BIM EXPERIMENT MODULE AND ITS FLIGHT ON MASER 10

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ABSTRACT

The Biology In Microgravity (BIM) experiment module was flown in microgravity during 6 minutes on the sounding rocket MASER 10 on May 2, 2005. Swedish Space Corporation, Dutch Space and CCM developed the BIM module under contract from the European Space Agency (ESA).

Two cell biology experiments were flown in the BIM module:
ACTIN, Role of microgravity on actin metabolism in mammalian cells. Investigator: Prof. Dr. Johannes Boonstra, University of Utrecht (NL).
AMUSE, Influence of microgravity on activation of NF-xB, a principal regulator of inflammation and immunity. Investigator: Prof. Dr. Maikel Peppelenbosch, University of Groningen (NL)

The BIM experiments were performed in 48 experiment units containing culture chambers and liquid storage reservoirs with additives, which were added to the culture chambers during the microgravity period of six minutes. Cultures in microgravity and on a 1xg reference centrifuge on-board the module were activated simultaneously with a reference on-ground. The experiment units were prepared hours before launch and were integrated in late access insert systems. The flight system was installed in the module via a hatch. The ground system, with the reference experiment units, was placed in an incubator.

During the flight, when microgravity was achieved, all actions were performed to activate and, just before end of microgravity, fixate the experiment samples. The thermal control and the centrifuge worked properly. Due to a hard landing the module was severely damaged, nevertheless almost all experiments could be saved.

1. INTRODUCTION

This project was a follow-on of the CIS modules, developed by Dutch Space, flown earlier in the MASER sounding rocket program [1]. The BIM (Biology In Microgravity) experiment module was built under contract from the European Space Agency (ESA) and was flown on the MASER 10 on May 2, 2005 (Fig. 1).

The Swedish Space Corporation conducted the project together with Dutch Space and CCM as subcontractors for the experiment system and for the experiment units, respectively.

Fig. 1. BIM experiment module with late access insert

2. EXPERIMENT DESCRIPTION

2.1 Experiment unit principle

In 1992, CCM developed the second generation plungerbox unit. Since then, these units have been used in large numbers for all kinds of biological experiments in different space missions.

Fig. 2.1.1. Functional principle of a plungerbox unit
A plungerbox unit (80x40x20 mm³) contains six cylindrical storage compartments (1 ml) and one or two flat rectangular culture compartments (1 ml). The liquid from a storage compartment can be flushed into the culture compartment when a spring-loaded plunger is released by a command from the electronic control unit. The incoming liquid will replace the liquid inside the culture compartment (refreshment rate: 85%). Fig. 2.1.1 shows the operational principle.

The plungers are released by means of an electrically operated thermal cutter, which cuts the wire that retains the plunger. The electronic control unit (ECU) is capable of activating 8 plungers every second, because the μg period is only 6 minutes, and a lot of plunger activations are required at the beginning and at the end of the experiment.

Both experimenters used the same type of unit for the MASER 10 mission: a plungerbox unit with two culture compartments, each connected to three storage compartments. In such a unit, two experiment samples can be processed independently. Fig. 2.1.2 shows the actual flight units. The units are positioned inside the BIM between six bars and can be fixed easily with a snap-in clamping piece. This fixation automatically locks the electrical connector (Fig 2.1.3). After integration in the module, the experiment control unit is connected to to the BIM electronics, by means of a serial interface.

2.2 Experiment Sequence

The complete microgravity experiment consists of the following sequence of events:

- Experiment unit preparation: the scientists load the plungerbox units with the biological samples and liquids and hand them over for inspection by ESA and CCM
- Pre-flight inspection: for each unit an inspection sheet is filled out, so that the essential pre-flight data are saved. In case of an error, the unit is returned to the PI or replaced by a spare unit
- Integration into the LAI and ground reference rack: CCM integrates the units into the facility and checks the electrical functionality of the ECU
- Sealing of the LAI: verification of centrifuge operation & proper balancing and subsequent vacuum check by DS and SSC.
- Integration of the LAI into the BIM: the LAI is transported to the launcher and inserted into the BIM module by DS and SSC.
- Check out of integrated flight system: SSC checks all the integrated electronics systems and the centrifuge is tested for a short time at low speed
- Launch of the rocket
- Plunger activations: during the microgravity period of 360 s, the plungers are activated automatically by the ECU, according to the plunger activation time line, defined by the PI. At the beginning and at the end of the microgravity period, a large number of activations is required (see Fig 2.2.1).
- Recovery: after the landing of the payload SSC and DS people fly by helicopter to the landing site, remove the LAI from the BIM module and bring it back to Espace.
- Post-flight inspection: CCM personnel removes the plungerbox units from the facility and together with ESA the critical data are noted on the post flight inspection sheet.
- Hand over to the PI: the plungerbox units are handed over to the experimenter, who will take care of the biological sample material, or take the units home for further investigations in his own laboratory.

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3. EXPERIMENT MODULE

3.1 General description

The BIM module contains the late access experiment and thermal, mechanical and electrical subsystems. The module experiment is a late access part of the module and is contained in a pressure tight compartment. The temperature in the module is controlled with a thermal bath before flight.

A ground reference experiment, contained in an incubator, is integrated and performed simultaneously with the module flight experiment. It is controlled and monitored with a desktop PC.

3.2 Experiment System

The BIM Experiment System consisted of two parts:

- The Late Access Insert (LAI) that is introduced into the module and that contains the flight experiment units, distributed over a microgravity set and an in-flight 1g reference set on a centrifuge
- The 1g Set-Up that is accommodated in the ESRANGE blockhouse and that contains the 1g ground reference experiment units

The system is completed with a carrier to transport the thermally active LAI from integration hall to the launcher.

Late Access Insert (LAI)

The Late Access Insert is represented in Fig. 3.2.1, in which the constituting elements are indicated:

- The pressure-tight cover, made of stainless steel (with a thermal insulation cover for flight, see Fig. 1) and with an O-ring seal (Eriks)
- The centrifuge that holds 16 experiment units in two rows of eight, their electronic control unit and four temperature sensors behind a 18 channel slip ring capsule (Moog AC6023-18)
- Two symmetric microgravity racks (one visible), each holding a stack of eight experiment units and four temperature sensors
- ECU Boxes, one on each µg-rack and one inside the centrifuge, that control the experiment units
- Bottom assembly that contains the thermal control elements (labyrinth heat exchanger, 4 Micronel F41 fans, Minco 9501 heater mat, temperature sensors and thermocouple), a pressure sensor (Motorola MPX5100) and all interface connectors
- Slide-in Table that constitutes the mechanical and thermal interface with the upper experiment deck inside the BIM module

Fig. 3.2.1. Drawing of the Late Access Insert

The LAI thermal control is based on forced convection and the concept is illustrated in Fig. 3.2.2. Air is circulated, in basically a symmetric way, by four small fans along the microgravity racks and the centrifuge and through a labyrinth heat exchanger inside the LAI Bottom Assembly. The concept was verified by (limited) thermal modelling and (extensive) testing performed on a prototype model. The air circulation was trimmed by adjusting a hole pattern in the deck of the Bottom Assembly and the overall thermal balance could, in principle, be optimized by adjusting the conductive thermal bridge towards the Slide-in Table. In practice, the mounting stands-offs created a thermal bridge as required and no further trimming was necessary.

A sufficient thermal capacity for in-flight heat exchange inside the BIM module was provided by the dedicated ‘upper’ experiment deck with pre-flight temperature control (see section 3.3).

Fig. 3.2.2. Concept of the LAI thermal control

The LAI is provided with two sets of eight Smartec SMT 160-30 temperature sensors that were calibrated for a 0.1 °C read-out precision. These sets were distributed in a symmetric way over the LAI structural elements in order to verify the lack of thermal gradients. Both sets were used during acceptance testing and one set only was used by the BIM module electronics. One sensor was designated ‘control sensor’.

The thermal control sensors (a Cu/Co thermocouple for non-flight and Smartec sensor for flight situation) were carefully mounted on a dedicated small copper heat
exchanger so as to enable proper control of the circulating air temperature instead of the LAI structure. This set-up, and part of the labyrinth heat exchanger, is shown in Fig. 3.2.3. The LAI thermostat, suitably provided with its insulating mantles, performed well within the specification, which required thermal gradients to be within ± 0.2 °C at a set-point of 36.5 °C.

The LAI, complete with 32 experiment units, had a mass of 18.3 kg. Despite this, the late access insertion into the BIM module could be performed without problems. The LAI without cover is pictured in Fig. 3.2.5.

![Fig. 3.2.3. Thermal control sensors on heat exchanger](image)

A cut-through view of the centrifuge structure is given in Fig. 3.2.4, showing the central electromotor (bottom), the various structural parts, the co-rotating ECU and the slip ring capsule (top). Although several 'soft mounting' concepts were introduced right from the start, the requirement for extremely low induced vibration levels, as generated by another module in the MASER 10 payload, was only met after extensive testing, some design iteration and the ensuing dynamic balancing exercises. Eventually, the initially selected motor/gearbox combination was abandoned and the centrifuge was straightforwardly driven by a motor without gearbox (Escap RE 25; 48 VDC version). A very satisfactory performance was obtained in the end.

![Fig. 3.2.4. Cut-through view of the LAI Centrifuge](image)

The LAI Bottom Assembly had four connectors: two on the front (connection to the BIM module, see Fig. 1) and two on the rear (auxiliary thermal sensors and thermocouple for pre-flight thermal control). Moreover, a valve was introduced at the rear side to allow for pressure equilibration before removal of the cover, when needed.

The BIM 1xg Set-Up consisted of a rack for 16 experiment units on two parallel panels, their ECU, 8 Smartec temperature sensors and their read-out electronics (SMTAS08) that relied for thermal control on a commercial incubator (Kendro Hereaus B6) set at 36.5 °C (Figs. 3.2.6 and 3.2.7). Thermal gradients were minimized by means of two fans in the rack and by wrapping the rack into a thermal insulation cover (not shown).

![Fig. 3.2.6. Block diagram of the BIM 1xg Set-Up](image)

The experiment unit rack was tumbled from upright to horizontal position at the start of the microgravity phase in order to achieve the same orientation with respect to the 1xg-vector as in the in-flight centrifuge. The post-flight situation was simulated by switching the incubator off and setting its door ajar.
3.3 Module System

The module has a length of 506 mm and a mass of 48.8 kg. The mechanical system consists of an outer structure of Al-alloy, to which the main deck is attached. The outer structure is insulated with glass fiber insulation and equipped with two lids. An insulation tunnel, made of Divinycell HT 50, see Fig. 3.3.1, for the late access insert, is together with the module insulation a part of the experiment thermal subsystem. The outer structure is equipped with a late access hatch for installation of the late access insert. The experiment system, the Late Access Insert (LAI), is mounted on an experiment deck with a slide in system and constitutes the LAI thermal control system. The experiment deck has an integrated heat exchanger connected to an external remote controlled thermal bath. For mechanical and thermal insulation, the experiment deck is fixed to a main deck with vibration dampers.

The main deck which holds the experiment deck, and on the lower side the electronics systems, is fixed to the outer structure with vibration dampers.

The outer structure has umbilicals for cooling fluid and EGSE connection. The module is vented through the outer structure.

Main components of the BIM module:
- Late access insert (LAI) system containing 16 experiment units for microgravity and a 1g reference centrifuge with 16 experiment units
- Outer structure with hatch and lids
- Main deck connected to the outer structure with dampers
- Experiment deck with heat exchanger for liquid cooling loop and with mechanical locking system for the LAI
- Thermal insulation tunnel for the LAI
- Electronic control system
- Batteries
- Software

3.4 Electronics System and Software

The experiment is controlled by a PC/104 system that incorporates real-time operating system software. The PC/104 system controls the experiment system flight sequence and starts the experiment units sequence automatically during flight. The flight sequence can be overridden by tele-command. All data is transmitted to ground via the telemetry system and stored onboard at 25 Hz during the active phase of the experiment.
The main parts in the PC/104 system are:
- CPU including memory flash disc
- I/O cassette, analogue and digital input/output
- Motor control
- Power control
- Serial communication

Other units are:
- Temperature sensors interface
- TM/TC interface
- Housekeeping unit
- Batteries and DC/DC converters

3.5 Ground Support Equipment

The module was operated and monitored during tests and flight by EGSE including power control and module/experiment checkout computers.

Included in the module EGSE:
- PC with operator interface to the module
- Ethernet connection to the service module EGSE
- Power control unit and launch box with power supply
- Remote controlled thermal bath
- Monitoring PC in scientific center

4. MASER 10 CAMPAIGN AND FLIGHT

4.1 Preparation

The campaign took place at ESRANGE, Kiruna, Sweden on April 20 - May 2, 2005. It included preparation on module level as well as tests on payload level. The main events are listed below:
- Preparation of experiment and module
- Preparation of labs and blockhouse
- Bench test with MASER service module
- Module check on launcher
- Induced vibration check
- Launcher and blockhouse preparations
- Preparation of payload in launch tower
- Test count down and Launch Readiness Review

4.2 Hot Countdown

The final hot count down started on May 2, 2005. The scientific preparation for the flight started the day before after noon. The integration of the experiment units in the LAI occurred during the night and the final verification of the LAI was finalized at about 4.5 hours before lift-off. When the late access was finalized at -4 h, the module was powered on and the thermal control activated, keeping the experiment on 36.5 °C. The module was then running until activation for the lift-off.

4.3 Flight and Early Recovery

The lift-off of MASER 10 occurred at 7:00 h in the morning, local time, on May 2, 2005. The thermal control was successful during the 4 hours of incubation time, before flight and during flight, keeping the temperature and gradient within the requirements. All activations were preprogrammed in the module electronics and in the experiment control units. After despun of the payload, the centrifuge was activated and run with nominal speed until it was shut off after microgravity. All actions of the experiments were successfully fulfilled.

Due to a hard landing the payload was seriously damaged. The LAI was in one piece but not possible to dismount from the module at the impact site. The complete module was brought back in a helicopter to Esrange about 2 hours and 15 minutes after lift-off. Thanks to the pressure tight cover the LAI was mechanically stable and damaged only on one side. Inside, most mechanical joints were broken. However, all plunger box units could be dismounted and only two microgravity units and two on the 1g reference centrifuge were crashed.

4.4 Results of the Flight & Conclusion

In general the PBUs performed nominal. As each experiment unit contains two experiments, one out of 96 experiments was lost (in the 1g Set-Up). Experiment temperatures were nominal, both absolute and relative. The centrifuge start and stop sequence was nominal and the centrifuge did not induce any disturbance influencing other experiments in the payload. From a technical point of view the overall design of the BIM module and its operation on the MASER 10 flight were both very successful. The scientific results of the mission will have to be reported by the investigators after a careful examination of the retrieved sample material.

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6. REFERENCES