Presentation

ARCHIMEDES — A BALLOON MISSION TO MARS LEAD BY THE GERMAN MARS SOCIETY

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ABSTRACT

ARCHIMEDES is a small advanced interplanetary space mission which deploys a balloon to the atmosphere of planet Mars. This mission concept provides science capabilities complementary to orbiter and parachute descent missions.

The ARCHIMEDES mission comprises a super pressurized balloon equipped with a scientific payload carrying a high resolution planetary camera, a magnetometer, and a meteorology package. These sensors are suspended beneath a 14 m diameter balloon in a small gondola of 4 kg. The aerobot itself has a mass of 16 kg and floats at approximately 2 km altitude. In addition to the instruments located in the gondola, ARCHIMEDES carries an entry flow experiment and an accelerometric measurement package which are jettisoned after atmospheric entry.

The aerobot is transported to Mars aboard the AMSAT P5-A Mars orbiting spacecraft with a planned launch in 2009. AMSAT P5-A also provides a data communication link with planet Earth and tracks the aerobot by means of radio ranging.

Key words: Mars; missions, balloon.

1. INTRODUCTION

Early 2002, the project to deploy a ballon to the atmosphere of Mars was named ARCHIMEDES, in commemoration of the Greek philosopher who discovered the floatation principle, and whose name can be made forming an abbreviation for "Aerial Robot Carrying High Resolution Imaging, a Magnetometer Experiment and Direct Environmental Sensors". The mission concept is described in section 2.

The ARCHIMEDES mission enables the acquisition of unprecedented data on the upper atmosphere, the lower atmosphere, and the surface of Mars. Because the atmospheric entry will be conducted with the balloon inflated, the spacecraft has a very low ballistic coefficient and therefore provides the unique opportunity to determine the density profile in the upper atmosphere layers by accelerometer measurements (section 3.1). Additionally to demonstrating the technology for inflatable atmospheric drag devices on Mars, ARCHIMEDES carries a significant technology experiment to gather crucial hypersonic flow data during entry of a large body into the Martian atmosphere (section 3.2). This data will be invaluable for future heavy landers and aero-assisted manœuvres.

Floating in the lower atmosphere, ARCHIMEDES provides meteorological in situ measurements over much longer time scales than possible during parachute descents (section 3.3). From the altitude of a few kilometers, ARCHIMEDES observes a larger area than a lander mission at a higher resolution than an orbiter mission, by this bridging the gap between preceeding Mars missions (section 3.4). ARCHIMEDES will also be the first probe performing an aeromagnetic survey on another planet (section 3.5).

Currently, two mission profiles are under investigation. Depending on the availability of envisaged balloon materials, ARCHIMEDES will either sink all the way to the ground, albeit gradually, or float sustained at 2 km above nominal zero over the northern hemisphere of Mars. The status of the ARCHIMEDES mission preparation is summarized in section 4.

2. MISSION CONCEPT

2.1. Balloon inflation

Extensive studies conducted throughout the past years have indicated that both the concept of in-

Proc. '3rd International Workshop Planetary Probe', Anavyssos, Attiki, Greece, 27 June – 1 July 2005 (ESA SP-607, April 2006)

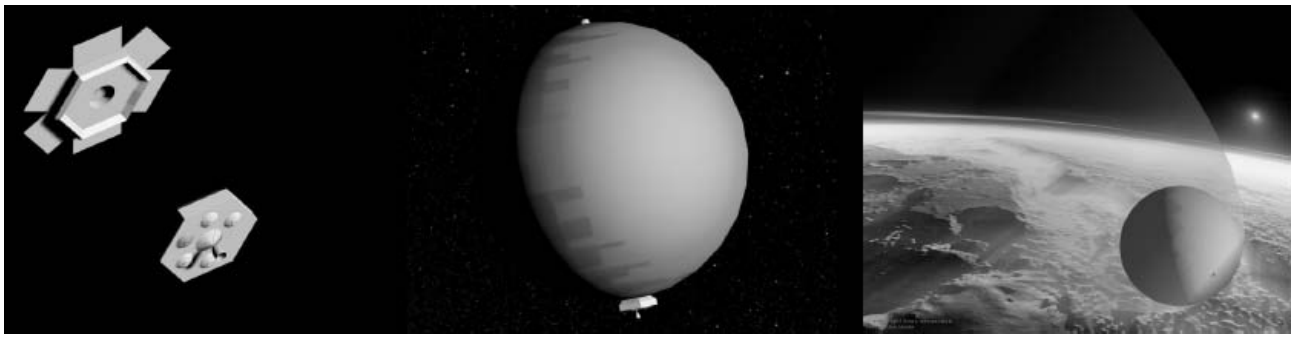

Figure 1. Illustration of the entry sequence. From left to right: Separation, inflation, and atmosheric entry.

flating the balloon during descent and the concept of inflating the balloon from the ground (Ref. 1, 2) pose immense technical hurdles that need to be overcome. Both result in extremely complex spacecraft designs and mission sequences that would be difficult to implement while meeting the forseen launch window of 2009. Hence, a different concept has been developed, whereby the balloon is foreseen to be inflated out in space while approaching the planet, and subsequently used as a hypersonic drag device to slow down the the space craft for descent towards its operating altitude (Ref. 3, 4, 5). The entry sequence is illustrated in Fig. 1.

For the balloon skin material, transparent Polybenzobisoxazole (PBO) thin film with an aerial density of 17.5 g/m^2 would be the favoured material. PBO is resistent enough to support the entry of the inflated balloon without any additional shielding and yet light enough to allow sustained floating in the lower atmosphere. The balloon will be inflated with 1860 g of helium to an overpressure of 1–2 hPa.

2.2. Launch and Cruise

The spacecraft Archimedes is planned as a piggyback payload to the AMSAT P5-A spacecraft, cf. Fig. 2. The launch is currently foreseen in 2009 with an Ariane 5 rocket. AMSAT P5-A is a follow on project to the 650 kg communication satellite AMSAT P3-D that was placed in Earth orbit on November 14, 2000, by Ariane V135 (Ref. 6, 7). Like P3-D, P5-A will be a project led by AMSAT Germany relying on the launch adapter hardware and satellite bus envelope that AMSAT developed for the Ariane 5 rocket. Since the launch vehicle will be bought by other customers, P5-A will be a secondary payload only, and therefore be placed in a geostationary transfer orbit (GTO) at a time not necessarily suitable for a trans-Mars-departure. As a result, the vehicle will have to perform an epoch synchronisation manœuvre prior to its outbound engine burn.

During interplanetary cruise, Archimedes will be held in hibernation mode for most of the time.

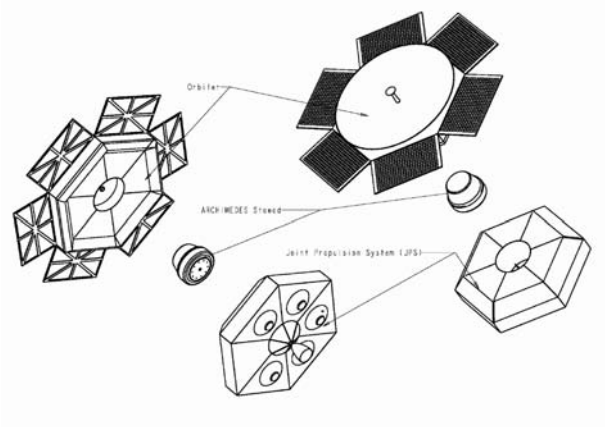

Figure 2. Configuration of the AMSAT spcecraft, exploded view.

Power, thermal control and data transfer will be provided directly through P5-A. Batteries will be charged and a flight system health check will be performed prior to separation.

2.3. Approach and Entry

The AMSAT P5-A is planned to have a highly eccentric orbit with a pericentre altitude of 4 000 km and an apocentre altitude of 20 000 km. Once the desired orbit around Mars has been established and conditions are deemed favourable, P5-A will orient itself into the appropriate orientation for Archimedes release and spin up. Archimedes will then separate from P5-A and autonomously perform a deorbit manœuvre, decelerating itself onto an approach trajectory. The flight system will then de-spin the spacecraft and deploy and inflate the balloon hull (cf. Fig. 1). Subsequently, the propulsion system and the inflation gas system will be jettisoned.

Roughly six and a half hours into approaching Mars, Archimedes will enter the atmosphere for the first time and decelerate, thereby lowering its apocenter significantly. Repeated passes through the Martian

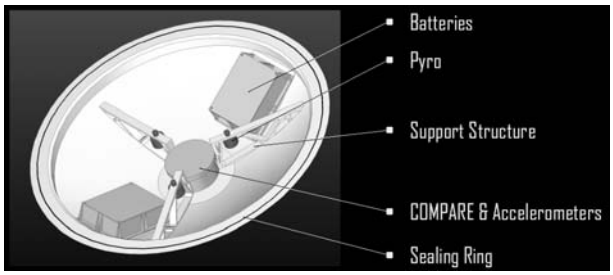

Figure 3. Illustration of the equipment in the nose cone assembly.

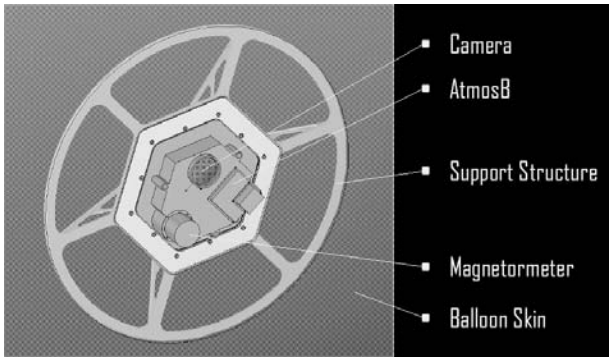

Figure 4. Illustration of the experiments in the gondola.

atmosphere will slow the vehicle so that it eventually sinks towards its operating altitude. Finally, the protective nose cone assembly with the two entry experiments (section 3.1 and section 3.2) will be jettisoned (cf. Fig. 3), and the gondola lowered underneath the balloon (cf. Fig. 4). It is suspended by a bridle that is long enough to prevent the gondola's solar cell ring from being shaded by the large balloon.

2.4. Operation

During its mission, ARCHIMEDES is foreseen to operate at an altitude of about 2 km above nominal zero over the northern hemisphere of Mars, resulting in ground clearances of up to 7 km in some areas. In Fig. 5, simulated drift trajectories based on a general circulation model of the Martian atmosphere — the *Mars Climate Simulator* (Ref. 8) — are shown.

Sustained flotation requires PBO as balloon material which may be rather difficult to abtain. A fallback option would be to use a heavier but more abundand balloon material, which would cause the balloon to sink all the way to the ground, albeit gradually.

During its operation, ARCHIMEDES will use the AMSAT P5-A orbiter to communicate with planet Earth, as the small transceiver in the gondola is not capable of establishing an interplanetary space communication link. At the same time, radio ranging techniques will be employed by P5-A to track ARCHIMEDES during its flight across the surface of Mars. Operations are planned to be performed using the AMSAT deep space antenna in Bochum, Germany.

2.5. Baseline Configuration

The ARCHIMEDES configuration is based on the P3-D design and on design concepts AMSAT previously drafted for the P5-A (Ref. 9, 10). The configuration is driven by the design goal to integrate ARCHIMEDES into P5-A with optimizing the entire mission rather than one of the two spacecrafts. The design has not yet been finally approved.

The baseline configuration option is referred to as "Joint Propulsion System" (JPS) option. The main characteristic of this option is a highly integrated overall system design which consists of three major parts:

1. The P5-A Orbiter,
2. the ARCHIMEDES vehicle, and
3. the joint propulsion system (JPS).

The P5-A orbiter consists of its communication payload and flight computer, a High Gain Antenna (HGA) and various smaller low gain antennas, various scientific experiments, navigational instruments, and solar panels. The payload bay for the orbiter's electronics is a flat, six-sided compartment. The HGA is placed on top, surrounded by the solar panels.

The ARCHIMEDES probe consists of the packaged balloon skin and the gondola (cf. Fig. 4) stowed inside the Nose Cone Assembly (cf. Fig. 3) with the entry experiments COMPARE (cf. section 3.2) and AMS (cf. section 3.1).

The JPS assembly carries the spaceflight system's thrust structure and 400 N rocket engine, two MMH (fuel) and two N_2O_4 (oxidant) tanks, the Helium tank pressurization system, and the balloon's floatation gas tank. It will serve as the spacecraft's cruise propulsion system and will later, when P5-A has established its final orbit, function as a de-orbit stage for ARCHIMEDES.

2.6. Possible Mission Scenarios

The prefered option would involve the probe to bounce off the atmosphere once to slowly spiral its way in, a concept named "Go-Around-To-Float" (GATF). This would yield prolonged measurement time in the tenuous upper atmosphere layer, slow

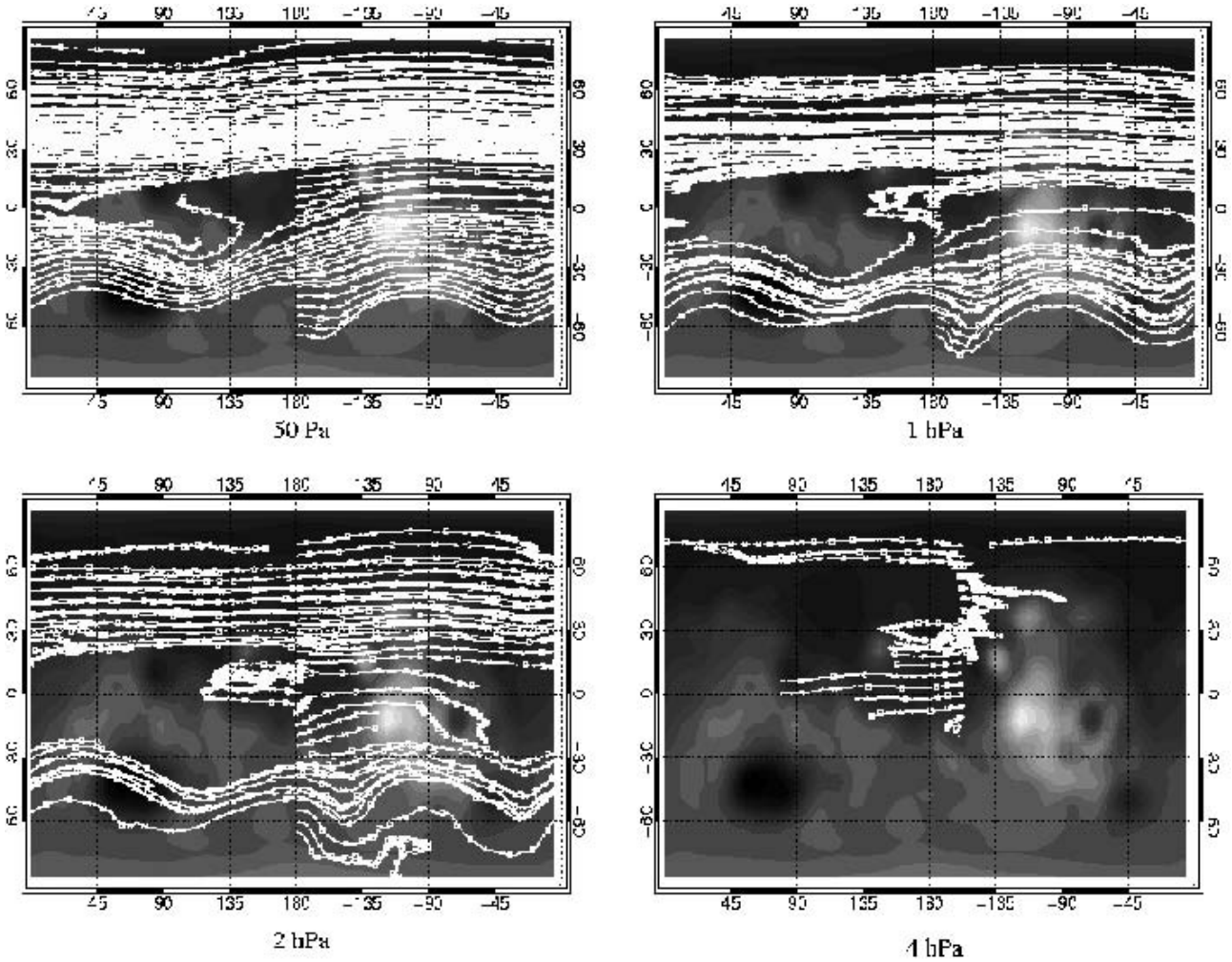

Figure 5. Simulated drift trajectories at different pressure levels for various starting points. The squares mark one day time lags. The background shading indicates the Martian topography.

the descent and thus extend the time to over six to twenty hours depending on local atmospheric conditions and entry precision. However, the entry point cannot be determined precisely in this scenario due to uncertainties in the atmospheric conditions.

Apart from the prolonged measurement time in the upper atmosphere, the advantage would be that resulting entry loads are so small that ordinary materials could be used, and packaging and inflation becomes much easier.

Should the material PBO that allows floatation not be available, a fallback option has been devised, according to which the balloon would be made of conventional material, and be allowed to sink all the way to the ground, a concept named "Go-Around-To-Ground" (GATG). This is the option referred to as "Baseline" in all engineering reports, since PBO thin films, though technically possible, are not commonly produced in larger quantities.

For all mission options, ARCHIMEDES would be visible by the P5-A satellite on entry, allowing for a continuous data transfer. Therefor the decelaration measurements in the high atmosphere (cf. section 3.1) would make the mission already a partial success even if the spacecraft is lost during entry.

The two options would both be equipped with enough battery power to keep the probe functional until at least one successive satellite pass. By this, images from the surface and other data that were collected with the satellite being already below the horizon could be recovered.

3. SCIENCE PAYLOAD

3.1. Accelerometer measurments during entry

The accelerometric measurement package is built by the TU Iasi, Romania. It will acquire unprecedented

data on the density of the Martian higher atmosphere.

The few data we have on Mars upper atmosphere are due to the Mars Global Surveyor successive passes during the process of adjusting (lowering) its orbit. However, these data are not very precise (the sensitivity of measuring acceleration has been of the order of 1 μg) and are already old. Currently, there is virtually no reliable data and no acceptable model for the upper Mars atmosphere (70 to 140 km height). Determining the density profile above 70 km will enhance our knowledge on Mars and on the planetary atmospheric processes in general.

The flight dynamics and flight stability for blunt objects at supersonic and transonic velocities in very low-pressure atmospheres is not well understood. We lack experimental data and validated models on the flight stability for such conditions. Acquiring such data is expected to significantly help revealing and explaining processes not investigated until now.

3.2. Entry flow experiment

The COMbined Planetary entry And trajectory Rebuilding Experiment (COMPARE) is contributed by the TU Stuttgart, Germany. The experiment is a synopsis of measurement principles such that stagnation point temperature, convective heat flux, plasma radiative heat flux, and total pressure are measured simultaneously. Fig. 6 shows the mechanical design of the COMPARE system.

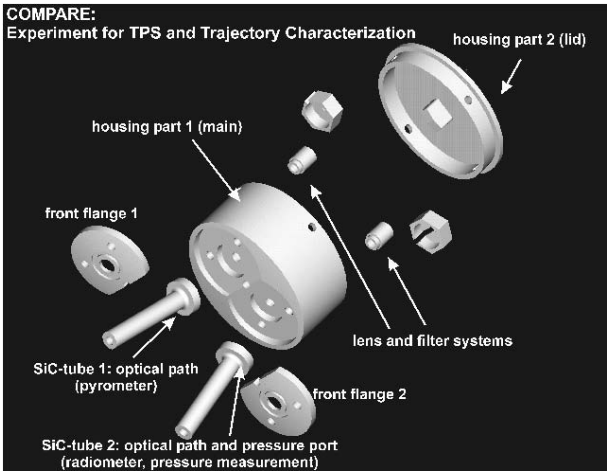

Figure 6. Mechanical design of the COMPARE system.

Typically, fast atmospheric manœuvres and/or manœuvres in atmospheres that consist of carbonaceous molecules such as CO_2 lead to radiative heat fluxes. Thus for missions to Mars or Venus, radiation heat fluxes have to be considered for the TPS design of the concerned vehicles. As the radiative heat fluxes increase with the size of the vehicle, they have to be taken into account for future crewed missions to Mars.

3.3. Direct Environmental Sensing

ATMOS-B is a compact miniatyre sensor suite accommodating pressure, temperature, and humidity sensors and required transducer electronics. It is provided by the Finnish Meteorological Institute. Hardware consists of an electronics board (about $50 \times 60 \times 15$ mm) and an external sensor platform (about $15 \times 200 \times 1$ mm). The electronics board contains the transducer and the pressure sensors. The external sensor platform supports atmospheric temperature sensors and a humidity sensor. Fig. 7 shows the ATMOS-B mock-up. Eventually, the aerial platform itself contributes to environmental sensing due to the fact that it represents a test particle that can be traced to investigate atmospheric motions on a planetary scale.

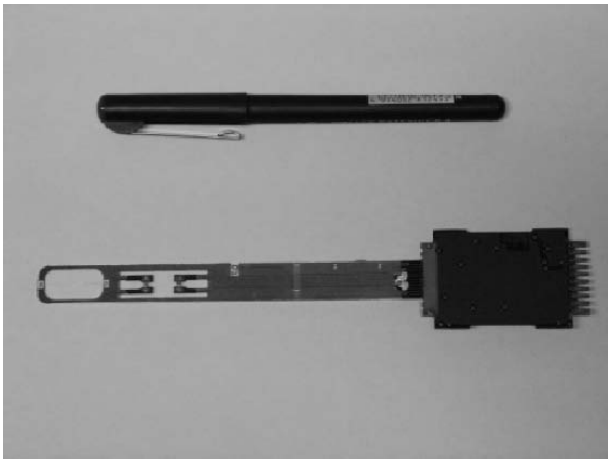

Figure 7. ATMOS-B mock-up.

3.4. Camera Experiment

The a high resolution planetary camera is provided by DLR Berlin, Germany. The camera experiment has to fulfill a variety of measurement objectives during the different phases of the mission. The measurement objectives translate into the main functional requirements for two different camera types:

1. Downward-looking camera for observation of the surface during descent/floating, oriented nadir or slightly oblique up to 3° out-of-nadir, spatial resolution 0.7 m/pixel at 7 km altitude, imaging in black and white.

2. Sideward-looking camera, $60° \times 60°$ field of view centered at 75° out-of-nadir allowing to observe from 45° below to 15° above the horizon, imaging with at least two colors to discriminate between bright dust and condensates by two separate but coaligned camera heads with different filters (blue, red).

Fig. 8 presents a block diagram of the ARCHIMEDES camera experiment. It is composed of three

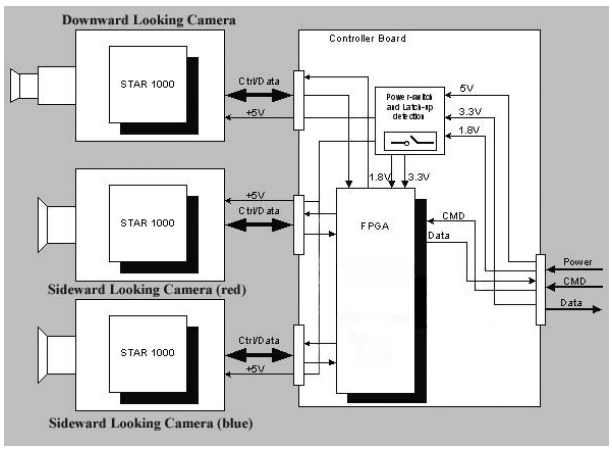

Figure 8. Block diagram of the ARCHIMEDES *camera experiment.*

identical camera heads (1× downward-looking, 2× sideward-looking) which differ only in their optics. The detector foreseen is the FillFactory STAR 1000 APS CMOS detector with 1024×1024 pixels on a 15 μm square pitch as used for the Robotics Component Verification on the International Space Station (ROKVISS) camera developed by DLR. The space qualified wide-angle lens for the ROsetta Lander Imaging System (ROLIS) camera onboard ESA's ROSETTA lander will be used as optics for the two sideward-looking camera heads. The downward-looking camera will be equipped with an optics of 150 mm focal length and a FOV of $5.9° \times 5.9°$. An optical window within the ARCHIMEDES protective nose cone will allow imaging also prior to jettisoning of the cone.

3.5. Magnetometric experiment

The ARCHIMEDES magnetometric experiment is provided by TU Braunschweig, Germany. It consists of a magnetic sensor, see Fig. 9, and the electronics board. The sensor is a vector compensated 3-component fluxgate sensor mounted on the E-box. Together with the electronics it weights only 200 g and the power consumption is 500 mW. The magnetometer provides at least the magnitude of the magnetic field with a resolution of 10 pT and a noise level below 10 pT/$\sqrt{\text{Hz}}$ at 1 Hz. The spatial distance of

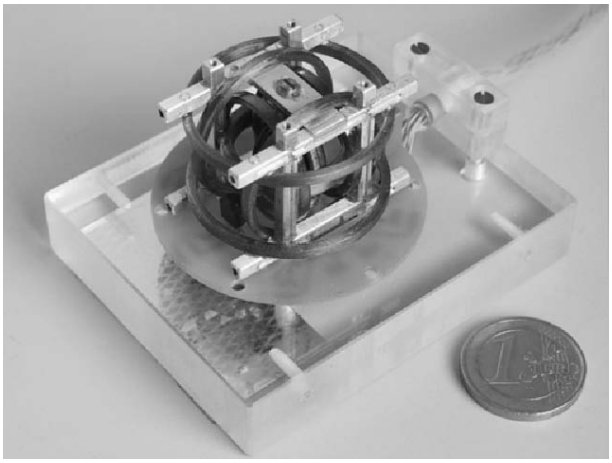

Figure 9. Vector compensated 3 component fluxgate sensor as planned to be used for the ARCHIMEDES *magnetometric experiment.*

measurement points depends on the sampling rate of the magnetometer and the balloon's velocity. Distances of 20 m to 100 m are expected.

4. STATUS AND OUTLOOK

As of June 2005, three testing programs have been initiated and are currently ongoing. The first program researches packaging and deployment analysis comprising of a series of parabolic flight tests, various packaging and inflation tests, and the development of deployment mechanisms. The second program has been initiated to find suitable balloon skin materials, testing samples thereof and testing production and processing techniques. The third program deals with the hypersonic, transonic and subsonic flow field, flight dynamics and chemical atmosphere-material interactions. This program comprises of Computational Fluid Dynamics (CFD) analyses, trajectory analyses, towing and drop tests and flight studies. A decision about the final configuration of the spacecraft is expected to be reached in the first half of 2006, and detailed design is planned to be completed by the end of 2007.

ACKNOWLEDGMENTS

This paper utilizes information from the ARCHIMEDES Mission Science Proposal authored by Björn Grieger, Hans-Ulrich Auster, Hannes S. Griebel, Jan Grosser, Ari-Matti Harri, Georg Herdrich, Harald Hoffmann, Thomas Kersten, Riccardo Nadalini, Jouni Polkko, Thomas Schramm, Oliver Stenzel, Horia-Nicolai Teodorescu, and Martin Tschimmel.

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