Zero Launch Mass 3D Print Head

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Introduction

- To create a sustainable long term human presence on other planetary bodies, structures must be constructed to protect people, equipment and resources from environmental conditions such as:
  - Vacuum
  - Radiation
  - Micrometeorites
  - Large Thermal Changes
  - Dust
  - Rocket Plume Blast Effects
  - Topography
  - Night Conditions
- Costs and logistics make the provision of construction materials from Earth impractical – indigenous resources must be used
- Polymer composite concrete can be locally sourced and is a suitable construction material
- The Zero Launch Mass 3D Print Head was developed to demonstrate automated additive construction of civil structures

Goals & Requirements

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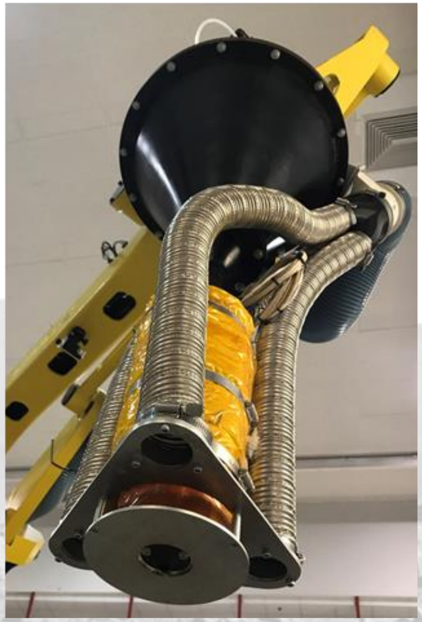
- Goal:
  - To 3D print a proof of concept habitable structure using ISRU materials in the form of a dome
- Requirements, the printed structure shall:
  - Be a one meter diameter, one piece, without support structure
  - Consist of at least 70% regolith derived materials with the remainder from in-situ resources
  - Be constructed via an automated 3D printing process

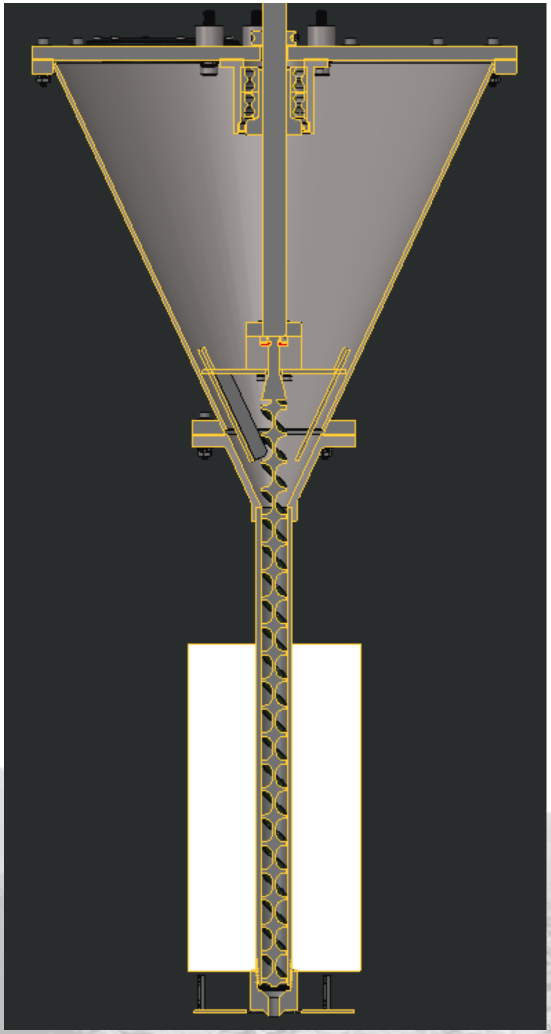
Key Performance Parameters			
Parameter	**State of the Art**	**Threshold for Success**	**Goal**
ISRU Material Usage	None	70% Regolith Derived	85% Regolith Derived
Overhang Capability	Use of Support Material	Ogive Shape	Dome Shape

ZLM Print Head Design

ZLM System Overview

- Structure
- Feeding/ Conveying
- Heater
- Fume Extractor
- Dry Air Purge





ZLM Print Head Design

- Mounted to a FANUC M-410iC/185
  - Four Degrees of Freedom
  - Max Print Height = 5.5 ft

Construction Materials

- The Project focused on two materials:
  - Powdered Black Point-1 (BP-1) regolith simulant and High Density Polyethylene (HDPE)
  - Pelletized basalt glass fibers and Polyethylene Terephthalate Glycol (PETG)

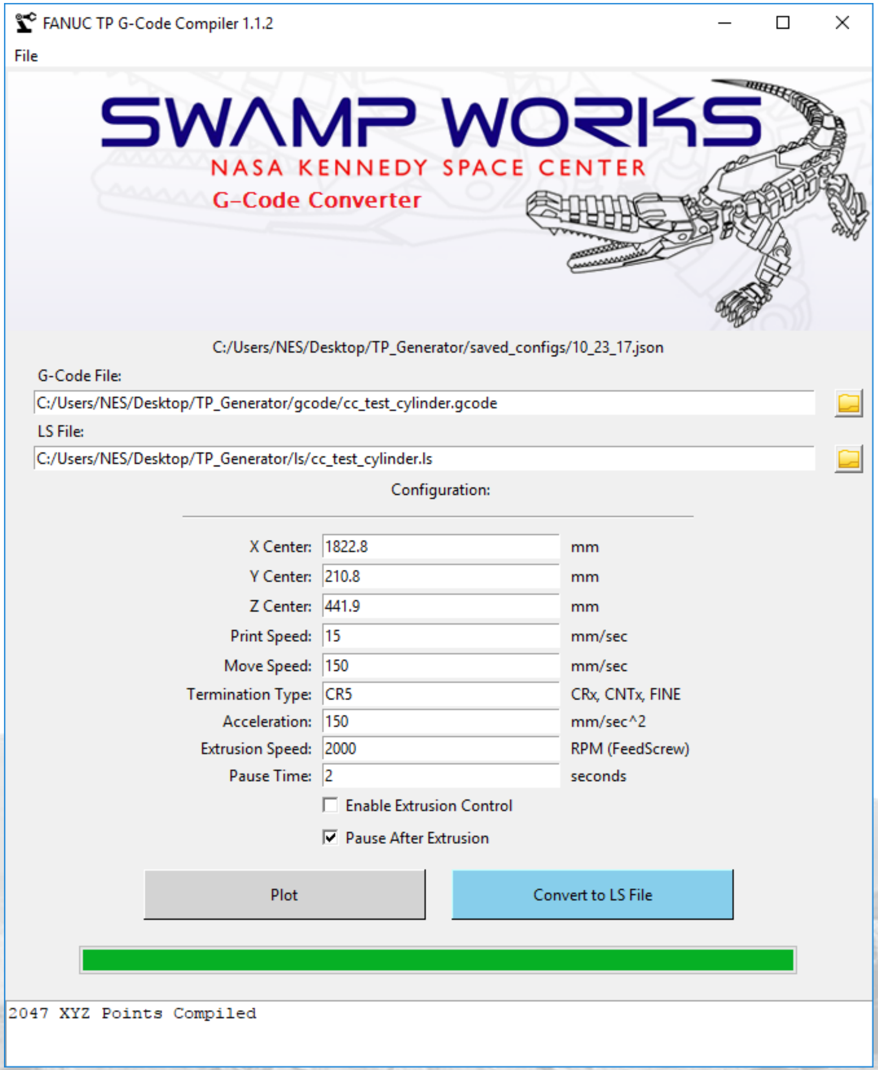
Software

- For this project the goal was to use existing Slicer software and g-code to control the robot
- This would provide a workflow to design in CAD, slice, and print nearly anything
- FANUC industrial robots cannot interpret G-Code and have very limited program memory. Several solutions were investigated:
  - Building custom “Teach Pendant Programs”
  - Streaming points to the robot using FANUC Socket Messaging and a custom modified driver
- Building Teach Pendant programs was the best solution.
  - Motion performance is greatly improved by using look ahead functions and kinematics only available when using “Teach Pendant Programs”

Software

- To be able to build custom teach pendant programs, software was developed with the following capabilities:
  - Convert G-Code to Proprietary Teach Pendant Programs
  - Extract all motion and extrusion information from G-Code
  - Allow user to shift the coordinates to the desired robot tool frame
  - Modify commands to include custom motion between extrusions for cleaner print results
  - Allow configuration of the following parameters:
    - X,Y,Z center
    - Print speed (mm/sec)
    - Movement speed between extrusion (mm/sec)
    - Termination type of motion
    - Acceleration value (mm/sec^2)
    - Feed system motor speed (rpm)
    - Pause times when starting and stopping extrusion
    - Enable/disable extrusion control
  - Generate a 3D plot of the toolpath for verification
  - Allow Saving/Loading of configurations for later use
  - Provide a GUI interface for operation

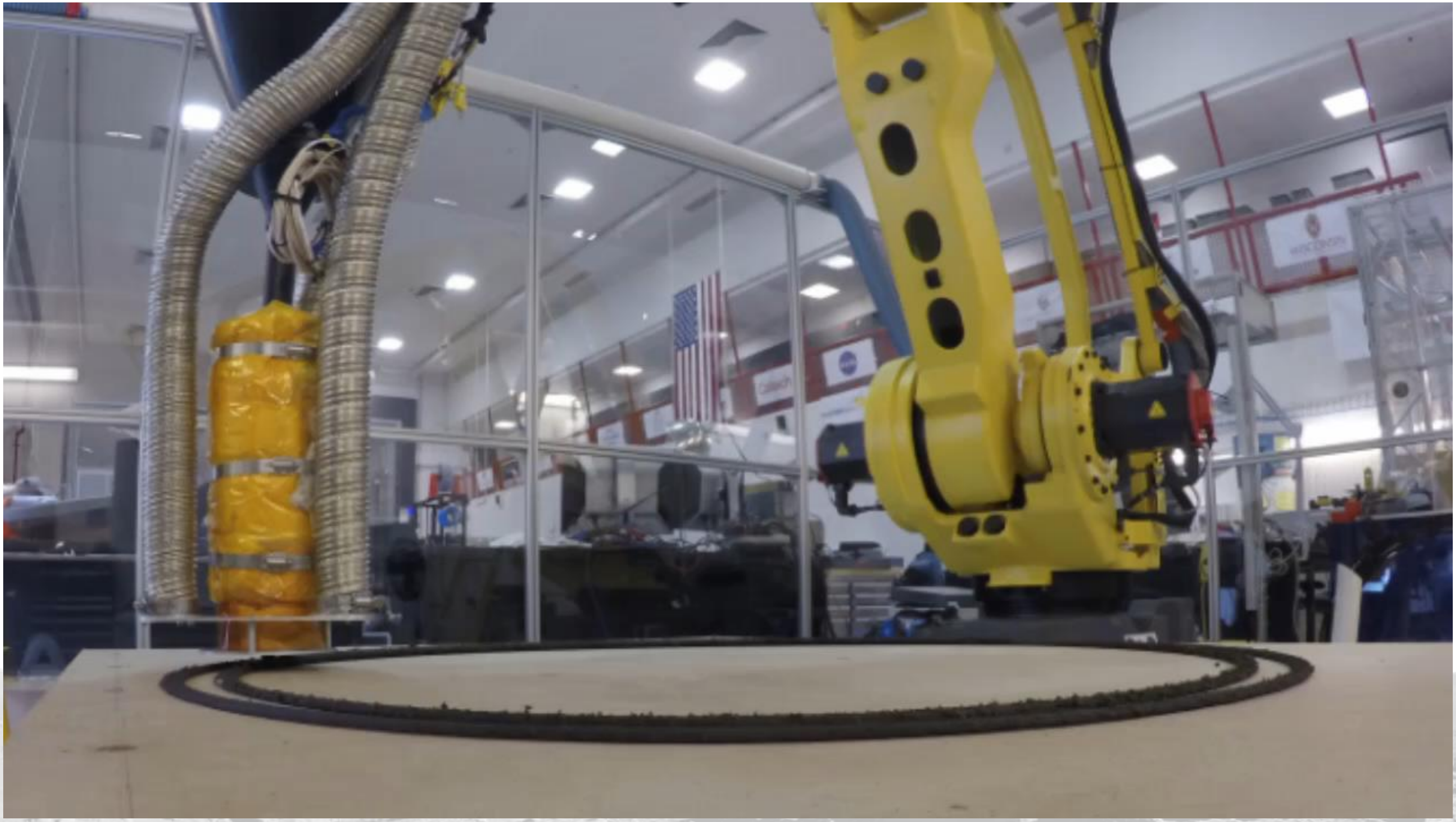
Software Screenshot



Results

- The ZLM print head project successfully met the objectives
- Maximum overhang angle of 35 deg from horizontal
- The project took the concept from TRL2, to TRL3
- Getting adequate print results required fine tuning of:
  - Temperatures
  - Extrusion Speeds
  - Print Speeds
  - Material Selection and Composition
- A one meter diameter ogive was printed without any additional support material

Time-Lapse Video



Ogive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Lessons Learned

- Eliminating Moisture In Raw Materials is crucial
- Feed screw design is critical
- Controlling Nozzle Temperature improves print consistency
- Material selection is key to Eliminating Warping and Cracking
- Using industry standard pelletized materials simplifies the system
- Industrial robots with 6DOF or more would allow for many improvements to the toolpath and printing process
- Existing toolpath generation software does not work well for additive construction, specialized software needs to be developed

Future Direction

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- Future work goals are to take the technology to TRL6, making it feasible for a mission to the Moon and Mars.
- The goals for future work include:
  - Development of custom "additive construction" focused software suites to allow smarter toolpath generation
  - Revised print head design for higher flow rates and increased print speed and quality
  - Development of custom materials for stronger prints, etc.
  - Automation of entire system, addition of material feed system
  - Increase print volume
  - Demonstrate printing of a full scale habitat
  - 6 DOF arm, free form 3D printing
  - Demonstrate additional applications, e.g. Barrier Wall…

Pictures

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Questions?