NDSU NORTH DAKOTA STATE UNIVERSITY

Move That Goo!

2023 NASA X-Hab Academic Innovation Challenge

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MOON TO MARS EXPLORATION & HABITAT SYSTEMS • ACADEMIC INNOVATION CHALLENGE •

Executive Summary

On May 5, 1961, Alan B. Shepard became the first American in space (K. Mars); since then, NASA has made leaps and bounds in space exploration and continues to develop new technologies. Through their X-Hab program, NASA has teamed up with the National Space Grant Foundation to fund our student-centered project with one main goal: Move That Goo! Liquid amine absorption is a method by which CO_2 is removed from an environment and is intended to be the primary method for CO_2 removal for NASA's sustained human presence on extraterrestrial bodies such as the Moon and Mars. Liquid amines can be highly viscous when absorbing CO_2, thus the team needed to produce a design that could move a high viscosity fluid while staying under the power requirement of 1 kW and allowing a few square meters in a closed system.

Prompted by NASA and with the support of our faculty mentors, we have been tasked with the research, development, production, and testing of a system able to move a high viscosity liquid amine which requires adequate air exposure to absorb carbon dioxide from a habitat atmosphere in low gravity. The system is split into two main groups, fluids, and materials, with two separate teams of students assigned to their half of the design. The fluids team is responsible for everything in the design that directly touches the fluid. The materials team is responsible for the test stand to which the fluids team's design is attached to as well as additive manufacturing material selection.

In the first semester, the team focused on brainstorming ideas, design selection, budget creation, and CAD modeling. Multiple concepts were generated but the team decided on a design to get the high viscosity fluid to move around a rectangular channel using a screw conveyor mechanism. The liquid must be moved by the turning screw from the thermal chamber going around a rectangular trough back to the thermal chamber. The screw and the trough geometry will be important to allow for the high viscosity fluid to flow, utilizing surface tension to maintain contact to the trough as seen in Figure 1 below.

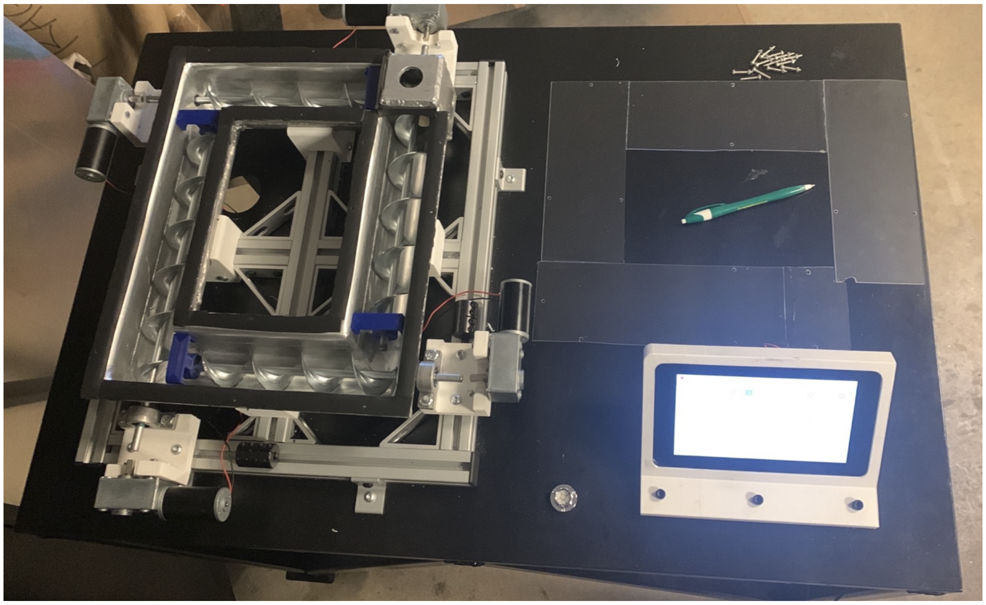


Figure 1: Trough Assembly

Fluids Team Design Detailed Design Documentation

Problem and Objectives

The objective of this senior design project is to design a manifold that can move a high viscosity fluid to simulate the liquid amine and removal of CO_2. The team conducted a voice of the customer survey with Grace at NASA to get a better understanding of the customer requirements. The intent is for this system to be used in a habitation on Mars to reduce the amount of CO_2 in the air. The system will be running continuously and will need to remove 1 kg of CO_2 per person per day. It has a power limitation of less than 1 kW. For the scope of the project, the screw conveyor will need to fit on a bench stand/tabletop and be portable so being lightweight is also necessary. From these customer specifications, the team worked out some engineering specifications. The team selected Mars as the basis for this habitation which means the gravity is 3.721 m/s^2 and all the specifications must work in that gravity. To keep it lightweight, the team settled on a maximum weight of 706 pounds as this is like other designs in use. The maximum power usage is 1 kW as stated in the customer requirements set by NASA. The system needs to be able to move a fluid with at least 10,000 cPs at a flow rate between 10 to 15 mL. The expected outcomes of this project include the selection of a high viscosity fluid that simulates the liquid amine and a system capable of moving the high viscosity fluid. The most difficult part of the assembly process was setting up the motor controller for the motors as we had to control four motors with two controllers and one raspberry pi and ran into complications along the way.

The most important aspect of this project was finding a trough system that fit our size range. The best option was to manufacture our trough system, using the Aluminum sheet metal. The troughs were created by Ben Moreno at MidAmerica, and the screws, motors, and other components were ordered online by miscellaneous other parties. Once the team had the troughs, the screws were cut down to size and holes drilled for the bolts. The acrylic was cut to fit over the top of the troughs with foam tape underneath to provide a sealed barrier. Seals were placed between the screw shaft and the trough and sealed with silicone sealant. The trough was fitted to the tabletop and the raspberry pi slotted into the mount on the tabletop. The troughs were then leak tested to verify that everything was properly sealed. Once everything was sealed and leak tested with water, the system was filled with ultrasound gel and was able to move the gel at the desired flow rate of 10-15 mL/min consistently. The design needed to fit on a tabletop, be portable, operate in microgravity, and be sized up for future use. It also was required that the design use one kilowatt of energy or less. Multiple concepts were generated such as a triangular manifold, centrifuge, and belt conveyors but the team decided to use a screw conveyor design with multiple screws. When selecting a design, the team performed CFD analysis and RPM calculations to determine if the design could achieve the desired flow rate while keeping below the energy requirement. Once the design passed the CFD and RPM calculations, the team moved forward with manufacturing and testing. The team decided to use an ultrasound gel as the fluid with its viscosity being 130,000-180,000 centipoise and its capability to be watered down to allow a wide range of viscosities to be evaluated. Viscosity tests were performed on the gel to verify multiple different viscosities could be met in the range provided by NASA, and motor and fluid flow testing to make sure the motors could reach and maintain the desired flow rate. The materials team oversaw creating the tabletop that the screw system would rest on which is what makes the design portable and provides an appropriate tabletop area for use in testing.

Computational Fluid Dynamics Analysis

Computational Fluid Dynamics, or CFD, is performed to find different fluid velocity profiles and magnitudes for the scope of this project. To achieve this, ANSYS CFX was utilized as the CFD software to perform the analysis. The parameters of the simulation contain the following simplifying assumptions. Fluid completely fills the trough, along with the boundary layer in the clearance of the screw and the trough. This simulation does not take into effect airflow over the screw and is enclosed. The criterion for the simulation is a two millimeters per second inlet velocity and then observing the velocity profiles along the volume of the screw. The outlet is modeled as a relative atmospheric pressure condition. The fluid was defined as ultrasound gel with its specific material properties such as density and dynamic viscosity values. Another thing that was taken into consideration was the frame motion of the rotating body of the screw, with a 0.2049 radians per second defined rotation. With these parameters, a simulation is performed. The solver control is set to a convergence criteria of 1e-6 RMS value of the different parameters in the solution. The solution was solved as a transient problem, with Second Order Backward numerical method. The transient simulation runs for 120 seconds with timesteps of 2 seconds to observe the progression of the fluid throughout multiple revolutions of the screw. The solution converged to the targeted residual values quickly, with only slight oscillations well below the 1e-6 value. The results were obtained from the solution and displayed graphically, along with the obtained flow rate value at the outlet. The outlet flow rate slowed to 14.12 mL/min, only slightly deviating from the targeted value of 15mL/min, verifying that the viscous effects of the gel would not inhibit the flow to an unsatisfactory degree. Below in Figures 2 and 3, the model's geometry and mesh of the simulation, along with the vector streamlines of the screw, can be seen.

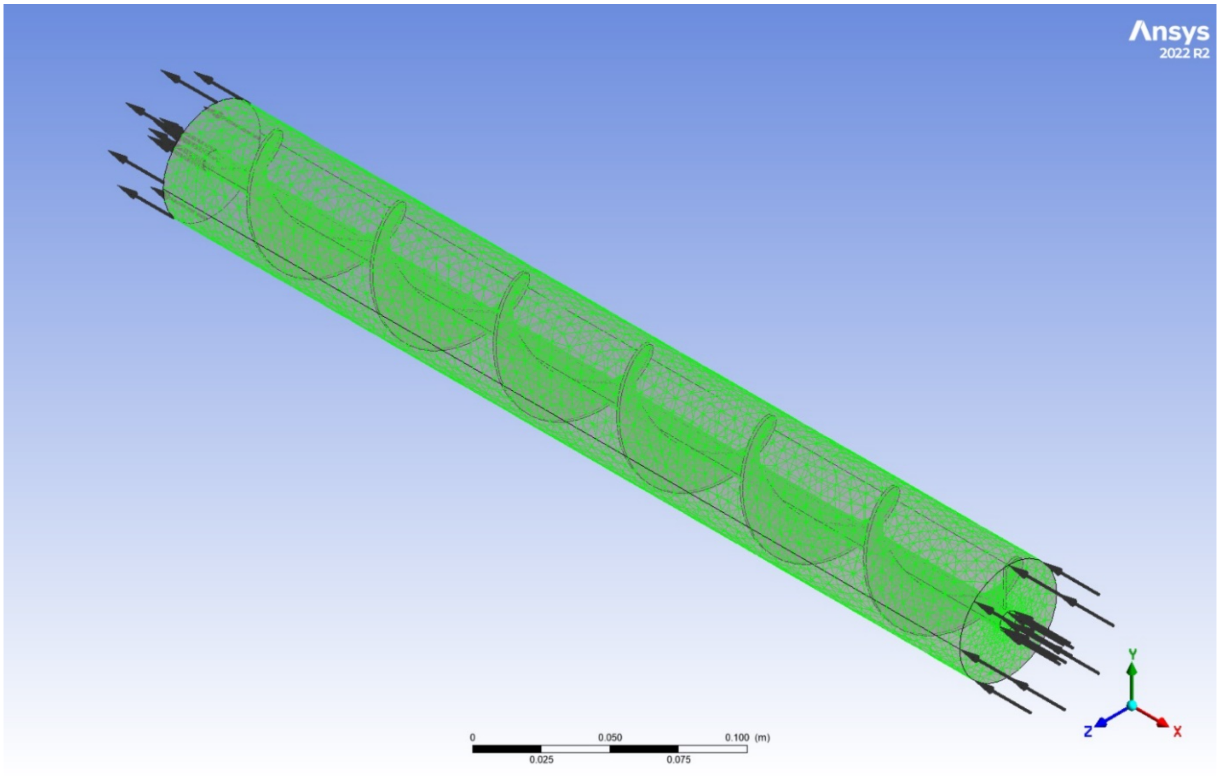


Figure 2: Inlet and outlet conditions with mesh of geometry

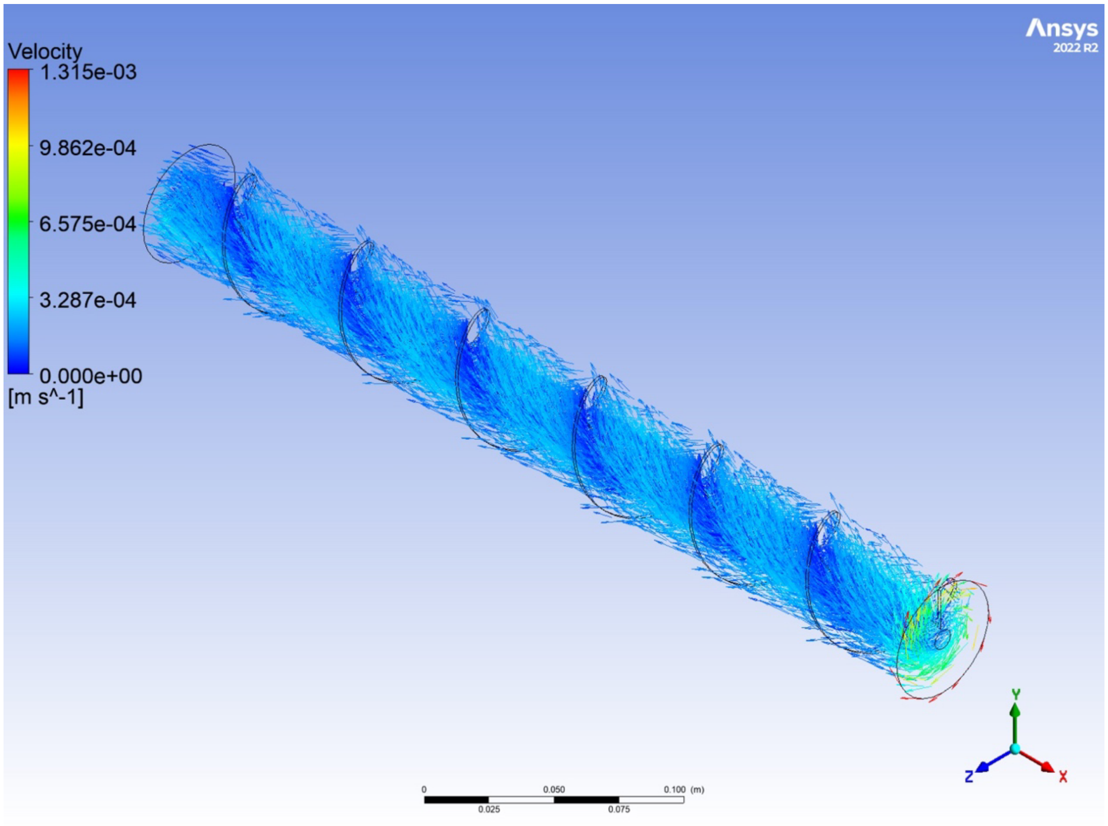


Figure 3: Velocity vectors across the length of the screw.

Laboratory Test Plans and Results

To perform the computational fluid dynamics analysis of liquid amine flow through the troughs network, it was necessary to know the motors abilities to rotate the screws blades to allow space for the new material to enter the trough network. To find the mass flow rate values, produced at each speed setting, a fluid flow calibration will be used to measure the volume displaced over a given time. Also, an experiment will be conducted to investigate the effect of screw speed on the required power and conveying capacity of a screw conveyor.

To investigate the effect of screw clearance between the screw and the trough, a clearance of 1.5 mm will be considered. The trough volume was determined through measuring the volume of each trough which gave us a total of 4620824 mm^3. The actual volumetric capacity was expressed in mm^3. The actual capacity of a screw conveyor is less than the theoretical capacity.

Electronics Test Plan

The electronics assembly was connected using the following set up shown in Figure 4. The Raspberry Pi was attached to the display using the ribbon wire while the male-to-male jumper wires from the 5V and GND pins on the display board was attached to the corresponding 5V and GND pins in the 40-pin group on top of the Pi. These jumper wires provide power to the display through the Pi. The 12V Micro-USB power supply was connected to the Micro-USB port on the Pi and plugged in. The display turns on and displays the Raspberry Pi desktop.

Figure 4*:* Initial electronics setup using SB Components motor controller.

To connect the Motor shield motor controller to the top of the Pi, the male 40 pin group of the Pi was inserted into the female 40 pin group of the motor controller. The jumper wires connected in the previous step were disconnected and then reconnected to the same pins on top of the Motor shield to do so. The motor supply port was connecter to the DC power connector using male-to-male jumper wires, and the 12V Flex Connector power supply plugged into that. For ease of assembly, two female-to-male jumper wires were connected to each motor port. The corresponding red and black wires from a motor were then plugged into the jumper wires for Motor1 for the initial test.

The motor controller supplies power to the DC motors according to a power percentage written in a python program. The proper packages corresponding to the purchased motor controller first were first downloaded and then written into a python code. The first test code runs a single motor for a designated amount of time. While the motor was running, group members recorded how long the motor would take to finish a designated number of revolutions. A single motor at full power was found to run at about 12 rpm, shown in Table 1.

Table 1*:* Results of single motor test.

Trial	Revolutions	Time	Percent of full speed (14 rpm)
1	10	51.2s	11.72 rpm
2	10	50.08s	11.981rpm
3	10	50.15s	11.964 rpm
4	10	50.12s	11.971 rpm
5	10	49.6s	12.1 rpm

When additional motors were connected to the motor controller, it was observed that the combined motors ran much slower at full power. Thus, true system motor speed can only be determined by evaluating all motors at the same time. Unfortunately, the 12V power supply was not enough to power all four motors simultaneously.

After running into the issue with the power consumption of the motor controller, the team decided to use the Adafruit stackable motor controllers and utilize two controllers at the same time. This way, the two motor controllers can be powered separately and provide a more consistent power supply to the motors. The set up for the Adafruit motor controllers is the same as the SB components Motor shield, other than stacking the 40 pin groups of the controllers on top of one another. The stacked motor controllers had the added complication of unevenly distributing power to their corresponding motors. It was discovered that the motor controllers had a significant difference in motor speed for the same power percentage as shown in Figure 5. The cause of this discrepancy was not clear, but it was not within the scope of this project to determine the root cause.

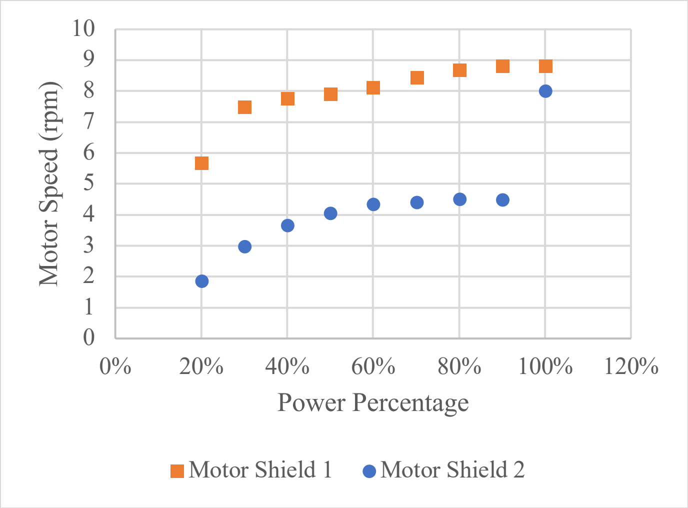


Figure 5*:* Comparative output of motor speed with respect to power percentage.

To have all four screws rotate at the same speed, the motor controllers must be run at differing power levels. The goal therefore was to find the combination of percentages that give motors from both controllers the same speed. Since Motor Shield 1 consistently had a higher speed, it was assigned a varying low power percentage while Motor Shield 2 was given a constant higher percentage. The point at which both motor controllers output the same motor speed was where Motor Shield 1 was run at 18% power while Motor Shield 2 was run at 100% power, shown in Figure 6. The resulting motor speed was about 4.75 rpm.

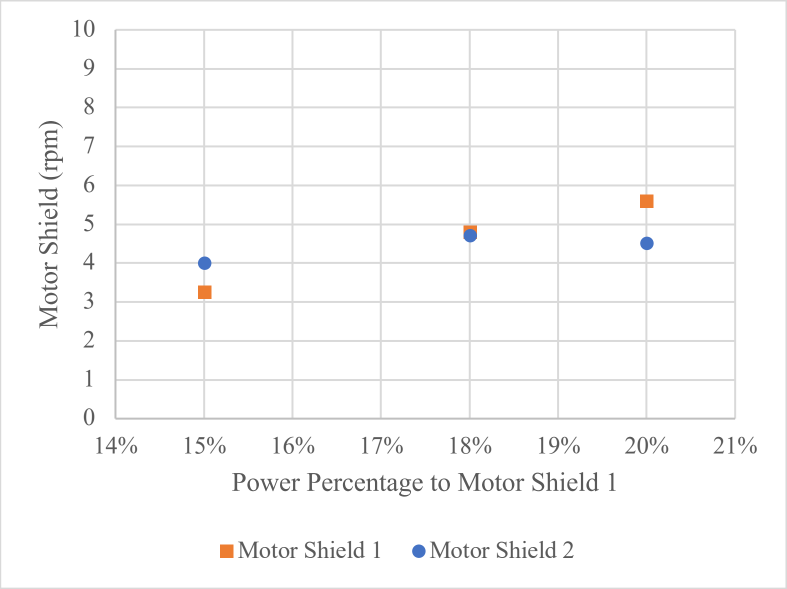


Figure 6: Output motor speed from both motor controllers with respect to power percentage. Motor shield 1 was given varied power while Motor shield 2 was held at a constant 100%.

Flow Test Plan

The flow test plan was achieved by connecting the screw conveyor into the test trough via the oil seal and bearing. It was ensured that the motor is coupled to the shaft of the screw and that the motor is mounted properly. The motor assembly was then connected to the Raspberry Pi controller and tested to ensure it is powered and functioning. Once the assembly of the test trough was completed, the system was filled with a specified amount of test fluid. This can be either full capacity or some value below that for each test that is performed. The initial volume of the test trough fluid was measured to run the motor at a set RPM. The fluid was collected as it reached the end of the trough, while timing the time it takes for the trough to empty. The time taken was recorded, and the volume collected of the gel. The test was repeated with various RPMs to calibrate the flow rate based on the RPM of the motor and screw assembly. The results of the testing can be seen in Table 2. The various RPMs are controlled by power control through the programming of the motor controller, found in the Electronics test plan.

Table 2: Flow rate Testing

Trials	Revolutions	RPM	Time	Collected Volume	Volumetric Flow Rate mL/min
1	2.5	0.8333	180s	50mL	16.6667
2	3	1.5	120s	40mL	20
3	4.75	2.375	120s	45mL	22.5
4	5	2.5	120s	60mL	30
5	5.75	2.875	120s	75mL	37.5

Total testing of the entire test stand, not of just the single test trough, can then be performed with the calibrated RPMs to see if the flow rate needs to be further adjusted.

The second phase of the flow test was the viscosity testing. The samples of the ultrasound gel were prepared to be used in the rotational rheometer ARES-G2. The ultrasound gel was prepared at various levels of aqueous solution with water, with different percentages/volumes of water added to the samples as shown in Table 3. As the gel is a shear thinning fluid, the viscosity values are provided at 4 different shear rates, 0.5, 1, 5, and 10 1/s. Figure 7 shows the results of the testing with the different ratios gel and water mixed together as a solution. This was done with increasing levels of water to dilute the gel to lower the viscosity as shown in the figure.

Table 3*:* Viscosity Testing

Samples	Volume of ultrasound gel (mL)	Volume of water (mL)	Percent Aqueous	Viscosity, 0.5 (1/s) Shear Rate (cP)	Viscosity, 1 (1/s) Shear Rate (cP)	Viscosity, 5 (1/s) Shear Rate (cP)	Viscosity, 10 (1/s) Shear Rate (cP)
Ultrasound gel	60	0	0%	94102.6	65292.2	28123.5	16707.4
High Range	60	7.5	11%	89669.4	60908.1	27762.6	17703.7
Middle Range	60	15	20%	91948.3	60382.5	25592.8	16113.1
Low Range	60	30	33.3%	60342.	41807.4	20122.8	13495.7

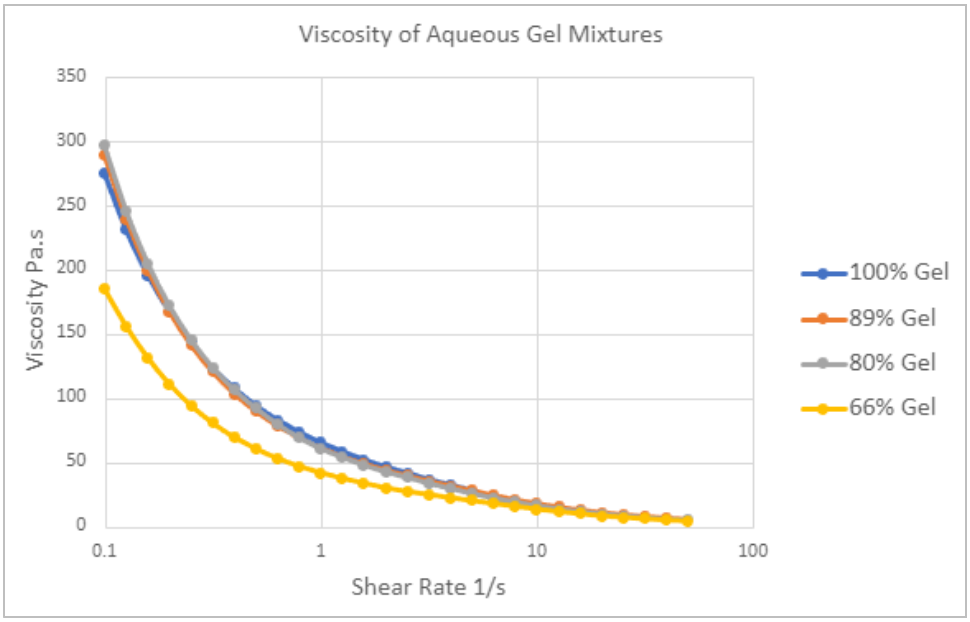


Figure 7*:* Viscosity of Aqueous Gel Mixtures

Trough Assembly

The trough base was manufactured at Mid America Steel. After receiving the trough, the trough holes and welds were buffed out. The four screws were cut to size and grinded down accordingly to ensure they did not contact the sides of the trough. The trough was then put onto the test stand and the trough holders were moved accordingly to properly support and level the trough. The end shaft bearings, motors, and couplers were attached to 3D printed mounts that were made by the Materials Team. Oil seals were put on each of the screws, and the screws were fitted into place in the trough and through the end shaft bearings into the couplers. The hanger bearing hole locations were marked, and the screws and trough were removed to drill the holes. The trough and screws were replaced onto the test stand, and the couplers were tightened against the screws and motors. The oil seals were then sealed into place with sealant, and the hanger bearings were slid onto each screw and attached with bolts and nuts, with the bolt on the inside of the trough. Acrylic was then cut down and sized to the trough. Holes were drilled into the top part of the trough lip, and foam tape was put down. The acrylic was then marked with the holes and drilled through. Bolts and nuts were used to attach the acrylic pieces to the trough, sealing the system. A ball valve was attached to the bottom of the system under the reservoir.

Ethical Consideration

The work presented in this report is accurate to the best of all project members' knowledge. Additionally, all ideas and work in this document are the original work of all members. All ethical obligations were followed throughout the project. Ethical obligations are stated as such.

Safety Consideration

All team members have been trained in the use and disposal of hazardous waste as in compliance with the NDSU safety office. All hazardous waste that will be used in this project will be labelled properly, stored in closed compatible containers in the proper place, and will be removed by the proper authorities no longer than 9 months after the start date. Due to the use of a viscous liquid in this project waste should be stored in jugs provided by the NDSU safety office. All team members have completed both the shop and the Auxiliary shop training.

The team made the design with the assumption that only experienced engineers will be operating the system. There are moving parts with this design, but they will be moving at a slow speed. Once the system is up and running, it will require little to no interaction from the operator except for monitoring of the speeds and flow rate as well as draining and replacing the fluid as necessary. In the event something goes wrong with the system, it can be shut off manually by cutting it off from the power. The Raspberry Pi will be monitoring the speeds of the motors and flow rate to allow for early intervention if something starts to go wrong.

Engineering Standards Used

The engineering required standard that will be used is ASME. The team will also be using the ASME engineering standards for handling hazardous materials, the welding and manufacturing standards. Additional standards that will be utilized in this project are related to testing.

Conclusions

In conclusion, despite delaying the final concept selection, the team was able to complete all the goals originally planned. A final concept design of screw conveyor was selected for pulling and pushing the fluids Ultrasound gel around the length of the trough. Due to insufficient trough system that fit our size range, the team decided to manufacture the trough system using the Aluminum sheet metal. The CFD analysis of the screw design was calculated using the mass flow rate at various speed, the results were obtained from the solution and displayed graphically, along with the obtained flow rate value at the outlet. The outlet flow rate slowed to 14.12 mL/min, only slightly deviating from the targeted value of 15mL/min, verifying that the viscous effects of the gel would not inhibit the flow to an unsatisfactory degree. The motors' abilities to rotate the screws blades depends on the power supply. When additional motors were connected to the motor controller, it was observed that the combined motors ran much slower at full power. Thus, true system motor speed can only be determined by evaluating all motors at the same time. Unfortunately, the 12V power supply was not enough to power all four motors simultaneously.

Recommendations

For future projects, the team would like to recommend frequent communication when speaking with the sponsor and determining the project constraints to prevent any delays in the project. This was a large obstacle for us that contributed to some delays in concept generation.

Acknowledgements

The team would like to thank Dr. Ali Amiri, Dr. Yildirim Suzen, and Dr Jessica Vold for their mentoring and guidance on this design project. A special thanks goes to Ben Moreno at Mid America Steel for manufacturing the troughs. We would also like to thank Dr. Ali Amiri for his guidance as the senior design coordinator. We also greatly appreciate the assistance of the NDSU Mechanical Engineering Department on this project. Finally, we would like to thank NASA for providing funding to this project.

Materials Team Detailed Design Documentation

Design Problem and Objectives

Through the X-Hab program mentioned above and NDSU's Design Project course for senior mechanical engineers, two student teams were tasked with designing and testing a liquid amine distribution and collection system used for atmosphere revitalization as well as a test stand for the system. Our team, the materials team is responsible for designing and building the test stand and securing the fluids team's design to the test stand. Our goal in designing the test stand is to fulfil our duties of properly securing and supporting the fluids team's design while staying within the engineering constraints given by NASA. The constraints given by NASA that are relevant to our team for the overall system are to:

- Not exceed 700 pounds (lighter than the current air revitalization system on the International Space Station)
- Not exceed a volume of 18.8 cubic feet (smaller than the current system on the ISS)
- Be able to operate in Mars gravity of 12.2 feet per second squared to simulate a Martian habitat
- Not exceed flammability requirements of 80%/20% oxygen/nitrogen at 5 pounds per square inch (NASA standards)
- Have a Factor of Safety of 3-4
- Have a design life of 4-5 years or greater

Some of the design constraints listed above have cost implications associated with them. To minimize our weight, we need to use lighter materials that still meet our strength needs. Commonly, a lighter material with high strength will be more expensive than a heavier material with a similar strength. Finding materials that meet the flammability requirements can also impact the overall cost.

After our project introduction and team formation we had a kickoff meeting with the NASA team in charge of our X-Hab project to get all our engineering constraints. Our given constraints are based on being smaller and lighter than the current air revitalization system on the International

Space Station. Our test stand must be able to hold up to 700 pounds and the fluids team's design must occupy less than 18.8 cubic feet. Since our design is dependent on what the fluids team designs, our process covered more general design features of our test stand until the fluids team finalized their design. After having problems in the conceptual design stage, the fluids team settled on a screw conveyor system. Following the final design changes made by the fluids team early in semester two, our test stand configuration was adjusted to accommodate their final system design. After performing finite element analysis (FEA) with the ANSYS program, our test stand components were shown to provide optimal support with deflection and stress values well within the design parameters. Through material and part sourcing and the manufacturing process, our test stand was completed and combined with the fluids team's system and equipment (Figure 8).

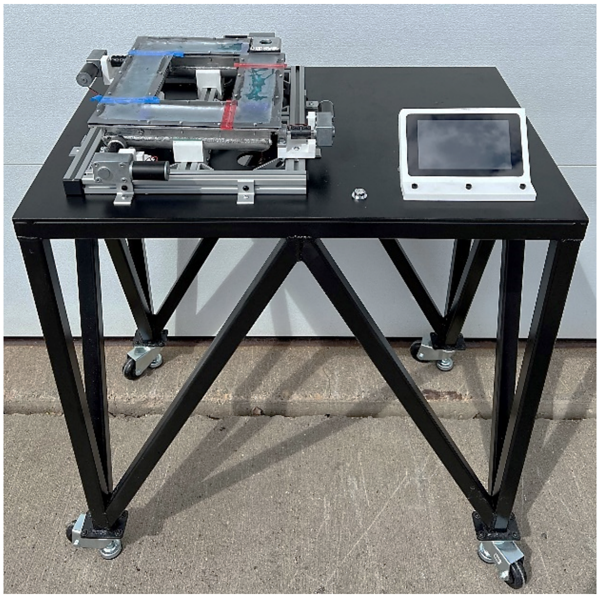
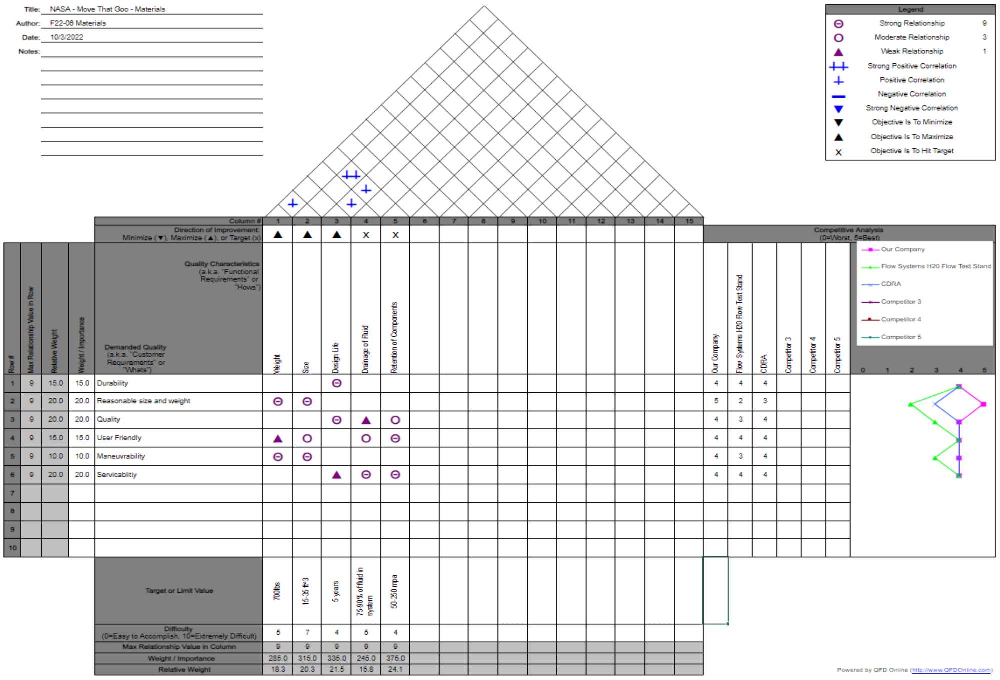


Figure 8: Final Product

Quality Function Deployment (QFD)

The first step in our design process was to develop our constraints by considering the customer requirements and the functional requirements. With the help of the QFD diagram shown in Figure 9 and the customer requirements we received during our kickoff meeting with NASA's X-Hab team, we developed our engineering constraints that would be used as the backbone for the rest of our designing process.



Title: NASA - Move That Goo - Materials
Author: F22-06 Materials
Date: 10/3/2022
Notes:

Legend		
⊖	Strong Relationship	9
○	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

Competitive Analysis (0=Worst, 5=Best)

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Our Company	Flow Systems H20 Flow Test Stand	CDRA	Competitor 3	Competitor 4	Competitor 5
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▲	▲	x	x																
				Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Weight	Size	Design Life	Drainage of Fluid	Retention of Components																
1	9	15.0	15.0	Durability			⊖													4	4	4			
2	9	20.0	20.0	Reasonable size and weight	⊖	⊖														5	2	3			
3	9	20.0	20.0	Quality			⊖	▲	○											4	3	4			
4	9	15.0	15.0	User Friendly	▲	○		○	⊖											4	4	4			
5	9	10.0	10.0	Maneuvrability	⊖	⊖														4	3	4			
6	9	20.0	20.0	Servicablitiy			▲	⊖	⊖											4	4	4			
7																									
8																									
9																									
10																									
				Target or Limit Value	700lbs	15-35 ft^3	5 years	75-90% of fluid in system	50-250 mpa																
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	5	7	4	5	4																
				Max Relationship Value in Column	9	9	9	9	9																
				Weight / Importance	285.0	315.0	335.0	245.0	375.0																
				Relative Weight	18.3	20.3	21.5	15.8	24.1																

Powered by QFD Online (http://www.QFDOnline.com)

Figure 9: Quality Function Deployment

Our function diagram was developed by both teams which broke down the main functions of our system. The functions in the diagram were split into fluids functions and materials functions. This diagram can be found in Appendix A-4. From our given functions, we were able to develop concept fragments that were put into a concept combination table shown in Table 4. From this combination table we were able to formulate multiple combined concepts that could be scored against one another.

Table 4: Concept Combination Table

Function	Fluid flows into manifold	CO2 absorbed	Fluid collected	Fluid goes to reservoir	Test stand
Sub Problem	Holding of the fluid distribution mechanism	Holding of channels	Holding of the fluid distribution mechanism	The fluid needs to be held in a reservoir, waiting to be pumped back into the system	Structure
Solutions	Rubber lined hose clamp	Slotted sections	Rubber lined hose clamp	Reservoir clip	Tube steel
	Open shelving area for free use (no tube fasteners)	Bolts and nuts	Open shelving area for free use (no tube fasteners)	Pull strap	80/20 aluminum track
	Integrated channels in clear plexiglass sheet (for the wall of the test stand)	Latching mechanism	Integrated channels in clear plexiglass sheet (for the wall of the test stand)	L-bracket hooking mechanism	Polymer composite
	Tube fasteners	Permanent connection (adhesive)	Tube fasteners	Latching mechanism	Tube aluminum

Concept Drawings

Without knowing anything about the fluids team's design (since they haven't designed anything yet) we ran into the problem of what our design would look like and the overall structure of it. Having all our design questions we asked our mentors for advice. Our mentors instructed us to design our test stand concepts with a black box as the fluids design. This gave us some general guidance to start drawing up possible designs. Although our designs might not have been anything close to a finished product, it allowed us to dial in on some key elements of our design. Figure 10 shown below are concepts drawn from each member of our group combining a row of concept fragments from the concept combination table.

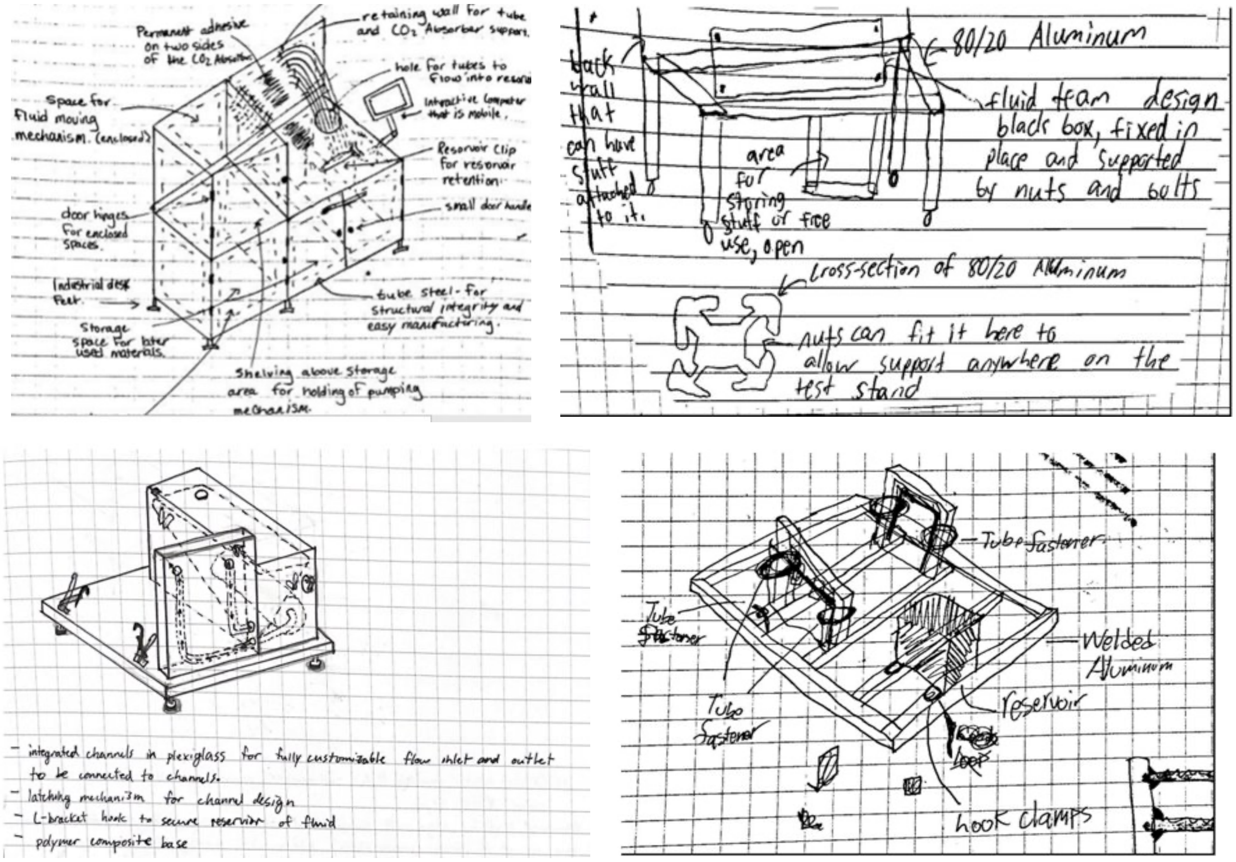


Figure 10: Concepts

Concept Screening/Scoring

After we had developed and drawn multiple concepts, it was time to screen and score the concepts. Shown in Table 5, we set our four main designs into the screening matrix and started our screening based on our selection criteria. After eliminating the concept shown in Figure 6 and combining the concepts shown in Figure 3 and Figure 4, we set the remaining three concepts into our scoring matrix shown in Table 6. From our scoring matrix, we decided to develop the combined design.

Table 5: Concept Screening

Screening Matrix	**Concepts**			
Selection Criteria	**1**	**2**	**3**	**4**
Durability	+	+	-	0

Reasonable Size and Weight	-	+	+	0
Quality	+	0	-	+
User Friendly	0	+	-	+
Maneuverability	0	+	-	-
Serviceability	-	0	+	0
Sum +s	2	4	2	2
Sum 0s	2	2	0	3
Sum -s	2	0	4	1
Net	0	4	-2	1
Rank	3	1	4	2
Continue?	**Yes**	**Yes**	**No**	**Combine with 2**

Table 6: Concept Scoring

		1		**2**		**2_4**	
		Tube Steel		**80/20**		**Combination**	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Weight	25%	2	0.5	4	1	4	1
Size	25%	3	0.75	3	0.75	4	1
Design Life	15%	3	0.45	4	0.6	4	0.6
Drainage of Fluid	10%	4	0.4	2	0.2	3	0.3
Retention of Components	25%	4	1	3	0.75	4	1
	Total Score	3.1		3.3		3.9	
	Rank	3		2		1	
	Continue?	**No**		**No**		**Develop**	

Semester I Design Decisions

With the basic factors of our concept selected, we were able to mature our design and start some basic CAD modeling of our test stand. Our team decided to use extruded aluminum from a company by the name of 80/20. We chose to use their materials due to their high strength, highly customizable aluminum structure system. With our main material chosen, we began CAD modeling a system, shown in Figure 11, that was able to hold a rough idea of what the fluids team was designing. Because the fluids design was not finalized, there were no structural calculations done to justify the design of our stand. After review, the fluids team decided that they were going to change their design to something completely different. Once the fluids team finalized their concept, our team was able to complete the first iteration of our final design, shown in Figure 12. Our first iteration of our design focused on the general placement of support beams and holding devices to properly secure the fluids team's design. Having done no structural calculations, our team performed finite element analysis (FEA) of the CAD model with a total assumed load of 1300 newtons distributed at multiple points using ANSYS. The results shown in Figure 13 suggested that more structural support was needed to reduce both the maximum deflection and the maximum principal stresses. Additionally, we decided to remove the upper section of the test stand because it provided little structural support and obstructed the working and observable area of our system.

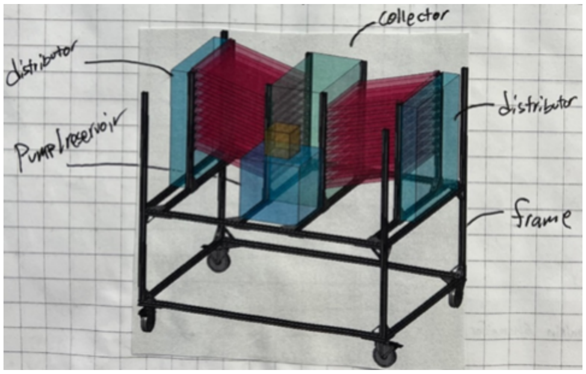


Figure 11: Initial CAD Model of System

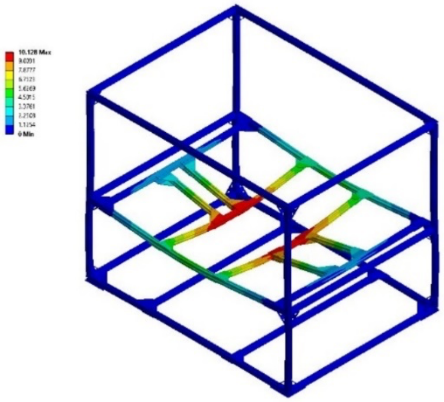


Figure 12: Final Design Iteration 1

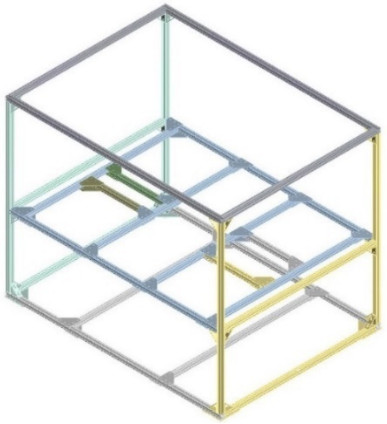


Figure 13: Final Design Iteration 1 FEA

Using some basic statics calculations, shown in Appendix A1, we redesigned our test stand to provide more support and greatly reduce the deflection and stress of the structural members. From those calculations and suggestions, our final design was modeled in CAD (Figure 8) and FEA was performed using the full weight and distribution of the fluids team's CAD model (Figure 14). The results from FEA showed a maximum deflection (0.49mm) within a reasonable range and a maximum stress of 56.53 MPa which gives our test stand a factor of safety of 4z32.

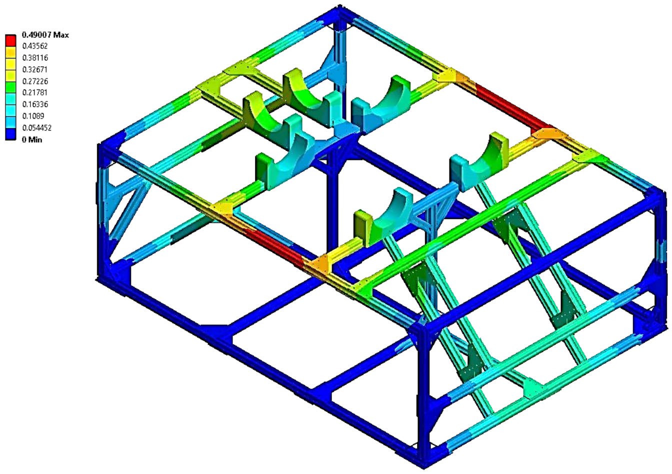


Figure 14: Final Design Iteration 2 FEA

Semester II Design Decisions

Following the first semester design decisions and communications with NASA, the fluids team made the entire system much smaller, which led to another entire design change for the team. The team had selected tube steel as the main material that would support the fluids team's design. Along with the tube steel, an 8020 subassembly was designed to hold the fluid moving system as it had great adjustability considering the dimension tolerances needed to be met. To ensure no movement took place, the team designed 3D printed motor mounts, display holder, and trough supports. FEA was conducted to ensure that the test stand was able to hold the fluid system efficiently. The final load of the fluids team's design was determined to be about 40lbs. From the analysis, the total deformation was calculated as $1.63\text{x}10^{-002}$mm. The maximum equivalent stress was calculated as 0.929MPa. The factor of safety for the test stand was determined as 200, which proved that the system was slightly structurally overdesigned. Figure 15 provides a visual representation of the analysis performed on final design iteration 3.

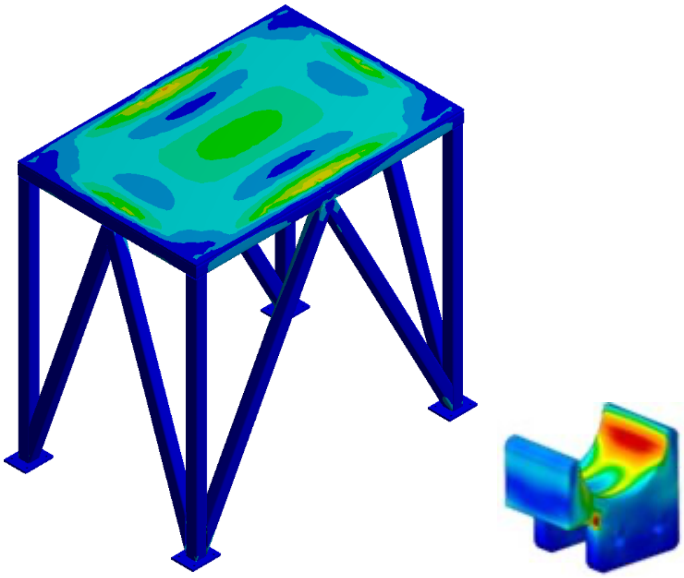


Figure 15: Final Design Iteration 3 FEA

Manufacturing

Once all the materials and sourced parts were received and 3D printing was completed, the manufacturing process could begin. All the pre-cut tube steel was set in order to make sure all components were close to the desired geometries, and the plate steel was water jetted to form the tabletop with desired holes. Next, the steel parts were welded to the tabletop including the legs, braces, and caster plates, as designed. As this process took place, other team members assembled the precut 80/20 aluminum system and attached the 3D printed motor mounts and trough holders. After welding was completed, the table was wiped down to remove excess debris and oil from the metal surface, and the table was spray-painted gloss black. After the table finished drying, the leveling casters, 80/20 system, 3D printed display holder, and bubble level were attached by bolts or screws, completing the manufacturing process. The welding, 80/20 system assembly, and painting processes can be seen in Figure 16.

Figure 16: Welding, 80/20 System Assembly, and Painting

Ethical Consideration

Although our team and its members are not graduated and certified mechanical engineers, we still believe it is our duty for every member to follow the National Society of Professional Engineers' Code of Ethics for Engineers (Code of ethics) while doing any engineering work (including this project). Using this code of ethics, we ensured that our design has a high factor of safety to prevent structural failure and possible injury to those in proximity to the test stand.

Safety Considerations

Due to the use of fluids in the screw conveyor system that is not completely sealed, our test stand was designed to have leveling casters that have rubber feet to provide a stable, level, stationary experimental surface for system operation.

Conclusions

As the first semester came to an end, we were able to successfully design a test stand that can safely secure and support the fluids team's design. With our design process being limited by the progress of the fluids team, we noticed that there was a large amount of confusion and a wide range of conceptual designs generated. Once the fluids team had finalized their design, we were able to make quick progress with our final design iterations. There was quite a steep learning curve for ANSYS, and we had some trouble analyzing our test stand but managed to figure it out on time. Our final test stand design properly holds and supports the fluids team's design, and we are all happy with the way it looks and functions.

Acknowledgements

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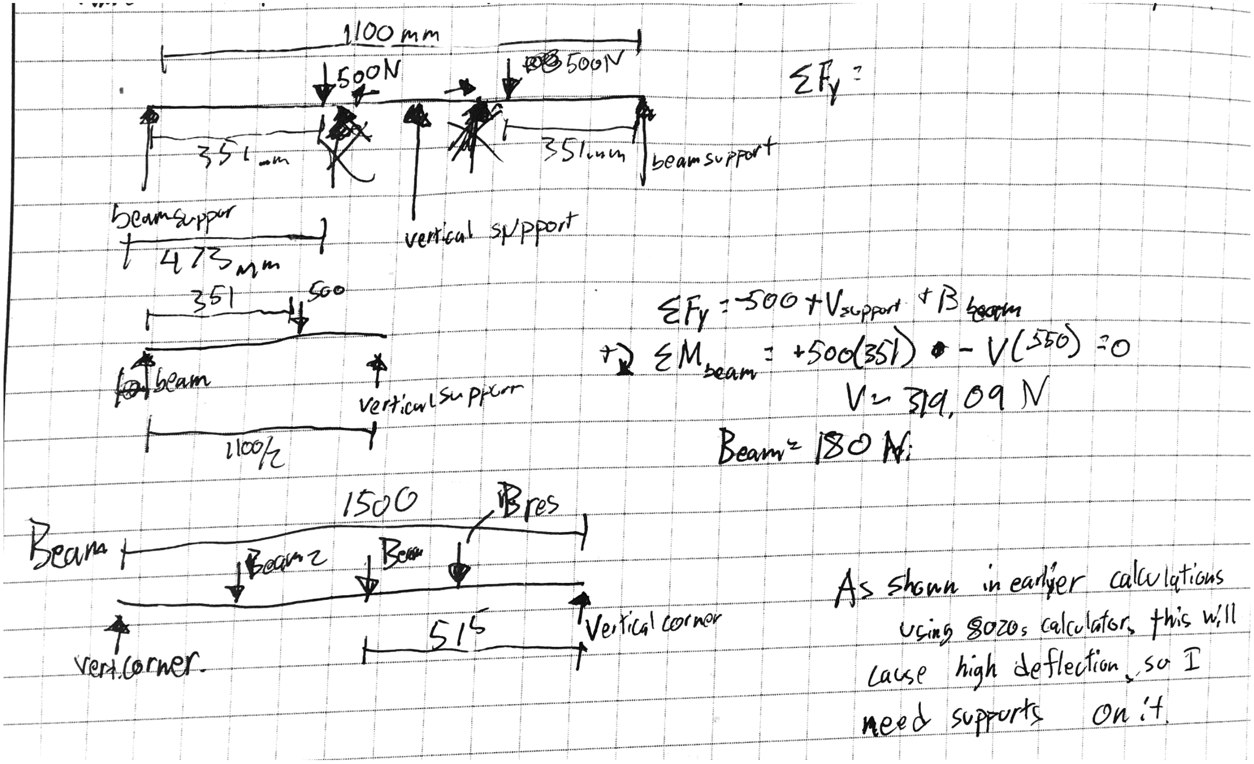
Appendix

A1 – Math Justifying Supports



$\Sigma F_y =$

$\Sigma F_y = -500 + V_{support} + B_{beam}$

$\circlearrowright + \ \Sigma M_{beam} = +500(351) - V(550) = 0$

$V = 319.09\ N$

Beam = 180 N

As shown in earlier calculations using 8020s calculator, this will cause high deflection, so I need supports on it.

A2 – Function Diagram