SPACE DEPOT – Passive Capture Tool Dock

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ABSTRACT

The Passive Capture Tool Dock (PCTD) provides a simple and reliable docking solution for EVA tools used during spacewalks. It is designed for passive retention, which allows one-handed operation by astronauts wearing EVA gloves. The dock is fully compatible with the MWS Swingarm system, ensuring smooth integration with existing EVA setups. The design emphasizes ease of use, fatigue reduction, and mechanical reliability in a microgravity environment. Analytical modeling was conducted to verify performance, strength, and operability under space conditions.

Project Background

Extra-Vehicular Activities (EVA) are essential tasks routinely performed aboard the International Space Station (ISS). Different tools are used during these missions and it is crucial to have a secure stowage system for these tools that are ergonomically viable for astronauts to use during these long EVAs.

The current stowage system used aboard the ISS uses a bayonet type twist locking system that requires two hands to actuate. The goal of this project is to create a new tool stowage system that requires one hand to stow and retrieve tools. This new system will help astronauts aboard the ISS by providing them with a less physically and mentally demanding tool capture process throughout prolonged missions outside of the ISS.

Objectives

The main goal of the Passive Capture Tool Dock (PCTD) is to design a passive retention docking system, which will store the EVA tools for use in extravehicular activities. The PCTD will be designed to be properly integrated with the MWS Swingarms. Another primary feature of this product is the ability of the astronauts to easily and fully operate with only one hand, which will ensure a fatigue reduction both mentally and physically. The actual process of passively securing and retrieving the tools will be a simple and efficient process, due to the fact that it takes into account the limited mobility of the EVA gloves and the space suit overall.

ANALYSIS

Analysis for T-Handle Ball Detent

Conservative design allowable axial load:

$$F_{allow,axial} = \frac{F_{cat,PO}}{FoS} = \frac{575}{5} = 115\ lbf$$

For engineering purposes, the axial through-force carried by the T-handle ball lock pin, along its shaft axis, should be limited to approximately:

$$F_{allow,axial} \approx 115\ lbf$$

The expected operational axial load of interest, Fop=15 lbf, is significantly lower than this allowable:

$$\frac{F_{op}}{F_{allow,axial}} = \frac{15}{115} \approx 0.13$$

indicating a large margin with respect to the ball-lock pull-out capacity.

The catalog also provides a minimum double-shear strength for the stainless 3/8 in pin:

$$V_{cat,DS} = 10{,}200\ lbf$$

Applying the same $FoS = 5$ to obtain a conservative allowable double-shear load:

$$V_{allow,DS} = \frac{V_{cat,DS}}{FoS} = \frac{10{,}200}{5} = 2{,}040\ lbf$$

Therefore, the pin in double shear can conservatively sustain transverse loads on the order of:

$$V_{allow,DS} \approx 2.0\ x\ 10^{3} lbf$$

which is typically much higher than any expected manual or operational sideloading for a T-handle tool dock application.

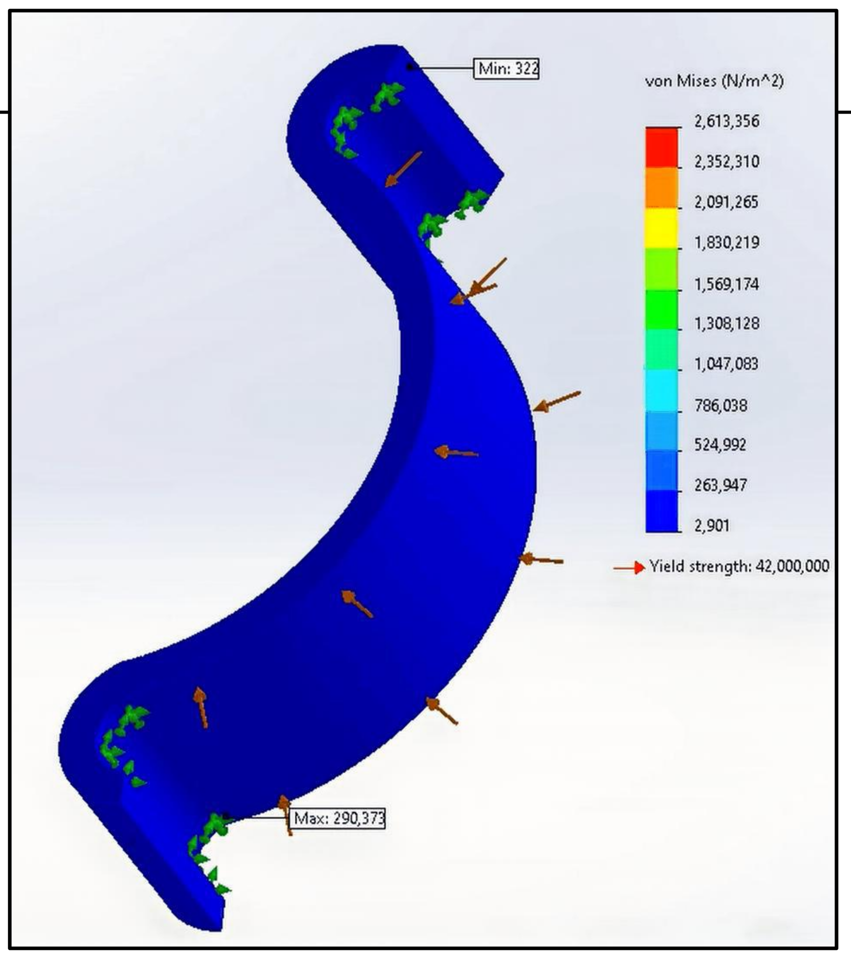

Figure 1: Finite Element Analysis of PETG Leaf Spring

Analysis for Linear Snap Action Mechanism

The stress components are listed below:

Direct Shear Stress

$$\tau_s = \frac{V}{A} = \frac{V}{0.11045} = 9.05\ V\ psi$$

Bending Stress (from load eccentricity e)

$$\sigma_b = \frac{V * e * c}{I} = \frac{V(0.125)(0.1875)}{9.70x10^{-4}} = 24.17\ V\ psi$$

Torsional Shear Stress

$$\tau_s = \frac{T * c}{J} = \frac{40(0.1875)}{1.94x10^{-3}} = 3{,}866\ psi$$

Axial Stress

$$\sigma_a = \frac{N}{A} = \frac{50}{0.11045} = 453\ psi$$

Combined von Mises Stress

The total stress in the pin under combined loading is given by the von Mises relation:

$$\sigma_{vm} = \sqrt{(\sigma_a + \sigma_b)^2 + 3(\tau_s^2 + \tau_t^2)}$$

Substituting all components:

$$\sigma_{vm} = \sqrt{(453 + 24.17V)^2 + 3[(9.05V)^2 + (3866^2)]}$$

Solving for allowable force, set $\sigma_{vm} = \sigma_{vm,allow}$:

$$\sqrt{(453 + 24.17V)^2 + 3[(9.05V)^2 + (3866^2)]} = 8000\ psi$$

Solving for V:

$$V_{allow} = 137\ lbf\ (single\ shear)$$

This means that the device can withstand approximately 9x the force that is required under nonideal conditions.

Figure 1 shows a simplified element analysis (FEA) of the PETG leaf springs models used in the PCTD. The von Mises stress distribution illustrates that the spring experiences mostly low stress (the blue region). This indicates efficient load distribution through the curved geometry. The maximum stress appears near the fixed ends with a stress value of approximately 290 kPa. The materials yield point is 42 MPa, which is significantly higher than the maximum stress experienced by the leaf spring.

MODELS

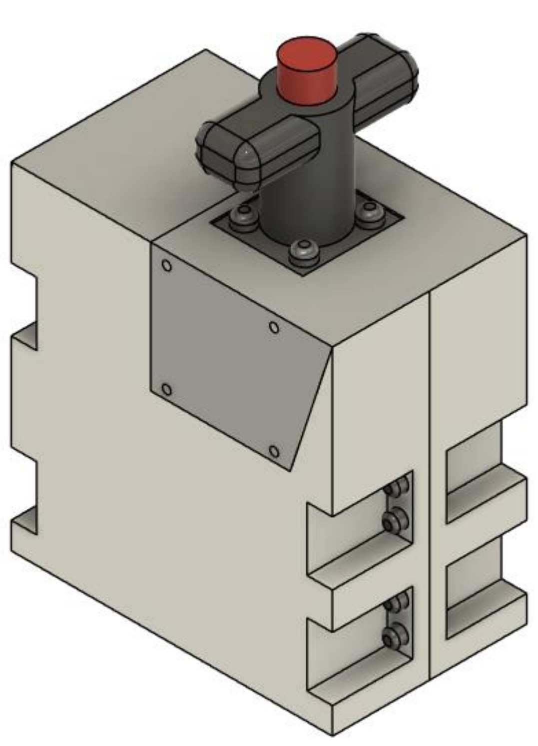

Figure 2: Closed/Locked View of the PCTD

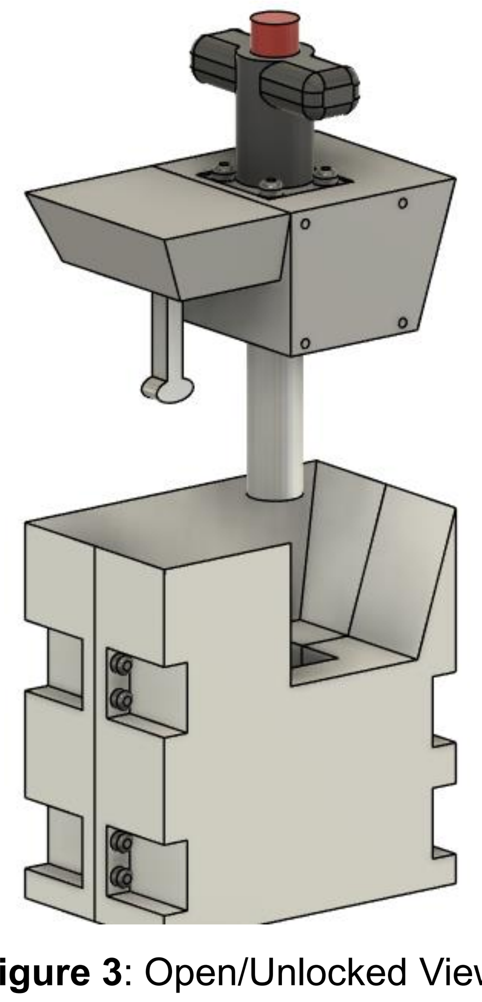

Figure 3: Open/Unlocked View of the PCTD

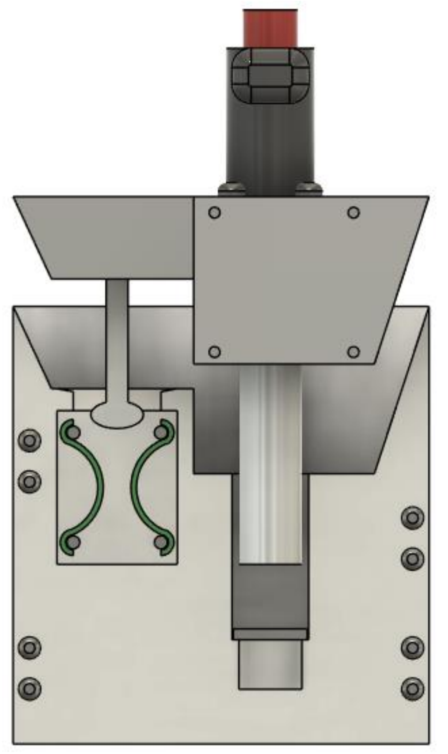

Figure 4: Cross-Sectional View of the PCTD

FUTURE WORK

- Perform material testing for strength and wear
- Conduct functionality testing for repeated use
- Complete environmental and durability testing
- Perform additional finite element analysis
- Optimize tolerances and clearances
- Refine locking mechanism reliability
- Explore design improvements for weight and manufacturability

CONCLUSIONS

- The PCTD meets its main goal of enabling efficient and secure tool handling during EVA operations.
- Testing and analysis confirm the durability and stability of the design under expected space forces.
- The passive capture mechanism offers a significant improvement in ergonomics and time efficiency.
- The system enhances astronaut safety and productivity by minimizing effort and tool loss risks.
- Future work will focus on prototype integration into EVA simulations for final validation.

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References

[1] NASA, 2025, FY26 Micro-g NExT Challenge Descriptions [Online]. Available: https://www.nasa.gov/wp-content/uploads/2025/08/fy26-micro-g-next-challenge-descriptions.pdf. [Accessed: 01-Dec-2025]
[2] NASA, "Thermal Control Systems," NASA Glenn Research Center. [Online]. Available: https://www.grc.nasa.gov. [Accessed: Apr. 2, 2026].
[2] MatWeb, "Aluminum 6061-T6; 6061-T651," MatWeb Material Property Database, 2024. Available: https://matweb.com.
[3] Budynas, R. G., and Nisbett, J. K., Shigley's Mechanical Engineering Design, 11th ed., McGraw-Hill Education, New York, 2020.
[4] Young, W. C., and Budynas, R. G., Roark's Formulas for Stress and Strain, 8th ed., McGraw-Hill Education, New York, 2012.
[5] Peterson, R. E., Peterson's Stress Concentration Factors, 3rd ed., Wiley-Interscience, Hoboken, NJ, 2008.
[6] NASA, NASA-STD-3001, Volume 2: Human Factors, Habitability, and Environmental Health, National Aeronautics and Space Administration, Washington, D.C., 2011.
[7] NASA, ISS Safety Requirements Document (SRD), National Aeronautics and Space Administration, Johnson Space Center, Houston, TX, latest rev.
[8] NASA, JSC 65829: Structural Loads and Dynamic Environments for Launch, EVA, and ISS Operations, Johnson Space Center, Houston, TX, 2013.
[9] NASA, SSP 30256: EVA Interface Control Document, International Space Station Program, Houston, TX, 2015.
[10] NASA, Mini Work Station (MWS) Interface Standards, International Space Station Program Office, Houston, TX, 2014.
[11] NASA, Neutral Buoyancy Laboratory (NBL) Approved Materials List, Johnson Space Center, Houston, TX, latest revision.
[12] M. Tymrak, M. Kreiger, and J. M. Pearce, "Mechanical properties of components fabricated with open-source 3-D printers under realistic environmental conditions," Materials & Design, vol. 58, pp. 242–246, Jun. 2014.
[13] ASTM International, "ASTM E4-22: Standard Practices for Force Verification of Testing Machines," West Conshohocken, PA, USA, 2022.
[14] NASA, "NASA-STD-5001B: Structural Design and Test Factors of Safety for Spaceflight Hardware," Washington, DC, USA, 2016.
[15] ISO, "ISO 12107: Metallic materials — Fatigue testing — Statistical planning and analysis of data," Geneva, Switzerland, 2012.
[16] ASTM International, "ASTM E466-21: Standard Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials," West Conshohocken, PA, USA, 2021.