Low Earth Orbit Operations Passive Capture Tool Dock

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Abstract

Extravehicular activities (EVA's) demand intuitive, one-handed tool storage systems that remain secure under limited dexterity and visibility. This calls for a solution that allows "blind" installation and removal of EVA tools while maintaining single-fault-tolerant retention and compliance with Neutral Buoyancy Laboratory (NBL) safety requirements. We propose a passive push-then-twist capture mechanism that enables astronauts to stow and retrieve tools. A tool-mounted stem-featuring a lead-in cone, retention neck, and lower cone-interfaces with two spring-biased prongs housed inside a cylindrical dock. During insertion, the stem cams the prongs outward and snaps into the retention neck for non-back-drivable holding; a short, deliberate twist aligns release paths for removal, fulfilling the two-action release criterion.

The team has completed initial CAD modeling, load-path analysis, and hazard identification following NBL guidelines. Upcoming work includes spring sizing, stress verification (Factor of Safety ≥ 2), glove-on usability testing, and prototype fabrication using approved materials from the NBL Materials List [2].

By combining passive mechanics, intuitive operation, and strict adherence to NASA safety protocols, the design aims to improve EVA tool management efficiency and reduce astronaut workload in low-Earth-orbit operations. Pioneer 39's concept represents a reliable, ergonomic step toward safer, faster, and more autonomous tool handling for future missions.

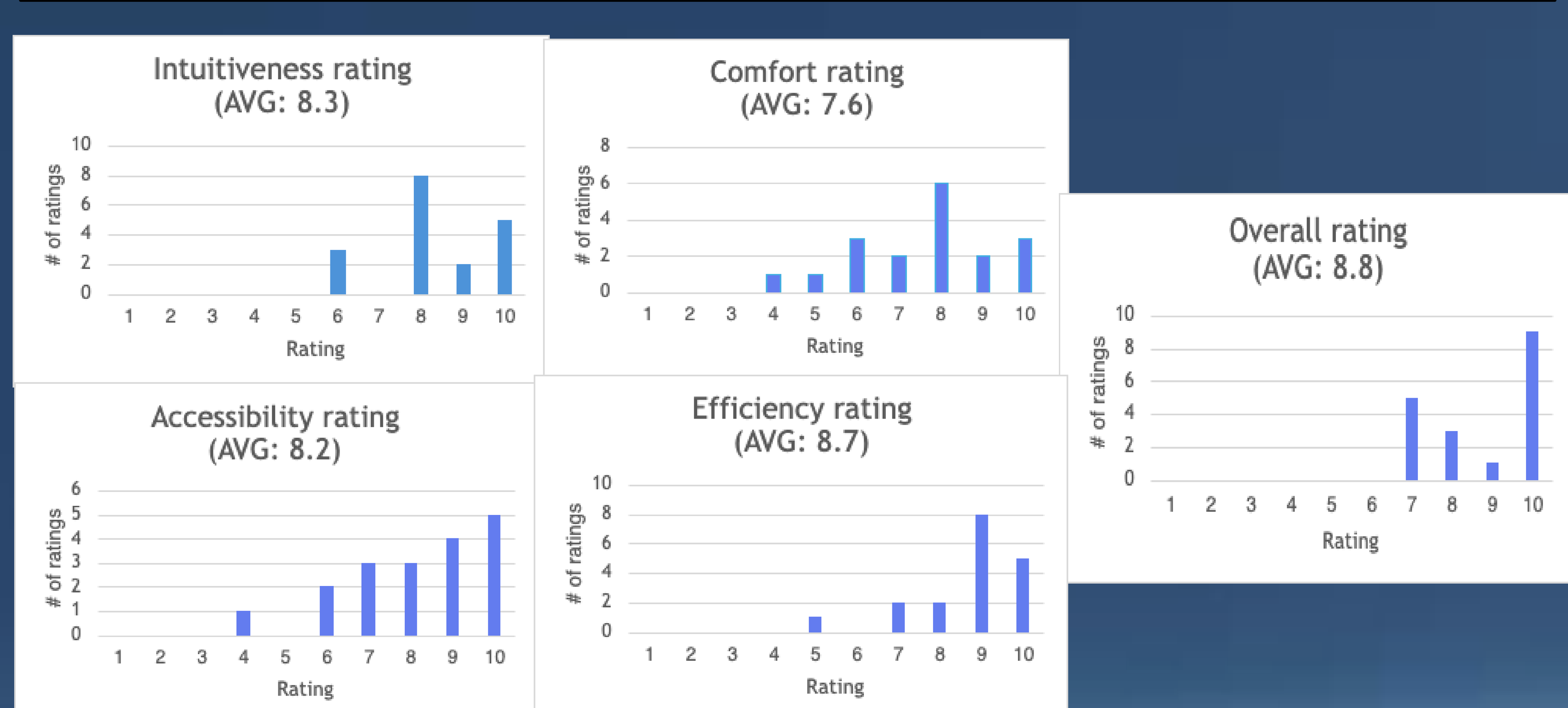
Our problem and requirements

Astronauts on spacewalks have to stow-away and grab tools while wearing thick gloves and with limited visibility. Current clips often need an extra switch, which slows work and risks dropping the tool. NASA's briefing asks for a dock that lets you push a tool in with one-hand, ideally without looking, all while keeping it secure even if one part fails.

To meet this, the dock must allow one-handed, preferably blind install and only release after two separate actions; stay under 2 lb and fit inside a 5×5×5-in space; push/twist forces must remain low; while being able to hold at least 15 lb using only manual power; it must pass stress checks with a safety factor of 2 or more; sink in water; use NBL-approved materials (printed parts ≥75% infill) [2]; and follow NBL safety labeling with no non functional sharp edges or pinch points.

User-Experience Experiments

In this experiment we let random college students test out our mechanism and rate it from 1-10 for 5 metrics. Intuitiveness, Comfort, Accessibility, and Efficiency for users.



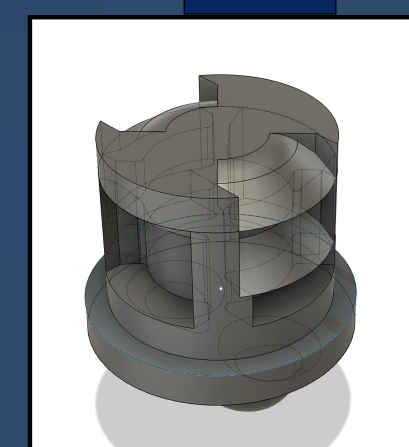
Timeline

October 10th:	Final Concept Chosen
October 13th:	Midterm
October 20-24th:	Prototype and Bench tests
November 10th:	Poster/Video
November 17th-18th:	Showcase

Design Evolution

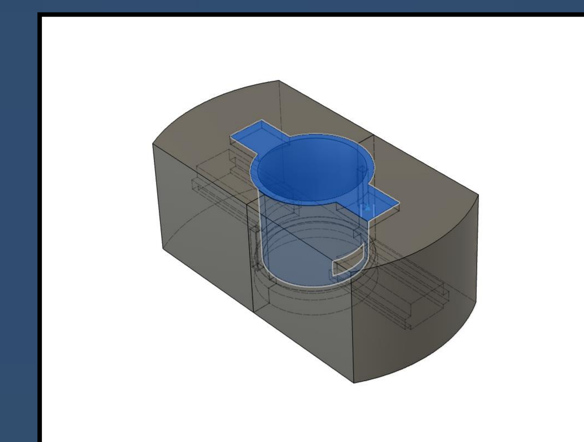
Final Version

STEM



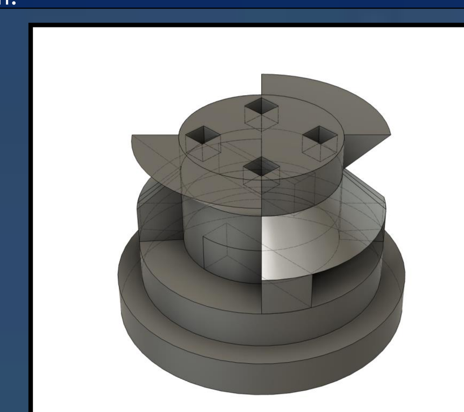
In our final iteration, additional internal walls were introduced to prevent the prongs from misaligning during insertion. The geometry now restricts prong movement to a single guided path, achieved by aligning the inner walls parallel to the prong's axis. A secondary inclined wall was added to encourage smooth movement into the second-stage cavity (which holds the prong in place), ensuring sturdy engagement and simple extraction.

SHELL

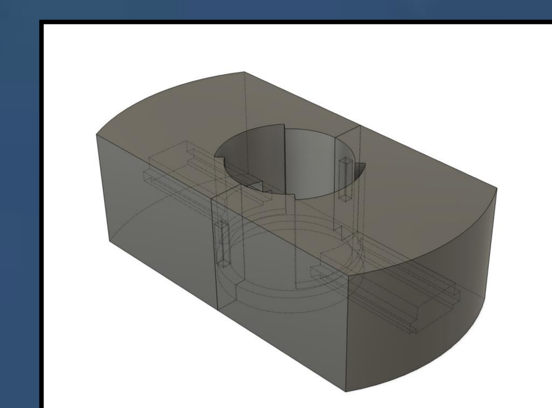


Version 3 of our shell incorporates a new ***single*** insertable plug design, rather than two separate walls, allowing for even simpler installation.

Version 2

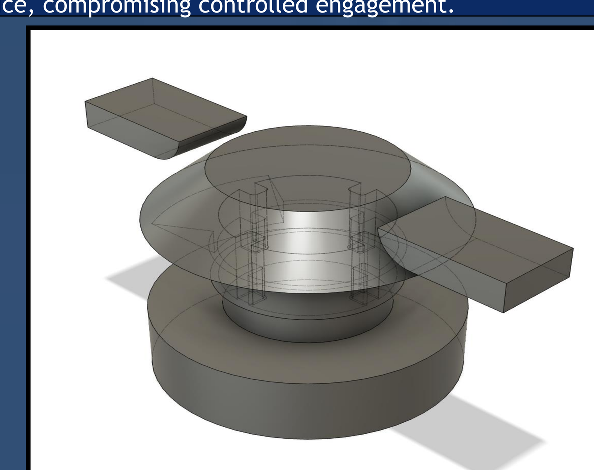


Recognizing the mechanical complexity introduced by moving components, the center ring was eliminated, and the middle section was redesigned as a static two-stage cylindrical structure. This iteration incorporates a ramp geometry that, when applied with force and aligned properly, enables single-fault-tolerant engagement. The issue? The absence of a wall between two angled ramps allows the prongs to enter through the top apertures and extend into the lower section of the device, compromising controlled engagement.



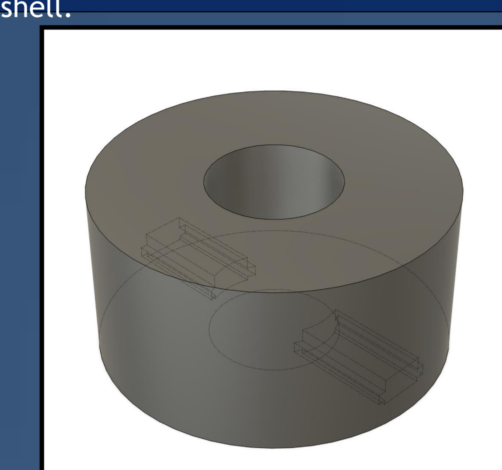
This design incorporates two plates that slide into the new pattern seen near the circle above. After the springs and prongs are inserted, installation of a wall keeps the plate acting against the prong, preventing the prong from flying out of the shell.

Version 1



V1 of our prong contained a moveable center ring, capable of moving vertically along the inner cylinder of the stem.

After further testing and consideration, we realized that the unrestricted movement could cause the device to behave in unintended ways in zero-gravity situations.



V1 of our shell was torus-shaped and contained nothing but two holes on the insides, created with the intention of holding our springs and prongs.

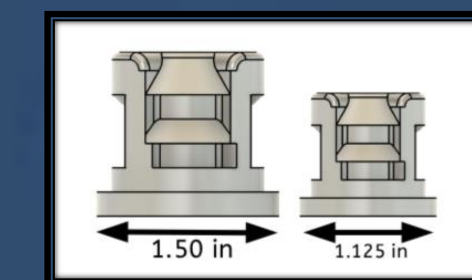
We quickly discovered an issue of the prongs flying out of the device due to a lack of a holding or locking mechanism for them.

Automated Robotic Arm Testing

At Houston City College Center of Manufacturing excellence, students have access to robotic arms that they can program for various uses. We as Pioneer 39 have decided to use them to repeatedly test our passive capture tool dock, programming the robot to click in, twist, and pull the stem out of the shell.

We currently have completed 9 hours and 47 minutes of stress testing on the current prototype which equates to 5,870 cycles, surpassing our expectations. Our current goal in this test with the robot arm is to get 14600 cycles complete which equates to 1460 minutes, or an astronaut using it 40 times everyday for a year straight. Some of our initial tests we used a 3d print made of an ABS plastic and we ran that for 25 minutes, or 250 cycles and our prongs look like the photo to the right of this, our current prototype has already been made of a nylon infused plastic and has lasted much longer than the ABS prongs and it is not even the material we could be using in the end.

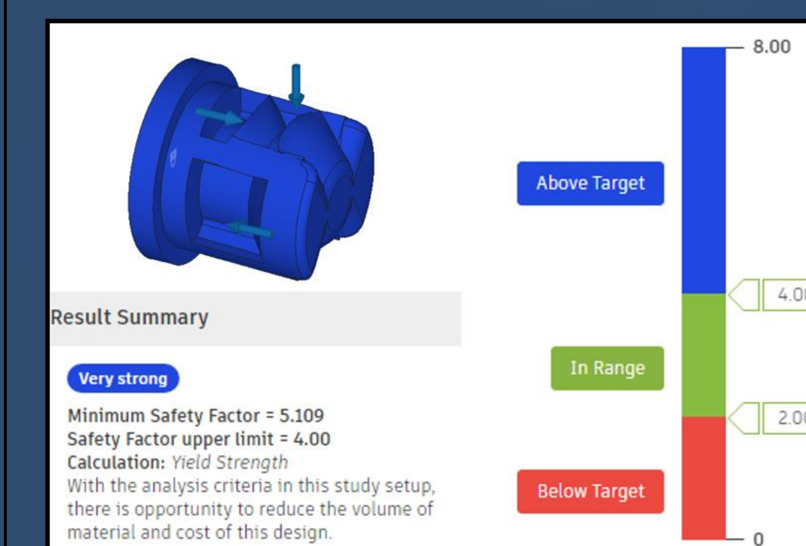
Finite Element Analysis



The following analyses of the **stem** assume it is machined out of solid aluminum and is **scaled down** by a factor of 0.75x. Each arrow indicates a directional force. The minimum safety factor indicates the smallest multiple of the given force (in this case, about 65 newtons) before strain occurs.

NOTE: The following analyses and simulations were created using Fusion 360. Our material choice was made in reference to the STANDARD MATERIALS AND PROCESSES REQUIREMENTS [1]

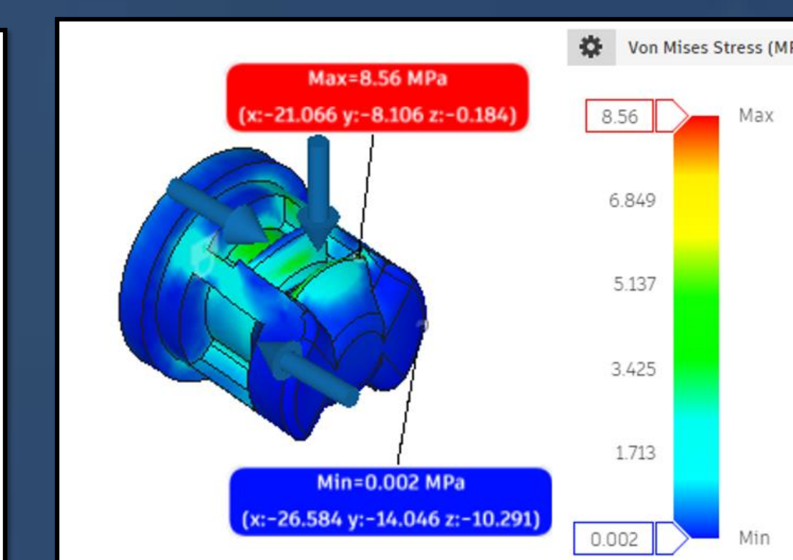
Safety Factor Analysis



NOTE:

Min SF = 5.109 (> 4.0 target) → safe with margin.
Loads: three 65 N forces as shown.
No yield expected.
It is possible to trim low-risk areas.

Von Mises Stress Analysis

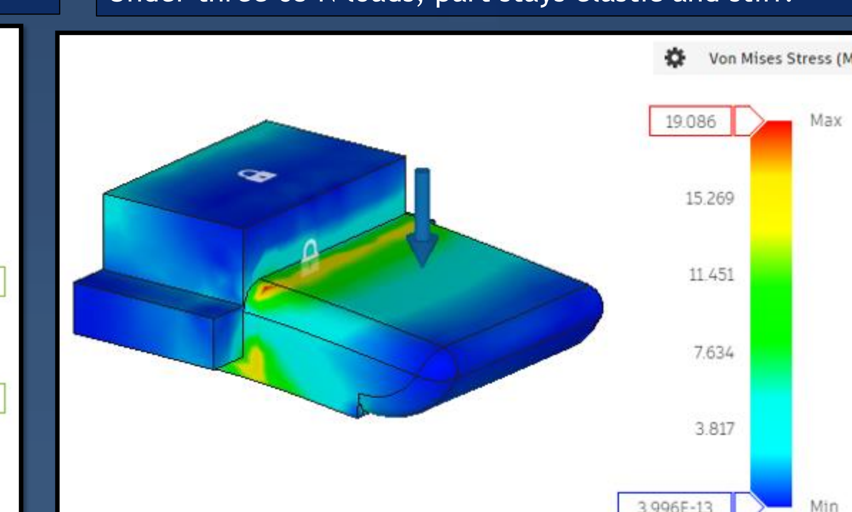


NOTE:

Max = 8.56 MPa, far below yield (≈ SF ~5).
Hotspot at a corner; fillets keep it controlled.
Large low-stress regions → weight-reduction candidates.
Under three 65 N loads, part stays elastic and stiff.

NOTE:

Min SF = 14.41 (> 4.0 target) → extremely safe/overbuilt.
Load case: three 65 N forces as shown.
No yield risk.
Weight-reduction is possible, away from the main load path.



NOTE:

Max = 19.1 MPa, far below yield (SF ≈ 14).
Local hotspot at the step/fillet near the arrow; keep/soften fillets.
Broad low-stress regions → pocket/trim material.
Re-check margins at 2-3× load and off-axis cases.

Conclusion

The Passive capture tool dock has met all the requirements demanded for the EVA tool belt, giving astronauts an intuitive one-handed blind installation tool storage. Using the push and twist internal mechanism provides a single fault tolerant retention, while remaining compliant with the NBL's standards with the choice of our materials. Testing under simulated NBL environment (Light-chlorinated pool) with test subjects demonstrates the intuitive design of our mechanism and demonstrates readiness for LEO.

Future considerations:
- More testing with multiple full metal prototypes
- Stress testing
- Different internal buckle mechanisms
- Downscaling with metal prototypes
- Adding accessibility (Twist/Turn label)

Acknowledgements:

Pioneer 39 would not be possible without the key contributions and insight of Peter Devries, our faculty advisor. We'd also like to thank the staff of both Katy Makerspace and Stafford makerspace for lending us key facilities and tools to make our prototypes. Lastly, we are grateful for TSGC and NASA for giving us the opportunity to make this presentation possible.

References:

[1]"Superseding NASA-STD-6016B STANDARD MATERIALS AND PROCESSES REQUIREMENTS FOR SPACECRAFT," 2021. Available: https://standards.nasa.gov/sites/default/files/standards/NASA/C-w/Change-1/1/Historical/2021-09-30-NASA-STD-6016C-Approved.pdf
[2] "Neutral Buoyancy Laboratory - NASA," NASA. https://www.nasa.gov/johnson/neutral-buoyancy-laboratory/

Background of poster is Saturn 5 at liftoff