THE MASER 11 MICROGRAVITY ROCKET FLIGHT

G. Florin, K. Löth, A Værnéus, P. Holm, C. Lockowandt, J. Thorstenson, L Lyckman
Swedish Space Corporation, Box 4207, 171 04 Solna, Sweden, Email: gunnar.florin@ssc.se

ABSTRACT

This was the 11th MASER flight of the Swedish Space Corporation (SSC) Microgravity Rocket programme. MASER 11 carried 4 experiment modules.

The CDIC-2 created chemo-hydrodynamic pattern formation at a two-dimensional interface of two liquids.

The BIOMICS used a model system to get better understanding of the dynamics of blood cells, i.e. their transport and motility in blood vessels.

The XRMON Metal Foam investigated the growth kinetics and stability of Al-based metallic foams under microgravity, using X-ray radioscopy as diagnostic tool.

The SOURCE was a benchmark type of experiment on fluid behaviour in tanks under weightlessness to verify numerical predictions.

The experiments were successful to 100 %, and were safely recovered after landing.

The Service Systems included high-speed telemetry/telecommand link of 20 Mbps to transmit measurement data and CCSDS compatible ground transmission of real-time high-quality digital video images from the 9 onboard cameras, providing scientists the ability to monitor and control their experiments during the microgravity period

The 382 kg payload was launched by the 2-stage solid fuel VSB-30 rocket motor, providing an apogee of 270 km and close to 6½ minutes of microgravity.

1. MISSION DESCRIPTION

MASER 11 was launched on 15 May 2008 at 06.00 LT from Esrange Space Center in northern Sweden. The mission was accomplished by SSC and its sub-contractors for the European Space Agency (ESA).

The industrial teams were as in table 1.

Table 1. Industrial teams

BIOMICS	SSC, Lambda-X
SOURCE	SSC, DTM
CDIC-2	SSC, DTM, Techno System Dev.
XRMON Metal Foam	SSC
Service Module	SSC, DLR
Recovery Systems	DLR
Rocket Motor and Flight Systems	DLR
DVS	SSC, Techno System Dev.

The Swedish Space Corporation sounding rocket programme MASER provides a payload, consisting of 4 to 7 experiment modules (17" diameter), with about 6-8 minutes of high quality microgravity, normally less than $1x10^{-5}$ g in all axes. During the flight, it is typical to interact with the experiments in real-time using high speed telemetry and telecommand as well as real-time high resolution digital video received on ground.

Figure. 1 MASER 11 Launch from Esrange launch site

For MASER 11, the 2-stage VSB-30 solid fuel rocket motor was used. The payload included 4 experiment modules and had a total mass of 382 kg and a length of 5.12 m.

The duration of the microgravity phase was 6 minutes and 29 seconds. During the flight, the four experiments were carried out, see Table 2.

The CDIC fluid science experiment required thorough preparations, using the laboratories in the launching area before flight. XRMON Metal Foam had requirements on pre-heating prior to lift-off. BIOMICS utilized one of the advantages with sounding rockets; installation of the experiment cells into the payload during the countdown sequence.

All experiments contained systems for optical monitoring. The X-ray diagnostics system of XRMON used on-board storage of the scintillator CCD images. The CDIC-2, SOURCE and BIOMICS modules contained video cameras, and the images from the in total 9 cameras were during the flight stored and also transmitted to ground in compressed format by the Digital Video System (DVS) and the MASER Service Module occupying 10 Mbps dedicated bandwidth. In addition, there was one analogue camera recording the

Proc. '19th ESA Symposium on European Rocket and Balloon Programmes and Related Research, Bad Reichenhall, Germany, 7–11 June 2009 (ESA SP-671, September 2009)

deployments of the recovery parachutes, plus one on-board flight observation camera filming the complete flight and recovery operations.

Telescience was used via ISDN lines in order for a scientific groups in Belgium to monitor the execution of their experiment.

1.1 Scientific success rate

100 % scientific success rate is attributed to the MASER 11 flight, and several of the experiments modules are candidates for re-flight on the MASER 12 mission, eg with different experiment setups to complement the sets of data already gathered.

During the flight, the DVS down-linked perfect digital video images to the scientists, and the on-board video storage of all experiment module worked flawlessly.

2. MISSION OBJECTIVES

The four experiments in MASER 11 were as listed in table 2 below.

Table 2: Experiments on MASER 11

Module	Experiment	Investigator
SOURCE	Convective Boiling and Condensation: Local Analysis and Modelling of Dynamics and Transfers	Dr. Catherine Colin IMFT – Toulouse Dr. Michael Dreyer ZARM – Bremen Dr. Philipp Behruzi EADS – Bremen Dr. Jerome Lacapere Air-Liquid
CDIC-2	Chemo-hydrodynamic Instabilities and Pattern at Interfaces between reactive Solutions	Dr. Kerstin Eckert Technische Universität – Dresden
XRMON Metal Foam	In-situ X-ray Monitoring of advanced Metallurgical Processes under Microgravity And Terrestrial Conditions	Dr. Francisco Garcia-Moreno Helmholtz-Zentrum Berlin für Materialien und Energie / Technisches Universität – Berlin
BIOMICS	Dynamics of cells and Biomimetic Systems	Prof. Chaouqi Misbah, Dr. Thomas Podgorski Laboratoire de Spectrométrie Physique, CNRS / Université Joseph Fourier – Grenoble Dr. Natacha Callens Microgravity Research Center, Université Libre de Bruxelles – Brussels

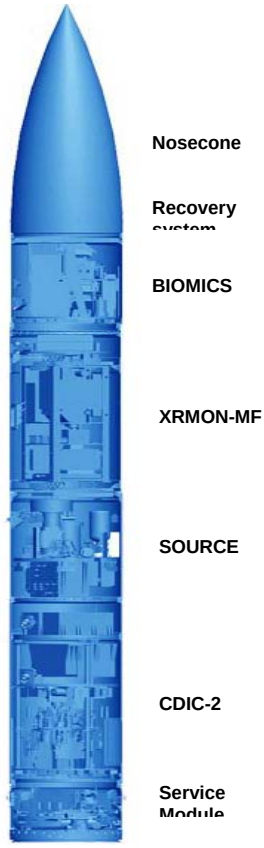

Figure 2. MASER 11 Payload

2.1 CDIC-2

CDIC-2 is a rebuild of the successful CDIC-1 experiment module flown on MASER 10, which unfortunately was completey destroyed at the hard landing. The 93 kg and 1.111 m long CDIC-2 experiment module performed the experiment of ***Dr K. Eckert, Technical University of Dresden***, Germany. The objective of the experiment was to create and investigate Chemo-Marangoni Convection of a liquid interface between N-Hexane and Myristochloride. The experiment was carried out in four experiment systems; two identical Hele-Shaw cells, and 2 capillary cells. The phenomenon was observed by three kinds of optical instruments, interferometers, shadowgraph and also shadowgraph with light sheet for Particle Image Velocity measurements.

Although the module was based on the CDIC-1, the optical system, experiment cells and digital video system designs were modified.

2.1.1 Overall design

The module was pressurised. Its outer structure was equipped with two late access hatches for filling of experiment liquids.

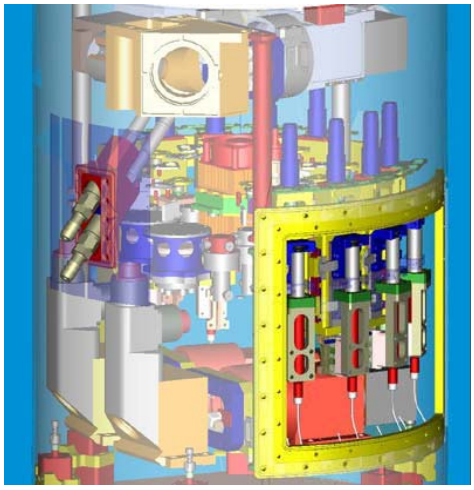

Figure 3. Mechanical view of the CDIC2 module

The images of the optical instruments were recorded by digital high-resolution 1600x1200 DALSA 2-M30 B/W cameras. The five camera images were stored without compression (lossless) on-board in flash memories, and were also for guidance down-linked during cell filling at 6 frames per second with compression factors of 48-77, see figure 4.

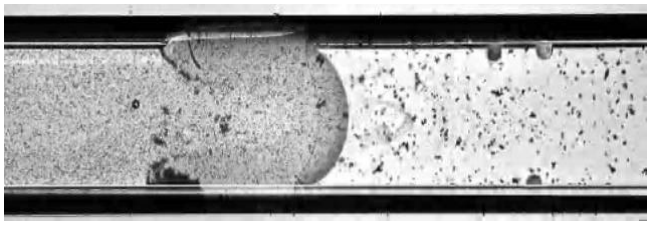

Figure 4. Shadowgraph image, compression factor 53

2.1.2 Experiment process

At start of microgravity, the liquids were injected into the cells. Based on the real time images, the scientists could adjust the filling by sending telecommands. The experiment progress was visually observed throughout the remaining microgravity period.

2.1.3 Flight results

The module performed excellently throughout the entire mission.

The onboard stored, high-resolution images made it possible for the PI team to perform quantitative measurements on the image data.

During the flight, the PI team had access to real-time down-linked images of the experiment on 4 consoles, which enabled the PI team to monitor and control the experiment throughout the flight, a possibility the team took full advantage of.

The experiment success rate is estimated to be 100 %.

2.2 SOURCE

SOURCE is an experiment which aims to perform studies on fluid behaviour in tanks in microgravity, as part of the COMPERE program about research in fluid behaviour in propellant tanks.

The scientific responsibility of the experiment included four participant teams: ZARM, IMFT, Astrium and Air Liquide.

The objectives of the experiment were to

- To observe the effect of wall heat flux on the contact line and the free surface
- To observe the boiling bubble behaviour on a local heater
- To observe the effect of depressurization

SOURCE is one of the experiment module candidates for re-flight on MASER 12

2.2.1 Overall design

The 640 mm high and 47 kg module containes a pressurised experiment cell with transparent wall, in which the experiment liquid during the flight is exposed to pressures varying from 3 to 1 bar and 25-100° C temperatures. To achieve local boiling, a local heater in contact with the experiment liquid is used.

The optical system with digital Dalsa camera (1600x1200 pixels) provided a resolution of 20 px/mm for a view of 80x60 mm. Images at a speed of 32 MBps were stored in a solid state flash memory, and also downlinked to ground for real-time analysis and interaction during the experiment.

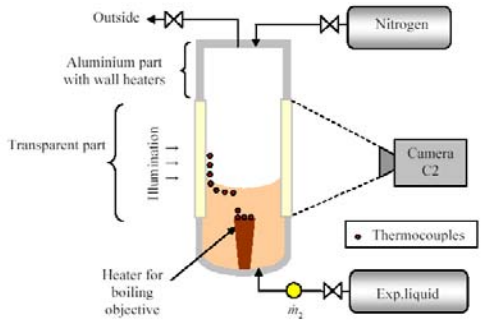

Figure 5. The experiment system (ESA picture)

2.2.2 Experiment process

Before flight, the top of the experiment quartz cell is preheated to achieve a constant temperature gradient at the wall. In our case, the top of the cell is heated to 105°C. At the same time, the temperature of the experiment liquid (HFE7000) in the reservoir is regulated to 25°C. The pressure in the experiment cell is adjusted to 3 bars by applying nitrogen gas into the cell.

At the beginning of the microgravity phase, the liquid is pumped into the experiment cell to a predefined level. The temperature difference between the hot cell wall and the cold liquid creates Marangoni convection. The

change of the contact angle and the free surface shape are observed.

After the Marangoni phase power is applied to the internal heater to create boiling. The bubble behaviour regarding growth, detachment, motion and re-condensation is observed at different power levels.

After the boiling phase, the experiment cell is rapidly depressurized and the behaviour of gas bubbles in the liquid and the free surface are studied.

2.2.3 Flight results

The module performed excellently during the whole flight. The liquid was pumped into the experiment cell at 3 bars of gas pressure at a temperature environment of 25-100°C. During an observation period of two minutes marangoni convections and the impact effect of a hot wall on a cool liquid could clearly be observed. The boiling and depressurisation studies followed the marangoni phase. The high-performing imaging system enabled an in-detail study of the boiling and movements of bubbles. The module was after the flight successfully recovered and restarted for post flight analyses.

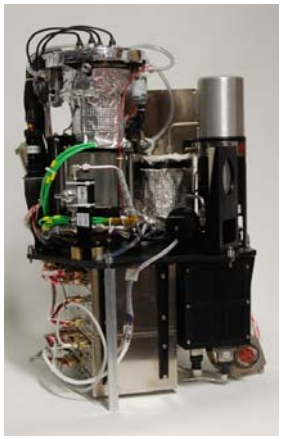

Figure 7. The SOURCE module

3. XRMON

With the XRMON Metal Foam experiment, X-ray is for the first time used as diagnostic toll in sounding rockets. XRMON focuses on in-situ experimental investigations of fundamentals in solidification of metal and important phenomena in the fields of materials processing.
The aim of the XRMON Metal Foam experiment on Maser 11 was hence to investigate the growth kinetics and stability of Al-based metallic foams under microgravity, using X-ray radioscopy as diagnostic tool. XRMON Diffusion experiment will fly on MAXUS 8, and XRMON Gradient Furnace is one of the experiment candidates for flight on MASER 12.

3.1 Overall design

The 1000 mm 89 kg module houses within its volume an X-ray source, X-ray diagnostic system and image data recording system. The module was pressurized at 1 bar during flight, to avoid high voltage arcing and to provide cooling air during flight. A mechanical vibration damping system with wire dampers safeguarded in particular the sensitive X-ray detector during the ascent phase, and a furnace for sample processing.

The X-ray system consists of the microfocus X-ray source, and the CMOS flat panel sensor, providing a resolution in the sample of approximately 10 µm.
To protect the operators and the environment from un-intentional X-ray exposure an inner radiation tight structure was used.

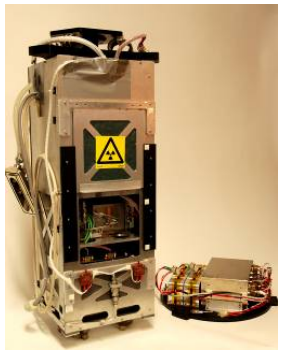

Figure 8. The X-ray tight damped inner structure to the left, electronics deck to the right. Access hatch is open, showing the furnace inside

3.2 Experiment process

The sample of Al alloy is produced with a powder metallurgical foaming route with titanium hydrogen agents. This makes the foaming process simple; nothing more than heating of the solid sample is needed. At heating the hydrogen starts the foaming in the metal melt. The sample foaming procedure and heating profile was completely automatic and followed a pre-set profile including preheating and forced cooling. X-ray images of the process were stored with 1 Hz acusition rate.
X-ray radioscopy is an ideal diagnostic tool for in-situ metal foam analysis in the liquid state.

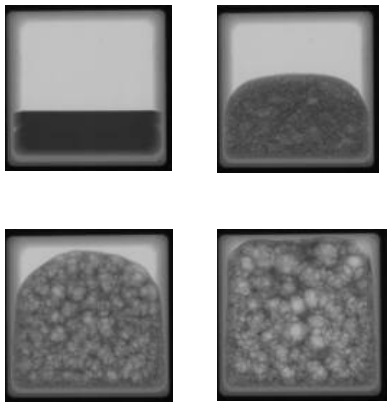

Figure 9. Foam generation in XRMON during flight

3.3 Flight results

The experiment worked excellently during the MASER 11 flight. The experiment cycle was executed on automatic control during the whole flight. After return of the payload the system was connected to the ground support system and the image sequence retrieved.

This showed that good quality foam had been created and monitored with the expected resolution.

3. BIOMICS

The purpose of the BIOMICS experiment was to study the flow of cells in the blood vessels, specifically the dynamics of blood platelets. Vesicles can mimic a few but fundamental cell flow behaviours.

The principle of the experiment was to establish a shear flow of the sample, comprising a water solution with vesicles, between two rotating parallel disks. The movement of the vesicles in the liquid under shear flow was monitored with a digital holographic microscope. The vesicles were produced from lipids by the scientific group.

BIOMICS is one of the experiment candidates for flight on MASER 12.

3.1 Overall design

The 640 mm 63 kg module was pressurized to 1 bar during flight. The outer structure is equipped with a late access hatch for filling/mounting of samples at the launcher. The module is temperature controlled with an external heater/cooler.

Figure 10. BIOMICS experiment module

The 100 mm diameter shear flow chamber is the heart of the experiment. The experiment is performed in the shear flow chamber, which comprises one fixed bottom transparent disk and a rotating top transparent disk, separated by a 170 µm distance where the samples fill. The top disk is rotating with different speeds.
A digital holographic microscope including camera and laser illumination, monitored the position and shape of the vesicles in the shear flow chamber in 3 dimensions. An overview camera was used for monitoring of the rinsing and filling of the shear flow chamber

3.2 Experiment process

The movements of the vesicles in the liquid were monitored with the holographic microscope. The images were processed after flight and revealed the 3D pictures of the vesicles.
The samples were injected by syringes via a pinch valve into the shear flow chamber at start of microgravity. Magnetic stirring devices stirred the vesicles before they were injected. The filling of the chamber was a critical task as air bubbles should be avoided in the chamber.

The experiment shear flow chamber was observed by an overview camera and the holographic microscope camera during the whole flight.
The images were stored on-board and were also compressed and transmitted with a lower frame rate to ground during the flight to enable for the operator to follow the experiment. This made it possible for the operator to take actions in case of bubbles or too high/low concentration of vesicles in the chamber.

3.3 Flight results

The performance during flight was excellent. The filling of the chamber was performed without any detectable bubbles and the two different samples were used during flight. The density and composition of vesicles in the two samples were nominal during flight.

4. MASER SERVICE SYSTEMS

With MASER 11, the new European Recovery System was used for the first time in the MASER programme, as well as the VSB 30 rocket motor. After the crash of MASER 10, a new Service Module with enhanced performance was developed by SSC and DLR Moraba.

4.1 MASER Service Module - MASM

The main objectives for the MASM were to provide the 1.25 Mbps down-link telemetry of housekeeping and 10 Mbit/s digital video data link as well as to provide the up-link telecommand receiving system. All downlinks as well as the uplink are CCSDS-compatible. The total available bandwidth for telemetry down-links that the MASM can provide is 20 Mbps (4x5 Mbps).

The Rate Control System (RCS) in the MASM adjusted the rates of the payload initially after de-spin and was prepared to further decrease the rate during microgravity if it had been necessary. No RCS action

was required, though, as there were low microgravity levels throughout the whole flight.

The MASM measured the accelerations during the mission with a set of accelerometers measuring in course range during the boost and atmospheric descent phases, and in fine mode during the microgravity phase, with a a resolution of 4µg.

4.2 Digital Video

The Digital Video System (DVS) was first proved on MASER 9 as a redundant video system. In MASER 10, the Digital Video 5 Mbps transmitter replaced the earlier used analogue TV transmitters, and the Spacewire interface between the DVS and the MASM was introduced. With MASER 11, the system was further improved, now transmitting images of 9 cameras sharing 10 Mbps bandwith link (2*5Mbps transmitted).

The DVS compressed and transferred the video data of CDIC-2, BIOMICS and SOURCE over the Spacewire interface to the MASM for ground transmission. The DVS also performed on-board recording of uncompressed video data from CDIC-2 and SOURCE, whilst XRMON and BIOMICS used other recording systems.

The images were displayed on six different screens in the launching area block house, where the scientists could observe and directly interact with their experiment.

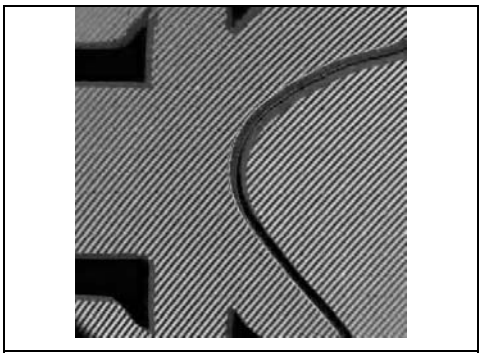

Figure 11. Down-linked compressed CDIC-2 interferometer image (factor 48).

4.3 Recovery Phase

The European Recovery System performed excellently, and landed the payload with a descent speed of ~ 8 m/s. The payload was brought back to Esrange after 2½ hours after the launch.

5. MASER 11 FLIGHT DATA

Launch date	15 May 2008
Launch time	06.00 LT
Launch inclination	87.8°
Apogee	251.93 km
Micro-g time	6 m 29 sec (389 sec from +65 to +454) sec)
Rate control	No action during flight
Landing site	56 km downrange
Recovery return	+146 minutes

Figure 12. The Maser 11 impact point

6. FUTURE MISSIONS

It is planned to launch MAXUS 8 in autumn 2009, MASER 12 in autumn 2010 or spring 2011 and PHOCUS in summer 2011.