Key Experiments within the Shefex II Mission

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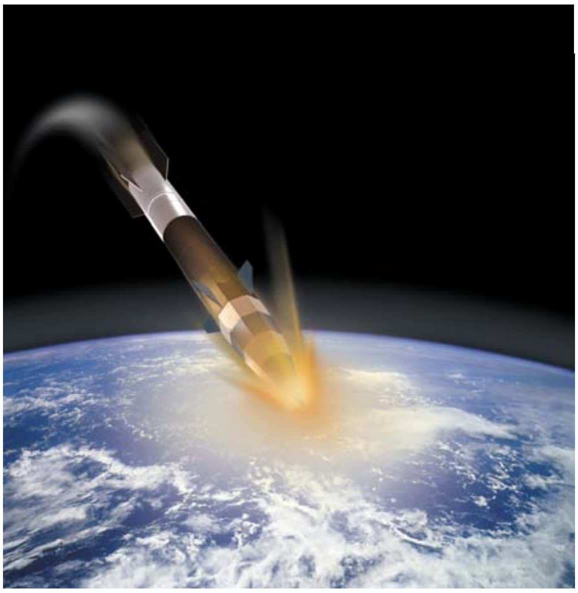


Abstract

After the successful hypersonic flight of SHEFEX I the next mission is under development. Within this paper the basic goals, architecture and key experiments of the SHEFEX II mission will be presented. Also launched by a two staged sounding rocket system, SHEFEX II will be a consequent next step in technology test and demonstration. Considering all experience and collected flight data obtained during the SHEFEX I Mission, the test vehicle will be re-designed and extended by an active control system, which allows active aerodynamic control during the re-entry phase. Thus, ceramic based aerodynamic control elements like rudders or flaps, mechanical actuators and an automatic electronic control unit will be implemented. Special focus will be taken on improved GNC Elements. In addition, some other experiments including a FADS system, an actively cooled thermal protection element, advanced sensor equipment, high temperature antenna inserts etc. are part of the SHEFEX II experimental payload.

Introduction

One key technology for returnable space transport vehicles, hypersonic aircraft or winged first stage of a space transportation system is the structural design of hot structures at exposed locations of the vehicle (e.g. nose, wing leading edges, control flaps, air intake etc.) and the overall fuselage design considering the thermal loads. Besides high temperature resistant materials, also structures or single components cooled by special physical effects are candidates for extremely exposed locations at the fuselage and the engine. For the fuselage and wing design different design solutions are possible. In addition to the classic variants like TPS protected conventional structures or hot skin structures, the basic shape approach may influence the system performance and cost frame of the vehicle.

Another key technology is simulation and prediction of aerodynamic and aerothermodynamic phenomena and effects occurring during atmospheric re-entry. Thus accuracy and reliability of simulation tools and ground testing facilities control margin policy and safety of vehicle lay out and mission success.

In addition, autonomous aerodynamic control during re-entry and final approach using moveable rudders, flaps or fins is an essential technology for future re-entry vehicles.

A lot of development effort can be done on ground or using ground based test facilities. However, a flight test is extremely important to set a reasonable development step forward. The challenge to deliver flight hardware which has to operate in a very reliable way during the mission speeds up development process and supports learning curve significantly. However, a rather complex test vehicle or demonstrator requires a reasonable time frame and financial resources. Thus, an optimal compromise is to reduce size and complexity of the test vehicle, to simplify trajectory requirements and to use a cheap launcher system and existing ground support.

Figure 1: Launch of SHEFEX I at Andoya Rocket Range in October 2005.

After demonstration within the SHEFEX I mission sounding rocket systems are suitable to perform re-entry related flight experiments. Having the SHEFEX I in a "passive" re-entry configuration only stabilized by a conic tail and fins, the SHEFEX II payload will be provided by an active aerodynamic control system.

Lay Out of the Launcher

After a trade off of different launcher configurations and examination of each possible performance and related trajectory, a final 2 stage configuration was chosen considering Brazilian solid rocket boosters derived from the S 40 family. Within table 1 the basic characteristics of both configurations are summarised.

	SHEFEX I	SHEFEX II
Payload	250 kg	380 kg
Apogee	210 km	260 km
Downrange	230 km	1150 km
Max. Speed	Ma 6.5	Ma 10-12
Stages	2	2
Experiment time	20 sec	45 sec
Re-Entry angle	84 °	35°

Table 1: main characteristics of the SHEFEX I and II launcher configurations

As a rocket vehicle to fulfil the demands on payload capacity and re-entry velocity, the two-stage Brazilian VS-40 sounding rocket was considered. The vehicle was originally designed as a vacuum test bed for the S-44 apogee motor used in the Brazilian VLS satellite launcher programme. The S-40 motor is part of the VLS vehicle operating as the third stage. The S-44 motor and also the

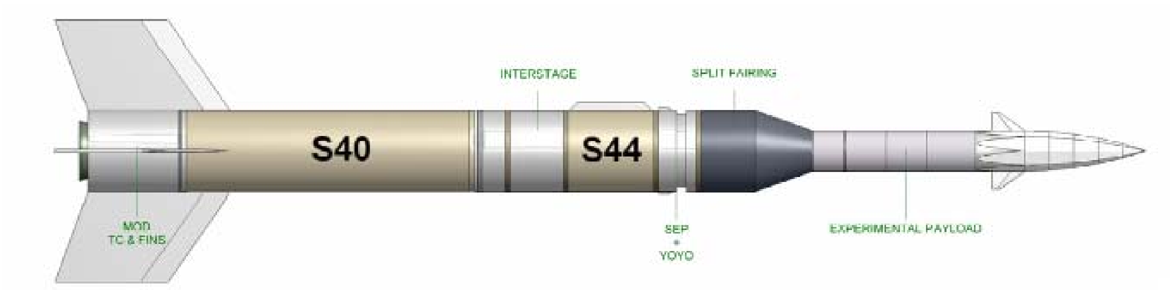


Figure 2: S 40 Launcher system for SHEFEX II and payload configuration

interstage adapters are lightweight structures built of Kevlar composites. The VS-40 was first launched successfully in April 1993 achieving an apogee of 950 km and a ground range of 2680 km with a payload mass of 197 kg and 81.8 deg of launch elevation. Up to now, two flights are recorded, both successful.

Description of the SHEFEX II Test Vehicle

In the opposite to SHEFEX I the shape of the test article was chosen to create a symmetric re-entry body stabilized by tail fins and 4 movable small canards near the front area of the cylindrical pay load segments. Within the cylindrical segments all necessary subsystems like navigation platform, power cells, RCS- unit, data acquisition, parachute and recovery system, telemetry, etc. are integrated.

The front tip area of the SHEFEX II re-entry vehicle is designed using the facetted shape design as used within the first mission.

However, for the flight experiment a compromise between a consequent facetted shape using only a low number of plane areas, a certain inner volume for sensor integration and boundary shape of the rocket fairing has to be found. Within figure 2 the preliminary outer shape is depicted. The tip is divided within 5 sections. The front section includes a leading tip insert and an integral facetted ceramic nose cone.

Mounted on top of the second stage the payload will be separated before re-entry to begin an autonomous flight till final breaking manoeuvre and parachute deployment.

Including the payload the overall length of the system is 12, 6 m. The overall mass of the system is 6,7 tons. The S 40 solid rocket motor acts as first stage. Within 60 seconds after ignition a propellant mass of 4 tons lifts the SH II system up to 54 km height. Within the first ballistic phase after separation of first stage, the second stage, also a solid rocket motor (S 44) will be re-pointed to a more flat attitude before its ignition. The 800 kg propellant mass of second stage boosts the SHEFEX II payload to an apogee of approx. 260 km. After a de-spin manoeuvre separation from rocket motor will be initiated and attitude control will orient the payload for re-entry at approx. 35°. Re-entry and so the start of experiment phase will be at 100 km when atmosphere effects became reasonable.

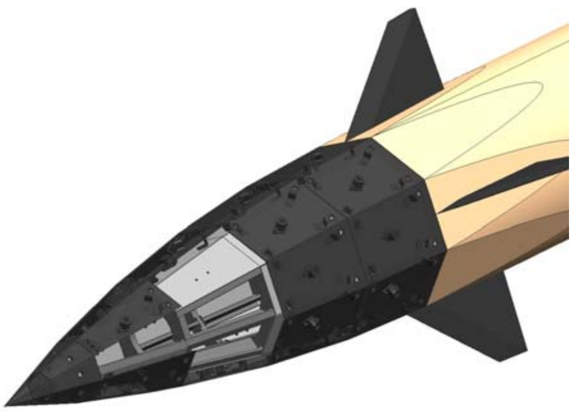


Figure 3: Detail of the payload Tip including TPS (dark grey) inner Alu substructure (light grey) and actuator module.

The current flight envelope estimates a max. Mach number during entry up to Ma 11 (approx. 3 km/sec) for 45 seconds. This high Mach number will cause extreme heat fluxes at the payload tip and sharp leading edges at the canards and stabilizers. So temperatures above 1800 °C may occur at

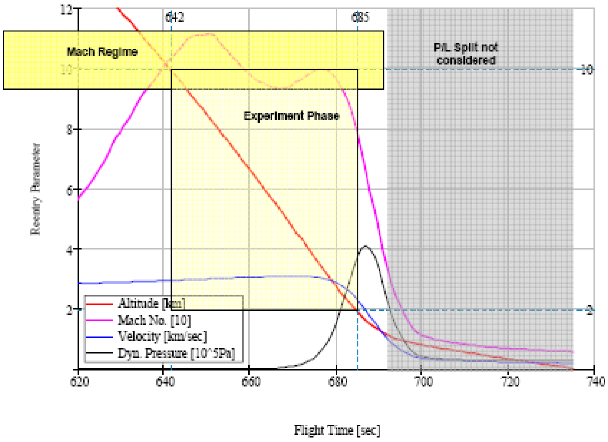


Figure 4: Predicted gas flow conditions during re-entry

these exposed locations. The dynamic pressure will increase up to 4 bar at the end of entry trajectory at 20 km.

During the experiment phase a maximum entry velocity of Ma 10 to 12 is expected for 45 seconds. Thus, the heat loads will cause a temperature distribution between 2000°C at the sharp leading tip and up to 900 °C at the rear panels. In addition, some hot spots at the edges are expected. Considering these flight conditions, the heat loads are not representative for a RLV re-entry, however, it allows to investigate the principal behaviour of such a facetted ceramic TPS, a sharp leading edge at the canards and fins and all associated gas flow effects and their structural response.

Key Experiments

The primary substructure of the payload tip is similar to the SHEFEX I concept and consists of a aluminium frame created by stiff booms and spares. The free space is closed by flat aluminium panels, which create an inner mould line (IML). The panels are also used for mounting the TPS facets and experiments. Inside the frame, some measurement equipment is integrated. These items are boxes for thermocouple connection and compensation, pressure transducers, a pyrometer system, data processing boxes and subsystems for passenger experiments.

The tip geometry is symmetrically divided into 8 identical facets in circular direction and consists of 5 segments along the tip to the actuator module interface. Thus, the payload tip houses 40 single flat areas. 32 of them are available for different experiment positions.

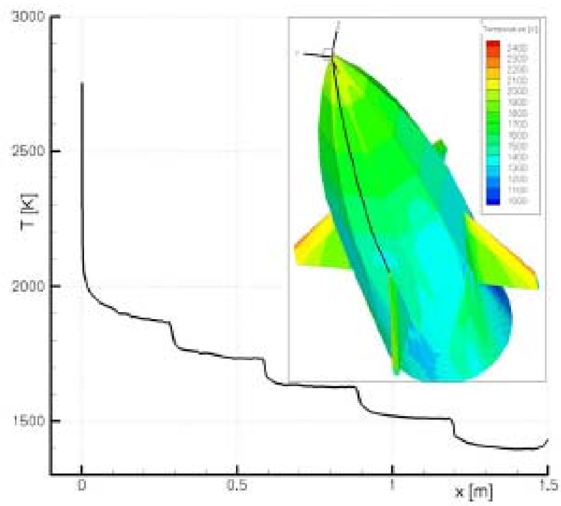


Figure 5: predicted temperature distribution at radiation adiabatic boundary conditions

As shown in figure 5 with exception of the forward tip area, the heat fluxes have individual nearly constant values at each segment. The heat flux decreases from segment to segment in rearward direction. Thus, each segment is suitable for different TPS concepts and materials due to their specific limit temperature.

Flush Air Data System (FADS)

Within the nose cone tip some special arrangement of 8 pressure sensors will be implemented to investigate possibility of a flush air data system, which may be useful for vehicle control (pitch and yaw) against gas flow direction during hypersonic flight. However, this is a passive experiment with no interaction of SHEFEX II active control. But pressure data assessment shall allow a comparison of vehicle orientation data got by GNC platform and advanced algorithms for pressure data processing. From a structural point of view, the integration of pressure holes and tubing within the hottest area of the vehicle is a challenging issue.

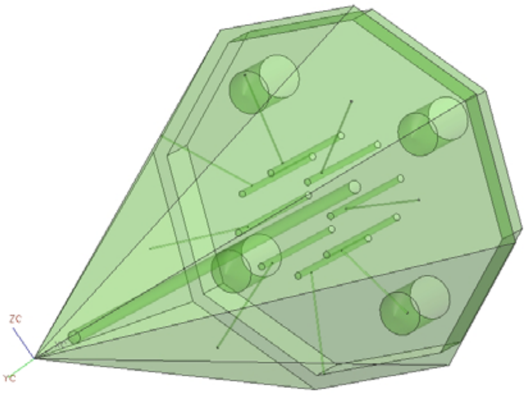


Figure 6: CMC Nose with integral pressure sensor holes for the FADS

Thermal protection systems TPS

The second section includes 8 single TPS or material experiments designed very similar to those, which are flown already on SHEFEX I. Main element of the concept is a fiber ceramic cover plate, supported in all directions by a so called central post and flexible stand offs at the corners. Thus, the thermal expansion will be not suppressed. Beneath the cover plate a lightweight fibrous ceramic insulation felt is inserted. Key element of this TPS concept is a ceramic fastener, used for the connection of the panel to the CMC stand off and central post. A novel CMC fastener consisting of a bolt with a conical or spherically shaped head and a split threaded shank has been developed at DLR. At first, the fastener is screwed in with no deformation. When the torque moment reaches a particular level, the shank of the fastener, which is in the nut, is pressed together until the inner cone or the slot limits further deformation. By drawing the inner cone with a pin axially, the shank of the fastener is spread back resulting in a pretension in both radial and axial directions as both flanges of thread and nut are pressed together. Thus the torque moment during fastening is low. This is another positive effect, because the torsion strength of CMC materials is usually low due to the low interlaminar shear strength of the material. Thus, the screw rivet design provides and combines nearly the same functionality as a common screw and a blind rivet, but the internal stress distribution is more adequate due to CMC material properties. To loosen this element it is only necessary to press down the conical locking element.

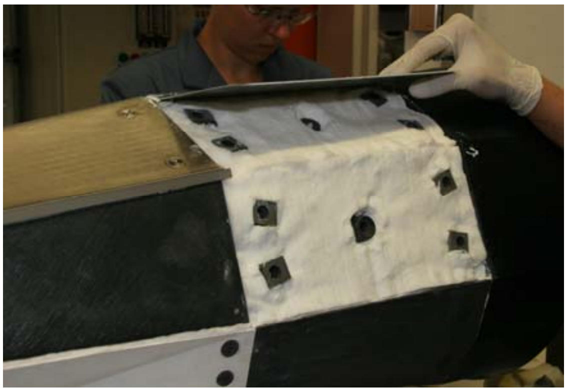


Figure 7: C/C-SiC standard TPS as mounted on SHEFEX I

Within the SHEFEX I project, the detailed shape of the fastener has been improved and mechanical strength could be significantly enhanced. Within SHEFEX II further optimisation could be achieved in terms of reliability and mounting rules. Thus, the demonstration of functionality and reliability for operational application of such screw rivet attachments is on track.

The second key element for the TPS is the seal design at the interfaces between the panels. During the nose cap development for X-38 a rigid and flexible seal combination was developed. During a lot of ground tests within plasma wind tunnel test facilities, the performance and reliability could be demonstrated. However, the manufacturing effort was rather high to adopt the rigid seal contour close to the panel shape. Within the SHEFEX shape including a certain number of different angles at the interface chamfers, a lot of different single parts would be necessary.

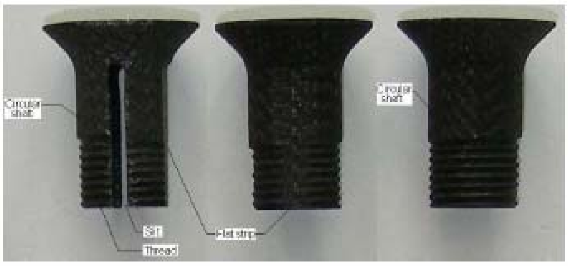


Figure 8: CMC screw rivet fastener for panel attachment

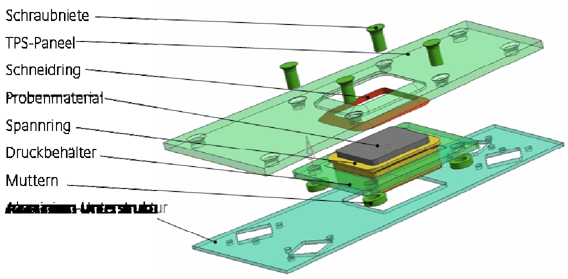
A new approach will be performed within the SHEFEX project. Within DLR an oxide ceramic based CMC material was developed during the last years. The so called WHIPOX material can be used as an oxidation stable alternative to carbon based CMCs. However, temperature stability is limited and a special coating is necessary to improve emissivity and catalytic behaviour. Nevertheless, this material provides a flexible intermediate state during the manufacturing process. Thus, it is possible to shape a component (in case of SHEFEX the rigid seal) during assembly. Hardening will occur during operation.

Using this property, it is possible to shape and cut all required seal components from one uniform unfired WHIPOX tape. A typical seal interface was tested within a plasma wind tunnel and handling procedure, seal performance and temperature stability could be demonstrated successfully.

Besides DLR`s C/C-SiC material for the cover panels, 3 facets of the second segment are covered by passengers on SHEFEX II, two different C/SiC materials developed by EADS ASTRIUM and one C/SiC Panel developed by MT-Aerospace.

4 TPS-elements of the third segment are provided with patch antennas behind. This is to demonstrate functionality of “hot” antennas which are able to be integrated within a heat shield of a re-entry vehicle. The cover panels are made from DLR`s WHIPOX oxide based ceramics to take benefit from their electromagnetic permeability. 2 facets contain the actively cooled TPS experiment, which is described in the following chapter. The last 2 facets are covered by the standard C/C-SiC TPS system.

Within the 4th and 5th segment a number of passengers and standard TPS elements are located. Besides the surface protected flexible insulation SPFI 2 metallic TPS elements from EADS ASTRIUM are integrated.



Actively cooled TPS AKTIV

At DLR an actively cooled TPS concept is under investigation. Based on the very good experience got during development of an effusion cooled ceramic rocket engine burning chamber, it seems to be possible to transfer this technology for the design of extremely loaded sharp leading edges or flat TPS elements exposed to heat fluxes beyond materials temperature limits. First screening tests of different porous ceramic materials and cooling gases showed a promising potential for this technique. Significant cooling effects at rather low gas consumption could be demonstrated within a plasma channel test sequence at hypersonic gas flow conditions. However, a large effort has to be invested to investigate and understand the responsible parameters for an optimal cooling effect considering the thermal conductivity and interactions between the surrounding gas flow and boundary layer.

Figure 9: Plasma wind tunnel test sample of an actively cooled TPS panel

Active cooling systems are of special interest for use in severe thermal environments where the passive systems are inadequate. The transpiration cooling experiment uses a porous ceramic material at the outer surface through which a coolant flows into the boundary layer. Thus, transpiration cooling is effected by two physical phenomena, as there are the porous structure being convection cooled by the coolant and the coolant layer on the outer, hot surface, lowering the heat transfer from the high-enthalpy environment to the vehicle surface.

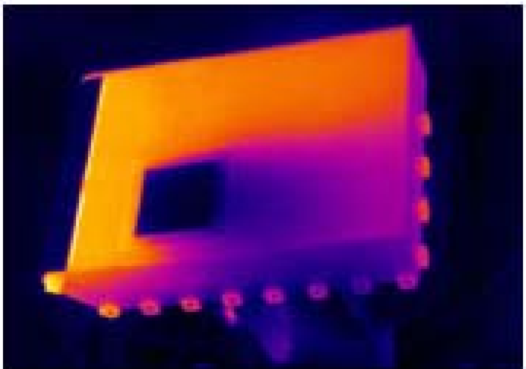


Figure 10: Thermal image of the sample during test

In the centre of a pair of the flat thermal protection system (TPS) panels, a porous probe will be inserted. This porous probe is to be run through by the coolant and is pressed into the surrounding C/C-SiC TPS-material by a compression ring. The pressure reservoir is flanged to the C/C-SiC ceramic by riveted ceramic fasteners. The reservoir itself is made of stainless steel.

To this point, a numeric FE-analysis of the experiment set-up was performed. Investigations of a similar set-up were successfully completed in a plasma wind-tunnel and provide a basis for the present experiment. In addition, the impact to the whole gas flow characteristic at the payload tip caused by the boundary layer interaction with the cooling gas will be simulated by CFD and wind tunnel investigations.

Active aerodynamic control

The first cylindrical part behind the facetted payload tip includes the aerodynamic flight control unit. The active part is an actuator system to move the 4 canards. Interaction with the RCS system at altitudes above 70 km and continuously changing aerodynamic sensitivity till payload split at 20 km require challenging advanced control algorithms and high speed actuators.

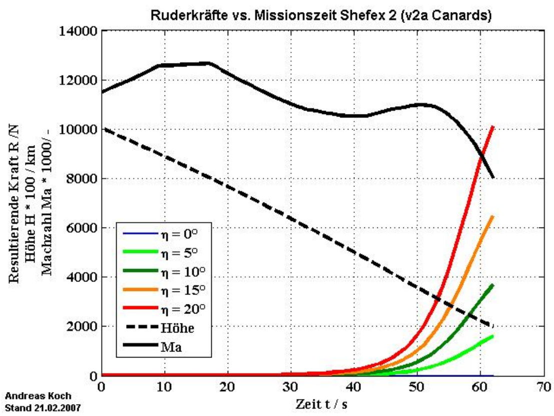


Figure 11: Increase of bending forces at the canards during entry.

The canards themselves are highly thermomechanically loaded structures. Due to limited shaft diameter and very high bending loads, a CMC/metallic hybrid structure was chosen for structural design. The leading edge structure is made from C/C-SiC fiber ceramic to withstand the expected high temperatures of 1700°C at the leading edge. The canard main structure is made from a Titanium alloy to carry bending loads and to transfer torsion from the actuators. Special attention has to be paid for the attachment design between Titanium and CMC to balance thermal expansion mismatch.

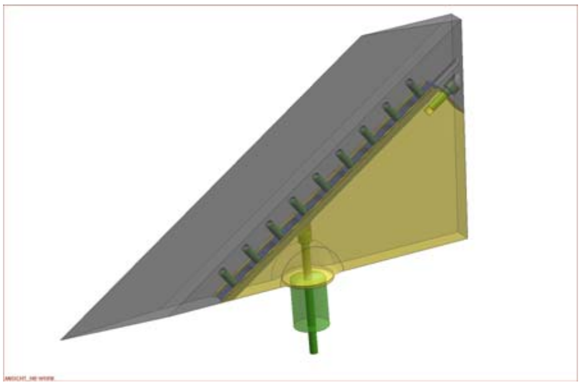


Figure 12: Hybrid CMC (grey) and metallic (yellow) canard structure

Instrumentation

The whole tip structure will be instrumented with up to 60 thermocouples, 1 pyrometer, 24 pressure sensors and 8 heat flux sensors. In addition, some accelerometers will be integrated. Special care will be applied to the integration of the pressure and heat flux sensors within the TPS elements. This is to minimize secondary gas flow effects at the sensor/ceramic interface at the outer surface. Otherwise, the heat flux signal may be disturbed by local turbulence or stagnation areas. All signals will be processed and send to the data storage and telemetry system by special multi function cards also integrated within the payload tip. Lessons learnt from SHEFEX I and parallel on ground testing and calibration promises a high quality of flight data, which will allow optimisation and calibration of CFD tools for further reliable aerothermodynamic vehicle lay out. For example transfer functions for thermocouple signals are very important to recalculate true surface temperature from raw thermocouple signals, which are located some mm below surface and significantly influenced by adhesive layers and build in conditions.

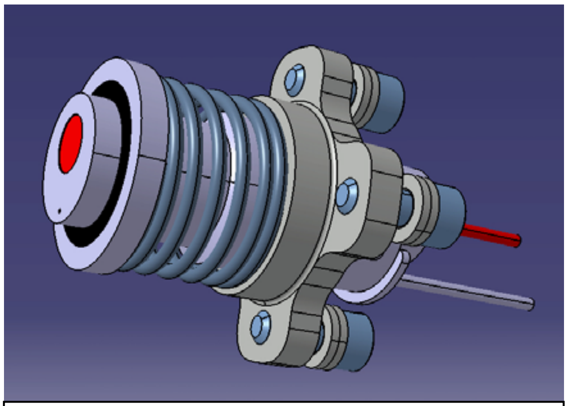


Figure 13: Integral heat flux and pressure sensor.

MPB and the University of Stuttgart provide additional instrumentation in terms of fiber optic sensor and a pyrometer and radiometer sensor combination respectively.

Mounted on top of the second stage the payload will be separated before re-entry to begin an autonomous flight till final breaking manoeuvre and parachute deployment.

Mission Scenario

The current trajectory calculations result in a down range in the order of 1200 km which requires an additional down range telemetry tracking station for complete coverage. Andoya Rocket Range in conjunction with its remote launch facility and telemetry station on Svalbard is equipped with glass fibre data links from Svalbard to Andoya serving real-time communication. A down range in the order of 1500 km is not a restriction as the Norwegian Sea and polar cap is available for impact. The current scenario is based on a launch from Andoya Rocket Range with an azimuth of approximately due north and over flying the island of Svalbard providing down range telemetry tracking. The impact point then would be approximately 200 km east of Longyearbyen. The map shows a possible ground track for the SHEFEX 2 mission. In case of reduced down range, the annual movement of the pack ice border north of Svalbard has to be observed to set the launch window. As daylight and good pack ice conditions are requirements the Northern hemisphere spring time starting in the month of May would be attractive. The worst ice conditions due to summer warming and Gulf Stream are to be expected by late summer in the month of September

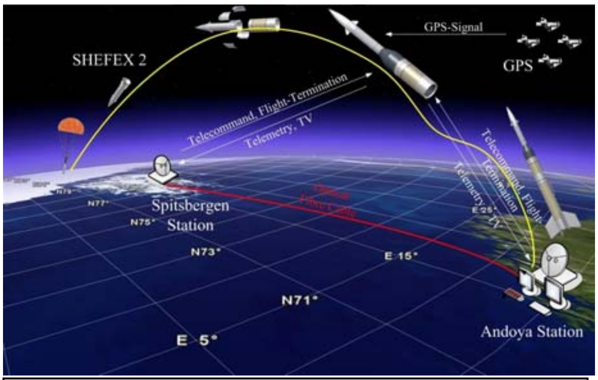


Figure 14: Mission phases and schematic telemetry links.

Conclusions

At present, the SHEFEX II launcher configuration, the experiment lay out and mission profile is finally defined. The mission profile will offer enough experiment time and sufficient re-entry speed to take the next step in flight testing. All key experiments are established and finally accepted. The detailed structural design and preparation of aerodynamic basic data base and determination of aerodynamic parameter for active control is completed and manufacturing of launcher and experiment hardware will be initiated in October 2008. Start of integration is planned in summer 2009 to meet the launch window in spring 2010.

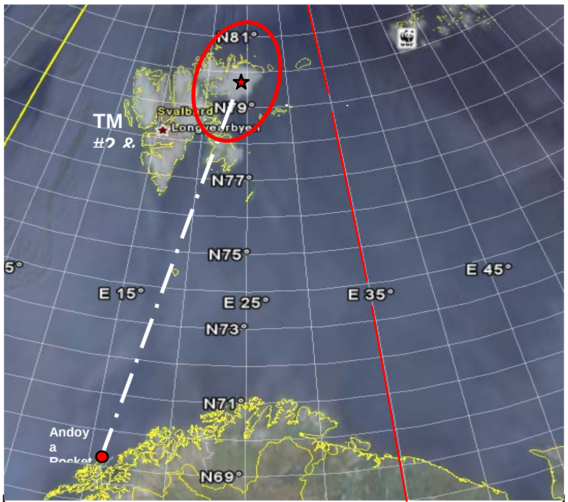


Figure 15: Planned ground track of the SHEFEX II mission.

Figure 17: REX Free flyer – One proposal for application of SHEFEX derived technology.

Outlook

Shefex II is one more step forward within DLR's roadmap for the development of hypersonic and re-entry technology. A first application is planned within the Returnable Experiment REX. Such a system shall provide a free flying platform with a high micro g quality for a few days. The return capability, active aerodynamic control during re-entry and the special container technique derived from sounding rocket experiment set up shall provide a cost effective and easy access for experimenters. In addition or as a kind of dual use, such a vehicle may be used operational for micro g experiments in orbit for a few days and following return to earth. This looks promising, to close a gap between drop tower tests, sounding rocket missions and long term experiments at the ISS.Thus, the currently prepared SHEFEX II mission is not a single project or “only” a re-flight of the first experiment. This project is part of a long term flight test program for re-entry technology and related development items. In parallel, the SHEFEX flight test philosophy provides a lot of possibilities for further developments in the field of hypersonic air transport.

The following DLR Institutes and Facilities participate within the SHEFEX II Project:

Institute of Aerodynamics and Flow Technology, Braunschweig / Göttingen and Wind Tunnels Section, Cologne, Institute of Structures and Design, Stuttgart, Institute of Flight Systems, Braunschweig; Institute of Materials Research, Cologne, Institute of Aerospace Systems, Bremen, Mobile Rocket Base MORABA, Space Operation and Astronaut Training, Oberpfaffenhofen

Figure 16: Development road map for SHEFEX technology.

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