Concept Generation

Introduction

Upon hearing a problem statement, the primary instinct of engineers is to latch onto the first idea that comes to mind. While the idea may have merit, this style of automatic thought holds the potential for inherent bias and misunderstanding of the project brief. As the project scope narrows, unknown variables or goals may become apparent, and this first idea may no longer meet the new requirements. To help break out of this habit, engineers must take time to brainstorm potential solutions that not only solve the issue but also do so in a way that satisfies design requirements. While at first daunting, this process can shed light on potential solutions that weren't previously thought possible. As well, it helps the engineer break from habit and develop a creative muscle that some in the field lack.

For Team 517, this process is relayed in the following sections. Through a series of brainstorming techniques and thought experiments, the team developed 100 potential concepts for the thrust stand. They range from high fidelity to quite outlandish, but the point of this exercise was to force the team to think outside the box and outline different methods of meeting design requirements.

Concept Generation Techniques

Brainstorming is a practice everyone engages in from an early age. Whether to solve a brain teaser or navigate social situations, people are inherently curious and seek solutions. In the engineering field, concept generation is done both intuitively and iteratively. As mentioned previously, automatic, surface-level thinking engages people's instincts and guides them to immediate conclusions about a problem. While this may result in internal bias, it also retains the benefit of being quick and effective at solving a range of problems. This technique is primarily reminiscent of the crapshoot method where a team gets together and begins throwing ideas together. Some resultant ideas may be lackluster, but others may help shed light on previously hidden problem characteristics.

This method, among others, was employed by Team 517 to help generate 100 thrust stand concepts. In conjunction, a morphological chart was developed to field a large field of potential ideas. Team 517 also took inspiration from nature, using biomimicry to generate ideas. Lastly, the anti-problem method was employed to shed light on potential pitfalls the team should avoid. These methods are outlined further below, and a full set of 100 concepts are shown in the appendix.

Morphological Chart

Team 517 generated a broad set of functions the stand should achieve in a previous section of this evidence manual. Taking from these, the team developed a morphological chart, outlining potential solutions or systems that could satisfy these functionalities. With assistance from a ChatGPT conversation (OpenAI, 2024), solutions to core functionalities were investigated and assembled into a morphological chart below.

Table 5: Morphological Chart for Green Propellant Thrust Stand

Morphological Chart	Functions			
	Accurately Measure Thrust	Accurately Measure Temperature	Made of Easily Accessible Materials	Calibrates in a Vacuum
Solutions	Piezoelectric Sensor	Thermocouple	Aluminum	Software Calibration
	Capacitive Force Sensor	Thermistor	Stainless Steel	Remote Calibration Equipment
	Strain Gauge Load Cells	Resistance Temperature Detector	Composite Materials	Wireless Communication Protocols
	MEMS-Based Force Sensors	Infrared Sensor	Ceramic Materials	Smart Sensor Technologies
	Optical Force Sensors	Solid-State Sensor	Plastic Materials	Data Fusion Techniques
	Flow Sensors	Fiber Optic Temperature Sensors		
	Functions			
	Easily Cleanable	Microcontroller accounts for error	Thruster Orientation	Generic Stand Type
	Smooth, Non-Porous Materials	Error Correcting Codes	Vertically Mounted	Horizontal Stand
	Modular Design	Sensor Fusion Techniques	Horizontally Mounted	Vertical Stand
	Protective Coatings	Feedback Control Systems		Seesaw Stand
	Drainage Features	Data Validation Techniques		Torsional Thrust Stand
		Checksum and Cyclic Redundancy Check		Beam Deflection Stand
				Electromagnetic Balance Stand

In the morphological chart above, seven different functions were investigated. In conjunction, the discussion with ChatGPT (OpenAI, 2024) utilized to generate a set of generic thrust stand types. While these vary in cost, benefits, and application, the team thought it necessary to keep an open mind on what kinds of stands currently exist and so listed some that may not fit the budget or scope of this project. Some of the functions are worded slightly different than their counterparts in the Functional Decomposition section of the evidence book for clarity's sake. Between the methods discussed, this strategy was the primary source of ideation for the team. Below is a brief list of a few concepts generated using this method, while the rest are listed in the overall concept chart in the appendix.

Table 6: Concepts Generated from Morphological Chart

Concept (#)	Description
41	A vertically mounted thrust stand made of aluminum with modular components utilizes MEMS-based force sensors for precise thrust measurement, complemented by infrared temperature sensing and data validation techniques to ensure accuracy by minimizing errors.
42	The thrust stand utilizes Optical Force Sensors to accurately measure thrust on a vertically mounted setup while monitoring temperature with an infrared sensor. Constructed from stainless steel with smooth edges, it features wireless calibration and feedback control systems to minimize errors in measurements.
44	The thrust stand, constructed from ceramic materials, utilizes a piezoelectric sensor to measure force applied vertically and features drainage capabilities. An infrared sensor monitors temperature, while remote equipment calibrates the system, employing feedback control to correct any errors.
45	Capacitive force sensor measures thrust on a see-saw stand, recording temperature with a solid-state sensor. The stand is made of plastic materials with protective coatings, calibrating with software and using data validation techniques to account for error.

The concepts listed above are shown more so as a proof of concept for using the morphological chart. They aren't necessarily the most important, and the other ones generated in the appendix table demonstrate the same style of concept generating technique. For this process, the team also employed ChatGPT (OpenAI, 2024) to formulate morphological chart concepts into sentence format so they would read better. This idea is reflected in the table above and in the concepts chart present in the appendix.

Anti-Problem

Team 517 used anti-problem to help with ideation. This process involved having the team solve problems about a thrust stand that were the opposite of the problems that the team currently faces. By doing this, it allows the team to look at the project from a completely different perspective, and as ideas are thought of for the opposite problem, connections can be made to the present design problem and reveal new ideas. The table below shows an anti-problem that was brought up, and the ideated solutions for it. Taking the anti-problem solutions and thinking about how they can apply to the original design revealed unique ideas for measuring thrust.

Table 7: Anti-Problem Example for Green Propellant Thrust Stand

Anti-Problem	
Anti-Problem Statement:	**We want to make the thrust measurement as inaccurate as possible.**
Solutions:	**Characteristics:**
Mount the thruster at a 45° angle	Thruster Mounting Angle
Don't mount the thruster at all	Thrust mount
Pick the most inaccurate thrust sensor	Thrust Sensor Selection
Increase vibrations across the stand	Balance and Weight Distribution
Increase torque exerted on the thruster from fluid lines	Rigid Fluid Lines
Make sure the thruster and instrumentation are invisible from the view ports	Thrust Stand Orientation
Make the thrust stand as heavy as possible	Stand Weight
Make sure the thrust sensor is mounted at an angle	Thrust Sensor Mounting Angle
Don't calibrate the thrust sensor before firing the thruster	Sensor Communication

Anti-Problem	
Anti-Problem Statement:	**Make the propellant residue as messy as possible and spray all over the vacuum chamber.**
Solutions:	**Characteristics:**
Take out the flame bucket	flame bucket position
vertically mount the thruster downward so the plume sprays upwards	thruster mounting position
make a reverse flame bucket that helps spread the plume out	flame bucket geometry
increase thrust to increase plume and excretion	thruster magnitude

Table 8: Concepts Generated from Anti-Problem Method

Concept (#)	Description
7	A problem with the thrusters is keeping them in one place as they fire. The anti-problem to this statement is to instead embrace this movement and have the thruster fire in a single axis direction, measuring thrust based on velocity and distance travelled.
9	Relying on the flame bucket, measure the amount of propellant residue left over after firing and calculate thrust based on mass flow rate and time fired.
18	Piezoelectric sensor directly under the thruster mount

Crap Shoot

The crapshoot method is a very broad method of ideation. By essentially going on ramblings about different topics and possible ideas for design, fully fleshed ideas can be formed by the breadcrumbs of conversation done during crapshoot. Crapshoot method can bring in creativity from any source by allowing the team to go on tangent about anything, so long as they strive to bring the conversation back to thrust stand designs in some way.

Table 9: Concepts Generated from Crap Shoot Method

Concept (#)	Description
6	The idea of water displacement was mentioned, which gave rise to the idea of a thrust stand that measures force based on the displacement of a liquid in a defined amount of time. This would give a mass flow rate that can be used with velocity to calculate force.
13	While talking about outside work and projects that team members do outside of school. Hardness testing was brought up and it was considered to measure force. By placing a pointed tip on the thruster and using known materials, a type of hardness testing can be performed where the measurement of interest is instead the force applied to a material with a known hardness.
8	At some point in the ideation discussion, it was mentioned that ideas were 'butting heads' with each other. This caused the idea to fire 2 thrusters against each other, with 2 known but different velocities. Thrust can be measured based on the direction and magnitude of displacement.
11	While talking about car racing, the track design and centrifugal force involved in these races led the team to ideate a thrust stand design that allows the thruster to fire in a circular track and measure thrust based on its travel around the track and the speed at which it travels.

Biomimicry

Another concept generation tool used was biomimicry, which helped develop concepts #96, #97 and #99. Ideas inspired by biomimicry come from animals and their functions, such as muscles in the human arm and the pressure change in pufferfish. These ideas generated using biomimicry utilized unique traits and abilities of animals to aid in the design for measuring thrust in a thrust stand.

Table 10: Concepts Generated from Biomimicry Method

Concept (#)	Description
96	The idea of using some sort of thrust measurement that mimics the human arm and bicep, where thrust generates upward lift near the “hand”, and moves upward as if flexing the bicep. A strain gauge would be located on the “bicep” area of the arm to measure the force caused by the thruster.
97	The idea of using some sort of thrust measurement that mimics the human arm and triceps, similar to the human arm and bicep idea. Thrust generating near the hand area would be measured by the strain gauge on the “triceps” area of the arm. The advantage and difference that this idea has over the bicep concept is that no movement is required to measure thrust, while the bicep arm concept requires movement, like mimicking flexing a bicep. When flexing the human triceps, much lower movement is required to feel a flex, being an advantage in designing a lower range of motion for the thruster setup.

99	Thinking of a pufferfish that expands and deflates, a thruster fires into an inflated bag, and the pressure change is measured in the volume of the inflatable bag to measure the thrust.

Medium Fidelity Concepts

While generating concepts is good creative practice, the real mental test occurs when a design team must narrow them down to more promising solutions. For Team 517, this derivation process occurred in a team meeting where potential solutions for critical functionalities were combined and analyzed together. As the morphological chart already outlined these functions, the team utilized this tool to generate higher fidelity concepts. In this section, medium fidelity solutions for the thrust stand are outlined in the table below. These solutions cover most of the critical functionalities but may lack in certain aspects when compared to higher fidelity concepts. These differences are primarily outlined by current MSFC thrust stand conventions and how compatible the function solutions are with one another.

As a note, these concepts may not explicitly match their counterparts in the complete appendix chart. These descriptions are a bit more fleshed out and detailed. This was done primarily to save space in the appendix section.

Table 11: Outlined Medium Fidelity Concepts

Concept Name and Number (#)	Detailed Outline
33	This thrust stand design would be a vertical stand mounted in the vertical direction. To ensure there is no corrosion or wear of the stand, it would be made of stainless steel. The design would also be made with smoothed edges and a drainage system to encourage easy cleaning with water. The measurements taken would be checked for errors using a data validation and error correction code. Measurement tools would be wired to a computer for acquisition.
34	This stand would employ a piezoelectric force sensor to measure thrust and a thermistor to gauge the plume temperature. Vertically mounted, the thruster would fire into the piezo, compressing the sensor to generate an output voltage. Made of composite materials, the stand would also be wirelessly calibrated and feature error correction codes and data validation methods to account for sensor error. To assist with cleanliness, this stand would also feature a modular design and drainage surfaces to redirect water away from the stand.
35	A vertically mounted thrust stand that works using a see saw mechanical system in the vertically mounted direction. When the thruster is fired, force would be diverted through the see-saw to a strain gauge load cell for measurement. Temperature measurement would be positioned in the plume region using a type k thermocouple. The thrust

	stand would be made of composite metal, which is inexpensive and could be tailored to be light weight. Sensors would feed through the vacuum to a computer, where error computation would be done through error correction coding and data validation. To keep the stand clean, a protective coating would be put over the composite metal that could endure the propellant spray and resist corrosion. Cleaning would also be made possible through a modular design, so individual pieces could be cleaned in detail.
36	To diversify solutions, this torsional thrust stand would feature horizontal mounting to measure the torque and thrust produced by the thruster. Thrust would be measured using a capacitive force sensor and thruster temperature monitored by an infrared sensor. For material selection, this stand would feature a stainless-steel construction to account for current corrosion problems associated with aluminum and ASCENT. For calibration purposes, the stand would feature wireless communication protocols. The microcontroller would account for errors using data validation techniques and error correction codes. In terms of cleanliness, a modular design and non-porous surfaces would be employed.
37	Making a thrust stand out of stainless steel to keep light weight and stop corrosion. Further cleanliness can be accomplished by smoothing the edges of the stand and adding drainage grooves to help with water

	cleaning. Force would be measured using a strain gauge load cell, and firing would occur in the horizontal position, making the thrust stand horizontally mounted. Temperature reading would be gathered by a thermistor, which could feed data wirelessly along with other sensors to a computer outside the vacuum. The data collected would be validated and run through an error correction code.

High Fidelity Concepts

Using the same method, high fidelity solutions for the thrust stand were generated and are outlined below. Based mostly on intuition and background knowledge, the team believes that these concepts hold the best chance of not only achieving critical targets/functionalities but also configuring together function solutions.

As a note, these concepts may not explicitly match their counterparts in the complete appendix chart. These descriptions are more fleshed out and detailed. This was done primarily to save space in the appendix section.

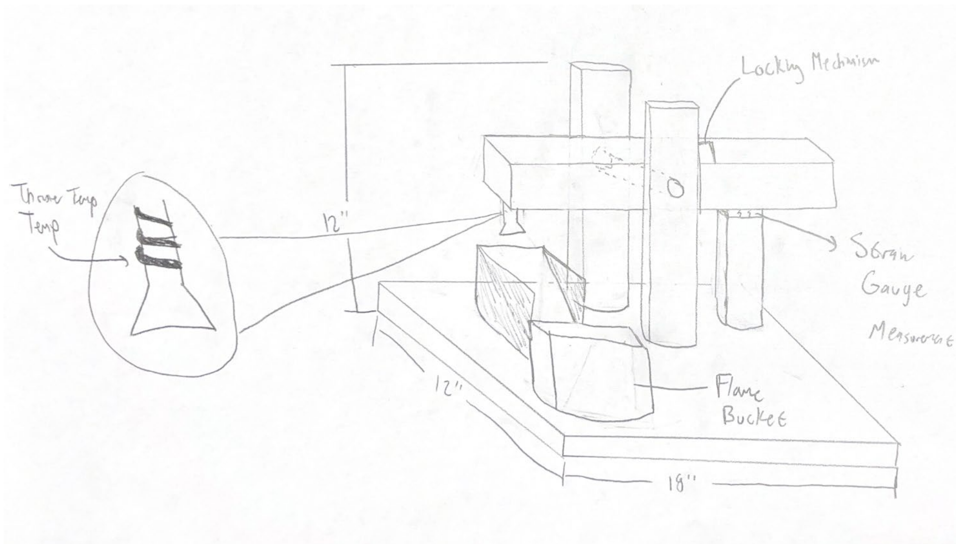
Table 11: Outlined High Fidelity Concepts

Concept Name and Number (#)	Detailed Outline

30	This thrust stand measures thrust with strain gauge load cells and monitors temperature using a thermocouple, all constructed from stainless steel with smooth, non-porous surfaces. It features a modular design with drainage capabilities and calibrates through wireless communication protocols. To ensure accuracy, the system employs error-correcting codes, feedback control systems, and data validation, mounted vertically on a seesaw stand for precise measurements.
31	This thrust stand measures thrust with a piezoelectric force sensor and monitors temperature using a thermocouple, all constructed from stainless steel with smooth, non-porous surfaces. It features a modular design with drainage capabilities and calibrates through wireless communication protocols. To ensure accuracy, the system employs error-correcting codes, feedback control systems, and data validation, mounted vertically on a seesaw stand for precise measurements.
32	Thrust stand measuring thrust with strain gauge load cells and monitoring temperature using a thermocouple, constructed with a mix of stainless steel and aluminum with protective coatings. It features a modular design with drainage capabilities and calibrates through wireless communication protocols. The system uses error-correcting codes, data fusion, and data validation, and is mounted vertically on a seesaw stand for precise measurements.

Concept 30 (HF)

Figure: Concept 30 Conceptual Rendering



Concept 30 is a high-fidelity concept developed from the Morphological Chart in Table 5. This thrust stand is made of stainless steel in order to prevent corrosion from the propellant used in the thruster, ASCENT. Stainless Steel also provides the design with a properties that will resist the high temperatures that the thruster will output.

The thrust stand is in a vertical orientation, in a see-saw configuration. While firing downward, the arm in this configuration will rotate about an axis fixated between two towers and will push into a strain-gauge load cell set up to measure the thrust that is exerted. A locking mechanism that is made from the structure will be present in order to keep the arm horizontal, so that when no thrust is generated, the arm of the see-saw configuration will not rotate away from the strain gauge. The structure of the stand will feature a flame bucket that will divert flow into an area to move heat away from other components like sensors and fluid lines. Modular design will exist that will allow parts of the stand to be interchangeable, allowing for adaptability for

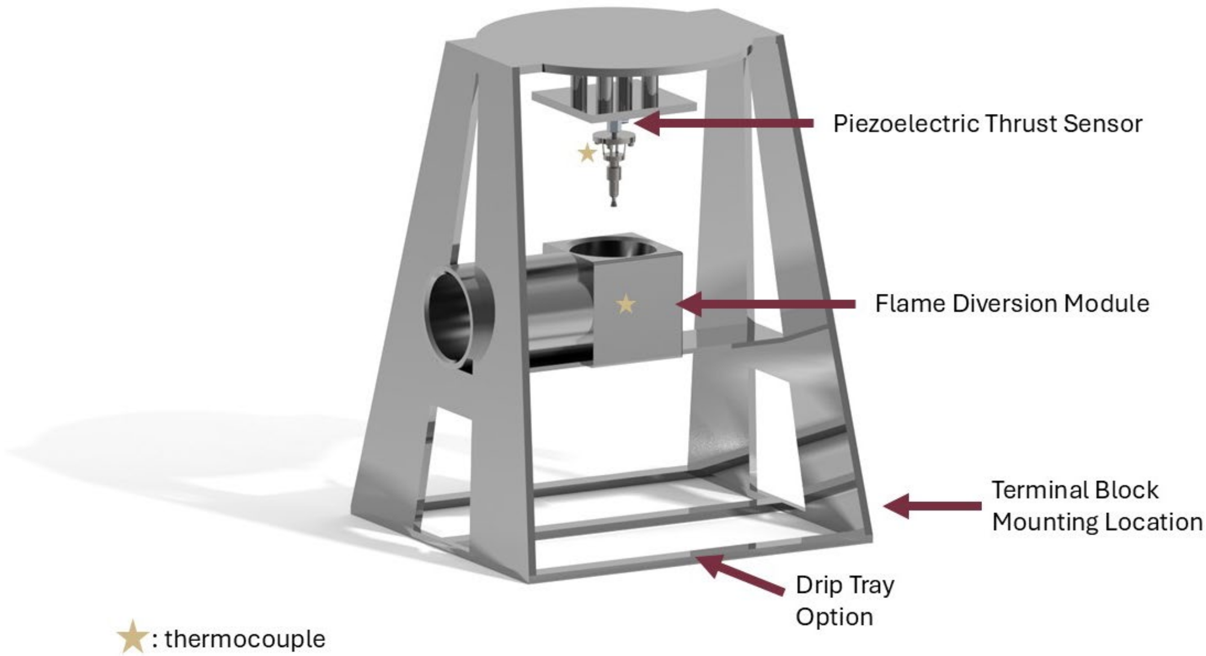
0.1mN to 5N thruster components. Drainage features will allow leaked propellant and water during cleaning to be removed from the stand easily, promoting cleanliness.

A thermocouple will be used to measure the temperature of the thruster and the plume temperature in order to withstand high temperatures and also be able to accurately record the temperature range required.

Calibration will occur wirelessly in order to remotely calibrate the thrust stand. For accuracy, error correcting codes that can account for uncertainty will be used, as well as feedback control systems that reiterate to create more accurate data, and data validation to confirm accurate data.

Concept 31 (HF)

Figure: Concept 31 Conceptual Rendering



Concept 31 is a high-fidelity concept derived from the morphological chart, shown in Table 5. It is a vertically mounted, stainless steel, modular thrust stand with an optional drip tray in case of drainage. Vertical mounting reduces potential external forces and fully utilizes the additional height allowed by the volumetric constraint. Stainless steel construction allows for high heat exposure with low risk of deformation. It is also chemically compatible with ASCENT, the thruster propellant, to prevent corrosion in case of leakage. The system is modular to allow for deep cleaning and makes the setup and breakdown of the stand easier by allowing different parts of the stand to be detachable and carried in/out of the vacuum chamber separately.

The thrust stand utilizes a flame diversion module to direct the flame produced by the thrust into the open volume to the left of the thrust stand, shown in the figure above. This module has an embedded thermocouple for measuring the plume temperature of the flame before the directional influence. The thermocouple can be easily disconnected from the terminal block and is also able to be removed and replaced within the module. The stand has an additional removable thermocouple mounted directly above the thruster which also interfaces with the terminal block.

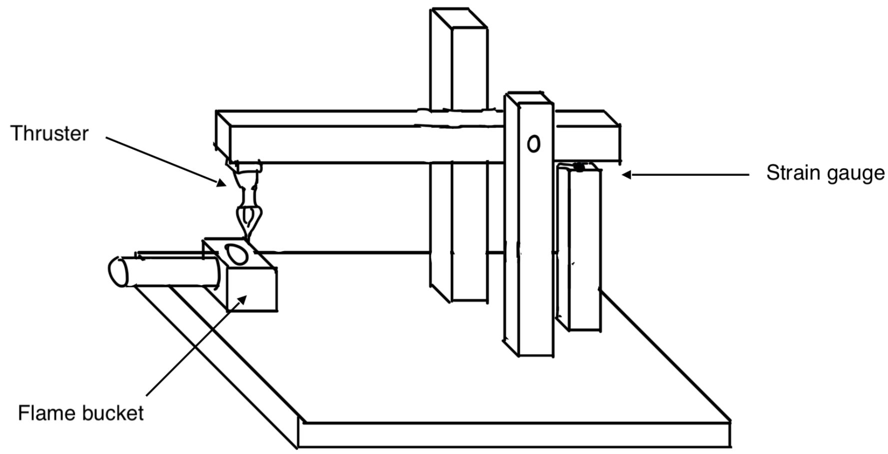
To measure thrust, a piezoelectric thrust sensor is used to directly interpret force into a readable voltage. The conceptual rendering, shown above, is based on a Model 209C02 Miniature ICP® force sensor in an integrated link configuration which measures force along the z-axis in both directions. An insulator is placed within this linkage to mitigate conductive heat transfer directly to the sensor. This is especially beneficial for calibration as it accounts for the reference force present due to gravity's effect of the thruster's mass.

The calibration of the thrust stand occurs remotely via a detachable wired connection from the terminal block. The connection wire passes through an airtight access in the vacuum chamber and interfaces with a microcontroller-driven processing unit for data collection and processing. The calibration is initiated on the processing unit by direct user input.

Data processing onboard the microcontroller contains a feedback control system which calculates the overall error as well as the differential between theoretical expectations and the raw data values. The raw data along with error and data validation metrics are stored by the microcontroller on an accessible drive for direct use by the research team conducting the test.

Concept 32 (HF)

Figure: Concept 32 Conceptual Rendering



Concept 32 is a high-fidelity concept derived from the morphological chart shown in Table 5. It will be a modular design constructed from a mix of stainless steel and aluminum with protective coatings and drainage features for easy cleaning. The stand will be vertically oriented with thrust firing downward in a seesaw-like configuration. The thruster will fire into the pivot arm, applying force downward on the other end of the arm into a strain gauge sensor, effectively measuring thrust. Parts that will encounter the propellant, ASCENT, will be made of stainless steel and will allow for high-heat exposure and corrosion resistance. Other parts will be constructed from aluminum for cost and weight efficiency. The modularity will allow for deep cleaning as well as making assembling and dismantling the stand easier.

The thrust stand utilizes a flame diversion module to direct the flame produced by the thrust at a 90-degree angle into the open volume to the left of the thrust stand, shown in the figure above. This module has an embedded thermocouple for measuring the plume temperature of the flame before the directional influence. The thermocouple can be easily disconnected from the terminal block and is also able to be removed and replaced within the module. The stand has an additional removable thermocouple mounted directly above the thruster which also interfaces with the terminal block.

To measure thrust, strain gauge load cells will be used. Deformation caused by the lever arm pushing down on the strain gauge from the thrust will give the thrust measurements. The calibration of the thrust stand occurs remotely via a wireless connection from the terminal block and a controller handled by the user. The calibration is initiated on the controller by direct user input.

Data processing on the microcontroller contains a sensor fusion technique which combines data from multiple sensors to create a single data point that is more accurate and reliable than what could be achieved using any one sensor alone. The raw data along with error and data validation metrics are stored by the microcontroller on an accessible drive for direct use by the research team conducting the test.

Conclusion

Concept generation serves as a classic exercise in brainstorming and can highlight potential solutions previously unthought of. For Team 517, this process primarily involved the use of a morphological chart to generate a variety of solutions directly tied to core functionalities. While this process is repetitive by nature, it helped highlight how potential solutions may impact one another. Resultant concepts ranged from potentially useless to promising solutions. These more enticing ideas will serve as the basis for concept selection.