

Containerless Processing on ISS: Ground Support Program for EML

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Abstract

EML is an electromagnetic levitation facility planned for the ISS aiming at processing and investigating liquid metals or semiconductors by using electromagnetic levitation technique under microgravity with reduced electromagnetic fields and convection conditions. Its diagnostics and processing methods allow to measure thermophysical properties in the liquid state over an extended temperature range and to investigate solidification phenomena in undercooled melts.

The EML project is a common effort of The European Space Agency (ESA) and the German Space Agency DLR. The Microgravity User Support Centre MUSC at Cologne, Germany, has been assigned the responsibility for EML operations. For the EML experiment preparation an extensive scientific ground support program is established at MUSC, providing scientific and technical services in the preparation, performance and evaluation of the experiments. Its final output is the transcription of the scientific goals and requirements into validated facility control parameters for the experiment execution onboard the ISS.

Motivation for electromagnetic processing in space

Containerless processing in the earth laboratory is an attractive way to provide high-purity environment to high-temperature or highly reactive materials. It is particularly suited to give access to the meta-stable state of an undercooled melt. In the absence of container walls, the nucleation rate is greatly reduced and high levels of undercooling can be obtained. Electromagnetic levitation is also suited for the in-situ study of properties of metallic melts. It allows to levitate bulk samples of several grams at high temperatures (well above 2000°C) and to measure the thermophysical properties of freely suspended liquid melts.

However, there are limitations to terrestrial electromagnetic levitation, due to sample deformation, turbulent currents and high process temperatures caused by the required high electromagnetic fields. Most of these effects can be avoided if performing electromagnetic levitation under reduced gravity conditions.

For the electromagnetic positioning of a sample against external residual forces in the microgravity environment, only weak field strength is required. Therefore, disturbances of the liquid sample by the magnetic field such as stirring or shape deformation are avoided. It becomes possible to reach very low process temperatures and to access deep levels of undercooling, respectively. Furthermore, thermophysical data of materials can be derived over a large temperature range including the undercooling regime.

EML Payload and Experiment Overview

The electromagnetic levitation Facility EML is planned to fly in the Columbus Module of the International Space Station in ESA's European Drawer Rack. The EML accommodation in EDR

is depicted in Fig. 1. EML is a successor of the German payload TEMPUS, which has been successfully flown on the Spacelab Missions IML-2, MSL-1 and MSL-1R. In recent years, EML development models have repeatedly been flown on parabolic flight and TEXUS missions.

The EML facility is equipped with the so called SUPOS (Superpositioning) coil system, which allows to decouple heating and positioning of the sample. Several diagnostics are available for the experiment performance. From the top, the temperature is measured with a pyrometer and two digital video cameras are used for the process control and scientific aims. The side view camera is a high speed camera and will be used for frames rates up to 30 kHz.

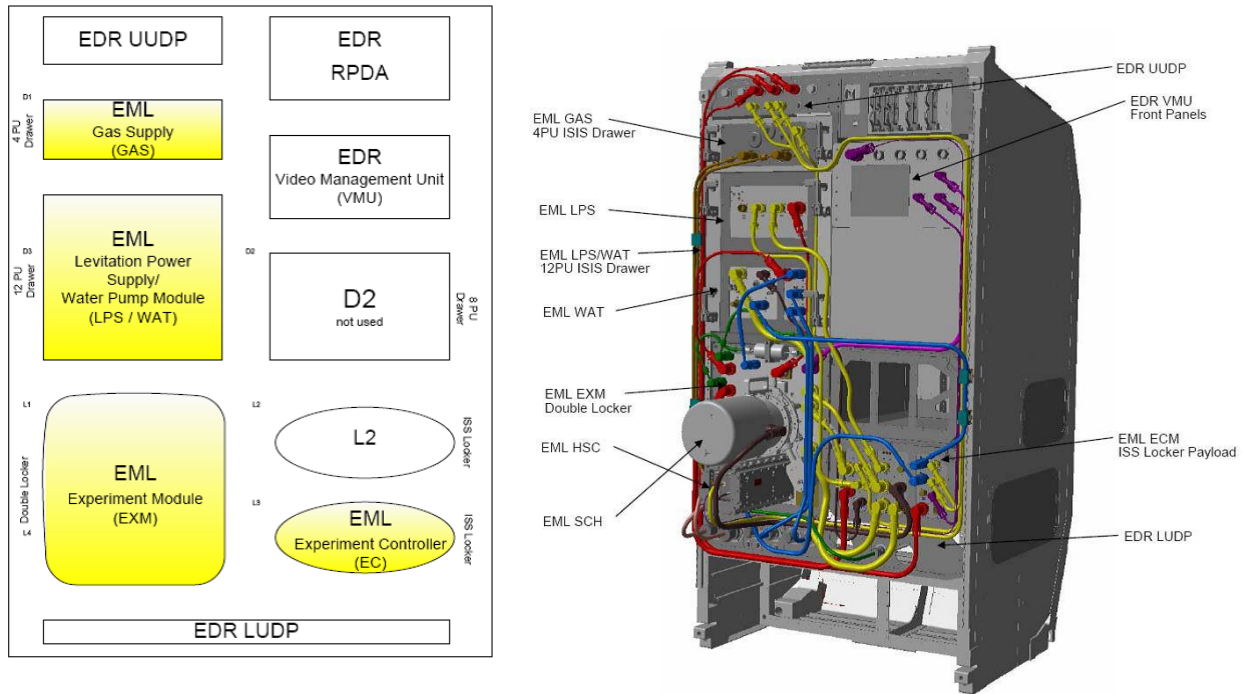


Fig. 1: EML Accommodation in European Drawer Rack (figures provided by Astrium)

Fig. 2: EML coil and CuCo sample in a sample holder (TEXUS campaign)



The planned experiments cover two major groups measurement of thermo-physical properties (viscosity, surface tension, density, thermal expansion, etc.) and solidification. For investigation of the sample solidification the solidification can be triggered at an aimed undercooling level, the growth velocity of the solidification front can be measured via the high speed camera and after the experiment the micro-structure of the in microgravity solidified sample can be analyzed.

EML is able to process liquid metals or doped semiconductors containerless by the electromagnetic levitation technique in the range of 600 to 2000°C. The absence of gravity allows to decouple heating and positioning and to work under an environment with reduced

electromagnetic fields and convection conditions. The experiments are divided into the following classes:

Class A: Undercooling and solidification speeds

Measurement of undercooling temperature (with pyrometer)

Measurement of solidification velocity with optional high-speed video

Triggering of solidification by touching the undercooled sample with a nucleation trigger needle (part of sample holder)

Class B: Heat capacity, effective thermal conductivity, enthalpies, solid fraction

Modulation of the heating input power into the sample, measure temperature response

Measurement of the electrical power loss to the sample

Class C: Surface tension and viscosity

Pulsing the heating field to induce surface oscillations in the molten sample to observe surface oscillation frequencies and decays by video cameras

Class D: Thermal expansion

Measure the sample size with video cameras using subpixel resolution techniques

Class E: Electrical conductivity

Measure electrical data of the levitation system and optionally additional electrical diagnostic circuits to detect the changes of the coupling between the RF magnetic fields with sample temperature.

All experiment classes require an ultra clean processing environment in form of either ultrahigh vacuum or high purity noble gas atmosphere at reduced pressure inside the hermetically tight process chamber.

EML Operations Overview

As an ESA payload, EML will be operated by the Microgravity User Support Center in Cologne, Germany, which is one of the nine User Support and Operation Centers (USOCs) in Europe. The European USOCs are responsible for the different ESA racks and experiments onboard the International Space Station. The tasks of the USOCs are to prepare on-orbit operations, conduct these and also act as a link between the responsible investigators and the experiments. Before the experiments are operated the ground segment has to be prepared and procedures need to be developed and validated. These depend on the experiment and can also involve the scientists as to what they want to achieve. Another important task is to support the crew training that has to happen on ground long before the actual experiment takes place. During on-orbit operations it is the USOCs responsibilities to receive telemetry from “their” payloads and send the necessary telecommands to perform the experiments. Also the scientists get their data usually from the USOCs.

EML will be integrated in Columbus Rack EDR. This drawer rack will be operated from the ERASMUS USOC in Noordwijk. Both USOCs are part of the established ESA Ground Segment in which MUSC acts as the Center responsible for EML operation. As such MUSC is responsible for planning and preparation of the EML on-orbit activities and for executing these and ERASMUS, as Facility Responsible Center for the EDR Rack, provides the single point-of-contact for all EDR real-time operations.

EML is planned for an in-orbit lifetime of 6 batches with 18 samples each, shared between a broad international scientific community. For the first batch of experiments, ten research teams are planning for 36 individual investigations, all requiring multiple melt and solidification cycles on one sample.

Data services to and from EML (Commanding, Telemetry and file uplink) are based on the utilization of the standardised systems available to all European USOCs - customised for EML requirements. In that scenario, MUSC will be responsible for the operation preparation for the experiments in EML, e.g. the development of crew and ground command procedures and all additional operational products (e.g. ground displays) needed to perform the experiments onboard the ISS.

For the operation of the latest parabolic flight and sounding rocket campaigns, MUSC has developed an EML specific evaluation software for science telemetry and video which is already in use during current campaigns. With this software – TeVi – the scientists can monitor the video and housekeeping data of his experiments in parallel. For the process analysis the video data can be displayed in slow motion or frame by frame synchronously with the sample and facility data. A subroutine for the oscillation analysis of oscillating samples was added. It allows to measure the edge of the sample and to calculate two perpendicular radii, the area, center of mass etc. of the sample for each frame. From this data viscosity and surface tension data can be derived. A FFT from a selected region of the data can be performed and the oscillation frequency measured. In a further step the surface tension is calculated from the oscillation frequency. Fig. 3 shows screen shots of the TeVi tool for a parabolic flight experiment.

The EML data are archived in a data archive based on the Hypertest platform. This archive was adapted to the structure of EML data and archives, video and facility data and documents from the historic missions. The data are stored together with metadata, which enables the user to search the data after sample material, principal investigator, campaign etc. The data can be distributed easily and fast via this archive and can be downloaded into the TeVi tool. The archive serves also as long term data archive fulfilling ESA and DLR data holding policies.

The existing tools will be adapted to serve the science teams during EML ISS operations.

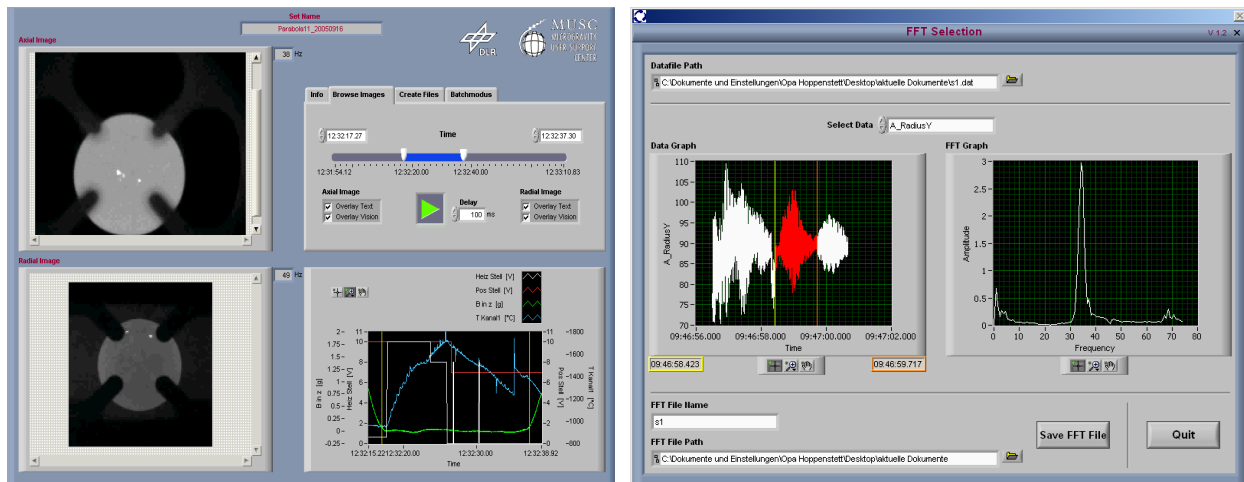


Fig. 3: Screenshot of the TEVI software. Left: synchronous display of video and facility data, Right: FFT analysis and oscillation frequency

Experiment Preparation: Ground Support Program

The experiment preparation is embedded in the overall operations preparation at MUSC. The so called ground support program covers all the activities needed to transcribe the individual scientific ideas into verified experiment and facility control parameters and files. It provides the

scientific users with technical and scientific services in the preparation, performance and evaluation of the experiments.

The ground support program consists of three major parts:

Sample Characterization:

The determination of certain sample properties which are mandatory for the individual EML experiment execution process are provided as a service to the science teams.

The knowledge of the amount of sample material evaporating from the sample surface during processing is essential because the evaporated metal dust is a resource in the EML. The deposited metal layer growing on the coil is limited and the evaporated metal must not exceed certain limits. Therefore the evaporation rate of the each flight sample composition is measured by MUSC in a dedicated ground model on sample material provided by the science teams.

The set-up consists of a UHV chamber in which a sample is heated to specified temperature. The mass loss is determined by an oscillating quartz crystal, refer to Fig. 4 and Fig. 5.

The obtained data are later used for experiment planning purposes and finally the experiment execution in-orbit. During the real-time experiment operation, the evaporation rate is used to observe that the element specific limit values are not exceeded and to monitor the layer thickness growing on the coil.

For the detailed planning of the experiments the coupling of each sample to the RF field has to be known. Since EML is not designed to levitate samples under terrestrial conditions all ground based measurements are performed on samples suspended in the coils. Due to the longstanding history of EML, a number of experimental data stemming from parabolic flight and sounding rocket campaigns are available and will support the experiment development.



Fig. 4 (left): UHV Chamber with oscillating quartz crystal for mass loss/evaporation rate determination

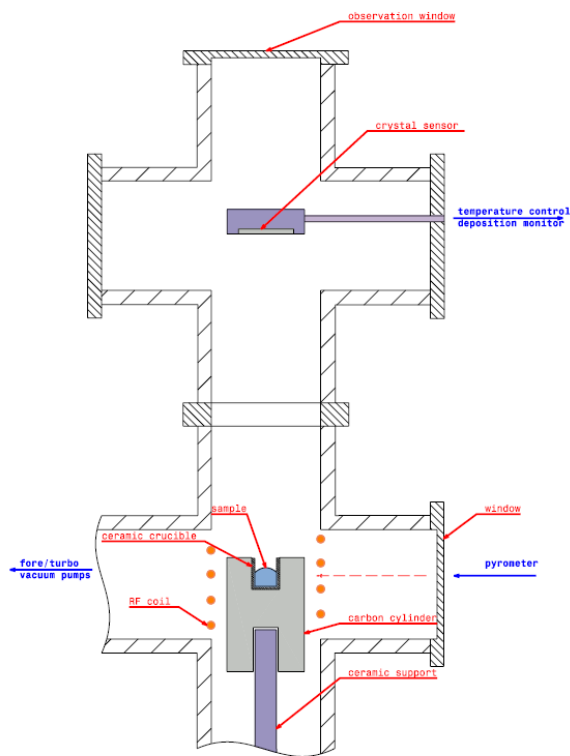


Fig. 5 (right): Sketch of the vacuum chamber; the lower part shows the sample placed in the ceramic crucible and the graphite cylinder within the HF coil. The oscillating quartz crystal is placed in the upper part.

The obtained coupling data are later used in order to simulate the required temperature time profile of the sample with an EML simulator software.

For a correct temperature measurement with the pyrometer onboard, the sample emissivity is measured in the EML ground model. The sample is heated until melting sets in and by a comparison of the measured and literature melting point the emissivity can be derived. The optical setup and used pyrometer of the ground model is comparable to the EML facility.

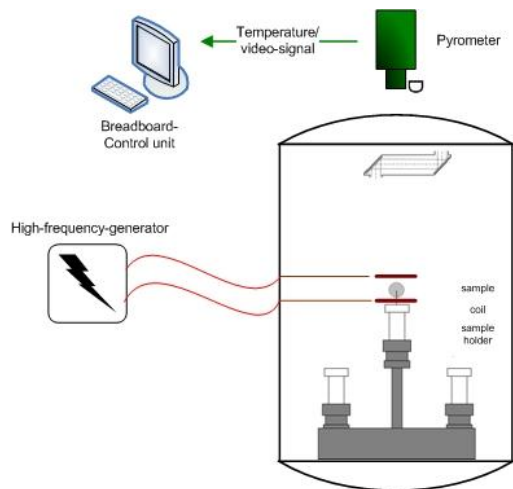


Fig. 6: EML Bread Board for Coupling Efficiency Measurements

Experiment development

The first step in the experiment development is the definition of the individual operational process flow for each experiment, yielding the outline of all nominal and contingency operation. For that purpose, so called science protocols are prepared on behalf of and in cooperation with the science teams, describing key temperatures of the samples to be reached, facility settings (camera, pressure, etc.) and a detailed experiment planning. These science protocols are the base for the further development of the parameter sets.

EML experiments consist of two sets of parameters. The experiment parameters EPs define the experiment as planned. The so called limit parameters LPs provide an independent guard rail envelope of RF values for each experiment that can never be exceeded.

The core parameters for both EP sets are developed with the EML experiment simulator, which currently predicts temperature time profiles from applied RF parameters and the coupling behaviour of the sample to the RF field. The EML experiment simulator will be upgraded by a facility part and enables MUSC to simulate the facility behaviour for an experiment run and to schedule the experiments accordingly.

Experiment verification

After development of the parameter sets they must be validated in a representative EML model. For this purpose, the Operational Model (OM), which also acts as flight spare will be used. During the validation the parameter sets will be processed on a suspended high melting sample and thus the parametersets and the experiment performance can be validated. Especially the timing and interleaving of the two independent sets of parameters will be checked. This task will be performed in close cooperation with the involved scientists, using the verification runs for

user training on the operational environment they will use later during on-board experiment performance.

Summary and outlook

The EML facility is currently under development and is planned to be launched in 2013. The scientific users of the EML are supported by the DLR MUSC, which performs an extensive scientific ground support program. This covers the sample characterisation, experiment preparation and validation of experiment parameters.

The experiments onboard the ISS are controlled and operated from the control room at DLR MUSC in Cologne via a dedicated ground segment.

After the experiments the scientists are supported by the data evaluation and long term archiving of the data.

Acknowledgements

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