THE MASER-10 MICROGRAVITY ROCKET FLIGHT

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ABSTRACT
The MASER 10 was launched on 2 May 2005. This was the 10th flight of the Swedish Space Corporation (SSC) Microgravity Rocket programme. MASER 10 carried 4 experiment modules.

The BIM module contained two biological experiments, investigating the effects of microgravity in mammalian cells.

The ITEL-2 module investigated Interfacial Turbulence in an Evaporating Liquid with a free liquid surface.

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

The TRUE-2 measured the effect of Thermal Radiation Forces on a solid disc crossed by a heat flux.

The experiments were successful to 100% during the flight. After hard payload landing, the final success rate has been estimated to 90%.

The Service Systems included high-speed telemetry/telecommand link to transmit measurement data and CCSDS compatible ground transmission of real-time high-quality digital video images from the 7 onboard cameras.

The 351 kg payload was launched by the last existing Skylark rocket motor, providing an apogee of 252 km and more than 6 minutes of microgravity.

1. MISSION DESCRIPTION
MASER 10 was launched on 2 May 2005 at 07.00 LT from Esrange in northern Sweden. The Maser 10 mission was accomplished by SSC and its subcontractors for the European Space Agency (ESA).

The industrial team were as in table 1.

Table 1. Industrial teams

<table>
<thead>
<tr>
<th>BIM</th>
<th>SSC, CCM, Dutch Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDIC</td>
<td>SSC, DTM, Techno System Developments</td>
</tr>
<tr>
<td>ITEL-2</td>
<td>SSC, Lambda-X</td>
</tr>
<tr>
<td>TRUE-2</td>
<td>SSC, Mars Center, DTM, Techno System Developments</td>
</tr>
<tr>
<td>Service Module</td>
<td>SSC, DLR</td>
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<tr>
<td>Recovery</td>
<td>DLR</td>
</tr>
<tr>
<td>Separation bay</td>
<td>DLR</td>
</tr>
<tr>
<td>DVS</td>
<td>Techno System Developments</td>
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</tbody>
</table>

The Swedish Space Corporation sounding rocket programme MASER provides a payload, consisting of 4 to 7 experiment modules (17") diameter, with about 6 minutes of high quality microgravity, normally less than $10^{-5}$ 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.

Fig. 1 MASER 10 Launch from Esrange launch site

For MASER 10, a 2-stage Skylark 7 solid fuel rocket motor was used, the last remaining Skylark rocket motor. The payload included 4 experiment modules and had a total mass of 351 kg and a length of 4.97 m.

The duration of the microgravity phase was 6 minutes and 1 second. During the flight, the four experiment modules carried out five experiments, see Table 2.

The CDIC fluid science experiment and the biological experiments ACTIN and AMUSE in the BIM module required a thorough preparation, using the laboratories in the launching area before flight. ACTIN and AMUSE also utilized one of the advantages with sounding rockets; installation of the experiment cells into the payload during the countdown sequence.


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Both the CDIC module and the ITEL-2 module contained video cameras, and the images from the in
total 7 cameras were during the flight compressed and
transmitted to ground by the Digital Video System
(DVS) and the MASER Service Module.

Telescience was used via ISDN lines in order for two of
the scientific groups, in Belgium and Italy, to monitor
and the execution of their experiments.

1.1 Coping with payload induced vibrations
The g-levels of the mission were below $1 \times 10^{-3}$ g in all
axes, but special precautions had to be taken for this
mission, since two of the experiments were very
sensitive. The ITEL-2 experiment had a free and flat
liquid surface that was observed by a very sensitive
Schlieren optical system and the TRUE-2 experiment
included a delicate balance that measured a very small
force.

Hence, with the purpose to identify induced vibration
sources and effects, SSC performed suspended payload
tests a couple of months before the integration and test
(AIT). During these tests, the payload first represented
the BIM and ITEL-2 flight experiment modules and the
MASM. The disturbance source (BIM centrifuge) was
operated, and the images from ITEL-2 and the
acceleration levels in the MASM were simultaneously
recorded. By this method, a good characterisation of the
sensitivity of the ITEL-2 experiment for different
acceleration levels and frequencies was achieved. As a
result of these tests, considerable effort was invested in
reducing the BIM centrifuge vibrations to a minimum.

During the system AIT, new suspended payload tests
were performed with all modules present. The results
from these tests served as input to the establishment of
the experiment time-line planning for the flight, where
centrifuge spin-up and action on motors had to be
performed before the ITEL-2 experiment observations
would be valid.

1.2 Scientific success rate
Due to a failing recovery system, the main parachute did
not deploy. In spite of the hard landing on a frozen lake,
almost all biological samples of ACTIN and three
quarters of AMUSE were undamaged as well as the
biological experiment data stored on flash-memory. All
image data from the three ITEL-2 digital video tapes
and the CDIC on-board flash-memory stored image data
were retrieved. High rate sampled experiment data of an
ITEL-2 cracked flash memory remains to be retrieved
by specialists. The low rate sampled data was however
already transmitted to ground.

During the flight, the DVS down-linked perfect digital
video images to the scientists, and the on-board video
savings of CDIC and ITEL-2 experiment modules

Fig 2. MASER 10 Payload
worked flawlessly. The TRUE-2 scientific data was also successfully down-linked during the flight.
Hence, in spite of the hard landing, the scientific success rate had been estimated to 90%.

2. MISSION OBJECTIVES
The five experiments in the four experiment modules were as listed in Table 2 below.

Table 2: Experiments on MASER 10

<table>
<thead>
<tr>
<th>Module</th>
<th>Experiment</th>
<th>Investigator</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDIC</td>
<td>Chemically Driven Interfacial Convection</td>
<td>Dr. K. Eckert, Dresden Technical University (D)</td>
</tr>
<tr>
<td>ITEL-2</td>
<td>Interfacial Turbulence in Evaporating Liquids</td>
<td>Dr. P. Colinet, MRC, Université Libre de Bruxelles, ULB (B)</td>
</tr>
<tr>
<td>BIM</td>
<td>AMUSE: Influence on microgravity on the activation of NF-KB</td>
<td>Prof. M.P. Peppelenbosch, University of Groningen (NL)</td>
</tr>
<tr>
<td></td>
<td>ACTIN: Role of microgravity on actin metabolism in mammalian cells</td>
<td>Prof. Dr. J Boonstra, University of Utrecht (NL)</td>
</tr>
<tr>
<td>TRUE-2</td>
<td>Thermal Radiation forces in Unsteady conditions Experiment</td>
<td>Prof. F.S. Gaeta, Mars Center, Naples (I)</td>
</tr>
</tbody>
</table>

Fig 4. BIM module with Experiment System.

3. BIM
The BIM (Biology In Microgravity) experiment module contains two experiments, ACTIN, of Prof. Dr J Boonstra, University of Utrecht, (Netherlands) and AMUSE, of Prof. M. Peppelenbosch, University of Groningen (Netherlands).

2.3 Experiment System

Fig 3. Experiment System, with a central centrifuge, sketch by Dutch Space

The experiments were performed in Experiment Units (EU) in which the biological samples were activated in the beginning of and fixed at the end of the microgravity phase.

The experiments were activated in 3 different environmental conditions: on-board the module in microgravity; in an on-board Ig reference centrifuge; in a parallel Ig reference on ground.

The flight EU were accommodated in a late access Experiment System with defined temperature and atmosphere.

The Experiment System was installed in the BIM module 4 hours prior to launch and was designed to be retrieved from the module at the landing site because of the limited lifetime of the samples.

The ground reference experiment was performed in an incubator.

2.4 Flight Result
The experiment worked perfectly during flight.
However, due to the hard landing, it was not possible to retrieve the Experiment System alone. The recovery helicopter brought back the complete BIM module, still in one piece although severely damaged. At the opening of the unit, it was realised that the experiment cells were seemingly quite intact; 22 of 24 ACTIN cells were unaffected as well as 6 of 8 AMUSE cells.

Since ACTIN had triple cell set-up, the loss of 2 cells was, as a first estimation, assumed to be acceptable, and the scientific mission was estimated to be 100 % successful. AMUSE, having no cell redundancy, suffered an estimated 50 % loss of scientific value.
The requirement to maintain the cells above freezing temperature after landing and during recovery was seemingly respected, in spite of the lack of functioning temperature regulation system after the landing.

3. TRUE-2

The "Thermal Radiation forces in Unsteady conditions Experiment" (TRUE-2) experiment, of Prof. F.S. Gaeta, Naples, (Italy) was dedicated to detect and measure the Thermal Radiation Force (TRF) created by a heat-flux crossing a solid disc immersed in liquid.

Fig 5. Principle of TRUE

The objective of this second flight of TRUE-2 experiment was to measure, with a much improved force sensor, the intensity of TRF in a system constituted by a solid disc (slab) crossed by a heat flux during a thermal transient. The disc was directly linked to a sensor capable of measuring a force in the magnitude of the expected TRF (in the order of 0.1 μN).

3.1 Overall design

Fig 6: TRUE-2 module

The TRUE-2 module featured six experiment cells that were placed on the experiment deck. The overall design of the TRUE-2 module was similar to TRUE on MASER 8 but the interior of the experiment cells and in particular the force sensors were completely different.

3.2 Flight results

The experiment module and the cells worked perfectly during the flight, and the operators stationed at the experiment control console at Espace interacted with the experiment during the flight. The PI in Italy was in constant voice and picture contact with the experiment operators during the flight, and could also follow the experiment performance over ISDN link.

The scientific results were not affected by the hard landing, and the experiment success rate is estimated to be 100%.

4. ITEL-2

The scientific objective of the experiment "Interfacial Turbulence in Evaporating Liquids" (TEL) of the Principal Investigator Pierre Colinet from Université Libre de Bruxelles (ULB), Belgium, was to observe cellular convection (Marangoni-Bénard instability) in an evaporating highly volatile liquid with a free surface. ITEL-2 is a re-flight of ITEL on MASER 9.

Fig 7: ITEL-2 Experiment module

4.1 Experiment process

During flight, the liquid was injected into the cell and a free liquid surface was established. The evaporation rate of the free surface was controlled by regulating the gas pressure and gas flow.

An interferometric optical tomograph successfully measured the distribution of temperature in the evaporating liquid and a Schlieren system visualized the
temperature gradients inside the liquid together with the liquid surface.

Fig. 8: Simplified sketch of experiment cell

The Schlieren and tomograph images from three analogue cameras were recorded on 3 digital video recorders onboard and 2 selectable camera images could also in compressed form be transmitted in real time to ground via the Digital Video System.

4.2 Flight results

Throughout the flight, compressed digital video images were received by the scientists and the experiment operators, who could interact with the experiment. The experiment data and images were also linked to ULB over ISDN link. In spite of the hard landing, the digital video tapes were intact and data could be retrieved. High ratio sampled data stored on a flash memory card remains to be retrieved. The experiment success rate is estimated to be 100%.

5. CDIC

The 86 kg and 1.1 m long “Chemically Driven Interfacial Convection” (CDIC) experiment module performed the experiment of Dr K. Eckert, Technical University of Dresden, Germany. The objective of the experiment was to create chemo-hydrodynamic pattern formation at a two-dimensional interface of two immiscible liquids, one organic and one aqueous. The experiment was carried out in four identical Hele-Shaw cells. The phenomenon was observed by two types of optical instruments, interferometers and shadowgraphs.

5.1 Overall design

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

The images of the optical instruments were recorded by digital high-resolution 1600x1200 DALSA 2-M30 B/W cameras. The four camera images were by the DVS lossless stored on-board in flash memories, and were also down-linked for guidance during cell filling at 10 frames per second with compression factor 60, see fig 9.

5.2 Experiment process

At start of microgravity, the liquids were injected into the cells. The video cameras were switched on before microgravity and enabled the scientists, stationed in front of 4 video screens in the block-house, to monitor via the digital video down-link, the crucial first phase of the liquid injection in 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.

5.3 Flight results

As the DVS storage unit survived the hard landing, onboard recorded uncompressed image data could be retrieved already at the launch site, to be analyzed by the scientists. The experiment success rate is estimated to be 100%.

6. MASER SERVICE SYSTEMS

The Rocket Motor was the last Skylark motor available, and the successful launch ended a launch record of more than 440 launches. The obtained apogee was 252 km, providing 6 minutes and 1 second of microgravity.

6.1 MASM

The main objectives for the MASM were to provide the 1.25 Mbit/s (5 Mbit/s transmission was possible) downlink telemetry of housekeeping and 5 Mbit/s CCSDS-compatible digital video data link as well as to provide the up-link telecommand receiving system. 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 acceleration during the mission with three fine accelerometers and one three axis coarse accelerometer.

6.2 Digital Video

The Digital Video System (DVS) was first proved on MASER 9 as a redundant video system, transmitting ITEL images.

In MASER 10, the Digital Video transmitter replaced the earlier used analogue TV transmitters. There were two DVS, one for the 3 analogue cameras in ITEL-2 and one for the 4 digital cameras in the CDIC. The two
DVS were interfaced to the MASM by Spacewire links and the six video channels shared the 5 Mbit/s link to provide real-time, high-quality video images to the scientists and experiment operators.

The DVS compressed the ITEL-2 and CDIC onboard images in real-time and transferred the video data over the Spacewire interface to the MASM for ground transmission. In the CDIC module, the DVS recorded the uncompressed video data on-board.

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

![Down-linked compressed digital video image of CDIC experiment cell](image.png)

Fig. 9. Down-linked compressed digital video image of CDIC experiment cell

and initial spikes at 0.3 mg, resulting from TRUE-2 motor actions

![Maser 10 Flight 2005-05-02, X-axis accelerometer, 25 Hz Low Pass filter](image.png)

Fig. 10. Maser 10 accelerometer data.

8. FUTURE MISSIONS
It is planned to launch MAXUS 7 in spring 2006 and MASER 11 in spring 2007.

### 6.3 Recovery System

Due to a failure in the recovery system, the main parachute did not deploy. Hence, after the drogue chute cut, the payload experienced a free fall from more than 3 km height.

The payload was brought back to Esrange after slightly more than two hours after the launch.

### 7. MASER 10 FLIGHT DATA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch date</td>
<td>2 May 2005</td>
</tr>
<tr>
<td>Launch time</td>
<td>07:00 LT</td>
</tr>
<tr>
<td>Launch inclination</td>
<td>86.2°</td>
</tr>
<tr>
<td>Apogee</td>
<td>252.3 km</td>
</tr>
<tr>
<td>Micro-g time</td>
<td>361 sec (+72 to +433 sec)</td>
</tr>
<tr>
<td>Rate control</td>
<td>No action during flight</td>
</tr>
<tr>
<td>Landing site</td>
<td>96 km downrange</td>
</tr>
<tr>
<td>P/L localisation</td>
<td>+ 70 minutes</td>
</tr>
<tr>
<td>Recovery return</td>
<td>+132 minutes</td>
</tr>
</tbody>
</table>

The micro-g levels were < 10⁻⁵ g in all axes, apart from occasional spikes at 10⁻⁴ g, due to experiment actions