COSMIC

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Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

COSMIC Capstone Challenge: Final Briefing

# GatorChomp, University of Florida
# Galactic Autonomous Twin Operational Robotic Arms (GATOR Arms)

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Mentor: Mr. Brian Nufer

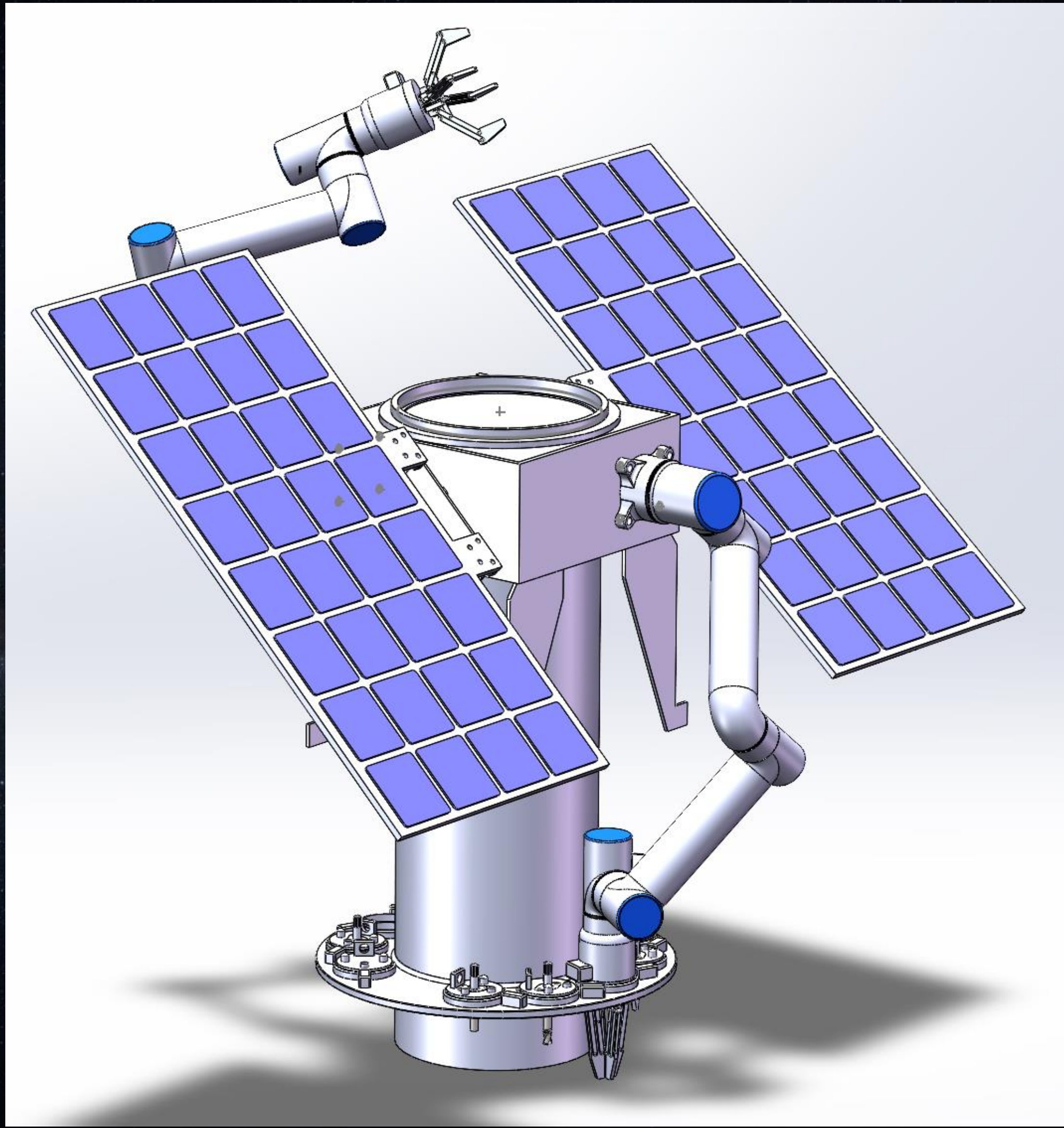
April 16th, 2025

# Executive Summary

*Galactic Autonomous Twin Operational Robotic Arms*

- Current space robotic arm systems are too complex, large, expensive, and single mission focused for use in ISAM
- We propose a small-scale, autonomous twin robotic arm system with interchangeable end effectors for ISAM capabilities
- Twin arms and interchangeable end effectors enable novel complex and precise ISAM operations
- Small-scale and low-cost design reduces the barriers for adoption and expands user base

- Current Status: TRL 2-3
- Abstract accepted at Small Sat Conference
- Proposal submitted for NASA Tech Leap Competition



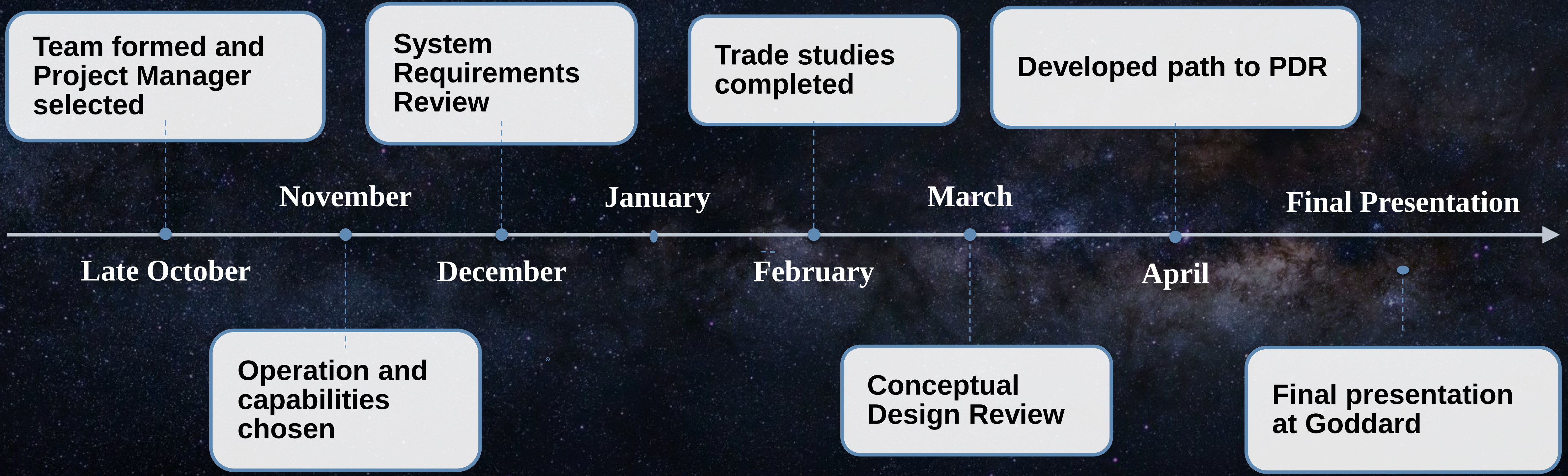
# Team Overview

*11-person team of MAE engineering students at the University of Florida*

*Not pictured: Anais Mera-Sarnelli, Andrew Dishchuk, Priyakrit Rathore*

# 2.4 Systems Engineering Milestones

*Project timeline and systems engineering milestone from our first meeting to today.*




**GATOR Arms Project Timeline and System Engineering Milestones**

# 1.1 Impacts

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- The successful demonstration of autonomous robotic arms with interchangeable tools would significantly impact future space missions by enabling modular, adaptable spacecraft designs.

- These capabilities could improve spacecraft functionality by allowing in-orbit maintenance, upgrades, and reconfiguration, thus reducing the need for entirely new builds.

- The arms will also have the ability to service and extend the lifespan of existing satellites through repairs and component replacements.

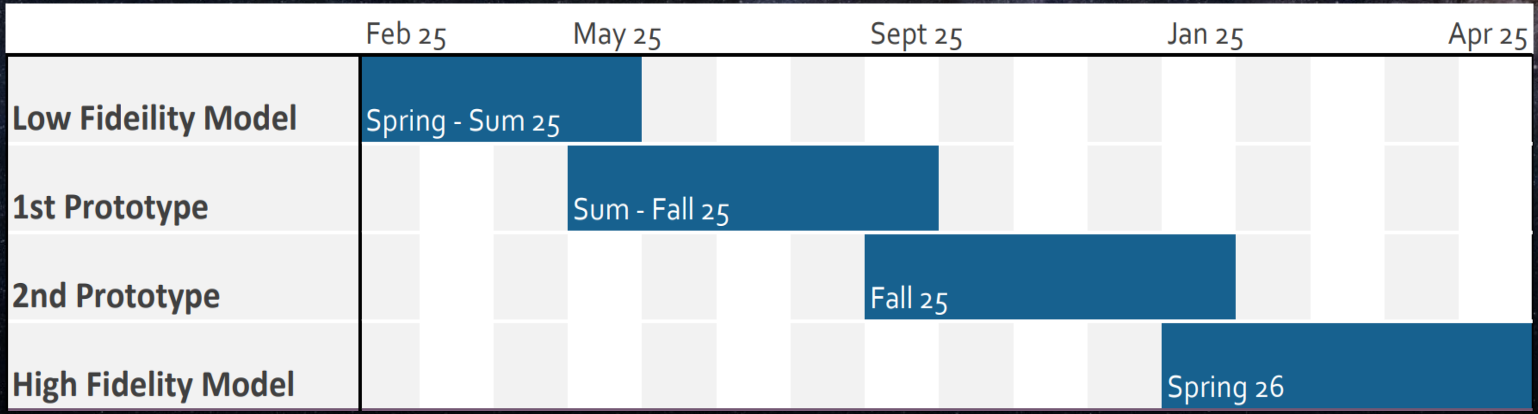
- The technology is largely self-sufficient, however, advancements in autonomous navigation, standardized satellite interfaces, and tool design could further enhance its effectiveness across diverse mission profiles.

**Interchangeable tools enable modular spacecrafts and extend lifespans through in-orbit servicing**

# 1.2 Feasibility

*Current Development Timeline*

- Submitted a proposal for this design to NASA TechLeap Prize for $500k and a flight test
  - Plan is to develop up to three models over the next school year
- Final exit criteria for this award is TRL 6 for flight test
  - Current design and development is at TRL 2-3
  - Intermittent models will have exit criteria TRL 4 and TRL 5
- Fully developed and functioning model can be achieved with further testing and funding by 2030




**Overall, attainable by 2030**

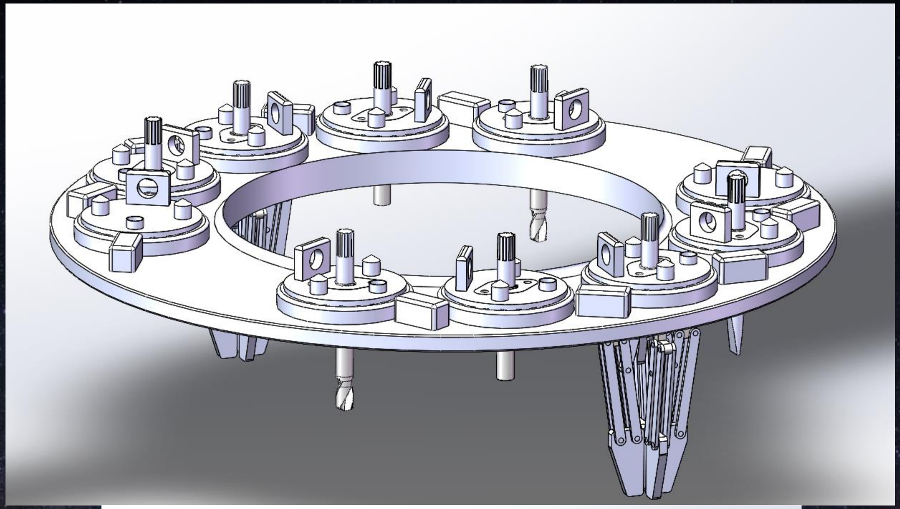
# 1.3 Innovation

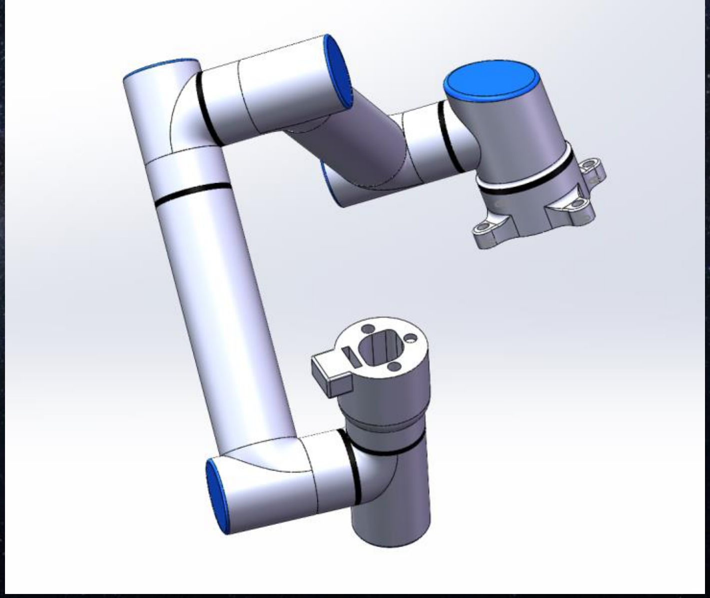
*Where Innovation is Advanced*

- While robotic arms have been used in space before, a compact, modular arm system with interchangeable tool attachments has not been demonstrated in space before.

- Large dual arms have been prototyped on Earth with generic manipulators but was focused on GEO servicing (DARPA). GATOR Arms specializes with a small system architecture for LEO.

- The interchangeable tool system and focus on on-orbit maintenance adds an inventive, pertinent layer of utility and mission capability. This interchangeability has not been demonstrated prior and is the main focus on GATOR Arms.





**A compact, modular arm with interchangeable parts is a novel solution for on-orbit operations**

# 1.4 Required Elements

*Capabilities and operational environment*

- GATOR Arms performs 3+ autonomous operations to demonstrate in-space servicing or assembly capabilities
  - Visualizing and determining target object position.
  - Interchanging tools for desired operation.
  - Articulating target object.
  - Performing tasks on target, such as fastening, drilling, or scanning.

- Considered extreme temperatures and conducted a thermal analysis in System Tools Kit (STK) to ensure components operate under these conditions
  - Temperature range of –81.3 to 25.8 Celsius in orbit
  - Multilayer Insulation Coating (MIC) has been chosen to keep components within operating conditions.
  - Additional thermal analysis is necessary to determine internal temperatures from components.
  - Additional vibration testing and FEA analysis is essential before launch.

**Design satisfies autonomous requirements and considers operational environment.**

# 1.4 Required Elements



*Volume and mass*

- Proposed design components currently fit inside the 17.0" x 16.4" x 27" internal volume provided.
  - Nvidia Jetson Orin Nano reserves 3.9" x 3.1" x 1.1" of space.
  - Stepper motor controller occupies 6.5" x 4.7" x 1.4" of space. Because two controllers are needed, stacking the boards in a vertical fashion will ensure everything fits inside given volume.

- The twin arms and tool belt will fit inside launch fairing.
  - The full payload fits within the 16' diameter x 47' tall Falcon 9 fairing.
  - Payload dimensions are 32" x 23" x 41".

- Mass analysis was performed and found that a fully loaded satellite is below the 70kg payload limit.
  - A fully loaded payload is 20.4 kg.
  - The heaviest contributors were the tool belt, stepper motors, and solenoids amounting to 5.4 kg, 5.4 kg, and 1.8 kg, respectively.

**Design fits within volume constraints and weighs 20.4 kg.**

# 1.4 Required Elements

*Power and cost*

- Processing is handled by a Nvidia Jetson Orin Nano.
  - Signals are sent from the computer to Nema-17 motors that control rotations at each joint of the arm.
  - Each Nema-17 has an encoder to accurately determine where the arm will move.
- Peak power consumption amounts to 339 W. The proposed bus provides enough power for operations.
  - Computer consumes 25 W.
  - Stepper motors consume the most power, up to 148 W.
- A cost analysis was performed and reports a total cost of $4231
  - Materials used (Aluminum 6061, Stainless Steel 304, Titanium Ti-5Al-2.5Sn): $53
  - Component cost: $4000
  - Thermal insulation: $178

**Total cost is $4231 and total peak power consumption is 339 W.**

# 1.7 Trade Studies

*Relevant academic literature*

- Kush, T. (2024). Utah Small Satellite Conference. In *Results from On-orbit Operation of CubeSat-scale Robotic Arms on the International Space Station* (pp. 1–10). Salt Lake City; USU. Retrieved 2025, from https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=5871&context=smallsat.
- The source above is an example of a set of small scale robotic arms made for cubesats that was tested in the International Space Station. Its similar to out current idea in some ways but is less modular and not test in a free space environment.

- F. F. Badavi, D. O. Adams, and J. W. Wilson, "On the validity of the aluminum equivalent approximation in space radiation shielding applications," *Advances in Space Research*, vol. 46, no. 6, pp. 719–727, Sep. 2010, doi: https://doi.org/10.1016/j.asr.2010.04.006.
- A. Rosh-Gorsky *et al.*, "3D Printing of Composite Radiation Shielding for Broad Spectrum Protection of Electronic Systems," *Advanced Materials*, vol. 36, no. 33, May 2024, doi: https://doi.org/10.1002/adma.202403822.
- The two above sources discuss radiation shielding of aluminum and composites and helped guide decision making on what material is best for this design.

**Sources that have been useful throughout our design process**

# 1.7 Trade Studies



*Relevant academic literature*


- S. Guertin, "Raspberry Pis for Space Guideline." Available: https://nepp.nasa.gov/docs/papers/2021-Guertin-Raspberry-Pi-Guideline-CL-21-5641.pdf
- M. Cabanas-Holmen *et al.*, "Predicting the Single-Event Error Rate of a Radiation Hardened by Design Microprocessor," *IEEE Transactions on Nuclear Science*, vol. 58, no. 6, pp. 2726–2733, Nov. 2011, doi: https://doi.org/10.1109/tns.2011.2168978
- A. Sánchez-Alvarez, D. Luna-Moreno, J. A. Hernández-Morales, J. O. Zaragoza-Zambrano, and D. H. Castillo-Guerrero, "Control of Stepper Motor Rotary Stages applied to optical sensing technique using LabView," *Optik*, vol. 164, pp. 65–71, Mar. 2018, doi: https://doi.org/10.1016/j.ijleo.2018.02.115.


- The first two sources give insights on how radiation affects computers in space. The last source gave information on the importance of encoders and how they operate.

**Sources that have been useful throughout our design process**

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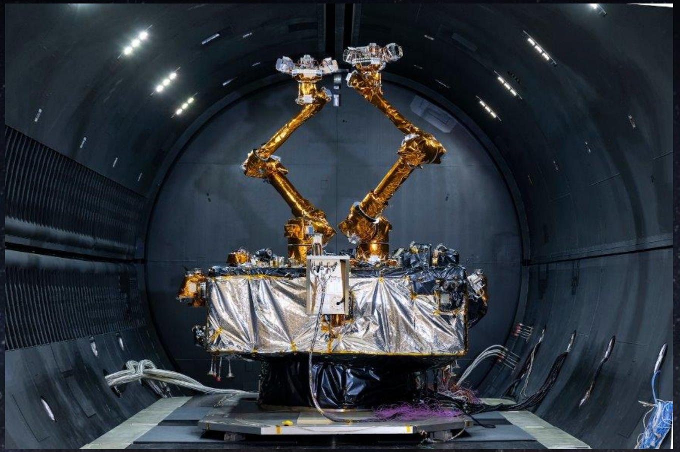
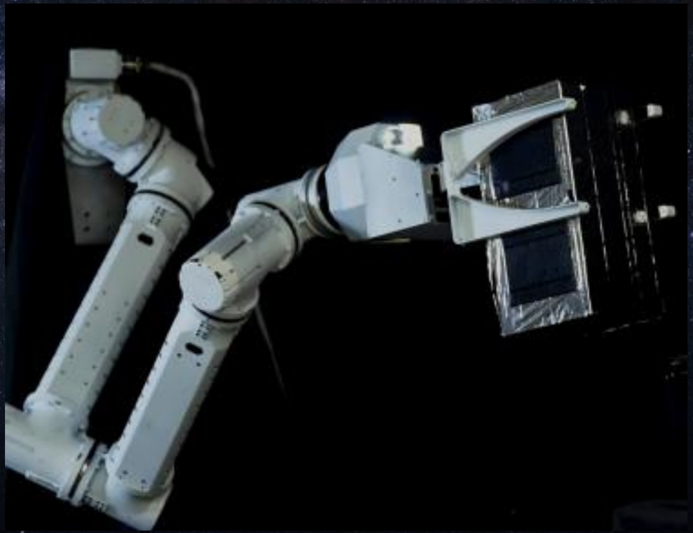
# 1.7 Trade Studies

*Current robotic arm systems being developed*

- DARPA Robotic Servicing of Geosynchronous Satellites (RSGS) – TRL 6
  - Large scale servicing of GEO satellites with dual arms and manual operation
  - Has yet to launch to space after years of delays
- GITAI Inchworm Robot – TRL 7
  - Single medium scale arm designed for ISAM



*DARPA RSGS*



*GITAI Inchworm Robot*

**Two other space robotic arm systems currently being developed**

# 1.7 Trade Study Comparison

*Comparing Current Design to GITAI Arm*

- Comparing one GATOR Arm to GITAI arm
- GATOR Arm features 6 DOF
- Current design has an extended length of 30",  roughly half the length of GITAI.
- GATOR Arm is a fraction of the weight of GITAI.
- The GATOR Arms utilize less power.
- Temperature ranges between the two arms are comparable.
- Development costs for GITAI arm has been in the millions, and production cost is estimated to be much larger than GATOR arms.

| | Spec | Unit |
|---|---|---|
| Degree of Freedom (End Effector) | 7 (2) | |
| Dimensions | 2 | m |
| Weight | 50 | kg |
| Drive Power Supply | 24-48 | Vdc |
| Power Consumption | 60 standby, 200 peak | W |
| Temperature | -20 to +60 | ℃ |
| Rated Continuous Joint Torque @ Ta=25℃ | 368 | Nm |
| Rated Maximum Angular Velocity | 32.6 (@ 24V input)64.9 (@ 48V input) | deg/s |

GITAI Arm specs

**Comparable specs for a fraction of the cost**

# 1.5 Risks

*CONOP and list of risks.*

- The goal of the GATOR arms is performing ISAM capabilities with the satellite. Risk will stem from failures that interfere with the completion of those ISAM capabilities.
  - Various risks are graphically displayed using a risk matrix.
  - Risks are categorized through various ratings.
    - 1 - Items will cause the total loss of the mission or the loss of human life if they fail.
    - 1R - Items are those for which crit 1 loss occurs if the primary and backup redundant hardware fail.
    - 2 - Loss of one major objective for the mission.
    - 2R -Items are those for which crit 2 loss occurs if the primary and backup redundant hardware fail.
    - 3 - Failure causes inconvenience for users.

Impact →

| Likelihood ↑ | Negligible | Minor | Moderate | Significant | Severe |
|---|---|---|---|---|---|
| Very Likely | Low Med | Medium | Med Hi | High | High |
| Likely | Low | Low Med | Medium | Med Hi | High |
| Possible | Low | Low Med | Medium | Med Hi | Med Hi |
| Unlikely | Low | Low Med | Low Med | Medium | Med Hi |
| Very Unlikely | Low | Low | Low Med | Medium | Medium |

**Risk matrix explanation.**

# 1.5.1 Risks

*List of risks.*

| Criticality | Risks |
|---|---|
| 1 | 1.1 Computer Failure (ORIN NANO)<br>1.2 Charging Failure (SOLAR)<br>1.3 Memory failure (SOLAR) |
| 1R | 1R.1 Main satellite GNC: There are redundant systems to prevent mission loss in the case of GNC system failure. |
| 2 | 2.1 Cold Welding: Will be prevented using coats on the interactive materials.<br><br>2.2 Motor Failure: No possible back-up, it removes our ability to complete any tasks. Doesn't immediately end the mission since there are two arms. Turns into a criticality 1 risk after one arm fails, the next motor to break on the secondary arm means total mission loss. |
| 2R | 2R.1 Tool-set Failure: A mission operation is lost when a set of tools become inaccessible. Loss of the whole belt would be a criticality 2 failure as it would only allow missions with the tools installed. |

**Table of risks and their criticality rating.**

# 1.5.2 Risks

*Risk matrix.*

| Risk Matrix | Minor | Moderate | Significant | Severe |
|---|---|---|---|---|
| Very Likely | | | | |
| Likely | | | | 1R.1 |
| Possible | | | 2.2 | 2R.1 |
| Unlikely | | 2.1 | | 1.1, 1.2, 1.3 |

**Risk matrix of previously listed risks.**

| Risks |
|---|
| 1.1 Computer Failure (ORIN NANO) 1.2 Charging Failure 1.3 Memory failure |
| 1R.1 Main satellite GNC: There are redundant systems to prevent mission loss in the case of GNC system failure. |
| 2.1 Cold Welding: Will be prevented using coats on the interactive materials.<br><br>2.2 Motor Failure: No back-ups for individual motors. Doesn't immediately end the mission since there are two arms, however risk becomes criticality 1 after one arm fails, the next motor to break on the secondary arm means total mission loss. |
| 2R.1 Tool-set Failure: A mission operations is lost when a set of tools become inaccessible. Loss of the whole belt would be a criticality 2 failure as it would only allow missions with the tools installed. |

# 1.6 Path to PDR

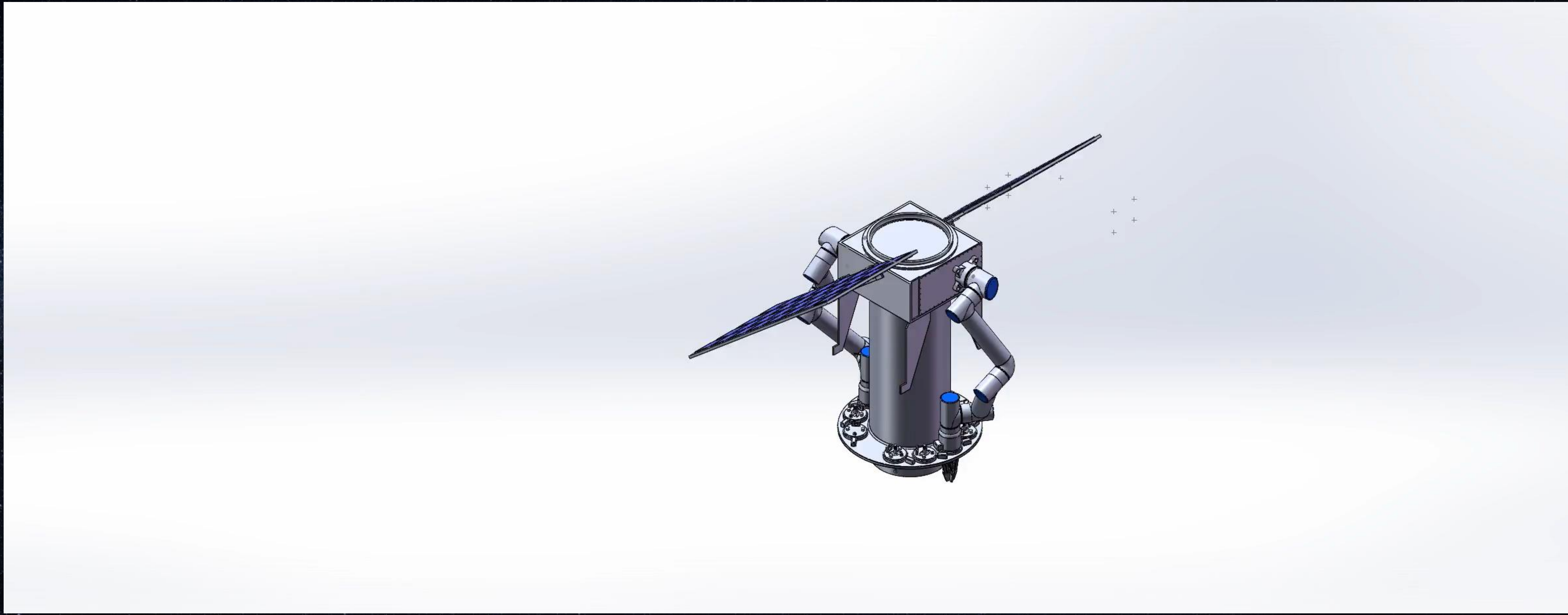
*Next steps for PDR*

- Arms to be integrated into a readymade satellite or platform that can accept data and transmit during frequent (but not necessarily continuous) passes.
- BCT X-Sat Venus Class Bus provided as host vehicle.
- Prepare for Thermal Vacuum (TVAC) testing and Vibration testing.
- Reduce severe risks of the hand grip weakening to the point of lost function and the tool changing module failing.

**BCT X-Sat Venus Class Bus as host vehicle, thermal and vibration testing needed**

## 2.1 Design Animation

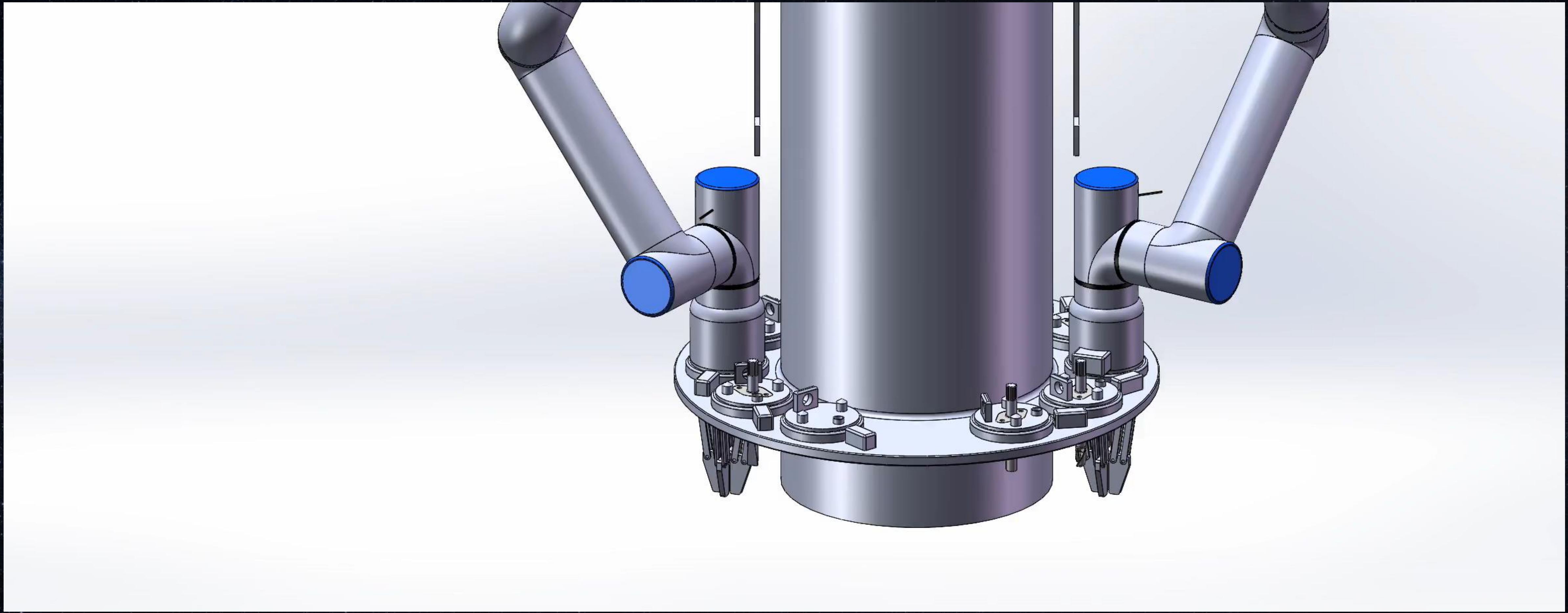
# 2.1 Animation of Payload



Payload Overview

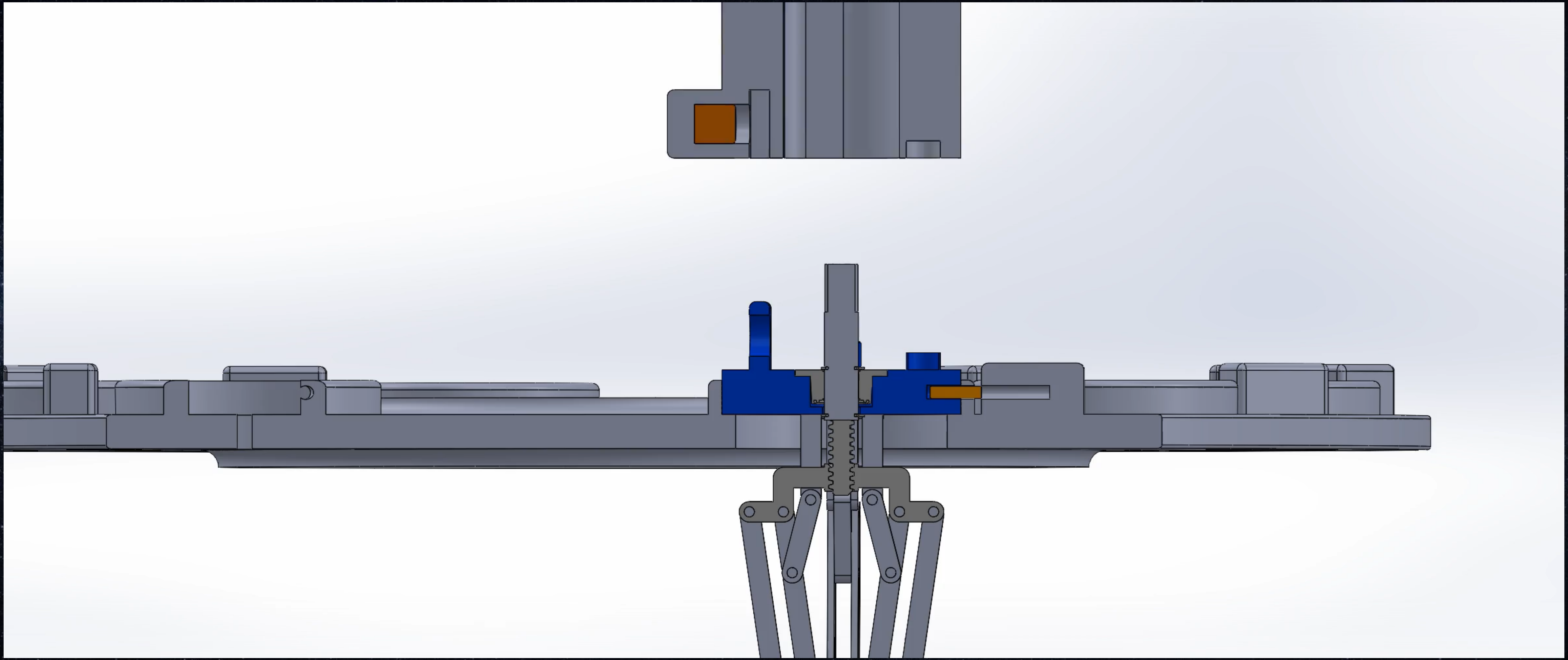
# 2.1 Animation of Tool Belt and Arms





**Tools in Tool Belt Overview**

# 2.1 Animation of Tool Attachment/Detachment



**Attaching and Detaching with Solenoid Locking**

# 2.1 Animation of Object Manipulation

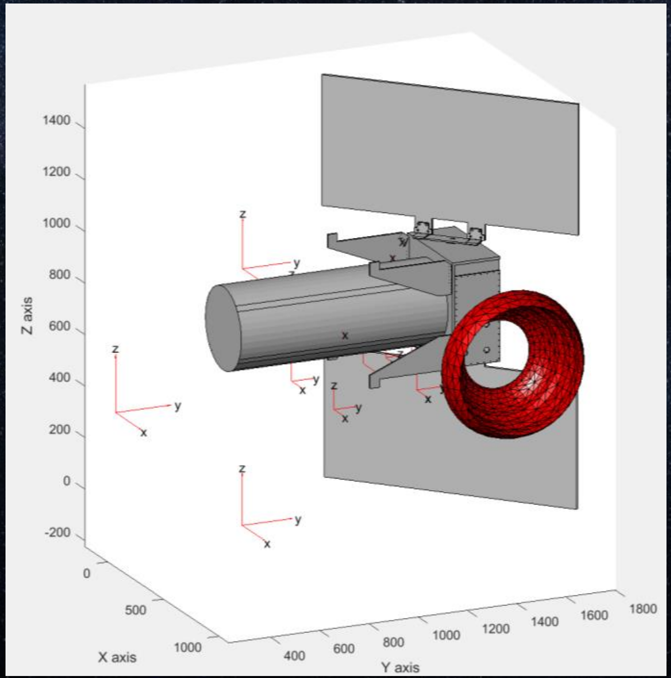


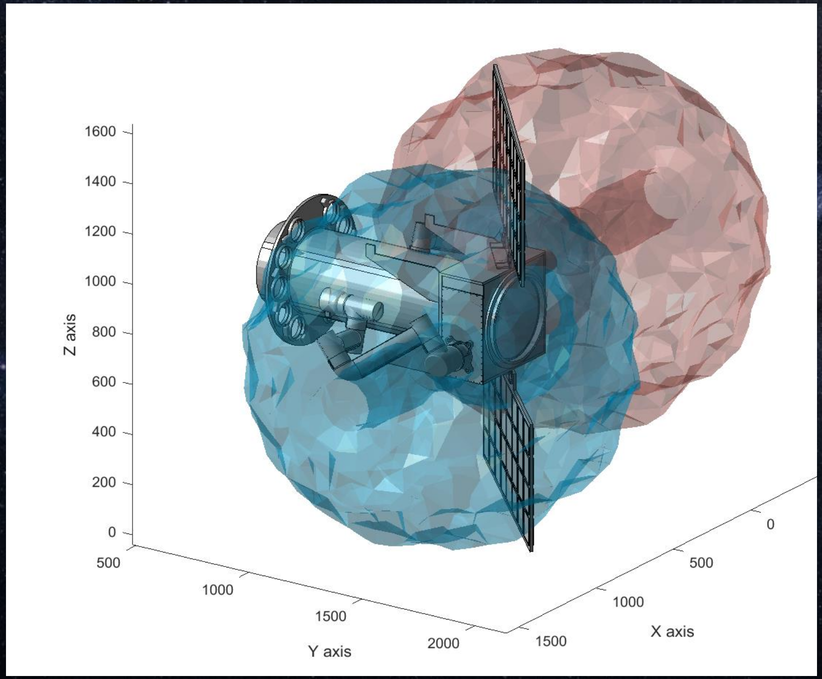
Solving Cube Demonstration

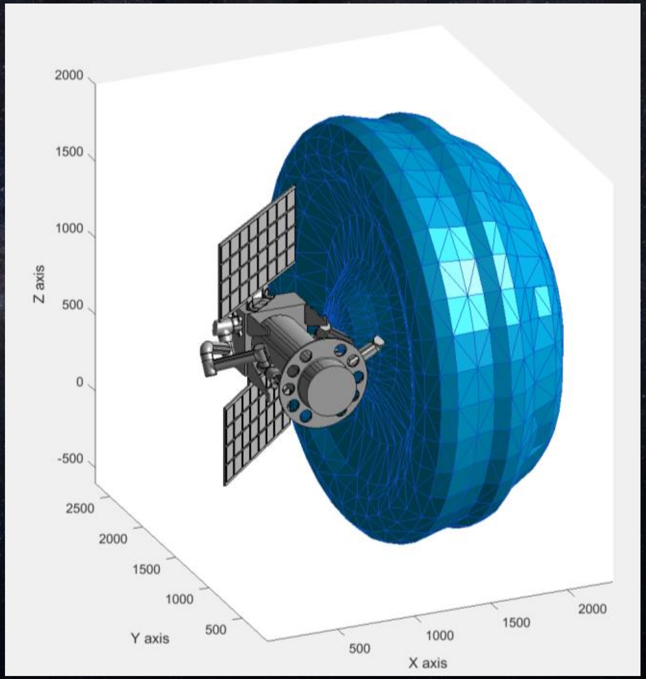
# 2.2 Robotic Arm Work Envelope

*Using Forward Kinematics to contextualize the range and effectiveness of the arm's design*

- Implemented an iterative forward kinematics method to create a work envelope of the different arm design using homogenous transformations for each joint
- Utilized the different work envelopes to select the design best suited to achieve the objectives

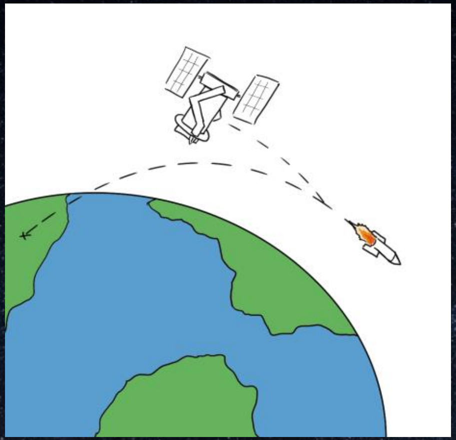


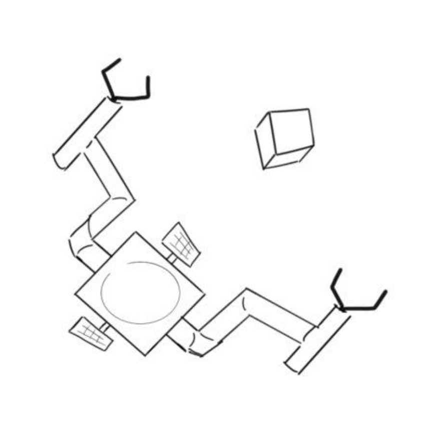




**Validation of the arms design by work envelope analysis**

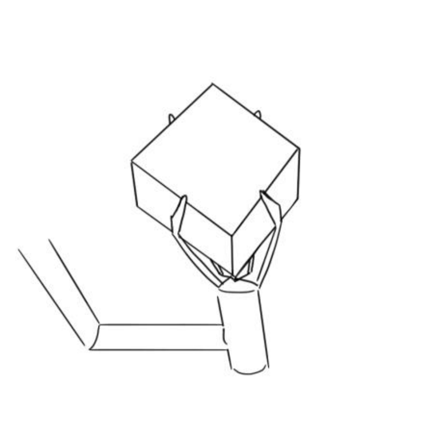
# 2.2 Storyboard of Complete Operation



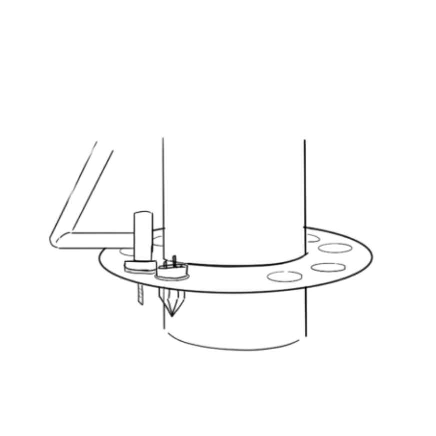
1.Launch



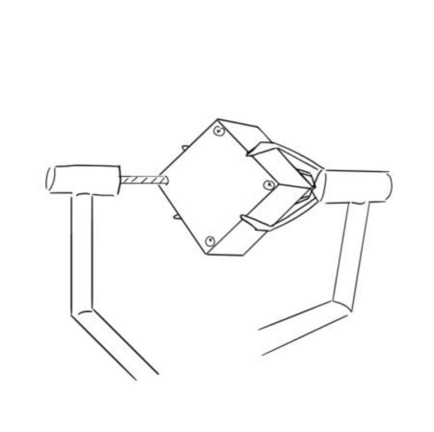
2. Target object



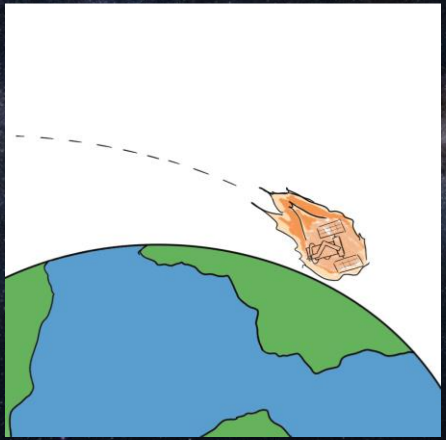
3. Articulate object



4. Change tools



5. Performing ISAM capability



6. Deorbit

**An example CONOPS for Gator Arms**

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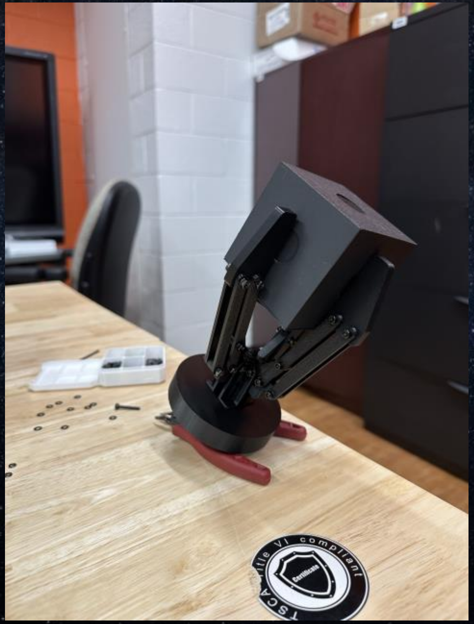
# Prototype

*Hand Tool Prototype*

- This prototype is a modular hand designed for precision tasks. It facilitates the articulation, capture, and manipulation of small satellite components.
- We developed this prototype in order to address the need for autonomous servicing that would extend the lifespan of satellites currently in orbit.



**This prototype displays the ability of precise, modular servicing of satellites.**

# 2.3 Data Handling and Comms

*Requirements for automated inspections and ISAM operations*



- Automated ISAM operations, 3D scanning and inspection do not require real time downlinks, observers, or full-time operators. Mission commands and instructions will be uploaded and initiated remotely
- Uplink and downlink bitrate of approximately 1kbps and 1 Mbps, respectively, during normal engineering operation
- Data from tools (tactile sensors, cameras, IR scanners, etc.) and stepper motor encoders will be serialized for transmission through the rotary connectors to the computer housed in the bus

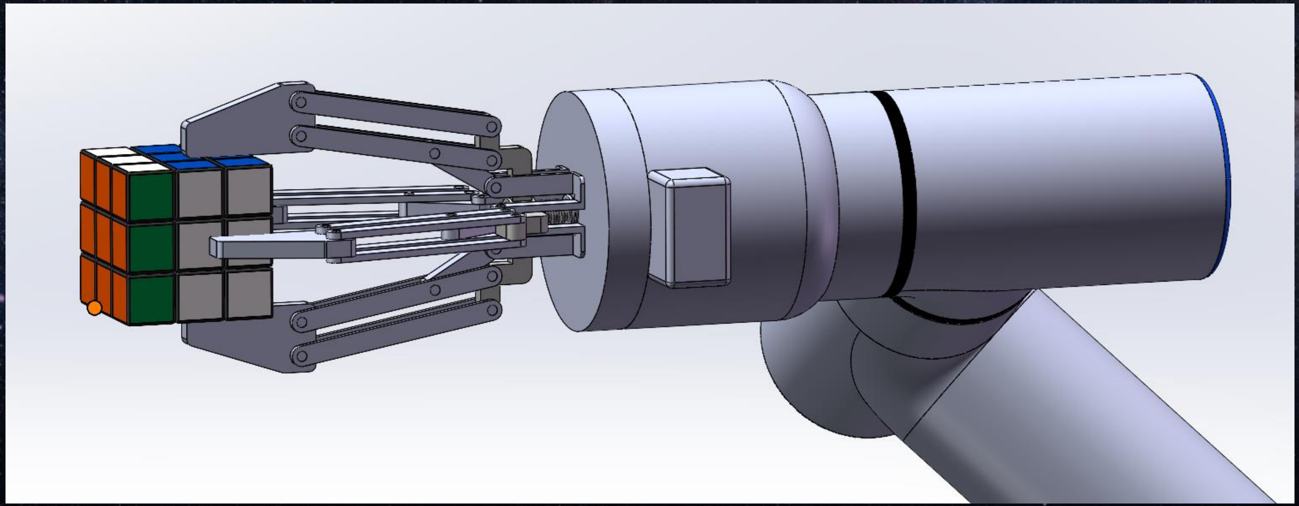
| Operation | Uplink | Downlink |
|---|---|---|
| Emergency | 500 bps | 10 kbps |
| Normal / Engineering | 1 kbps | 1 Mbps |
| Special | 1 Mbps (memory reload) | 5 Mbps (mission data) |

**Low-Bitrate Uplink and Downlinks Capable of Initiating Automated ISAM Operations**

# 3.1 Most Innovative Concepts Considered

*Key Innovations Enabling Efficient Small Sat Servicing*

- Designing interchangeable tool attachments enables task-specific operations and extends arm versatility.
- Scaling the robotic arm system for small satellites makes precision servicing feasible for smaller missions
- Incorporating autonomy allows the arm to operate without real-time human control, critical for efficient on-orbit response.



**Interchangeability, Small-Scale, and Autonomous**

# 3.2 Most Important Technology Gaps

- Accurate machine learning identification of tools, parts, and satellite damage
  - In order to perform repairs in space with different sets of tools, a machine learning algorithm with the ability to identify and accurately determine areas in need of repair and the tools required for the repair operation
- Precise control systems for robotics in space
  - The arm must have precise dynamic movement and improved capacity to model those movements to improve the feasibility of the mission
- Smaller and longer-life stepper motors that can withstand the harsh environment of space
  - Smaller and longer-life stepper motors would see that the arms would be lower mass, require less shielding, and would also lower the cost of the arms while increasing the possible lifetime

# 3.3 Biggest Challenges Encountered

*3 Primary Technical Challenges*

- Sizing the stepper motor, encoder, and gearset packs for each rotational joint
  - Small (NEMA 17) motors were selected to fit within the 3-inch diameter frame
  - Large planetary gears to regain torque require significant length
  - Solved with creative placement of motors
- Modelling the dynamics of a sufficiently complex robotic arm
  - Arm needs to be capable of linear movement at the end of its range for tool changing and complex ISAM operations
  - Increased arm complexity makes modelling the dynamics and programming movement more difficult
- Data processing and transmission introduced challenges with joint complexity
  - Each encoder adds 10 lines of data and power transmission per joint – solved by serializing data at each joint
  - Data processing (from camera, tactile sensors, and encoders) completed locally on the bus processing unit
  - Algorithms will use arm and bus camera data to determine object positioning and required arm movement

**Solving stepper motor size, modelling of dynamics, and data processing / transmission**

# 4.1 Paper



- Paper details the driving purpose behind the mission and innovation of the design
- Overview of the design of arms, potential tools, and their applications
- Future testing of the design on objectives
- Risk mitigation
- Prototyping and development budget
  - 400-word abstract
  - 11-pages
  - 6 References included
  - Abstract accepted to the 39th Annual Small Satellite Conference in August 2025

**Paper was written detailing work on COSMIC. Abstract accepted at Small Satellite.**

# Summary/ Conclusion/ Highlights



- GATOR Arms is a small-scale, autonomous twin robotic arm system with interchangeable end effectors for ISAM missions.
- Since our team formed in October, we have:
  - Down-selected from over 30 concepts
  - Completed our Systems Requirements Review (SRR)
  - Conducted trade studies
  - Iteratively designed and modeled the GATOR Arms
  - Conducted structural, mechanical, thermal, and kinematic analyses
  - Submitted an abstract to the Utah State Small Sat Conference that was accepted!
  - Submitted a design proposal to the NASA Tech Leap Challenge
- In the future, we plan to the raise the TRL of the system through prototypes and laboratory testing with the eventual goal of a demonstration in a space environment.

**Summary of the development of GATOR Arms over the past 6 months.**

# Questions



## Questions?

# Backup Slides

# Backup Slide – Material Feasibility

- Likely maximum force for drilling a ½” hole in aerospace grade aluminum ($P$): 50 lbf
  - Drilling Torque, Thrust and Power Calculator – Kennametal
- Aluminum frame outer radius ($D_o$): 3 in
- Aluminum frame inner radius ($D_i$): 2.8 in
- Frame length at maximum extension ($L$): 30 in
- Moment ($M$) required from base motor to apply drilling force $P$ at length $L$: 1500 in*lb
  - $M = P * L = 50 * 30 = 1500\ in * lb$
- Moment of inertia ($I$) for a pipe with outer radius $D_o$ and inner radius $D_i$: $0.95889\ in^4$
  - $I = \frac{\pi({D_o}^4 - {D_i}^4)}{64} = \frac{\pi(3^4 - 2.8^4)}{64} = 0.95889\ in^4$
- Maximum tensile stress ($\sigma$) for a pipe with moment of inertia $I$ with a moment $M$ applied, where the point of maximum stress is on the outer surface of the pipe ($c$): $2.346\ Kpsi$
  - $\sigma = \frac{M*C}{I} = \frac{1500 * 1.5}{0.95889} = 2346.46 \frac{lb}{in^2} = 2.346\ Kpsi$
- 6061 T6 aluminum yield stress ($\sigma_y$) = $40\ Kpsi$
  - Aluminum 6061-T6; 6061-T651 - MatWeb

**Expected maximum tensile stress does not exceed yield strength for aluminum**

# Backup Slide – Material Selection

- 6061-T6 Aluminum was chosen because of its high strength-weight ratio. Aluminum is relatively cheap, saving on costs as well.
  - Aluminum performs as a radiation shielding material.
  - 6061 because of its higher strength and comparable corrosion resistance when compared to pure aluminum (1060).

- Stainless Steel 304 was chosen as spacers in the robotic arm to avoid cold welding rotating joints during operation.
  - Stainless steel 304 is preferred over traditional carbon steel because of its better outgassing, corrosion resistance, and thermal properties.

- Titanium Ti-5Al-2.5Sn was selected for the tool material. Titanium has a high strength and toughness.
  - Ti-5Al-2.5Sn was preferred over traditional grade 5 titanium because the chosen alloy is cheaper while still retaining important qualities. Grade 5 titanium is often used for more critical structural components.

# Backup Slide – Cost/Mass and Power

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- Additional details:
- Material cost was calculated by how much mass was used in the design. The material cost does not account for cost of buying stock.
- The mass of one arm (including stepper motors and solenoids) is 6.1 kg.

| Component | Cost | Weight (kg) | Power (W) |
|---|---|---|---|
| Materials: | | | |
| Aluminum 6061 | $39.47 @ $4.00/kg | 9.87 | |
| Stainless Steel 304 | $2.53 @ $2.50/kg | 1.05 | |
| Titanium Ti-5Al-2.5Sn | $11.25 @ $15.50/kg | 0.73 | |
| Total: | $53.25 | 11.65 | |
| | | | |
| Components: | | | |
| Nvidia Jetson | $250 | 0.174 | 25 |
| Nema-17 (L) | $2400 @ $200/each | 5.4 | 136.8 |
| Nema-17 (S) | $400 @ $200/each | 0.9 | 11.46 |
| Arduino Nano Every | $120 @ $12/each | 0.06 | 1.8 |
| Octopus V1.1 | $100 @ $50/each | 0.357 | 96 |
| TMC5160 | $180 @ $15/each | 0.054 | ~ |
| Solenoid H2206 | $450 @ $45/each | 0.78 | 52 |
| Solenoid F1564L | $100 for 2 | 0.998 | 16 |
| Total: | $4,000 | 8.723 | 339.06 |
| | | | |
| Thermal: | | | |
| MIC insulation | $177.50 @ $50/ sq ft | ~ | |
| | | | |
| Grand Total: | $4,230.75 | 20.4 kg | 339.1 W |

# Backup Slide – Electrical Routing

- Nvidia Jetson Orin Nano, TMC5160, Octopus V1.1 board, Arduino Nano Every and Nema-17/encoder unit work together to adjust positioning of arms.
- The signal flow follows this path: Nvidia ---> Arduino Nano ---> TMC5160 ---> Nema17/encoder unit
  - The Arduino Nanos and TMC5160 are positioned at each motor. The Arduinos serve as a local hub to serialize data and reduce wire clutter. The TMC5160s act as current gates, they send out bursts of current to control the motor in "steps".
- The flow of power follows this path: PSU ---> Octopus V1.1 Board ---> TMC5160
  - Additionally, the Nvidia needs to be powered and is connected to PSU through a buck converter if necessary.
  - The Octopus V1.1 acts as a voltage regulator, that only outputs one voltage (cannot be changed per motor connection). If one needed varying voltages per motor, step-down converters would be needed.
  - The Octopus V1.1 can be given additional function by adding a temperature sensor to its dedicated temperature port to measure the internal ambient temperature for analysis.

**Nvidia --> Arduino --> Stepper Driver --> Stepper Motor**

# Backup Slide – Space Environment Analysis

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- The temperature ranges the satellite will experience in orbit were determined using the System Tools Kit (STK) program.
- Orbital parameters from ISS Zarya 25544 were used in the analysis.
  - These parameters closely resemble the expected Low Earth Orbit (LEO) conditions for our satellite.
- A simulation period of 1 year was used to assess thermal conditions.
- The resulting temperature range from the STK simulation was **–81.3°C to 25.8°C.**

# Backup Slide – GITAI comparison

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| | Spec | Unit |
|---|---|---|
| DOF | 6 | |
| Dimensions | 0.76 | m |
| Weight | 6.128 | kg |
| Drive Power Supply | 24 | V |
| Power Consumption | 156 peak | W |
| Temperature | 0 to 50 | ℃ |

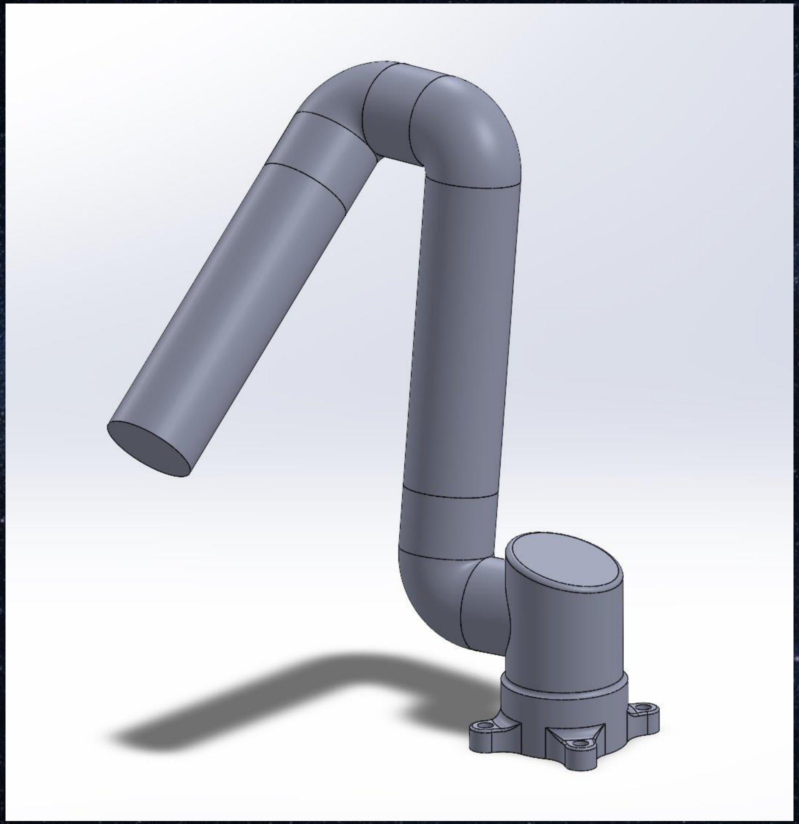
| | Spec | Unit |
|---|---|---|
| Degree of Freedom (End Effector) | 7 (2) | |
| Dimensions | 2 | m |
| Weight | 50 | kg |
| Drive Power Supply | 24-48 | Vdc |
| Power Consumption | 60 standby, 200 peak | W |
| Temperature | -20 to +60 | ℃ |
| Rated Continuous Joint Torque @ Ta=25℃ | 368 | Nm |
| Rated Maximum Angular Velocity | 32.6 (@ 24V input)64.9 (@ 48V input) | deg/s |

- GATOR Arm (left) is 38% of the size compared to GITAI, and 12% of the weight.
- Power consumption is 22% less than GITAI.

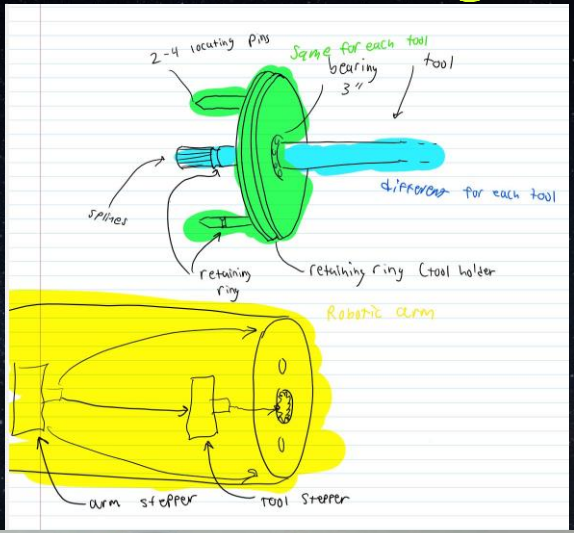
**GATOR Arms can provide value at a fraction of the cost.**

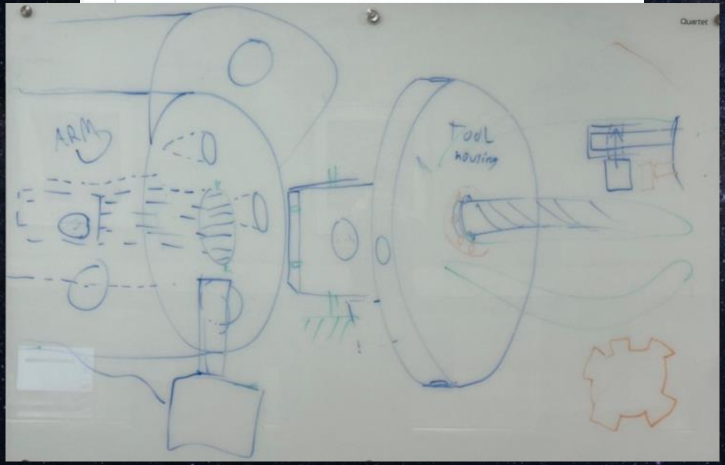
# Backup Slide – Robotic Arm Design Variations



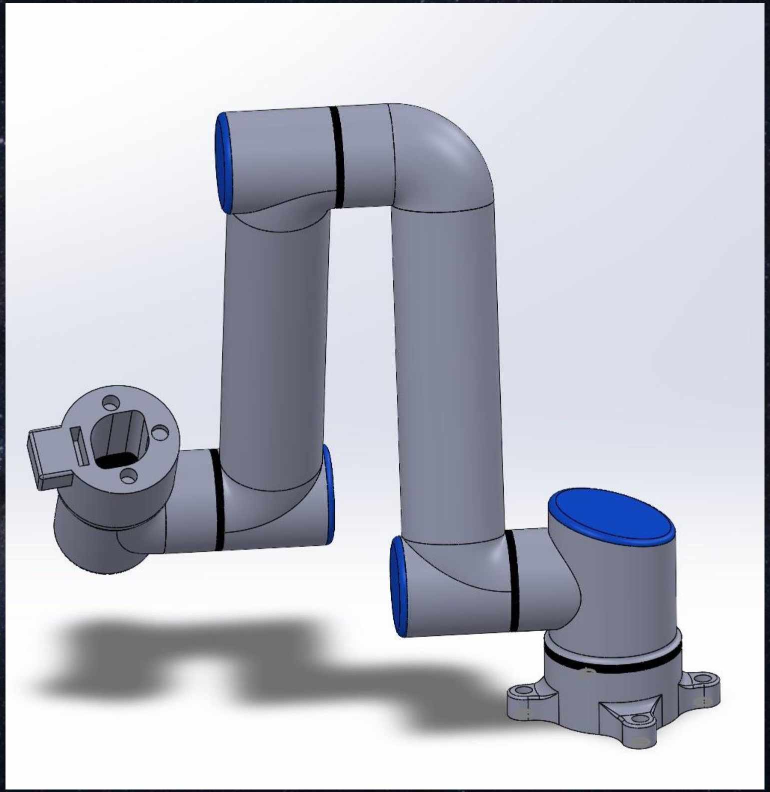


Initial arm design



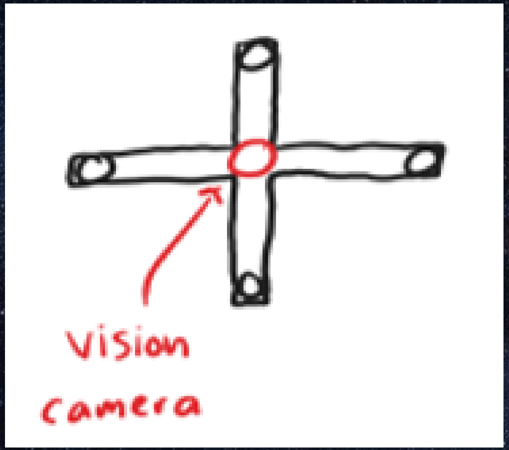




Universal interface design

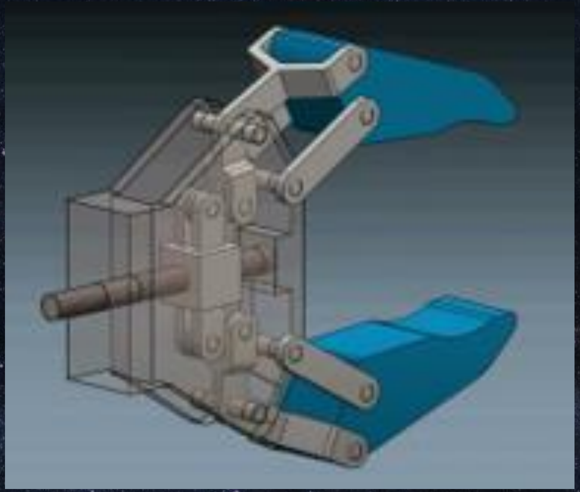


Final arm with end joint fitted
to attach to universal interface

# Backup Slide – Hand Design Variations

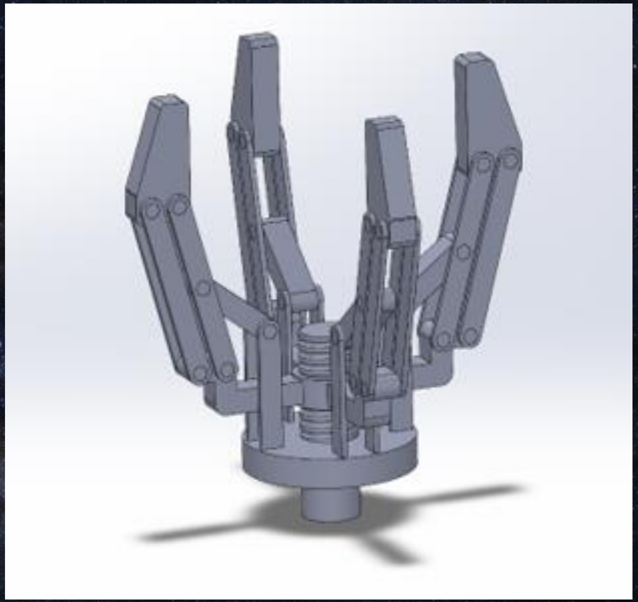



4 sliding finger
hand with vision
camer in palm



2 finger pincher

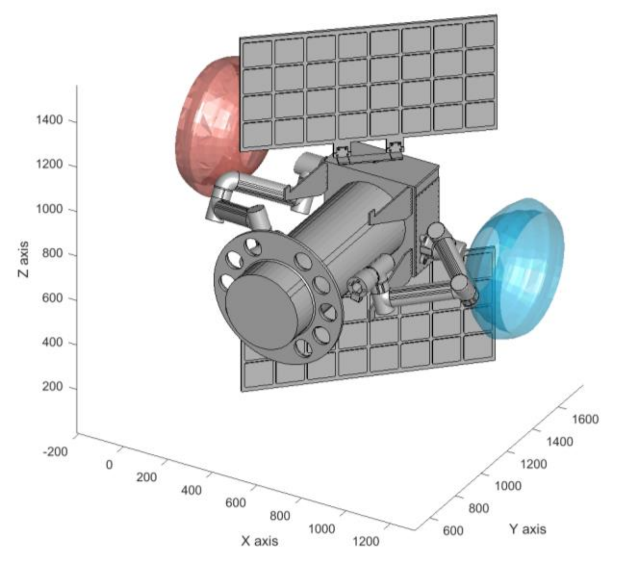
3 finger grabber

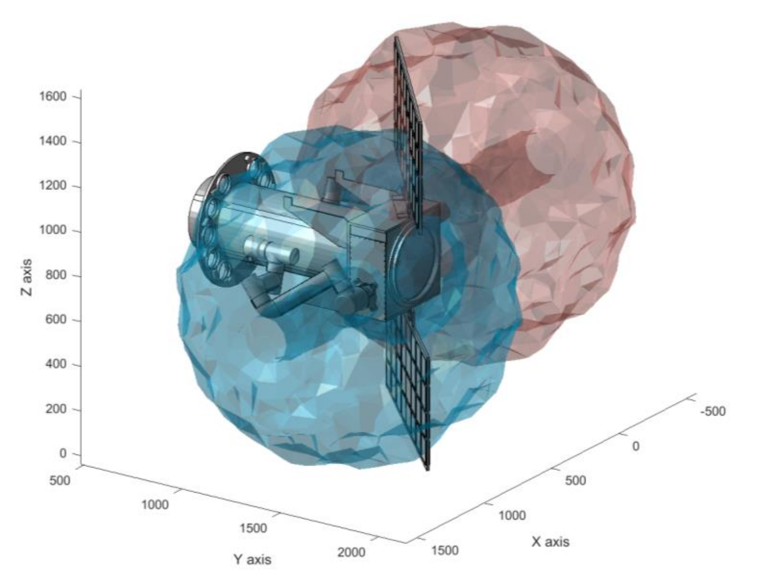


4 finger screw grabber

# Backup Slide – Work Enevlops

- MATALB programs developed to create a point cloud of possible end effector locations for different robotic arm configurations by iterating through the angles for each revolute joint in the arm.
- The end effector locations calculated by utilizing a series of homogenous transformations at each of the different revolute joints as is standard procedure for a general Forward kinematics analysis.
- Separate program created to visualize and contextualize the envelope by importing satellite and arm geometry into the model to check for overlap between the work envelopes of the two arms.




**Utility of envelope-based analysis for different arm design**

# Backup Slide – Part Drawings

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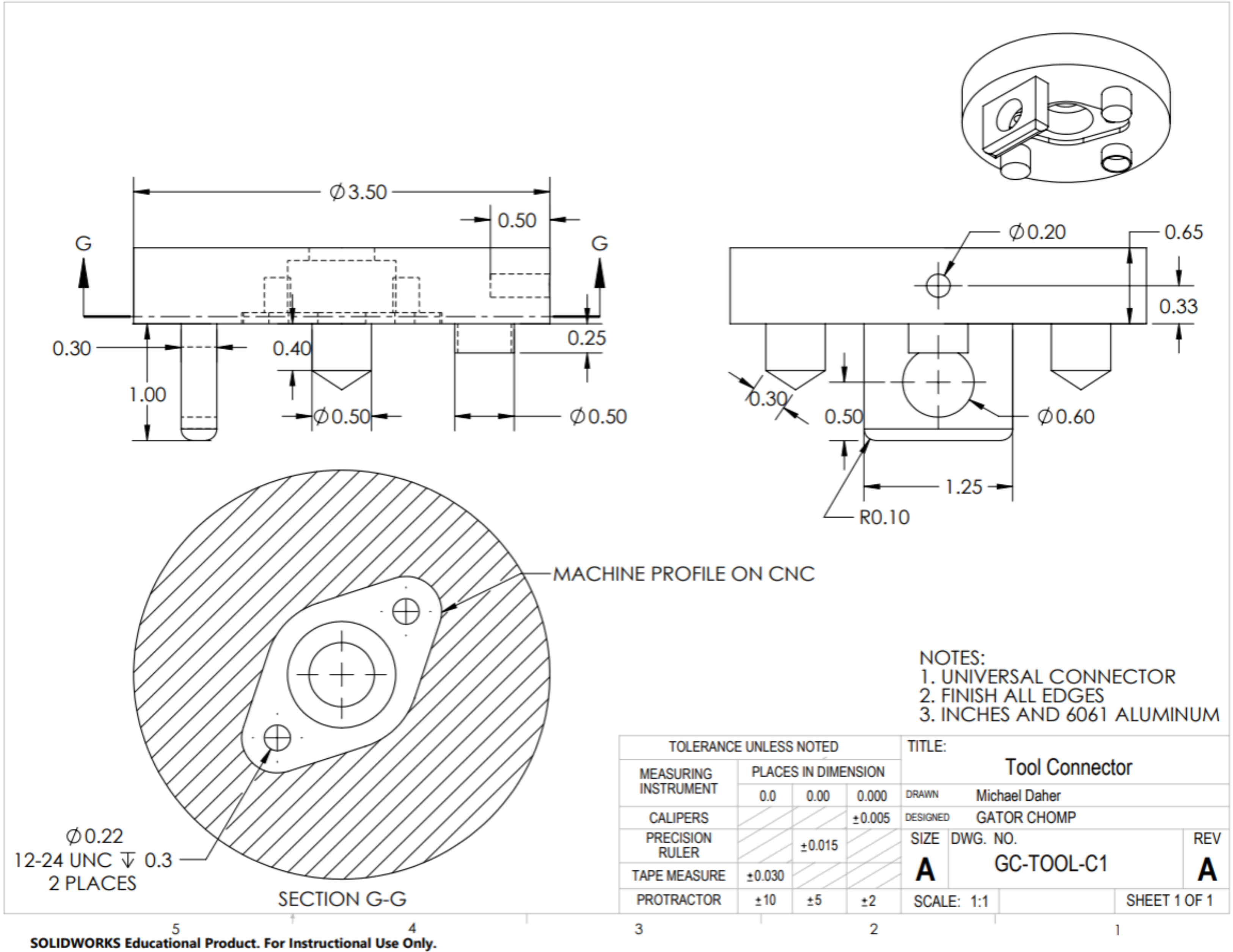
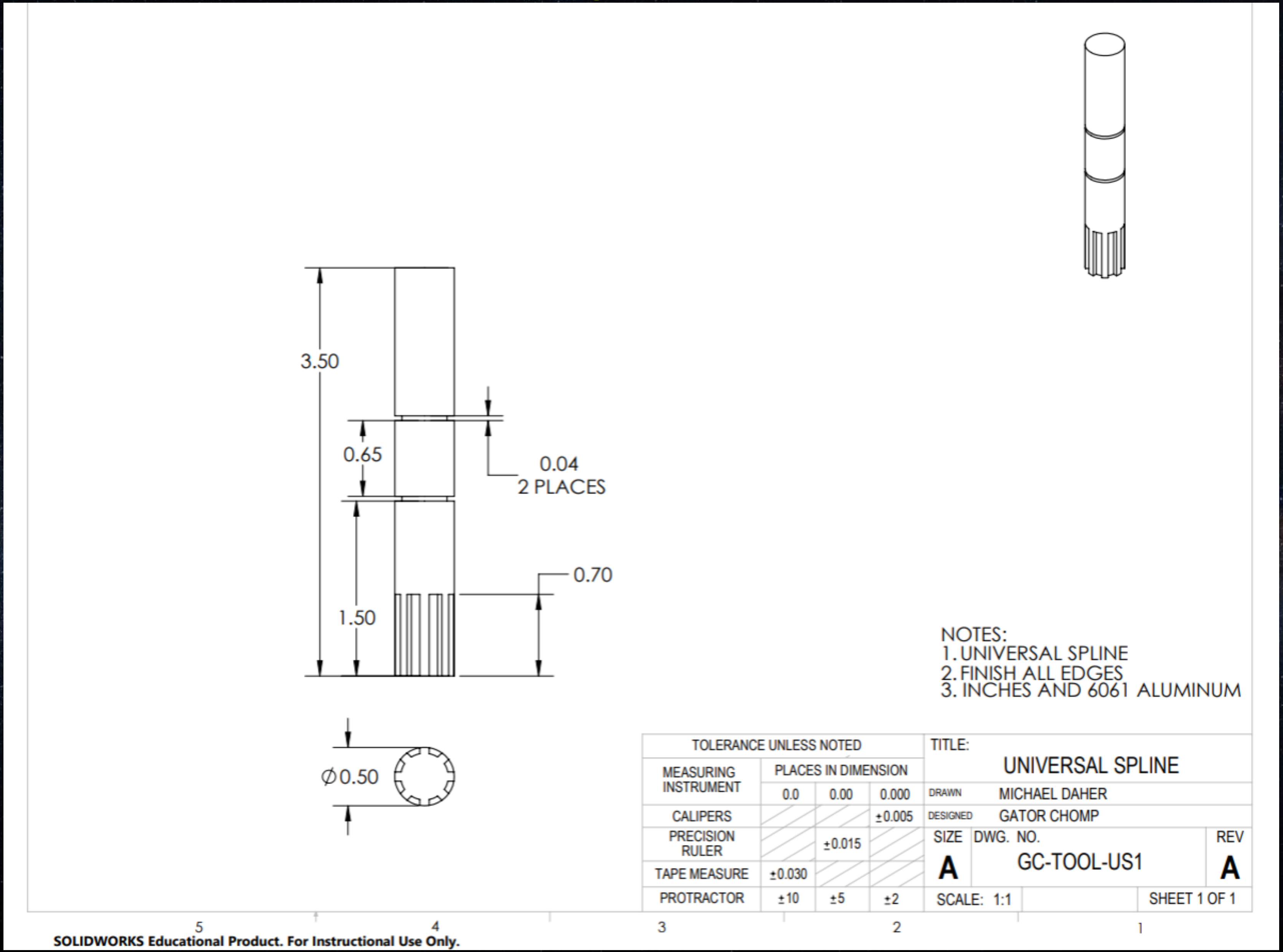



| TOLERANCE UNLESS NOTED | | | |
|---|---|---|---|
| MEASURING INSTRUMENT | PLACES IN DIMENSION | | |
| | 0.0 | 0.00 | 0.000 |
| CALIPERS | | | ±0.005 |
| PRECISION RULER | | ±0.015 | |
| TAPE MEASURE | ±0.030 | | |
| PROTRACTOR | ±10 | ±5 | ±2 |

| TITLE: Tool Connector | | |
|---|---|---|
| DRAWN | Michael Daher | |
| DESIGNED | GATOR CHOMP | |
| SIZE A | DWG. NO. GC-TOOL-C1 | REV A |
| SCALE: 1:1 | | SHEET 1 OF 1 |

# Backup Slide – Part Drawings



# Backup Slide – Part Drawings

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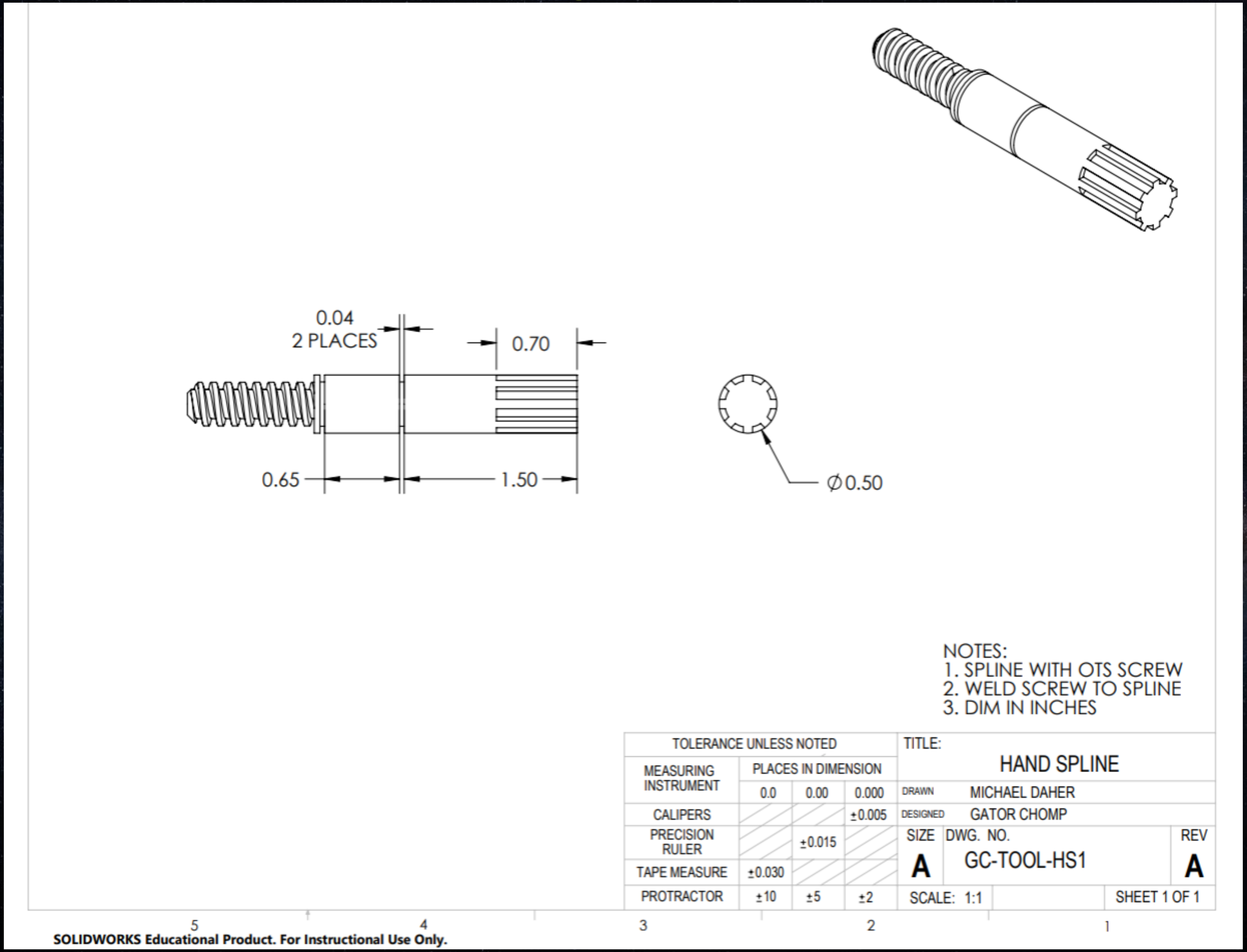

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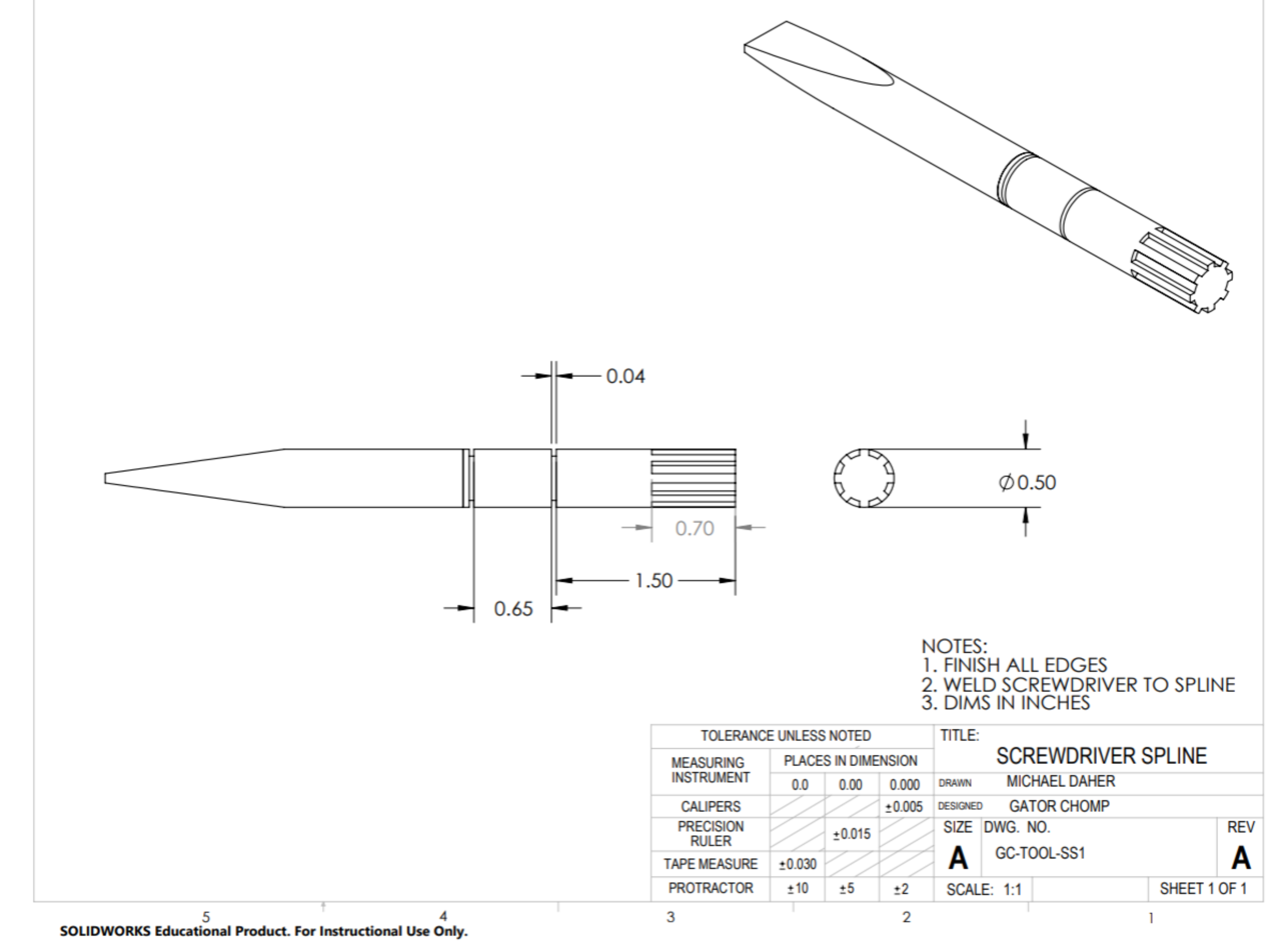

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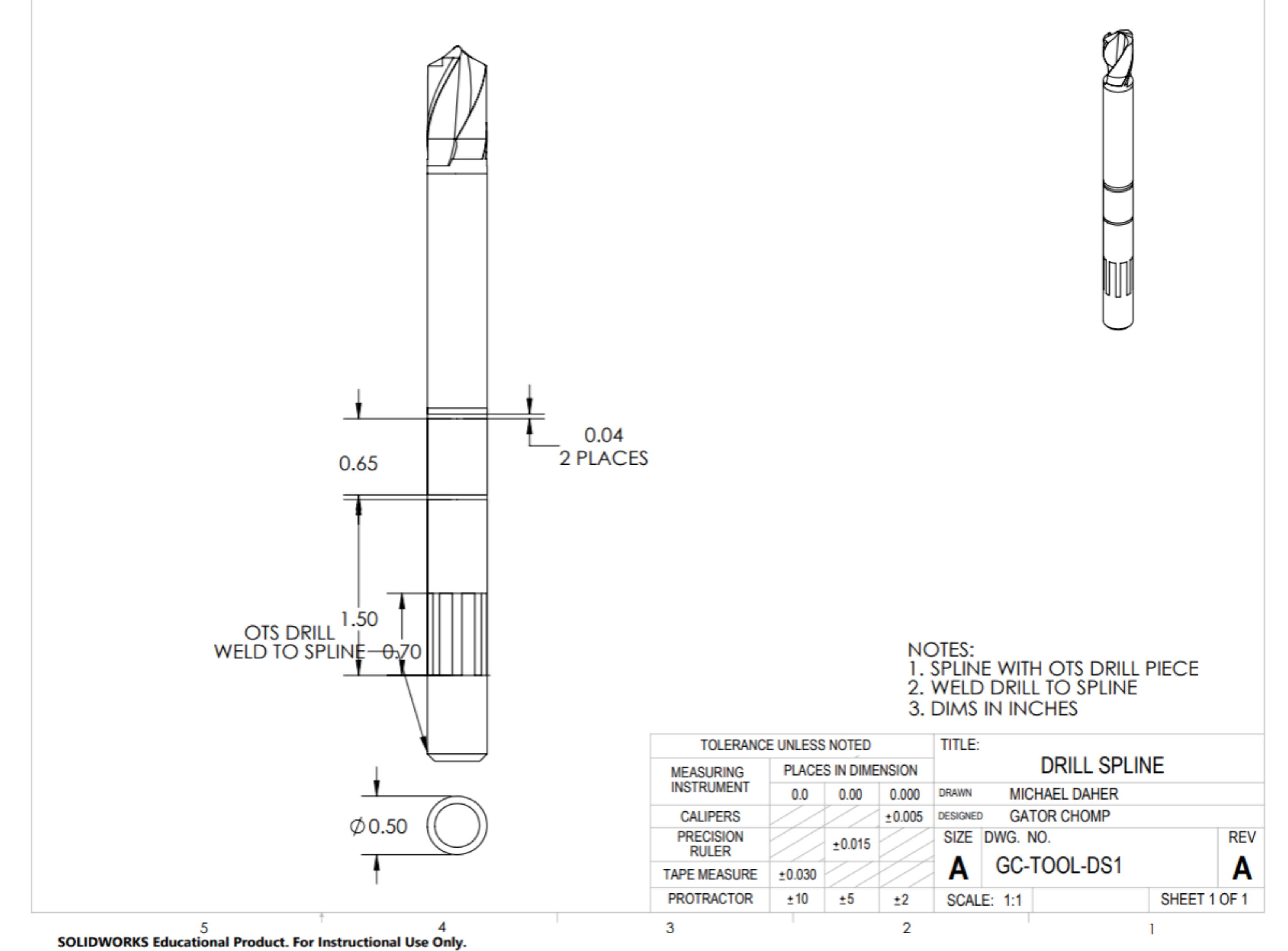

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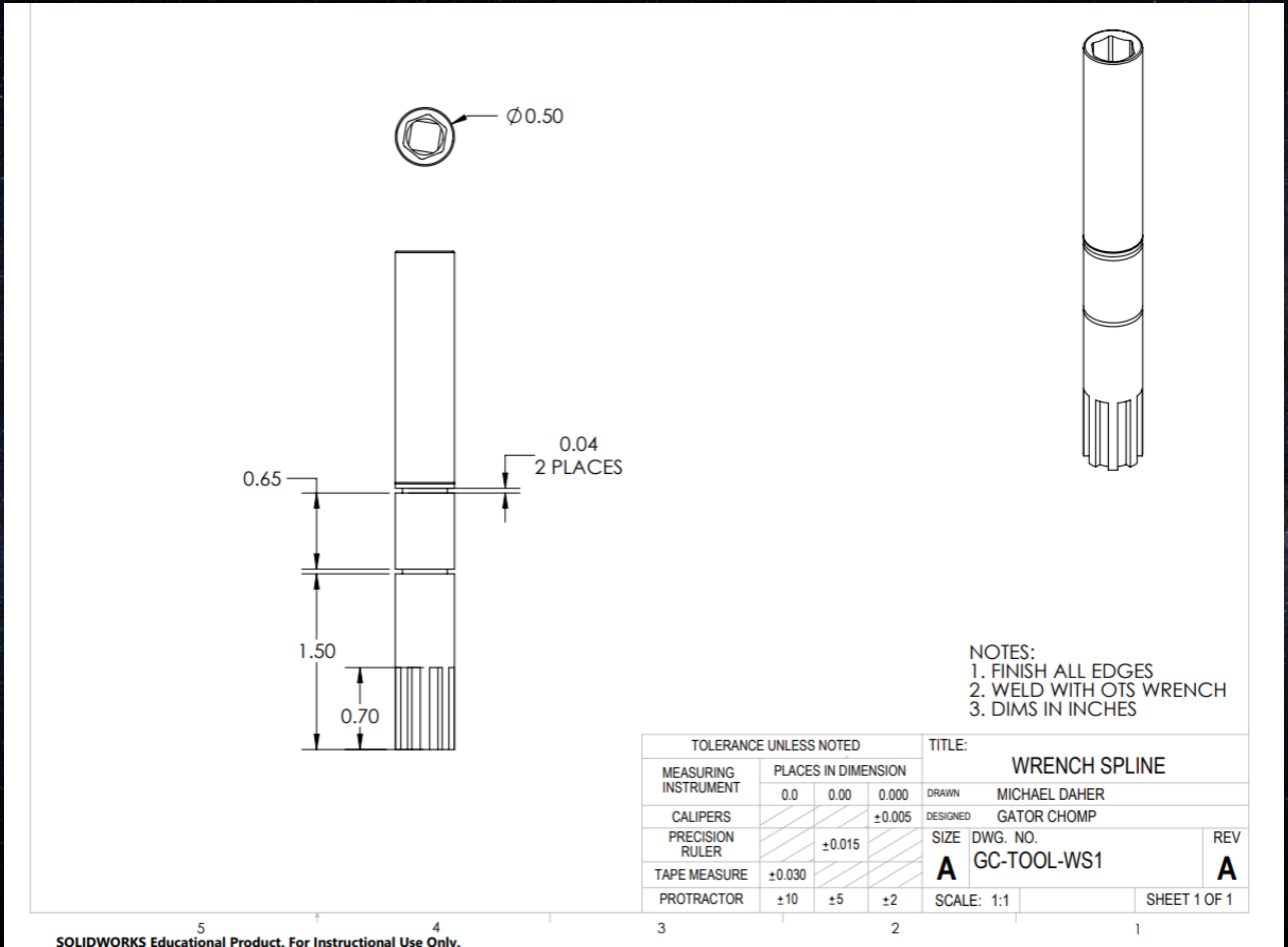

# Backup Slide – Part Drawings

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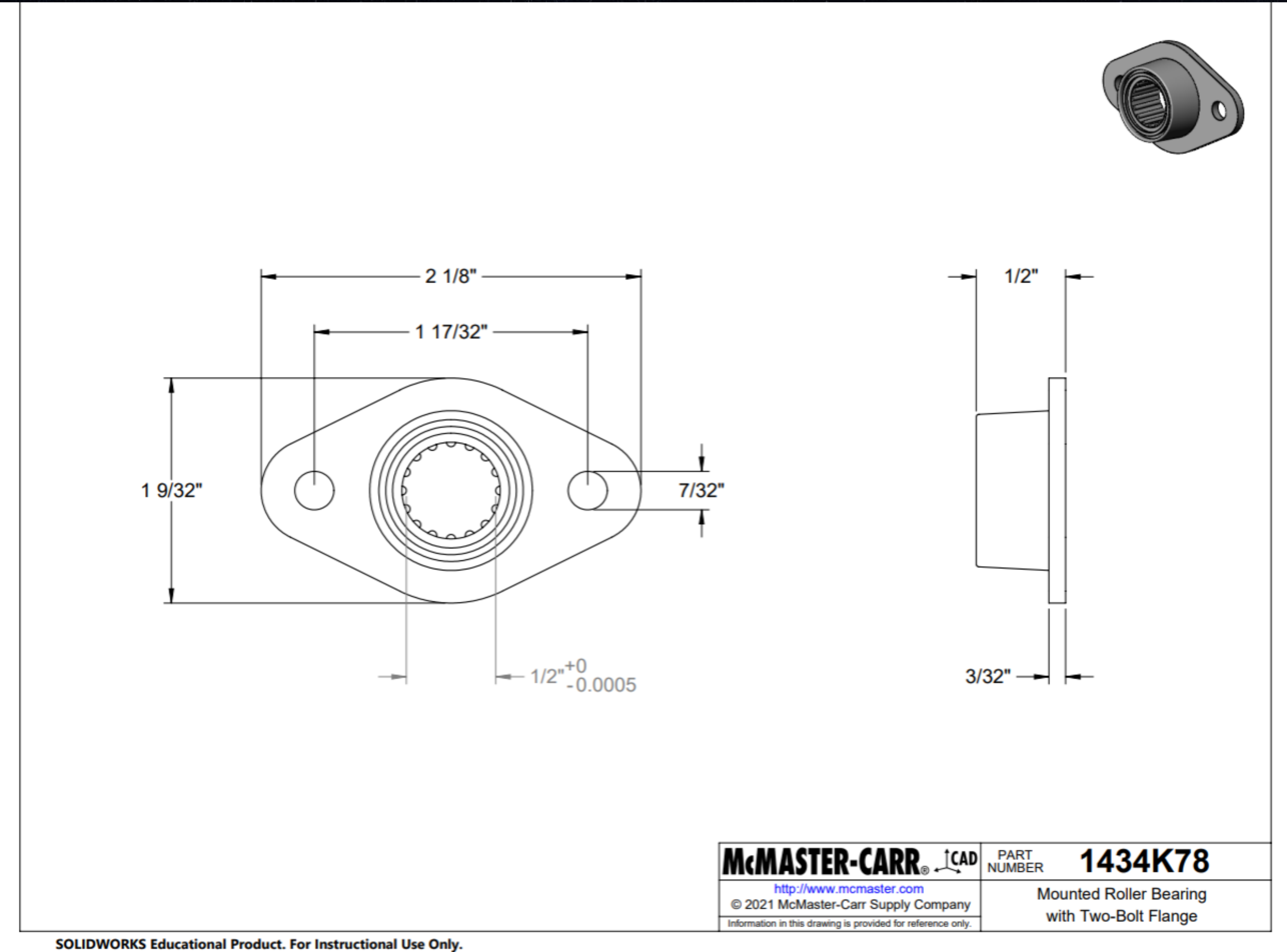
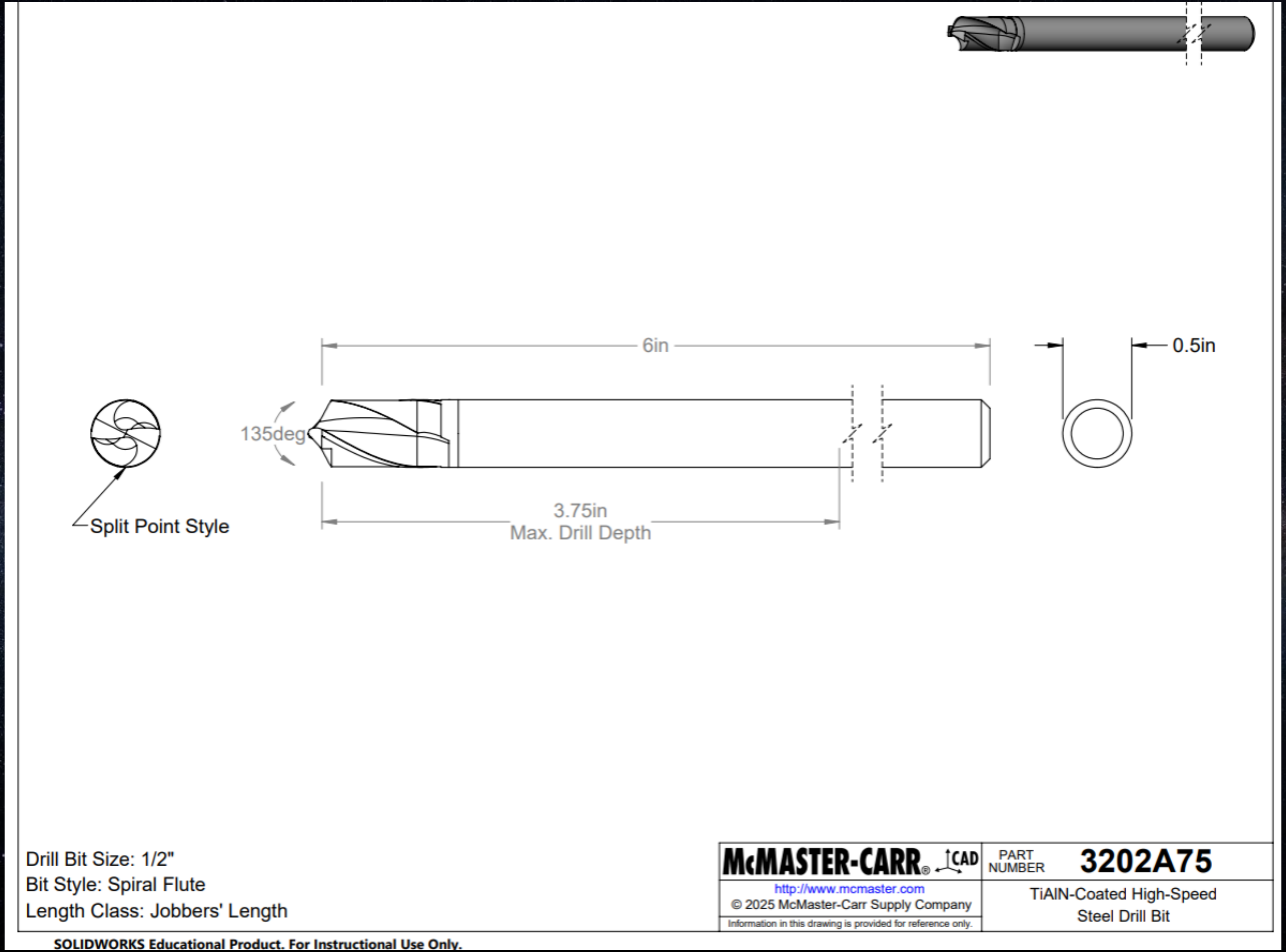


# Backup Slide – Part Drawings





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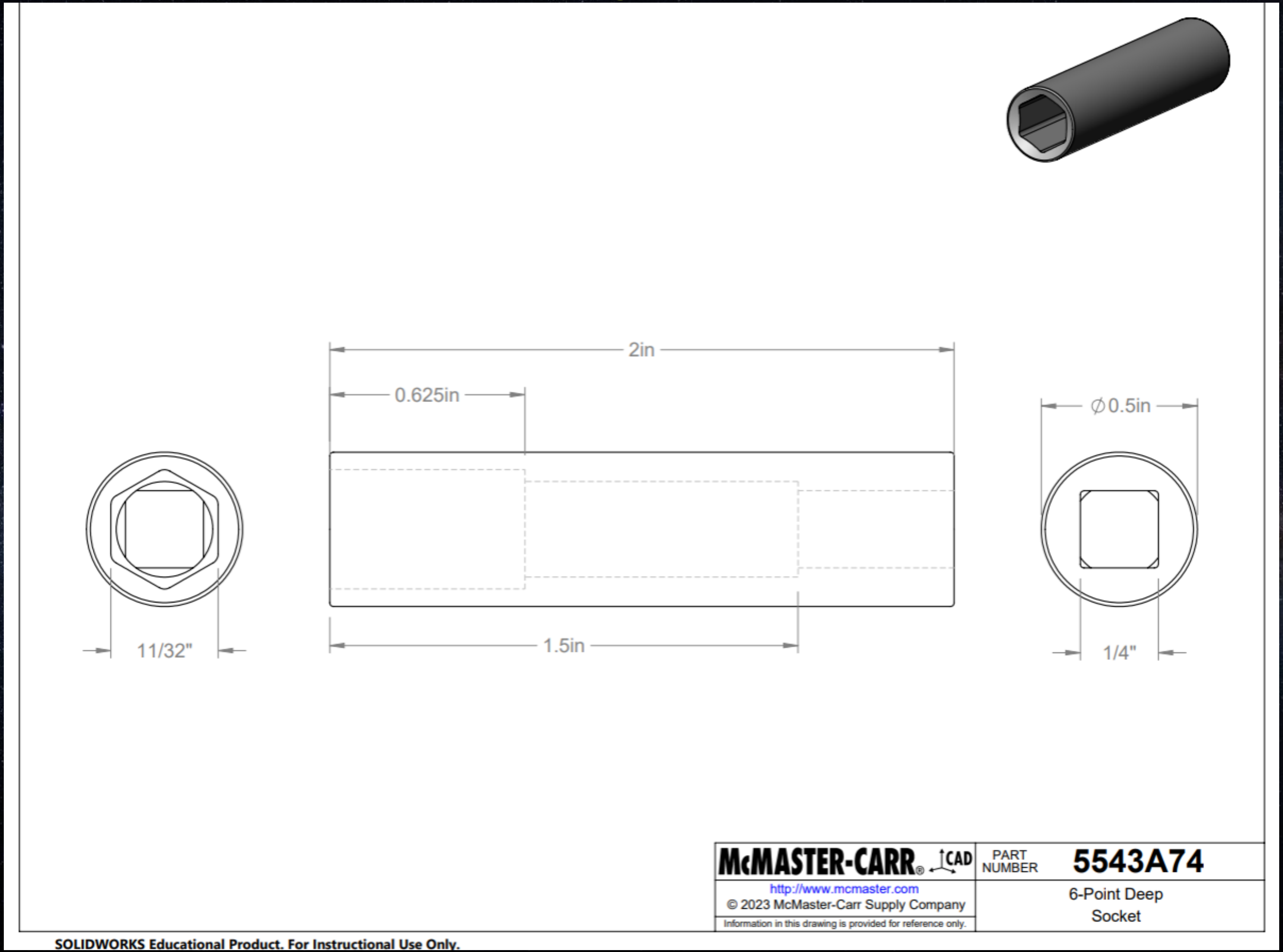

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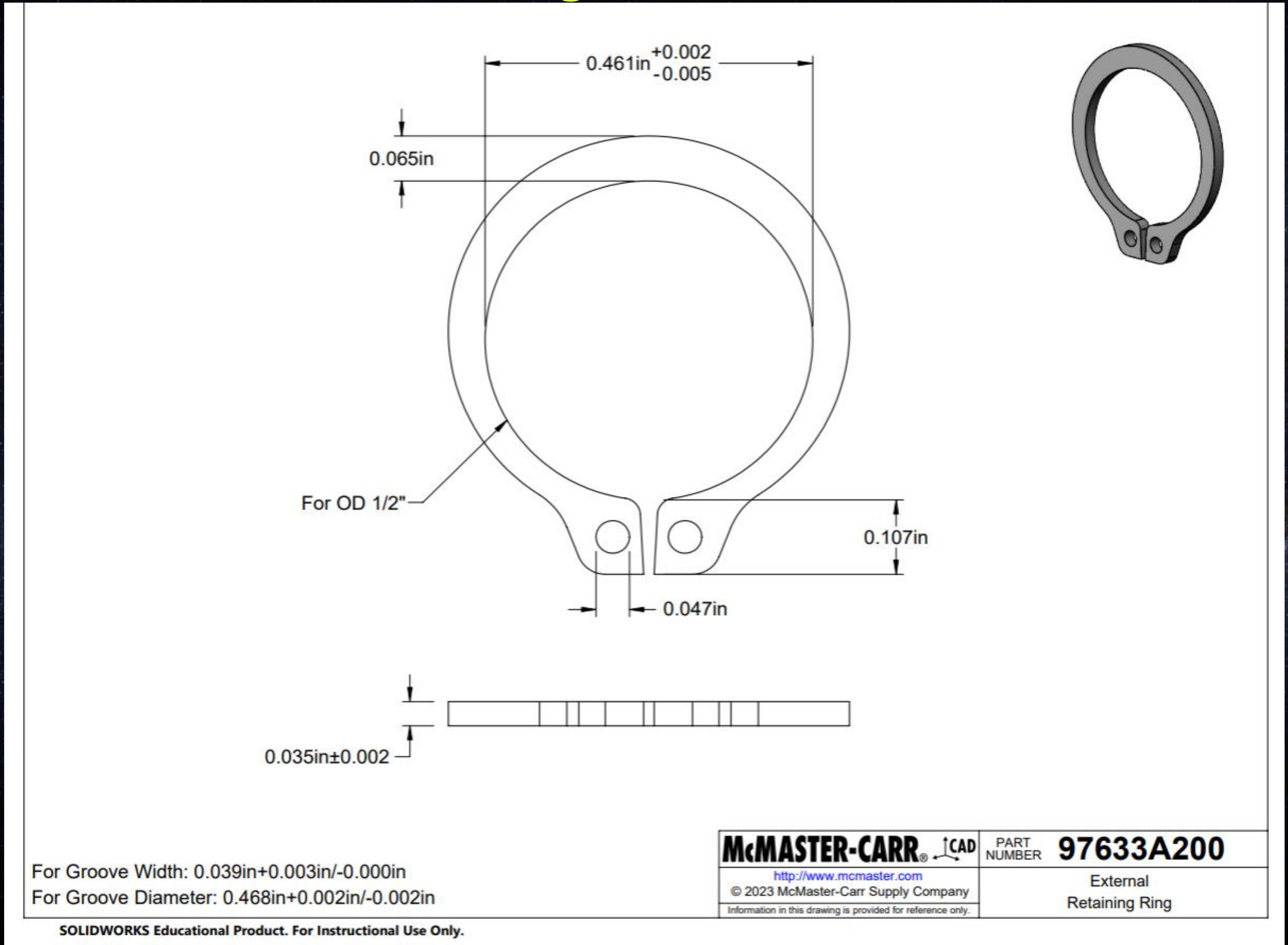

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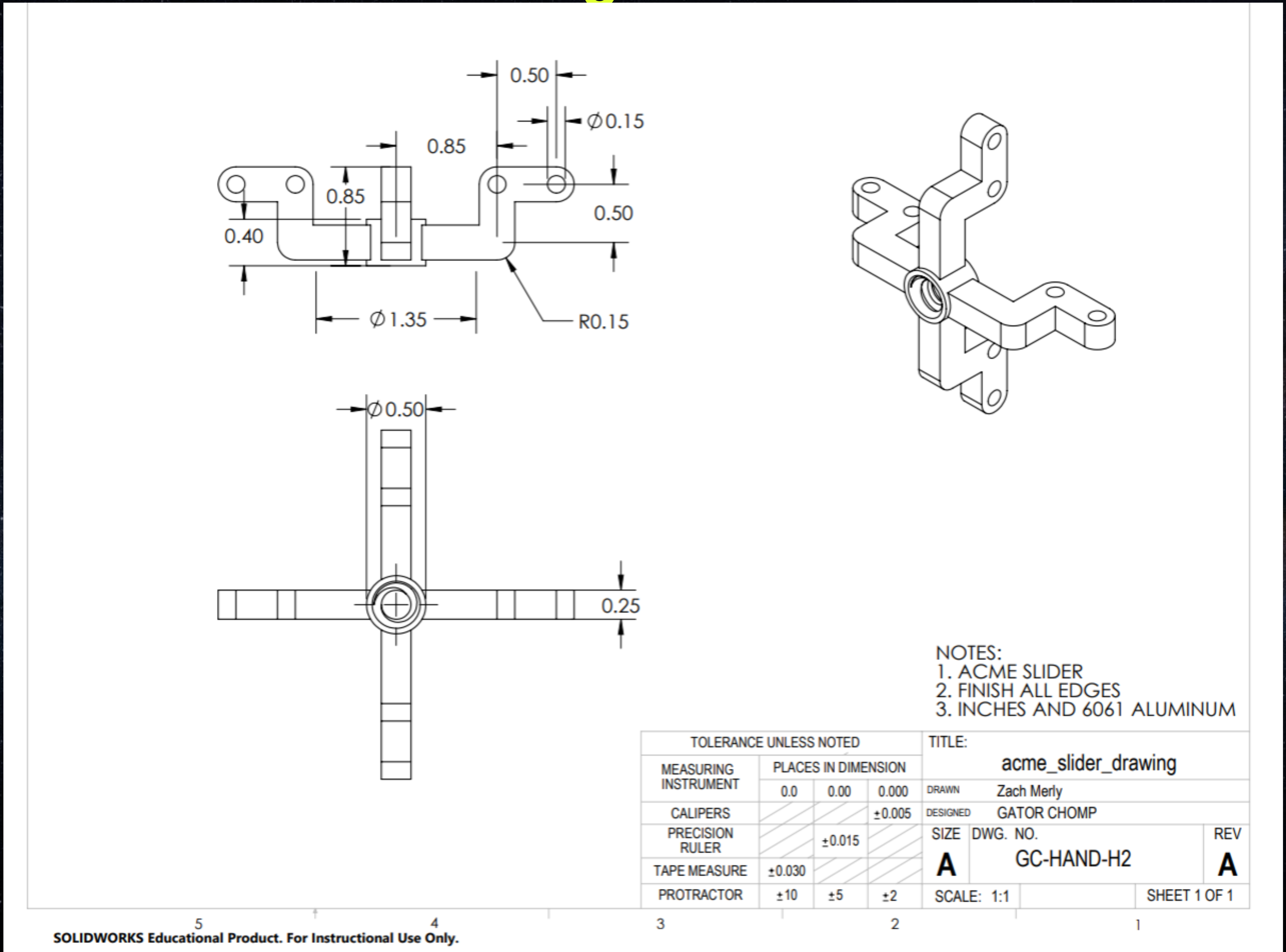

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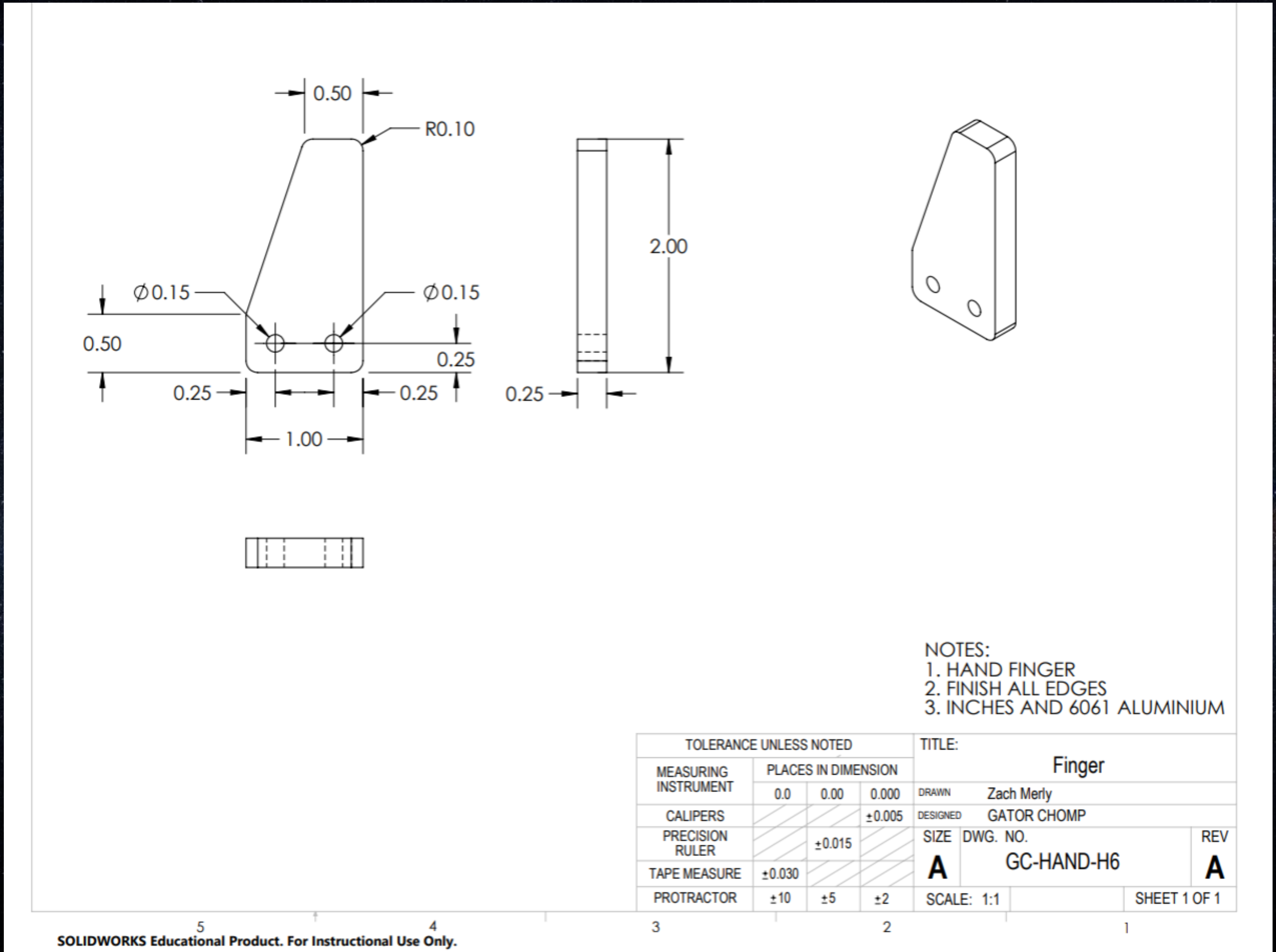

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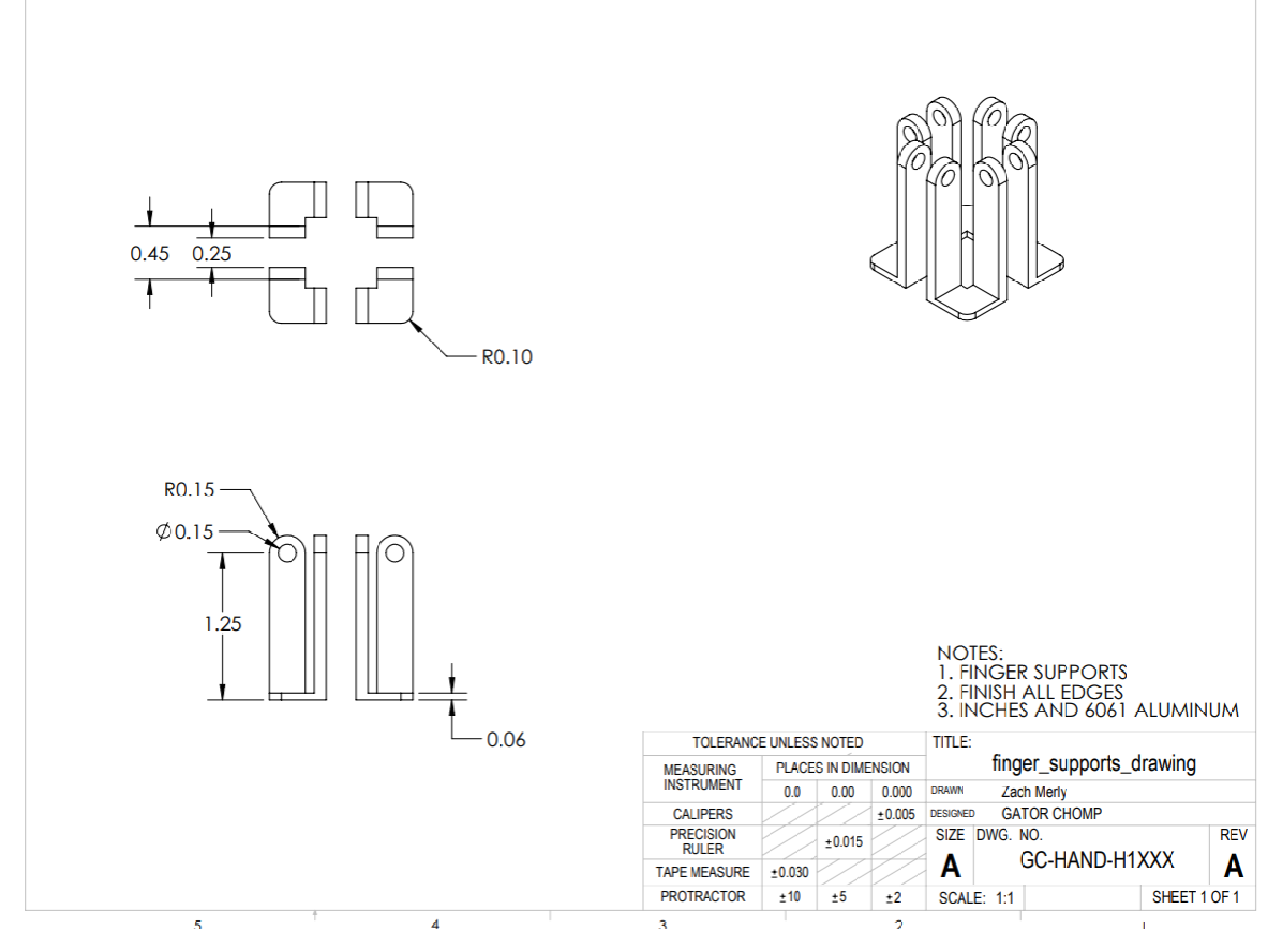

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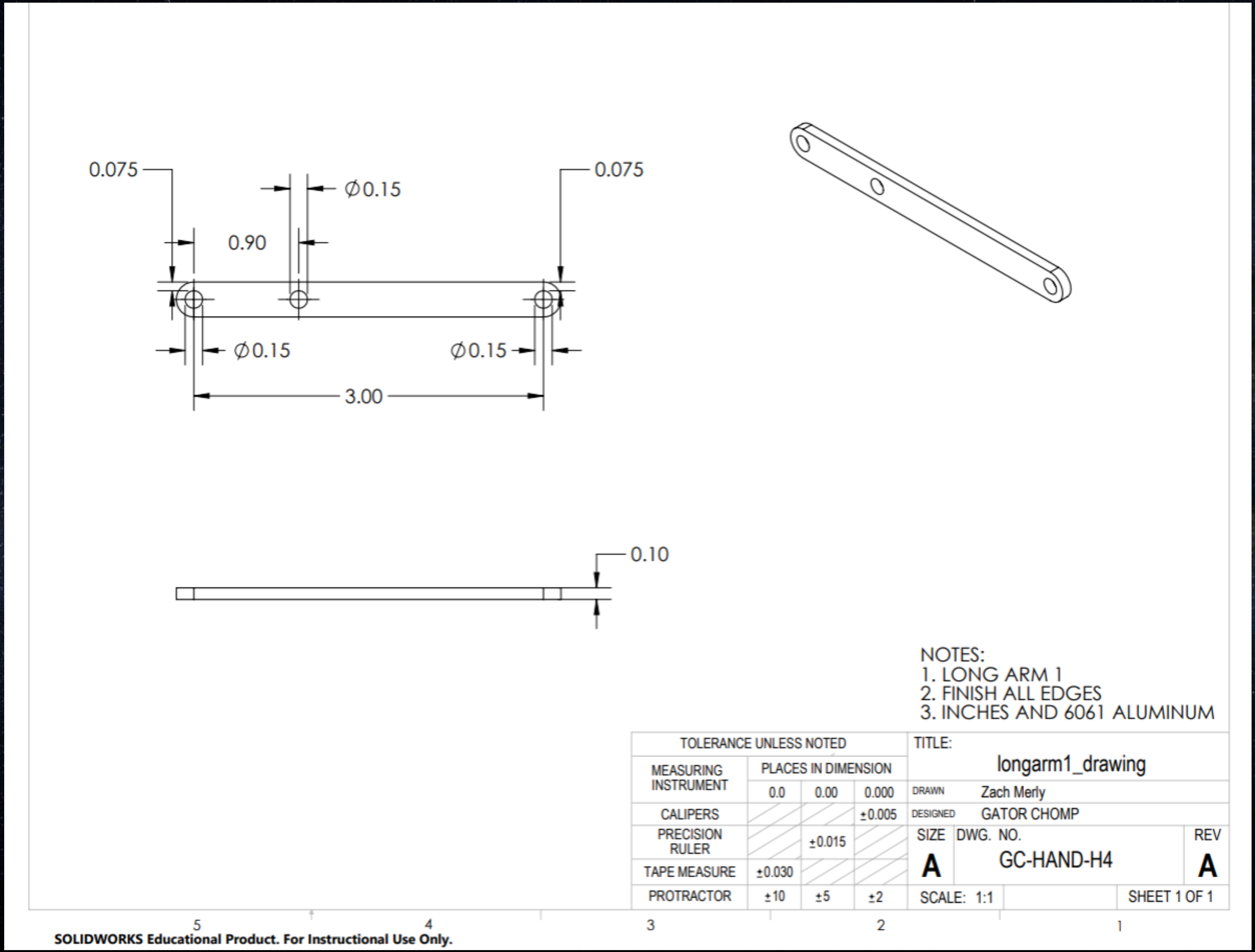

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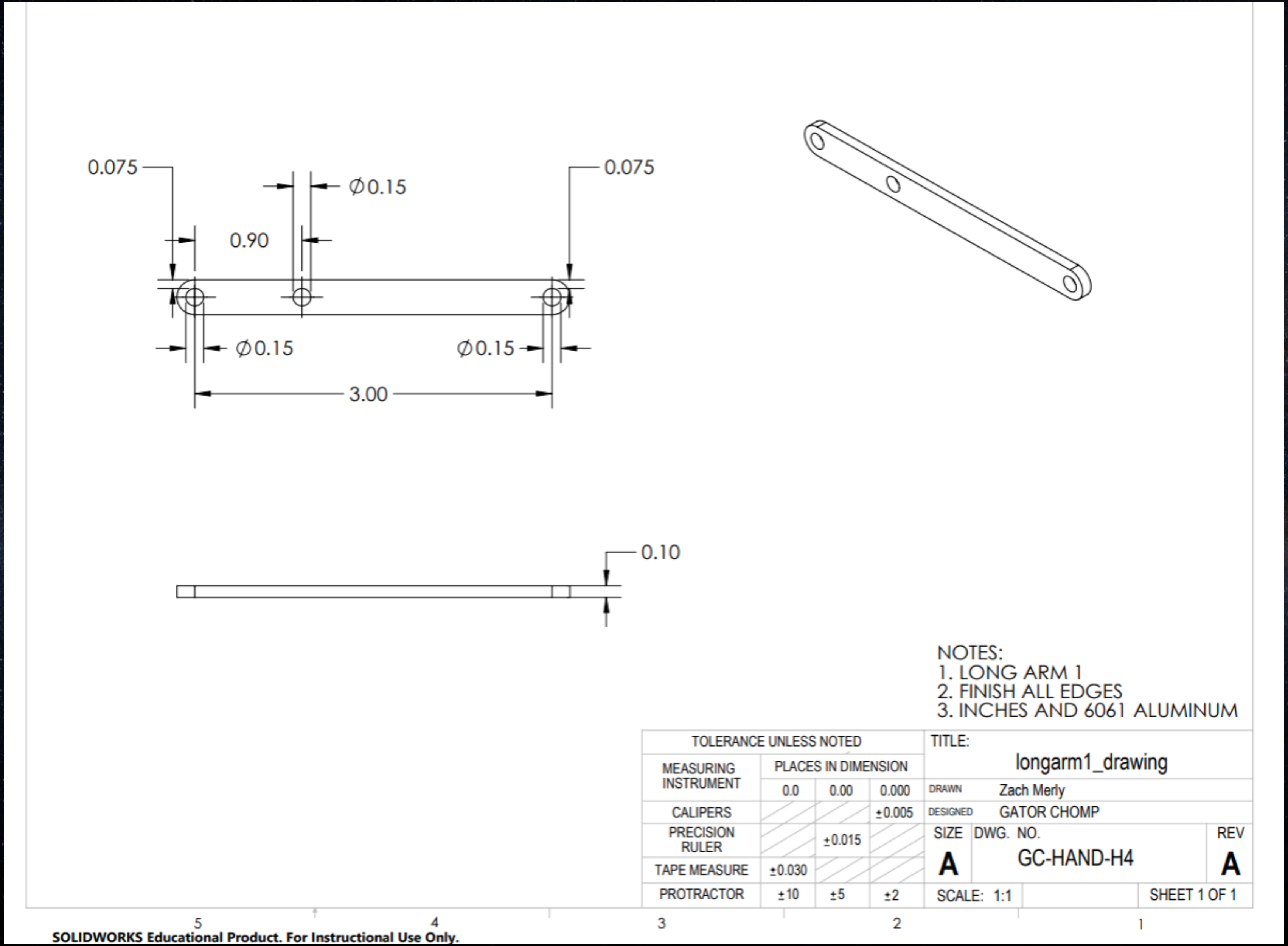

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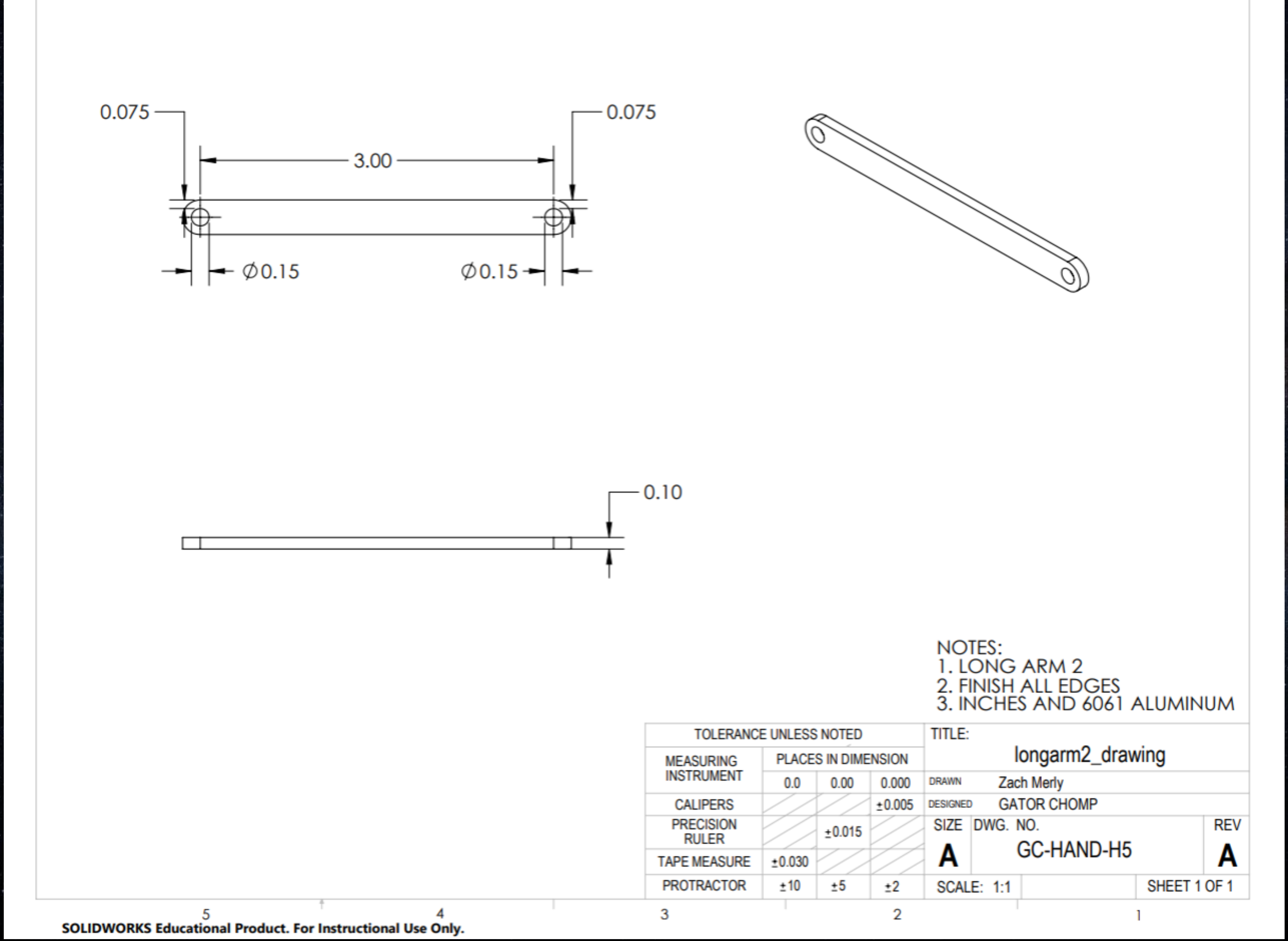

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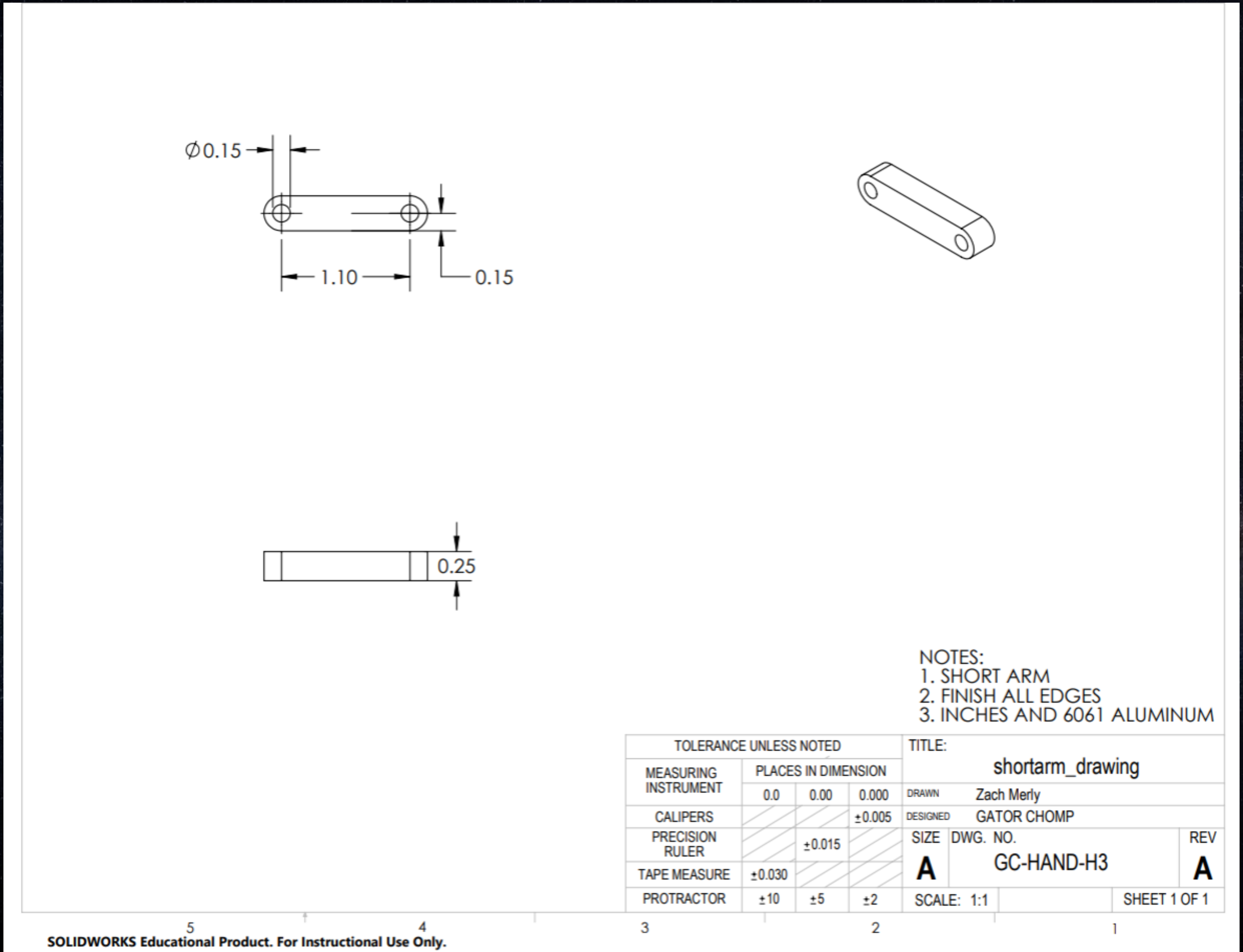

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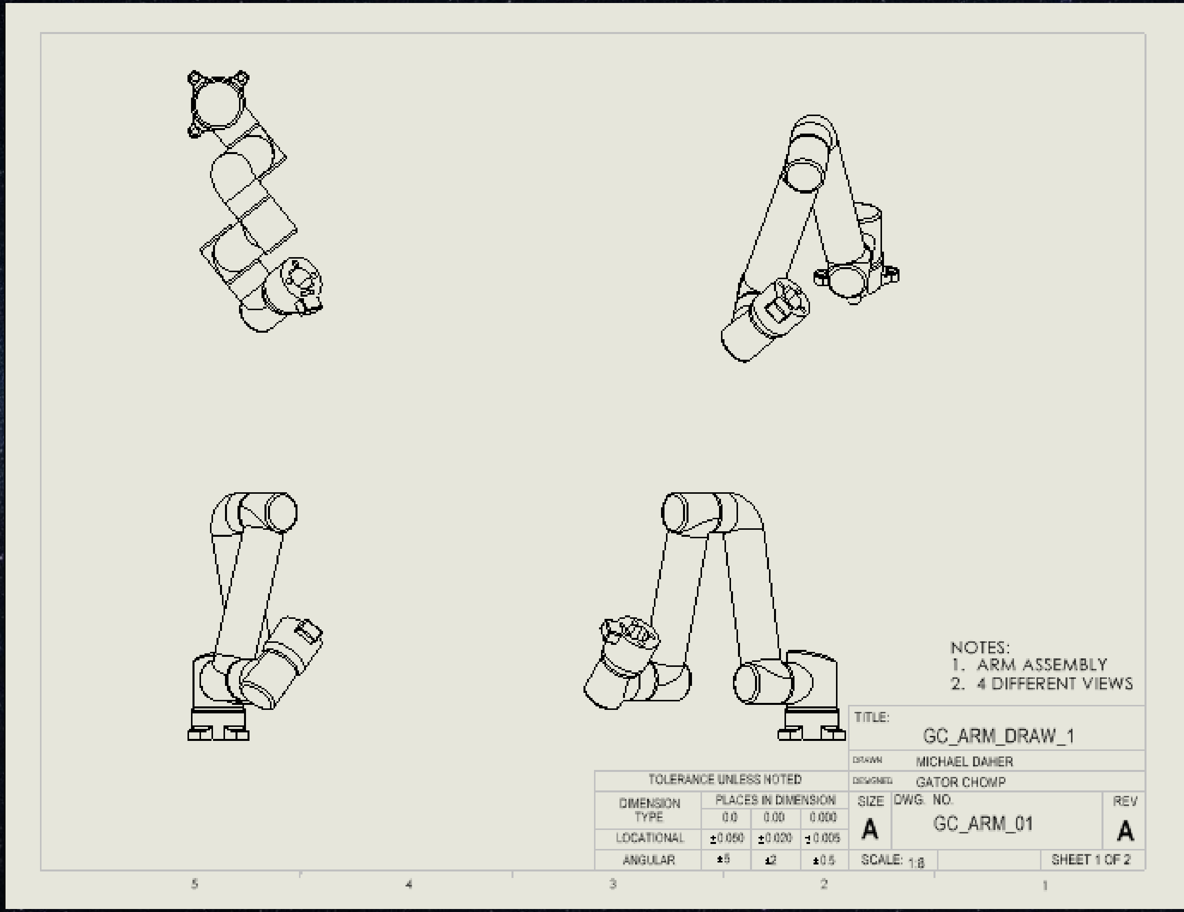
# Backup Slides – Assembly Drawings

*Arm Assembly*




| ITEM NO. | PART NUMBER | DESCRIPTION | VENDOR | QTY. |
|---|---|---|---|---|
| 1 | GC_ARM_B1 | ARM BASE | MCMASTER | 1 |
| 2 | GC_ARM_B2 | ARM BASE COVER | MCMASTER | 1 |
| 3 | GC_ARM_J1 | ARM JOINT | MCMASTER | 4 |
| 4 | GC_ARM_A1 | ARM | MCMASTER | 2 |
| 5 | GC_ARM_R1 | BASE ROTATOR | MCMASTER | 1 |
| 6 | GC_ARM_R2 | ROTATOR | MCMASTER | 4 |
| 7 | GC_ARM_S1 | SPACER | MCMASTER | 2 |
| 8 | GC_ARM_J2 | ARM JOINT 2 | MCMASTER | 1 |
| 9 | GC_ARM_T1 | JOINT END TOOL ATTACHMENT | MCMASTER | 1 |

TITLE: GC_ARM_DRAW_1
DRAWN MICHAEL DAHER
DESIGNED GATOR CHOMP
SIZE A | DWG. NO. GC_ARM_01 | REV A
SCALE: 1:1 | SHEET 2 OF 2

**Arm drawing and BOM**

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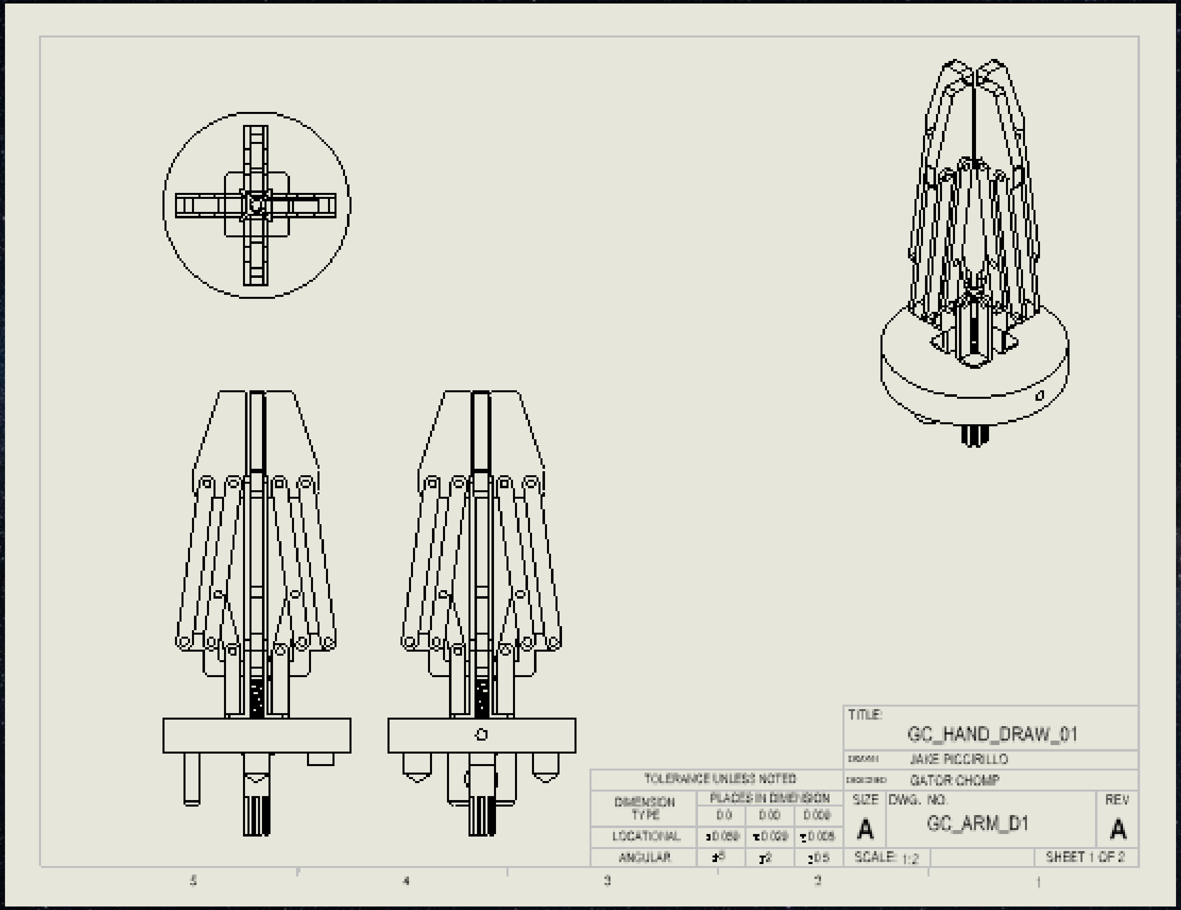
# Backup Slides – Assembly Drawings

*Hand Assembly*




| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | GC_HAND_H1 | HAND BASE | 1 |
| 2 | GC_HAND_S1 | SPLINE | 1 |
| 3 | 97633A200 | External Retaining Ring | 2 |
| 4 | 1434K78 | Mounted Roller Bearing with Two-Bolt Flange | 1 |
| 5 | 98980A114 | 304 Stainless Steel Precision Acme Lead Screw | 1 |
| 6 | GC_HAND_H2 | SUPPORT | 1 |
| 7 | 95365A521 | Cast Iron Precision Acme Round Nut | 1 |
| 8 | GC_HAND_H3 | ARM | 8 |
| 9 | GC_HAND_H4 | BOLTS | 24 |
| 10 | GC_HAND_H5 | SHORT ARM | 4 |
| 11 | GC_HAND_H6 | LONG ARM | 8 |
| 12 | GC_HAND_H7 | FINGER | 4 |

NOTES:
1. BILL OF MATERIALS

TITLE: GC_HAND_BOM_01
JAKE PICCIRILLO
GATOR CHOMP
SIZE A | DWG. NO. GC_HAND_DRAW_01 | REV A
SCALE: 1:1 | SHEET 2 OF 2

**Hand drawing and BOM**

# Backup Slides – Assembly Drawings

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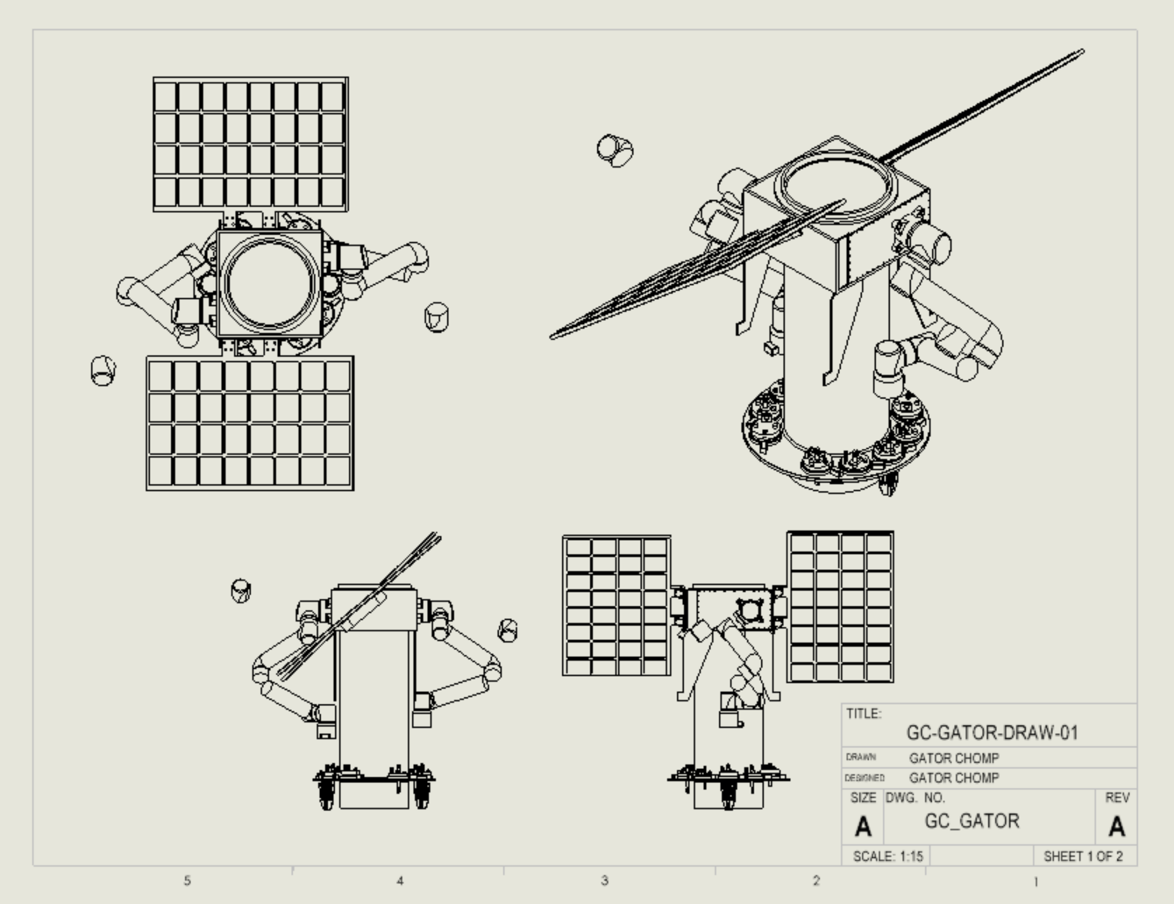
*GATOR Assembly*




| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | BCT_VENUS_HEAD | | 1 |
| 2 | BCT_PAYLOAD | | 1 |
| 3 | BCT_SUPPORT | | 4 |
| 4 | BCT_WALL_PANEL | | 1 |
| 5 | BCT_ATTACHMENT | | 1 |
| B | BCT_HEAD | | 1 |
| 7 | BCT_LAUNCHCOVER | | 1 |
| 8 | BCT_SOLAR | | 2 |
| 9 | BCT_SOLAR_ATTACH | | 4 |
| 10 | BCT_SOLAR2 | | 2 |
| 11 | robotic_arm_assembly_v2 | | 2 |
| 12 | GC_TOOL_T1 | TOOL BASE | 1 |
| 13 | GC_HAND | HAND | 2 |
| 14 | GC_TOOL_S1 | SCREW DRIVER | 2 |
| 15 | GC_TOOL_D1 | DRILL | 2 |
| 16 | GC_TOOL_W1 | WRENCH | 2 |
| 17 | GC_TOOL_C1 | CAMERA | 2 |

TITLE: GC_GATOR_DRAW_01
DRAWN GATOR CHOMP
DESIGNED GATOR CHOMP
SIZE A | DWG. NO. GC_GATOR_DRAW | REV A
SCALE: 1:1 | SHEET 2 OF 2

**GATOR Arms drawing and BOM**

# Backup Slide – Really Good GATOR Arms




2025 NCAA National Champions