Operation Manual

RE-RASSOR Shoulder Phase II

Team 512

Morgan Causey, *Mechanical Systems Engineer*

Megan Kimsey, *Systems Engineer*

Ibrahim Nabulsi, *Testing Engineer*

Gissel Reynoso, *Mechatronics Engineer*

Joseph Vogl, *Design Engineer*

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Project Overview

The objective of this project is to create a 3D-printed, motorized, scaled down version of NASA's RASSOR shoulder and arm to help introduce STEM concepts in middle and high schools. RE-RASSOR stands for Research and Education – Regolith Advanced Surface Systems Operational Robot. This is an element of a robotics initiative developed by the Florida Space Institute and Florida Space Grant Consortium.

The RASSOR was deployed by NASA on the lunar surface to excavate, haul, and dump regolith on the moon. The research and education initiative, coming from the Florida Space Institute and the Florida Space Grant Consortium, is based on NASA's Mini-RASSOR, developed in the SwampWorks Laboratory (an environment for rapid, innovative, cost-effective exploration mission solutions). The Mini-RASSOR was created to allow for substitution of parts for mission-oriented pieces as necessary and if desired. 3D-printed substitutions were developed across several universities in Florida (including the FAMU-FSU College of Engineering) which has reduced the cost of the complete rover from about $15,000 to about $800.

Fig 1. NASA's Mini-RASSOR (front left) compared to NASA's RASSOR (back right)

The project sponsor, the Florida Space Grant Consortium, shares their existing 3D-printable (STL) part files with the student engineering team. These files are what the team is constrained to build within.

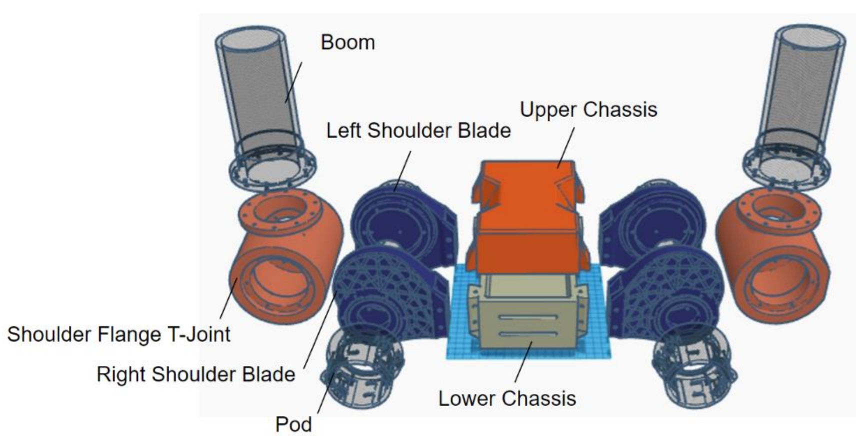


Fig 2. Florida Space Grant Consortium's RE-RASSOR 3D-printable (STL) files

The team adds a motor and a gearbox system that fits within the Shoulder Flange T-Joint. The motor, used to power the gearbox, moves based on computer code. The gearbox increases the torque that comes from the motor. This torque allows for the upward and downward motion of the arm so it can lift weight. Team members use Computer Aided Design to model and test the parts within the gearbox. The engineering students calculate the proper sizes for the gears and housing. Then, testing the motion of the gears takes place to make sure they turn easily. The team also tests the amount of force that the arm and shoulder can withstand, determining if the system can lift 25 pounds.

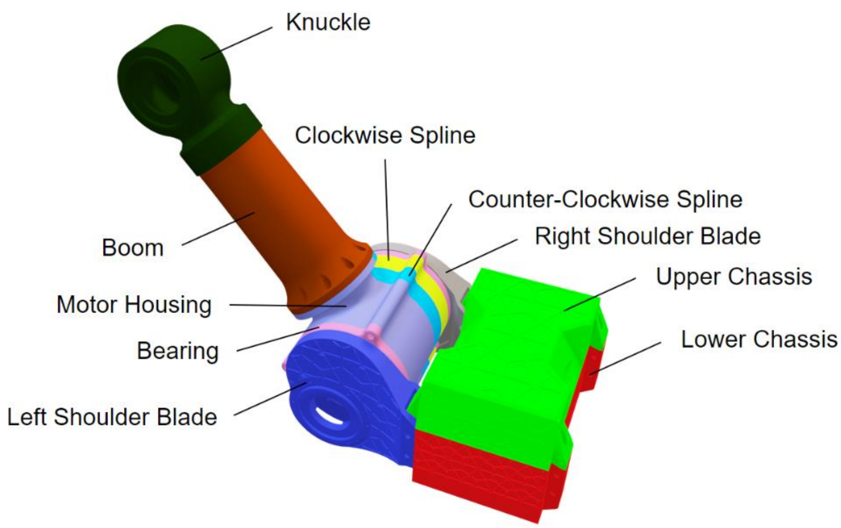


Fig 3. 3D Model of Senior Design Team 512's completed RE-RASSOR shoulder and arm assembly

Schools can easily reproduce Senior Design Team 512's completed RE-RASSOR shoulder and arm assembly using a 3D printer. The parts can be printed in classrooms using easy to access, readily available printing files. After the parts print, students can follow this simple operation manual to assemble and work the RE-RASSOR model. Upon assembly, the educational model can lift up to 25 pounds. Showing how the RASSOR works gives students exposure to real life technology, inspiring these students to choose STEM related fields as part of their future endeavors.

Component Description

3D-Printed Components

1. **Left Shoulder Blade** – This part is placed on the left side of the shoulder joint, and it functions to hold the entire assembly together, attach the shoulder assembly to the chassis, as well as allow for rotation of the arm. The left shoulder has an inner casing for a bearing built into the outer surface of the extruded circular section. The slot shaped like a portion of a circle, ranging from the top of the part to the dovetail, is to allow for passing of the boltheads during rotation of the arm. The crescent shaped hole in the part is to allow wires to pass through.

Fig 4. Left Shoulder Blade

2. **Right Shoulder Blade** – This part is similar in structure, shape, and function to the left shoulder blade. The difference here is that the extruded circular section of this shoulder joint incorporates gear teeth that mesh with the gearbox located inside.

Fig 5. Right Shoulder Blade

3. **Harmonic Gear with Clockwise Spline** – This component is what holds the planetary and sun gears together. It incorporates a clockwise spline, that way when the planetary gears inside are rotating around the ring of the harmonic gear, there is flexibility of the harmonic gear as well as a compressed fit onto the planetary gears.

Fig 6. Harmonic Gear with Clockwise Spline

4. **Harmonic Gear with Counterclockwise Spline** – This component has identical function as the previously mentioned harmonic gear, however the spline displays a counterclockwise direction. This allows the planetary gears to have better compression in both directions, reducing the chances of gear teeth skipping during the upward and downward motion of the arm.

Fig 7. Harmonic Gear with Counterclockwise Spline

5. **Planetary Carrier** – This component allows the user to correctly space the planetary gears 120 degrees apart from one another during assembly.

Fig 8. Planetary Carrier

6. **Planetary Gears** – These three gears are spaced 120 degrees apart around the ring of the harmonic gear, with the sun gear meshing with all three. The planetary gears have 36 teeth and a module of 1. The planetary gears are 2 inches in height.

Fig 9. Planetary Gears

7. **Sun Gear** – This one gear attaches to the shaft of the motor, which sits directly in the center of the harmonic gears. Like the planetary gears, the sun gear is also 2 inches in height; however, they have 12 teeth and a module of 1.

Fig 10. Sun Gear

8. **Thin Ball Bearing** – The quantity of this part in our assembly is two, attaching to both the left and right shoulder blades. The bearing outer casing sits around the extruded circular section on the inner part of each shoulder blade. This mentioned section of the shoulder blade has an incorporated groove around the outside. With this mentioned groove and the groove in the inner section of the bearing, BBs can be press-fitted in between and inserted. This thin ball bearing design allows for the rotation of the shoulder.

Fig 11. Outer Casing of the Thin Ball Bearing

9. **Boom and Knuckle** – The boom (or arm) and knuckle together make up the arm of the RE-RASSOR. The boom is what attaches the shoulder to the knuckle, and the knuckle is where the drums (which excavate regolith) would be placed on the actual RASSOR robot. The line which connects the weight to the arm is looped and tied around the knuckle.

Fig 12. Boom

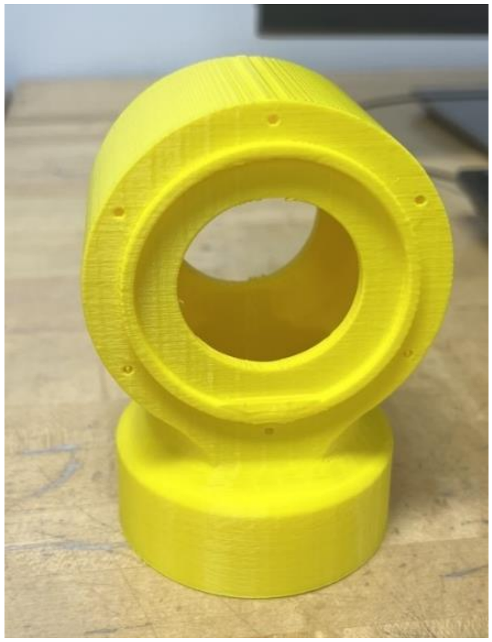


Fig 13. Knuckle

10. **Motor Housing** – This part is included in the shoulder joint and is strictly meant to hold the motor and house it in a secure place. It has 5 holes; 4 small holes that screw the motor to the part, and 1 hole that allows for the shaft of the motor to fit through and connect to the sun gear.

Fig 14. Motor Housing

11. **Chassis** – This part is a direct model of the RASSOR chassis. It was obtained directly from the 3D-printable files given to the team via the Florida Space Institute and the Florida Space Grant Consortium.

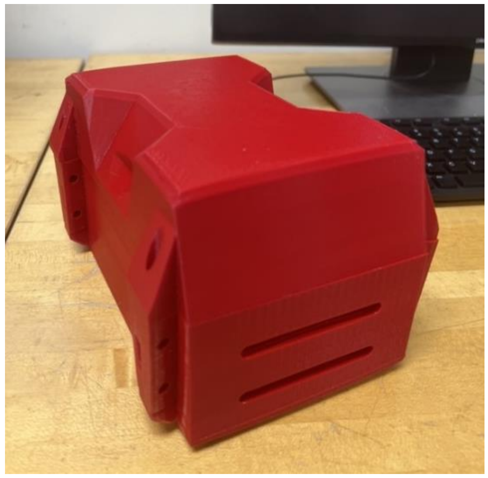


Fig 15. Chassis

Fastener Components

1. **Alloy Steel Socket Head Screw** – Made of Black Oxide, M5 x 0.8 mm Thread, and 130 mm Long. This screw is utilized to hold the Shoulder Flange T-Joint together.

Fig 16. Shoulder Joint Screws

2. **Alloy Steel Socket Head Screw** – Zinc-Flake Coated, M5 x 0.8 mm Thread, and 14 mm Long. This screw is utilized to hold the Boom (arm) to the Shoulder Flange.

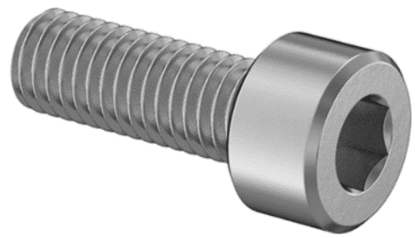


Fig 17. Boom (Arm) Screws

3. **Alloy Steel Socket Head Screw** – Made of Black-Oxide, M5 x 0.8 mm Thread, 40 mm Long, Fully Threaded. This screw it utilized to secure the shoulder assembly to the dovetails of the chassis.

Fig 18. Dovetail Screws

4. **Steel Thin Hex Nut** – Low-Strength, Zinc-Plated, M5 x 0.8 mm Thread. This nut is utilized to compress each part and fasten the screws into plate.

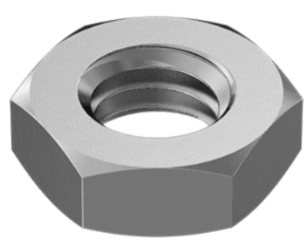


Fig 19. Nuts

Electrical Components

1. **Arduino MEGA Microcontroller** – This device is a microcontroller board which will store the code and actuate the motor, in addition to controlling the safe operation of the arm as it lifts the weight and slowly puts it back down.

Fig 20. Arduino MEGA Microcontroller

2. **NEMA 23 Motor** – This is a small stepper motor that has a max torque of 1.9 Newton-meters and has a rated current of 2.8 Amperes. The shaft rotates 1.8 degrees per step (200 steps/rev).

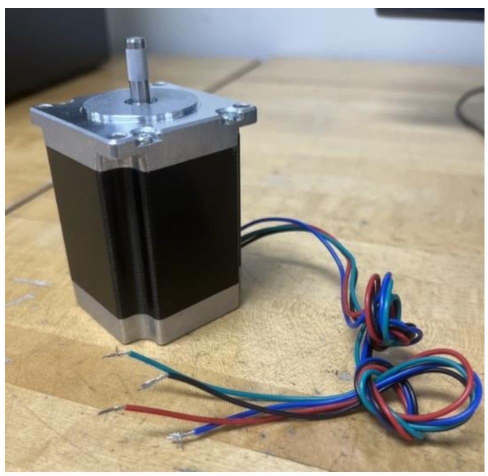


Fig 21. NEMA 23 Motor

3. **TB6600 Motor Driver** – This device acts as the transmission between the Arduino and the motor. It supplies the correct number of volts and amps that the motor needs, and works under the control of the Arduino and the stored code within.

Fig 22. TB6600 Motor Driver

4. **Male-Male Jumper Wires** – These additional wires are required outside of the ones that come pre-connected to the stepper motor. The wires are necessary to connect the power supply to the motor driver, as well as from the motor driver to the Arduino.

Fig 23. Male-Male Jumper Wires

Other Components

1. **Bullet Balls (BBs)** – These are utilized within the bearing casing, creating a thin ball bearing that allows the arm to rotate up and down within the shoulder blade.

Fig 24. Bullet Balls (BBs)

2. **Lubricant for Bearings** – This food grade lubricant is used for the bearings because it has an oil-based consistency, allowing it to seep between the BBs. By lubricating the bearings, it helps to reduce friction between the PLA and the BBs.

Fig 25. Lubricant used on the bearings

3. **Lubricant for Gears** – This food grade lubricant is used for the gears because it has a thicker consistency, providing more surface contact on the gears. By lubricating the gearbox system, it helps to prevent ware on the gears.

Fig 26. Lubricant used on the gears

4. **Plastic Dowel Pins** – The dowel pins are used as locators to ensure that the parts assembling together to create the Shoulder Flange T-Joint align.

Fig 27. Dowel Pins

5. **Bucket and Weight** – This bucket is attached to the knuckle (otherwise known as the end of the arm) with 25-pound rated fishing line. The weight is located inside the bucket, and the line is attached at the center of the handle of the bucket.

Fig 28. Bucket for Weight

Fig 29. 25-Pound Weight

Wiring Diagram

Below is the wiring diagram by which the Arduino and motor connect, as well as the power supply which keeps the electrical components working and operational.

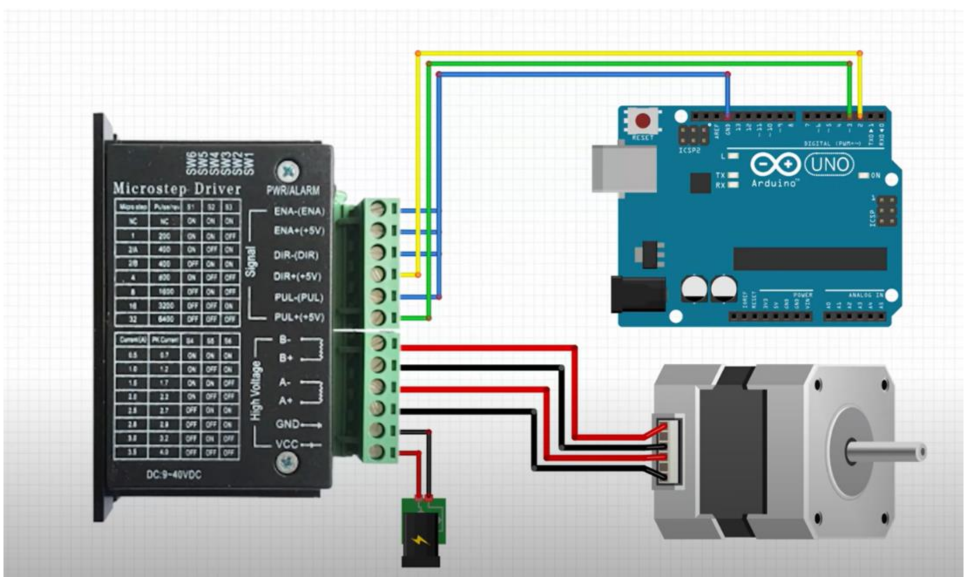


Fig 30. Arduino Wiring Diagram

Code for Arduino MEGA Microcontroller

Below is the code for the Arduino, which powers the NEMA 23 motor for the RE-RASSOR Shoulder Phase II Project. The code allows for the motor shaft to slowly begin accelerating, obtaining a slow and gradual velocity before it reaches a maximum constant velocity. Then it begins decelerating, causing the velocity to slowly and gradually decrease. At this point, the arm is stopped at maximum angle for maximum lift. Then, the motor begins rotating in the opposite direction to allow for a safe and slow drop of the weight that is attached.

```
#include <AccelStepper.h>

// Define stepper motor connections and motor interface type. Motor interface type must be set to 1 when using a driver:
#define dirPin 2
#define stepPin 3
#define motorInterfaceType 1

// Create a new instance of the AccelStepper class:
AccelStepper stepper = AccelStepper(motorInterfaceType, stepPin, dirPin);

void setup()
{
//Serial.begin(9600); //define baud rate
Serial.println("Testing Accelstepper"); //print a message
stepper.setMaxSpeed(720000); // steps/second
stepper.setAcceleration(100);
}
void loop()
{
// Set the target position:
stepper.moveTo(30000);
// Run to target position with set speed and acceleration/deceleration:
stepper.runToPosition();
delay(1000);
stepper.moveTo(0);
stepper.runToPosition();
delay(1000);
}
//we want sun to spin 54 times = 10800
// 1 step  = 1.8 degrees
// 200 step = 360 degrees
// if we want it to move 15 deg/sec = 8.333 steps/sec
// one rotation is 6.33 sec at a speed of 15 deg/sec
// 54*6.333
//https://forum.arduino.cc/t/loop-1-rotation-with-acceleration-and-deceleration/904712/10
```

Fig 31. Arduino Code

Required Tools

There are few tools and components required for assembly of the RE-RASSOR Shoulder Phase II. The team recommends using the exact ones that are listed. Team 512 makes no guarantee of components other than the ones listed here working successfully for the intended purpose. See below for the complete list:

1. **Allan Wrench**
    a. M5, 2.5 mm: Pittsburgh SAE & Metric Long Reach Hex Key Set, 36 pc.

2. **Screwdriver**
    a. *Optional*: Pittsburgh Ratcheting Screwdriver Set, 34 pc.
3. **Screws**
    a. Alloy Steel Socket Head Screw: Black Oxide, M5 x 0.8mm Thread, 130mm long
    b. Alloy Steel Socket Head Screw: Black Oxide, M5 x 0.8mm Thread, 40mm long
    c. Alloy Steel Socket Head Screw: Zinc-Flake Coated, M5 x 0.8mm Thread, 14mm long
4. **Nuts**
    a. Steel Thin Hex Nut: Zinc-Plated, M5 x 0.8mm Thread
5. **Clamps**
    a. *Optional*: 4/6/8/10 in Quick Grip Ratchet Bar Clamps
6. **Dowel pins**
    a. Acetal Dowel Pins: 3/32" Diameter, 1/2" Long
7. **BBs**
    a. Crosman Copperhead 4.5mm Copper Coated BBs: EZ-Pour Bottle, 1500 ct.
8. **Lubricant**
    a. Super Lube Multipurpose Synthetic Grease: PTFE, White, 3 oz
    b. Super Lube Synthetic Lightweight Oil: PTFE, White, 4 oz
9. **Electrical**
    a. CNC Stepper Motor Nema 23: Bipolar, 2.8A, 269oz.in/1.9Nm, CNC Mill Lathe Router
    b. Stepper Motor Driver TB6600: 4A, 9-42V, Nema 17 Stepper Motor Driver CNC Controller Single Axes Phase Hybrid Stepper Motor for CNC/4257 86 Stepper Motor
    c. Power Supply: DC 12V, 2A
    d. Arduino Board: Mega 2560

Integration

3D-Printing Parts

This product is intended for ages 11 and up. Team 512 assumes the adult using this product for instruction has basic knowledge of how to operate their 3D-printer. If one has never used their 3D printer before, please familiarize yourself with 3D-printing and start by printing a simple calibration cube, which can be found on Thingiverse.com.

In order to create the RE-RASSOR Shoulder Phase II Project, one must begin by 3D-printing the components. All the STL files for the 3D-printed components ready to be printed can be found here: https://web1.eng.famu.fsu.edu/me/senior_design/2023/team512/. Download the zip file, click "Extract", then open each file in a 3D-printing slicing software. Team 512 recommends using the slicing software called "Ultimaker-Cura" to slice each part, but this specific software is not required. Note, your 3D printer must be set up with the software before you can download the STL files. Separately upload each file to the slicing software, then slice using these settings:

1. **Left Shoulder Blade**
    a. Infill: 20%
    b. Wall Thickness: 0.8
    c. Layer Height: 0.2

2. **Right Shoulder Blade**
    a. Infill: 20%
    b. Wall Thickness: 0.8
    c. Layer Height: 0.2
3. **Harmonic Gear with Clockwise Spline**
    a. Infill: 20%
    b. Wall Thickness: 0.4
    c. Layer Height: 0.2
4. **Harmonic Gear with Counterclockwise Spline**
    a. Infill: 20%
    b. Wall Thickness: 0.4
    c. Layer Height: 0.2
5. **Planetary Carrier**
    a. Infill: 20%
    b. Wall Thickness: 1.2
    c. Layer Height: 0.2
6. **Planetary Gears**
    a. Infill: 20%
    b. Wall Thickness: 1.2
    c. Layer Height: 0.2
7. **Sun Gear**
    a. Infill: 20%
    b. Wall Thickness: 1.2
    c. Layer Height: 0.2
8. **Thin Ball Bearing**
    a. Infill: 20%
    b. Wall Thickness: 0.4
    c. Layer Height: 0.2
9. **Boom and Knuckle**
    a. Infill: 70%
    b. Wall Thickness: 1.6
    c. Layer Height: 0.3
10. **Motor Housing**
    a. Infill: 20%
    b. Wall Thickness: 0.8
    c. Layer Height: 0.3
11. **Chassis**
    a. Infill: 20%
    b. Wall Thickness: 0.4
    c. Layer Height: 0.3

Please note, Team 512 recommends using these exact settings, and not altering any other settings for simplicity purposes. Each part should be oriented with the maximum surface area touching the bed. If there are areas of the part that do not mesh with the bed, one will need to enable supports. Once 3D-printing is complete, there should be 16 total parts created. Some parts will require the removal of supports. Note that parts can be made of various colors, not the ones that are explicitly specified in this instruction manual.

Assembly

Below is step by step instructions for how to take each part and component and turn it into a full-fledged assembly. Follow each step closely and take caution at every point. It is recommended that at least two people put it together.

Step 1: Begin by placing the motor into the motor housing. Align the shaft through the central hole of the housing, as well as the four holes on each corner of the motor. Apply the screws through the 4 corner holes to secure in place. Tighten with the required tool.

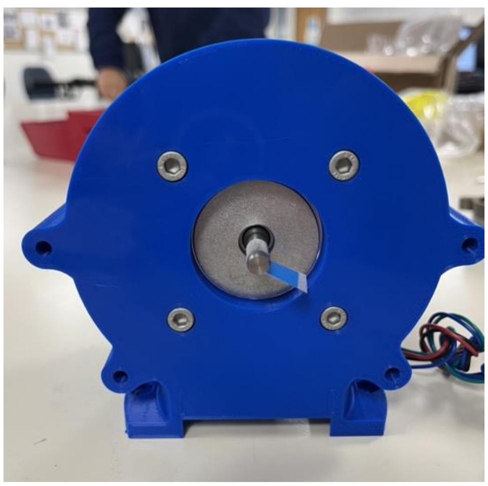


Fig 32. Front of Motor Housing with motor

Fig 33. Back of Motor Housing with motor

Step 2: Begin assembling the gearbox. Locate the three planetary gears (black) and sun gear (yellow). Use the planetary carrier (yellow) to space and secure the planetary gears 120 degrees apart from one another. With the gear teeth meshed properly, insert the sun gear into the center.

Fig 34. Front Planetary Gear Assembly

Fig 35. Back of Planetary Gear Assembly

Step 3: Locate both harmonic gears (blue and white). Place the dowel pins in the holes on the white harmonic gear (the piece with a slice of the shoulder flange attached). Then, stack the side of the blue harmonic with the lip onto the side of the white harmonic with the corresponding lip, ensuring the dowel pins go through both harmonics and that the surfaces are flush with one another. Note, the bolt holes should line up exactly for both harmonic gears.

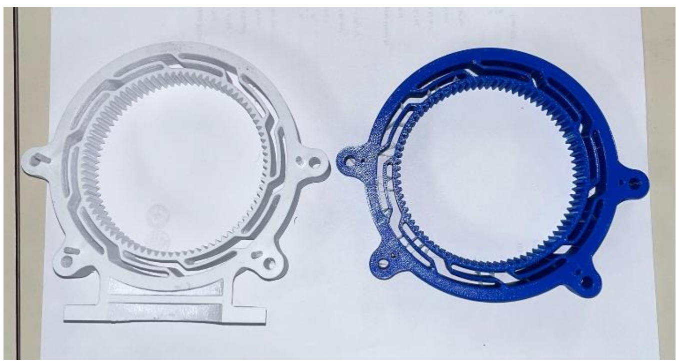


Fig 36. Harmonic Gear with clockwise spline versus Harmonic Gear with counterclockwise spline

Step 4: Gently press the planetary and sun gears together inside of the stacked harmonic gear. Ensure that the gear teeth of the planetary gears and the gear teeth on the harmonic mesh well together. Once the gears are pressed together, remove the planetary carrier using any tool to pry it off. Note, make sure the gears stay in place when removing the planetary carrier.

Fig 37. Planetary gearbox assembly

Step 5: Attach the bearings (red and gold) to each shoulder blade (grey). Place the outer ring of the bearing over the extruded circular section of each blade. Begin press fitting BBs into the groove that now exists between the bearing ring and the shoulder blade. It is advised to press enough BBs to nearly fill the entire ring of the bearing, but not completely, allowing for smoother motion. Then, add dowel pins in the appropriate holes of the bearings.

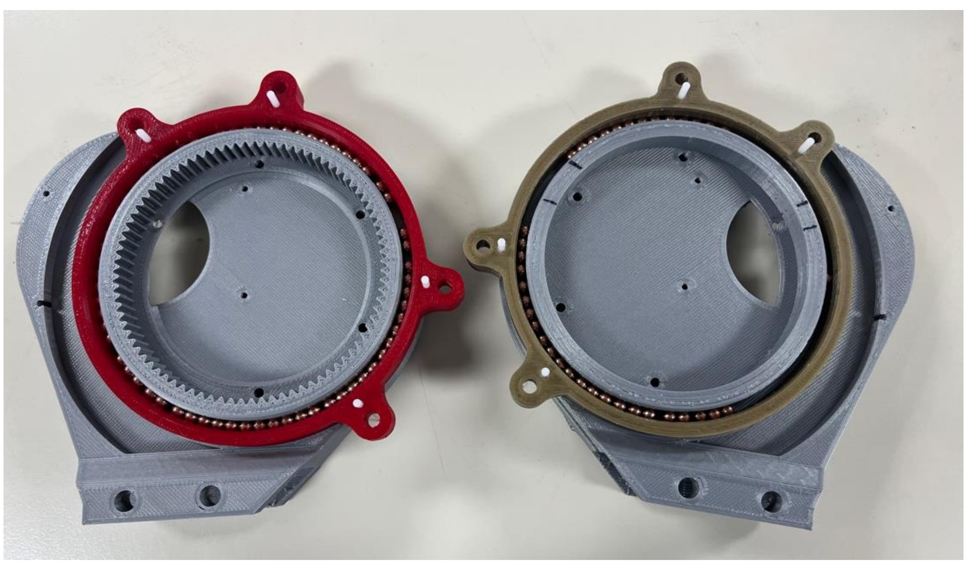


Fig 38. Shoulder blades with bearings attached

Step 6: With the gearbox fully assembled, press the remaining portion of the planetary gears into the gear found on the side of the right shoulder blade. Ensure that the holes align properly. The planetary gears should be flush with the exterior surface of the harmonic gear; however, the sun gear should be poking out. This is because the sun gear will attach to the shaft of the motor.

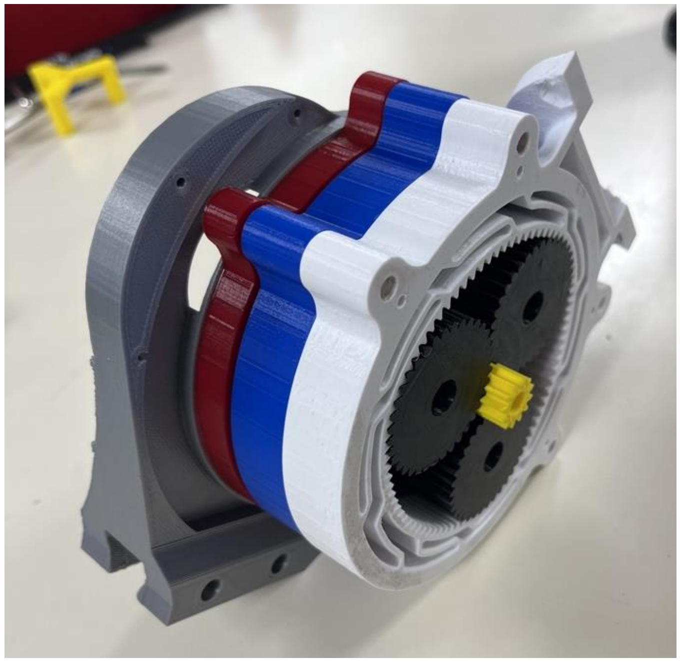
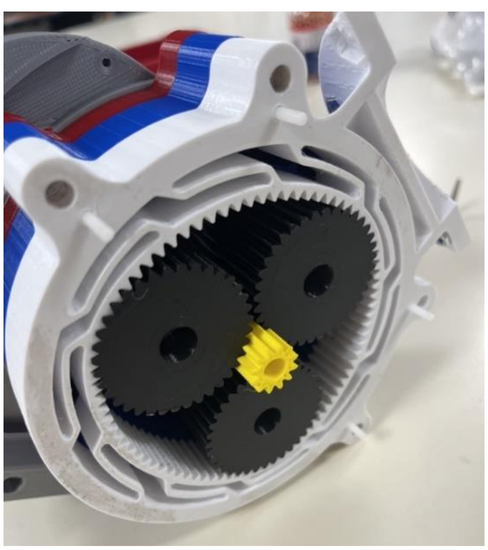


Fig 39. Full gearbox assembly

Step 7: Place dowel pins on the outward surface of the newly completed gearbox. Align the dowel pin holes on the motor gear housing with the dowel pins that were just placed. Push down on the motor gear housing. If done correctly, the shaft of the motor should fit nicely and smoothly in the hole on the sun gear. Do not use too much force, as it is crucial not to damage the shaft of the motor. Ensure the shaft properly connects with the sun gear.



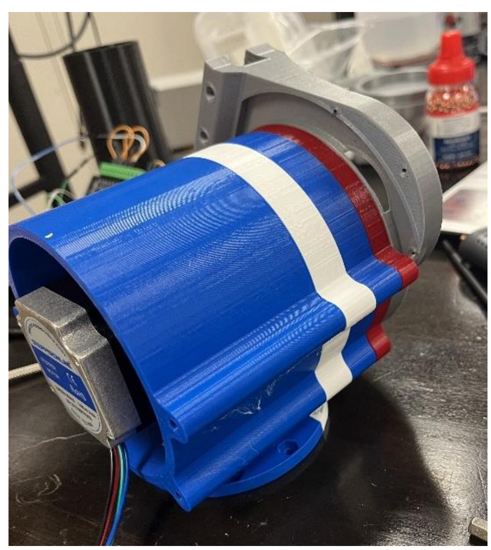


Fig 40. Dowel pins on the outward surface of the newly completed gearbox

Fig 41. Shoulder assembly including motor housing

Step 8: Attach the end of the motor housing to the bearing on the other shoulder blade. Align the dowel pins on the shoulder blade onto the opposite end of the motor housing. This will line up all bolt holes across the newly completed shoulder joint. Note, the various sections of the shoulder flange should all be pointing outward and away from the chassis. Now, thread the 130 mm long screws through all four bolt holes, then apply a nut at the end to secure the entire shoulder together.

Fig 42. Completed shoulder joint assembly

Step 9: Slide the shoulder blades onto the chassis using the dovetails as a guide. Once they are properly guided onto the chassis, use the 40 mm long screws to secure the shoulder blades in place.

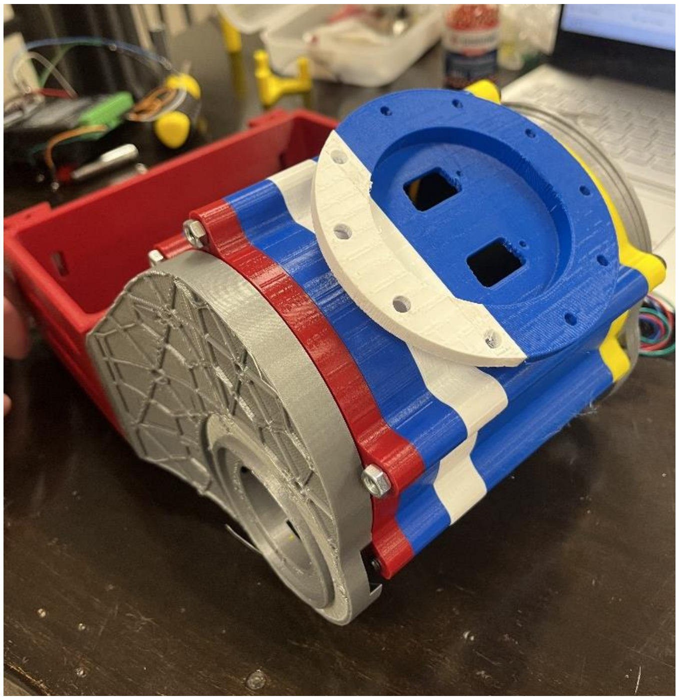


Fig 43. Completed shoulder joint assembly attached to the chassis

Step 10: Press fit the hex nuts into the extruded hex shape on the underside of the shoulder flange. Then align the holes of the shoulder flange and arm flange properly. Afterwards, stick screws down through the holes while placing a finger underneath to hold the nut in place. Tighten using the required tool. Lastly, press fit the knuckle onto the boom.

Fig 44. Completed RE-RASSOR arm and shoulder assembly

Step 11: Wire the motor to a power supply. Refer to the wiring diagram above in the operation manual. Then connect the Arduino as instructed in the diagram. Make sure to upload the given code for the Arduino. Ensure the proper motor drivers and proper power supply are used.

Operation

In order to safely operate the assembly, there are several important factors to consider. They are wiring the motor correctly to the power supply, using the Arduino as intended and integrating it with the other electrical components, properly putting the parts together, and hooking the weight on to the arm.

To correctly wire the motor to the power supply (as well as the wiring for other additional components) make sure to follow the wiring diagram closely. This diagram is provided in the previous pages of the operation manual. Visit the section, "Wiring Diagram" for more information and details on this process. To avoid any potential injury, make sure the power is off when putting wires together or taking them apart.

To use the Arduino as intended, simply download the provided file by going onto our website at https://web1.eng.famu.fsu.edu/me/senior_design/2023/team512/. Or, simply open the Arduino application and start a new file. Once open, you will see a section that reads "void setup()" and a section that reads “void loop()”. You can copy and paste our code, or make adjustments to it, to fit your needs. In any case, make sure to save the file. With the Arduino board connected to the computer, click “Sketch” then click “Upload” after the file has been properly saved. This will let the Arduino know exactly how to operate the motor, and at what speeds, times, and direction the motor shaft should move. Follow along with the referenced wiring diagram to see how this device is integrated with the rest of the electrical components.

To properly put the parts together, please ensure that nothing is being forced. All parts should mate relatively easy, so if they do not fit properly this could be an issue of a bad print. Please see the later section on troubleshooting for more information on this matter. Note that forcing parts together could create a pinch point. To avoid self-injury or bodily harm, inspect parts for any errors in the finish before pushing too hard or applying too much force. Keep your hands and fingers away from such points and always think before doing. Read the instructions for assembly carefully and follow them closely. Additionally, use the lubricants as necessary and apply a generous amount to the gears and to the bearings to allow for smoother motion.

To safely attach the weight to the arm, it is recommended to use fishing line. Any bucket will do, but it is important the bucket be one that is strong enough to hold up to 25 pounds. The user should tie a secure and tight knot at the center of the handle of said bucket. Make sure that it is a knot that cannot be undone easily. Then, place weight into the bucket. A single 25-pound weight is preferred, but smaller weights can be added in. If the approach of multiple small weights is taken, be sure that the smaller weights are stacked as neatly as possible and placed into the bucket as central as possible in order to reduce the chances that the bucket wobbles or moves around while being lifted. Exceeding 25 pounds is not recommended. It is critical that the bucket and weight at the end of the cable be as uniform as possible and experience little to no movement while being lifted otherwise the system may experience failure, which may potentially cause injury. The other end of the cable can be looped through the hole of the knuckle, then tied using a secure knot. The length of the cable will depend on what table the system is placed on, how tall the table is off the ground, and what kind of bucket is used. We recommend using a length that is about the distance from the bucket handle when the bucket is placed on the floor, to about a foot above the table. Before operating, the chassis should be clamped to the table and weight should be added to the hollow inside in order to secure the system to ground.

To start, turn on the power supply. Send the signal to the Arduino. The code which was provided will be able to tell the motor shaft exactly how it needs to move. It will have a slow start, then increase its speed, then come to a slow stop. This provides for smooth acceleration curves which will prevent any jerking motion while the arm is moving with the weight. The motor shaft will then begin rotating slowly in the opposite direction to place the weight back on the ground after it has been lifted. While the arm is moving and the weight is being lifted, be sure to keep feet away from underneath the weight to avoid any potential injury.

Troubleshooting

There are several potential aspects of the project where error may be encountered. Below is a list of potential issues that may be encountered while assembling the RE-RASSSOR Shoulder Phase II project with their suggested remedies.

Issue #1: Poor-Quality 3D-Printed Part

- ***Remedy***: Team 512 recommends printing the STL files that are provided, without making any changes. Changing the given files can be grounds for error in the prints. Only experienced and trained professionals should consider adjusting any of the 3D models.
- ***Remedy***: Check your 3D-printer to make sure it is leveled correctly. Without the proper z-axis alignment, a part will not stick to the printer bed as expected.
- ***Remedy***: Check the temperature of your 3D-printer bed and nozzle. Make sure that the temperatures used are the same as the temperatures recommended by the manufacturer for the PLA used.
- ***Remedy***: Try to print the poor-quality part in a different orientation. You may have chosen an orientation that was not best suited for each part.

Issue #2: Gearbox or Bearings Not Working Properly

- ***Remedy***: Team 512 recommends using the provided lubricants as they are food safe, electronic safe, and non-toxic. Applying these lubricants to the gears and to the bearings can allow for smoother motion, as well as reduce friction. Apply as necessary but note, this may be messy.

Issue #3: Ware/Cracking of the 3D-Printed Parts

- ***Remedy***: Due to the mechanical properties of PLA and depending on usage, gears may eventually wear down and be unable to perform the same. One can reprint fresh gears to replace the worn-down ones.
- ***Remedy***: Due to the mechanical properties of PLA and depending on usage, the dovetails of the chassis may eventually crack due to fatigue. One can reprint a fresh chassis to replace the cracked chassis. Team 512 recommends adding weight to the chassis during operation, to help secure the system to a ground.

Issue #4: Print is Warping

- ***Remedy***: For some 3D-printers, heat may not evenly be distributed to the bed, resulting in large parts having edges that may not stick. Try using a glue stick directly on the bed prior to starting large prints.

Issue #5: 3D-Print is Incomplete

- ***Remedy***: Check the nozzle of your 3D-printer to make sure it is not clogged. Clogging of the nozzle can prevent material extrusion.
- ***Remedy***: The PLA going into the extruder may have snapped. Check the roll of PLA and ensure that it is being properly fed into the extruder.

Issue #6: Shoulder Joint Screws Do Not Fit

- ***Remedy***: Lubricate the screws with the oil-based lubricant to help them glide through the bolt-holes easier.