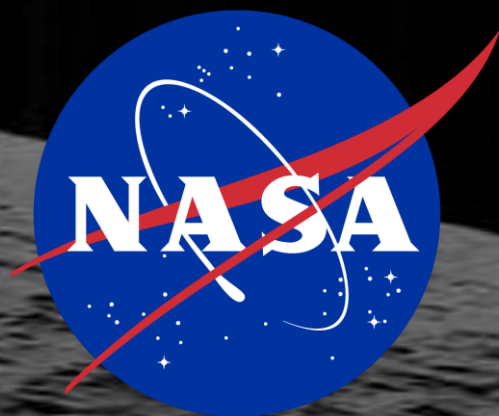




Lunar Assembly and Service by Autonomous Robotics (LASAR): Towards laser manufacturing on the Lunar surface

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Introduction

To support development of Lunar infrastructure, LASAR will enable:

- Structures such as the Tall Lunar Tower (TLT) assembled and joined on the Lunar surface
- Laser beam welding attuned for a thermal vacuum (TVAC) environment resembling the Lunar surface
- Supervised autonomy using flight-forward computer such as the High-Performance Spaceflight Computer (HPSC)
- Non-contact non-destructive evaluation (NDE) of welds followed by repair in TVAC

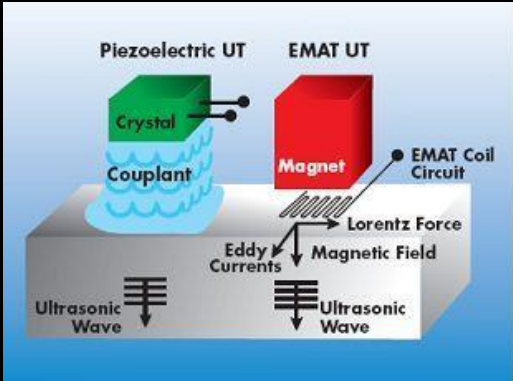
Objectives

Demonstrate:

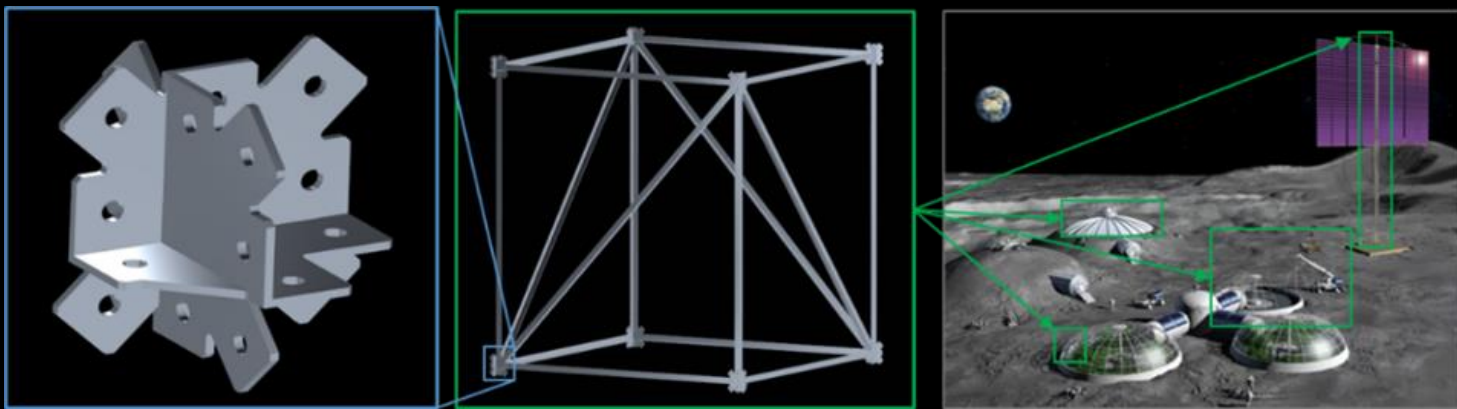
- Laser optics ruggedized for TVAC
 - Cryogenic and elevated temperatures; vacuum
- Laser beam welding (LBW) and repair within TVAC using appropriate parameters
- Non-contact non-destructive evaluation (NDE) of welds suitable for space environment by Electromagnetic Acoustic Transducer (EMAT)
- Innovative “Snowflake” joint geometry suitable for use in Lunar infrastructure such as TLT, readily welded
- Supervised autonomy of robotic arm hosting laser optics running on flight-forward computer



Vacuum and temperature capable robotic platform



EMAT



Depiction of “Snowflake” joint connecting truss in TLT

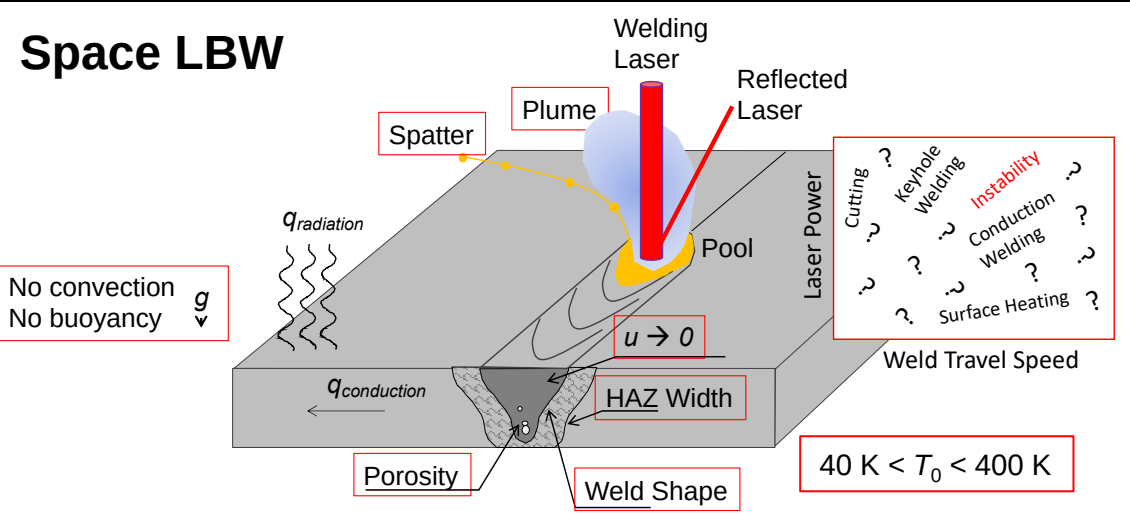
State of the Art

Welding promising for in-space joining (at right).

Laser Processing

- Focused laser beam suitable for welding
- TVAC alters welding parameters
- Laser optics not designed for TVAC

Method → ↓ Criteria	Fasteners/ rivets	In-Space Welding (ISW)
Joint strength & rigidity	●	○
Joint hermeticity	●	○
Joint mass	●	○
Joint design & manufacturing simplicity	●	○
Joint reliability	●	○
Repair versatility	●	○
Associated cost & upmass	●	○
● - Poor ● - Satisfactory ○ - Good		

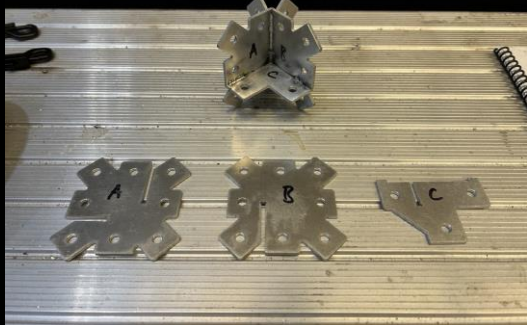


Robotics

- Commercially available robotic manipulators are not TVAC compatible
- Realtime, precise 6 Degree of freedom positioning not available in TVAC
- Autonomous manipulation with perception untested in TVAC

Structure

- Snowflake joint assembly originally designed for fillet welds
- Design will be iterated to better accommodate spot and/or lap welds



“Snowflake” joint assembled and hand-welded

Methodology

Innovative Project Management Approach

- Hybrid, Adaptive PM
- Objectives divided by sub-team; matrixed with external partners
- Two-week Agile sprints

Sub-teams

Laser Processing

- Laser welding and NDE systems
- Integration of manufacturing platform components

Robotics

- Advanced robotics software demonstrated on HPSC computer hardware

Structures

- Snowflake joint design iterations
- Assembly fixturing, structural performance of welds

External Partners



Ruggedized LBW (delivery fiber and optics) for TVAC

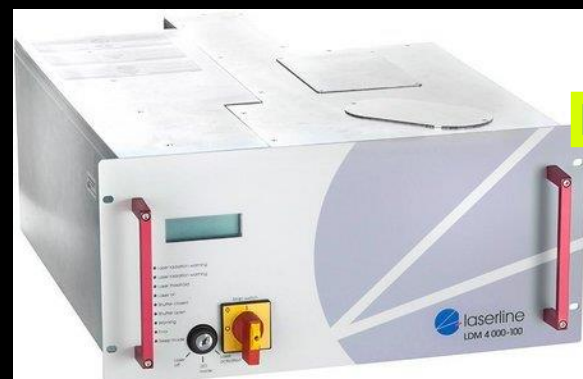


TVAC capable robotic manipulator

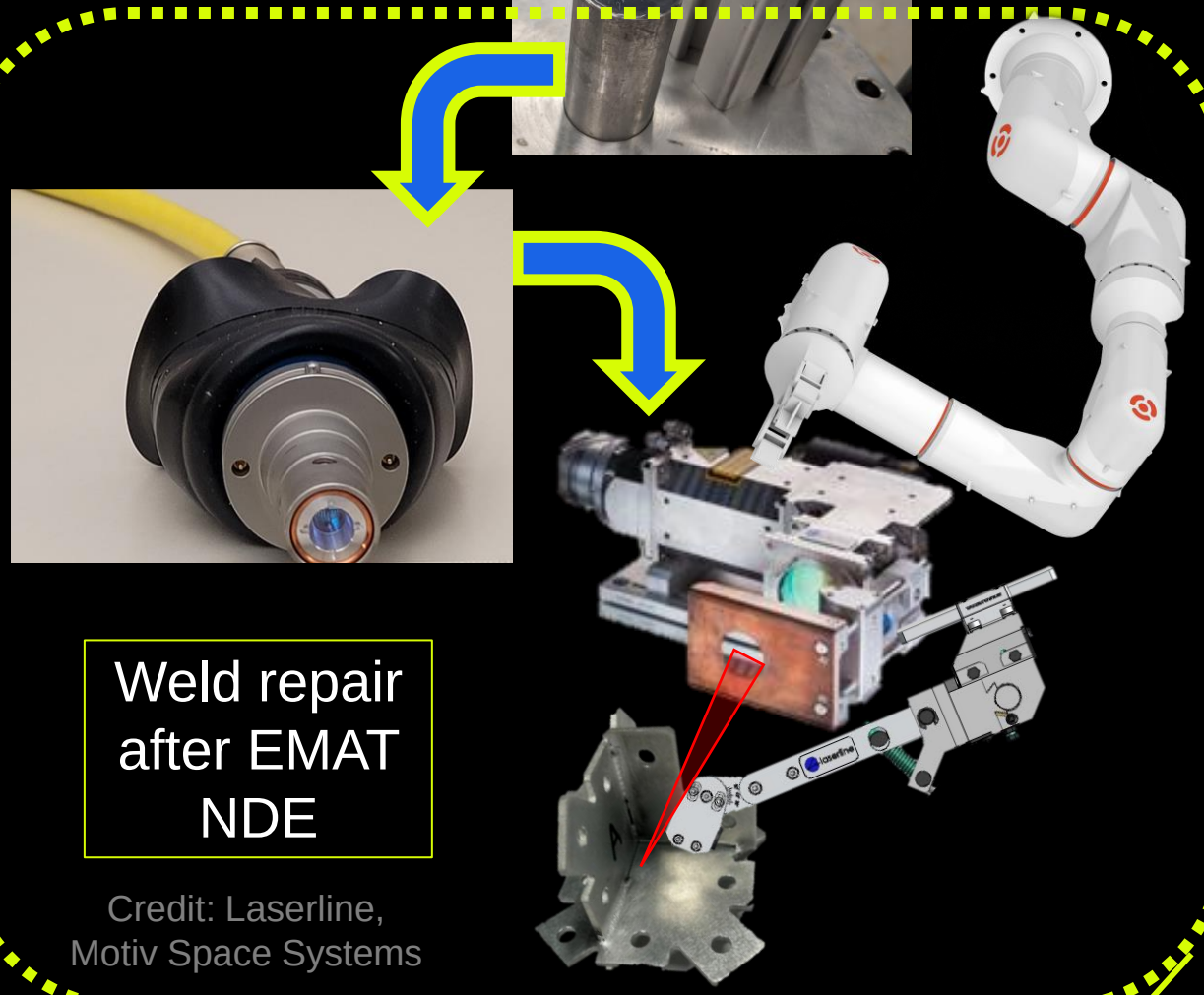


Motion planning and robotic perception software

Robotic LBW within TVAC



Notional depiction of integrated TVAC LBW demonstration with ruggedized optics on robotic arm



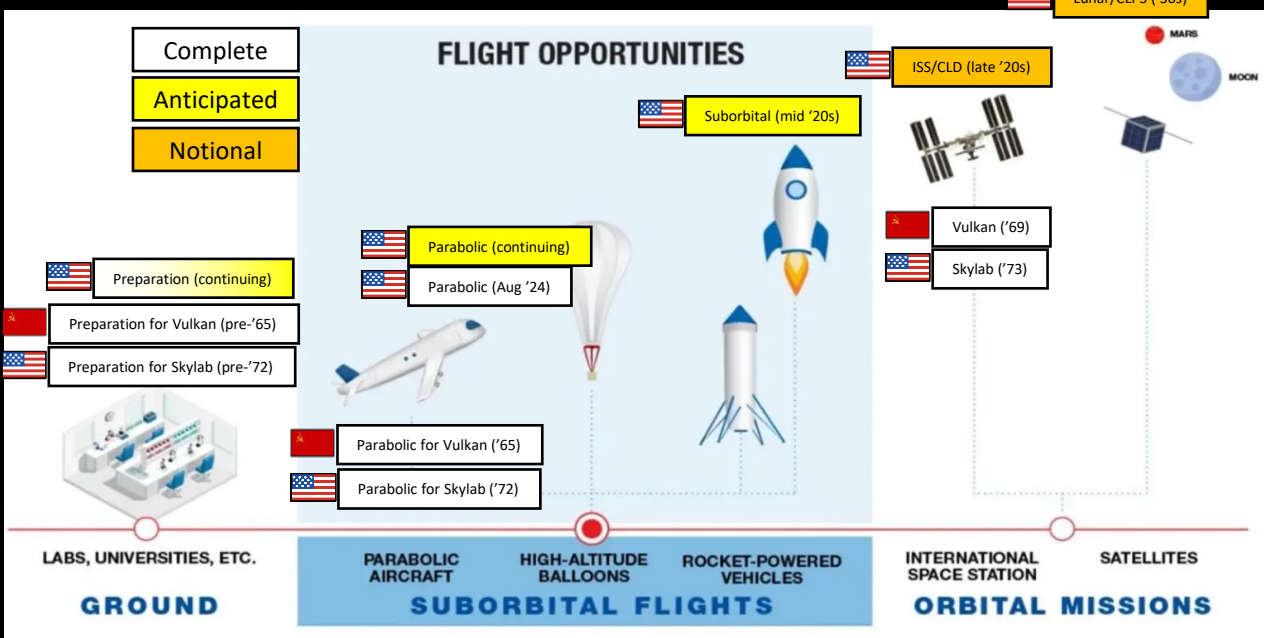
Components within dashed lines are within V-20 TVAC at MSFC (shown above)

Post-weld characterization:

- Metallography and chemistry
- Mechanical testing
- Assessment of TVAC compatibility

Related and Future Work

Related work includes a variety of ground and flight experiments to progress LBW towards in-space use:

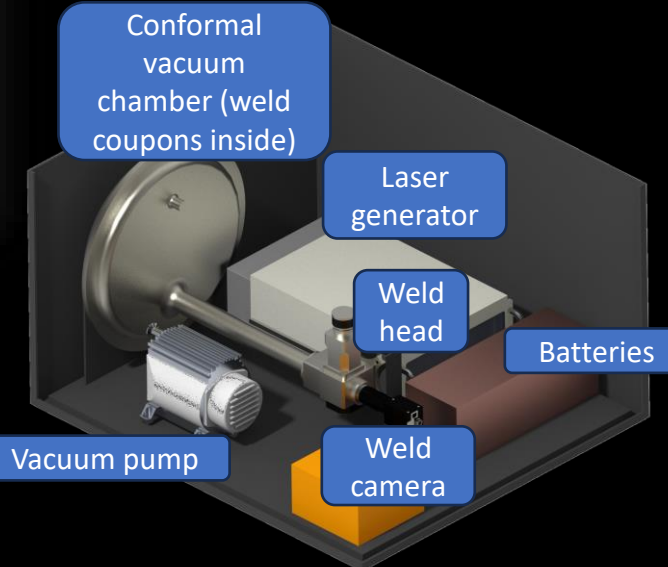


Underlying graphic from Kelly et al. in ASCEND 2020, 2020. doi:10.2514/6.2020-4135. USG work.

Technology maturation of LBW following archetypal progression of flight experiments from Earth to Moon



Parabolic flight of LBW within vacuum chamber demonstrated with common aerospace alloys; results to anchor computational models



Conceptual design for suborbital LBW experimental module developed with MSFC Advanced Concepts Office; prototyped with initial operating capability on ground



The laser welding test setup in the Flat Floor Robotics Lab. To the left, the space tug approaches the robotic arm that will perform the weld. To the right, the parts to be welded together are shown.

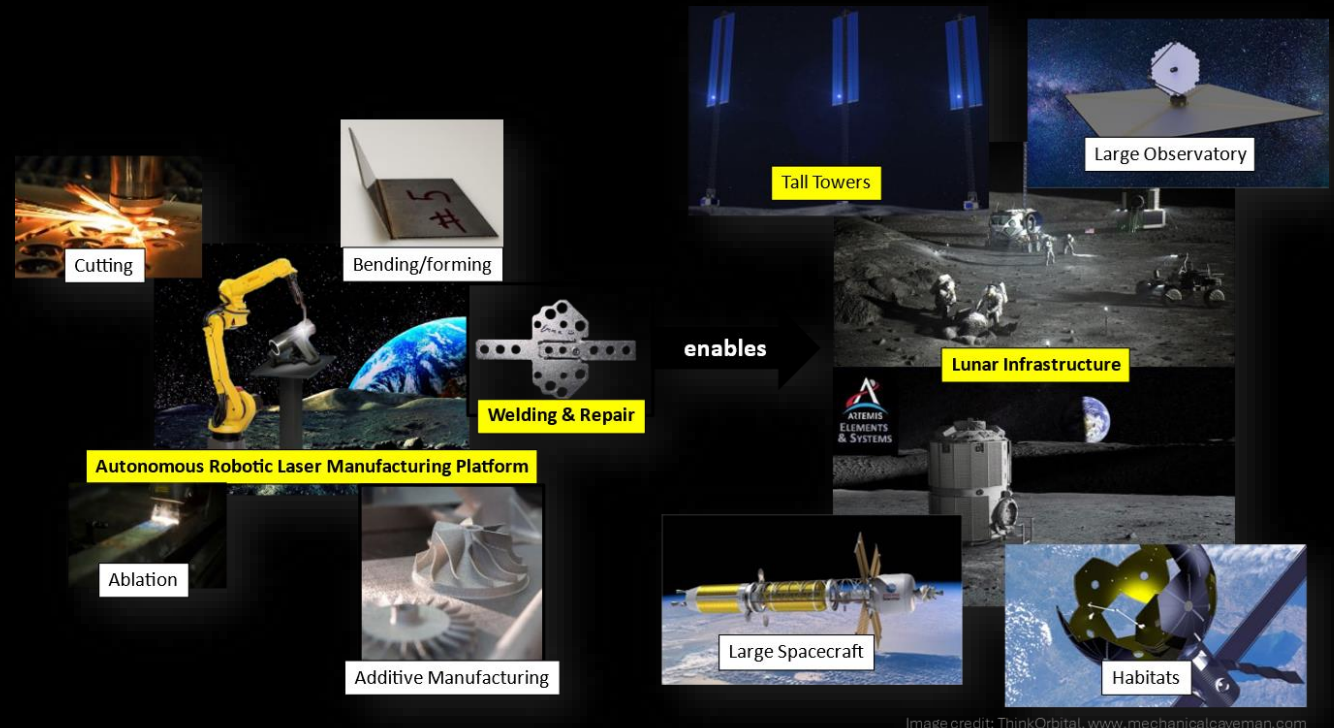
To enable a prospective Lunar surface demonstration, the following tasks remain:

- Ruggedization of laser generator (diodes, controls, etc.) for TVAC, radiation, shock/vibrations, etc.
- Ruggedization of scanning laser optics to facilitate laser forming, additive manufacturing, and more
- Dexterous manipulation of joint into fixturing
- Reduction of SWaP to suit CLPS or similar
- Protection of laser optics from metal vapor

Conclusion

LASAR will serve as the first demonstration of robotic in-space welding within a TVAC environment to progress towards in-space manufacturing on the Lunar surface. Afterwards, these capabilities will exist:

- Cryogenic and elevated temperature LBW
 - Simultaneously within hard vacuum
- Decoupling of laser generator from laser optics, optics being ruggedized for the Lunar surface
- Non-contact NDE of welds apt for Lunar surface
- Weld repair within TVAC
- Innovative “Snowflake” joint geometry suitable for multiple assembly & joining methods
- Supervised autonomy using flight-forward compute



Acknowledgements

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