbit, MIRKA separated from FOTON shortly after the deorbit impulse for an independent re-entry flight. MIRKA experienced a maximum heat load of up to 1.6 MW/m² at the stagnation point before landing.
Besides the temperature measurement by PYREX, the RAFLEX experiment was aboard to determine aerodynamic data and vehicle attitude and the HEATIN experiment to investigate the overall TPS performance and to verify numerical methods of heat flux calculations. The overall results of the measurement systems used during the MIRKA re-entry can be found in reference [20]. Figure 2 shows the measurement locations of the experiments. As examples the design and the results for the measurement system PYREX-M are shown very briefly. The development history, however, is not presented here and can be found in the related references.

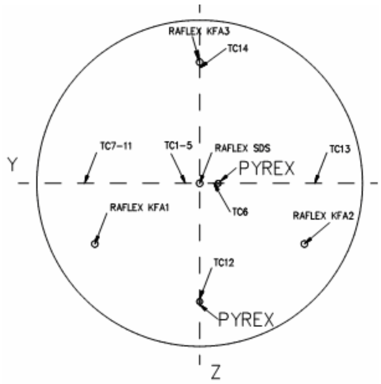

Figure 2: MIRKA capsule experiment measurement locations.

3.1 PYREX MIRKA

PYREX on MIRKA is a two channel pyrometer that measured temperatures and heat fluxes at two positions of the thermal protection systems of MIRKA during the capsule's re-entry. Figure 3 depicts the lower half-sphere of the capsule in which the experiments were mounted.

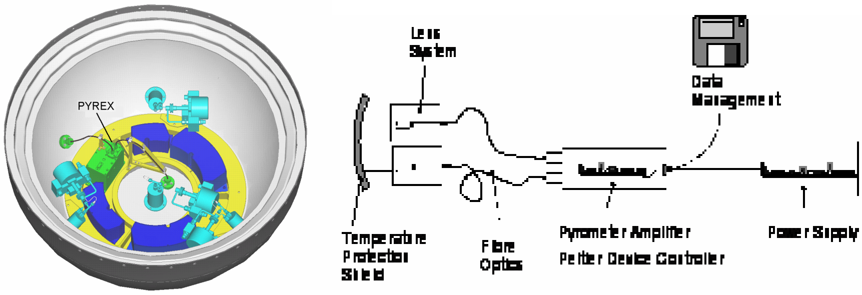

Figure 3: MIRKA capsule with experiments (PYREX in green colour) and schematic of PYREX-M

One of the PYREX sensor heads was positioned on the -Y system axis close to the expected stagnation point; the second one was positioned on the +Z system axis at an angle of 48° from the expected stagnation point of the MIRKA capsule, see figure 2.
Due to the nature of the heat shield the radiation measurement of the stagnation sensor seemed to be disturbed. For the 48° sensor an aperture correction could be made leading to the temperature history shown in figure 4. From the data histories it seemed to be clear that a pollution of the sensor head optics took place during the heating of the TPS system. The time history of this pollution is not restorable from the data available. The effect of the pollution is a decrease in the measured radiance intensity level and thus a lower calculation of the temperatures if the clean preflight calibration is applied. Therefore, the real re-entry temperature history of the 48° position C/SiC shield has an upper temperature limit corresponding to the postflight calibration with polluted optics and a lower temperature limit corresponding to the clean optics situation of the preflight calibration using the IRS black body source. Both temperature limits are shown in figure 4. Another correction of the 48° position temperature data should be applied to the temperature increase profile. The very sharp temperature increase at about 1312 s could not be explained by the thermal behavior of the C/SiC shield. The preliminary data obtained by the RAFLEX experiments and the HEATIN thermocouple data did not show any signs of dramatic heat load changes which might explain such an

C/SiC temperature increase. The dynamic appearance of the original data led to the explanation that a partial closing of the SiC tube aperture of 5 mm diameter by a particle which was then removed by the pyrolysis gas flow at 1312 s. The opening of the aperture would have increased the measured radiant intensity. The following method was applied for correction under the second assumption that the aperture was partly closed. The response of the photodiode current, and, therefore, the temperature for a given calibration, can be analytically calculated as a function of the aperture diameter for a given constant radiant intensity. By decreasing the aperture diameter, the intensity and thus the temperature decreases. By an iterative calculation with a decreasing SiC tube aperture, the upper temperature of the increase was lowered until a smooth transition without the sudden increase was reached. At that point the 5 mm diameter SiC aperture was analytically decreased to about 3.3 mm in diameter which results in a reduction of the measured radiant intensity of about 40 %. If a particle had partly closed the aperture until the time mark of 1312 s, the temperature was then calculated too low with the full aperture calibration.

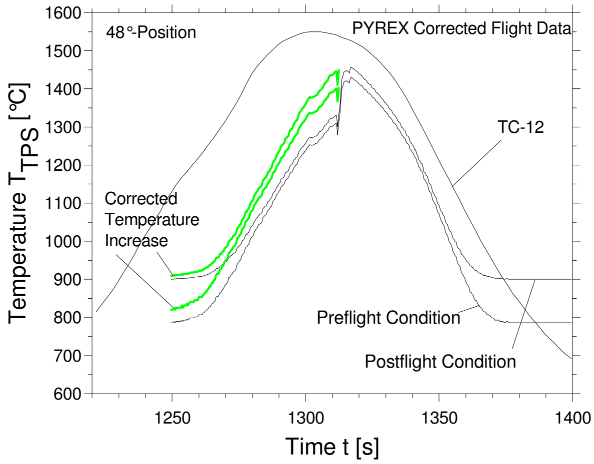

Figure 4: MIRKA capsule with experiments (PYREX in green colour)

This analytical procedure was based on a description of the transfer function of the system using the adequate transfer function for its sub-systems as shown in figure 3. Correspondingly, a simple simulation tool was developed where the transmission function for the photo current of the photodiodes

$$I = \int L_\lambda(\lambda,T) F_{mp-fo}(d_{mp}, d_{fo}, a)\tau_{fo}(\lambda, L)\tau_{filter,tot}(d_{fi}, \lambda)s(\lambda)d\lambda \quad \textbf{(1)}$$

was used for the correction procedure explained above. Here, L_λ is the Planck radiation, λ is the wavelength, T the temperature, $F_{mp\text{-}fo}$ is the geometry factor for the radiation between measurement point and fiber optic entrance, d_{mp} is the diameter of the measurement point, d_{fo} is the diameter of the fiber optics entrance, a is the distance between them, τ_{fo} is the transmission of the fiber optics, L is the fiber optics length, $\tau_{filter,tot}$ is the total transmission of the used filter system (630 nm) and s is the spectral sensitivity of the photodiode.

The subtraction of the smoothed data from the original raw data enabled the derivation of oscillations that were similar to damped oscillations. Further investigation showed that the oscillations were due to signal decrease resulting from temperature decrease. A significant dominance of two frequencies could be observed. Via Fourrier analysis a frequency spectrum was obtained with the two dominant frequencies 0,65 Hz and 0,93 Hz. The accuracy of this analysis may be low as only 64 data points were available for the analysis. A comparison with the RAFLEX data (about 0,75 Hz) and the MIRKA system data (about 0,8 Hz) allow for the statement that the frequencies are due the changes of the capsules orientations. However, it has to be pointed out that based on the data the angular frequencies are not really seen by PYREX. In contrast the frequencies have rather to be considered as “global” frequencies. In addition, both heat capacity and heat conductance may lead to a “blurring”.

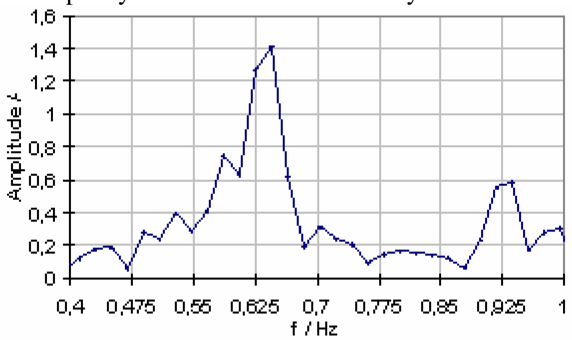

Figure 5: Frequency spectrum of the processed PYREX MIRKA data

4 Developments for the Mission EXPERT

The three instrumentations PYREX, PHLUX and RESPECT are described in diverse references [16, 19] such that this section is to show the principle designs only. In addition, the design process may be considered as very dynamic as presently the CDR activities are ongoing.

4.1 PYREX

The success of the missions EXPRESS and MIRKA in terms of the high thermo-mechanical loads during the system tests and the flights, the functionality of both PYREX systems after the missions, the measured temperatures and the short response time which allowed for the determination of rotational speed of MIRKA justify the statement that the PYREX-system is space qualified.
With the 6-channel PYREX-KAT38 system intended to be used for the X-38 an advanced measurement system capable to be integrated with respect to the vehicle's data analysis system is provided.
PYREX-EXPERT will deliver the temperature distribution and related temperature profiles of the EXPERT nose structure during entry. The results will enable the validation of the applied numerical codes and statements on the behavior of the TPS-materials during entry. Thermal effects resulting from manoeuvres e.g. rolling during the entry phase will be seen. A post-flight numerical analysis will deliver heat flux profiles.
In Fig. 6 the positions of the sensor heads together with a schematic view of the PYREX EXPERT system is shown. It consists of several subdevices. Each of the six sensor heads has a lens system to focus on the specified position on the C/C-SiC nose cone structure. The fibre optics are attached to the sensor heads and transmit the radiation to the sensor unit containing electronics. Data transfer, power and control signals are transmitted to the vehicle system. A portable computer, which can be switched to the sensor unit, enables preflight tests. Both EXPERT's power system and the data system are attached to the sensor unit. The sensor unit is equipped with an independent memory bank (flash disc).
Sensor head 1 is placed in the vehicle axis region while the 5 other SHs are distributed in order to obtain the maximum information with respect to the overall temperature and heat flux distribution. Sensor head 6 is almost at the edge of the nose structure. Therefore, the system can be combined with the adjacent PHLUX sensors (see section below) in order to have a maximum information e.g. by the performance of a relaxation experiment.

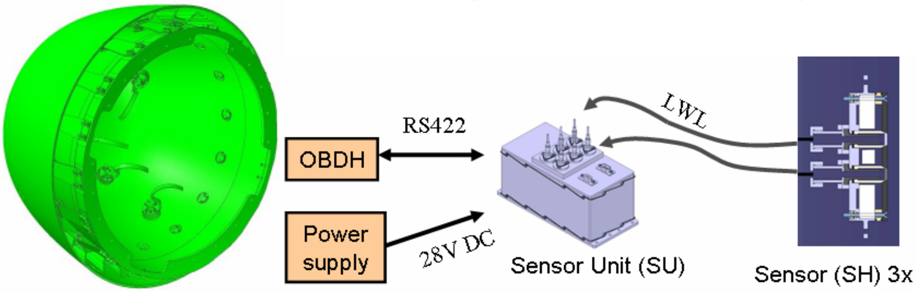

Figure 6: EXPERT nose structure with PYREX senor heads and schematic view of PYREX

The sensor heads are used to fix the lens systems with the attached FOs behind the nose TPS structure points to be measured and guarantee a precise adjustment to the measurement positions. Each senor head consists of a SiC tube that provides the optical path, an inconel flange and the lens system made of sapphire. The SiC tube protects the lens system from pollution by dust particles. It is required in order to prevent the tube from touching the TPS. The mass of one SH is about 0.25 kg. Its diameter is roughly 50 mm; its height is about 50 mm. A temperature resistant seal is attached to prevent hot gas flows through the SH. The lens system and the attached FOs can be easily removed from the SH, e.g. to check the transmission of the FOs, and can later be re-installed with a high reproducibility in regard to the optical adjustment.
The routing of the six fiber optics is a major concern as there is a minimum bend radius of about 70 mm. General damage caused by other systems or parts must be prevented. Therefore, each SH is equipped with a fiber optic bracket to prevent the fibers from being damaged.
The radiation collected from the lens system of the SHs is carried through the bundled FOs to the photodiodes of the sensor unit (SU) which is the grey box shown in figure 5. The FOs can be dismounted on both sides: from the SU and the SHs. This fulfills an important requirement that the whole nose cone must be able to be dismounted from the remaining EXPERT vehicle without a lot of effort provided that there is accessibility.
The SU contains the optical system in front of the six photodiodes. In addition, there are three high Ohmic resistors per channel, an AD-converter and the Peltier cooling system to keep the photodiodes at constant 293 K. This is necessary to reduce thermal noise during measurement.

A controller arranges internal data storage and output via RS422 interface to the vehicle data system. Power supply is guaranteed by integrated DC/DC converters powered by a voltage of 28 VDC. The mass of the SU is roughly 2.5 kg. Its size is about 100x130x200 mm.
The filter system is placed between the FOs and the photodiode. Individual wavelengths may have to be used to take into account the different expected temperature ranges for the locations of the SH.
Data corrections, if necessary, are simplified. Such corrections can be required due to a soiled optical system or damage to the FOs. The Peltier system requires most of the power, which is less than 20 W. The SU includes a complete independent memory bank for data storage versus the PYREX EXPERT system time which is related to the mission time after the flight. This memory is preserved even in the case of a power failure.

4.2 PHLUX

A further payload to be contributed for EXPERT is a catalysis based experiment. It has the purpose to improve and support the chemical models used for the CFD calculations by flight data. The design of the system is based on the experiences with PYREX.
Since the heat flux on materials in dissociated air strongly depends on catalytic activities of the materials, comparison of two materials with different but known catalytic properties gives information about the recombination heat fluxes on these materials. From this information the dissociation degree of the re-entry plasma can be concluded employing both Goulard's theoretic investigations for stagnation point heating and numerical simulations using codes with surface reaction models as e.g. URANUS [6]. Recombination coefficients and emissivities for the PHLUX candidate materials measured in the inductively heated plasma wind tunnel PWK3 using a pyrometric double probe are presented [2, 10].
The proposed experiment consists of two sensor heads with inserts of different materials, whose catalytic activities differ. Each of the sensor heads contains a pyrometric device for the temperature measurement of the rear side of the material samples, see figure 7.
The measured temperature history on the sensor materials is the basis for the calculation of the heat flux on the sensor. An optical path is needed through the thermal insulation between the relatively cold supporting structure of the vehicle TPS, where the optical sensors are mounted, and the rear side of the sensor sample, where the temperature is measured. The optical signal from the sensor rear side is led through the optical path (silicon carbide tube) in the thermal insulation to the PYREX lens where it is focused. Furthermore, the fibre optic cable leads the optical signal to the conversion unit with the photo diodes. The converted (optical to electric) signal is recorded by the electronic unit of the three sensors. This unit has the same mechanical design as the PYREX SU, see figure 6. With the help of calibration curves the recorded signal can be transformed to temperatures. Finally, the heat flux on the sensor samples can be calculated from the samples' temperature response during re-entry.
For the qualification and calibration of the sensor the plasma wind tunnels (PWT) at the Institute of Space Systems (IRS), University of Stuttgart will be used during the phases C and D of the EXPERT program. The PWTs allow to simulate the aero-thermodynamic conditions around re-entry vehicles for the altitude range of 90 – 60 km. In particular, the inductively driven PWK3 will be used for calibration purposes as this facility is able to generate high enthalpy oxygen, nitrogen and air plasmas.
The results of the experiments are temperature histories and heat flux on the sensor samples during re-entry. The determination of the overall dissociation degree of the air plasma flow is possible by means of non-equilibrium codes such as the IRS URANUS code in combination with the already implemented surface reaction models.

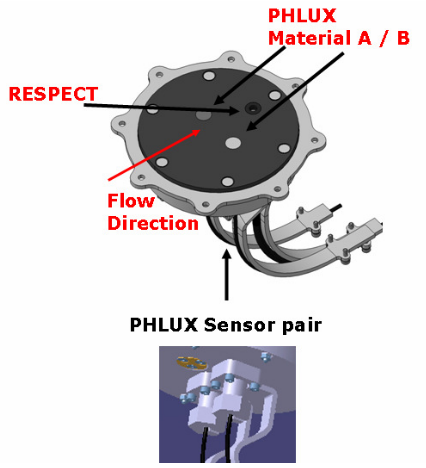

Figure 7: One of the three PHLUX Sensors (including the 2nd RESPECT sensor, see below)

4.2 RESPECT

Thermal and mechanical loads onto a space vehicle surface during re-entry are closely related to the plasma state and, therefore, to its chemical composition close to the wall. One way to gain the information about these quantities is given by emission spectroscopic measurements during re-entry flight. The main goal is to obtain more detailed information about the plasma state in the post shock regime of a re-entry vehicle by measuring the spectrally resolved radiation onto the surface. Due to the integrating character of the measurement, an extraction of temperatures or densities directly from the measured data is not possible. The obtained database will provide the radiation of multiple species for a comparison with the results of numerical simulations. The comparison will deliver the chemical composition spatially resolved and, therefore, help to validate the chemical models, which are implemented in the codes, if successful. If not, important information on necessary code improvements will be obtained.

For EXPERT, two measurement positions on the vehicle are planned to enable a monitoring of the spatial evolution of the plasma along the flow field. Each spectrometer will cover a minimal wavelength range from 200 nm to 800 nm with a resolution of about 0.5 nm. Therefore, the emission of relevant radiating air species such as N2, NO, N, O and N_2^+ will be obtained. Simulations of the expected spectrometer signal are under investigation. They will be used to decide whether the spectral range will be needed continuously or if a two channel version for each channel with restrictions in terms of spectral range but therefore improved resolution will be better suited. The use of a modified commercial spectrometer is planned. Different spectrometers are under consideration. The S2000 model from Ocean Optics is favoured since it has been already used for space applications. Two positions within the EXPERT capsule are foreseen. One in the nose structure near the stagnation region, the second will be combined with one of the three PHLUX sensors (see also Fig. 7).

For theoretical studies of the spectrometer system, a virtual spectrometer is simulated using a numerical simulation of the flow field provided by the URANUS code in combination with a spectral simulation of the emission with the plasma radiation database PARADE [16].

Based on the numerically computed plasma state an emission spectrum is computed in each grid point on the two optical paths. Then, all spectra are integrated along the line of sight yielding the simulated spectrometer response. Up to now, simulations were performed for entry velocities of 5 km/s and 6 km/s according to the first two EXPERT flights. Of particular interest is also the 6 km/s flight since dissociation and radiation are higher due to the higher enthalpy of the plasma.

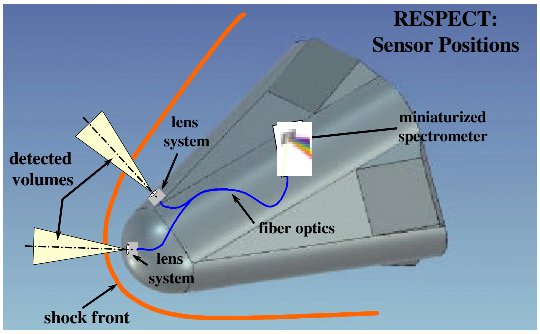

Figure 8: Proposed sensor positions of RESPECT on the EXPERT capsule.

5 STARDUST

With this project a spectroscopic measurement system had to be developed allowing for the airborne observation of the capsule during re-entry. A raw description of the overall project is given in reference [21]. A more detailed analysis which extends the present survey is given in [5]. The project itself was supported by the Steinbeis Transfer Centre Plasma and Space Technology which is also involved in the analysis of the data. For the sake of briefness, therefore, the reader is asked to assess these references in case of the need for more information.

It has to be emphasized that the post-flight analysis is a continuous process that is leading to a stepwise improvement of both considerations and results.

The mission itself was the first US mission for the exclusive exploitation of a comet (Wild 2) aiming for a sample return in the form of cometary dust. After the rendezvous in January 2004 (after almost 4 years travel time) the vehicle started its return back to earth and the small capsule containing the collected dust entered the atmosphere at January 15th 2006. The maximum radiation equilibrium temperature for the PICA TPS material would have been about 3700 K at a total heat flux of more than 11 MW/m^2 (peak heating). The actual ablation temperature, however, is 3000 K [21]. A corresponding OpenGL based animation was developed by the Steinbeis Transfer Centre Plasma and Space Technology [22]. This animation takes direct use of the trajectory data.

The measurement system SLIT is explained more in detail by Winter [5]. A summarizing description is that a manually tracked light amplifier was filmed by a video camera. In parallel a reflector telescope (f = 100mm, d = 50 mm) was used that was coupled via a fibre optic system to the slit spectrometer which was an Acton Sp300i (f = 300 mm, Grid 600 1/mm) using an electronically amplified Andor EMCCD as detector. The wavelength range was between 325 nm and 455 nm with a predicted pixel resolution of roughly 0,08 nm.
Within the first analysis a subtraction of background signal, an elimination of cosmic radiation, a wavelength- and intensity calibration, a sophisticated temporal and spatial assignment of the spectra, the determination of distance STARDUST-DC8 from GPS data, a separation thermal radiation (TPS) and plasma, a preliminary determination of heat shield temperature and a plasma emission analysis was performed [5]. A more detailed description of the set-up and the analysis activities is also given in [22].

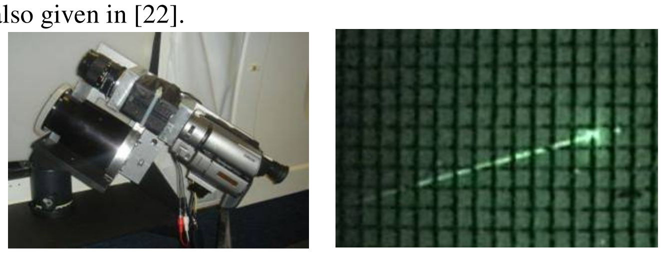

Figure 9: Camera and telescope (left) and tracking camera image of Stardust during entry (right).
Figure 9 shows the camera, the telescope and an image of STARDUST during entry. In Figure 10 an exemplary preliminary result is shown. Here, a direct calculation of thermal radiation without scaling was performed. The solid angle was determined via distance data from GPS. The spectrum was taken with an exposure time of 0.2 s at an altitude of 61.9 km (near peak heating). It was assumed that half of the radiation surface of the capsule was detected which result in a TPS temperature of 2950 K. The temperature was assumed to be isothermal for this first preliminary analysis. In addition, it must be clear that the accuracy of the results still has to be analyzed in detail e.g. for the shown spectrum between 250 and 2500 Photons reached the corresponding pixel.
The overall results of the project extend the results shown here by far. About two dozen of spectra were measured in different zones of and around the capsule (e.g. front or wake). First statements on equilibrium deviation can be made on a basis of radiation simulation. A profile over altitude for the preliminarily estimated wall temperature was obtained. In addition, very important statements on the species can be made. The overall analysis enables statements on improvements of the presently performed analysis, see references [5] and [23].
The measured data are unique in Europe and, additionally, an exchange of data between all of the participating teams is foreseen. A further data set that was obtained by Franziska Harms (SOFIA Institute/IRS) has not yet been analyzed in detail.

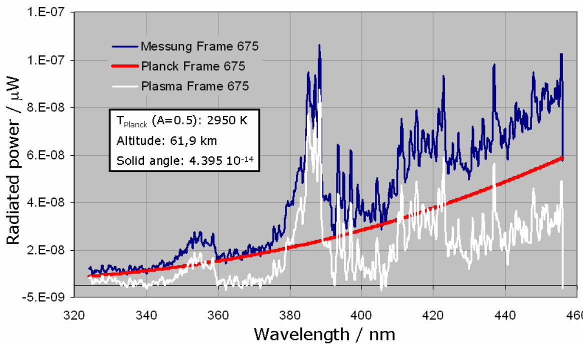

Figure 10: Spectrum at 61.9 km altitude, continuum radiation shown.

6. Summary

Examples for designed but also fully qualified and flown measurement systems are presented. For MIRKA the results of PYREX were shown as an example. Here, also the dynamic abilities of the fast temperature measurement method which leads to the potential to measure dynamic effects have to be emphasized.
The major present activities at IRS related to in-flight measurements are the Phase C development of the EXPERT instrumentations and the post-flight analysis of the STARDUST data. This post-flight analysis consists of a 3 years program in which a numerical and an experimental assessment are foreseen. The STARDUST data are unique in Europe and will become reference for the modeling of hyperbolic re-entries such as they are e.g. foreseen in the AURORA program.

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