Levitation Experiments on ISS: Science and Applications

National Aeronautics and
Space Administration

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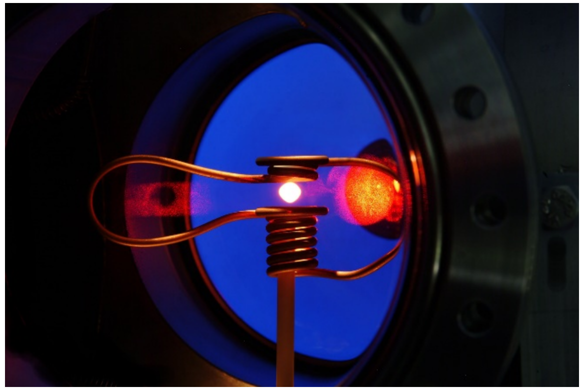
Levitation Facilities on ISS



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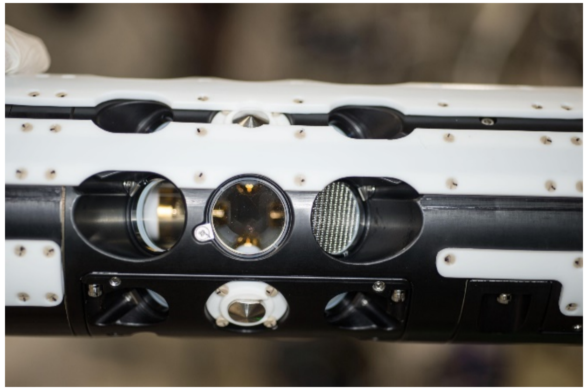
A sample being heated in ESA's Electromagnetic Levitator. Photo Credit: ESA/DLR



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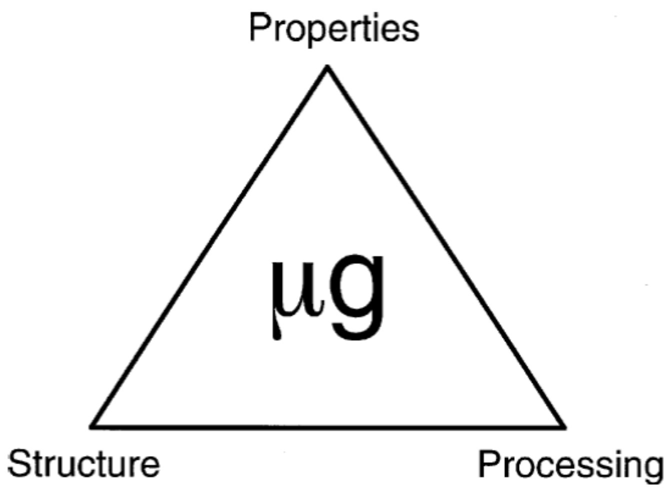
The Electrostatic Levitation Furnace (ELF) sample cartridge. Photo Credit: NASA

- **There are 2 levitations facilities currently in use on ISS**
  - ESA's International Space Station Electromagnetic Levitator (ISS-EML)
    - Has been in operation since 2015.
    - US investigators are on several of the European research projects.
    - The experiments are split into Batches of 18 samples each.
      - Batch 1 is complete and scheduled to return this year
      - Batch 2 is on ISS and experiments are ongoing
      - Batch 3 is being prepared for operation
      - Batch 4 is in planning discussions
  - JAXA's Electrostatic Levitation Furnace (ELF)
    - Launched to the ISS in 2015 and has initiated operations.
    - The ELF sample holder contains 15 samples.
    - In 2016 NASA selected four proposals to the MaterialsLab NASA Research Announcement (NRA) for experiments on the ELF.

Why Levitation in Microgravity

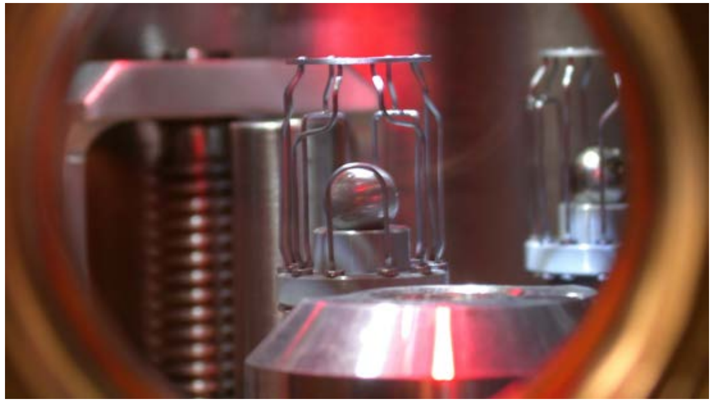
- **The International Space Station (ISS) provides a long-duration spaceflight environment for conducting microgravity experiments.**
- **The microgravity environment greatly reduces buoyancy-driven convection, pressure head and sedimentation in fluids.**
- **Many thermophysical properties can be measured in a levitator on Earth, but with convective contamination.**
  - This contamination plays a significant role in the formation of the intermediate phases.
  - In particular nucleation and viscosity measurements demand quiescent conditions.



Establishing quantitative and predictive relationships between the way a material is produced (processing), its structure (how the atoms are arranged), and its properties is fundamental to the study of materials.

ISS-EML Investigators

- **Robert Hyers (University of Massachusetts)**
  - Member of research projects: THERMOLAB, ICOPROSOL, and PARSEC
  - Objectives:
    - Provide magnetohydrodynamic (MHD) modeling support of macroconvection in various materials for PARSEC, THERMOLAB–ISS, and ICOPROSOL
- **Kenneth Kelton (Washington University in St. Louis)**
  - Member of research projects: THERMOLAB, ICOPROSOL, and QUASI
  - Objectives
    - Determine the influence of liquid and solid short-range order on the nucleation barrier.
    - Correlate the nucleation kinetics with the local structure of the liquids.
- **Douglas Matson (Tufts University)**
  - Member of research projects: PARSEC, THERMOLAB, and ELFSTONE
  - Objectives:
    - Investigate the effect of fluid flow on the solidification path of peritectic structural alloys.
    - Research the influence of convection on the formation of different microstructure in a wide range of commercial alloys.



An EML sample ready to be processed. Photo credit: DLR.

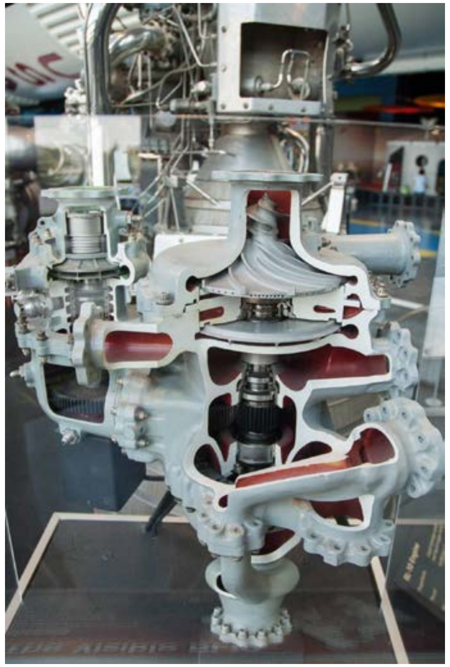
– **ISS-EML Research Teams with US involvement**
  - ELFSTONE: Electromagnetic Levitation Flight Support for Transient Observation of Nucleation Events
  - PARSEC: Peritectic Alloy Rapid Solidification with Electromagnetic Convection
  - THERMOLAB – ISS: Thermophysical Properties of Liquid Metallic Alloys – Modeling of Industrial Solidification Processes and Development of Advanced Products
  - ICOPROSOL: Thermophysical properties and solidification behavior of undercooled Ti-Zr-Ni liquids showing an icosahedral short-range order
  - QUASI: Quasi-Crystalline Undercooled Alloys for Space Investigation

Research on ISS-EML

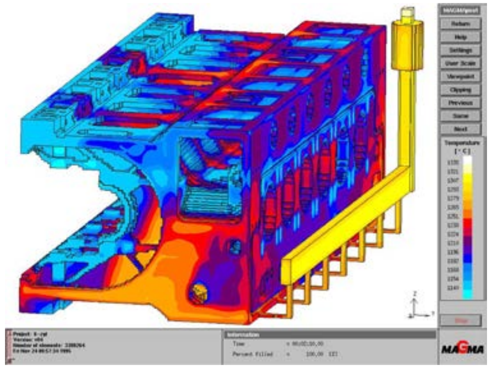
- **High quality thermophysical properties of high-temperature materials are critical to develop accurate models of**
  - Casting
  - Welding
  - Metal additive manufacturing

- **Thermophysical properties could lead to more efficient and more reliable production of metallic parts for**
  - Space Exploration
  - Commercial applications
  - Industrial applications

- **In many cases, the accuracy of available property data is the limiting factor in the predictive capabilities of the models.**



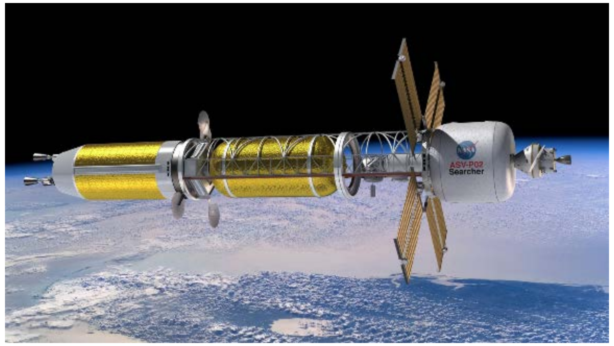
The RL 10 turbopump. Photo credit: NASA.



A model of a casting process.

Application: High Temperature Materials for Nuclear Thermal Propulsion

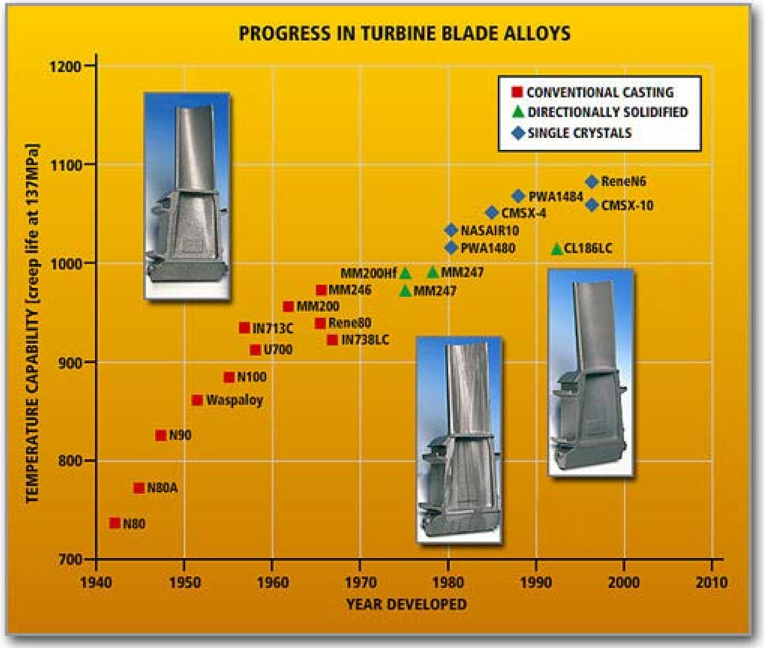
Fuel rods for nuclear propulsion.
Photo Credit: NASA



Concept of nuclear-thermal crew transport
for Mars mission. (NASA Illustration)

- **The US investigators and their teams are collaborating with ESA's THERMOLAB project**
  - One part of THERMOLAB is measuring thermophysical properties and solidification behavior of zirconium alloys used in nuclear reactors
  - Alloys provided by Areva
    - a French manufacturer of nuclear power plants.
  - Synergistic design goals with NASA NTP
  - Measurements will improve manufacturing of reactor components
    - leading to higher performance and higher reliability
  - The results of this study will be used to improve safety, reliability, and cost of nuclear power in space and on Earth

Application: Turbine Blades



Evolution of nickel-based superalloys. CMSX-10 data is currently being evaluated following successful testing during ISS-EML Batch 1.
Photo Credit: NASA

- **THERMOLAB has tested 3 Ni-based superalloys (CMSX-10, MC2, and LEK-94) in ISS-EML Batch 1.**
  - Superalloys are key materials for turbopumps in chemical rockets.
  - Superalloys are also the key component in jet engines; better superalloys allow more efficient airliners and military aircraft.
  - Measurements will improve manufacturing of superalloy components, leading to higher performance and higher reliability.
- **The US Investigators collaborate with ESA's THEMOLAB project on measuring thermophysical properties of metals and alloys.**
  - These properties are critical to accurate models of casting, welding, and metal addtive manufacturing.
- **Better models improve the quality, reliability, and cost of manufactured parts.**

ELF Investigators

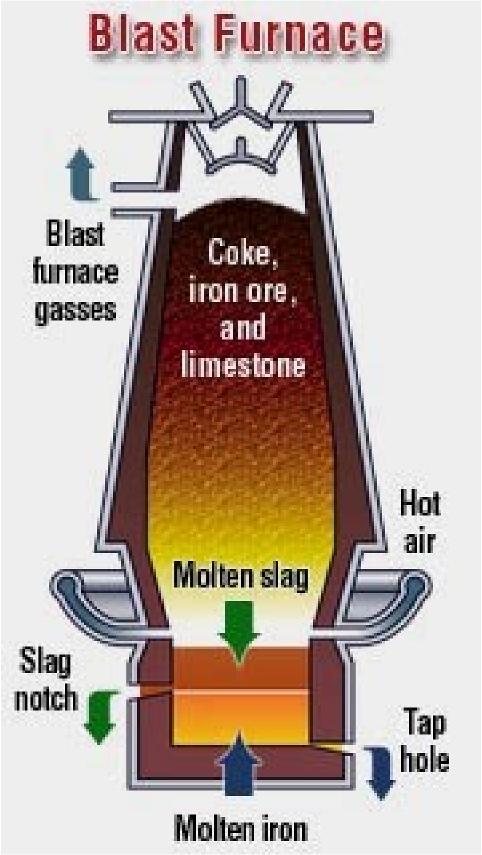
- **Robert Hyers (University of Massachusetts)**
  - Modeling and Simulation of Electrostatically Levitated Multiphase Liquid Drops
    - Dr. Hyers is a Co-Investigator on a Japanese research team.
    - Experiments for this project on ELF began in 2018.
  - Thermophysical Properties and Transport Phenomena Models and Experiments in Reduced Gravity
- **Douglas Matson (Tufts University)**
  - Round Robin - Thermophysical Property Measurement
- **Ranga Narayanan (University of Florida)**
  - A Novel Way to Measure Interfacial Tension Using the Electrostatic Levitation Furnace
- **Richard Weber (Materials Development, Inc.)**
  - Microgravity Investigation of Thermophysical Properties of Supercooled Molten Metal Oxides

Levitated sample in the ELF ground unit. Photo Credit: JAXA.

Model of ELF hardware.
Photo Credit: JAXA.

Application: Steel Industry

- **Dr. Hyers is collaborating with Japan to investigate the effects of the interfacial phenomena between the molten steel and the oxide melts during processing from the viewpoint of the thermophysical properties.**
  - During steel making processes, such as continuous casting, the impurity in the cast steel is influenced by the interplay between the molten steel and molten slags.
  - Understanding the interfacial phenomena is necessary in order to produce higher purity steels.
  - The results of the project are expected to be utilized for more efficient production of higher quality steel
  - The samples of interest are Iron/Welding Flux (Cao-SiO2-TiO2-FeO) and Iron/Slag (CaO-SiO2-Al2O3)



Schematic of a blast furnace, showing slag layer on top of molten iron.
Photo Credit: National Slag Association.

Exploration Relevance – MaterialsLab ELF Investigations

Metal Oxides

- The work seeks to make accurate measurements of equilibrium and supercooled melt density, viscosity and surface tension.
- Properties are an essential element of models that correlate properties and structure to advance development of applied materials and support fundamental understanding of glass formation and nucleation.
- The materials of interest are precursors to high value-added glass materials that are used in
  - Lasers
  - Optical communications
  - Imaging
  - Photonic devices

Round Robin

- The proposed work seeks to understand and control the sources of measurement error and to provide a baseline dataset for quantifying uncertainty in measurements (both space- and ground-based).
- The proposed materials have industrial applications
  - Casting
  - Nuclear fuel rods
  - Metallic glasses

Non-Linear Optical Materials

- Advance the fundamental understanding of the origins of photorefractivity in certain photorefractive crystals and the manufacturing processes needed to apply this understanding to new devices on Earth.
- Potential to enable several new kinds of photonic devices ranging from
  - Holographic storage (which would compete with flash memory, CD/DVD/BluRay, and hard disks)
  - Adaptive optics
  - Phase-conjugate mirrors (which can passively correct images of space from Earth)

Interfacial Tension

- Novel measurement technique useful for several materials and applicable to several industrial processes including:
  - Semiconductor crystal growth
    - Improved modeling of Czochralski and Bridgman process of single crystal encapsulated growth such as GaAs and GaSe
  - Additive manufacturing
    - Precise surface tension measurements allows prevention of droplet formation during selective laser melting process and is key to predictive controlled processing.
  - In-Space Welding
    - Tension forces dominate in space -- Capillary-driven flows influence structure and stability of welds

Conclusions

- **Materials Science research utilizing levitation is a significant portion of SLPSRA's funded efforts.**
  - Levitation research takes advantage of the unique microgravity environment available on ISS
- **This research has applications to NASA exploration needs as well as for ground-based industry.**
- **Applications include:**
  - Better turbine blades for aerospace engines
  - Higher quality steel
  - New materials for optical devices, lasers, and photonics
  - Improved semiconductor devices
  - Nuclear Thermal Propulsion (NTP)
- **Levitation research on ISS is ongoing**
  - Additional research is planned
  - SLPSRA is planning a joint Materials Science Workshop with CASIS at the ISS R&D conference in Atlanta, July 29 – August 1, 2019. Workshop details TBD.
    - Anticipate developing a new NASA Research Announcement (NRA)

- **Acknowledgment: NASA Space Life and Physical Sciences Research and Applications (SLPSRA)**