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The Mars Environment Analogue Platform long duration balloon flight

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Abstract

The MEAP (Mars Environment Analogue Platform) mission was to fly a stratospheric balloon on a semicircular trajectory around the North Pole in summer 2008. The balloon platform carried the high-resolution neutral gas mass spectrometer P-BACE (Polar Balloon Atmospheric Composition Experiment) as scientific payload. MEAP/P-BACE is a joint project between the Esrange Space Center, Sweden, the University of Bern, Switzerland and the Swedish Institute of Space Physics (IRF), Kiruna, Sweden. Mission objectives were to validate the platform for future long duration flights around the North pole, to validate the P-BACE instrument design for planetary mission applications (conditions in the Earth stratosphere are similar to the conditions at the Mars surface), to study variation of the stratospheric composition during the flight and to gain experience in balloon based mass spectrometry. All objectives were fulfilled.

Keywords: Long duration balloon flight; Mass spectrometry; Atmospheric composition measurement

1. Introduction

Circumpolar balloon flights in the northern hemisphere starting from Swedish Space Corporation's Esrange Space Center have been performed before during wintertime when the nights are dark and sensitive optical equipment is protected from the sunlight. When instruments are not sensitive to light, it can be advantageous to fly during summer time when the midnight sun helps charging on board batteries from solar arrays around the clock.

The MEAP (Mars Environment Analogue Platform) mission was a technology test mission for future long duration balloon flights around the North Pole during summer time. The flight was conducted by Swedish Space Corporation's Esrange Space Center.

The conditions in the stratosphere at a typical float altitude between 30 and 40 km altitude are somewhat similar to the conditions at the Mars surface (Table 1), although bulk atmospheric composition differs (Table 2). Nevertheless, the balloon flight opened up the opportunity to verify instrumentation and equipment for Mars landers under the real, not laboratory, condition of a flight.

The scientific payload consisted of the high-resolution neutral gas mass spectrometer P-BACE (Polar Balloon Atmospheric Composition Experiment), a neutral gas mass spectrometer of the time-of flight type for the analysis of ambient atmospheric gas with a mass resolution $m/\Delta m$ of about 1000 and 6–7 orders of magnitude dynamic range for 1-min measurements. A full mass spectrum from 1 to 1000 amu is obtained once every minute. P-BACE was built by University of Bern, Switzerland and Swedish Institute of Space Physics (IRF), Kiruna, Sweden (Abplanalp et al., submitted for publication). It was originally developed to study the Martian atmosphere from a landed spacecraft.

Primary mission objective for MEAP was balloon platform technology validation. This included a new power distribution system for the balloon platform including solar

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Table 1
Typical physical conditions in the Earth stratosphere and Mars surface (Lodders and Fegley, 1998; Yoder, 1995).

Parameter	Mars (surface)	Earth (30–40 km altitude)
Pressure	6.3 mbar	12 to 3 mbar
Temperature	−60 °C	−46 to −23 °C
Density	1.6×10^{-2} kg/m^3	0.4×10^{-2} to 1.8×10^{-2} kg/m^3
Solar constant	589.0 W/m^2	1367 W/m^2

Table 2
Atmospheric composition (volume mixing ratios) from Lodders and Fegley, 1998. Values indicated by $*$ are for Earth's troposphere. Composition of the Earth atmosphere is approximately the same from ground up to 120 km.

Gas	Mars (surface)	Earth (30–40 km altitude)
CO_2	95.3%	0.035%*
N_2	2.7%	78%*
Ar	1.6%	0.93%*
O_2	0.13%	21%*
CO	0.08%	0.013%*
H_2O	300 ppm	5 ppm
NO	100 ppm (120 km)	
Ne	2.5 ppm	
HDO	0.85 ppm	
Kr	0.3 ppm	
Xe	0.08 ppm	
O_3	0.04–0.2 ppm	

arrays, the thermal design of the gondola and satellite-based communication and tracking systems for both platform and payload. Primary mission objective for P-BACE was to verify instrument design and operations under flight conditions.

Secondary objective for P-BACE were atmospheric science questions: at an altitude of 40 km in the terrestrial atmosphere is close to the upper end of the ozone layer. This is a region in the atmosphere where photochemical reactions are favored by the absorption of solar UV photons. Additional chemical processes occur because of frequent ion-neutral reactions. Thus, a large variety of complex molecules are expected. Possible in-fall and decomposition of meteorites delivers Si, Mg, Ca, Fe, and other atoms that serve as catalysts for chemical reaction in the middle atmosphere or may be incorporated in chemical compounds. The high mass and time resolution and the high dynamic range made P-BACE ideally suited to investigate these processes.

2. Mars Environment Analogue Platform

2.1. Balloon

An 11 Million cft (334′700 m^3) Helium balloon, type Aerostar 11.82-1E-38, was used for the MEAP mission. The system carried a 452 m^2 Aerostar parachute in the flight train for descent. Including the gondola mass of 450 kg and 272 kg ballast, the total system had a mass of 1644 kg. This resulted in a predicted float altitude of 36.5 km. The relatively large size of the parachute gave a predicted impact speed of only 3.5 m/s. All included, the whole system was about 200 m in height at launch.

2.2. Mechanical design

The gondola main platform (Fig. 1) was built from a composite honeycomb plate of 1.6 m × 1.6 m footprint with reinforced attachment rails for the payload. An aluminum frame of 1.2 m height provided support for the roof to the platform. A secondary platform right under the roof provided additional mounting area for more lightweight equipment. All four sides of the frame structure were closed by aluminum panels after sub-system integration. Solar panels were suspended on each side in a frame below the main platform. Solar cells were fitted directly to lightweight aluminum honeycomb plates to save mass. Together with additional crash pads underneath the main platform, the solar array structure served as crash structure during landing. The ballast container was suspended using wires underneath the main platform between the solar panels. Several booms extended from the main platform, the longest with 3.7 m length supported the gas inlet filter for the P-BACE instrument, two short booms were used to get sufficient spacing between individual global positioning system (GPS) and Iridium communication antennas to avoid interference.

2.3. Thermal design

Thermal simulations showed the hot case to be the driver for the thermal design. The gondola was closed on all sides with aluminum panels. These and all other internal and external surfaces (except the solar arrays and the bal-

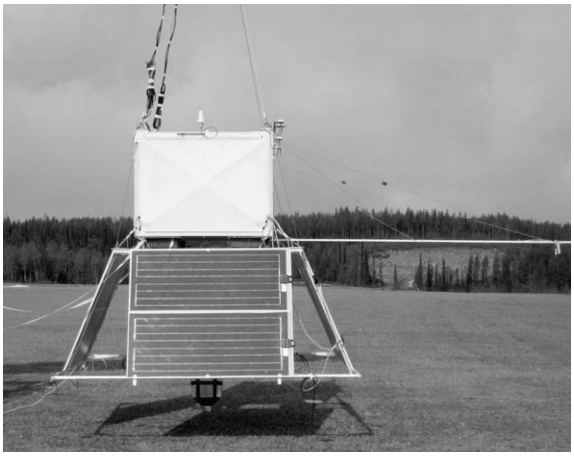

Fig. 1. MEAP gondola during a test on the balloon launch pad. The payload is contained in the white box mounted on top of the solar panel structure. The boom going to the right holds at its end the gas inlet filter of P-BACE (not visible). The gondola with solar panels is about 4 m in height.

last container) were painted white (Sherwin Williams White Appliance Epoxy with $\alpha = 0.2$ and $\varepsilon = 0.88$) or covered by white adhesive tape. This resulted in predicted temperatures inside the gondola between 0 °C and 40 °C.

2.4. Electrical design

The platform was powered by a total of 8 solar panels; two mounted on each side tilted 75° from horizontal for optimum Sun illumination. Each pair of panels provided more than 240 W when fully illuminated. Electrically, the panels were split in two independent strings each powering one of two redundant power regulators (Type Steca Power Tarom), charging two independent 24 V/48 Ah gel lead accumulators. Two DC/DC converters (XP-Power, model: MCC) connect the batteries to the platform power distribution system. This platform power system is controlled and monitored by the MSITel (Multi-Source Iridium Telemetry) platform control system.

2.5. Platform control

Two platform control systems were flown, MIP (Micro Instrumentation Package) and MSITel (Multi-Source Iridium Telemetry, LEN, Italy), a system under evaluation by Esrange Space Center. While the MIP system provided actual balloon control, the MSITel system controlled the platform power system, provided gondola housekeeping data and simulated balloon control as a test for future missions where only the MSITel system will be installed. For direct line-of-sight control MIP provides two VHF radio links, for beyond line-of-sight MIP contains two built-in Iridium satellite modems for command and control. MIP obtains position from two independent global positioning systems (GPS) receivers. MSITel uses two external Iridium satellite modems (NAL A3LA-D-NV) for telemetry and commanding. Similar to MIP, MSITel obtains position from two independent GPS receivers. As backup system, the Automatic Position Report System (APRS) also transmitted the gondola position via VHF. While inside air traffic controlled areas, the Air Traffic Control Transponders (ATC) were activated. Also, a radar reflector together with a strobe light was connected to the flight train.

2.6. Scientific payload

The neutral gas mass spectrometer P-BACE consists of a sealed pressurized vessel containing most of the instrument and an external gas inlet system with a micro particle filter at the end of a 3.7 m long boom. Total mass of P-BACE is 90 kg and peak power consumption is 150 W. P-BACE was electrically connected to the platform power system only. The P-BACE received and transmitted telecommands and telemetry via its two own Iridium satellite modems (NAL A3LA-DG) with integrated GPS receivers. These two modems were independent of the platform communication systems. This separation of the communication links considerably simplified the interface between P-BACE and MEAP. During the flight, this communication link was used to optimize instrument settings and to download quick look science data. P-BACE telemetry was also made available in real-time on a public webserver (http://www.irf.se/meap-pbace). Full science data was stored onboard on two redundant solid-state disks, recovered after the flight. A detailed description of P-BACE is found in Abplanalp et al. (submitted for publication).

2.7. Satellite links

During most of the mission communication with MEAP was through Iridium satellite links, a total of 6 Iridium satellite links were installed. Each Iridium link was either run in a 2400 bps real-time mode, in short burst data (SBD) mode or both. SBD mode allows communicating when the link was less reliable due to limited coverage or unfavorable link margin. The Iridium network buffers SBD messages up to 1960 bytes in size and automatically retries the transmission until the connection can be established. Compared to the 2400 bps real-time mode, this results in a more reliable transmission at the extent of a much lower data rate and a higher latency. Whereas MIP used SBD mode, MSITel used the 2400 bps real-time mode for data transfers. P-BACE used successfully both modes, depending on Iridium satellite coverage.

3. Flight

Several launch attempts were made after the opening of the launch window on 9 June 2008. Launch was successful on 28 June 2008, 05:07 UTC from Esrange Space Center,

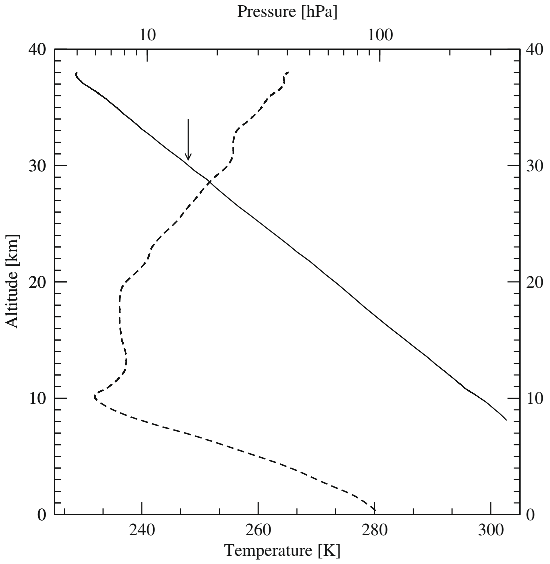

Fig. 2. Pressure profile (solid line) and temperature (dashed line) profile measured by P-BACE during ascent over Esrange. The arrow indicates the highest allowed operational pressure for the P-BACE gas inlet system. P-BACE measured atmospheric composition above this altitude.

Sweden, 67.89 N/21.08 E. MEAP operations were conducted from Esrange flight control center throughout the flight P-BACE operations were initially located at Esrange until shortly after launch and then transferred to Swedish Institute of Space Physics, Kiruna for the remainder of the flight. MEAP reached a float altitude of 38 km within 2 h and 22 min. Fig. 2 shows the pressure and temperature profile measured during the ascent. The flight lasted for 116 h at an altitude between 33 km and 38 km (see Fig. 3) over a distance of more than 5800 km (Fig. 4). Termination of the balloon flight was performed from the recovery aircraft close to the expected landing site. The descent on parachute took about 44 min and was observed from the recovery aircraft (Fig. 5). MEAP landed approximately 135 km east of Umingmaktok, Canada, 67.17 N/105.15 W on 3 July 2008 at 01:10 UTC on dry land from where it was recovered successfully (Fig. 6). Impact velocity was between 3.8 m/s and 5.5 m/s, slightly higher than predicted.

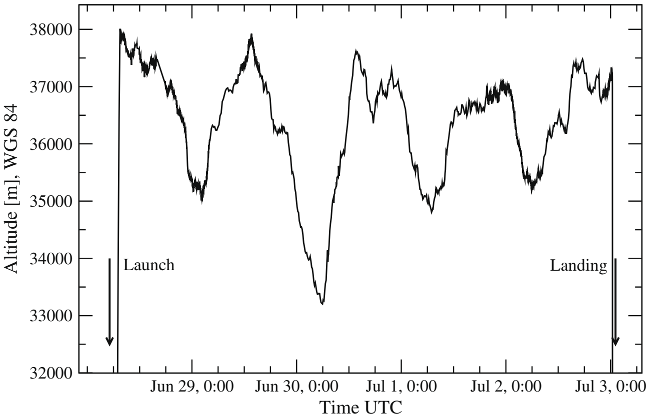

Fig. 3. Altitude profile of MEAP flight. The profile agrees well with the predicted float altitude of 36.5 km. The largest drop in float altitude occurred over Greenland.

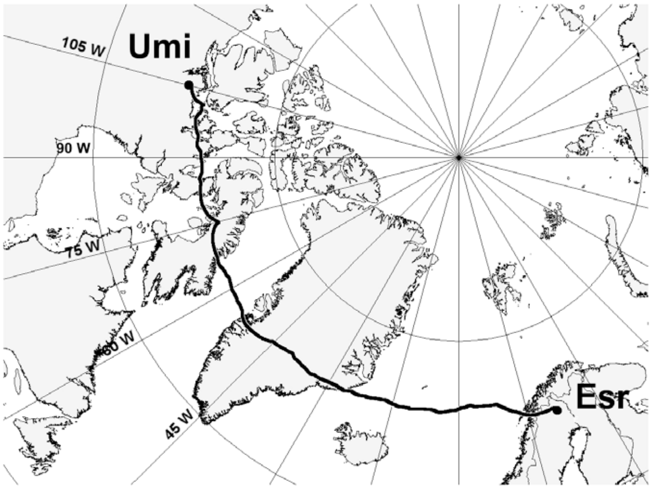

Fig. 4. MEAP flight trajectory with launch in Esrange, Sweden (Esr) and landing 135 km east of Umingmaktok, Canada (Umi). Total flight distance is about 5800 km.

Fig. 5. MEAP (white dot below parachute) during descent at an altitude of about 1200 m above sea level, a few minutes before impact on ground, as seen from the recovery aircraft.

Fig. 6. MEAP on ground near Umingmaktok, Canada, at 67.17 N/105.15 W. Where as the solar panels are crashed (being part of the crashable structure), the main platform is virtually undamaged. The platform continued transmitting data after touchdown.

4. Performance

4.1. MEAP

The platform performed nominal throughout the mission (Hedqvist and Poromaa, 2008). The solar arrays provided sufficient power to keep the batteries charged to 100% for most of the flight and the power distribution system performed nominal. Measured temperatures remained within predicted limits, including the temperature of the scientific payload P-BACE. The MEAP gondola survived the landing intact, with the solar panels crashed as designed (Fig. 6). MEAP was able to continue transmitting GPS position data via Iridium even after landing. Inspection of the accelerometers mounted on the P-BACE pressure vessel indicated a maximum shock amplitude of 20 g, likely from the parachute opening event. Communication via Iridium network proved reliable for long duration balloon missions.

4.2. P-BACE

The instrument hardware and onboard software performed nominally during the flight. Mechanical inspection after landing showed no visible damage. Iridium satellite link performance was within acceptable limits, a typical 2400 bps communication session lasted 15 min until signal was lost and the connection had to be reestablished. Having two redundant Iridium links available allowed to quickly reestablishing a 2400 bps link through the alternative link in case of loss of signal. Short burst data mode was successfully used during phases with low link margin. The GPS receivers were less reliable most likely due to too low atmospheric pressure and thermal issues in the externally mounted active antennas (NAL SAF4070-IG). However, in all cases GPS data could be recovered by combining with data recorded by MIP and MSITel. Both P-BACE internal solid-state disks were retrieved intact and all the science data were recovered. A total of 4538 high-resolution mass spectra were recorded onboard during the flight, of which 2% were downloaded already during the flight for quick-look purposes. P-BACE was in science mode for about 71% of the time, the rest was spent in engineering and test modes. For detailed analysis of science data, P-BACE is currently refurbished and postcalibrated at University of Bern. A preliminary report on science data is given in Abplanalp et al., submitted for publication.

5. Summary and outlook

The MEAP (Mars Environment Analogue Platform) mission successfully qualified platform systems for future long duration balloon flights around the North Pole during summer. The scientific payload P-BACE also fulfilled all of its objectives.

The successful flight of MEAP/P-BACE also opened the gateway for further missions with this or a similar instrument to perform, e.g. stratospheric studies: Investigations of stratospheric composition at altitudes up to 54 km; very little or no data from high-resolution in-situ composition measurements is available for these altitudes. Such a mission would be launched at Esrange during the turnaround period and go as high as possible. Such a payload would consist of P-BACE II, which will be integrated in a platform designed to minimize contamination, contain an improved air sampling and specialized pumping system and have provisions for aerosol collection and analysis and sample collection. Qualified by the MEAP flight, the P-BACE instrument will be or is proposed for planetary missions to Mars considered by JAXA, to the Jovian moon Io as part of NASA's Io Volcanic Observatory, which is currently under study, and for missions proposed in the framework of ESA's Cosmic Vision program to Jupiter and Saturn as well as a Chinese mission to the Moon.

Acknowledgments

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