



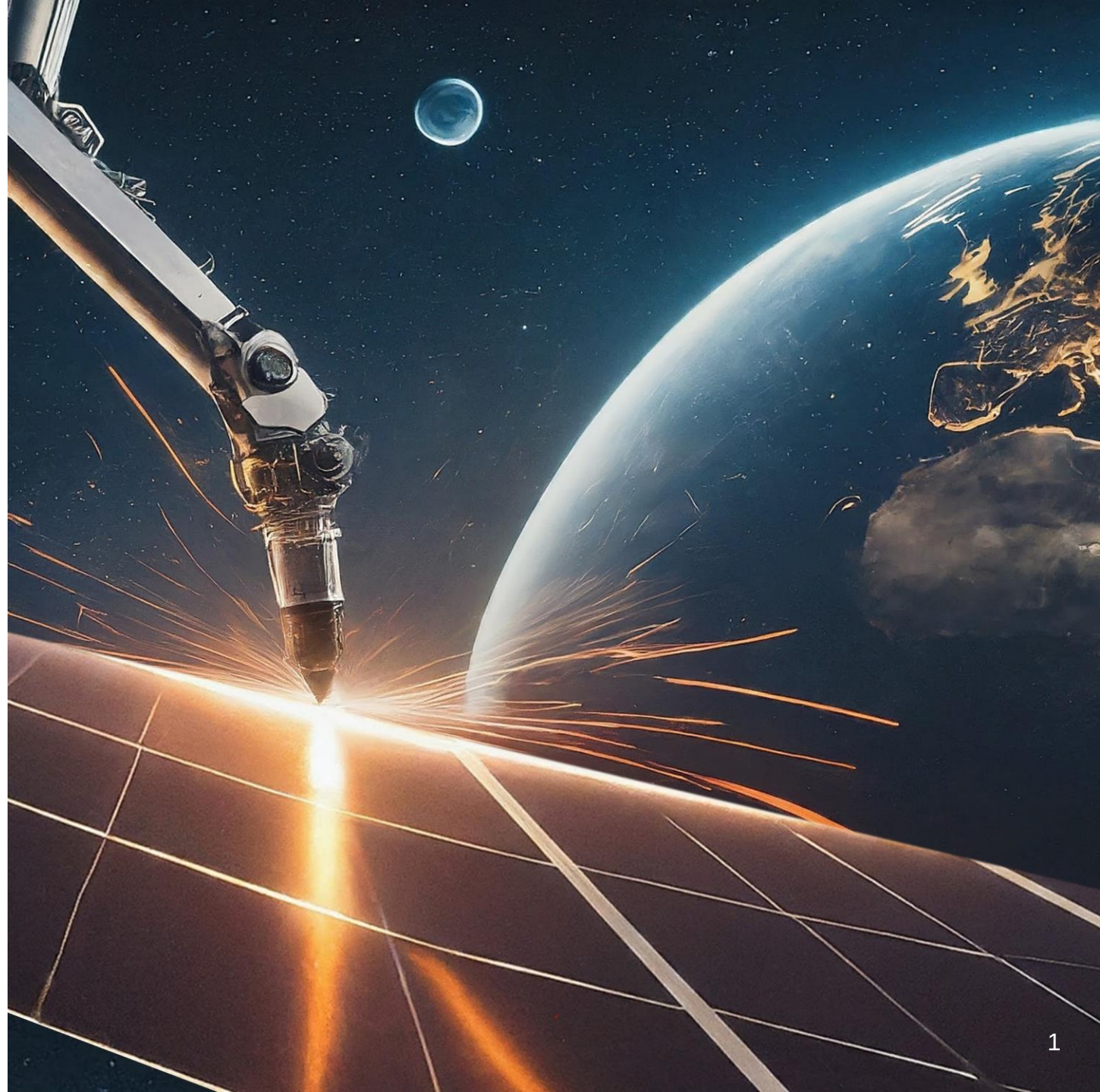
National Aeronautics and Space Administration

# Materials Joining Automation in Low Earth Orbit

Eric Brizes <sup>a</sup>

<sup>a</sup> NASA Glenn Research Center, Cleveland, OH

OFRN Opportunity Day. Virtual. March 20, 2024

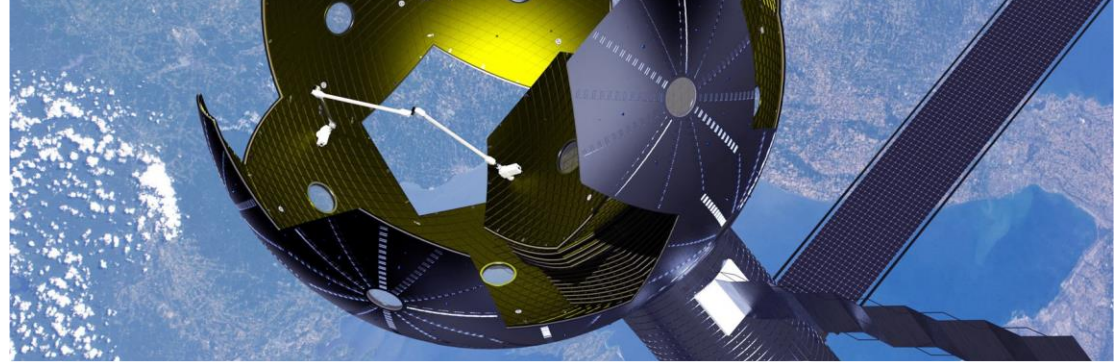


# Introduction

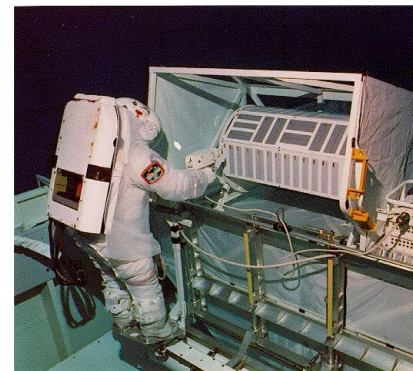
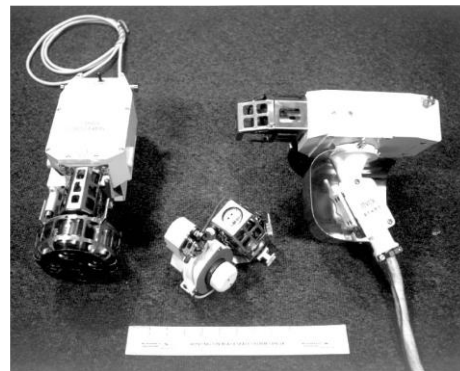
What does NASA envision for the future of materials joining in Low Earth Orbit?

- Robotic arms with weld heads strategically placed for component assembly
- Spider-like robots that climb trusses of spacecraft to join modules and expand structures
- Dedicated ISAM craft with programmable fusion welding capabilities

Ideally, limit dependence on astronauts for safety/reliability



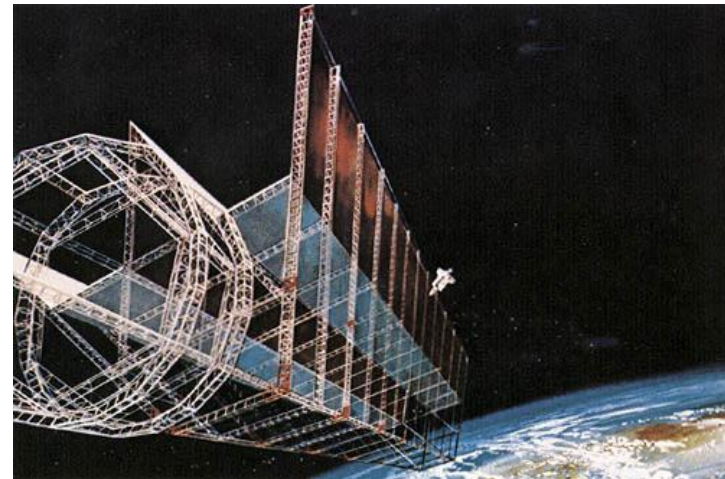
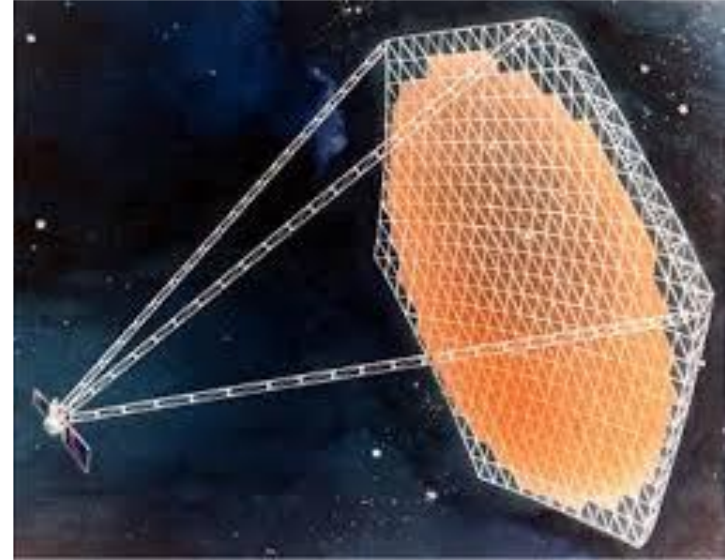
[1] J. Sowards



# Benefits of In-Space Welding

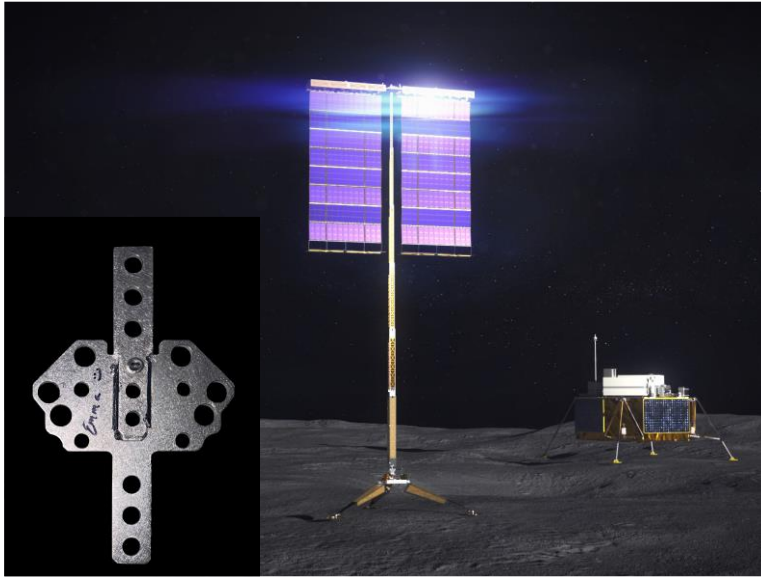
- Faster than mechanical fastening
- Joint strength matches the parent material with no added mass
- Welds are less susceptible to thermo-mechanical fatigue
- Joints can produce hermetic seals
- Enables component repair and servicing
- **Welding is crucial to overcoming launch vehicle size and volume constraints for building of large and complex structures in LEO**

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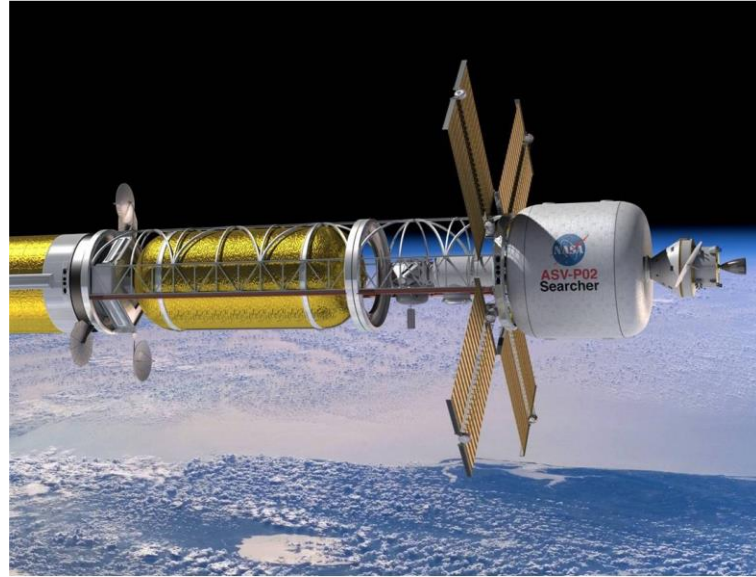


[1] J. Sowards

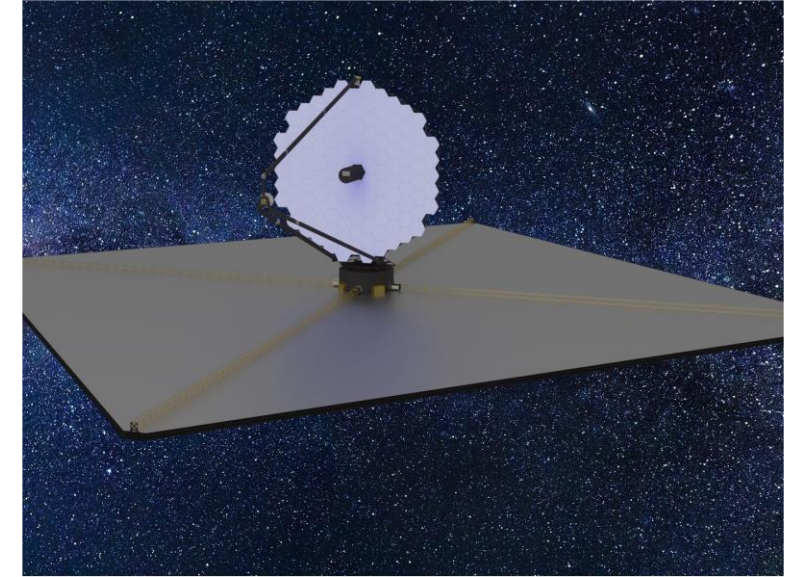
# Future Applications



Welding is being considered for joining truss connections of lunar solar arrays and communication towers. Tower truss connection made with handheld laser beam spot weld and lap welds.



Concept nuclear powered spacecraft; distance between inhabitants and the reactor to ensure astronaut safety from radiation. Welding is a candidate assembly process for building the structure.



Next-generation telescopes could benefit from welding in space. Shown above is the proposed Large UV/Optical/IR Surveyor (LUVOIR) telescope with its large sunshield system and a truss structure.

# Welding Process Considerations

**Table-3**  
Candidate Processes for In-Space Applications

| CRITERIA \ PROCESS         | EBW | GTAW | PAW | LBW |
|----------------------------|-----|------|-----|-----|
| OPERATOR/MISSION SAFETY    | ☐   | ○    | ●   | ●   |
| MICRO-G WELD QUALITY       | ○   | ○    | ○   | ○   |
| IVA & EVA FLEXIBILITY      | ●   | ○    | ○   | ○   |
| WORKPIECE VARIETY          | ☐   | ☐    | ○   | ○   |
| OPERATION MODE FLEXIBILITY | ○   | ○    | ○   | ●   |
| TOLERANCE FLEXIBILITY      | ☐   | ○    | ○   | ●   |
| POWER REQUIREMENTS         | ○   | ○    | ○   | ●   |
| ENERGY EFFICIENCY          | ○   | ○    | ☐   | ●   |
| CONSUMABLES REQUIREMENTS   | ○   | ☐    | ●   | ●   |
| EQUIPMENT SERVICEABILITY   | ☐   | ○    | ☐   | ●   |

LEGEND: ○ GOOD    ☐ SATISFACTORY    ● POOR

- What is the risk of malfunction and/or creation of reflected beams, weld spatter (micrometeoroids), or fumes?
- Can it be used both inside and outside of capsules/habitats?
- Is the process effective for a wide range of materials (aluminum, titanium, stainless steel, refractories) and joint designs?
- Will the equipment draw too much power?
- Does the joining process require an inert shielding gas or filler material?
- If the equipment breaks, will we be able to fix it?

[1] J. Sowards

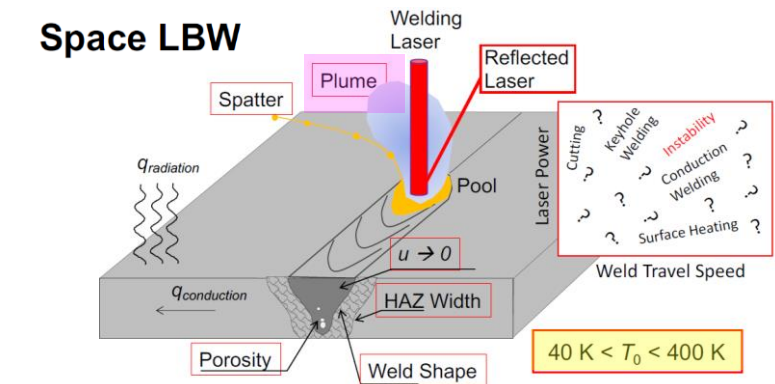
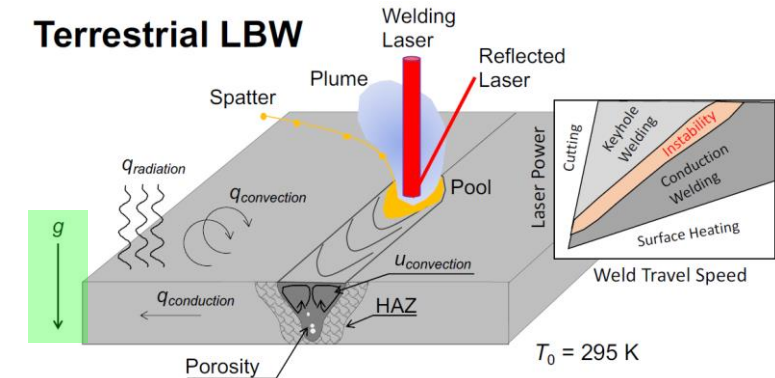
# Welding Parameter/Metallurgy Considerations

The following issues need to be addressed:

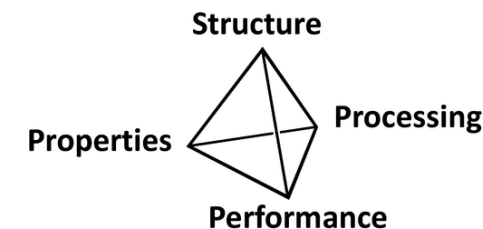
1. **Temperature** gradients and weld heat transport have profound effect on size of a weld and its metallurgical transformations and hence weld properties
2. Reduced **gravity** minimized buoyancy-induced convection which changes weld pool shape and porosity evolution
3. The **vacuum** of space promotes volatilization of light elements and modifies the dominant heat transport mode from convection to radiation.

How do these problems influence the materials tetrahedron?

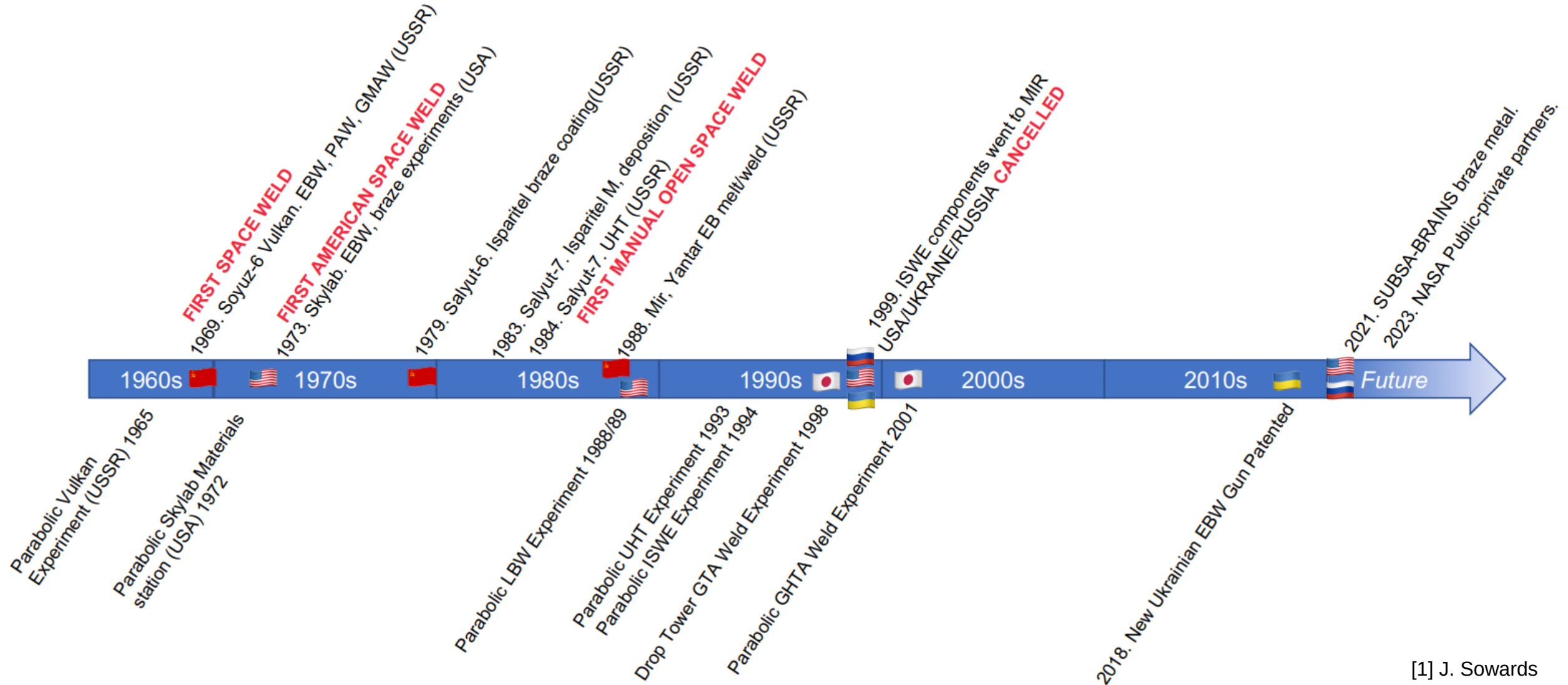
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# Timeline of In-Space Welding Activities



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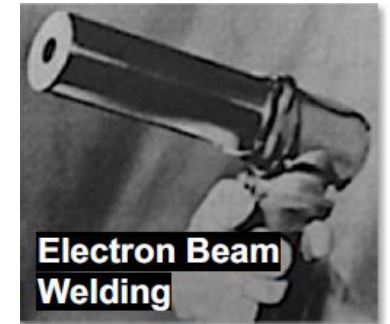
# Key Findings from Historical Experiments

- Electron Beam Welding, Gas Tungsten Arc Welding, Plasma Arc Welding, and Gas Metal Arc Welding have been demonstrated in-space.
- Laser Beam Welding has been demonstrated under vacuum/microgravity
- The strength of in-space welds are comparable to terrestrial welds
- Need to reduce reliance on astronauts
- Need to carefully consider safety reflected energy beams, spatter, fumes

But it has been over 50 years since the last American in-space fusion weld...

New technologies like laser beam welding have significantly advanced.

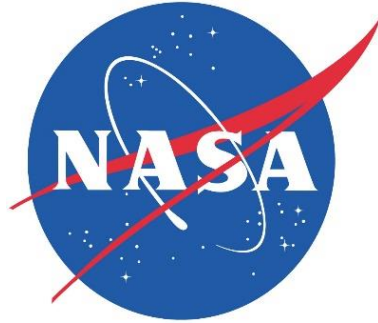
[1] J. Sowards



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# OFRN Project: Structural Materials Joining in Space



## ROUND 6 – AOI 5 Commercial Space in LEO

### 609 – Materials Joining and Automation in LEO

- In-person Kick-off meeting at NASA-GRC 12/5/2023
- Addressing NASA and AFRL need to develop joining of materials (metals, polymers, and composites) in LEO
- Hires to Date: 2 Engineers, 1 Graduate Research Associate, 11 Undergraduate Research Assistants, 1 Team Member at EWI

[2] E. Choi

# OFRN Project: Structural Materials Joining in Space



## Objectives

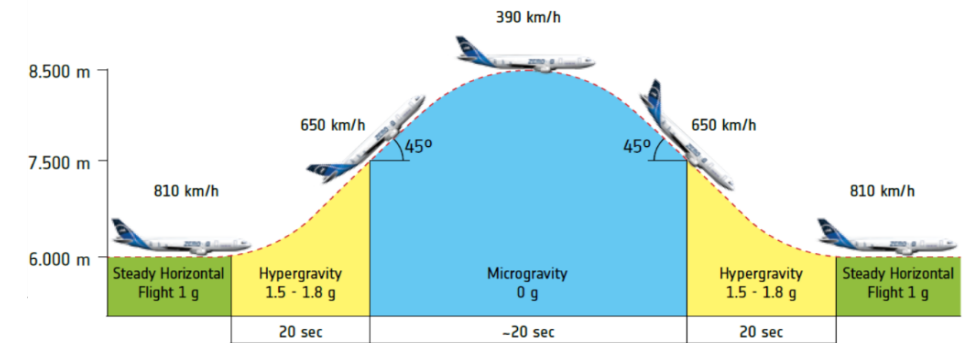
1. Mature the technology readiness level of LEO laser beam welding
2. Data collection for Integration Computational Materials Engineering (ICME) and other parallel modeling efforts
3. Understand the weldability of common aerospace alloys in the LEO environment

Performing joining processes in a self-contained vacuum chamber welding system aboard a parabolic variable gravity flight to reproduce in-space conditions.

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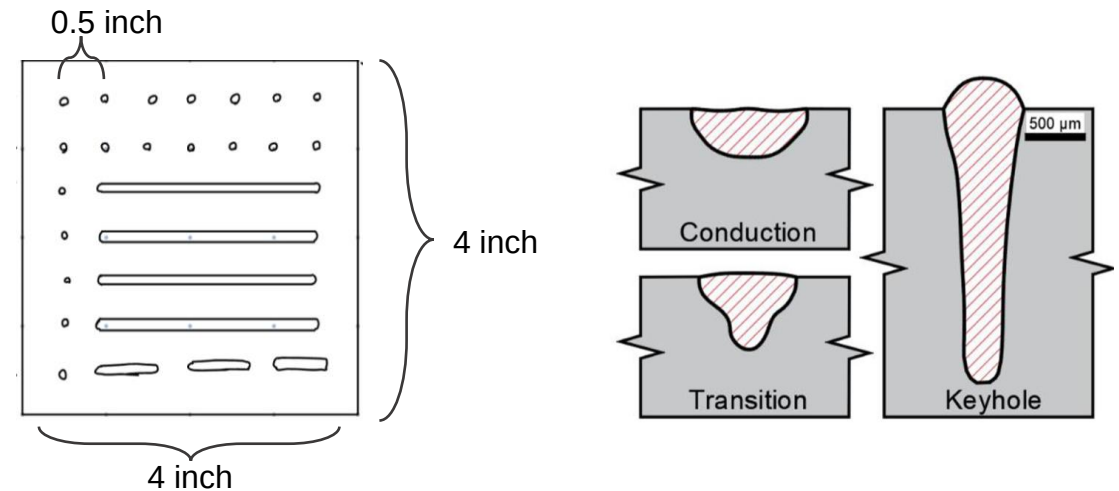
# OFRN Project: Structural Materials Joining in Space



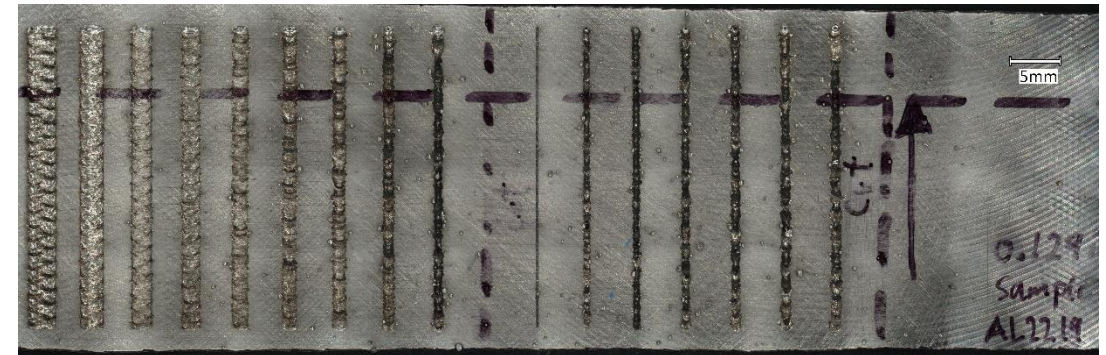
## Test Plan

- Materials
  - AL 2219, 316L SS, Ti-64
- Parabolic flight test conditions
  - Micro-gravity to hyper gravity
  - 0g ~ 1.8g
- Weld Parameters
  - Spot, bead on plate, lap-welds
  - Power, travel speed, focus, pulsing
- Temperature
  - Ambient temperature (293°K)
- Pressure
  - Weld Chamber:  $10^{-6}$  Torr
  - Low Earth Orbit (LEO):  $5 \times 10^{-8}$  Torr

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## Post-Test

- Data Analysis
  - Thermal and optical video for heat flow & laser plume physics
  - Accelerometer for gravity
- Weld Characterization
  - Optical microscopy, SEM / EDS / EBSD
  - Microhardness mapping



Xiris XIR-1800 Thermal Camera



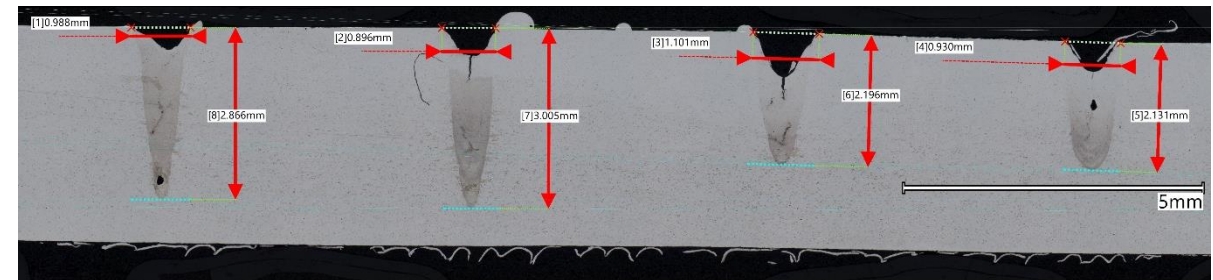
XVC-700 Weld Camera

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## Determine:

- The root cause of physical & metallurgical differences of in-space welds
- New allowables for the mechanical performance of LEO welds

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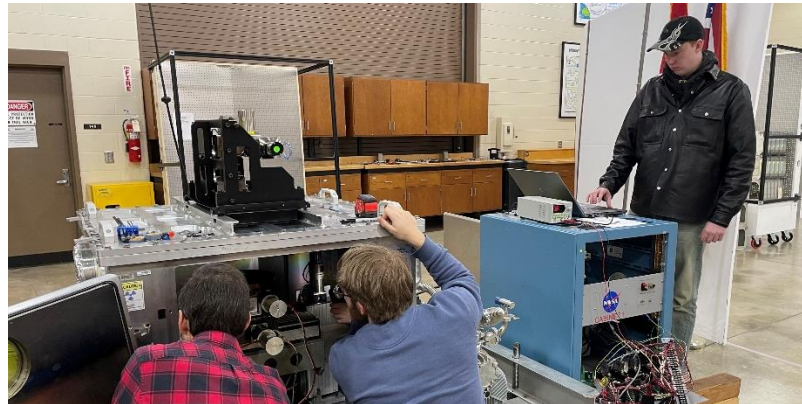
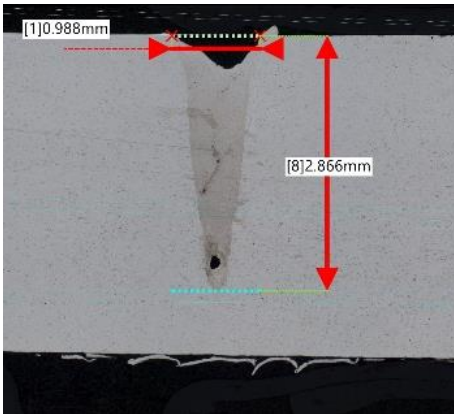
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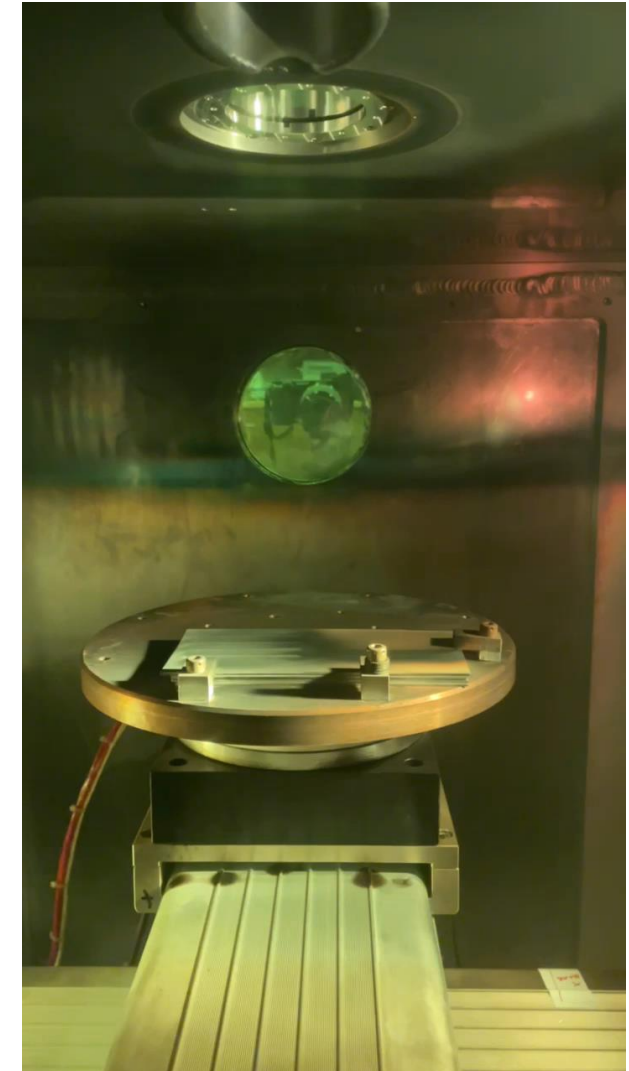
## Current Status

- Analysis of terrestrial weld parameters in atmospheric & vacuum condition
- Parabolic flight test parameter development
- Zero-G payload integration package regulations
- Camera and sensor integration for data collection

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## Future Work

System  
Upgrades:  
Temp/Sens.

Adaptation to Other Processes:  
Ultrasonic Welding, Cold Welding

Low Earth Orbit  
Laser Beam  
Welding

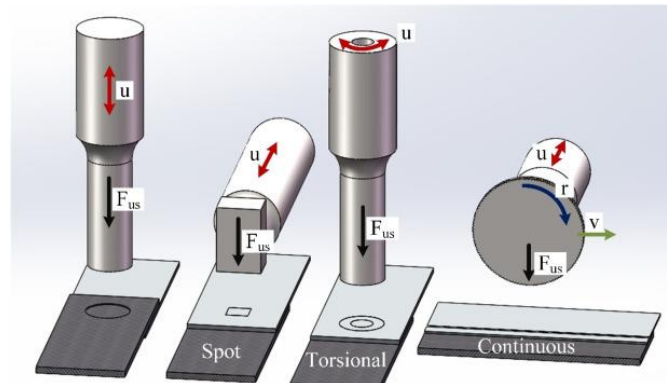


1<sup>st</sup> Parabolic  
Flight  
(Jul. 2024)

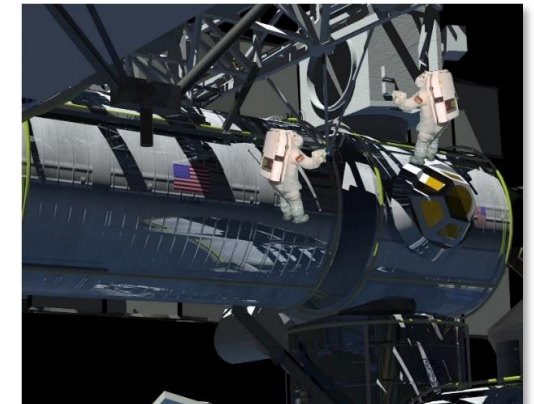
2<sup>nd</sup> Parabolic  
Flight  
(Jan. 2025)

Development of  
In-Space  
Welding System

[2] E. Choi



[2] E. Choi



# Get Involved

Please contact the team:

## OSU

- Prof. Antonio Ramirez
- Prof. Boyd Panton
- Eugene Choi

## NASA

- Jeff Sowards (MSFC)
- Eric Brizes (GRC)

## AFRL

- Andrew Hamilton

### Acknowledgements

#### OSU

A. Brimmer  
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M. Monocolova  
E. Sichel  
D. Adengada  
J. Horack  
N. Ames  
A. Nassiri  
K. Riffel  
D. Williams  
M. Mowrer  
C. Tkach

#### AFRL

A. Smith  
A. Gillman

#### NASA

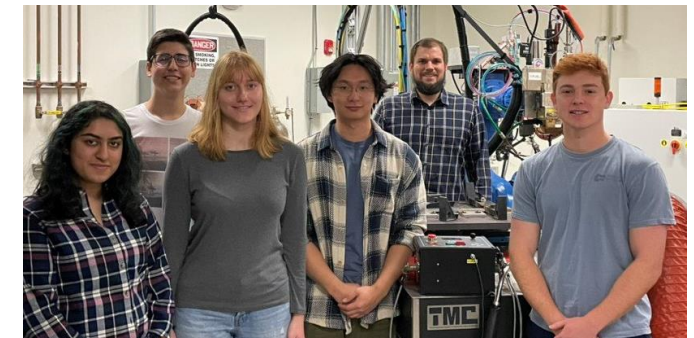
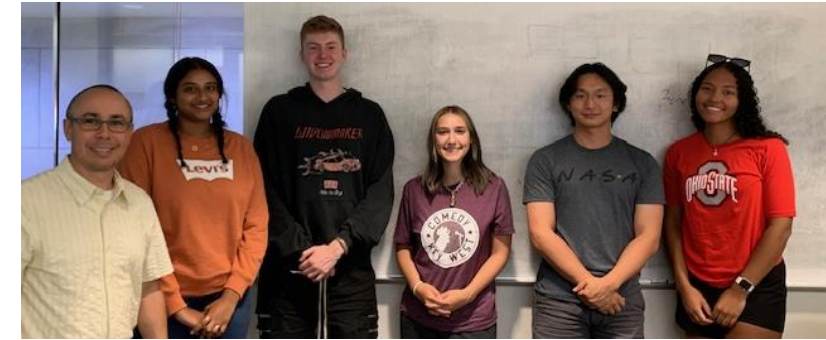
MSFC  
A. O'Connor  
W. Evans  
Z. Courtright  
E. Jaynes  
T. Bryan  
L. Littles  
C. Protz  
LaRC  
K. Taminger  
B. Taminger  
D. Mercer  
GRC  
B. Carter  
S. Miller

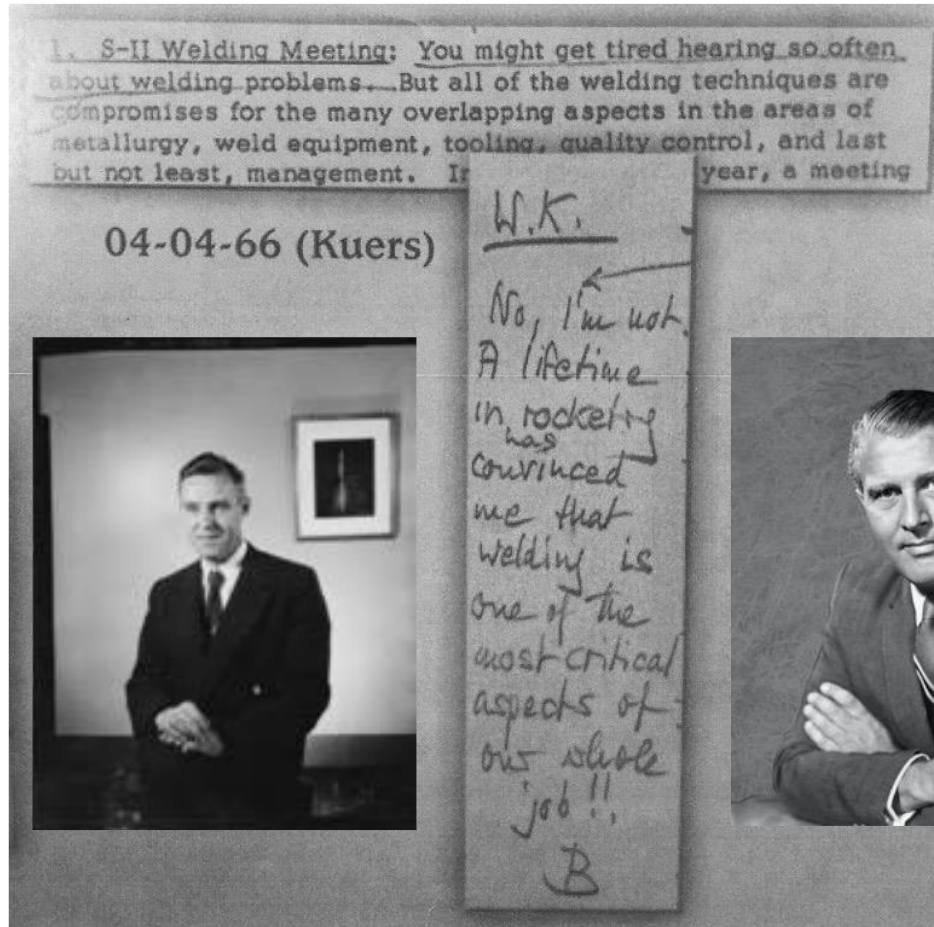
#### Lincoln Electric

E. Ash  
A. Croft

#### EWI

J. Hay





[1] J. Sowards

A lifetime in rocketry  
has convinced me that  
welding is one of the  
most critical aspects of  
our whole job!!

- Wernher von Braun (1966)

**Werner Kuers**  
MSFC Manufacturing  
Laboratory Director

**Wernher von Braun**  
MSFC Center Director,  
Deputy NASA Admin



# References

1. J. Sowards, "Welding in Space: Past, Present, and Future," *2023 AWS Professional Program*, Chicago, IL, 2023.
2. E. Choi, A. Brimmer, W. McAuley, S. Huetter, G. Smith, A. Shajahan, R. Morton, K. May, B. Panton, A. J. Ramirez, "Integration and Ground Demonstration of Self-Contained Laser Welding System for Parabolic Microgravity Experiments," *2024 Worldwide Advanced Manufacturing Symposium*, Orlando, FL, 2024.

