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STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

Development of Automated Material Handling System with Alternate Gripper Designs for the Purpose of Increased Performance & Worker Safety

DOE-FIU SCIENCE & TECHNOLOGY WORKFORCE DEVELOPMENT PROGRAM

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Principal Investigators:

Nicholas T. Espinal (DOE Fellow Student)
Florida International University

Patrick Folk (Mentor)
Savannah River National Laboratory

Ravi Gudavalli Ph.D. (Program Manager)
Florida International University

Leonel Lagos Ph.D., PMP® (Program Director)
Florida International University

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Applied Research Center
FLORIDA INTERNATIONAL UNIVERSITY

EXECUTIVE SUMMARY

This research work has been supported by the DOE-FIU Science & Technology Workforce Development Initiative, an innovative program developed by the U.S. Department of Energy's Office of Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2023, a DOE Fellow intern, Nicholas T. Espinal, spent 10 weeks doing a summer internship at Savannah River National Laboratory under the supervision and guidance of Patrick Folk. The intern's project was initiated on June 5th, 2023, and continued through August 11th, 2023, with the objective of improving the Surplus Plutonium Disposition (SPD) Program's material handling through the mechanical design of alternate robotic arm gripper designs.

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1. INTRODUCTION

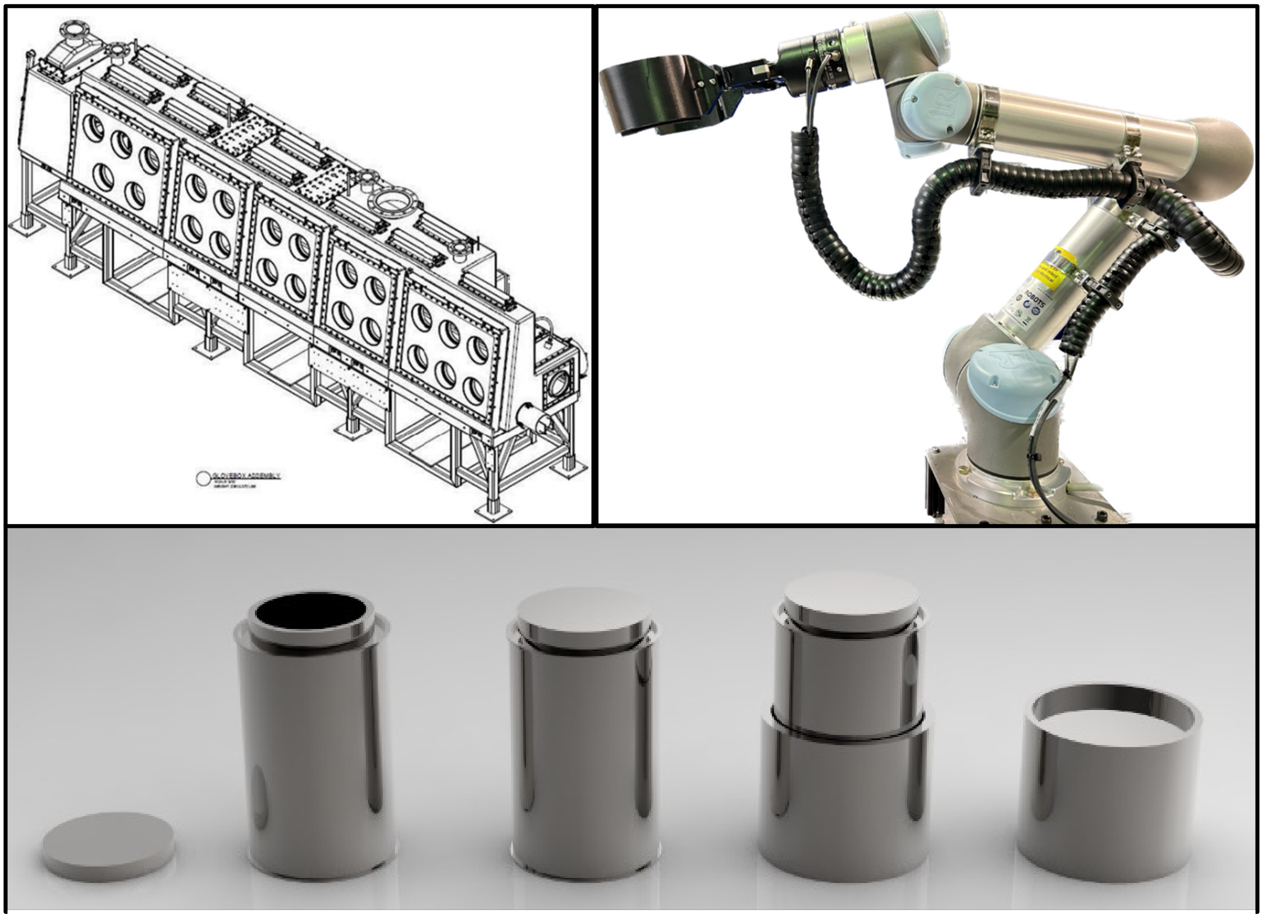

Figure 1 - (A - Top Left) Surplus Plutonium Disposition Glovebox, (B - Top Right) Robotic Arm with Gripper, (C - Bottom) From left to right, opened mixing can, closed mixing can, mixing can in die can, and compressed can.

Savannah River National Laboratory's (SRNL) Surplus Plutonium Disposition (SPD) Program leads the development and transition of automated unit operations for the processing of Plutonium oxide. In K-Area, Plutonium oxide is processed for disposal by hand in the glovebox shown above in **Figure 1-A.** The process is displayed with the modeled cans shown in **Figure 1-C**. A mixing can is opened, filled with material, mixed, set inside of a die can, and finally punched into compressed material. Replication of the process is constructed in A-area, where the mixing can weighs 1.6 kg (3.5 lbs.) and the compressed material weighs 4 kg (8.8 lbs.).

Due to the constant process of Plutonium disposition, the fatigue on workers and worker dose accumulates quickly over time. SPD aims to automate this process by using a robotic arm (shown in **Figure 1-B**) to replace the hands-on worker. Automation will:

- Reduce worker radiation dose.
- Increase process throughput.
- Reduce costs for the disposition of Plutonium oxide.

2. RESEARCH DESCRIPTION

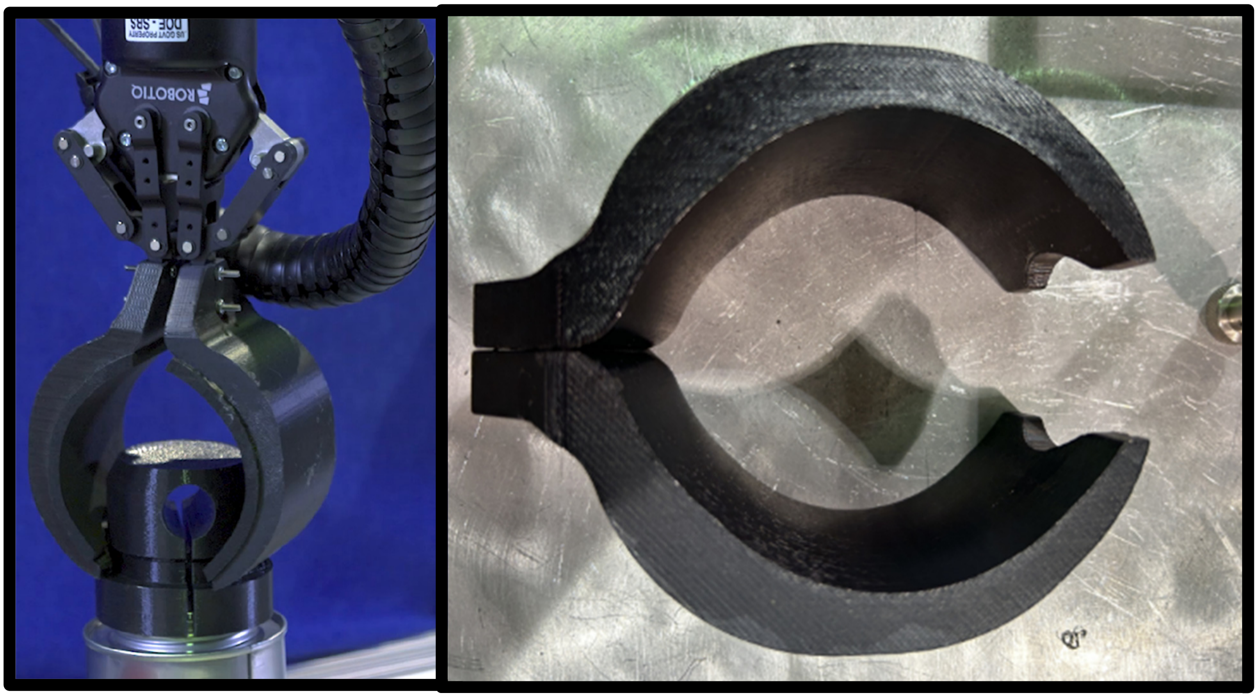

Figure 2 - (A - Left) Current Gripper with Opening Tool, (B - Right) Current Gripper Contour

The current gripper features a tool which is used to screw open and close the can body's lid, shown in **Figure 2 – A**. In **Figure 2 – B**, the inner contour of the gripper matches the outer contours of both the die can and mixing can.

Objective:

Improve material handling through alternate robotic arm gripper designs, construct grip strength sensor and other metrics to compare performance.

3. RESULTS AND ANALYSIS

The design metrics for alternate gripper designs were made to compare the performance of new designs to the current design. Performance is divided by the grippers two separate tasks: either handling or opening materials.

The gripper may use a separate tool to do either of these tasks. In the case it does not need a separate tool, the actions are therefore combined. Combining tasks saves time during process and allows more material to be processed over long periods of time. This is considered and advantage.

Task (Handling / Opening)
Encompass / Parallel
Combined Action (Y / N)
ROBOTIQ ™ Hand (85 / 140)
Approach (Axial / Perpend.)
Flexibility (low - High)
Assembly (Simple - Complex)
Material (ABS / TPU / SS)
Weight (kg)
Strength Average (kg)

Table 1 - Alternate Gripper Design Metrics

The ROBOTIQ ™ Hands of choice are either the 2F-85 and 2F-140 models (shown in **Figure 3 - A**). The 2F refers to the number of fingers (two) and the following number refers to the maximum space in between

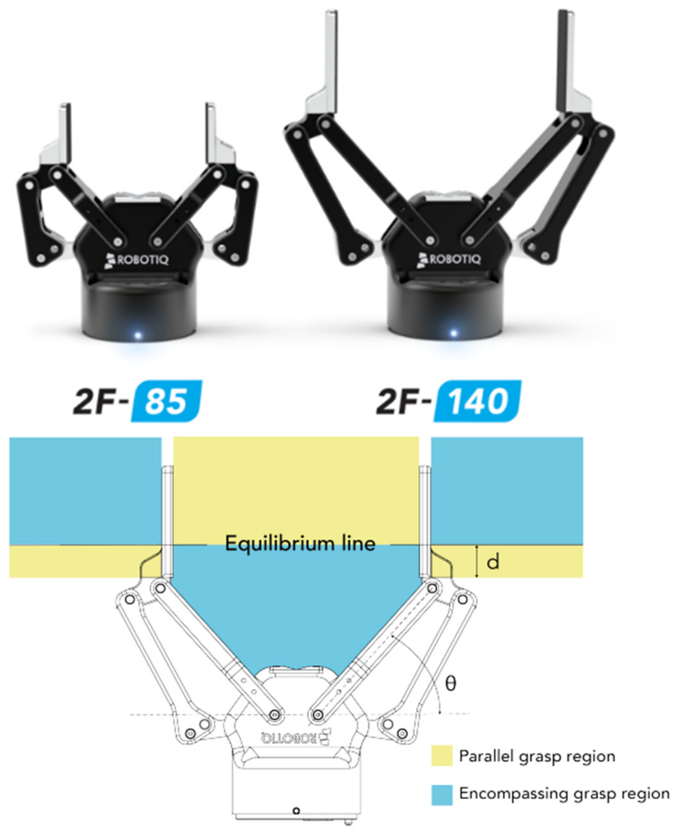

Figure 3 - (A –Top), ROBOTIQ ™ Hand Models,
(B - Bottom) Equilibrium Line for 2F Models.

the fingers in millimeters. The 2F-85 model is shorter, lighter and stronger. The 2F-140 is longer, heavier and weaker [1]. However, the 2F – 140 model is the only Hand capable of both Parallel and Encompassing Grasp, while the 2F – 85 model is only capable of Parallel Grasps. The encompassing grasp is the ROBOTIQ ™ Hand's ability to wrap fingers around circular contours. The zones of contact which activate either Parallel or Encompassing Grasp are divided by the Equilibrium Line, shown in **Figure 3 – B [2].** Using the 2F-85 for the Parallel Grasp and the 2F-140 for Encompassing Grasp are considered advantages. Otherwise, other design choices would be considered a disadvantage.

The approach which the gripper uses to either handle or open the materials can be improved. It is related to the axis of the cylindrical materials. If the approach for opening and handling materials are the same, the robotic arm will not need additional manipulation. This will additionally save time during the process and all more material to be processed over a long period of time. A combined approach for handling and opening would be considered an advantage.

Flexibility advantages depend on the task. The opening task does not require flexibility, as the mixing can's lid size will not change. Low flexibility in this task is considered an advantage. For handling, high flexibility is an advantage. The materials inside of the glovebox do change, the diameter of the mixing can is 98.6 mm, and the diameter of the shell can is 115 mm. Additionally, any material which is sent into the glovebox with a diameter between 98.5 and 115 mm can be handled by a flexible gripper.

Assembly should ideally be simple – meaning little to no assembly for maximum process output. If there are multiple components to be assembled, the design has an immediate disadvantage, in comparison to the original design.

Figure 4 - (A – Left) Rigid 3D Printed ABS, (B – Middle) Stainless Steel Nuts & Bolts, (C - Right) Flexible 3D Printed TPU.

Different materials were used to produce the gripper. Acrylonitrile butadiene styrene (ABS) is the very strong and rigid material used for the main base of the gripper, shown in **Figure 4 – A**. Thermoplastic Polyurethane (TPU) is the flexible material used for different attachments on the gripper, shown in **Figure – C**. Finally, stainless steel nuts and bolts were used to assemble the new gripper designs. Parts were modeled using PTC Creo Parametric 4.0 modeling software (**Figure 5 – A)**. ABS and TPU were printed with a Stratasys™ f370 Fused Deposition Modeling (FDM) 3D printer (**Figure 5 – B)**. The material section tracks the change in materials, not change in advantages in design.

Figure 5 - (A - Top) Stratasys ™ f370 3D Printer, (B - Bottom) PTC Creo Parametric

The weight of the gripper includes the entire addition of weight to the robotic arm at its wrist. This includes the ROBOTIQ ™ hand of choice and the gripper attached. Heavier gripper designs will be considered disadvantages.

Finally, the grip strength average is used to measure output force from the gripper design. The force is measured using an Omega LC321 – 500 load cell and is read using an input meter. Both are shown in **Figure 6**. The current design requires better grip and friction. Thus, higher force outputs are considered an advantage.

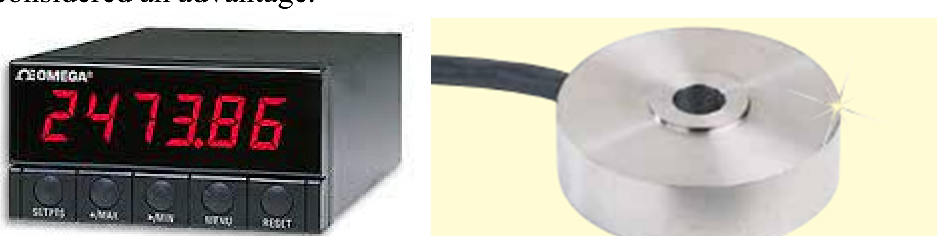

Figure 6 - (Left) Omega DP41 - B Universal Input Meter, (Right) Omega LC321-500 Load Cell.

The strength average is measured for either handling or opening. For handling, the force output on a mixing can and die can are measured. For opening, the force output on the lid is measured. For these three geometries, a specific grip strength sensor was designed, shown in **Figure 7.** The exploded view shows the inner adaptive core which will allow the load sensor to easily fit inside each of the three grip strength sensors.

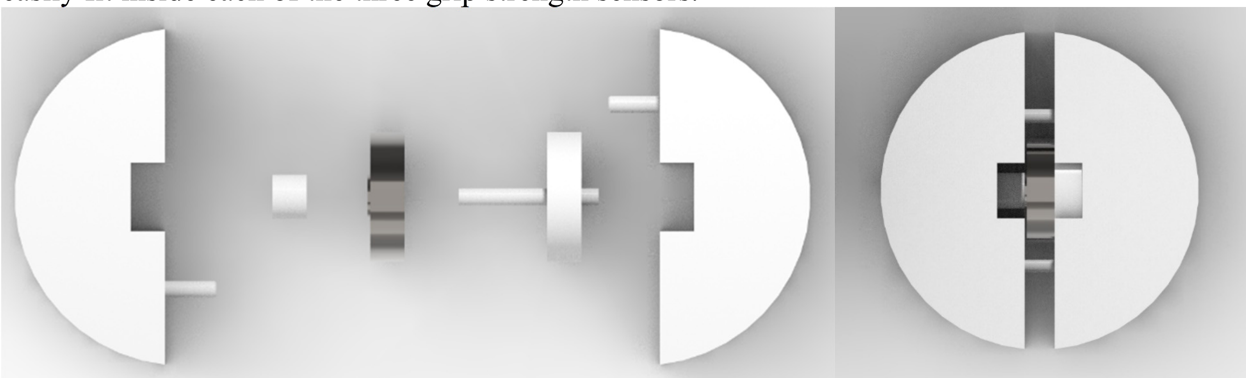

Figure 7 - (A - Left) Grip Strength Sensor (Exploded), (B - Right) Grip Strength Sensor Assembled.

The die can, mixing can, and lid will have its respective grip strength sensor. The sensors will be used to compare new gripper designs.

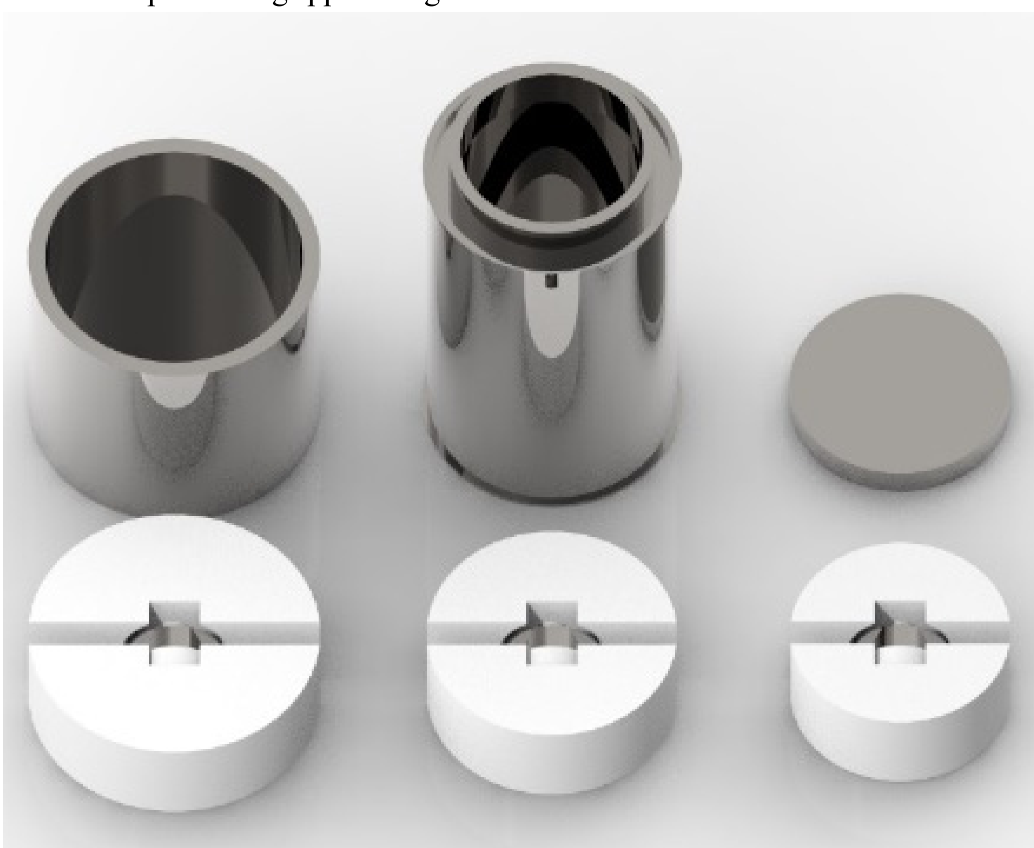

Figure 8 - Grip Strength Sensors for Die Can, Mixing Can and Lid.

Using the Alternate Gripper Design Metrics (**Table 1)**, the initial data for the Current Gripper was listed (**Table 2**).

	Current	
Task (Handling / Opening)	Handling	Opening
Encompass / Parallel	Parallel	
Combined Action (Y / N)	No	
ROBOTIQ ™ Hand (85 / 140)	85	
Approach (Axial / Perpend.)	Perpendicular	Axial
Flexibility (low - High)	Low	Low
Assembly (Simple - Complex)	Simple	Simple
Material (ABS / TPU / SS)	ABS / Foam	TPU / SS
Weight (kg)	1.14	
Strength Average (kg)	Can: 6.3	Lid: 2.1
	Die: 5.8	

Table 2 - Current Gripper Design Metrics.

As shown, the current gripper applied a parallel grasp with a 2F-85 hand. The gripper approaches perpendicularly to the materials' axis for handling and approaches axially for opening. There is low flexibility in both handling and opening, as the gripper itself is made of ABS, and a small layer of foam. The additional tool needed for opening uses very thick TPU and a small spring, which also provides little flexibility. The weight of the gripper and 2F-85 together were 1.14 kg (2.5 lbs.). Using the grip strength sensors, the strength average for the mixing can, die can, and lid are 6.3 kg (13.9 lbs.), 5.8 kg (12.8 lbs.), and 2.1 kg (4.6 lbs.) respectively.

Gripper Design – Mark I

The first gripper design uses the 2F – 140 hand with a parallel grasp (shown in **Figure 9**). The approach for handling and opening was the same. The gripper is composed of two different materials, an outer base of ABS and inner grip of TPU. The inner TPU is designed for high

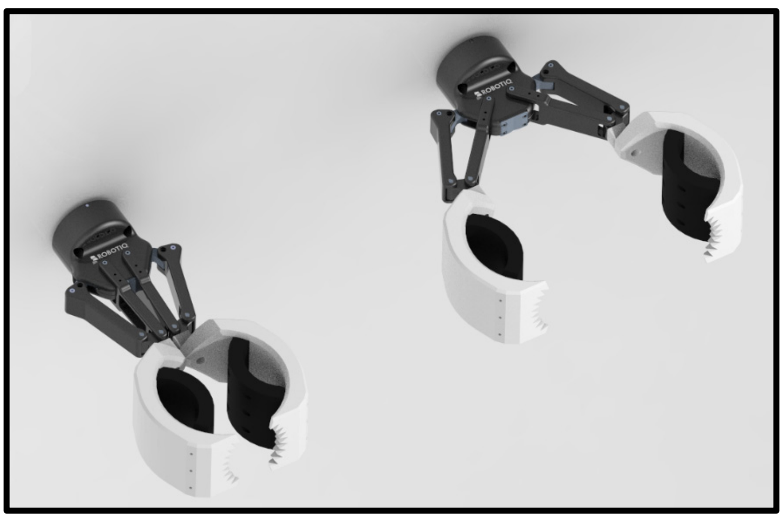

Figure 9 - Gripper Design - Mark I Open (Right) and Closed (Left).

flexibility, while the outer ABS is rigid. Attaching the two separate parts creates a more complicated assembly.

This gripper design features a serrated edge which applies pressure points around the mixing can lid. This addition of an opening tool onto the gripper adds a combined action of handling and opening, and thus no longer needs an additional tool. The edge is flat, shown in **Figure 9**, and has a curvature of the mixing can lid's diameter, shown in **Figure 10**.

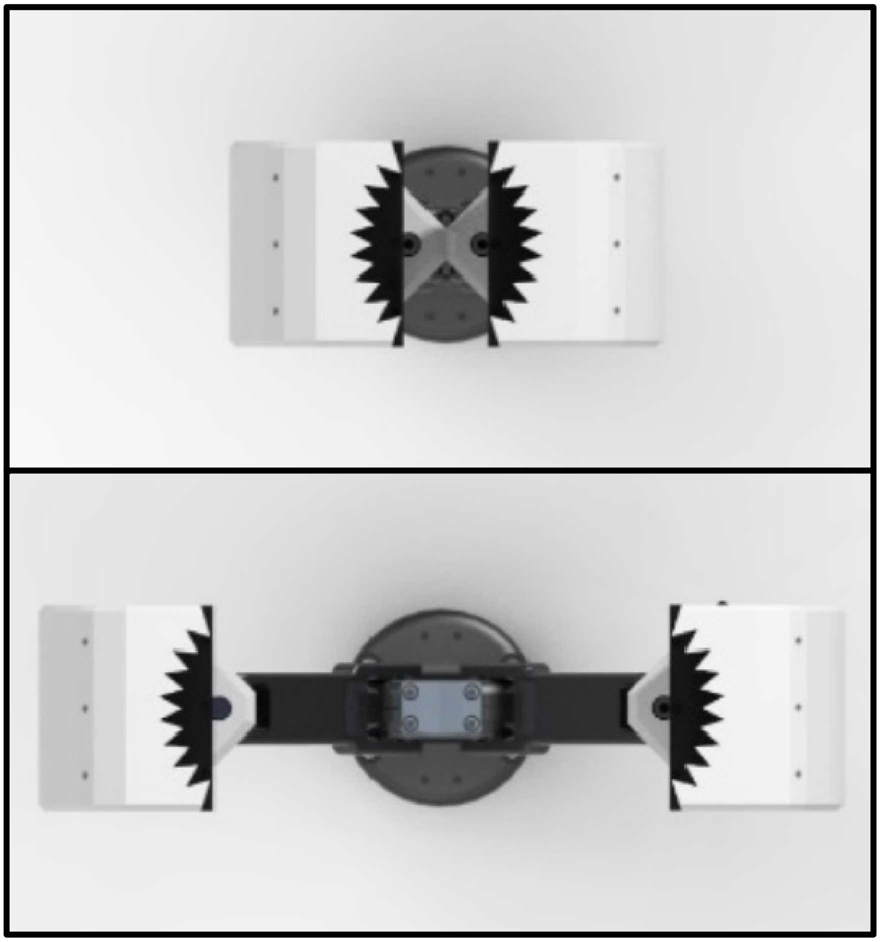

Figure 10 - Gripper Mark I Serrated Edge Closed (Top) and Open (Bottom).

Table 3 shows the design metrics of the first gripper design, with a summary of its improvements and disadvantages, up until the strength averages.

	Gripper Mk. 1	
Task (Handling / Opening)	Handling	Opening
Encompass / Parallel	Parallel	
Combined Action (Y / N)	Yes	
ROBOTIQ ™ Hand (85 / 140)	140	
Approach (Axial / Perpend.)	Perpendicular	Axial
Flexibility (low - High)	High	Rigid
Assembly (Simple - Complex)	Moderate	None
Material (ABS / TPU / SS)	ABS / TPU / SS	ABS
Weight (kg)	1.53	

Improvement
Disadvantage
No Change

Table 3 - Gripper Design I Metrics (No Strength Averages).

In the beginning of the design stage, it was made clear the current convex TPU model was too thick to use its flexible properties. Data was collected which shows the weakness and poor design of the first few models, shown in **Figure 11**.

The serrated edge applied on the mixing can lid had proven to apply more force. (3.3 kg compared to the current design's applied force of 2.1 kg).

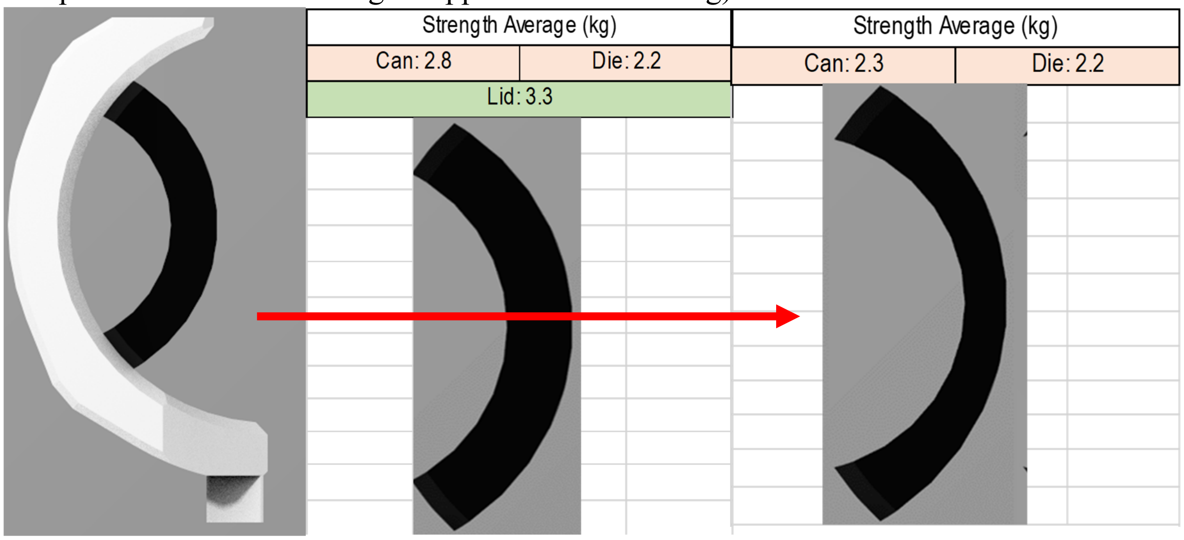

Figure 11 - First Convex TPU Grip Models.

Opposed to the convex TPU model, concave TPU models were designed. Their shape already adheres to the shape of the contour of the handled materials and uses the TPU material to flex into shape. The "W" shaped model had to be tested with and without a supported backing. A dovetail assembly was designed to add the backing, this is shown in **Figure 12**.

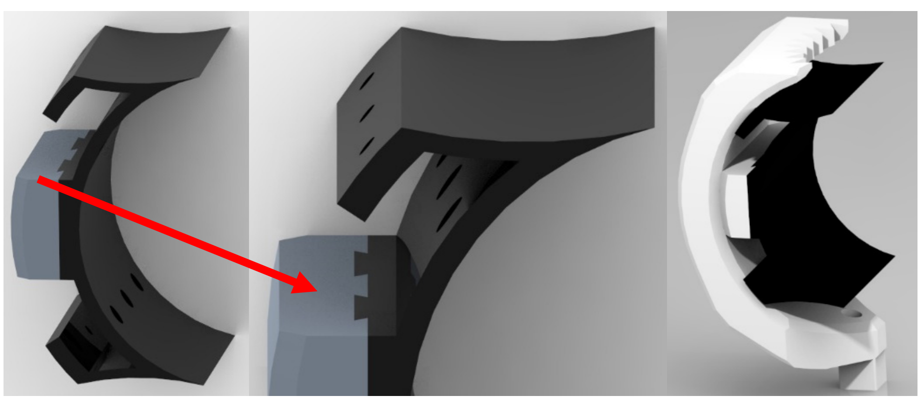

Figure 12 - First Concave TPU Grip Model with Dovetail

The support was proven to be unnecessary. The support, combined with the geometry of the TPU model, did not allow the TPU mold about the contour of the grip sensor. Without the support, the TPU model molded much better. Additionally, the force applied increased. The concave grip without support attached is shown in **Figure 13**.

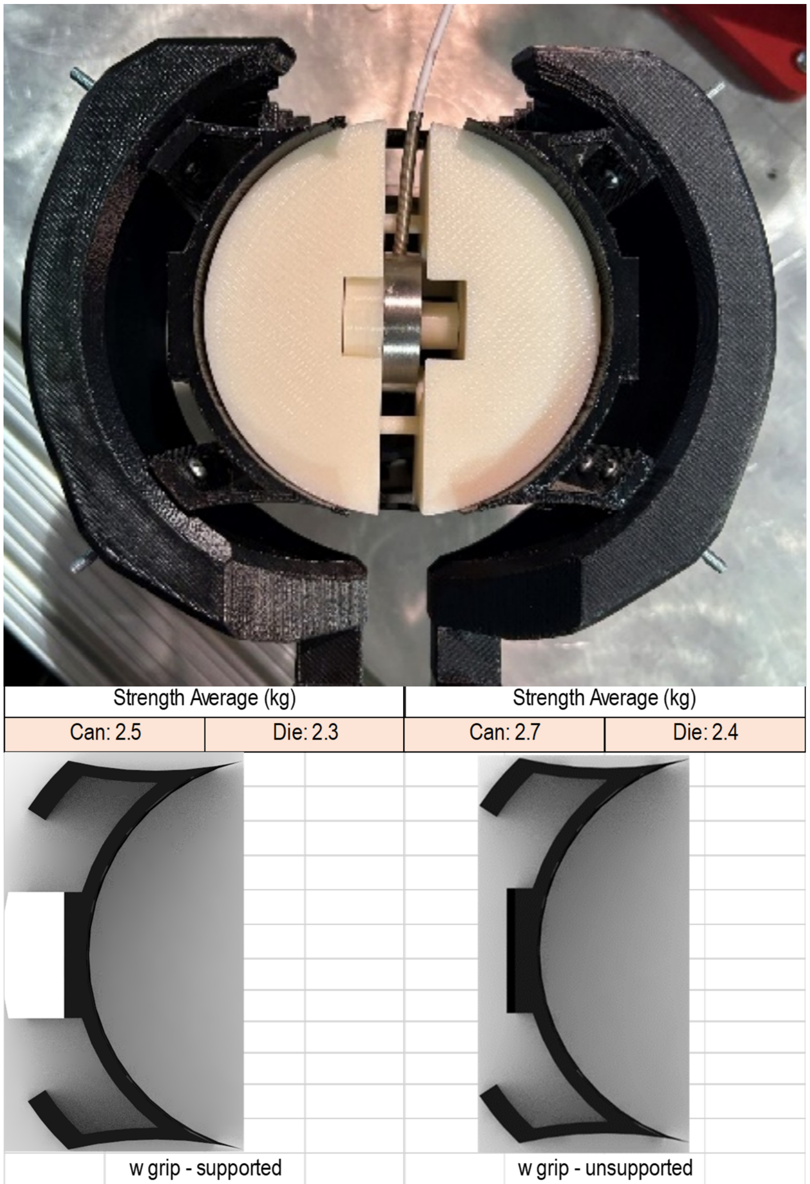

Figure 13 - (Top) Concave TPU Grips Attached, (Bottom Left) Supported Concave Grip, (Bottom Right) Unsupported Concave Grip.

To avoid the weakness of the 2F-140 hand, the ABS gripper base was converted to attach to the stronger 2F-85. The attaching end was modified with a slot versus a screw hole, shown in **Figure 14.** A circular clearance was made for securing bolts with a rachet.

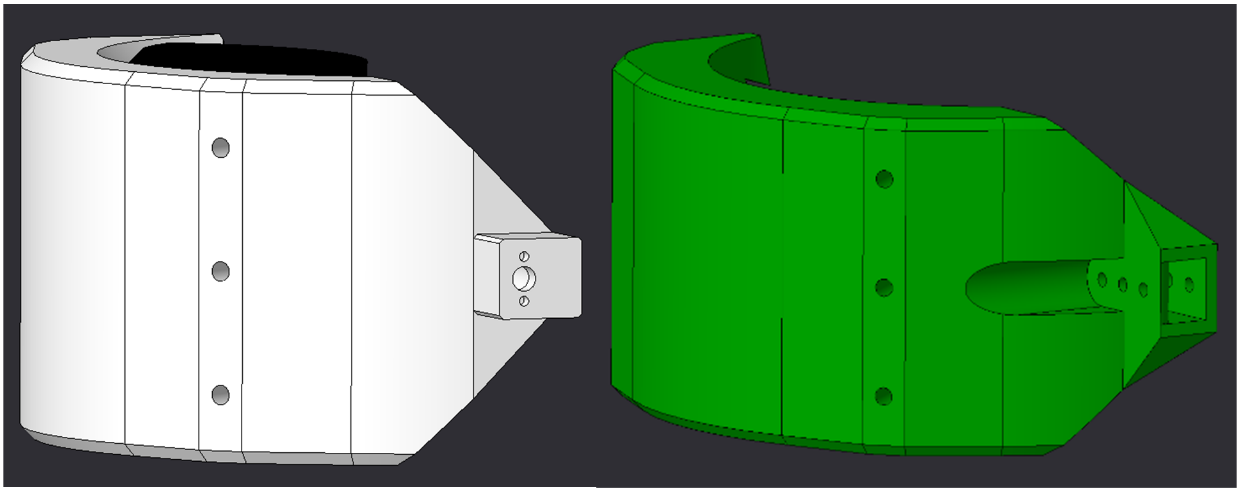

Figure 14 - 2F - 140 Gripper Attachment (Left), 2F - 85 Gripper Attachment (Right).

After switching the gripper to the stronger 2F – 85, the grip strength applied to the lid significantly increased from 3.3 kg (7.3 lbs.) to 5.8 kg (12.8 lbs.). The convex model was continued to be made thinner and was tested once more. The concave model's geometry was edited to test more beneficial changes. If the flexible edge which molded about the contour of the handling material was made sharper, the performance on strength improved as it can make better contact with material. **Figure 15** shows how the concave model outperformed the convex model, and how the concave model with the sharpest edge did best.

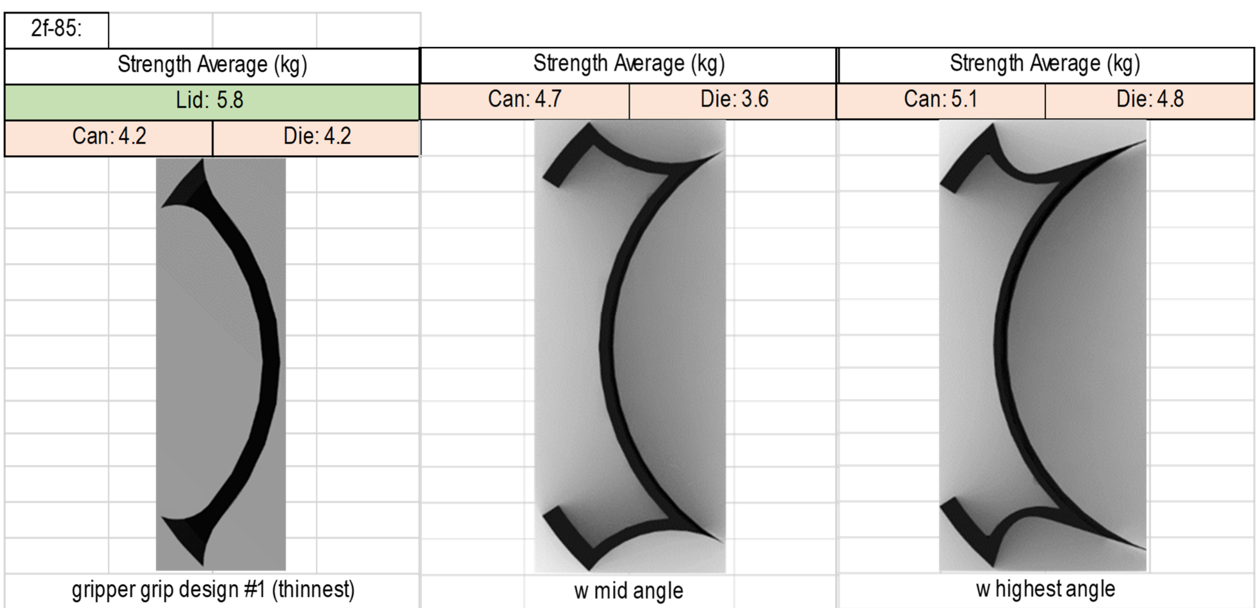

Figure 15 - Convex and Concave TPU Model Strength Performances.

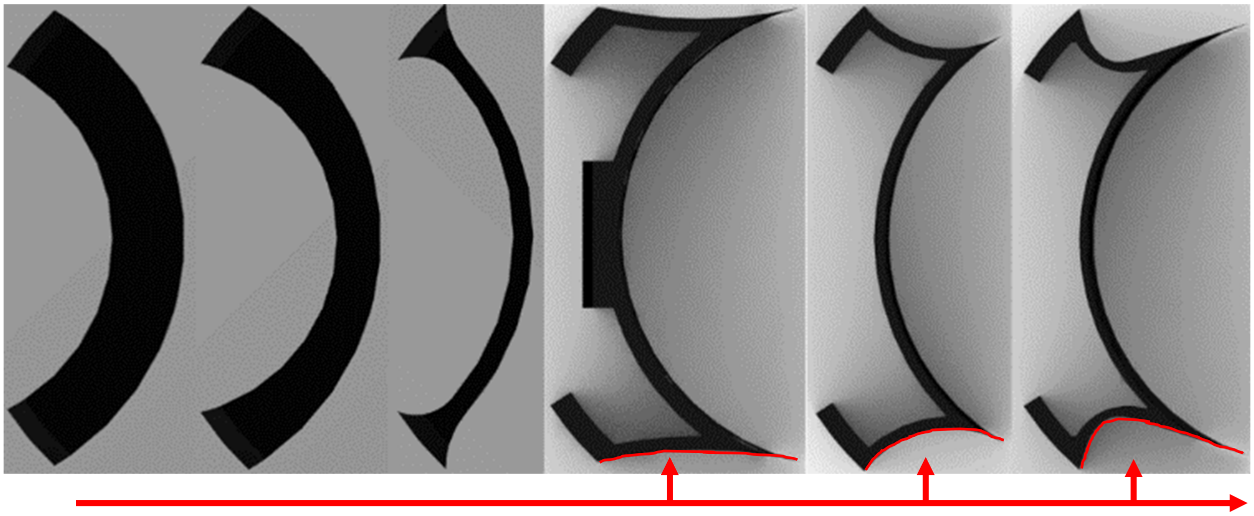

Figure 16 - Evolution of TPU Models.

Above in **Figure 16** shows the evolution of the TPU models for grasping material. Notice the increase in angle in the edge of the model which further sharpens the grip. This new data for the strength average provided a complete design metric for the first official Gripper design, shown in **Table 4**.

	Gripper Mk. 1	
Task (Handling / Opening)	Handling	Opening
Encompass / Parallel	Parallel	
Combined Action (Y / N)	Yes	
ROBOTIQ ™ Hand (85 / 140)	85	
Approach (Axial / Perpend.)	Perpendicular	Axial
Flexibility (low - High)	High	Rigid
Assembly (Simple - Complex)	Moderate	None
Material (ABS / TPU / SS)	ABS / TPU / SS	ABS
Weight (kg)	1.53	
Strength Average (kg)	Can: 5.1	Lid: 5.8
	Shield: 4.8	

Improvement
Disadvantage
No Change

Table 4 - Complete Gripper Design I Metrics

Switching to the 2F-85 greatly improved Gripper Design I, bringing outputted strength averages much closer to the current gripper. The weight change was negligible. Despite the shortcomings in the strength averages, the forces are still high and can potentially still perform well in material handling. **Figure 17** shows the clearances made in one TPU model which allows for rubber chords to be inserted. Attaching with adhesive, the rubber chords can provide additional friction to the gripper which will improve its performance in grasping material. Tests for actual handling and opening performance have yet to be constructed and measured.

Figure 17 - (Top Left) Clearances in TPU Model, (Top Right) Rubber Chord attached to TPU Model, (Bottom) Rubber Chords.

Gripper Design – Mark II

Gripper Design I incorporated a parallel grasp, but a design using the encompassing grasp was yet to be made. Gripper Design II features an encompassing grasp, utilizing the 2F – 140. The gripper is composed of two ABS fingers which attach to a TPU belt that flexes about the contour of the handled material. Notice, there are also clearances for rubber chords to increase friction. The edge of the finger also features a serrated end as an opening tool. The gripper is shown in **Figure 18**.

Figure 18 - Gripper Design - Mark II

Figure 19 - Modeled Gripper (Left) vs. Printed Gripper (Right).

Flexible material like TPU is particularly harder to model and predict using 3D software. **Figure 19** shows a side-by-side comparison of the modeled gripper vs the printed gripper. Gripper Design II worked well with the die can, however the mixing can was not properly grasped. This can be due to the geometry of the belt and where it attaches to the gripper. Additionally, the amount of material between the actual fingers prevented the fingers to join for the opening task. Gripper Design II does not contain data for the opening task in terms of performance for this reason. However, despite failing the opening task, this design outputted the greatest average strength of both new designs with 5.9 kg (13 lbs.) for the mixing can and 5.4 kg (11.9 lbs.) for the die. Gripper Design II is also lighter by 0.13 kg (0.3 lbs.). The design metric for Gripper Design II, excluding Opening Task Data is shown below in **Table 5**.

	Gripper Mk. 2	
Task (Handling / Opening)	Handling	Opening
Encompass / Parallel	Encompassing	
Combined Action (Y / N)	-	
ROBOTIQ ™ Hand (85 / 140)	140	
Approach (Axial / Perpend.)	Perpendicular	-
Flexibility (low - High)	High	Rigid
Assembly (Simple - Complex)	Moderate	None
Material (ABS / TPU / SS)	ABS / TPU / SS	ABS
Weight (kg)	1.01	
Strength Average (kg)	Can: 5.9	-
	Die: 5.4	

Improvement
Disadvantage
No Change
Data Needed

Table 5 - Gripper Design II Metric (Excluding Opening Task Data)

Gripper Design III

Due to the length of the internship and frequent use of additive manufacturing by SRNL Engineers, the parts in the latest design could not be printed or tested. They have been modeled and will be handed over to the development team for further testing. The latest design incorporates the concave TPU models of Design I and still uses and encompassing grasp from Design II with ABS Fingers. There are 4 concave TPU models which grasp the handled material and can flex to the correct diameter while still applying a large force.

Gripper Design III can be seen in **Figure 20 – A**, while **Figure 20 – B** shows the circular contour made by the encompassed ABS fingers and concave TPU models.

Figure 10 - (A - Top) Gripper Design III,
(B - Bottom) Gripper Design III (Side View)

4. CONCLUSION

Intern Nicholas T. Espinal's participation in SRNL's development of SPD's Automated Material Handling System resulted in the possible addition of a serration feature on the current end-effector used for automated handling of hazardous material for the purpose of reducing worker dose, cost, and increase in production. Nicholas used qualitative and quantitative data to verify the improvements of his designs. Additionally, three new gripper designs were developed and have been documented for further development and improvement. In his 10 weeks, Nicholas gained industry experience in terms of engineering, manufacturing, mechanical design, and methods for efficient development with the use of software, hands-on work, and insight through mentors.

5. REFERENCES

[1] *2F-85 and 2F-140 grippers*. Robotiq. (n.d.). https://robotiq.com/products/2f85-140-adaptive-robot-gripper

[2] Manual, I. (n.d.). *Robotiq 2F-85 & 2F-140 for e-Series Universal Robots*. https://assets.robotiq.com/website-assets/support_documents/document/2F-85_2F-140_Instruction_Manual_e-Series_PDF_20190206.pdf