## Functional Decomposition

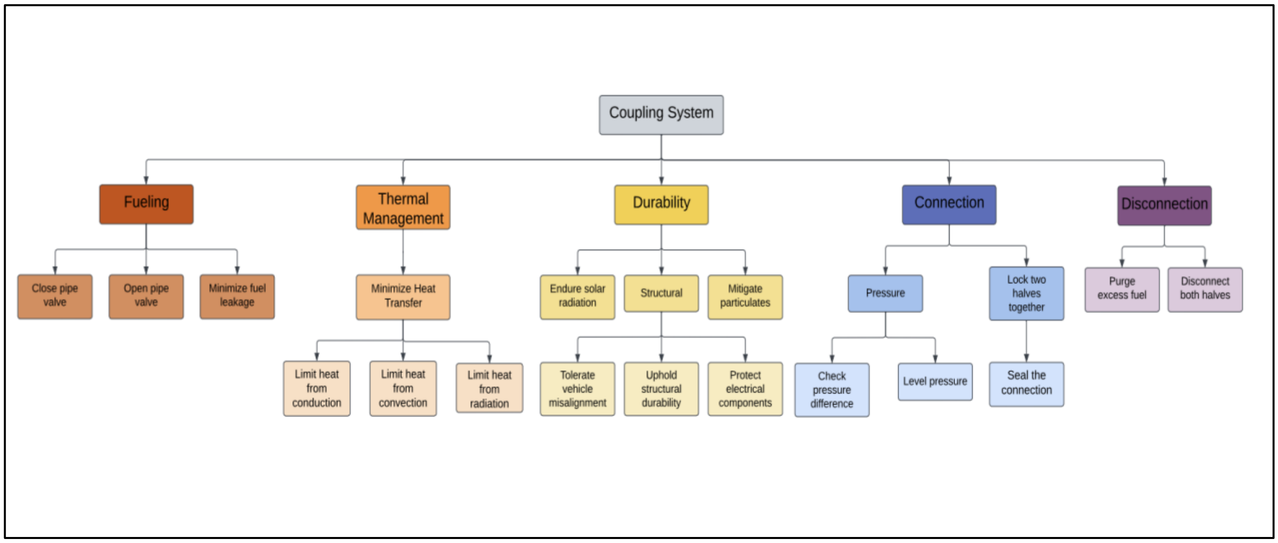
### 1.1 Introduction

The functional decomposition created for the project is used to break down the complexity of the project scope. It takes the system and breaks it down into simpler functions that work together to help the system run. The system was created based on the initial meeting with the sponsors and the customer needs gathered. The needs were then translated into the necessary functions that make up the system. By establishing basic level functions for the actively sealed cryogenic coupler, the team will be able to better identify the targets and metrics of the system.

### 1.2 Data Generation and Hierarchy Intro

To begin to break down our system, the team first revisited key goals, assumptions, and the customer needs that were collected and translated in Table 1. The product was then analyzed and broken down into its main functions and the components that support its respective function. They were then grouped into the subsystems that support the mission of its corresponding main function. The main functions and subsystems are not a rank of importance, but a group of supporting parts that make up the system as a whole. The functional decomposition shown in Figure 1 follows a tree hierarchy with the four main systems for our product: durability, thermal management, fueling, connection, disconnection. Figure 1 serves as a visual representation of our actively sealed cryogenic coupler system.

Figure 1. Hierarchy Chart




## 1.3 Hierarchy Chart Explanation

From the functional decomposition the team created a hierarchy chart of the main functions for the actively sealed cryogenic coupler. We took into consideration environmental factors such as radiation, temperature, debris, and gravity when developing the systems of the product. Environmental factors affect all the main systems of the product and played a large role in the system breakdown.

Fueling is one of the main objectives of the product and is governed by the open and close valves along with minimizing fuel leakage. The main purpose of our product is to create a coupler seal for cryogenic fluid transfer from one point to the other. The open and close values system facilitates the fueling process by sealing the end of the coupler and opening the coupler when appropriate. It serves to manage the fluid from the two points when appropriate. The team aims to control the flow of propellant for the fueling process to properly fuel the subject without waste or leakage. Regarding leakage, the team aims to minimize the amount of leakage during fueling. Temperature and radiation may impact the ability to retain fuel by wearing away piping, insulation, and the coupler itself. The team's goal is to select the appropriate materials and processes to limit the amount of leakage during the fueling process.

Thermal management is a concern for the team since it is directly impacting the cryogenic fluid flow. With that said the team wants minimize heat transfer of the system with the environment. Important considerations for heat transfer in or by the system may be due to conduction, convection, and radiation. Conduction from the insulation or the piping would directly affect the heat transfer of the system. The environmental temperature and solar radiation would add to the heat transfer on the system. Convection in the system would additionally affect heat transfer and need to be regulated. The coupler aims to transfer the fluid and increase temperature or lack of thermal management may lead to dissipation or fluid loss. Additionally, thermal management affects the longevity or lifetime of the product. Extreme temperature breakdown materials and cracks in metals may lead to more leakages.

Durability is crucial for the success of this project due to the harsh operating conditions. The design is intended for use in a lunar mission, where regolith could travel with the spacecraft from the moon's surface and contaminate the propellant. The spacecraft uses a reaction control system for alignment with the tanker, which releases high pressure gasses that may also contaminate the fuel. The alignment of the spacecraft and tanker may not be perfect, so it is essential that the coupler tolerates this and guides the halves together. The system also needs to be structurally sufficient to withstand launch forces as well as forces from the docking procedure.

Protecting from solar radiation is also important due to the low temperatures of the propellant. This heat can cause the fuel to boil off leading to further losses.

Connection for the systems regulates the pressure difference between the tanks of cryogenic fluid, as well as the locking of the two coupler halves. The connection must account for pressures affecting the system and fluid flow. The most important component of the connection is the seal created when the two halves come into contact. The quality of the seal affects the pressure level of the system and the amount of leakage from the seal. The changes in gravity will directly affect the fluid flow and the pressure in the system. The system aims to regulate the internal pressure to prevent leakage or expansion within the system. The system also needs to lock the two halves of the coupler together so that they remain properly sealed and aligned.

Disconnection is the final main system for the actively sealed cryogenic coupler. It accounts for the final process in the system. This part of the system must purge any excess fuel left over in the pipes and return it to the tank. Once the fuel is purged the halves of the coupler must disconnect, completely the process. The environmental factors of gravity and temperature would greatly affect the purging process and disconnection. Temperature extremes may make it difficult for the halves to properly disconnect without cracking. Additionally, a faulty disconnection may lead to a loss of any left-over fuel before it is purged.

## 1.4 Connection to Systems

The actively sealed cryogenic coupler system can be deconstructed into five sub-systems: durability, connection, disconnection, fueling, and thermal management. The first and fifth sub-systems deal with the survivability of the system and cryogenic fuel, while the remaining three sub-systems are mechanical operations that the system will perform. Each of these sub-systems contains several functions and sub-functions, all of which will work together in order to accomplish the goals of the system as a whole.

For the coupler to survive the various environments and conditions it will experience in its lifetime, first it will need to passively minimize heat transfer, endure potentially damaging solar radiation, retain structural rigidity, and mitigate particulate matter from interfering with the system. Then, the system will be able to perform its active mechanical functions of connecting the two halves of the coupler together, regulating the pressure differential, sealing the system, transferring fuel, purging the system of excess pressure, and finally disengaging the two halves of the system. In terms of priority, from first to last the sub-systems along with their respective functions will rank as; thermal management, durability, connection, fueling, disconnection. The integration of these sub-systems into the cryogenic coupler systems will ensure that the final design meets the needs of our customers and key goals of the project.

## 1.5 Cross Reference Table

The functional decomposition cross-functional relationship matrix, Table 2, shows how each functional system of the device relates to one another. The four main sub-systems are labeled in the columns of the matrix and the sixteen functions are along the rows of the left side of the matrix. Each ‘X’ indicates if the sub-system functions impact one of the four main systems of the device.

Table 2. Cross-Functional Relationship Matrix

| Functional Decomposition Cross-Functional Relationship Matrix | | | | | |
|---|---|---|---|---|---|
| **Sub-Systems** | **Durability** | **Connection** | **Fueling** | **Disconnection** | **Thermal Management** |
| Tolerate Vehicle Misalignment | X | X | | | |
| Uphold Structural Durability | X | | | | |
| Protect Electrical Components | X | | | | |
| Endure Solar Radiation | X | | | | X |
| Mitigate Particulates | X | X | X | | |
| Limit Heat From Conduction | X | | | | X |
| Check Pressure Difference | | X | X | | |
| Level Pressure | | X | X | | |
| Lock Two Halves Together | | X | | | |
| Seal the Connection | | X | | | |
| Open Pipe Valve | | | X | | |
| Minimize Fuel Leakage | | X | X | | |
| Close Pipe Valve | | | X | | |
| Disconnect Both Halves | | | | X | |
| Purge Excess Fuel | | | | X | |
| Limit Heat From Convection | X | | | | X |
| Limit Heat From Radiation | X | | | | X |

## 1.6 Smart Integration

The first function requires the use of two sub-systems, durability, and connection. If the vehicle is misaligned not only, would it prevent sealed connection but also could damage components of the device. A device that is unable to uphold its structure, protect electrical components, endure solar radiation, and limit heat from conduction, convection, and radiation will not be able to complete a lunar mission which is the reason it impacts the durability of the device as well as thermal management. Mitigating particulates requires three sub-systems, prevention of regolith/dust accumulation can prolong the durability of the device and will allow for better connection of both mating halves. Also, with no accumulation within the inside surface of the coupler, flow rates are unaffected and fuel contamination is prevented.

The seventh and eighth functions only relate to the connection and fueling sub-systems. As connection is made the pressure of the depot and vessel is obtained and to begin the transfer of fluid, pressure of both depot and vessel must be equal. Connection is made as the two halves are locked together to ensure a sealed connection. Opening and closing the valve only affects the fueling sub-system of the device because up to this point connection has already been made. The minimizing fuel leakage function confirms a successful design and relates to the connection and fueling sub-systems. A sealed connection achieves this function and verifies that fuel is not going to be wasted. Finally, the last two functions, disconnection of the halves and purging excess fuel, only relate to the disconnection sub-system. Regardless of other processes within the system these functions should operate on their own and permit proper disconnection.

## 1.7 Actions and Outcomes

The actively sealed cryogenic coupler is designed for use by space exploration companies to transfer cryogenic propellants in deep space with minimal losses. In order for this to happen, the coupler halves must connect, allow for fuel flow without leaking to the external environment, prevent all three modes of heat transfer from causing boil-off of the fuel, purge excess pressure, disconnect, and be durable enough to survive space conditions. To accomplish this, the coupler halves must lock together securely, a valve must start and stop fuel flow, and the pressure must be accurately monitored. The coupler must also protect from solar radiation and particulates.

## 1.8 Function Resolution

At its most basic level, the device has five main categories. The smallest component of fueling would be controlling the amount of leakage, the open pipe valve and close pipe value. Thermal management is governed by conduction, convection, and radiation minimization at its smallest level. The system durability must be able to tolerate misalignment, protect electrical components, and uphold its structural integrity. Connections of the system must have a sealed connection, as well as checking and managing pressure of the system. For disconnection, the coupler must disconnect both halves and purge any excess fuel. The overall function of the coupler system is to seal the connection between a tanker and spacecraft and allow for the transfer of cryogenic fuel.