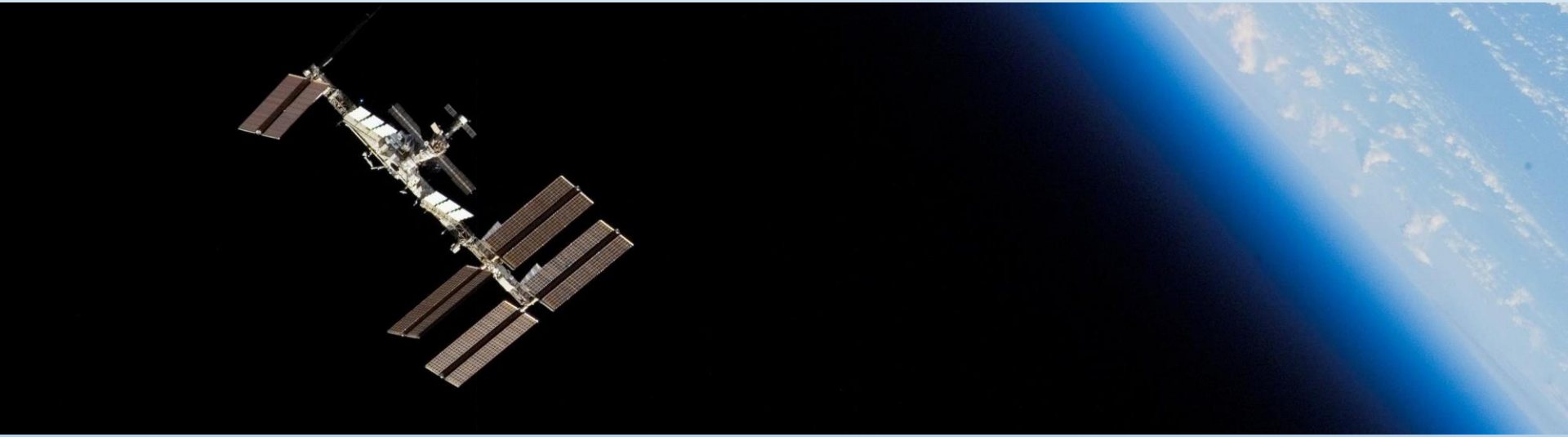
National Aeronautics
and Space Administration
Marshall Space Flight Center



Microgravity Solidification Experiments for the ISS

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Mechanical Engineering Student at Milwaukee School of Engineering

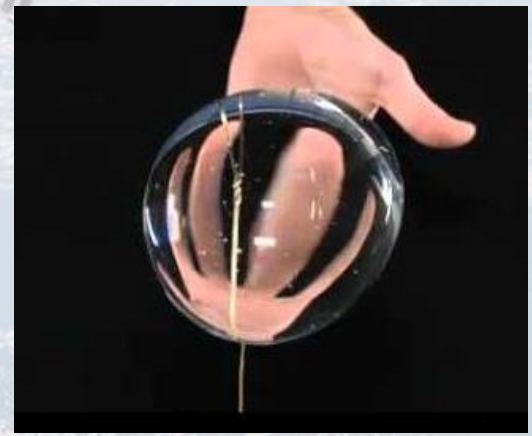
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Rahul Rameshbabu (Georgia Institute of Technology)

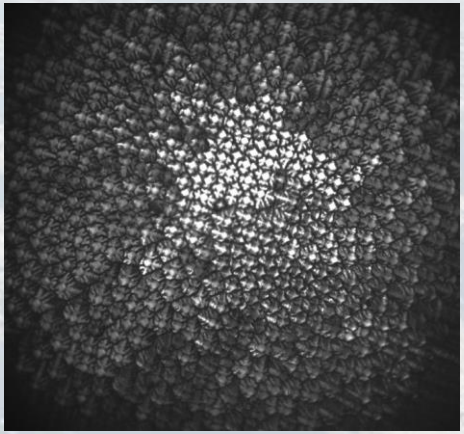
Microgravity Solidification Experiments for the ISS

Introduction to Microgravity

- Microgravity is the presence of a very weak gravitational force
- Commonly found near orbit (i.e. International Space Station)
- Microgravity reduces buoyancy and creates uneven particle distributions
- Microgravity also eliminates thermal convection
- Thermocapillary effects become primary in solidification in microgravity



Water with Minimum Buoyancy



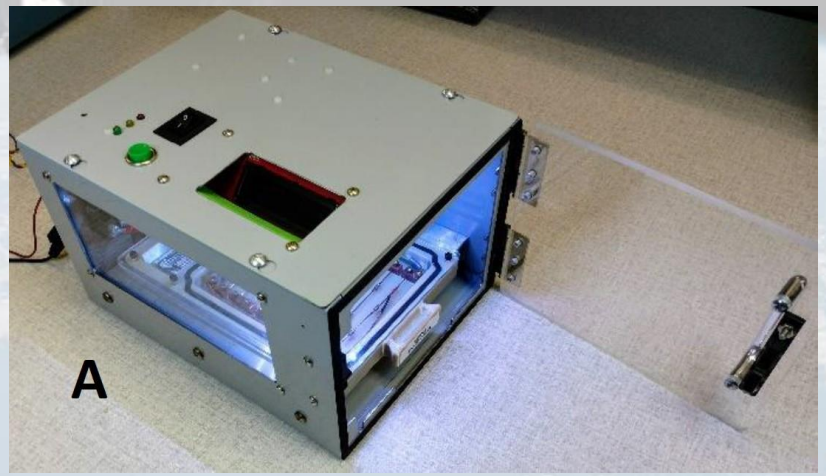
Cellular Pattern in Microgravity Taken by NASA

Microgravity Solidification Experiments for the ISS

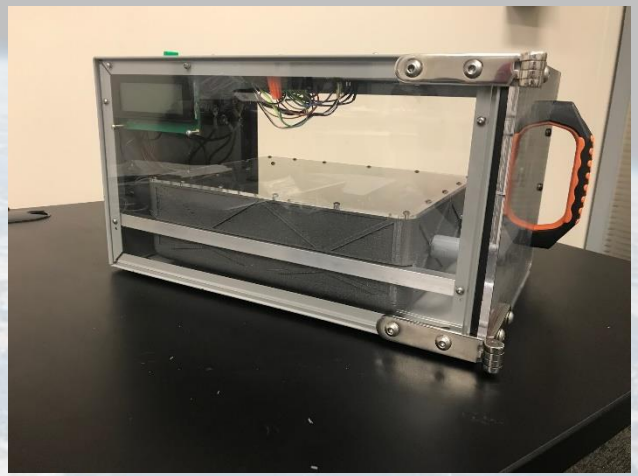
MMaJIC

Microgravity Material Joining Investigative Chamber (MMaJIC)

Prototype for ISS Space Hardware



First Prototype of MMaJIC Developed in 2017

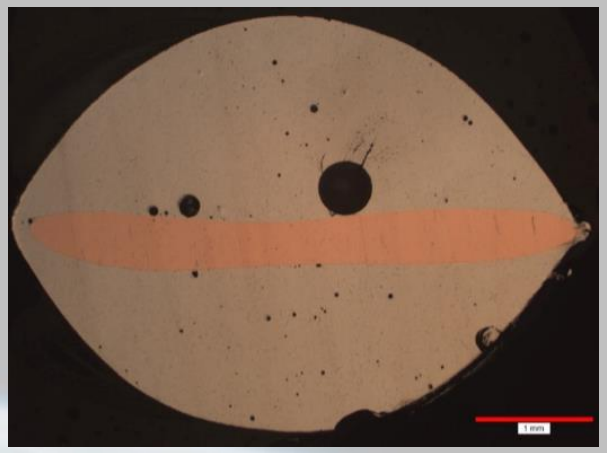


Second Prototype of MMaJIC Developed in 2018

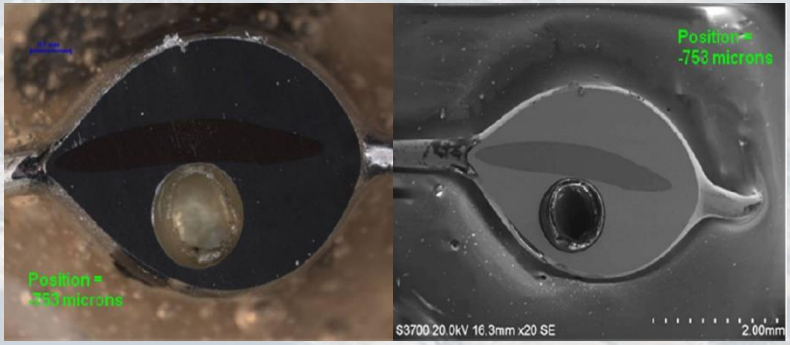
Microgravity Solidification Experiments for the ISS

Background of MMaJIC

- The study of soldering is a new topic that the ISS is investigating
- Solder joints will increase in porosity where wires connect
- The end result is that:
  - Weaker joints form
  - Electrical conductivity can be compromised
  - Thermal conductivity can be compromised
- To explore this concept, a housing apparatus is needed to be engineered



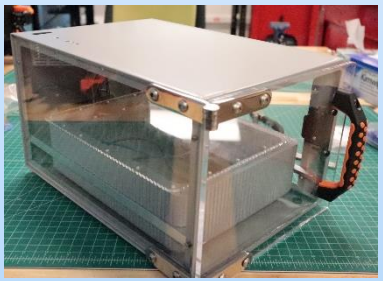
Optical micrograph view of flux bubbles forming in solder/copper wire



Micrographs from the ISSI experiments exhibiting a large bubble visible at the joint interface

Microgravity Solidification Experiments for the ISS

Requirements of MMaJIC

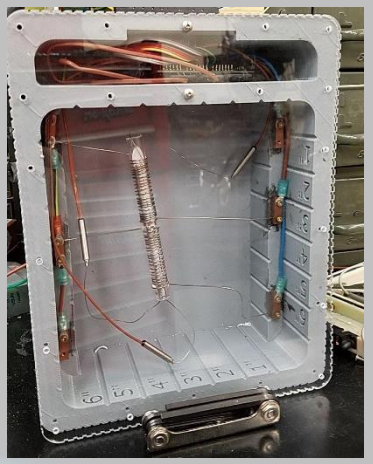
Mechanical	Electrical	Software/Controls	Experimental
• Interchangeable sample tray • Sealed and contained • Easy access for astronauts • Clear visibility for video recording	• Microprocessor (Arduino) • LCD display for monitoring status and temperatures • Temperature sensors and SD card storage • Camera monitoring	• Autonomous operation • Self-shutdown • Temperature control • Error detection	• Repeatable experiment • Sample trays that can be returned to Earth • Conduct multiple samples in tray • Obtain high quality video coverage
			

Requirements Table for MMaJIC

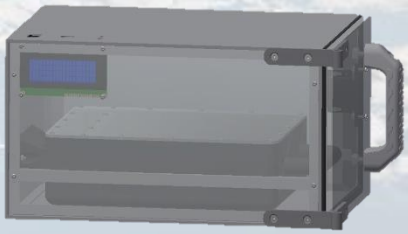
Microgravity Solidification Experiments for the ISS

MMaJIC Ground Prototype Features

- A housing chamber with a hinged door for access to trays
- 16V and 10 Amps can be supplied to kanthal wire around furnace
- Thermocouples storing temperatures and logs Time vs. Temperature of sample
- Temperature of wire and furnace can be controlled
- Shut-offs features for malfunctions, leaks, and absence of tray
- Only has power button



Tray for MMaJIC Furnace



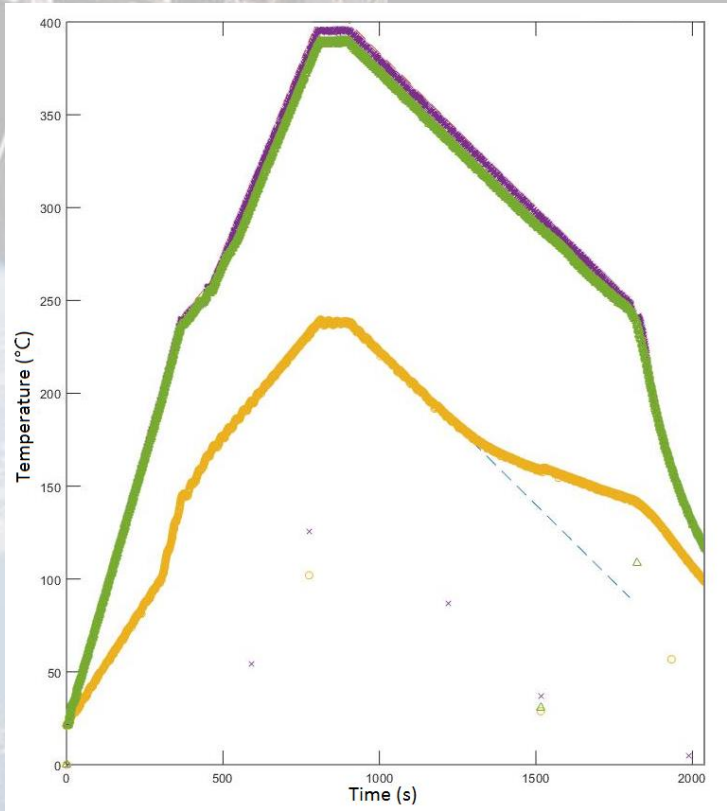
CAD Model of MMaJIC



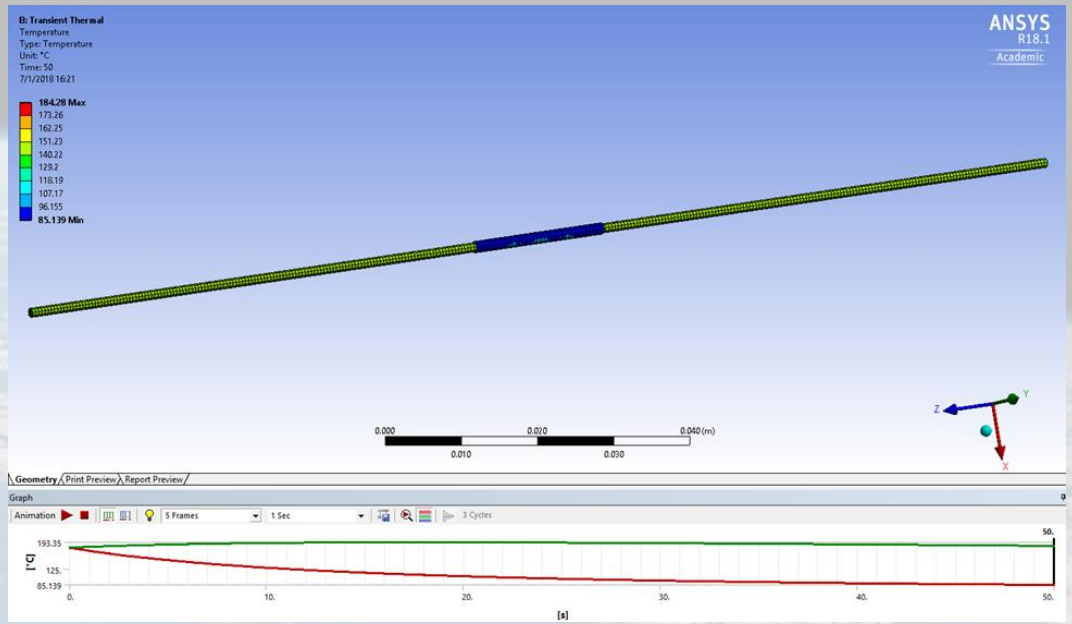
Tray for MMaJIC Solder Experiments

Microgravity Solidification Experiments for the ISS

MMaJIC Results



Solder Temperatures and Phase Change



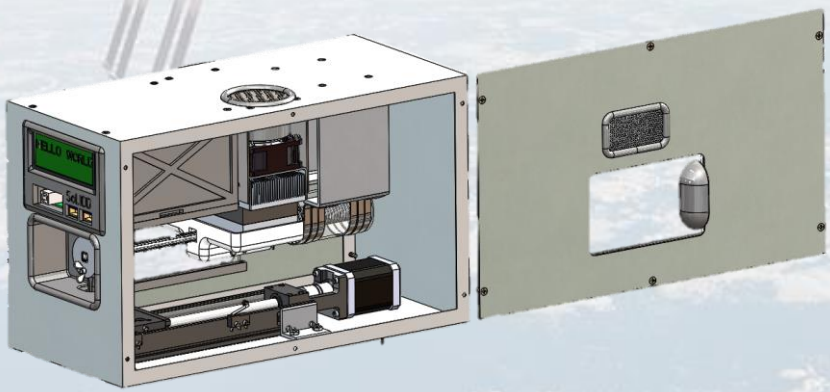
Transient Thermal Finite-Element Analysis (FEA)
Demonstrating Natural Cooling of Solder

Microgravity Solidification Experiments for the ISS

SoLIDD

Solid Liquid Interface Directional Device

Prototype for ISS Space Hardware



CAD Model of SoLIDD



Final Assembly of SoLIDD

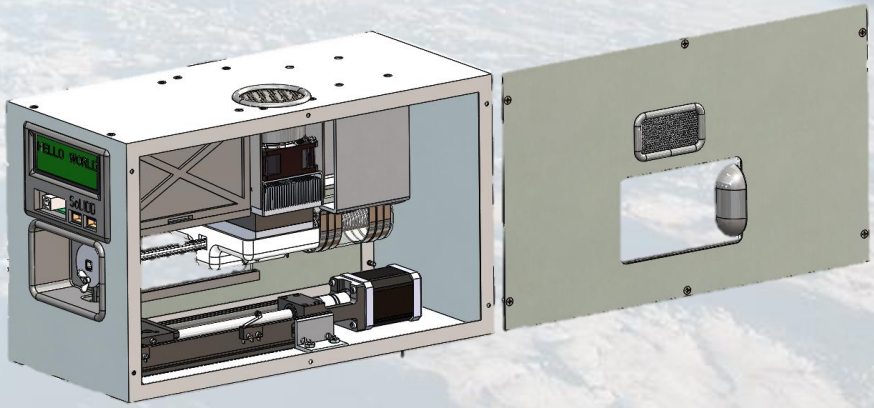
Microgravity Solidification Experiments for the ISS

Background of SoLIDD

- Pore Formation and Mobility Investigation (PFMI) was launched in 2002 to the ISS to study solidification growth
- It conducted over 20+ experiments until the unit was compromised
- This is highly important for casting for space manufacturing
- SoLIDD is the redesigned version of PFMI that looks at testing more samples
- SoLIDD contains a furnace, cooler, sample tube, and an actuator



PFMI Unit in MSG (Microgravity Science Glovebox)

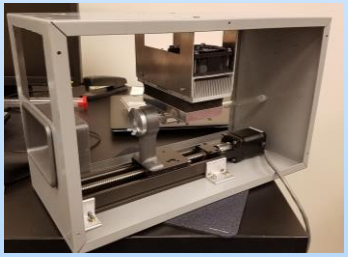


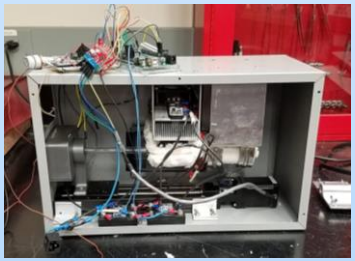
CAD Model of SoLIDD

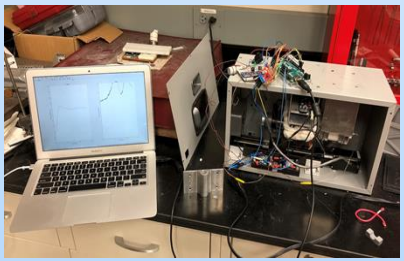
Microgravity Solidification Experiments for the ISS

Requirements of SoLIDD

Mechanical	Electrical	Software/Controls	Experimental
• Quick insertion of tube • Clear path to control panel, lights, and button • Actuator must transport sample • Furnace and cooler must be concentric and have contact with sample	• LEDs to designate status of sample • LCD display of status • Thermocouple monitoring temperature of furnace, cooler, and sample • Limit switches for actuator	• Autonomous operation • Self-shutdown • Temperature control • USB connection to ISS laptop for data • Programmable temperature setpoints and limits	• Must test metal and nonmetallic samples • Quick and easy for sample insertion • Camera monitoring • Multiple brackets for tube geometries • Cooler must have full contact with sample tube





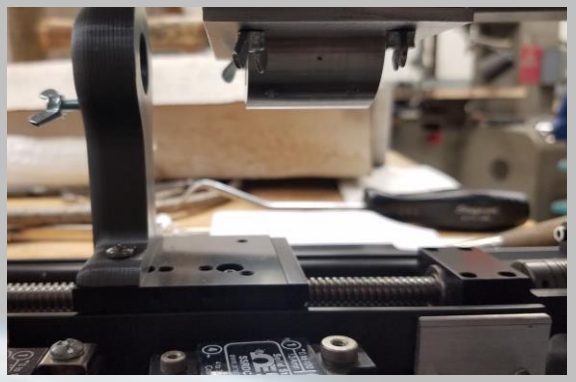




Requirements Table for MMaJIC

SoLIDD Ground Prototype Features

- A housing chamber with a user interface for sample insertion (via thumb screws)
- Sliding doors to change out cooler brackets (via thumb screws)
- 24V and 8 Amps can be supplied to kanthal wire furnace, electric cooler, and actuator
- Thermocouples storing temperatures and live-streams Time vs. Temperature
- Temperature of furnace and cooler can be controlled and once stable, the actuator drives the sample in



Sliding Door Opening for Interchanging Bracketing



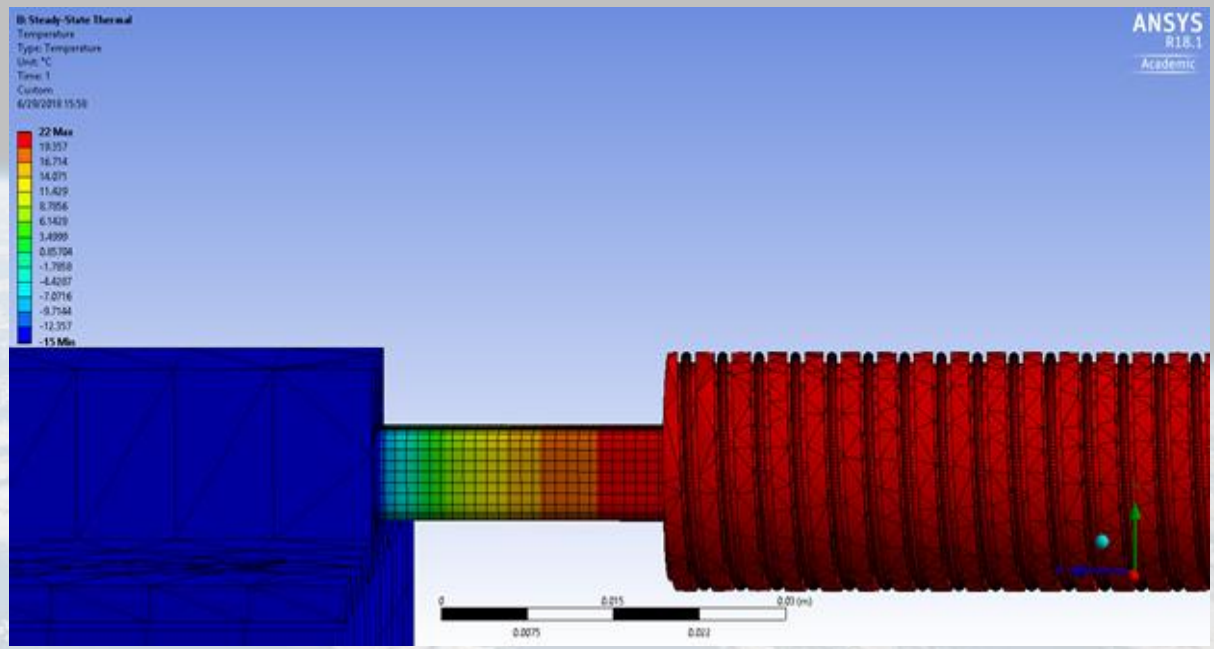
Sample Tube for SoLIDD

Microgravity Solidification Experiments for the ISS

SoLIDD Results



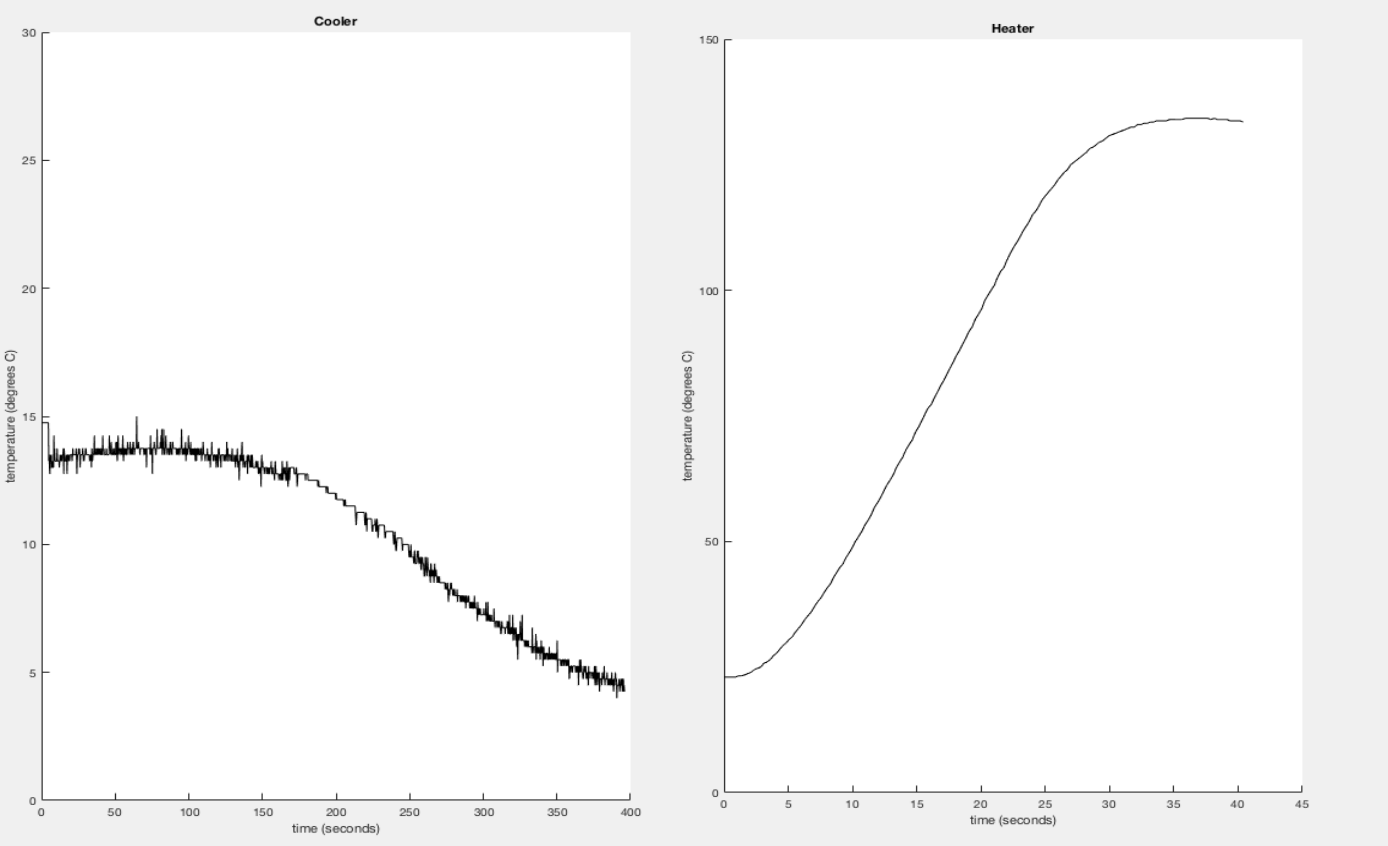
Successful Solid/Liquid Interface with Water and Ice



Steady-State Thermal FEA to Predict Solid/Liquid Interface

Microgravity Solidification Experiments for the ISS

SoLIDD Results



Controllers Limiting Temperature of Cooler and Furnace with No Overshoot

Outlook on MMaJIC & SoLIDD

- All mechanical, electrical, and autonomous systems worked for both experiments
- ISS officials at Johnson Space Center are highly interested in both experiments
- Could be contracted as space hardware for the Maintenance Work Area (MWA)
- MMaJIC will keep producing soldering and brazing samples in more trays
- SoLIDD will keep solidifying different materials in various sample tubes



Maintenance Work Area with Scott Kelly

Microgravity Solidification Experiments for the ISS

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Carey Harris – Engineering Assistance
David Dominguez – 3D Printing Assistance
Alabama Space Grant Consortium
Wisconsin Space Grant Consortium
NASA Marshall Space Flight Center
NASA MSFC Space Hardware/Robotics Academy

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Grugel, R. N., et al. "The In-Space Soldering Investigation (ISSI): Melting and Solidification Experiment Aboard the International Space Station." *44th AIAA Aerospace Sciences Meeting and Exhibit*. 2006.

Spivey, R., Gilley, S., Ostrogorsky, A., Grugel, R., and Smith, G. et al. “SUBSA and PFMI Transparent Furnace Systems Currently in use in the International Space Station Microgravity Science Glovebox.” AIAA 2003- 1362. *41th AIAA Aerospace Sciences Meeting & Exhibit*. 2003.