1.3 Functional Decomposition

Introduction

Prior to the development of a product, understanding the full scope of its intended functionalities is paramount to maintaining project directionality and mitigating extra work. From a systems engineering approach, this is best accomplished via the completion of a functional decomposition of the product. This process involves relating the needs of a customer into a functional hierarchy chart that demonstrates how various systems and their functionalities interact. While this flow chart provides a great visual, another crucial component lies in the creation of a cross-reference table. Providing a more implicit comparison, this table demonstrates how various functions can impact multiple systems and vice versa. In short, a functional decomposition assists the developer in defining what systems are needed and how their functionalities interact with one another.

Data Generation

As discussed previously, the intended functionalities of the product are defined by the interpreted needs of the customer. For Team 517, these needs were gathered during meetings with their sponsors from MSFC. During the first meeting, the sponsors provided specific key goals for the thrust stand and discussed how it needed to interface with their current vacuum chamber setup. In conjunction, Team 517 prepared various questions for the meeting, namely what improvements the sponsors would want to see when compared to previous iterations. From this meeting and notes provided by MSFC, the team gathered the basic system architecture for the thrust stand. During the second meeting, Team 517 brought more specific questions regarding sensors, accuracy issues, and funding to the sponsors. In a similar manner, the team at MSFC provided greater clarification and thruster visuals that helped Team 517 develop a better understanding of lower-level functionalities for the stand. This guidance combined with detailed meeting notes from MSFC provided the rest of the necessary information to complete the hierarchy chart.

Graphics Introduction

For the thrust stand, a functional hierarchy/flow chart (Fig. 1) was completed to demonstrate the breakdown from major systems to individual functionality. Beyond this, the hierarchy chart creates a modular perspective of the stand, helping to limit the scope of individual systems. It also assists in engaging individual team members' strengths as they can apply their skills to the stand's subsystems. Below, Team 517 has broken up the stand's hierarchy chart into its main subsystem levels (Figs. 2 - 4) to provide a better visual.

Also, a cross-reference functional decomposition table (Table 2) was constructed to show how functions and systems relate. Moving down the columns shows what functions are incorporated into each system, offering a more concise vision for how the systems will operate. Each row demonstrates the integration of functions into various systems. Compared to the hierarchy chart, functional integration is best represented by the table since the flow chart establishes each function under only one subsystem.

Functional Decomposition Gathering and Functional Relation Overview

Figure 1: Green Propellant Thrust Stand Functional Hierarchy Chart

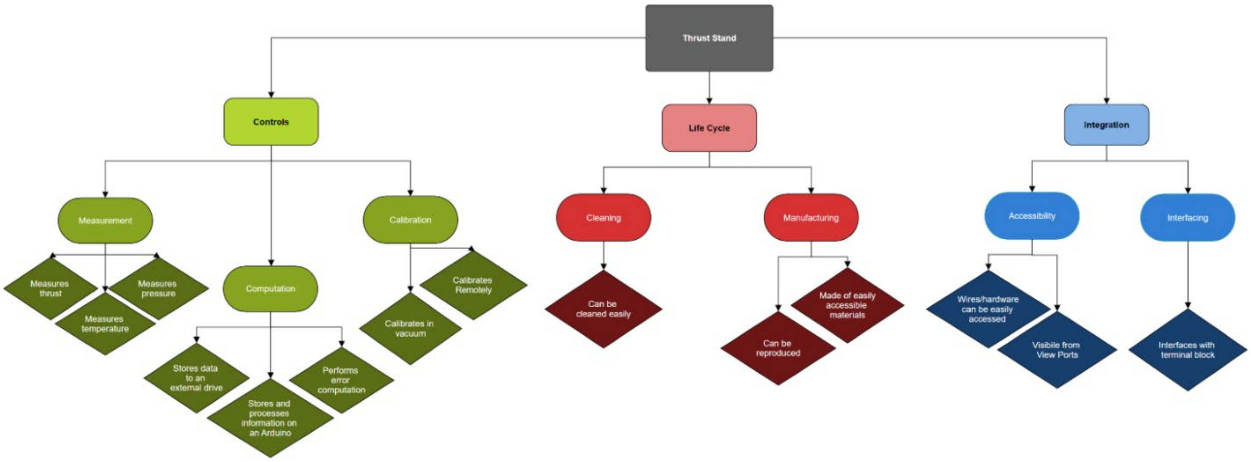
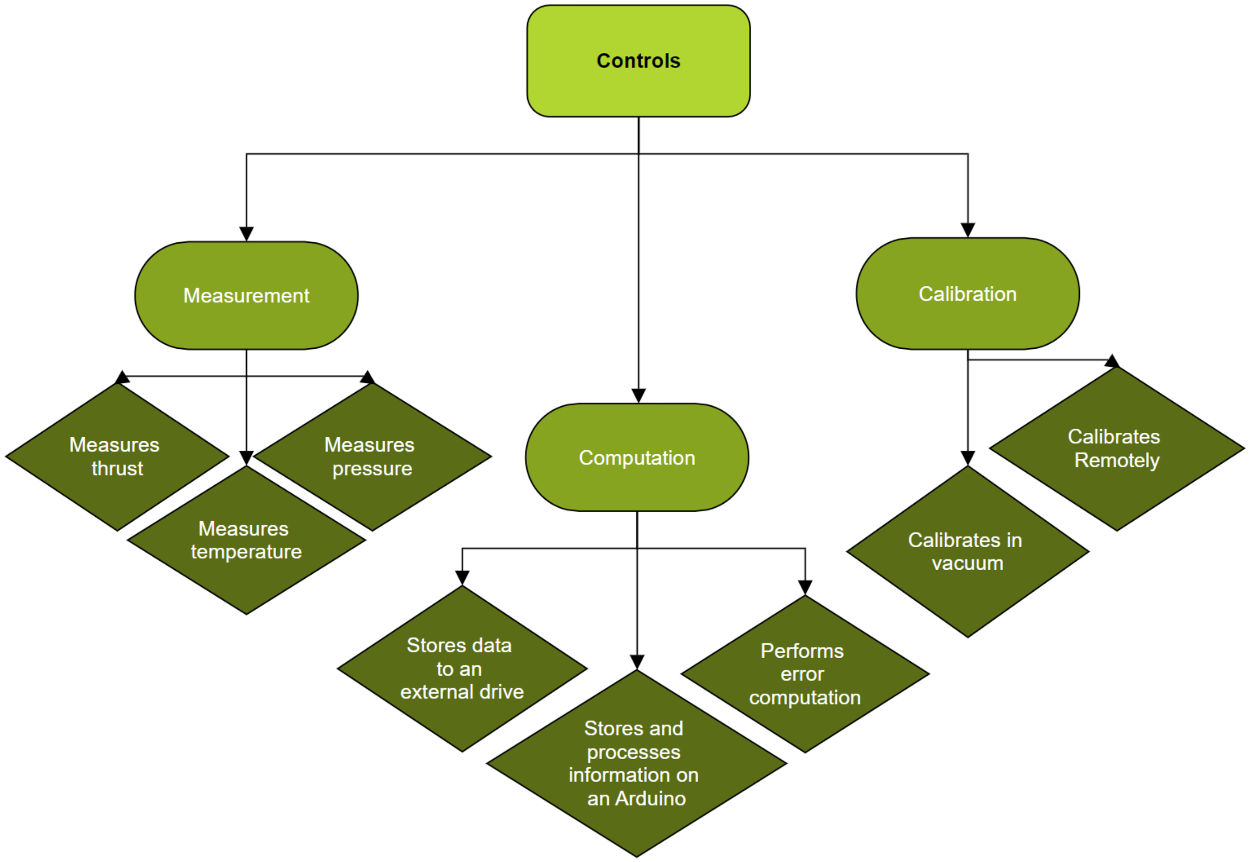


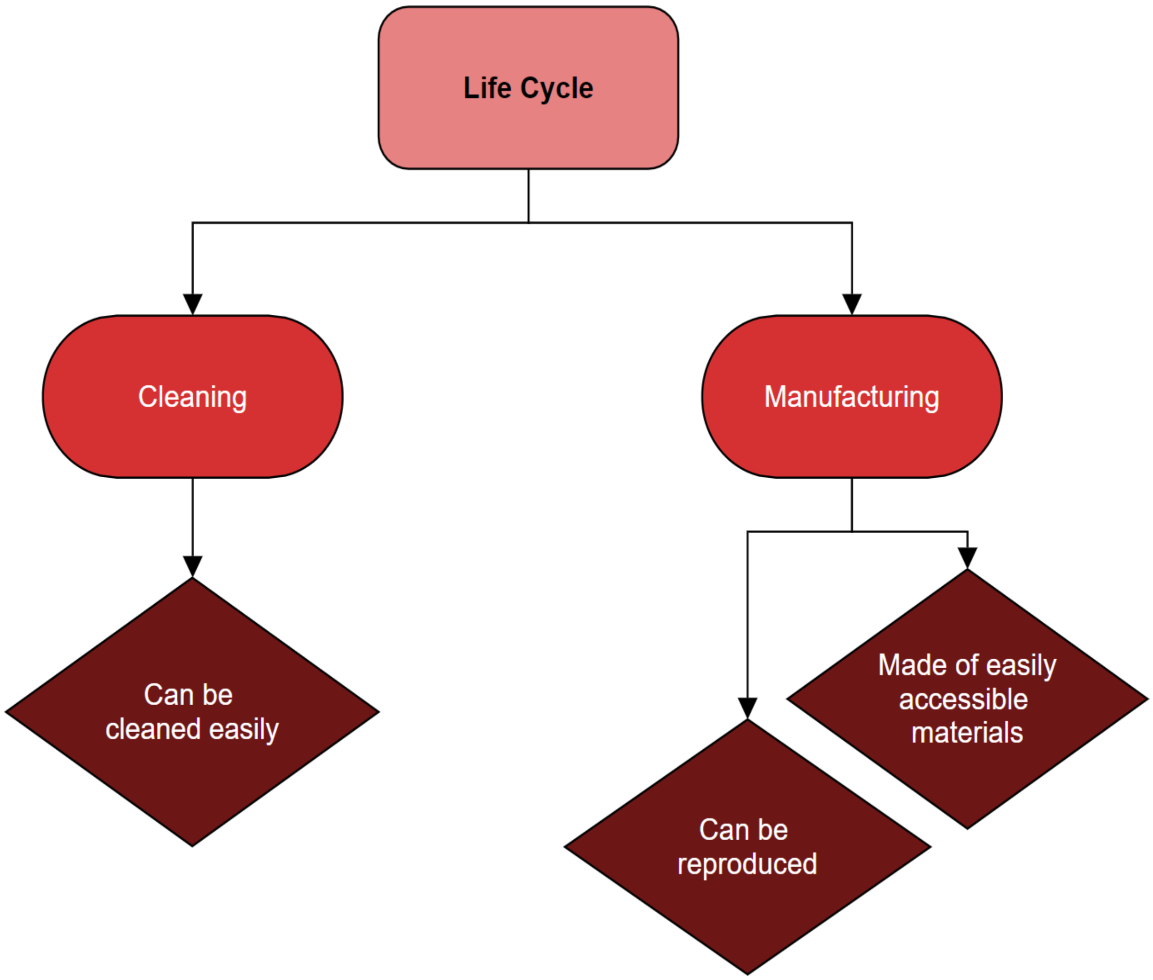
Figure 1 above shows the hierarchy chart for the entire thrust stand. Looking to the secondary level, three main subsystems came to light: controls, life cycle, and integration. After consolidating the interpreted needs, Team 517 deliberated and developed each system and their associated functionalities. During these discussions, it became clear that control was of the utmost importance mainly due to measurement and remote calibration objectives. Similarly, developing a product that was manufacturable with the ability to be cleaned by water remained a primary functional goal. While more of an adjustment for Team 517, integration into MSFC’s current setup was directly expressed by the sponsors and so became a systematic necessity. All systems will relate to one another in some manner, and these relationships are discussed further in the Smart Integration and Connections to Systems sections.

Figure 2: Controls Hierarchy Chart



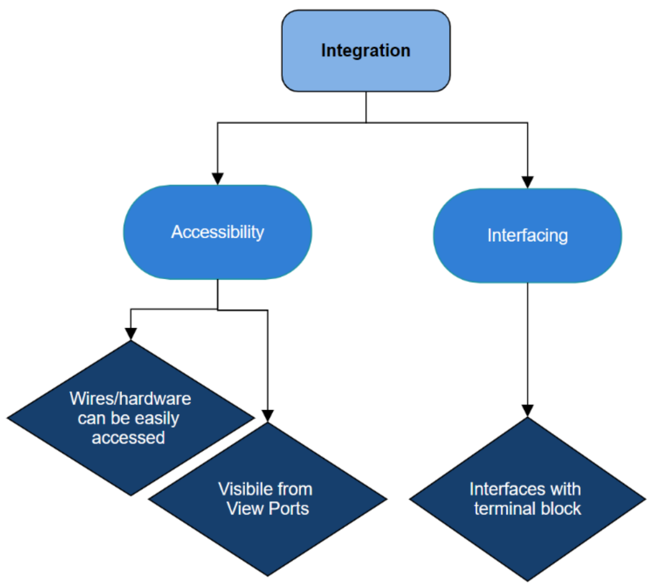
The figure above shows the stand's controls system hierarchy. In the secondary level, various subsystems are designated: measurement, computation, and calibration. While measurements will be primarily taken by various sensors, gauging thrust is the primary objective over measuring plume temperature or having pressure taps. According to the sponsors, the latter measurements would be very nice to have, but the thrust sensor will need to be integrated. Computation-wise, the stand will need to take data measurements, perform error calculations and process this information using an Arduino. MSFC gave Team 517 freedom to develop the method of data acquisition, and the team's experience using Arduinos served as the primary reasoning in choosing this method. Calibration of the sensors will have to be done remotely due to the vacuum-like conditions under which the stand will operate. Due to the remote nature, calibration falls under the controls branch.

Figure 3: Life Cycle Hierarchy Chart



The figure above highlights the life cycle branch of the stand's hierarchy. In line with one of the key goals, MSFC is looking for Team 517's thrust stand to be reproducible at the university level. This entails generating a design guide, but from a functionality standpoint, the stand will need to be machinable and made from easily accessible materials. To prevent corrosion and the buildup of soot, the stand will also need to be easily cleaned, most likely using water.

Figure 4: Integration Hierarchy Chart



The figure above provides a vision for the stand's integration system. As mentioned previously, one of the sponsors' requirements was to have the stand integrated into their current laboratory setup. The primary objective for integration is to have the measurement tools interface with the terminal block developed by the researchers at MSFC. This will make operation of the stand more fluid once testing begins since it will be able to simply plug into their current setup. Similarly, another one of the sponsor's hopes was to increase thruster visibility and accessibility for wiring. Visibility is of the utmost importance since it allows the researchers to set up cameras for testing and data acquisition. With knowledge of the vacuum chamber sizing, the team will make the thruster visible from view ports on the chamber's exterior.

Table 2: Thrust Stand Function-Subsystem Cross Reference

Functions	**Systems**		
	Controls	Integration	Life Cycle
Measures Thrust	**X**	**X**	
Measures Temperature	**X**	**X**	
Measures Pressure	**X**	**X**	
Stores data to external drive	**X**	**X**	
Arduino computations	**X**		
Performs error computation	**X**		
Calibrates in vacuum	**X**	**X**	
Calibrates remotely	**X**	**X**	
Easily cleaned		**X**	**X**
Reproducible			**X**
Made of accessible materials			**X**
Accessible wires/hardware		**X**	
Visible from viewports		**X**	
Interfaces with terminal block	**X**	**X**	

The cross-reference table above demonstrates how functions can populate more than one system. In conjunction with the flow chart, these tools provide a tiered sense of functionality and function-system interactions.

Connections to Systems

There are three overall subsystems of functionality critical to meeting the project objectives: Controls, Life Cycle, and Integration. The Controls subsystem is responsible for the collection and processing of data. The Life Cycle subsystem is responsible for the longevity and continued production of the device. Lastly, the Integration subsystem is responsible for how the device interacts with external systems in its environment. Given the information communicated with the team by NASA-MSFC, the subsystems are prioritized from left to right as Controls, Integration, and Life Cycle.

Influenced by the design requirements, the Controls subsystem breaks down into three categories of functionality: Calibration, Measurement, and Computation. Because the testing procedure requires a vacuum environment, the device must be able to calibrate both remotely and within a vacuum environment. This ensures that the baseline of the data occurs within the testing environment and reduces the possibility of external error during the calibration process. Within the next category, the device must be able to correctly measure the thrust, pressure, and temperature in critical locations. This reduces the need for additional devices within the testing process which could skew data or create inconsistencies. Within Computation, the device must process and record the measurement data, perform error analysis, and store both the calculated and raw data on an accessible external drive. This allows the data to be used within technical research for long-term development. The Controls subsystem functionality is ultimately the most critical to the operation usability of the thrust stand. Therefore, the team has ranked it as the highest prioritized subsystem.

The Life Cycle subsystem consists of cleaning and manufacturing functionality. The device must be easily cleanable to prevent long-term corrosion or damage to itself. This addresses a problem with past designs at NASA-MSFC where excessive crevices and sharp corners prevented propellant from being fully removed from the surface after a fuel system leak. The device also must be reproducible and made of easily accessible materials. NASA-MSFC intends to utilize universities to produce the thrust stand in the future. By maintaining this functionality, most universities should be capable of fully producing the final product in-house. The Life Cycle subsystem is important to the longevity and maintenance of the device but is not inherently critical to the operational function. Therefore, the team has ranked it as the lowest prioritized subsystem of the three.

The Integration subsystem determines how the thrust stand will interact with external systems. This falls into two categories: Accessibility and Integration. Hardware and wiring must be accessible by the end user due to any adjustments or failures that occur. Due to the experimental nature of the testing, unprecedented factors may affect the end user that require the end user to access these areas. In addition, these unprecedented factors require that critical functions always be visible so they must be visible from outside of the vacuum chamber. For Integration, the customer requested that all connections to the thrust stand terminate at the base and be connected via a terminal block. This allows connections to be disconnected for transport and adjustment. The Integration subsystem does not necessarily inhibit the operational function of the device during testing but is critical to the usability of the device by the customer. Therefore, the Team has ranked it as the second-highest prioritized subsystem of the project.

The overall subsystems of the project are prioritized from greatest to least as Controls, Integration, and Life Cycle. However, every effort will be made to fulfill all functional requirements with the given resources. Prioritization of systems is acknowledged as a general safeguard to resource scarcity of funding, time, or other relevant nature. This safeguard ensures that in the event of resource scarcity, functionality is prioritized based on how critical it is to the usability of the project by NASA-MSFC.

Smart Integration

The functions outlined for this project are not completely defined by one subsystem, which is documented by the table showing each function and it's connected to the overarching subsystems. In the Controls subsystem, multiple functions are completed by collaboration with Integration. For example, measuring thrust pressure and temperature also ties into the integration subsystem as these measurements will be taken through hardware that needs to connect through the terminal block. Storing information on an external drive is another control function that has ties to integration. The external drive will hold information obtained through interfacing with the hardware of the thrust stand.

In the Life Cycle subsystem, being easily cleaned overlaps with the Integration subsystem. This function allows the ability to prolong the use, or Life Cycle, of the thrust stand by making the removal of debris simpler which will prevent corrosion from leaking propellant and other produced effects. The relationship to Integration is that components of the stand need to be physically accessible, resulting in ease of cleaning, as well as being able to work around other structural processes of the stand such as the terminal block, wiring, and sensors. Without a relationship with Integration, the geometry of the thrust stand is ignored, resulting in buildup of waste in areas that may be unreachable and possibly resulting in a reduction of cleaning ease and effectiveness. By taking Integration into account, ease of cleaning can consider the structural geometry and the placement requirements of components.

Finally, in the Integration subsystem, interfacing with the terminal block is related to the subsystem of controls. This relationship is due to the terminal block being where many sensors and other hardware will connect, which are all controls related. Taking measurements and computing information will be made possible by ensuring the terminal block is set up correctly.

Table 3 below shows a ranking of each function based on how applicable it is to all three of the subsystems. The table ranks from 0-10, where 0 would be applicable to no subsystems, and 10 is applicable to all three subsystems.

Table 3: Thrust Stand Smart Integration Relationships

Functions	**Connection to subsystems ranking (1-10)**
Measures Thrust	8
Measures Temperature	7
Measures Pressure	7
Stores data to external drive	6
Arduino computations	3
Performs error computation	3
Calibrates in vacuum	7
Calibrates remotely	7
Easily cleaned	8
Reproducible	3

Made of accessible materials	4
Accessible wires/hardware	2
Visible from viewports	1
Interfaces with terminal block	8

The functions with the least amount of overlap were things like visibility from viewports, access to wires/hardware, and reproducibility. These functions fit in their respective subsystems, but do not have much to do with the other two subsystems. The lowest ranked function, visible from viewports, received a 1 since it was the least important function to the overall project, making it barely applicable to the integration subsystem. On the other hand, functions such as interfacing with terminal block and easily cleaned are ranked as higher due to their increased involvement and relationship with other subsystems. The terminal block requires collaboration with both Controls and Integration to complete its function, and being easy to clean will affect the overall health of the thrust stand, and could be detrimental to the controls, life cycle, and integration if ignored.

Actions and Outcomes

The project aims to create a thrust stand to reliably and accurately measure a 0.1 N class thruster using green propellant as the fuel source. The stand will measure thrust using a thrust sensor, temperature using a thermocouple, and pressure using a pressure port. The data will be stored into an external device as well as be read into Arduino while performing any error computation. Prior to testing, the stand will also need to calibrate its sensors remotely after the chamber is depressurized. The stand itself needs to be easily cleanable and made of a readily accessible material such as stainless steel. It will be capable of being manufactured reasonably by a machine shop. It will also need to be visible from the view ports in the vacuum chamber with any hardware or wires being easily accessible. The intention of this project is to provide improved accuracy of measurements to current designs testing green propellants. It is also intended for the design to be reproducible for other universities to test themselves as well as reproduce data.