Maneuverable Automated Tethered Space Tug Simulator

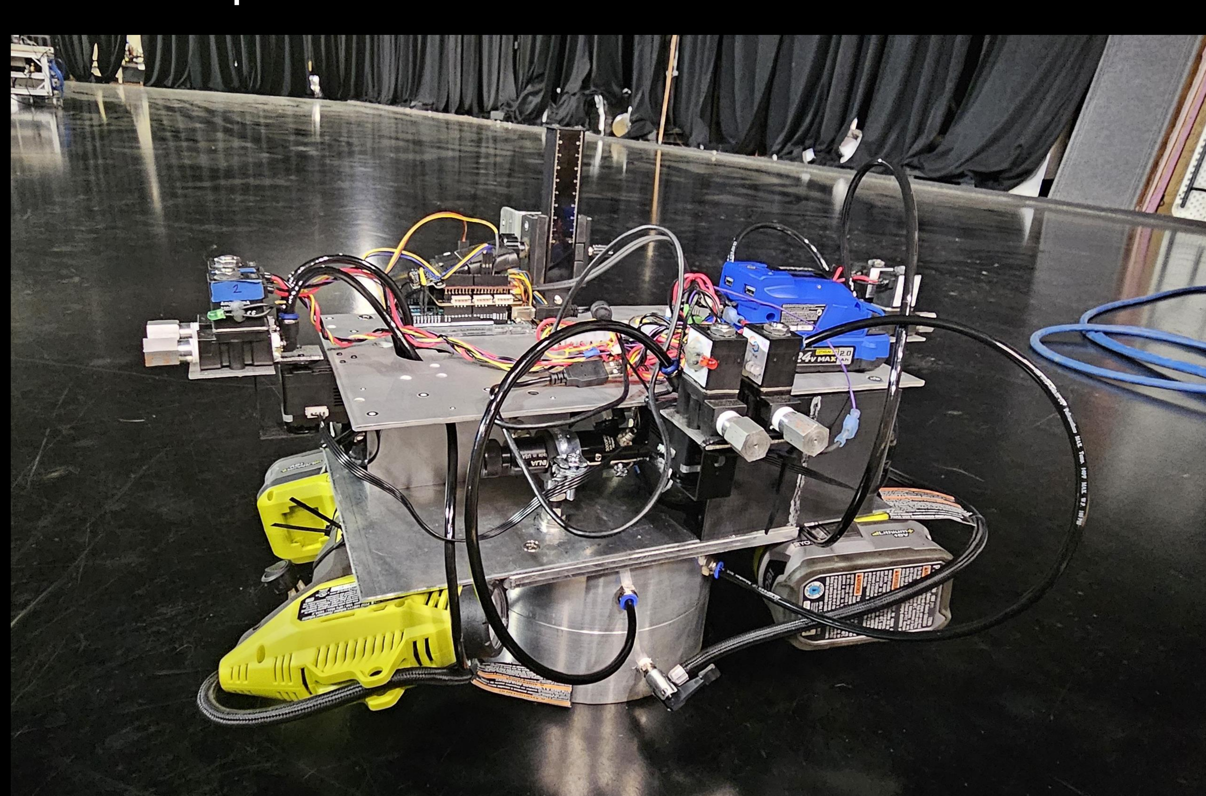
Emma Jaynes, John Inness, Alex Putman, Jason Lee, Kanak Garg

Introduction

- This TIP will develop autonomous capabilities for the space tugs in the Flat Floor Robotics Laboratory (FFRL) for use in support of In-Space Servicing, Assembly, and Manufacturing (ISAM) and future vehicles in the FFRL.
- The space tugs would be housed on larger spacecraft, such as ISS or Gateway, and deployed for various ISAM activities.
- When these activities are complete, the space tug can be reeled back to its host spacecraft.

Objectives

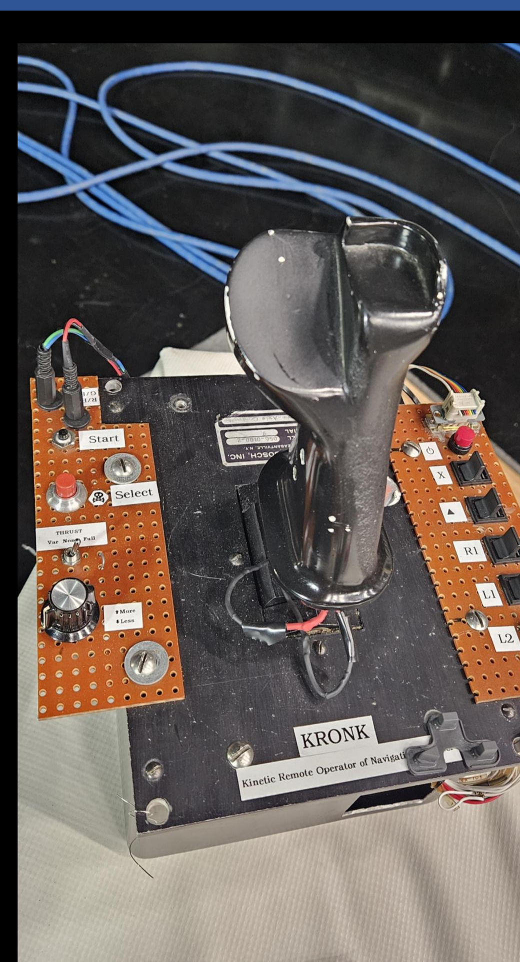
- Enable to the space tug to autonomously approach a specified location, following a specified trajectory, on the air bearing epoxy floor.
  - This involves a hardware upgrade and redesign of the current space tug.
  - This also involves implementing a closed-loop control software that will take human error out of the equation.



The current space tug assembly on the flat floor.

State of the Art

- ISAM applications require a high level of precision; one goal of this TIP is to reduce position/path uncertainty.
- Currently, the flat floor's space tugs are flown by a human pilot. Even a practiced pilot will see deviations from the planned flight path and end position due to human error.
- Closed loop control will improve position/path accuracy and allow for longer deployment lengths than what has currently been done in the FFRL.



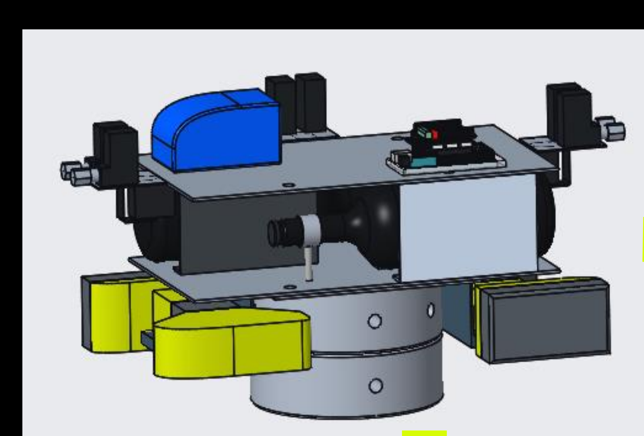
The current space tug controller.

KPPs	SOA	Target	Goal
Deviation from Path (cm)	16	8	5
Positioning Accuracy (cm)	+/- 10	+/- 5	+/- 2
Deployment Length (m)	3	12	24

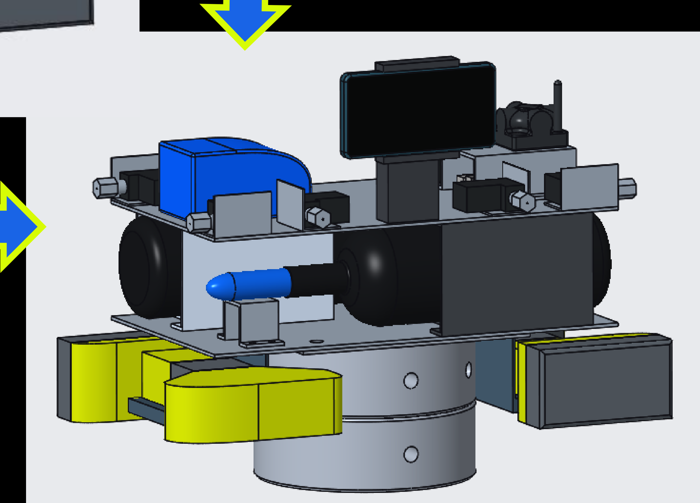
Methods: Hardware

The hardware upgrade of the space tug includes:

- Non-actuated thrusters for more precise control capability
- A new thruster configuration with each thruster mounted an equal distance from space tug's inertial axes, to simplify the closed-loop control software
- A mounted smartphone that will utilize existing Smart Video Guidance System (SVGS)
- A GPS beacon compatible with the FFRL's indoor GPS system
- Updated fill adapters and air tanks
- A new mount for the air inflators designed for ease of disassembly and reassembly



CAD Design of the Original Space Tug Assembly

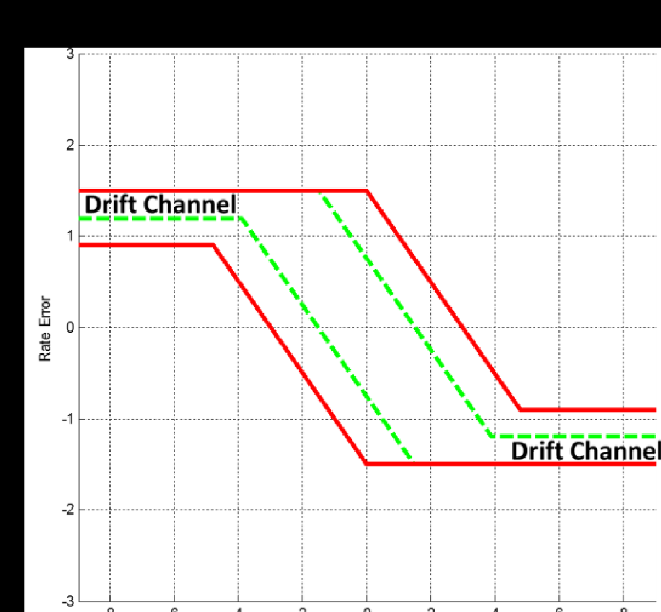


CAD Design of the Upgraded Space Tug Assembly

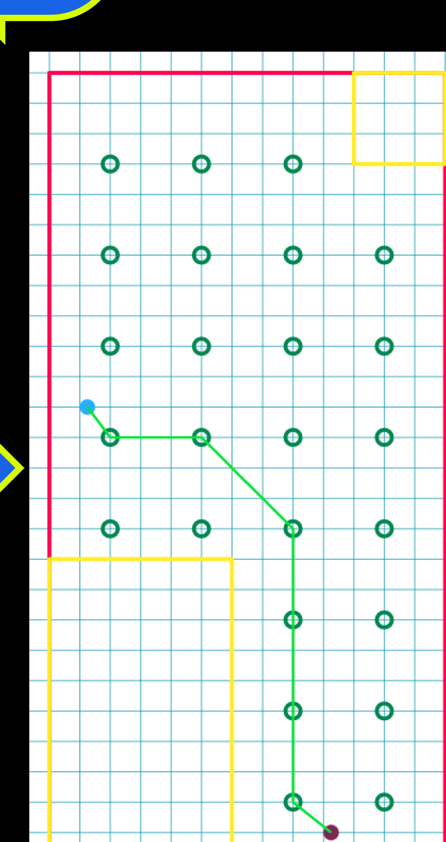
Methods: Software

In order to control and direct space tugs on the flat floor, a comprehensive guidance, navigation, and control system needed to be developed.

- The navigation system utilizes a combination of an indoor GPS system for total floor navigation and smart video guidance sensor for relative navigation when close to the desired servicing location
- The guidance system utilizes the A star algorithm to determine the fastest route from the tugs starting location to the desired end state location
- The control system utilizes a phase plane controller in order to determine which thrusters to fire and keep the tug operating within a safe operating limits both in translational speed and rotational speed



Sample Phase Plane Plot

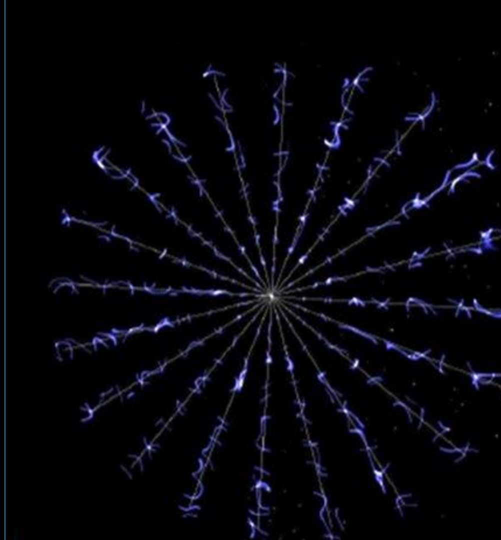


A Star Pathfinding starting from the maroon circle going to the cyan circle

Future Work

- Space tugs have been adapted for use in NASA's ISAM capabilities. Laser Beam Welding (LBW) tests were conducted on the flat floor in 2023.
- This test successfully demonstrated laser beam welding in an environment of simulated zero-gravity in two dimensions. In the future, tests like this can be entirely automated and completed wit the increased precision of this new spacecraft simulator. This will be more representative of practical in-space operations.

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.



Electric Sail concept design

- Space tugs also have applications for **electric sails**. E-sails utilize long conductive tethers which must be deployed, maintained in tension, and able to move in formation
- Space tugs can be attached to the end of the E-sail's tethers to achieve these capabilities. The FFRL can demo deployment test beds using several of these simulators, helping to close critical gaps for E-Sail development

Conclusion

Using prototypes developed over the last few years, this newest maneuverable, automated, tethered spacecraft platform is being designed and built for use in the Flat Floor Robotics Lab. This platform can directly support experimentation related to gaps such as:

- In-Space Joining of Structures and Materials
- Upgrading or installing instruments on large space stations, advanced space observatories, etc.
- Verification and validation of in-space assembled modular structures using metrology
- Electric sail tether deployment and formation control

Investing time and resources into these air bearing vehicles improves MSFC's capabilities and advances the meaningful work the center is able to support.

Acknowledgements

This project was funded as a Tier 3 proposal under the Technical Investment Program (TIP). Support from ES31 and EV41 has made this work possible.