THE MISSION MIRIAM-2: PUTTING A GOSSAMER BALLUTE THROUGH AN ATMOSPHERIC ENTRY FLIGHT TEST

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ABSTRACT

MIRIAM, short for 'Main Inflated Re-entry Into the Atmosphere Mission test', is a validation concept designed for the Mars ballute technology development programme ARCHIMEDES. This development programme is a joint effort of the Mars Society Germany and the University of the Federal Armed Forces of Germany in Munich, with further support by research institutes throughout Europe, the DLR and several industrial companies.

The scientific objective of ARCHIMEDES is to obtain measurements of the Martian atmosphere, magnetic environment and surface throughout almost the entire altitude range reaching from outer space to ground. This is facilitated by an instrument carrier attached to a large and gossamer thin film ballute.

MIRIAM was designed to validate the theory behind such a vehicle, test the newly developed technology in flight and to gain experience related to manufacturing, handling, flight operations, and gathering new scientific data on Mars and its atmosphere. A first MIRIAM test was flown in October 2008 from ESRANGE.

In this paper we focus on the second MIRIAM test, named MIRIAM-2, which is currently slated for launch in October 2014 on a two-stage Taurus-Improved Orion rocket, again from ESRANGE. The main objective of MIRIAM-2 is to obtain realistic flight data for the re-entry of such a low ballistic coefficient design. Aerothermodynamic studies based on different methods have been performed for the entry into both Mars and Earth atmospheres, and flight data is needed to validate those methods.

Presented will be the underlying theory, the mission and spacecraft design, the scientific experiments aboard, and expected improvements of the current body of knowledge. We will conclude with an outlook on further development, particularly the transfer of MIRIAM-2 results to a more accurate description of the atmospheric entry on Mars.

1 INTRODUCTION

Providing an instrument suite with access to a large altitude range and a meaningful dwell time in the atmosphere of planet Mars is of high scientific interest [1]. A Scientific Committee, formed by scientists from several research institutes around Europe, therefore drafted the reference scientific mission scenario which was used by engineers and scientists from the Mars Society Germany (MSD) and the University of the Federal Armed Forces of Germany in Munich (UBW) as a reference baseline in a study to find a practical technical solution. Because relatively high wind speeds thwart the deployment of large gossamer balloon hulls or aeroplane wings without considerable mechanical effort [2], ascending and flying through the air like on Earth is impractical on Mars. However, a high altitude mission might also descend from space, provided it can be built to decelerate at a sufficiently high altitude to make scientific gains possible and worth the mission effort. No conventional hypersonic aeroshell and parachute system will slow down sufficiently to allow deployment far enough above the surface, because its mass to drag ratio (expressed in the so-called "ballistic coefficient", or BC) is much too high. For a classic planetary probe the BC is typically on the order of 60 kg/m².

A low ballistic coefficient, in contrast, raises the entire deceleration profile to a regime where the atmosphere is less dense (a higher altitude), prolongs descent time and lowers the aerothermodynamic heat flux that the vehicle will have to absorb. This translates into an increased dwell time during descent, an increase in the accessible altitude range for in-situ measurements, and facilitates landing at a site with too high of an altitude

for heavier and speedier probes (such as Tharsis on Mars). In addition to this, a low or even adjustable ballistic coefficient may also be useful during aerobreaking phases.
The research effort therefore focused on the lowest ballistic coefficient which is technically practical [3]. This was found to be around 0.6 kg/m², some two orders of magnitude lower than that of ordinary probes, which is achieved by using a large and light inflatable sphere. The sphere in itself offers other benefits as well. Since it can be densely packed and deployed with a small number of moving parts, it offers an attractive alternative to rigid structures. In fact, the same technology might also offer a practical alternative if a large aerodynamic heat shield for a heavy payload is needed, especially when a rigid heat shield would be too big for the biggest rocket payload fairing. Last but not least, the ballute technology might also offer an inflatable solar sail structure
In order to validate the theories and technologies developed for such a configuration, the flight test concept MIRIAM was designed.

2 MIRIAM-2 MISSION DESIGN AND ANALYSIS

2.1 Objectives

The primary objective of MIRIAM-2 is to implement a MIRIAM flight test such that the validation of the key theories and testing of the technologies developed as part of the ARCHIMEDES programme [3] becomes possible.
Because a vehicle with such a low ballistic coefficient has never been subjected to a controlled atmospheric re-entry, this concerns mainly the validation of numerical flow field and trajectory prediction methods. Until now, these methods rely solely on models and assumptions extrapolated from existing datasets.
Because inflating a large gossamer structure automatically in space, the equipment designed for that purpose must also prove its reliability under space conditions.

2.2 Mission Scenario

The MIRIAM concept foresees a suborbital trajectory that allows simulating loads and speeds expected for an entry of an ARCHIMEDES type probe into the Martian atmosphere.
Figure 1 shows the mission scenario from launch to recovery. The ballute spacecraft is carried inside a transportation subsystem, which itself is part of a service spacecraft that also carries an inflation system, observation equipment and a launch vehicle interface. After reaching space, the service spacecraft is separated from the rocket and deploys the ballute spacecraft. Once the ballute is fully inflated, the service spacecraft uses cold-gas thrusters to pull away from the ballute spacecraft, which is then left to enter the atmosphere by itself.

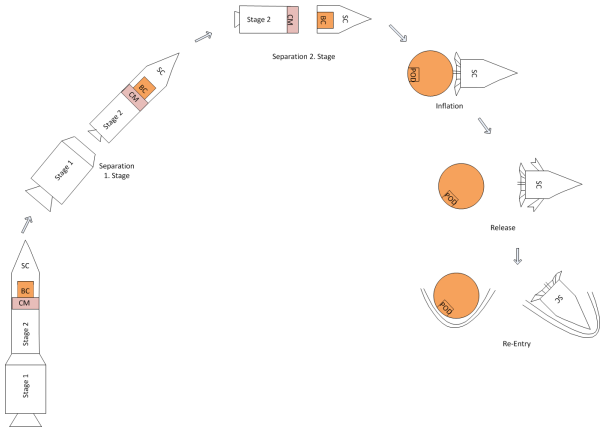

Fig. 1: MIRIAM-2 mission Concept and functional sequence.

2.3 Reference Trajectory

Two trajectory types were defined: The first, named “Bonneville”, is a steep ballistic trajectory that peaks at no more than 300 km altitude and has an entry angle of around 80 degrees at the atmosphere interface in 120 km altitude. The second, named “Sheridan”, is a relatively shallow trajectory that has an entry angle of around 6 to 25 degrees, simulating the entry of ARCHIMEDES at Mars even more acurately.
Both MIRIAM Sheridan and MIRIAM Bonneville trajectories can be achieved by conventional ballistic missiles or sounding rockets. However, due to the comparatively shallow angle, MIRIAM Sheridan requires either an intercontinental range or a rocket equipped with an actively control targeting mechanism and additional thrusters. Both are possible, however rather costly.
For MIRIAM-1 and -2, the MIRIAM Bonneville trajectory was thus chosen. It lies well within the capabilities of ESRANGE, and covers a downrange distance still small enough (approx. 80 km) to be able to retrieve the ballute spacecraft by helicopter within a day.
It is further believed that the basic theory should hold equally well for steeper entry angles, and that, if the observed trajectory and flow field are in agreement with data predicted by the aforementioned models, the prediction for future ballute missions of that sort should not be off by a significantly larger margin.

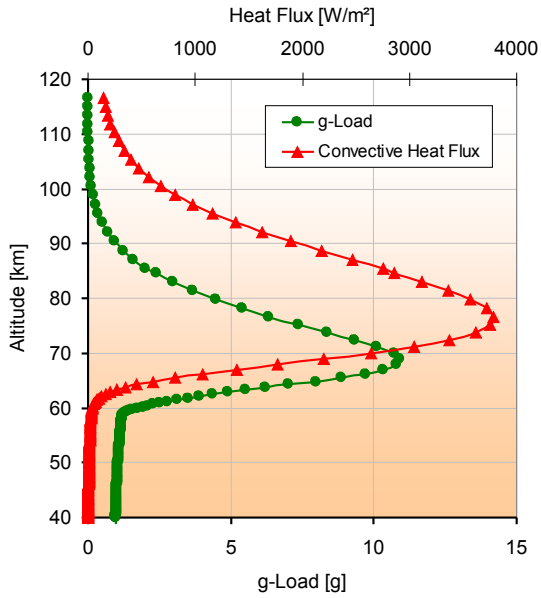

Fig. 2: g-load and convective heat flux prediction of a MIRIAM Bonneville type trajectory. Shown here is the design reference trajectory for MIRIAM-2.

The current design reference trajectory for MIRIAM-2 is Bonneville version 01. It has an entry velocity of 1.6 km/s and an entry angle of 79.2 degrees in 120 km altitude. Figure 2 shows g-load and convective heating predictions for this trajectory. Note that the convective heat flux is comparatively low, but that the g-load peak, albeit occurring at a higher altitude, is not significantly lower than that of an ordinary, heavy body re-entering from a similar altitude.

2.4 Aerothermodynamic Analysis

For the aerothermodynamic analysis of reentry flows, a lot of physico-chemical phenomena have to be taken into account in order to properly determine the mechanical and thermal loads, stability of the reentry body etc. These have to be determined at quite a few conditions along the trajectory, making a computationally efficient method a requirement.
Most of the past work for Archimedes (i.e. Mars atmosphere) was achieved be either using similarity laws (Sutton & Graves [4]), giving only stagnation point heat loads (such as the one given in Figure 2), or the full blown solution of the Navier-Stokes equations with complex modelling of thermochemical non-equilibrium (CEVCATS). However, during the analysis of Miriam ([5], i.e. earth atmosphere) the suitability of a second-order boundary-layer approach [6] coupled to the Euler equations was shown. For shock-layers, in which weak viscous-inviscid interaction prevail, the result is as good as with the more complex modelling of the Navier-Stokes equations at less than 1/10 of the computational time. For a ballute, the requirements are perfectly fulfilled at the windward side, which is of interest here.
In order to exploit this strategy also on Mars, the method has to be extended to model CO_2-N_2 mixtures. As a first step, chemical equilibrium conditions are considered. Typically this is modelled by a Gibbs free enthalpy minimisation procedure, which is far less complex than calculations in chemical non-equilibrium, but still rather costly compared to perfect gas solutions. Therefore, an interpolated data-base using bicubic interpolation (similar to [7]) of the state surfaces for CO_2-N_2 atmospheres was created recently [8], which is available now for efficient numeric investigations.

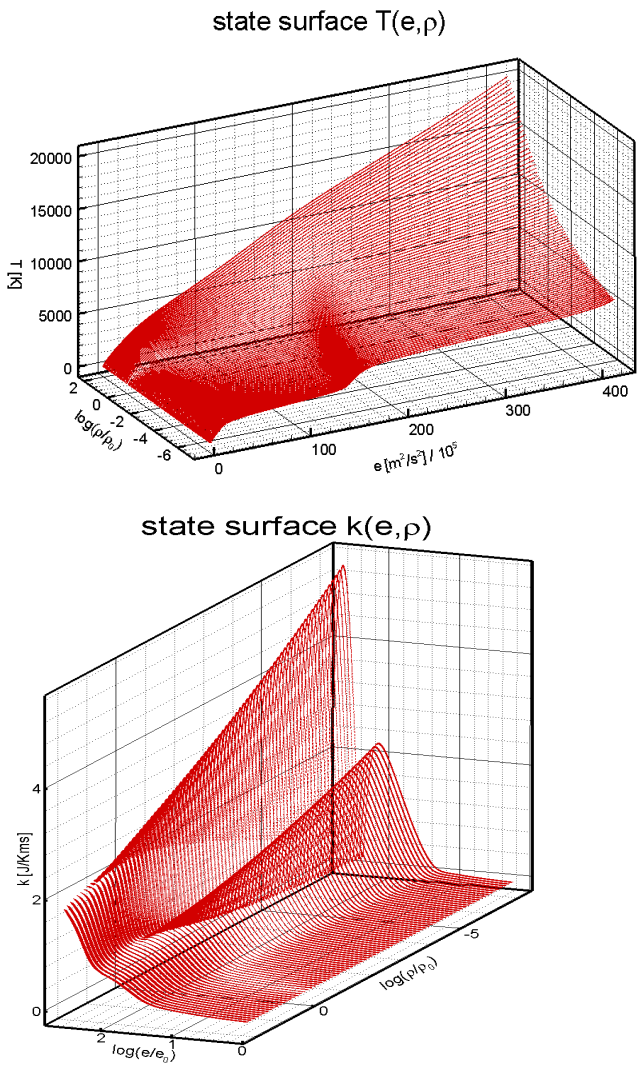

Fig. 3: Interpolated surfaces of temperature and heat conductivity, both as function of energy and density

Figure 3 shows some examples: the thermodynamic state surface of temperature as a function of energy and density, and the surface of the transport property heat conductivity. In both diagrams the regions of important dissociation / recombination effects is clearly seen, and more important for lower densities. Applied in the Euler-boundary layer method, only some 15% additional computing time is required than for a perfect gas simulation.
Figure 4 depicts the temperature field around a ballute spacecraft for Miriam (in air) and a hyperbola using the newly created state surfaces.

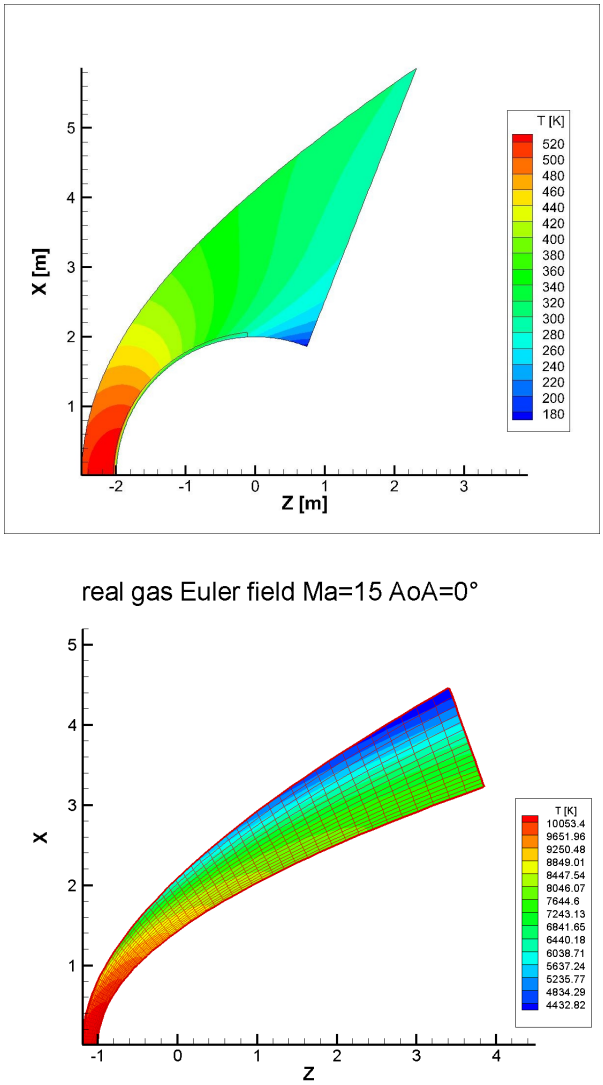

Fig. 4: Temperature field of Miriam in the earth atmosphere (top), and a hyperbola in a CO_2-N_2 atmosphere (bottom).

3 VEHICLE DESIGN

3.1 Ballute Spacecraft

The ballute spacecraft is divided into two main parts: the instrument pod which carries the payload and other spacecraft subsystems and the ballute itself, which alters the aerodynamic properties as desired by mission design.
The pod is therefore a small, dense, and hard object, with a structure made primarily of metals or rigid composites. It has a diameter of approximately 30 cm and weighs around 3 kg.
The ballute on the other hand is a large and light object, gossamer as compared to the pod, with a thin and flexible skin made from UPILEX thin-film. It has a spherical shape with a diameter of approximately 4 metres.

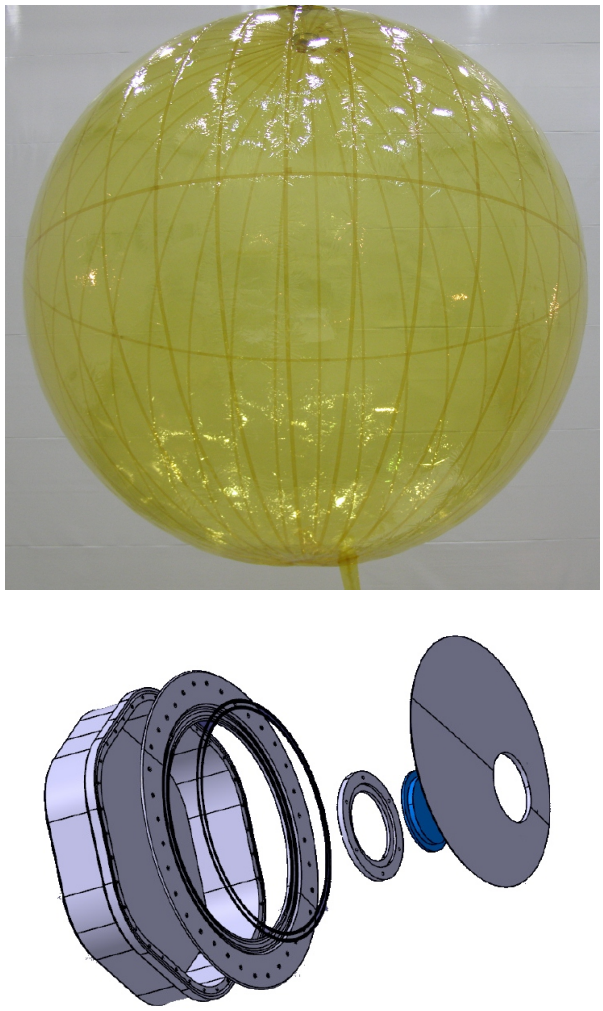

Fig. 5: MIRIAM-type 4 metre ballute (top) and exploded view of the instrument pod structure of the MIRIAM-2 ballute spacecraft (bottom.

The MIRIAM-2 ballute spacecraft therefore has a design ballistic coefficient of 0.56 kg/m².
Figure 5 shows a MIRIAM type ballute during a test at the company IABG Ottobrunn and an exploded view of the instrument pod structure. It is clamped to the south pole of the ballute, where the skin is clamped between the hexagonal aft body and the nose cover. The nose cover itself consists of a ring and a central lid featuring a window made from high temperature crystal glass. Sealing is provided by conventional o-ring seals.
To be able to reconstruct the actual trajectory and flight conditions, the ballute spacecraft will carry a miniature GPS receiver developed by the DLR, an accelerometer module (AMS), miniature gyroscopes, a flux-gate magnetormeter (MIRIMAG), a suite of flow field sensors (COMPARE), and temperature sensors mounted on the ballute skin. A miniature rearward-looking HDTV camera head will record the ballute behaviour during inflation and re-entry. While most of the numerical flight data is transmitted directly via a live UHF telemetry link, high-volume data will be stored aboard the ballute spacecraft's solid state memory module. The pod is therefore also equipped with a recovery beacon.

3.2 Service Spacecraft

The service spacecraft serves as carrier for the Ballute-Spacecraft during accent of the launch vehicle. It is fixed directly to the nose cone of the launch vehicle. After the upper stage of the launcher has been separated, the ballute is inflated by a dedicated system of the service spacecraft and subsequently the ballute-spacecraft is released. Both spacecraft follow now a ballistic trajectory towards the re-entry interface. Whereas the ballute spacecraft is decelerated relatively quickly by the atmosphere, the service spacecraft has no special provisions for controlled re-entry and descends and crashes eventually (s. Figure 1).
The service spacecraft interfaces with the launcher via the so-called camera module which is also part of the MIRIRAM-2 system. The camera module holds several cameras, which are documenting the separation process of the service spacecraft and, if orientation allows, the inflation process of the ballute.
Separation is provided by three pneumatic actuators which push the service spacecraft away from the camera module and thus from the launch vehicle. The required pressurised gas is stored in the camera module and the design of the pneumatic actuators is based on the design used by the launch authority itself for stage separation.
One of the core systems of the service spacecraft is the inflation and separation system for the ballute spacecraft. For provision of the required amount of gas to inflate the ballute, two high-pressure gas bottles are filled with helium up to a pressure of 200 atm. Once the inflation process is initiated, the high-pressure gas is flowing through different valves and throttles in order to obtain a final pressure in the ballute of no more than 10 hPa.
The down-regulation from 200 atm to 10 hPa and at the same time providing a specific mass flow profile during the inflation process is quite a challenging task. In addition, it has to be realised, that this inflation system is essential for the success of the mission and should not pose a single point of failure. After the test of different options, the system as depicted in Figure 6 and Figure 7 has been selected.

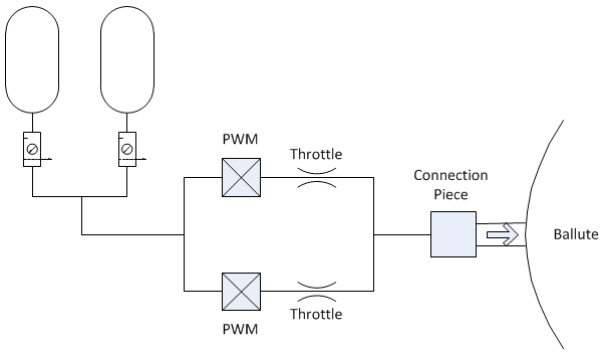

Fig. 6: Working principle of the inflation system.

Two parallel strings with magnetic valves, which are actuated via pulse-width-modulation (PWM), combined with two subsequent throttles allow a very precise regulation of the mass flow and inflation pressure. The profiles of the pulse width modulation of the two magnetic valves are selected in a way that even in case of failure of one magnetic valve a successful inflation of the ballute is still possible via the second string.
Once the inflation process is finished, the release of the ballute spacecraft is initiated. A special mechanism called "Blossom", which holds the ballute spacecraft and is opened already prior to inflation, now releases the ballute spacecraft by detaching the inflation hose from the connecting piece at the service spacecraft.

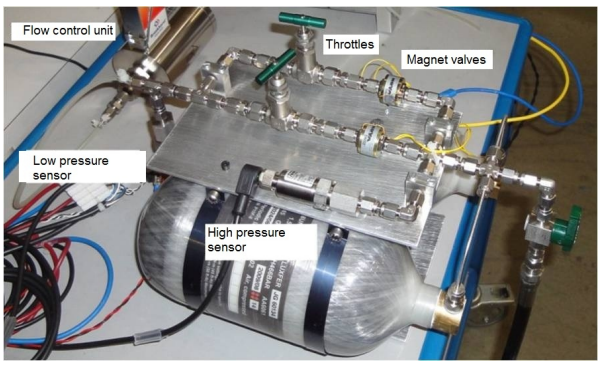

Fig. 7: Bread-board of inflation system during testing.

In order to ensure that no collision occurs during the following ballistic flight and re-entry phase, the service spacecraft activates after release of the ballute spacecraft a cold gas propulsion system (see Figure 8), which provides enough delta v to create a safe distance between ballute spacecraft and service spacecraft for the rest of the mission.

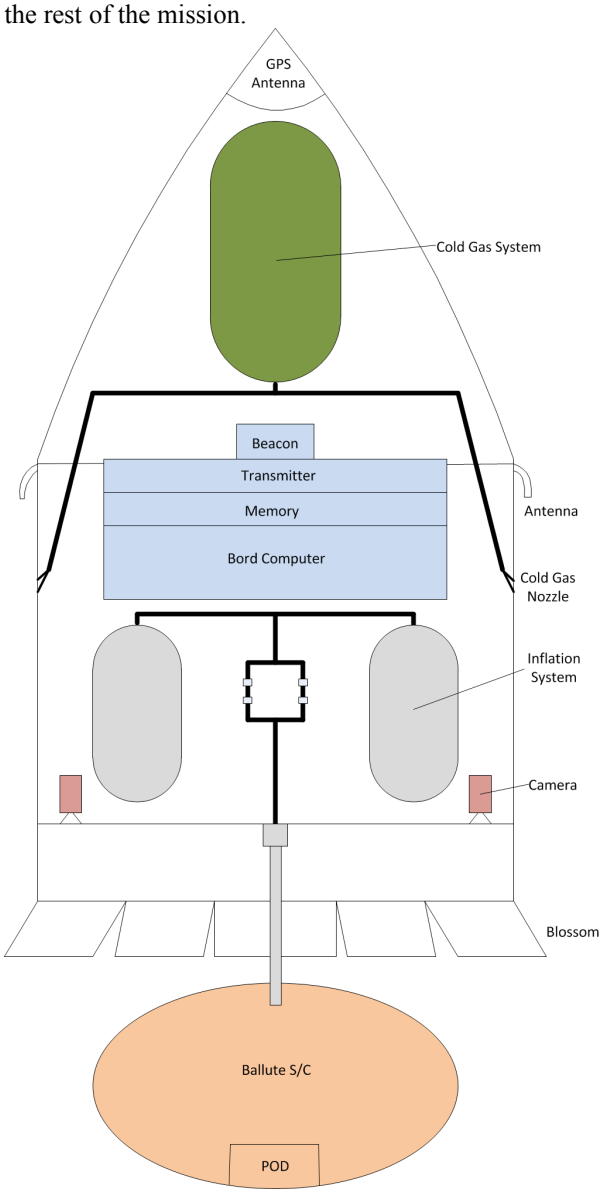

Fig. 8: Functional blocks of the Service Spacecraft.

For diagnostic purposes, the service spacecraft holds in addition several cameras to document the inflation process of the ballute. The signals of the cameras are partially stored on board and also directly sent to the ground station by S-band transmitters. During the entire flight relevant housekeeping data are transmitted via UHF to the ground station.
Even though the service spacecraft will crash into ground, it is expected that the on-board computer, and in particular the solid state memory board, will survive this and consequently a robust beacon is implemented, which will allow the localisation and recovery of the service spacecraft.

4 LAUNCH VEHICLE

The launch vehicle consists of a TAURUS motor as first stage and an ORION motor as a second stage (see Figure 9). This unguided solid propellant motor configuration has been launched at ESRANGE many years ago and will be re-qualified by DLR Mobile Rocket Base and the Swedish Space Corporation (SSC) in November 2012.
The Mobile Rocket Base, DLR has experience in launching sounding rockets over four decades. During their suborbital flight, sounding rockets reach altitudes of up to 1000 km depending on requirements. The majority of sounding rockets have been used for experiments which require exoatmospheric trajectories, as for example astronomy and micro-gravity experiments. Micro-gravity conditions are necessary for some technology, material science and biology experiments. In the past, sounding rockets have also been used for measurements in high atmosphere (mesosphere).

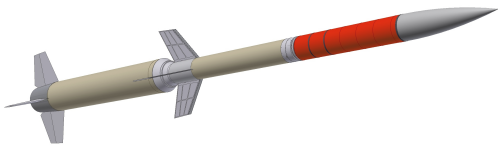

Fig. 9: The MIRIAM-2 vehicle has a TAURUS boost motor with an ORION second stage. The red section is the service and payload section. The MIRIAM-2 flight system composite will sit under the nose cone.

The payload is based on the modules with 356 mm diameter, which are also used in the REXUS project. The MIRIAM-2 vehicle's main payload consists of the motor configuration, a motor adapter, a recovery system, a service system and several experiment-modules including the MIRIAM-2 experiment.
The MIRIAM-2 launch vehicle implements the REXUS service system. This service-system can control the power supply and handles data communication and time event management of the scientific experiments. The REXUS service system has the capability to provide five experiments with 1 ampere at 28 volts and a serial data interface for up- and downlink. The service system provides GPS position and velocity data, 3-axis acceleration data and rotation rates from 3-axis rate gyros. A standard TV channel can be used by one experiment. More information on the REXUS service system can be found in [9].

The total lift-off mass of the MIRIAM-2 launch vehicle will be around 2000kg, of which 1800kg are contributed by the rocket motors and 155kg by the payload module including the scientific experiment equipment of around 90 kg (mostly the MIRIAM-2 spacecraft composite as shown in Figure 8).
Depending on the final payload mass the payload will reach an apogee of around 230 km, giving the MIRIAM-2 experiment a ballistic flight phase time of over 5 minutes above 100 km. This provides sufficient time to separate the different payload parts from the motor and to inflate the MIRIAM-2 ballute.

5 SELECTED PAYLOAD INSTRUMENTS

5.1 Accelerometer (AMS)

A system relatively slowly traversing the planetary atmosphere is an excellent opportunity to measure several static and dynamic parameters of that atmosphere, including gas density, particles, and wind velocities as functions of height. With a large area making the balloon very sensitive to winds and with the acceleration depending on the buoyancy and friction forces interplay, both these forces depending on the surrounding gas density, a descending balloon represents an excellent opportunity to perform indirect measurements on the atmospheric density and winds based on accelerations. Consequently, a consortium of partners from Romania, including the Technical University of Iasi, University of Pitesti and the Institute of Computer Science of the Romanian Academy proposed an acceleration measurement module and the related software for data processing as a component of the scientific instrumentation.
The main specifications of the system include a wide range of accelerations, from $10^{-5} m/s^2$ to $10^2 m/s^2$, and a resolution of 10 bits, with capabilities to remove noise for input SNR (signal to noise ratio) values as low as -20 dB. For this purpose, an adaptive module and an adaptive heuristic algorithm for data filtering were proposed and tested [10],[11]. The filter concept takes into account that the density of the atmosphere is increasing during the descent, implying a monotonic variation of acceleration, therefore favouring an approach based on the median-like filters. The filter is based on the properties of the median and the quantiles of a noisy, monotonically varying signal. Adapting the width of the filtering window during the descent according to the statistical properties of the signal and to a set of heuristic rules, the specifications were attained on surrogate data. While part of the processing of the raw data is performed on the module, a large part of the data filtering procedure remains to be done at the base station.

5.2 Ballute Interior Pressure (Atmos B)

The interior pressure of the balloon shall be measured using Barocap miniature pressure sensors. The complete Barocap sensor head and electronics transducer, ATMOS-B sensor unit, is a compact miniature sensor suite accommodating the pressure and housekeeping temperature sensors and required transducer electronics. Hardware consists of an electronics board (about 50 x 60 x 15 mm). Two Barocap sensor heads will be selected to cover pressure range from near vacuum to few hundred hPa or full atmospheric pressure (1000 hPa).
The Barocap pressure sensors have been developed by Vaisala for Vaisala environmental monitoring systems, barometers and atmospheric radio balloon sondes. Finnish Meteorological Institute has used Vaisala technology in several planetary missions: Mars -96, Mars Polar Lander ’99, Beagle-2 -03, Huygens Titan-lander (successful landing -05) and Phoenix ’07 Mars lander (successful landing on May -08). Mars Science Laboratory (launch 2011) will carry both pressure and humidity sensor systems as well as MetNet microlander (launch expected 2014 range).
The Miriam ATMOS-B instrument is a simplified version of the pressure, temperature and humidity instrument intented for the Archimedes balloon for Martian atmosphere. In addition for providing the ballute interior pressure in Miriam sounding rocket test in earth atmosphere, the Miriam test will provide a good opportunity to test the latest Barocap pressure sensors in flight-like conditions (launch, acceleration and shaking & vibrations of the sounding rocket) and thus obtain qualification experience for Archimedes and other future missions.
The expected pressure measurement performance of ATMOS-B will be (at low Martian atmosphere pressure range):
Resolution: 0.1 Pa, Repeatability: 0.5 Pa, Long term stability: 5…10 Pa.
The Archimedes ATMOS-B Science is especially concentrating to Planetary Boundary Layer. The atmospheric boundary layer (ABL) is often defined as that part of the atmosphere, which is directly influenced by the presence of the surface, and responds to surface forcings with a time scale of about an hour (e.g. Stull, 1981). The Martian ABL resembles the ABL in the deserts at the Earth due to the fact that in both cases the underlying surface is dry and the the soil surface consists of sand, rocks and dust.

5.3 Aerothermodynamics (COMPARE-M + PHLUX)

The sensor system COMPARE (COMbined Planetary entry And trajectory Rebuilding Experiment) is developed at the Institute of Space Systems of the University of Stuttgart for various entry mission scenarios. In combination with numerical tools it allows for the reconstruction of important trajectory parameters during flight. The application of COMPARE-M on MIRIAM-2 shown in Figure 10 will allow to further increase the Technology Readiness Level (TRL) of this sensor system with regard to upcoming re-entry missions with relative high entry velocities, e.g. ExoMars. The COMPARE-M experiment aims for the reconstruction of the total and ambient pressure, Mach number, velocity and the speed of sound of the re-entry as well as temperature distribution and heat flux at the Instrument Pod from which the specific enthalpy can be derived. A thermopile will record the radiation history which is expected to be only Albedo due to the low entry velocity of the MIRIAM-2 Ballute Spacecraft. But it still might contribute to the reconstruction of the tumbling rate due to relative high sampling rates of the detector. The development of the COMPARE sensor system is mainly based on previous experiences with already flight qualified sensor systems, e.g. RESPECT [12] for the ESA mission EXPERT and COMPARE for the SHEFEX II mission of DLR.

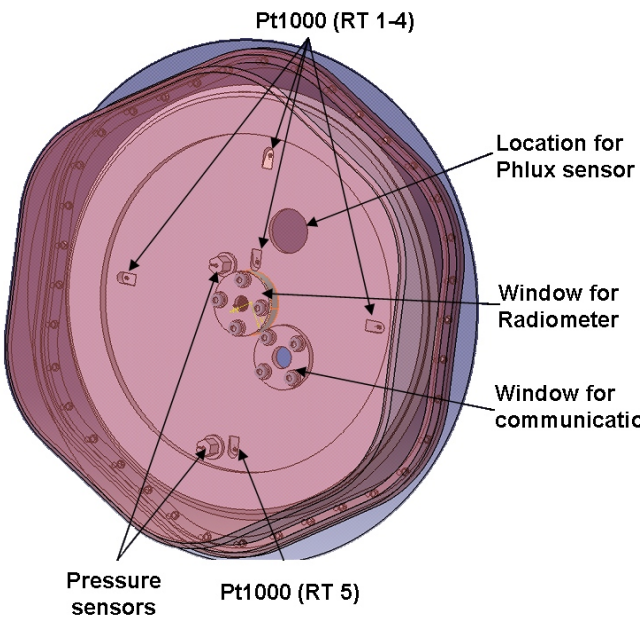

Fig. 10: Compare-M sensor distribution at the ballute pod.

Both of the aforementioned missions are planned to be flown within the next 12 months. The COMPARE system used for the suborbital re-entry mission SHEFEX II [13] of the German Aerospace Centre employs a pyrometer, a thermopile and a pressure detector.

For the MIRIAM 2 mission, significant modifications regarding the design were necessary, as for example the sensor unit is completely omitted and the electronics are integrated in the vehicle data handling system. Furthermore, Pt1000 detectors are used instead of a pyrometer system.

The sensor system COMPARE is particularly distinguished by the low mass, low power requirement and the relatively low complexity of the system.

The PHLUX sensor (see Figure 11) measures the time resolved atomic oxygen concentration in the atmosphere [14]. It was developed for ESA's re-entry capsule EXPERT. Its principle is based on the temperature measurements of two different materials that have different but known catalytic properties with respect to the recombination of atomic species in the re-entry plasma. Therefore, the materials experience different heat fluxes leading to different surface temperatures in the same flow conditions. The overall system response depends, of course, also on the thermophysical properties such as the emissivities of the materials.

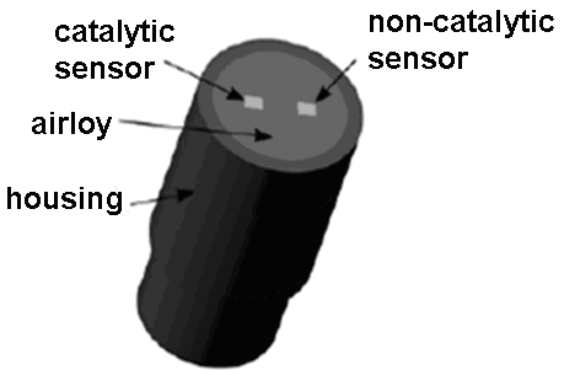

Fig. 11: PHLUX sensor head.

On high catalytic materials e.g., the number of recombination reactions of atomic species to molecules of the surrounding gas is much higher than on non-catalytic materials. The measured heat flux is therefore increased, i.e. in addition to convective and radiative heat flux, resulting from the release of chemical binding energy to the catalyst. By combining high and low catalytic material samples, the convective and chemical part of the total heat flow can be separated from each other based on the measured temperature difference on both samples. This measured temperature difference, or more precisely, the differing heat fluxes are, therefore, a measure of the amount of dissociated species. For the planned mission the dissociation degree of the oxygen is expected to be significant

while the dissociation of nitrogen is likely to be very low. Making use of the IRS CFD code URANUS may enable to derive important information on the energy accommodation as the ballute will presumably be in rather high altitudes over a significant period of time [15].

5.4 Magnetometer MIRIMAG

The magnetic field of the Earth offers the opportunity to reconstruct the orientation of the ballute as it reenters the atmosphere. Furthermore, an interesting transient event, such as e.g. a magnetospheric substorm, which produces the polar lights, might occur during the MIRIAM-2 experiment. The magnetic field at the ballute will be measured with a low-noise, digital and triaxial fluxgate magnetometer MIRIMAG (see Figure 12) of the Institute of Geophysics and extraterrestrial Physics of the Technical University of Braunschweig. These magnetometers have a long heritage in several space missions, e.g. CLUSTER, THEMIS or ROSETTA. The magnetometer relies on the well-known fluxgate measurement principle.
The magnetometer will be calibrated on ground using the IABG facilities in Munich and partially in space [16]. The magnetic measurements allow to reconstruct the attitude of the probe with respect to a rotation axis perpendicular to the nominal magnetic field. Since the position of the probe is known with high precision from the on-board GPS experiment, we can calculate the nominal magnetic field using the well-known International GeoReference Field (IGRF) for the planetary part and for the magnetospheric part the semi-empirical model of Tsyganenko [17], which is based on satellite data of several missions. Chances are that we also monitor a transient event like a magnetospheric substorm or other magnetospheric disturbances. Then our magnetic field data can be put into the framework with other continuously monitoring stations on ground and in space. Eventually, for the measurements at the ARCHIMEDES probe at Mars, the planetary magnetic field is more an unknown factor and of special interest to the planetary sciences. Mars does not maintain a strong dipole field like the Earth but remnant crustal magnetizations distributed mainly over the southern hemisphere. The origin of these magnetization is yet unknown, but is most likely the result of an ancient Martian dynamo process within the liquid part of the core. Some hypotheses exist on how an ancient Martian dynamo ceased to exist (cf. [18] for an overview) and left over these magnetizations. In order to further test the theoretical models, an improved knowledge of the Martian crustal magnetizations is necessary. The resolution of the magnetized surface areas equals approximately the altitude of the magnetometer above the surface. Several missions already measured the magnetic field of Mars such as Mars Global Surveyor or Mars Express. Up to date, there were no rovers on Mars which measured the magnetic field. In order to cover a larger area close to the surface, which would be required to measure smaller scale magnetic structures, a ballute like ARCHIMEDES is one of the most suitable approaches.
The inclusion of MIRIMAG on board MIRIAM-2 therefore not only serves as an important instrument to reconstruct the vehicle attitude, but also flight tests obtaining an areal magnetometric survey with a ballute spacecraft.

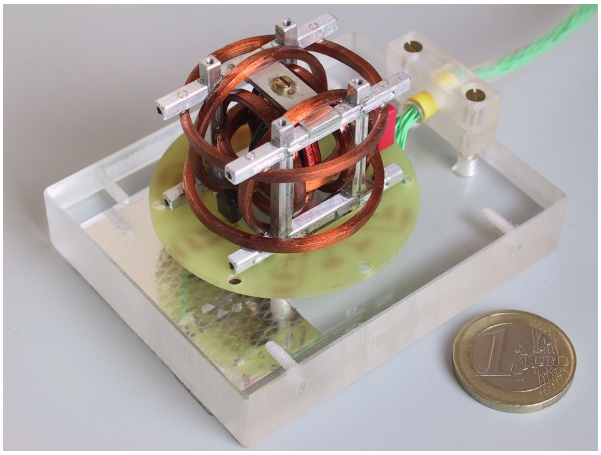

Fig. 12: Photograph of the magnetometer sensor, compensation and pick-up coils.

6 CONCLUSION AND OUTLOOK

The flight test system MIRIAM-2 is a significant improvement over our previous attempt MIRIAM-1, incorporating not only lessons learned but also new technologies that have not been available for MIRIAM-1, such as miniature HDTV observation cameras and a miniature space-grade GPS receiver.
MIRIAM-2 therefore promises to deliver the flight data required to advance the technology readiness level of the design described herein, but also to advance the ballute knowledge in general and to provide, for the first time, real world flight data of a vehicle with such a low ballistic coefficient.

7 REFERENCES

[1] Grieger,B., et al.,, "*The ARCHIMEDES Mission Science Proposal*", MPI Lindau, 2005

[2] H.S.Griebel, "*Methoden der Ballonentfaltung auf dem Mars Konzepte zur praktischen Durchführungund Versuchsanordnungen zu deren Erprobung RT-DA 03/01*", Technical University of Munich, 2002

[3] H.Griebel, "*Reaching High Altitudes on Mars with an Inflatable Hypersonic Drag Balloon (Ballute)*", Vieweg+Teubner, Springer Fachmedien, 2011, ISBN978-3-8348-1425-8

[4] K.Sutton, R.A.Graves jr., "*A General Stagnation-Point Convective-Heating Equation for Arbitrary Gas Mixtures*", , 1971

[5] L.Roscher, "*Aerothermodynamische Analyse des Wiedereintritts für das Höhenforschungsraketenexperiment MIRIAM*", Institut für Thermodynamik, Universität der Bundeswehr München, 2008

[6] Ch. Mundt, R.R. Boyce, E.H. Hirschel, "*Simulation of hypersonic, reacting flow around reentry bodies - Comparisons of numerical and experimental results*", Z. Flugwiss. Weltraumforsch, Bd. 19, pp.492-501, 1995, ISBN

[7] Ch. Mundt, R. Keraus, J. Fischer, "*New, accurate, vectorized approximations of state surfaces for the thermodynamic and transport properties of equilibrium air,*", Z. Flugwiss. Weltraumforsch, Bd. 15, pp.179-185, 1995, ISBN

[8] M. Starkloff, Ch. Mundt, "*Accurate interpolation of state surfaces for the rhermodynamic properties of equilibrium carbon dioxide – nitrogen atmospheres and their implementation in a coupled Euler – boundary layer method*", 3rd Int. ARA conference AA 1-2011-37, 2011

[9] J. Ettl, M. Pinzer, "*Principle Design of the Service Module of REXUS*", 19th ESA PAC Symposium, 2009

[10] Teodorescu, H.-N., "*An Adaptive Heuristic Filter for Acceleration Measurements in Planetary Atmospheres*", First NASA/ESA Conference on Adaptive Hardware and Systems. 15-18 June, , 2006

[11] Teodorescu, H.-N. Hagan, M., "*High Accuracy Acceleration Measuring Modules with Improved Signal Processing Capabilities.*", IEEE Workshop on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, 2007. IDAACS 2007. 6-8 Sept. 2007 , 2007

[12] Herdrich, G., Fertig, M., Lein, S., Löhle, S., Preci, A., Steinbeck, A., Wernitz, R., Auweter-Kurtz, M., Röser, H.-P., "*Current Status of Instrumentation Developments at IRS: In-Situ Investigations and Airborne Measurement Campaigns*", Acta Astronautica, 66(7-8), 1087-1098,

[13] A. Preci, G. Herdrich, M. Gräßlin, H.-P. Röser, M. Auweter-Kurtz, "*COMPARE, a combined sensor systems for re-entry missions*", Proceedings of the 26th International Symposium on Shock Waves, 559-564, Springer, 2009, ISBN978-3-540-85167-7

[14] S. Fasoulas, S. Loehle, A. Steinbeck, M. Eberhart, "*Atomic Oxygen Sensor Systems aiming in Flight Measurements on a sounding Rocket*", 20. ESA-Symposium European Rocket and Balloon Programmes and Related Research, 2011

[15] M. Fertig, S. Schäff, G. Herdrich, and M. Auweter-Kurtz, "*Influence of Chemical Accommodation on Re-entry Heating and Plasma Wind Tunnel Experiments*", AIAA 2006-3816, 9th AIAA/ASME Joint Thermophysics and Heat Transfer Conference, 2011

[16] Auster, H.-U., et al., "*Calibration of flux-gate magnetometers using relative motion*", Measurement Science and Technology, 13, p. 1124-1131, 2002

[17] Tsyganenko, N. A., and Sitnow, M. I., "*Modeling the dynamics of the inner magnetosphere during strong geomagnetic storms*", Journal of Geophysical Research, 110, A03208, 2005

[18] Stanley, S., and Glatzmaier, G. A., "*Dynamo models for planets other than Earth*", Space Sci. Rev.,, 152, p. 617-640, 2010