In-Space Incremental Sheet Forming

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Background

- Single-Point Incremental Sheet Forming (SPIF) is an adaptive manufacturing process for producing various complex sheet metal parts on Earth.
- Involves incrementally deforming clamped sheets of material using forming tools and programmed tool paths.
- As the tool moves along the surface of the sheet, it progressively displaces the sheet into the desired shape through localized plastic deformation.
- SPIF is entirely controlled by CNC processes within an XYZ plane, eliminating the use of specialized dies and components commonly used in traditional sheet metal forming techniques.

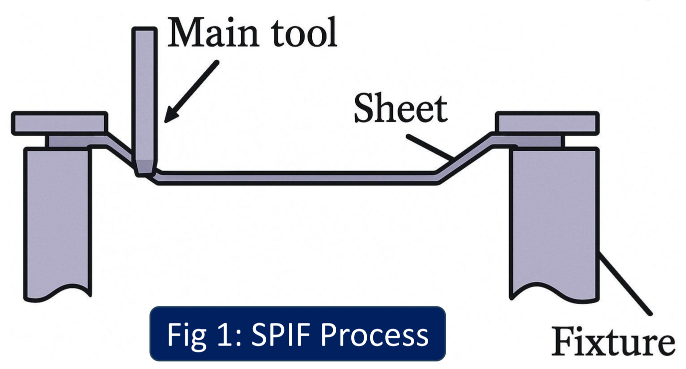


Fig 1: SPIF Process

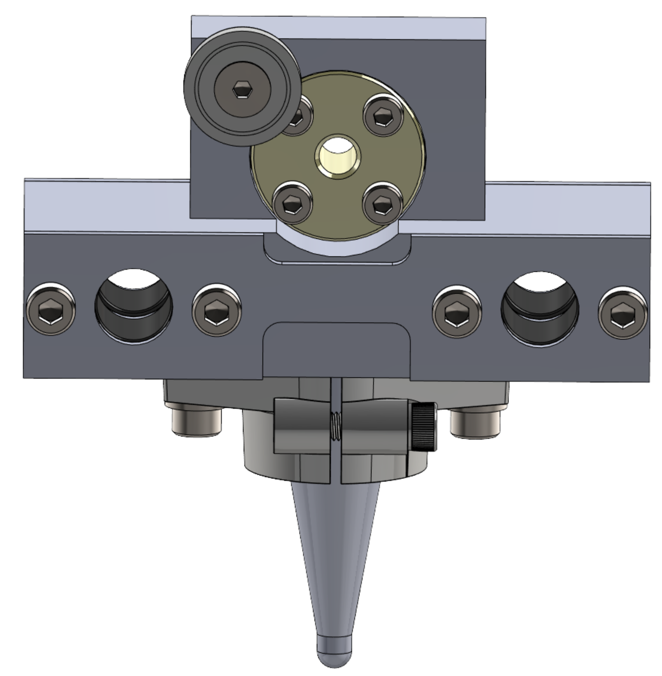
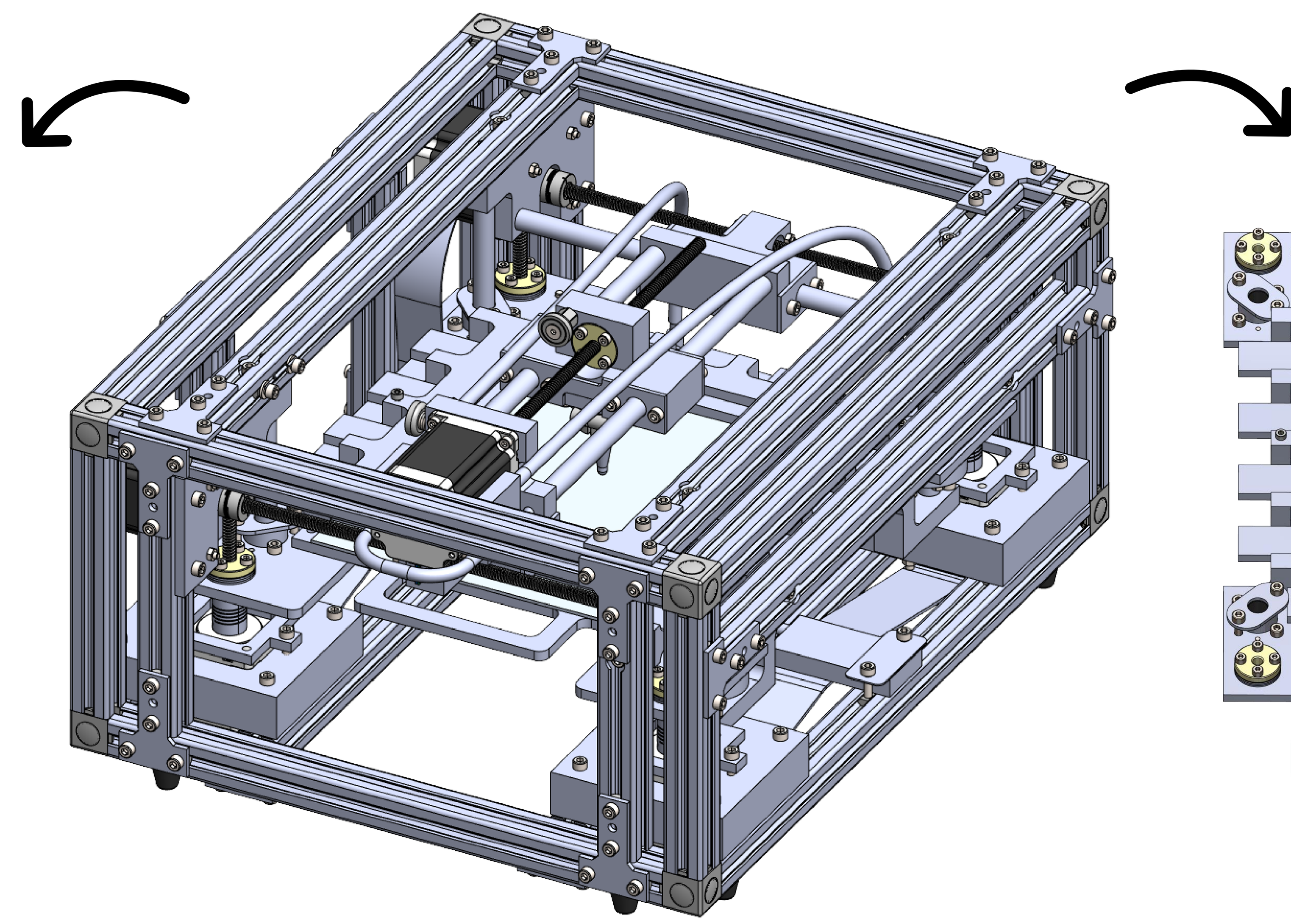


Fig 3: Sheet Forming Tool



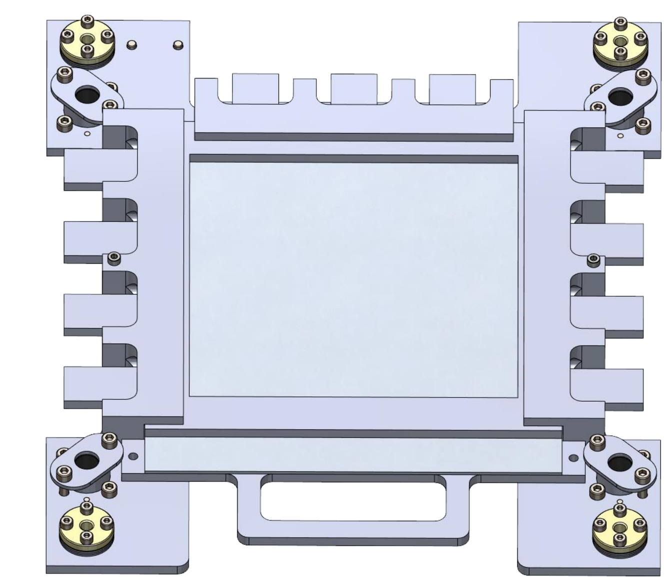


Fig 4: Sheet Clamping System

Clamping System

- Conventional ISF machines use bolted "sandwich" to fix workpiece. Instead, we have designed an entirely new mechanism using static friction.
- Banks of stacked wave springs exert varying normal forces onto workpiece based on workpiece thickness.
- Changing workpiece is substantially quicker, eliminating possible free-floating bolts in microgravity.
- Lowering the z-axis (clamping system) onto aluminum blocks compresses springs off the workpiece, allowing for workpiece to be removed.

Fig 14: Wave Springs

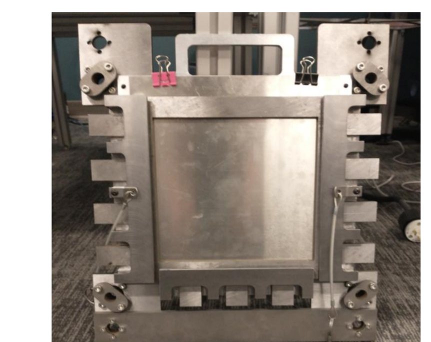


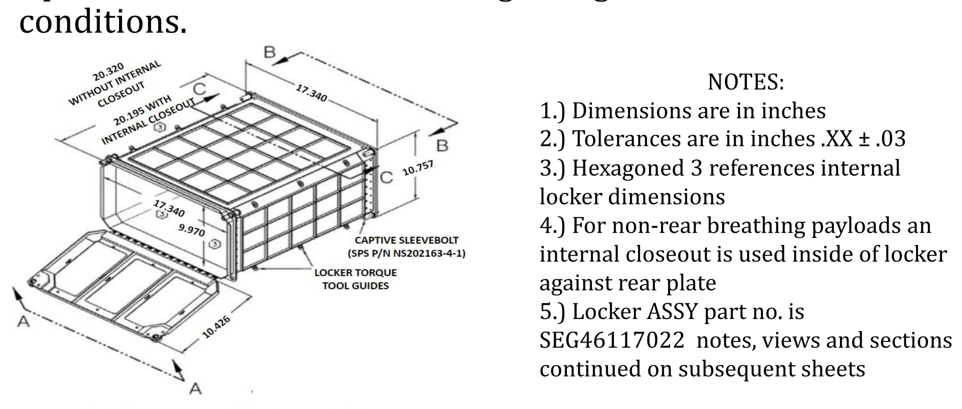
Fig 15: Machined Clamping System

Problem Statement

- Design, fabricate, and test a compact SPIF machine capable of operating within the constraints of vacuum and microgravity conditions aboard the International Space Station (ISS).

<u>The machine must conform to ISS standards and specifications, including the following key constraints:</u>

- Must fit within an ISS EXPRESS locker (20.19”x17.34”x9.97”).
- Power consumption cannot exceed 560W.
- Withstand G-forces of 10G minimum during launches.
- Operate with minimal to no outgassing under vacuum conditions.



Results

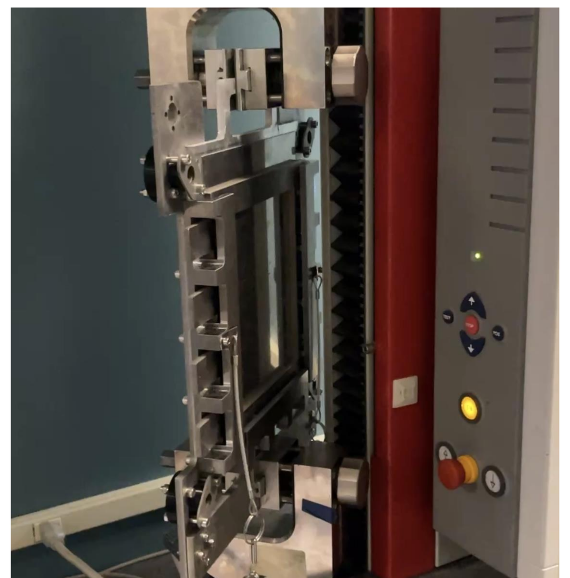


Fig 5: Zwick Frictional Force Setup

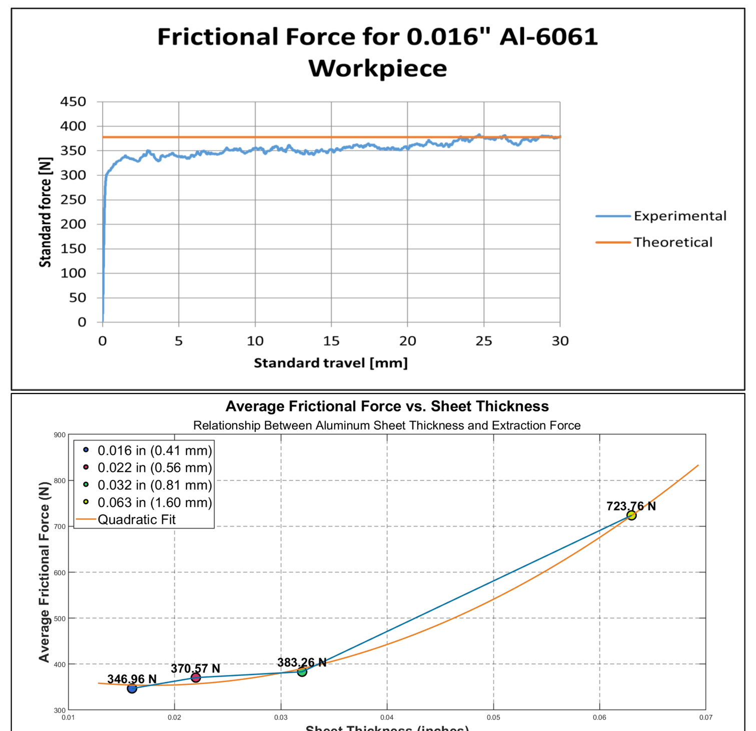


Fig 6: Zwick Test Results

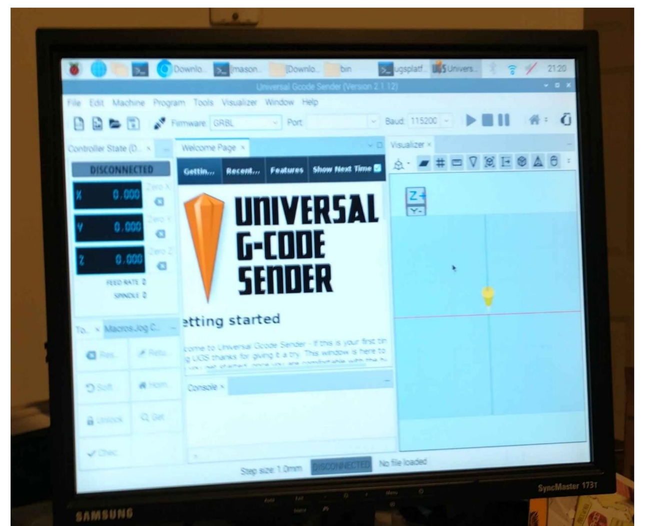


Fig 7: Tool Path Sender (UGS)

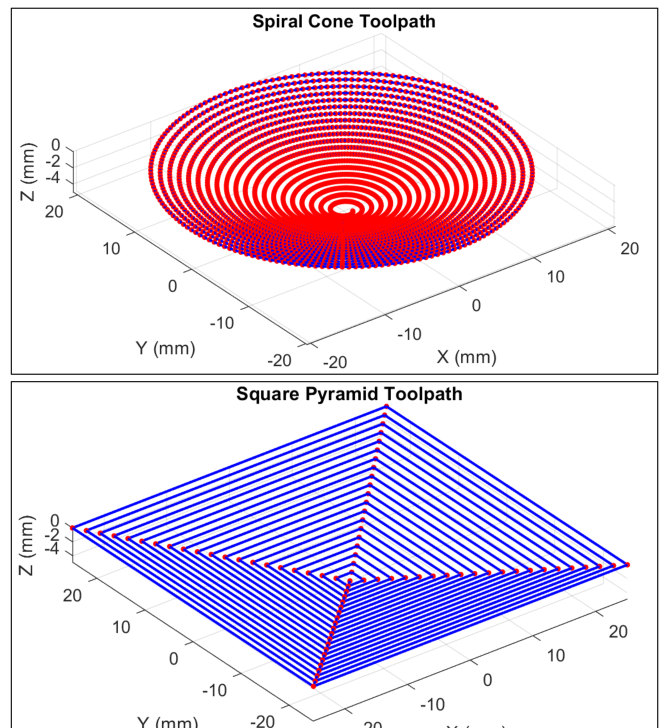


Fig 8: Generated Tool Paths

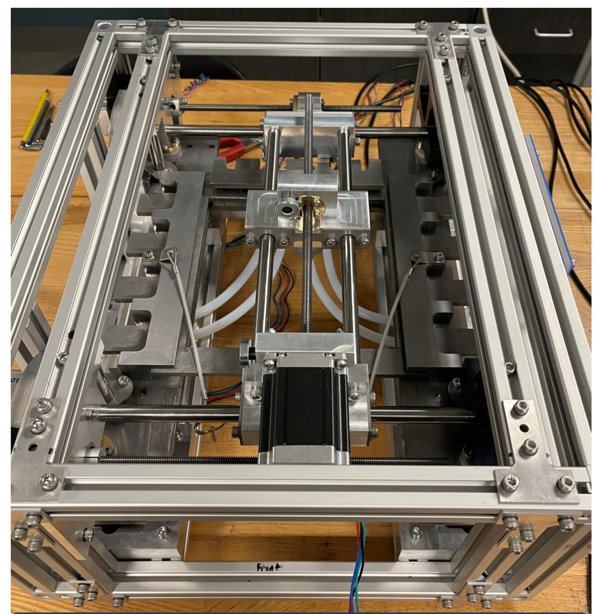


Fig 13: Fully Assembled Machine

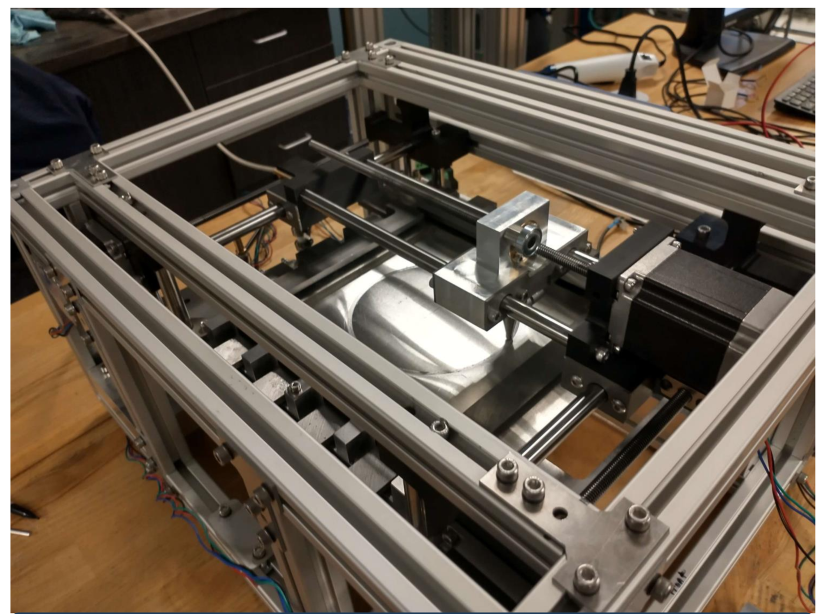


Fig 12: Forming Flat Bottom Helix

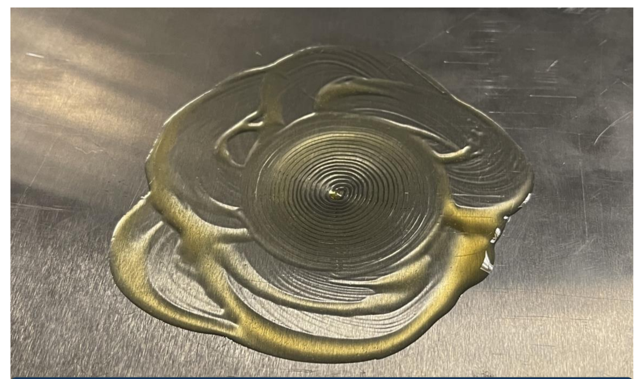


Fig 10: First Formed Sheet (Top)

Fig 11: First Formed Sheet (Bottom)

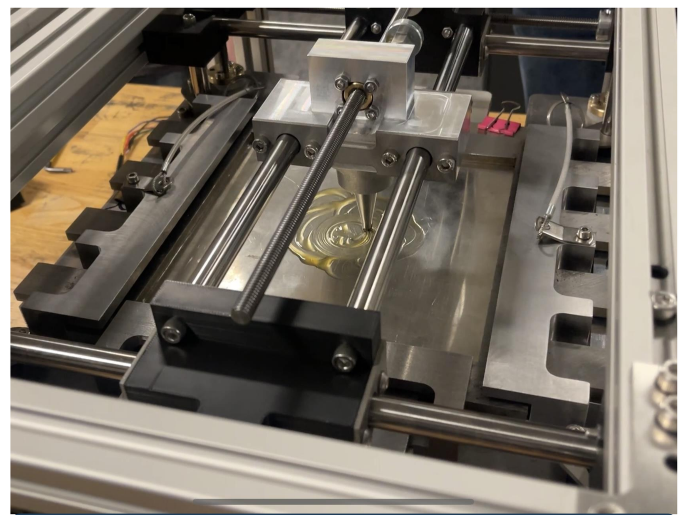


Fig 9: Sheet Forming Trial Run

Forming Tool

- Tool block allows for quick forming tool interchangeability of different tool head diameters and shapes.
- Designed to accept used tools from existing forming machines.
- Tool held within tool block by tightening M5 bolts/set screws to grip around the circumference.
- Magnetic limit switch is located on the tool block for position awareness as well as safety if movement surpasses intended limits.

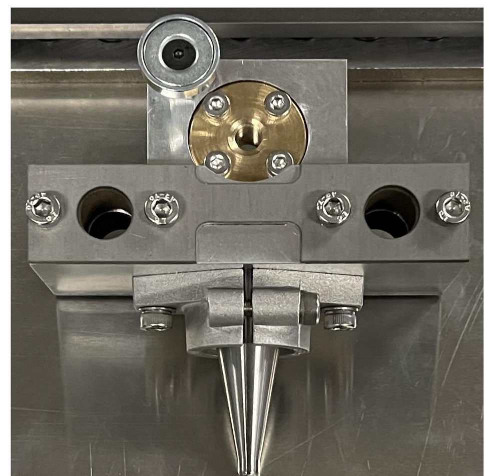


Fig 16: Machined Forming Tool

Methods

- Conducted comprehensive research on SPIF processes, material behavior under vacuum conditions, and ISS payload requirements.
- Developed CAD models of the complete machine assembly within SolidWorks, followed by finite element analysis (FEA) for structural integrity validation.
- Sourced specialized components and raw materials, subsequently fabricating aluminum/steel parts at the UNH Olson Center and machine shop.
- Integrated all subsystems including motion control, clamping mechanism, forming tool, and electronics into a final prototype.
- Performed preliminary testing to validate clamping system strength/sheet retention, x-y-z motion control/G-code scripts, and electrical system integration.
- Successfully executed forming operations under atmospheric conditions, with vacuum chamber testing planned to validate system performance under space-like conditions.

Conclusions

- Preliminary testing shows our proprietary clamping system can output forces significant enough to secure workpieces of various thicknesses and materials in place.
- Universal G-Code Sender (UGS) and GRBL was successfully integrated into our machine for full x-y-z motion control based on generated tool paths and electronics setup.
- Experimental sheet forming proves our SPIF machine can deform workpieces into various geometries within its confined volume at atmospheric conditions.

References

- https://www.nasa.gov/missions/station/quick-start-guide-to-payload-design/
- https://www.nasa.gov/forms/submit-a-question-for-nasa/
- https://ntrs.nasa.gov/api/citations/20190001390/downloads/20190001390.pdf
- https://www.mcmaster.com/products/straps/shock-absorbing-high-tension-tie-downs/load-securement-type~tie-down/
- https://www.amazon.com/home-garden-kitchen-furniture-bedding/b/?ie=UTF8&node=1055398&ref_=nav_cs_home
- https://www.engineersedge.com/calculators/force_required_strip_15799.htm

Electronics

- Electronic setup powers and controls components such as stepper motors/lead screws for x-y-z sheet forming.
- Arduino #1 runs GRBL (CNC firmware) and CNC-related hardware (e.g., limit switches).
- Arduino #2 monitors temperature and controls pause/resume/e-stop/coolant functions on Arduino #1.
- Raspberry Pi runs Temperature UI/G-Code sender (UGS).

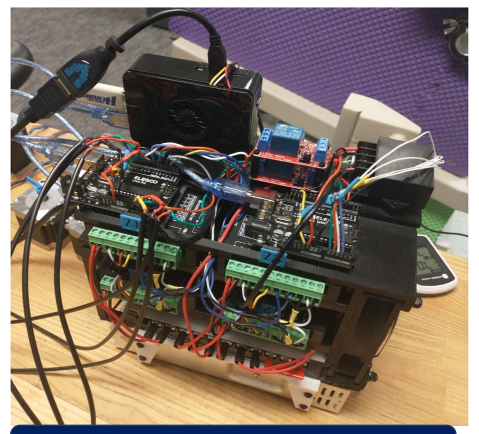


Fig 17: Electronics Setup

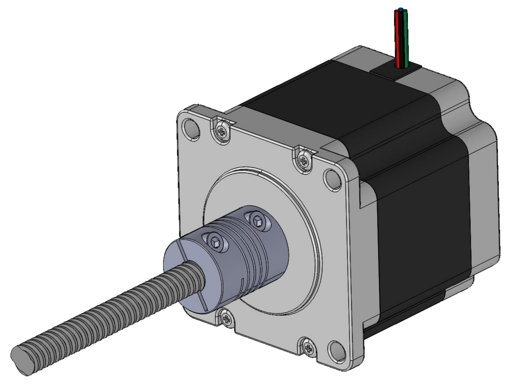


Fig 18: NEMA 23 Motor