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CUBESAT Power Module Snap-fit Mechanism

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by

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Executive Summary

The goal of this project is to engineer a snap-fit system to enable the ease of inspection & repair of a Power Module in a 3U CubeSat.

According to Heyman, Kanungo, and NASA, the cost of launching a 3U CubeSat can be up to 100,000 USD. Therefore, a more repairable & easily inspected CubeSat design can easily avoid unnecessary disposal of a CubeSat in the scenario of launch failure due to the power module. Moreover, according to SatSearch, the power module inside a CubeSat only lasts up to 10 years while the rest of the components (computer, camera, etc.) could last up to 25 years. The repairable and upgradable aspect of the Power Module can avoid the need to develop a new CUBESAT by allowing components to be replaced, extending the lifespan of a CubeSat.

With that in mind, this design will serve as a reference for future CubeSat designs, allowing engineers to be more mindful of failure modes & longevity of a CUBESAT unit. This project will serve as an example of the requirements and design selection processes to achieve that goal.

Introduction

The CUBESAT Power Module snap-fit system (inspired by the classic snap-fit design for plastic consumer products) is an easily 3-D printed system that allows for easy inspection, repair, and installation for the 3U CubeSat Power Module for the TUMBLER Project as well as serves as a template for future CubeSat projects.

As the cost of developing, manufacturing, and launching a CUBESAT is very expensive, the aspect of design for repairability is something an engineer should keep in mind while designing such a mission.

This project serves as an example of how a Power Module subsystem of a CubeSat for the TUMBLER project can be made more repairable and upgradable. This will be done through a series of design decisions for an optimal balance between structural rigidity, ease of fabrication, and ease of disassembly. In another word, this design will be as easy as possible to manufacture, made to make the process of upgrading or repairing the subsystem it is supporting easy while maintaining a good structural strength to serve as a mechanical support for the Power Module subsystem.

Lastly, my expectation is that the design process and final design can serve as a good reference for engineers designing future CUBESAT with longevity and repairability in mind.

CUBESAT Hardware options

As this Honors Contract project is an extension of the Senior Design TUMBLER team, the power module options will be identical to that of the TUMBLER system.

1. Power Module hardware

The components for a Power Module hardware (in general and for CUBESAT specifically) are battery cells, responsible for storing energy, and Power Management Boards, responsible for managing power for charging the battery cells and discharging power onto other electrical components in the CubeSat (camera, computer, etc.).

Firstly, due to the popularity, size advantage, and wide power management hardware support,, Lithium-polymer batteries and 18650 Lithium-ion battery cells are the best options for battery cells. Due to the more durable structure and upgradable nature of the 18650 Lithium-ion battery cells compared to that of the Lithium-polymer battery cells, according to BatteryPowerTips, the 18650 Lithium-ion battery cells make for a better candidate of the two.

Despite the lower power per weight density, the 18650 Lithium-ion battery cells still prove a more appropriate choice as the power requirement of the total system for a total one-hour mission is low. An example of a 18650 Lithium-ion battery cell implemented in the final design of TUMBLER CubeSat design is in table 1 below:

Table 1: 18650 Lithium-Ion Samsung Cell

Part	Quantity	Mass	Operating Temperature (Celsius)	Energy total (Wh)	Output Voltage (V)	Price ($)
Samsung 30Q 18650 3Ah cells	6	290g	-20 to 70	66	3.7	36

Figure 1: Samsung 30Q 18650 3Ah Cells

Secondly, due to the wide documentation, low price, and good open-source software support, the Geekworm PME for NVIDIA Jetson Nano and the Raspberry Pi V2.0 UPS HAT (as in figure 2) are chosen for comparison. Despite being designed for the Jetson Nano and Raspberry Pi 4B, these power management modules can power any system under 5V. Moreover, these two boards also enable power management through UART communication (as in Figure 3), indicating power consumption, power left, and charging rate for the 18650 Lithium-ion battery cells attached.

Figure 2: Jetson Nano UPS (on the left) and Raspberry Pi UPS (on the right)

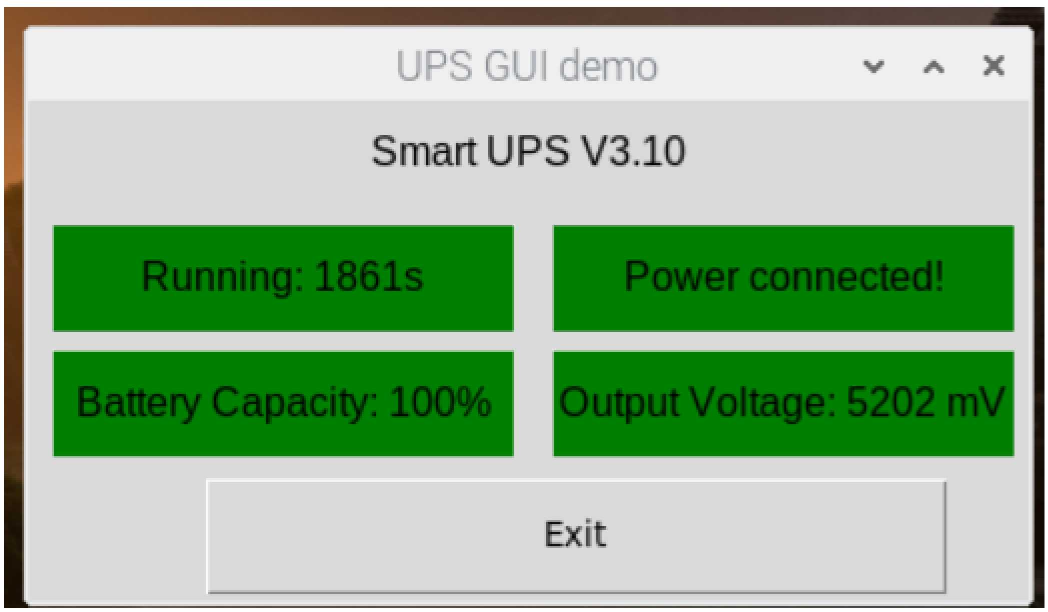

Figure 3: Raspberry Pi UPS UART Communication for charge status

After several design attempts, the Raspberry Pi V2.0 UPS HAT (as in Part 3: Design Option Evaluation) has been picked for the final design due to the smaller size, allowing a better snap-fit mounting system for the CubeSat.

2. CUBESAT Enclosure

The system enclosure was determined to be the ISISpace 3U Cubesat Structure (Figure 4). Moreover, due to the nature of the CubeSat mission to be determining the orientation of the CubeSat at all times with sensors and cameras mounted on top and bottom of the enclosure. Therefore, the best placement for the Power Module is the middle 1U unit.

Figure 4: ISISpace 3U Cubesat Structure

Power Module Snap Fit Mechanism requirements

1. Manufacturability

a. As repairability for the CubeSat Power Module is the goal of this project, it only makes sense that the Snap Fit Mechanism is easily repairable as well.

b. The most approachable manufacturing process in space is 3-D printing. According to NASA, the inclusion of 3-D printing machines on the International Space Station has solved the problem of long-duration space flight.

c. Therefore, firstly, the design needs to have thick walls, preferably above 3mm based on experiments, to reduce inconsistent & weak prints (example in Figure 5).

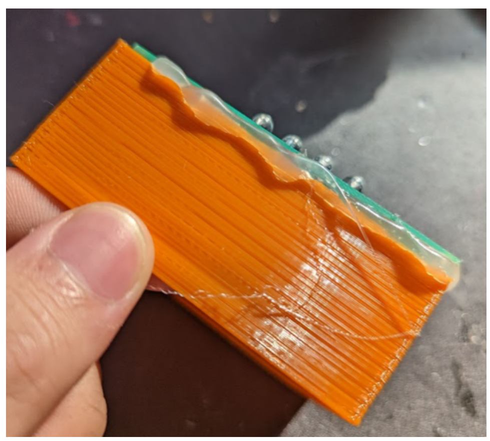

Figure 5: Weak print (layer adhesion even at maximum infill) at 1.5mm wall thickness

2. Easy installation & Simplicity in Design

a. For the system to be more repairable, the system should take as few tools as possible to assemble, and require as few motions as possible for disassembly and reassembly.

3. Durability & Power Module Structural Strength

a. Due to the limited space available, the snap-fit mechanism needs to also function as a good mounting point for the Power Module, providing structural rigidity with all 6 axes of freedom constrained.

Design Option Evaluations

There are several ways the Snap-fit system can function

1. Traditional Snap Fit Design

a. Cantilever Snap Fit Joint

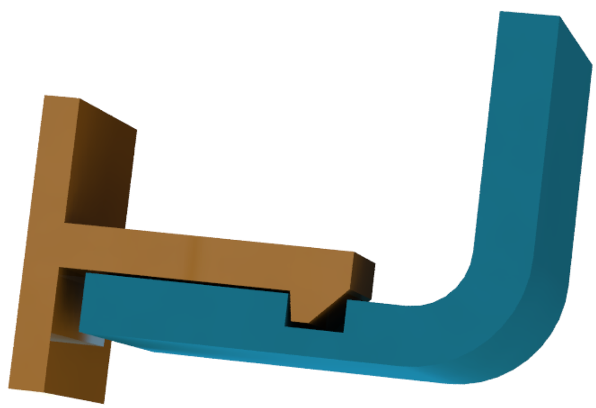

Figure 6: Cantilever Snap Fit Example

Frequently used for many consumer products, cantilever snap-fit joints are perhaps the most popular type of snap-fit mechanism.

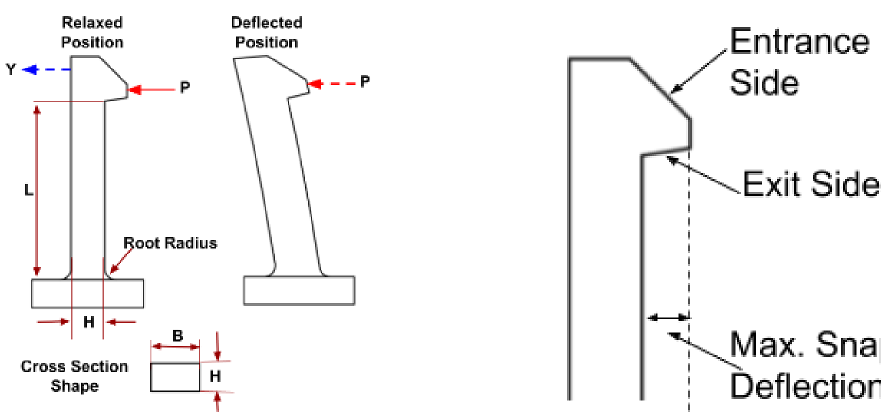

Figure 7: Cantilever Snap Fit Parameters

The maximum amount of deflection as above can be found from the beam theory, assuming uniform cross section and 3D printed at 100% infill.

$Y = 0.67 * \varepsilon * L^2/H$

Where:

Y: $Snap\ Deflection$

ε: $Maximum\ Permissible\ strain\ for\ Material$

L: $Snap\ Length$

H: $snap\ thickness$

To maximize the snap deflection that the mechanism can handle, material with maximum strain and the design with maximum snap length as well as minimum snap thickness is required.

As stated above, the snap thickness needs to be 3mm for consistent print quality. Moreover, with the limited space available, the maximum snap length is 19mm. With the two known variables, the maximum snap deflection can be derived from the most accessible 3D print materials.

Table 2: Material Selection for 3D Printing

Material	Maximum Permissible Strain	Maximum Snap Deflection (mm)
PLA	7.31%	5.89
ABS	7.73%	6.23
PETG	9.16%	7.38
Nylon	25%	20.15

Note: There have been developments on materials such as PLA+ and PETG+ that allow for much better mechanical properties, but the difference in chemical composition between manufacturers lead to little to no information on allowable strain on those materials.

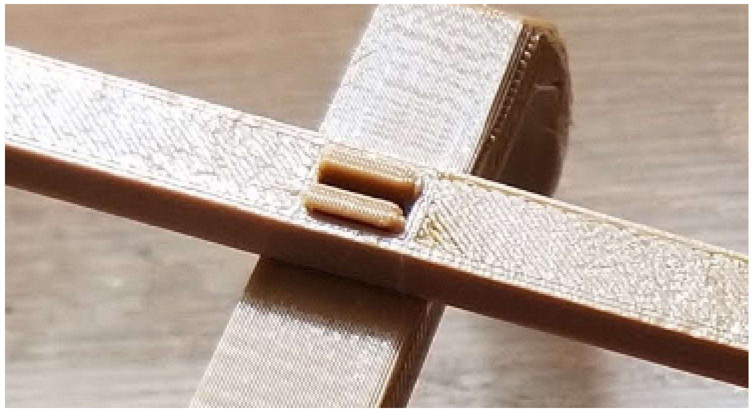

Figure 8: Cantilever Snap Fit testing

From many print tests, it is concluded that Cantilever snap-fit mechanisms are not a good fit for this application due to material failure on sustained loads for materials easy to maintain and operate such as TPU and PLA. Meanwhile, materials such as ABS, and Nylon provide relatively better durability but require intensive maintenance and expensive/bulky printers (as in Figure 9) to operate, going against the ease of manufacturing nature of this project.

Figure 9: Example for Industrial ABS & Nylon 3D Printer

a. Annular Snap Joint

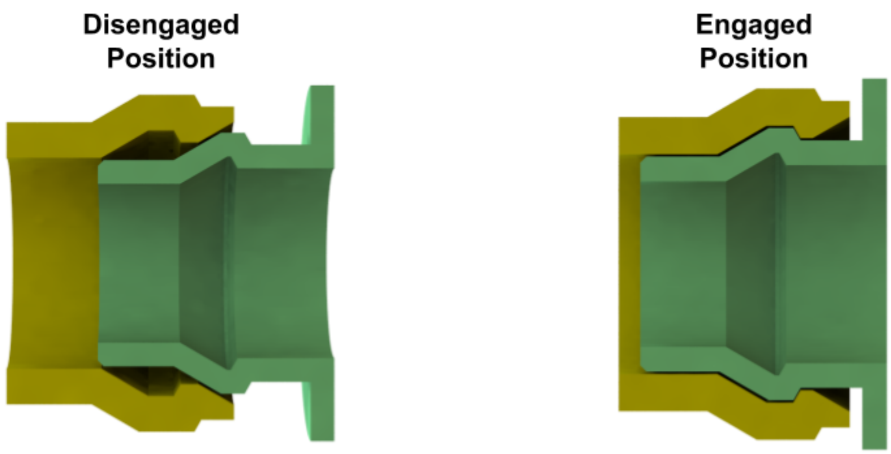

Figure 10: Annular Snap Joint

For this snap-fit mechanism, the disassembly process is to simply apply forces along the center axis of the cylindrical shapes, the same way a mechanical impact would happen during the CUBESAT operation. This means that either ease of disassembly or mechanical rigidity needs to be compromised. For that reason, this is not a viable option.

2. Mechanical designs

Besides the solution of traditional snap-fit designs, I have also created a design with a mechanical design that relies less on the material strain property and more on springs and friction for secured attachment.

a. Grabbing Mechanism

As in Figure 11, the mechanism is made of 2 grabbing arms screwed onto the enclosure acting as the “grabbing point”. Meanwhile, a 2-pin structure (as in Figures 11 and 12) is screwed to the 2 Power Module PCBs, acting as a part to be “grabbed” by the grabbing arms, providing ease of assembly & disassembly by a simple pull and push motion by the operator/engineer.

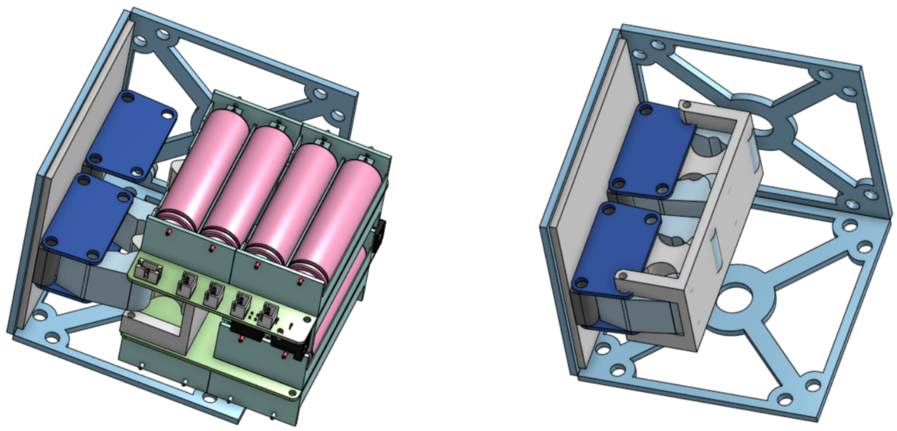

Figure 11: Grabbing mechanism

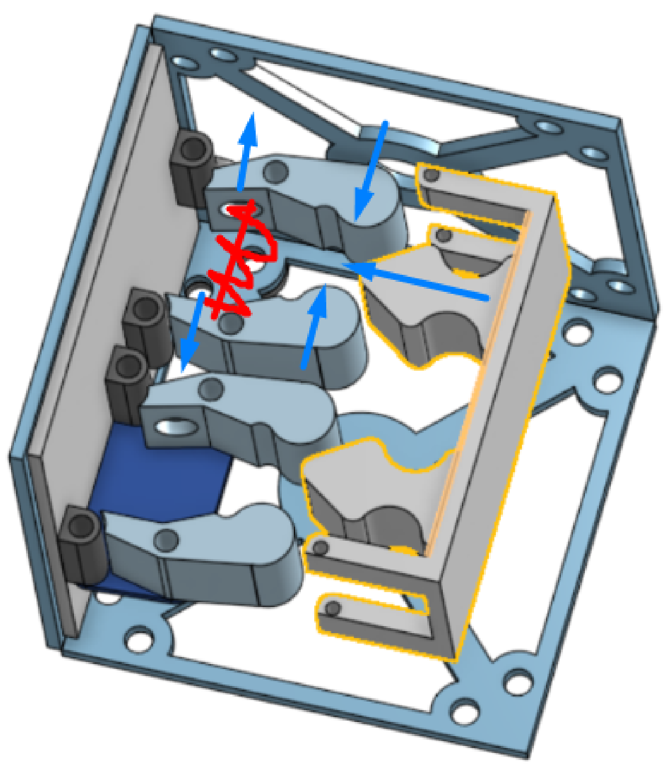

Figure 12: Spring-assisted mechanism

The way these mechanism works is as follows. As in figure 12, on each grabbing arm, there will be a spring (denoted in red) to provide “pushing” force on the arm (with the force direction

denoted in blue) to grab onto the pins. When the pin is pushed onto the grabbing arms (motion denoted in blue), the curvatures will allow for easy entry.

After much testing with a physical prototype, it is decided that this design choice is not a good long-term solution. The ease of assembly and disassembly means that the mechanism is not structurally reliable, having the PCBs hit against the walls of the enclosure, introducing structural issues and unwanted disturbances to the CUBESAT movement. Therefore, the oversimplification has affected the structural integrity of the design. By adding one more motion to the assembly and disassembly process of the design, the next, and the final, the design provides a good balance between structural strength and ease of use.

b. The Twist and Slide Mechanism (TASM)

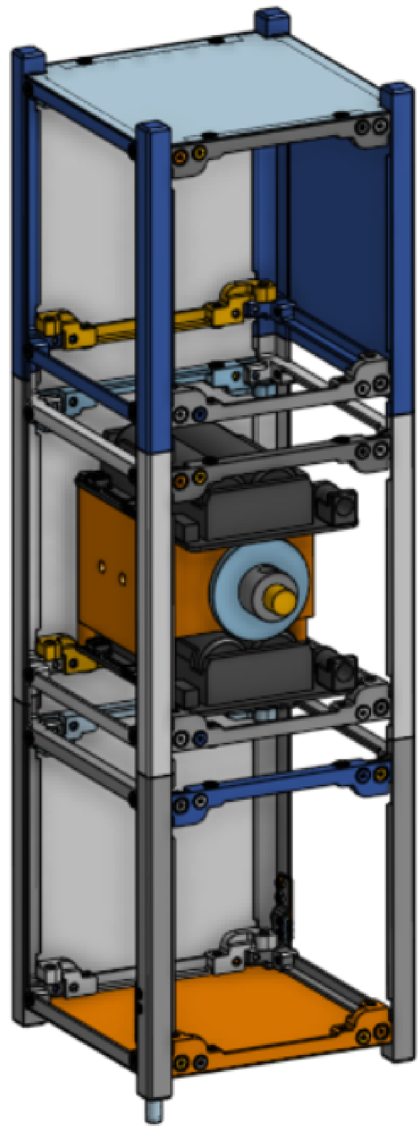

Figure 12: Twist and Slide Mechanism (TASM)

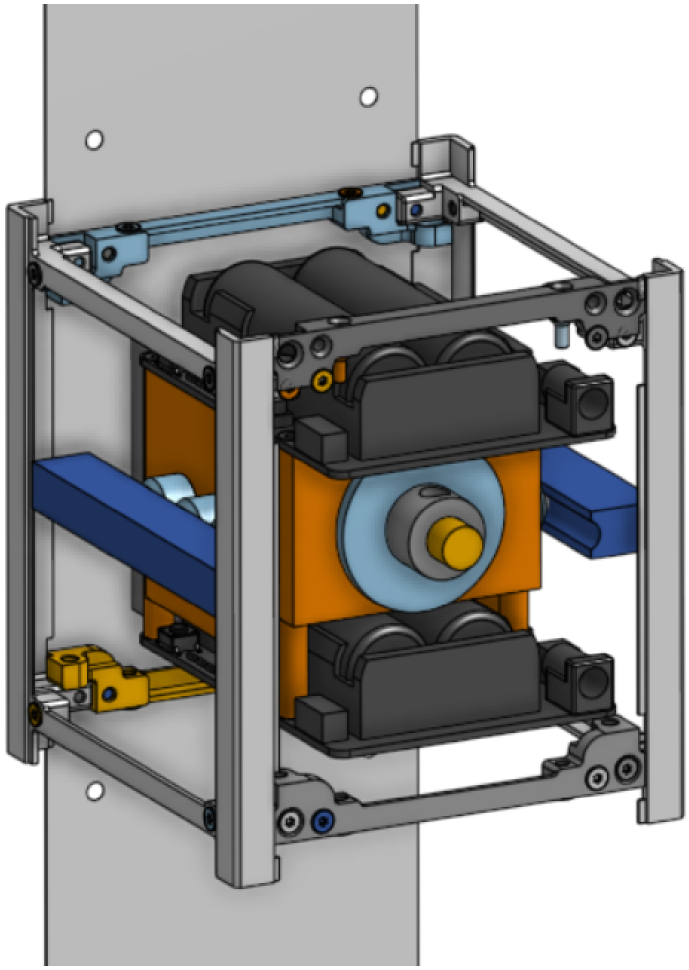

Figure 13: Zoomed-in view of TASM

As the name suggests, the mechanism is made of 2 parts: Twist and Slide. Firstly, the sliding mechanism is made of 6 of ¼ inch Stud-Mount Ball Transfer from McMaster Carr and 3D printed rails. Some lubricant is recommended for this mechanism. Secondly, the twist mechanism allows for structural strength. The operation for removal is simple (twisting the locking rod), the friction fit allows for no unwanted movement, and the Fillet design on the locking rod helps guide the operator to unlock the mechanism correctly. Moreover, the locking rod is separated into a friction disk (blue), a locking nut (gray), and the actual locking rod (yellow) for easy printing, assembly, and replacement. Lastly, the mechanism allows for all 6 axes of freedom to be locked.

An animation of the way these mechanism works is provided in the Youtube video as follows: https://youtu.be/YSh1q1xQEmw

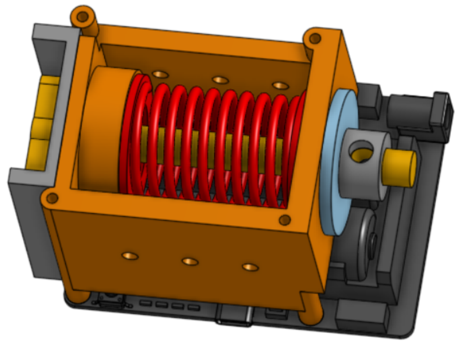

Figure 14: TASM Design Version 1

An addition of a tensioning element such as a spring was considered to reduce the reliance of friction fit (Figure 14). For non-frequent disassembly operations, this is not necessary, therefore, the design in Figure 15 is much preferred in most cases.

One thing to watch out for when designing a similar mechanism is that due to the low melting point of PLA (260 Celsius) and the nature of friction fit, partial melting and fusing of the parts in contact can occur at extreme temperatures. This would result in the inability to remove and repair the Power Module if needed. If the CUBESAT needs to operate in such conditions, the parts can be modified so that more heat-resistant materials (Nylon, ABS, metal) can be pre-fabricated to be used on contact points.

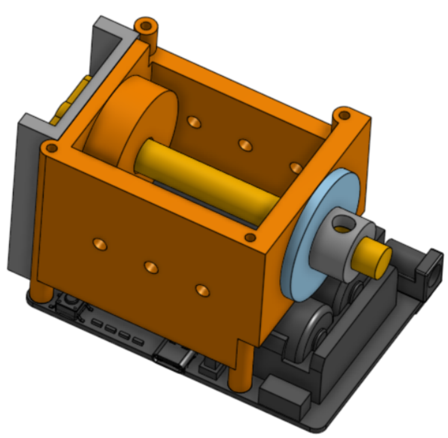

Figure 15: TASM Version 2

Fabrication

The final design is made of parts that can be easily 3-D printed in PLA. Below is an example of an inexpensive 3D Printer Ender 3 with 11 hours of print time with print settings for optimal strength.

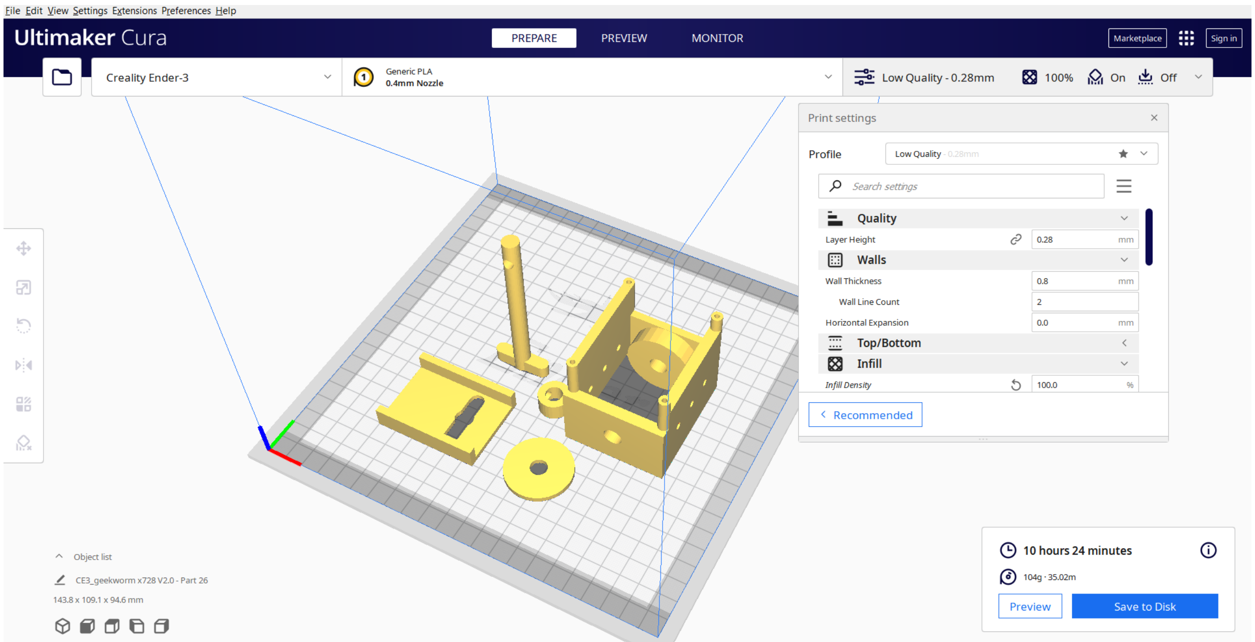

Figure 16: 3D Printing TASM

Conclusion

It is financially and technically beneficial to design the internal components of a CUBESAT, including the Power Module, with repairability and longevity in mind. Throughout the design process, a mechanically supported design with a two-motion assembly/disassembly process is the optimal design choice to achieve such goals. For ease of manufacturing, 3D printed parts made of PLA or PETG with thick walls (above 3mm) are the criteria for similar projects.

This project not only serves as a design process for the TUMBLER project specifically, but also as a starting point for other similar CUBESAT designs and internal components, not just Power Module specifically.

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