THE HYPERSONIC DRAG BALLOON ARCHIMEDES AND ITS RESEARCH AND TESTING PROGRAM

H.S.Griebel (1)(5), B.Häusler (1), C.Mundt (2), H.Rapp (3), H.J.Gudladt (4)

(1) Institut für Raumfahrttechnik, (2) Institut für Thermodynamik, (3) Institut für Leichtbau, (4) Institut für Werkstoffkunde, (5) Mars Society Deutschland e.V.

Universität der Bundeswehr München
Werner-Heisenberg-Weg 39
85577 Neubiberg
GERMANY

OVERVIEW

ARCHIMEDES is an effort to probe the atmosphere of planet Mars by means of a hypersonic drag balloon, a device commonly referred to as a “ballute”. The project is currently under study, proposed and supported by the Mars Society Germany, the Universität der Bundeswehr München, the AMSAT-DL .e.V. organization, the DLR, and several other research institutions and industrial companies. The probe is planned to be integrated into the AMSAT’s P5-A Mars satellite, and to be released from the spacecraft when in orbit around the planet. Launch for the probe is currently planned for 2011 as a piggyback payload on an Ariane V rocket, as it is standard practice for spacecraft of the German AMSAT section.

1. ARCHIMEDES MISSION

1.1. Mission and Mission Goals

The scientific scope of project ARCHIMEDES involves in situ measurements in the Martian atmosphere throughout almost the entire altitude range reaching from outer space to ground. [1]

An important goal of the project is also to demonstrate and qualify the ballute (balloon and parachute) technology for entry into planetary atmospheres at high velocities – typically occurring in the solar system- on a representative mission [2],[3]. The term “ballute” was first used by the Goodyear Aerospace Corporation when the pioneered the technology for NASA back in the 1960s. Although an actual flight test was never performed, data gained during their extensive testing program [4] can still be used today in the design phase of ARCHIMEDES.

1.2. Flight System Elements

The mission has three major flight system elements: The AMSAT P5-A Mars orbiting satellite, the Joint AMSAT-Archimedes Propulsion System JPS, and the ballute system ARCHIMEDES. (see FIG 1).

ARCHIMEDES rides in a container which is part of the balloon deployment system mounted inside the central structural core of the JPS. The JPS houses the cruise propellant tanks, the ARCHIMEDES gas storage and inflation system (IGSS) and the 400-N cruise engine. The P5-A satellite contains the solar arrays and power system, a 2-m dish high gain antenna (HGA) and an array of low gain omni antennas (LGA). It also contains the reaction control system (RCS), attitude control system and navigation and telecom subsystems.

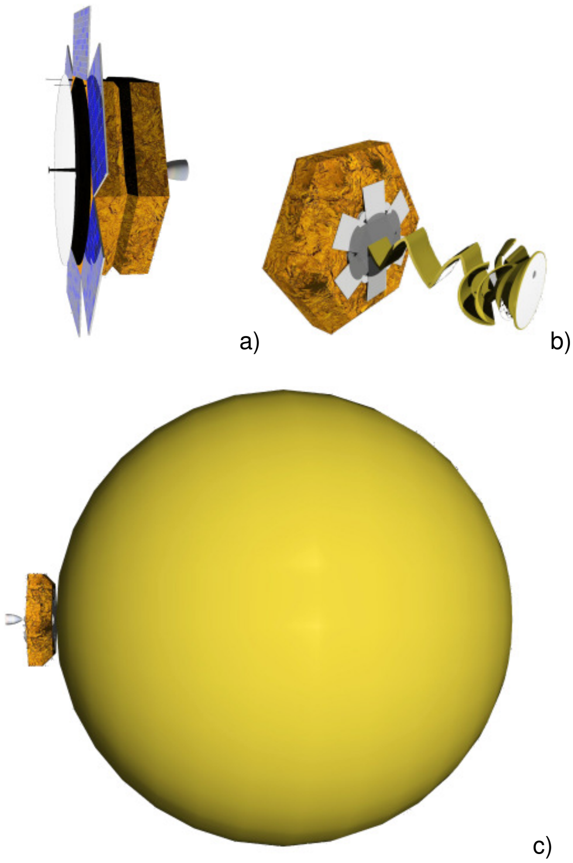


FIG 1. a) The AMSAT P5/A in cruise configuration. b) The ARCHIMEDES vehicle being deployed from the Joint Propulsion System Module (JPS). c) ARCHIMEDES fully inflated with the JPS module still attached to the North pole.

Total projected Earth orbit injection mass is 650kg, of which 110 kg are the orbiter. ARCHIMEDES accounts for 66 kg including the 34 kg flight system plus 32 kg inflation and packaging systems.

1.2.1. The ARCHIMEDES Spacecraft

A ballute is considered favourable for the given mission profile because a big and light weight inflatable configuration offers a very low ballistic coefficient. This results in a deceleration to subsonic speeds at altitudes greatly above the transition altitudes of conventional entry bodies. Even in the hypersonic flight regime, the craft is expected to heat up less than ordinary capsules, allowing measurements which would otherwise not be possible [3][5][6]. The ARCHIMEDES ballute is foreseen to be a Helium-inflated sphere of 10m diameter made of high temperature resistant thin-film material, carrying a 4.5 kg instrument pod with a nose cover assembly of 10kg, clamped to one of its poles. The total atmospheric entry mass of the ARCHIMEDES vehicle will be approximately 34 kg.

1.2.2. Payload Instruments

The payload foreseen for ARCHIMEDES is reflected in the mission name, which forms an abbreviation for “Aerial Robot Carrying High-resolution Imaging, a Magnetometer Experiment and Direct Environmental Sensors”. Hence, the primary payload constitutes a high resolution camera suggested by the DLR centre for planetary exploration Berlin, a magnetometer experiment provided jointly by the IGEP institute of the technical university of Braunschweig and the private company MAGSON of Berlin, and the so called ATMOS-B weather sensor suite provided by the Finnish Meteorological Institute (FMI) of Helsinki. Additionally, a pyrolytic compression wave temperature experiment by the IRS institute of the Technical University of Stuttgart and a high sensitivity accelerometer built jointly by the technical universities of Iasi and Pitesti in Romania are foreseen to ride in the nose cover assembly, which will be jettisoned after the transition to subsonic speeds.

To augment the science return of the mission, a low weight low power radar altimeter is currently under development for ARCHIMEDES which will give altitude accuracy between 1 and 10 meters for a range of up to 100km. The validation of this altimeter will be part of the flight test program for 2008 (see 2.3).

1.2.3. Balloon Deployment System

Proper packaging of the balloon is an important issue. Further, the balloon deployment system must guarantee the controlled unfolding of the balloon in space to minimize the risk of damage while the inflation is under way.

Because of reliability aspects a simple design was chosen for the deployment system. The packed ballute is held by a container which is self-opening by using a spring-loaded mechanism. It is clamped to the spacecraft by an attachment ring. The side panels of the container rest against the inner wall of the spacecraft and are kept on distance by Teflon® gliders to prevent jamming with the spacecraft structure. As soon as the ring is unlocked the springs will accelerate the box and the side panels will open automatically while the box is emerging from the spacecraft. Eventually the box is held back by retention wires, but the balloon package will continue its motion with a speed of approximately 1 m/s, which is sufficient to ensure a proper unfolding of the balloon.

1.3. Mission Sequence

The JPS provides propulsion for all manoeuvres from injection into Earth transfer and escape orbits, into Mars capture orbit until the deployment of ARCHIMEDES. The JPS will also function as a self-contained spacecraft once detached from the satellite, running on internal primary batteries for all orbit manoeuvres required to bring ARCHIMEDES onto its correct approach trajectory and the subsequent deployment and inflation of the balloon. Once this has been accomplished, the JPS uses cold gas thrusters to separate from ARCHIMEDES and discard itself.

When detached from the empty JPS, the P5-A satellite will depend on its RCS for orbit maintenance around Mars. It will act as a telecommunication relay satellite for ARCHIMEDES and later for other missions.

2. DEVELOPMENT AND TESTING PROGRAM

The Archimedes project is carried out solely by research institutes and private, non-profit organisations. Therefore the development and testing program has to adapt to a unique environment. At the same time it has to demonstrate the flight readiness levels of all major elements [7]. The ARCHIMEDES development and testing program is grouped in three major sub-programs, all conducted by individual institutes and teams: ARCHYFLOW, ARCHIMATTER and CLEOPATRA. These programs are outlined hereafter.

2.1. Flight Dynamics Analysis Program

All research activities related to flight dynamics, aerodynamics and thermodynamics are grouped under the ARCHYFLOW program, which stands for ARCHIMEDES Hypersonic Flight and Low speed descent. Most recently, 3D analyses of the aerothermodynamic behaviour during hypersonic flight were conducted, which involve the investigation of several trajectory points, investigations of aeroelastic effects and the confirmation of similarity laws concerning heat loads.

2.1.1. Trajectory

To prolong measurement time in the upper atmosphere, it is foreseen that the spacecraft will enter the atmosphere of planet Mars consecutively multiple times until it has lost enough speed to remain within the atmosphere for a final descent towards the ground. To prolong the descent time and therefore the measurement time in the lower atmosphere, the balloon is filled with Helium, which adds static lift to aerodynamic drag. Thereby, continuous measurement times of several hours ranging from the outermost atmosphere layers down to the ground are possible. The trajectory is simulated by a full 6-DOF trajectory integration [10][11] using the simplified aerothermodynamic heating model of Sutton & Graves [8] and the European Mars Climate Database (MCD) as a global atmosphere model [9].

The actual mission elapsed time and number of atmospheric entries have been determined by performing an error analysis and by studying “shallow”, “nominal” and “steep” cases for a refined entry trajectory simulation of a “normal” (34 kg entry mass) and “heavy” (65 kg entry mass) spacecraft. In a “heavy” and “shallow” case, the given spacecraft will enter the atmosphere up to 8 times before final descent, while in a “normal” and “steep” case the system will decelerate directly onto its decent trajectory without any further orbit revolution. The nominal case is a 2-entry mission, where the first entry into the atmosphere lowers the apocentre and the second entry leads to the final descent.

The results of the trajectory simulation for the nominal 2-entry “heavy” mission scenario are given as an example in tables TAB 1 and TAB 2, because these yield the highest possible balloon skin loads.

Orbit Number	*1*
Deceleration	*0.43g*
Time from Entry	*6h 34m 01s*
Altitue over Areoid	*90.5 km*
Flow Velocity	*4195 m/s*
Mach Number	*22.4*
Convective Heating	*4525 W/m^2*
Radiation Equilibrium	
Stagnation Point Temp.	*589 K*

TAB 1. Point of maximum heating in the nominal mission scenario.

Orbit Number	*2*
Maximum Deceleration	*1.73 g*
Time from Entry	*9h 18m 40s*
Altitue over Areoid	*55.2 km*
Flow Velocity	*1062 m/s*
Mach Number	*5.3*
Convective Heating	*563.6 W/m^2*
Radiation Equilibrium	
Stagnation Point Temp.	*354 K*

TAB 2. Point of maximum deceleration in the nominal mission scenario.

The trajectory simulation of these scenarios were used as input parameters to the CFD analysis (see 2.1.2), the results of which were then fed into a NASTRAN/PATRAN model [11] and a detailed thermal model [12] to determine design requirements for the balloon body (see 2.2) and other system parameters (such as power consumption, radio range and component thermal requirements).

2.1.2. Aerothermodynamics

In the framework of the ARCHYLOW program we performed further aerothermodynamical analyses to improve the knowledge about the loads and the dynamic behaviour of the balloon, allowing us to cope with unavoidable changes of the ballute trajectory.

Two reference points were selected for the analyses: the point of the trajectory where maximum stagnation point temperature occurs, determined as the radiation adiabatic temperature by a model [5] based on [8], and the trajectory point of maximum deceleration (see 2.1.1).

The CFD-work was performed using the CEVCATS-N code [13] which solves the Navier-Stokes equations together with models for thermochemical nonequilibrium on structured meshes applying a finite volume scheme and shock capturing. For the point of maximum thermal load a stagnation point temperature of some 480K is determined, which is lower than the expected temperature from the approximation of some 590K (see FIG 2 and FIG 3). The temperature curve along the balloon surface shows the usual drop. At the location of maximal mechanical load, the stagnation point temperature has fallen already to some 300K. For this case the anomaly of having a constant temperature level for quite an extended region on the balloon surface is found, which needs investigation and is explained up to now by numerical problems.

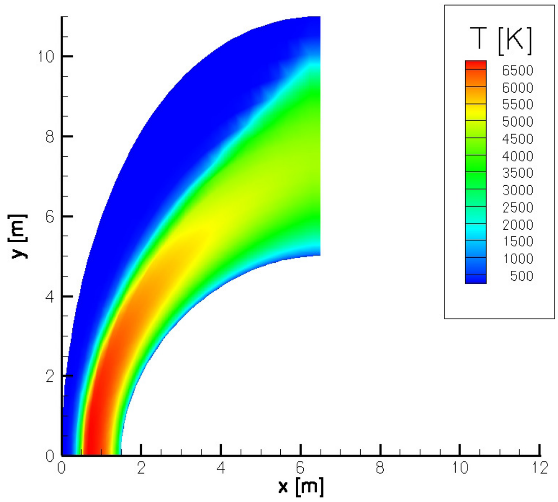


FIG 2. Temperature distribution in the flow field around ARCHIMEDES at the point of maximum heating as simulated by CEVCATS-N.

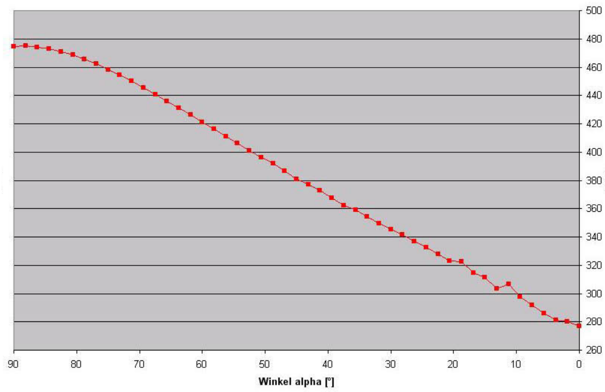


FIG 3. Temperature distribution on the ballute skin of ARCHIMEDES at the point of maximum heating as simulated by CEVCATS-N. 90° is the pole of the sphere (corresponding to the nose of the vehicle) and 0° its equator (corresponding to the shoulder). A south-pole-forward attitude is assumed for this simulation.

However, for the two trajectory points a similarity law for the scaling of radiation adiabatic temperatures [14],[15] was used and checked against its applicability in this regime.

The similarity law covers the general situation including turbulent boundary layers, different emissivity coefficients etc., and the reader is referred to the references [14],[15]. In our case however, with identical spacecraft reference lengths and the coefficients of emissions assumed constant, a relation is obtained depending only on recovery temperature T_r, radiation adiabatic temperature T_{ra} and Reynolds number Re:

$$\frac{T_{ra1}}{T_{ra2}} = \left(\sqrt{\frac{\mathrm{Re}_{ref1}}{\mathrm{Re}_{ref2}}} \frac{T_{r1}}{T_{r2}} \frac{(1 - T_{ra1}/T_{r1})}{(1 - T_{ra2}/T_{r2})} \right)^{\frac{1}{4}} \quad (1)$$

This similarity holds well with a deviation of approx. 4%.

Up to now, the balloon was considered to be a perfect sphere. Whether the mechanical and thermal loads encountered during entry lead to a deformation worth considering remains to be finally validated. A preliminary analysis was done using a finite element model. The analysis included as well the changes in internal pressure due to changes of the temperature of the He-gas as the external pressure field acting on the Archimedes ballute with its inertia. The results obtained from PATRAN/NASTRAN [16] showed a maximum change in contour of the order of 1% of the diameter indicating that the assumption of a sphere is justified [17].

2.2. Material Analysis Program

To resist high pressure and temperature during hypersonic flight the ballute has to be made of a high temperature resistant thin-film material or a laminate thereof. Such materials are tested under the testing program ARCHIMATTER, which stands for ARCHIMEDES Material Testing and Research. It involves testing of candidate materials under conditions which are expected for the mission. Program ARCHIMATTER is also targeted at exploring seaming and production techniques, including the development and testing of high strength high temperature resistant adhesive tapes.

2.2.1. Material Selection

In order to resist gradients in pressure and temperature that are characteristic for the Mars landing program the choice of material has been concentrated on two polymers named "UPILEX® S and RN", respectively. This thermoplastic material (polyimide) is well known for good mechanical properties at elevated temperatures. For polymeric materials energy elastic behaviour, as it is characteristic for metallic materials can be expected below the glass transition temperature, T_g. Consequently, the ultimate mission temperature should be lower than T_g. In case of UPILEX RN and S, T_g was expected to be 558 and 632 K, respectively. Taking model calculations into account, FIG 4 shows that 470 K may be the ultimate temperature for the balloon skin. Consequently, both polyimide can be used in the energy elastic region, e.g. below T_g.

2.2.2. Material Testing

Besides T_g, the storage and loss moduli, E', E'', have to be determined as a function of the temperature and the load frequency, f [18]. Especially the "stiffness" that corresponds to E' has to be investigated in detail. Both moduli were measured by a mechanic dynamical analyzer Q 800 from TA Instruments (DMA). In FIG 4 and FIG 5 the storage and loss moduli for UPILEX S and RN were plotted against the temperature, respectively. At first, for a given frequency of 1 Hz, T_g can be determined from the loss modulus. The second peak of this modulus is characteristic to Tg and was calculated to be 591 K and 527 K, respectively. Up to this temperature, the stiffness decreases from 8.5 to 2.5 GPa for UPILEX S and from 4.0 to 1.5 GPa for UPILEX RN, respectively. Consequently, with respect to stiffness the candidate S seems to be the best choice.

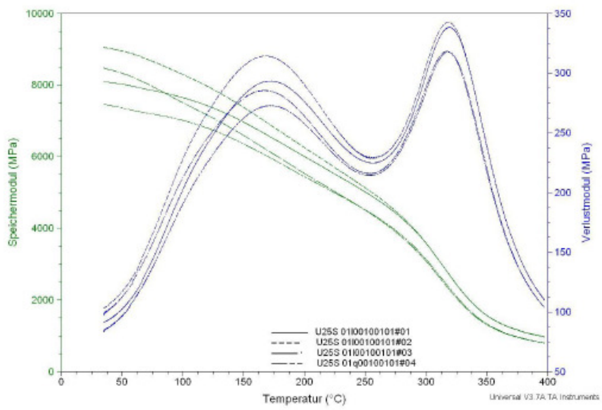


FIG 4. Temperature dependence of the storage (left hand side) and the loss (right hand side) modulus at 1 Hz for UPILEX S. T_g is represented by the second peak of the loss modulus.

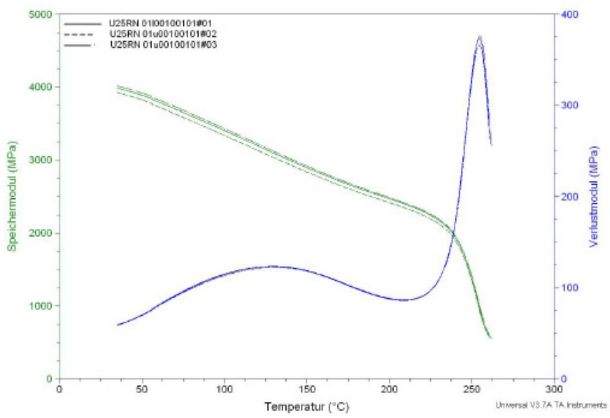


FIG 5. Temperature dependence of the storage (left hand side) and the loss (right hand side) modulus at 1 Hz for UPILEX RN. T_g is represented by the second peak of the loss modulus.

On the other hand, aside from permanent pressure resulting from the He gas, the balloon skin has to resist resonance effects. The latter affect the balloon size and, consequently, the pressure. This indicates periodic differences of the stress during the mission that can be simulated by fatigue experiments (S-N tests). At first, the characteristic frequency has to be calculated. It depends on the balloon diameter, as well as the storage modulus and, therefore, on the skin temperature. First calculations have shown that frequencies of 50 Hz may be taken into account for the mission [19]. Consequently, the mission time can be transferred into a characteristic number of load cycles N_c. For a successful mission, the cyclic live time N_f must be greater than N_c. The corresponding S-N tests undertaken with UPILEX S at 523 K and an amplitude of 25 MPa in skin stress have shown that the test specimen survive $5 \cdot 10^5$ cycles with a very high probability. In case of UPILEX RN, however, all tested specimens survive only $3 \cdot 10^5$ cycles at temperatures below 473 K. Again, UPILEX S seems to be the best choice for the balloon skin. In a next step, bonded structures of UPILEX will be mechanically tested prior to manufacturing the balloon.

2.3. Flight Testing Program

The flight and operations testing activities are carried out in the program CLEOPATRA. Tests in the past involved most notably a large scale deployment test done at the Olympia Hall in Munich, a parabolic flight test done on ESA's 40th parabolic flight campaign, and the in-space deployment test REGINA carried out with a miniature spacecraft launched on a ballistic sounding rocket from ESRANGE. During these tests, the principal concepts of ejecting the ballute could be verified.

Program CLEOPATRA will culminate in the in-space inflation and entry test MIRIAM. MIRIAM will test the complete mission scenario for the first time.

2.3.1. Parabolic Flight Testing

During the 40th ESA parabolic flight campaign a 1:2 scaled model of the ARCHIMEDES deployment system outlined in chapter 1.2.3 was verified.

The deployment system was designed, manufactured and qualified using facilities of the University of the Bundeswehr in Munich, Germany. By using servo-mechanic locks it was possible to recreate starting conditions with a folded, packed and locked balloon package in less than 50s after deployment which allowed excessive testing during the campaign. All test objectives were met, the reliability of the deployment system was found to be 94,6%.

2.3.2. In-Space Deployment Test REGINA

In spring 2006 a modified deployment system was tested with a REXUS rocket (project REGINA). Parallel to the improvement of already tested structural components the deployment system was enhanced to further improve reliability. A second mechanism was developed and implemented to separate REGINA from the REXUS rocket. For evaluation of the separation and deployment process a camera module was integrated in the REXUS rocket. After finishing the manufacturing process REGINA underwent excessive structural, dynamic and vacuum tests in order to guarantee complete conformance with sounding rocket flight specifications.

REGINA was flown on April 5th, 2006 and the balloon was deployed successfully.

2.3.3. Mission Flight Test MIRIAM

The next step in the development of ARCHIMEDES is the spaceflight test MIRIAM. Based on the architecture of REGINA, MIRIAM will not only be deployed, but also inflated. The inflation system will then be discarded and MIRIAM will enter the atmosphere with a fully instrumented pod carrying payload similar or identical to that on ARCHIMEDES (see FIG 7).

MIRIAM will not only test the deployment mechanism, but also the inflation process, the balloon behaviour and the high speed entry into the atmosphere on a ballistic trajectory. Performing trajectory- and CFD analyses for MIRIAM and comparing them with flight data will hopefully validate the theoretical models [20].

The spaceflight system consists of 3 major elements:

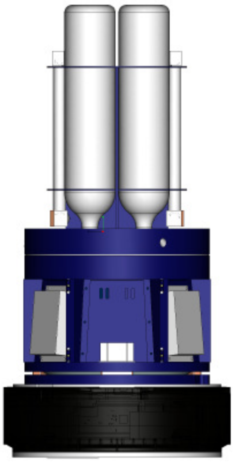
- The MIRIAM spacecraft which comprises an instrumented pod and the helium-filled hypersonic drag balloon.
  As stated above, MRIAM's pod instrumentation already closely resembles that of ARCHIMEDES, but purely for flight analysis purposes. The FMI-provided ATMOS-B pressure sensor is installed inside the balloon. The magnetometer for MIRIAM (MiriMag) is contributed by the IGEP institute and MAGSON. Paired with an optical still image camera it will yield attitude information. The still image camera though is a commercially available low resolution unit which can be integrated cheaply and easily and is sufficient for an occasional attitude fix in combination with the other sensors. A suite of two different sets of accelerometers built by the ARCHIMEDES team and the universities in Iasi and Pitesti, Romania will give deceleration and roll rate information.

- The Service Module (SM) integrates the functionality of the JPS and contains the inflation system, structural box, release mechanism, telemetry and a life television subsystem. It also contains a set of cold gas thrusters connected to the balloon inflation system tanks. These thrusters are used to pull the Service Module away from Miriam after inflation.

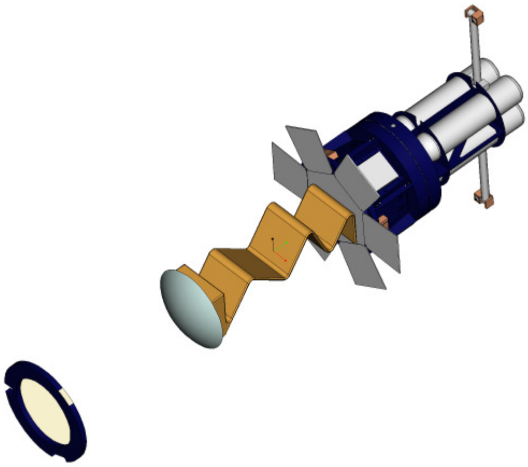
- The Camera Module which will remain attached to the rocket. It will document the release and operation of the SM/Miriam system, as well as provide the structural interface between the MIRIAM flight system stack and the REXUS payload section. The camera module will also house the release mechanism for the Service Module / Miriam combined system.

All three elements combined form the MIRIAM Flight System Stack (see FIG 6).

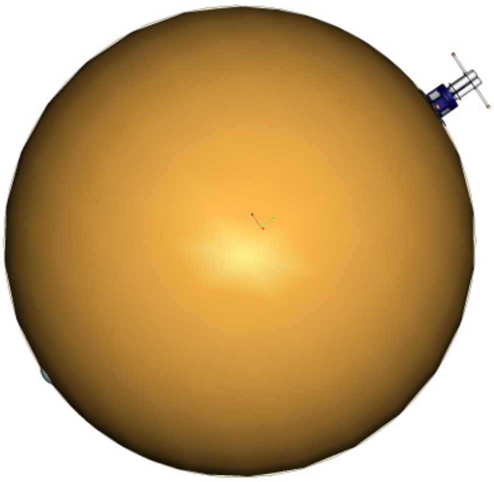
MIRIAM is currently prepared for a March 2008 launch from ESRANGE near Kiruna, Sweden on top of the REXUS4 two-stage ballistic sounding rocket.



a)

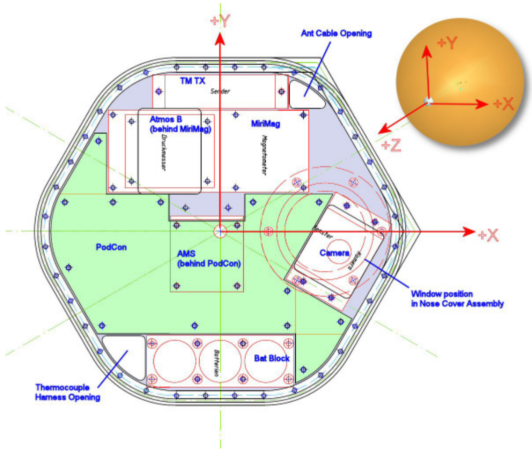


b)

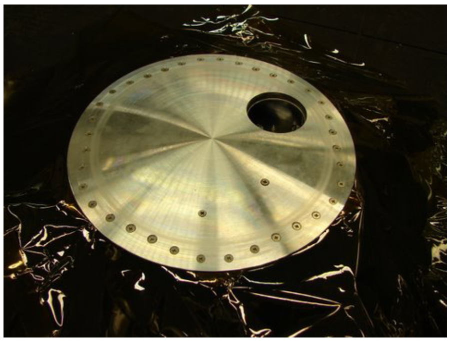


c)

FIG 6. The MIRIAM mission sequence and elements: a) the MIRIAM flight system stack, b) the deployment and c) the inflation of the Miriam spacecraft (the actual ballute).



a)



b)

FIG 7. Miriam's instrument pod: a) layout and instrument positions and b) engineering prototype. Note the camera window opening. The green area labelled "PodCon" represents the instrument pod's flight sequence control computer.

2.3.4. Altimetry Experiment RAPHAELA

The integration and operation of a new type of low power radar altimeter into the instrument pod of ARCHIMEDES would greatly enhance the scientific value of data collected, but was previously unavailable with respect to the stringent mass and power restrictions on board ARCHIMEDES. These requirements specify a total system mass of no more than 200g and a total power consumption of no more than 500mW, while giving a range accuracy of 10m or better for a maximum range of 100km.

Such a unit is currently developed by an ARCHIMEDES team member under a German research contract. However, the newly developed unit must be tested in a representative environment with representative ground clearance.

The name of the mission is RAPHAELA, forming an abbreviation for: „Radar And Photographic Altimetry Experiment for Low-power Applications". This test is flown prior to the flight of Miriam, and uses the same pod and ground hardware. In fact, Miriam's Engineering Model will be used for RAPHAELA, including the same flight computer, telemetry subsystem and camera, adding only a bigger battery pack, the reference GPS receiver and the newly developed radar altimeter [21].

Further to the radar altimetry test, methods of determining altitude by analyzing photographic images acquired in flight are explored and checked against the GPS reference data as well.

3. PROJECT TEAM

3.1. Spacecraft Development Team

Aside from the scientific instrument teams already mentioned (see 1.2.2), project ARCHIMEDES currently has the following institutions actively supporting the development effort:

- The Mars Society Germany (Mars Society Deutschland e.V.)
- The Institute of Space Technology, UniBw München
- The Institute of Lightweight Structures, UniBw München
- The Institute of Thermodynamics, UniBw München
- The Institute of Material Sciences, UniBw München
- The Institute of Photogrammetry and Mapping, UniBw München
- The Institute of Spaceflight, University of Applied Sciences, Bremen

Project ARCHIMEDES is specifically tailored to include students of various majors in an effort to foster education in a real space project and to motivate young people to pursue careers in the aerospace engineering and science.

3.2. Acknowledgements

The work described herein would not be possible without the continuing assistance and support of the following companies and institutions (no particular order):

- The DLR MORABA group (reporting to the German Space Operations Centre GSOC of Oberpfaffenhofen)
- The ESA Directorate of Human Spaceflight
- IABG mbH of Ottobrunn, Germany
- Lohmann Tapes of Neuwied, Germany
- Die Firma GmbH of Nurnberg, Germany
- Olympiapark München GmbH

In addition to these, a large umber of private individuals and small companies are actively supporting the development effort by both supplying equipment and hardware as well as personal and financial resources.

References

[1] Grieger,B., et al., “The ARCHIMEDES Mission Science Proposal”, Max-Planck-Institute for Solar System Research, Katlenburg-Lindau, 2005

[2] Katzlowski,M., Griebel,H., “The Atmosphere Entry of ARCHIMEDES Balloon”, 3rd International Symposium on Atmospheric Reentry Vehicles and Systems, Arcachon, März 2003

[3] Griebel, H., Häusler, B., Mundt, C., Rapp, H. “Project ARCHIMEDES – A novel approach to balloon deployment on Mars”, Paper IAC-04-Q.P.02, 55th International Astronautical Congress, Vancouver, 2004

[4] Jaremenko, I.M., “BALLUTE Characteristics in the 0.1 to 10 Mach Number Speed Regime”, Goodyear Aerospace Corporation, Journal of Spacecraft and Rockets, Vol.4, No.8, 1967, pp. 1058-1063.

[5] Mundt,Ch., Griebel,H., Welch,Ch., “Studies of the atmospheric entry of vehicles with very low ballistic coefficient”, 13th AIAA/CIRA International Space Planes and Hypersonic Systems and Technologies Conference, Capua, Italy, May 2005

[6] Mundt,Ch., Griebel,H., “Venus Balloon mission Archimedes-V with emphasis on surface and gas radiation phenomena”, 1st International ARA days – Atmospheric Reentry Systems, Missions & Vehicles, Arcachon, France, July 3-5, 2006

[7] Bayler, K., “Effective Testing of the Mars Ballon ARCHIMEDES Between Low Requirements and ECSS-Standards”, 6th International Symposium on Environmental Testing for Space Programmes, ESTEC, June 2007

[8] K. Sutton, R.A. Graves: “A general stagnation point convective heating equation for arbitrary gas mixtures”, NASA TR-R-376, 1971.

[9] Forget, Hourdin, Fournier, Hourdin, Talagrand, Collins, Lewis, Read, Huot: “Improved general circulation models of the Martian atmosphere from the surface to above 80 km”, Journal of Geophysical Research-Planet, vol 104, 1999

[10] M.Zuban, “Änderung der Ballonform von ARCHIMEDES in der Hyperschallströmung“, Diplomarbeit, Universität der Bundeswehr München 2006.

[11] M.Zuban, „Untersuchung des Atmosphäreneinflusses auf Raumflugbahnen im Radio Science Simulator des Instituts für Raumfahrttechnik“, 2. Studienarbeit, Universität der Bundeswehr München, 2005.

[12] L.Kotte, „Erstellung eines erweiterten instationären Thermalmodells der Raumsonde Archimedes“, Diplomarbeit, Universität der Bundeswehr München, 2007.

[13] S.Brück, R. Radespiel. J. Longo: “Extension of the Euler/Navier-Stokes Code CEVCATS to viscous non-equilibrium flows., DLR IB 233-95 A 64, 1996.

[14] E.H. Hirschel, Ch. Mundt, F. Monnoyer, M.A. Schmatz: Reynolds-number dependence of radiation-adiabatic wall temperature, MBB-FE122-AERO-MT-872, 1990.

[15] E.H. Hirschel: Basics of Aerothermodynamics, Springer, Berlin/Heidelberg/New York, 2004.

[16] MSC.NASTRAN User’s Manual Version 2005, MSC.Software Corp., 2005

[17] T.Schramm: Untersuchung der aerothermodynamischen und mechanischen Wechselwirkung am Mars-Ballon ARCHIMEDES, Diplomarbeit, Universität der Bundeswehr München, March 2007.

[18] C.Fiebig, „Untersuchung zur Materialsch¨adigung von hochfesten Polyimiden im Hinblick aufTemperatur- und zyklische Beanspruchung“, Diplomarbeit, Universität der Bundeswehr München, March 2007.
[19] F.Emmerling, „Analytical Analysis of Eigenmodes and Eigenfrequencies of a Thin Film Balloon“, Institute of Mechanics, Universität der Bundeswehr München 2006, personal communication.
[20] H.Griebel, „MIRIAM Spaceflight Test Mission Definition”, Version 2R1, The Mars Society Deutschland e.V., March 2007.
[21] H.Griebel, „RAPHAELA Altimetry Experiment Mission Definition”, Version 2R1, The Mars Society Deutschland e.V., March 2007.