MECH 4860

TRDC Engine Inhibiting System

Final Design Report

Submitted on December 1, 2014 by:

TEAM 20

Team 20 Advisor

Kathryn Atamanchuk, P.Eng.,MBA,

Team 20 Members

Clarence Cenina

M.S.M Tafti

Steven Thomasson

Michael Storozinski

University of Manitoba
Faculty of Engineering, EITC, E2-290
75 Chancellor’s Circle
Winnipeg, Manitoba, R3T 5V6
204.391.7372
ccenina3@gmail.com

December 1, 2014

University of Manitoba
Faculty of Engineering, EITC, E1-546
75 Chancellor’s Circle
Winnipeg, Manitoba, R3T 5V6

Attention: Dr. Paul E. Labossiere,

Our team is pleased to present to you our final report entitled *TRDC Engine Inhibiting System* on this Monday the 1st of December. We are confident that this report will satisfy the requirements of the engine inhibiting system requested by WestCaRD.

This report contains a research analysis, the detailed design including component selection, an evaluation of the design in terms of performance, risk management and assessment, bill of materials, and project recommendations.

Thank you for the opportunity to work with WestCaRD at the GE TRDC. Please address any questions or concerns regarding this report to the undersigned via phone at
or by email at .

Sincerely,

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Clarence Cenina
Team 20 Project Manager

Enclosure

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Glossary of Terms

TRDC	GE’s Testing Research and Development Center
Inhibitor Fluid	Specialized oil used to protect and preserve engine components from moisture during storage
Inhibiting	The process of purging/filling the engine’s fuel lines with inhibitor fluid
Thrust Frame	The structure where the turbine engines are mounted for testing
Doghouse	An enclosed room located at the top of the thrust frame where the lines supplying the engine with fuel and air are located, as well as the cables for electricity and instrumentation.
Cracking Pressure	The minimum fluid pressure required to open a one-way check valve
Hot Slush Process	Inhibiting an engine after testing; while it is spinning down to a halt
Cold Slush Process	Inhibiting an engine when it’s inoperable/in storage

Executive Summary

This report contains a final design proposal for an aircraft engine inhibiting system to be used by the GE Testing Research and Development Centre (TRDC). This system is capable of purging fuel from the entire fuel system of the gas turbine engine and replacing the fuel with inhibitor fluid to prevent corrosion and degradation to the engine components. This system also provides the TRDC with the ability to inhibit engines on-site, a function that is desired by the TRDC staff.

The final design is a mobile inhibiting system in the form of a four wheeled cart. The primary component of the system is an internal gear pump powered by an AC electric motor. It is capable of up to 250 psi to accommodate for cold weather operation when inhibitor fluid is more viscous. The 316 stainless steel piping system provides fluid supply to the pump, fluid output to the engine, and fluid bypass/return to the supply source. Standard 55 gallon barrels serve as the supply source, and are placed on readily available dolly carts for mobility. High pressure rubber hoses provide flexible connections to the supply source and to the engine. All the necessary valves and instrumentation are implemented to the piping system for shut off, component isolation, and manual flow control. The cart structure is designed around the pipe layout, and is made of readily available steel fabrication tubing. The overall size of the inhibiting system is 3.5’ L x 2’ W x 5’ H and fits through standard exterior door openings.

The final design is evaluated through a performance analysis process including pressure calculations, FMEA, and a final review of our customer needs. Through the analysis, our team has concluded that the proposed engine inhibiting system will perform to the required design pressure of 160 psi at -30°C, and provide the TRDC with the on-site inhibiting functionality that is desired.

1.0 Introduction

Winnipeg is home to the General Electric Testing, Research and Development Centre (TRDC). The operations at the TRDC facility are a collaborative effort between GE Aviation, StandardAero, and non-profit organization WestCaRD. Gas turbine engines are tested at the TRDC to ensure their compliance with performance and safety standards. These tests are performed at the TRDC by utilizing the technical expertise of GE and StandardAero in the field of gas turbine engine technology, along with the economic support of WestCaRD. While initially designed to be a cold weather testing centre, the TRDC has expanded to provide all-weather testing and development of gas turbine engines [1]. Some notable tests performed at the TRDC include the hail ingestion test, bird ingestion test, and the icing test, all of which are performed on a specially designed thrust frame. During the hail and bird ingestion tests, the gas turbine engine is run while the desired projectile, such as a bird carcass, is shot into the engine's internals to test for potentially catastrophic failure and performance losses. The icing test is performed only during the winter season and involves spraying water into a running gas turbine engine, causing ice to build on the engine and engine internals. The gas turbine engine must maintain performance specifications throughout the duration of the icing test. If a gas turbine engine passes the testing phase at the TRDC, the engine is certified for use on aircraft. A layout of the TRDC testing facility is shown in Figure 1.

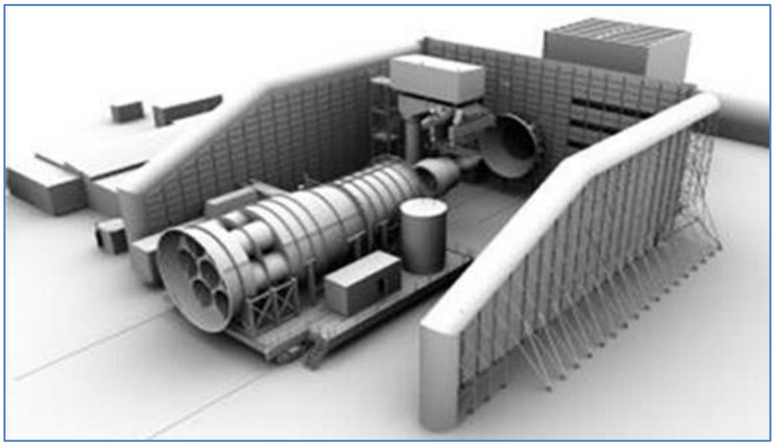

Figure 1 - The TRDC with wind tunnel and thrust frame [2]

The TRDC test area consists primarily of a wind tunnel and a thrust frame, and is surrounded on three sides with noise reducing walls. Tested engines are mounted on to the thrust frame, and all the supply lines and cables required for the engine are supplied by an enclosed room above the thrust frame known on site as the Doghouse.

1.1 Project Background

The primary focus of this project involves the fuel systems of the gas turbine engines tested at the TRDC. When gas turbine engines are sent to the TRDC, the engines can come in either an inhibited or non-inhibited state. An inhibited gas turbine engine has the fuel system filled with an inhibitor fluid, such as ACUMER 1010 or ROYCO 481, when the engine is not in use. The inhibitor fluid protects the fuel system from exposure to moisture, preventing component degradation and prolonging the engine lifespan. The inhibiting process can be done in one of two ways: hot slush or cold slush processes. The hot slush process is done while the mounted engine is spinning down after shut off (or still hot) and the inhibitor fluid is pumped into the engine's fuel system. The cold slush process is done when engine is disconnected from the thrust frame and the inhibitor fluid is pumped into the engine's fuel system while the engine is in a state where it cannot be started and is therefore inoperable (or cold).

Ideally, a gas turbine engine should be re-inhibited after the engine's test cycles are complete. However, there is currently no effective means of inhibiting an engine's fuel system on site at the TRDC. This is normally not an issue if the engine is immediately sent back to GE's primary test facilities in Cincinnati, as the engine can be inhibited there. If the engine must remain at the TRDC for further testing, then it is imperative that the engine is re-inhibited to preserve the fuel system in the event of long term on-site storage. In order to accomplish this, our team has been tasked with developing an engine inhibiting system for the TRDC to eliminate the need of immediately sending gas turbine engines back to Cincinnati for inhibiting.

1.2 Project Objectives

Our team's objective is to design an on-site engine inhibiting system for the GE TRDC which is capable of purging fuel from the fuel system of the gas turbine engine and replacing the fuel with inhibitor fluid. Based on our team's initial meetings with our clients at the TRDC, we compiled the following list of customer needs and the relative importance of each need, as seen in TABLE I.

TABLE I – CUSTOMER NEEDS

#	Customer Need		Importance
1	The system	is mobile for flexible application on-site or indoors;	5
2	The system	is readily compatible for a wide range of aircraft engines;	5
3	The system	is compatible with 1010 or 481 inhibitor fluid;	5
4	The system	can store enough inhibitor fluid to fill all engine sizes tested at the GE TRDC facility;	4

#	Customer Need		Importance
5	The system	supplies inhibitor fluid to engines, while still mounted on the test frame;	5
6	The system	can effectively perform the hot slush inhibiting process;	5
7	The system	can effectively perform the cold slush inhibiting process;	4
8	The system	can operate in the winter climate of Winnipeg, with temperatures as low as -30°C;	5
9	The system	operates in environmental conditions of Winnipeg (eg. heavy precipitation, blizzard);	3
10	The system	is easy to set up and operate;	4
11	The system	follows environmental and safety regulations of both GE and federal government, related to aircraft engine testing, preservation, storage and to testing and storage facilities;	5
12	The system	is aesthetically appealing;	1
13	The system	is easy to maintain;	2
14	The project	has a payback period of two years;	1

Originally, our team considered mobility and cold weather performance to be the two main criteria that the design of our inhibiting system must meet. However, after subsequent meetings with the client and an additional tour of StandardAero's Plant 6 location, our team grouped the customer needs into six design criteria that we used to rank design concepts during the conceptual design phase. The six design initial criteria include cold weather performance, mobility, system flexibility, user friendliness, ease of maintenance, and cost, and they are outlined in the following subsections:

1.2.1 Cold Weather Performance

The engine inhibiting system must be able to perform optimally during Winnipeg's cold winter season. This includes air temperatures as low as -30°C and possibly light precipitation, but system design is not expected to perform during heavy precipitation, as the icing test is only performed during ideal winter weather conditions. During these conditions, the system must be able to provide a maximum of 160 psi to the engine's fuel system.

1.2.2 Mobility

The engine inhibiting system should ideally be a mobile system that can be relocated between the TRDC and a nearby Preparation building. Our team initially thought the design of the system must be mobile, but our client clarified that if a stationary design provided more benefits in other design aspects, then the option to pursue an immobile design will be left to our team's decision. Therefore, while mobility remains a design feature preferred by the customer, it does not hold a level of importance as high as our team initially thought.

1.2.3 System Flexibility

The inhibiting system must be flexible enough to handle various tasks optimally. Primarily, this includes the ability of the design to perform both the hot slush process and cold slush process. However, system flexibility must also extend to the ability of the design to inhibit a wide range of engines, to use either 1010 of 481 inhibitor fluid, and to inhibit the engine when either on or off the thrust frame at the TRDC.

1.2.4 User Friendliness

The engine inhibiting system should be easy to use. The system should require only a few workers to operate optimally and, as requested by the client, should be as simple as connecting a few supply lines and feed lines and turning a valve or flipping a switch.

1.2.5 Ease of Maintenance

The engine inhibiting system should require little maintenance and be easy to maintain in the event that maintenance is needed. This includes easy accessibility to the design's components for repair or routine maintenance, and design simplicity to avoid unnecessary complexity and over-engineering that can negatively affect maintenance.

1.2.6 Cost

The implementation cost of the engine inhibiting system was initially expected to provide the client with a payback period of two years. This included the costs of design, materials, and construction, as well as running costs and the cost benefits of being able to inhibit the engines on site. However, subsequent meetings with the client confirmed that system functionality and performance are more important than cost reduction. Therefore, overall cost is the least important of the six initial design criteria compiled by our team. A more detailed cost overview can be found in Appendix C.

1.3 Technical Specifications and Metrics

In order to ensure our team's design concept meets the required criteria, our team has also compiled a table of applicable metrics that our team will use to assign measurements to each criterion. Many of these metrics are standard units of measurements, such as dimensions and performance specifications. However, due to the nature of the client's needs some of the following metrics, such as the inhibiting system's ease of use, are rated or compared in a more subjective manner rather than numerical measures of performance. Although this means that our team cannot assign units of measurement to these metrics (therefore not being true metrics), we will use the subjective metrics to rate the relative performance or compliance of certain criteria across all possible design concepts. Subjective metrics are rated on a scale of 1 to 10, with 10 being the highest possible value. Further information regarding the use of these metrics in concept screening is found in Appendix A. The metrics to be assigned to the design criteria are presented in TABLE II.

TABLE II – DESIGN METRICS

Metric #	Need #	Metric	Units	Marginal Value	Ideal Value
1	1, 4	Total mass of system	kg	N/A	N/A
2	1, 2, 4	Amount of inhibitor fluid stored in system	L	>100	>210
3	1, 10, 13	The system is easily transferable	Subj.	>5	10
4	2, 3, 5, 6, 7	Minimum required pump exit pressure	Psi	>218	>250
5	2, 5	Pipe diameters	in	1-1/2 2-1/2	1 2
6	2, 3	Maximum pressure in pipes	Psi	<400	<350
7	1,10, 13	Cart wheel sizes	in	5	8
8	2, 5	Required fittings and valves	List	---	---
9	3	Functional range of fluid kinematic viscosity [3]	$mm^2.s^{-1}$ (cSt)	10.15 2446	>10.15 <2446
10	6, 7, 8, 9	Functional range of temperatures the system operates in	°C	37.8°C -40°C	20°C -30°C
11	2, 4	Number of engines expected to be inhibited by the system in one year	Per year	<5	<10
12	5, 6, 7	Length of pipes	list	<10 ft <50 ft 15 ft	<9 ft <45ft 15 ft
13	1, 10, 13	The system is easy to use	Subj.	>5	>8
14	2, 5, 6, 7, 8	The system maintains performance when used in different conditions and methods of operation	Subj.	>8	10
15	10	Total time of the inhabitation process	Min	<10	<5
16	1, 10, 13	Maximum number of people required to operate the system	Operators	<4	1
17	11	System follows industry standards and safety codes	subj	10	10
18	12	Aesthetic appeal	Subj.	>1	10
19	14	Total cost of inhibiting system components	CAD $	<20000	<15000

1.4 Project and Product Constraints

Apart from the design criteria and metrics, our team has also determined a list of constraints and limitations involved in this project. Our team has divided these constraints into two subsections: project constraints which refer to the actual project as a whole, and product constraints which refer to the design concepts of the inhibitor system that our team is tasked to create.

Project Constraints

- Time

Product Constraints

- Size
- Weight
- Implementation costs
- Conformity to codes, standards, and regulations

Our project constraints are primarily limited to time. Due to the relatively short length of the school term, our team is forced to complete this design project in approximately three months, with the final detailed design and presentation to be completed on December 2, 2014. Therefore, our team must use the available time effectively to ensure that we approach each phase of the design project thoroughly. A more detailed breakdown of the project milestones and major deadlines can be found Appendix B.

Our product constraints are those that are placed on the overall design of our inhibitor system. Constraints such as size and weight depend on the type of system design that we intend to pursue and where and how it will be implemented. For example, if our team were to pursue a purely mobile inhibitor system that can be easily transported or relocated, then the size and weight of the design should be as small and light as possible while meeting our six design criteria. A two year payback period in implementation of the inhibiting system was initially considered. This was disregarded in later stages of the project as the customer specified that only the functionality of the system needs to be considered, and the cost payback is not a constraint. However, the team followed an economical approach in design of the system by selection of reasonably priced components, and avoiding extensive shipping costs through selection of North American suppliers. Lastly, the design must meet the applicable codes and standards as required by the TRDC, City of Winnipeg, and the Federal government. Throughout the design of an engine inhibiting system, only the concepts that met these standards were considered, and the final design components were selected to confirm with industry standards. A brief overview of the standards used can be found in Appendix D

2.0 Current Systems

A portion of our team's research included looking into current systems used to inhibit a gas turbine engine. The two inhibiting systems we were able to evaluate are found at the StandardAero Plant 6 and the General Electric test facility in Cincinnati. The inhibiting system located at StandardAero is a simple system containing a permanently mounted reservoir feeding two electrically driven pumps and filters located in a room on site which can be seen in Figure 2.

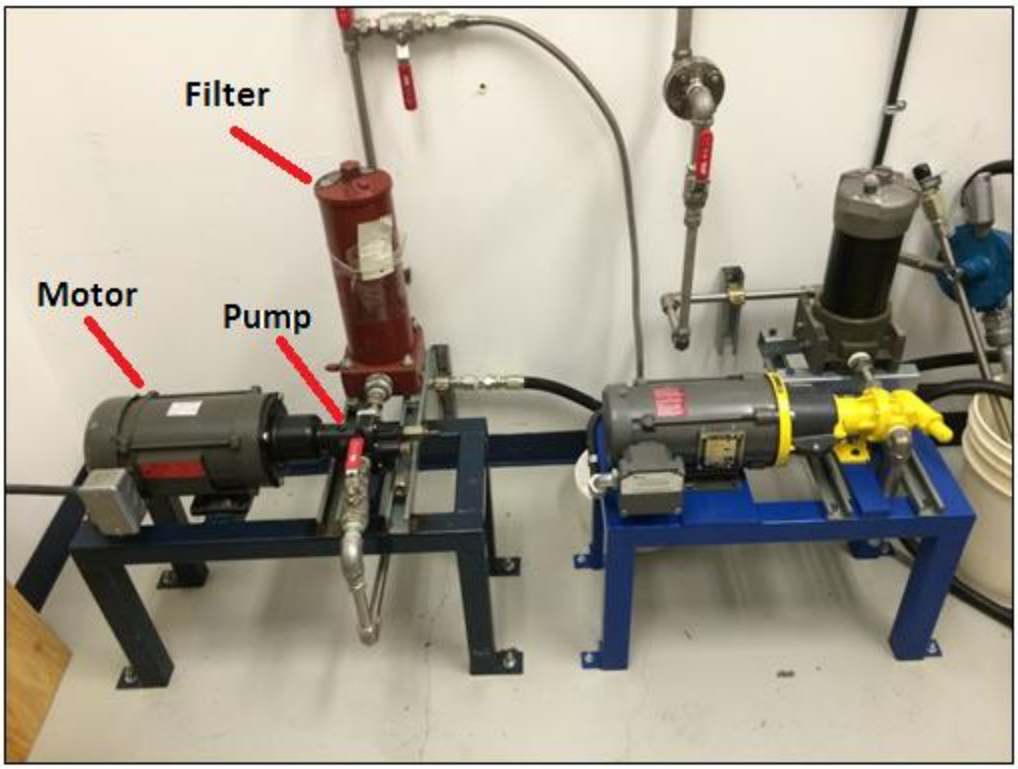

Figure 2 - Plant 6 Inhibiting System

One pump feeds one of two on-site test cells while the second pump feeds the other. The electric motors are hard wired into the building and the pumps are plumbed to hard lines with appropriate valves that feed into each test cell. This system is completely stationary, requiring an engine to move into position for inhibiting. Each test cell is built with a ceiling mounted track system allowing engines to be moved into the mounting frame. Engines on the frame can be run for testing and a hot slush can be performed when spinning down. To perform a cold slush, the engine starter is engaged, spinning the engine over while pumping the inhibitor fluid into engine. Variations of this system became a viable option by moving the engine and not the inhibiting system. The alternative system located in Cincinnati consists of a fluid reservoir, pump, regulators, filters, gauges and various plumbing components. This complex system is used to complete a cold slush only. Based on technical drawings provided by GE (which cannot be included due to legal concerns), the system is slightly larger than the Plant 6 system but is still small enough to potentially be adapted as a mobile system that can be transported to the engine.

Using the information obtained from of these two current systems, our team was able to develop concepts for an engine inhibiting system to be implemented at the GE TRDC.

3.0 Detailed Design

The design our team selected is a mobile inhibiting system on a four-wheeled cart, akin to a pressure washer. Since the design of the Plant 6 inhibiting system was found to be simple, our team decided that we can lay out the piping in such a way that a mobile cart can be built around such a concept. The primary components of the system are a gear pump, a sealed AC motor to drive the pump, an oil filter, the piping system, the cart, and the separate dolly cart for the barrels of inhibitor fluid. A 3D render of the system is shown in Figure 3, complete with a 55 gallon drum and the coupling point to the proposed Doghouse pipeline that will tie in to the existing fuel supply system of the thrust frame. The high pressure rubber hoses or hose coupling fitting used to couple the inhibiting system to the barrel of inhibitor fluid to the Doghouse line or engine are not shown.

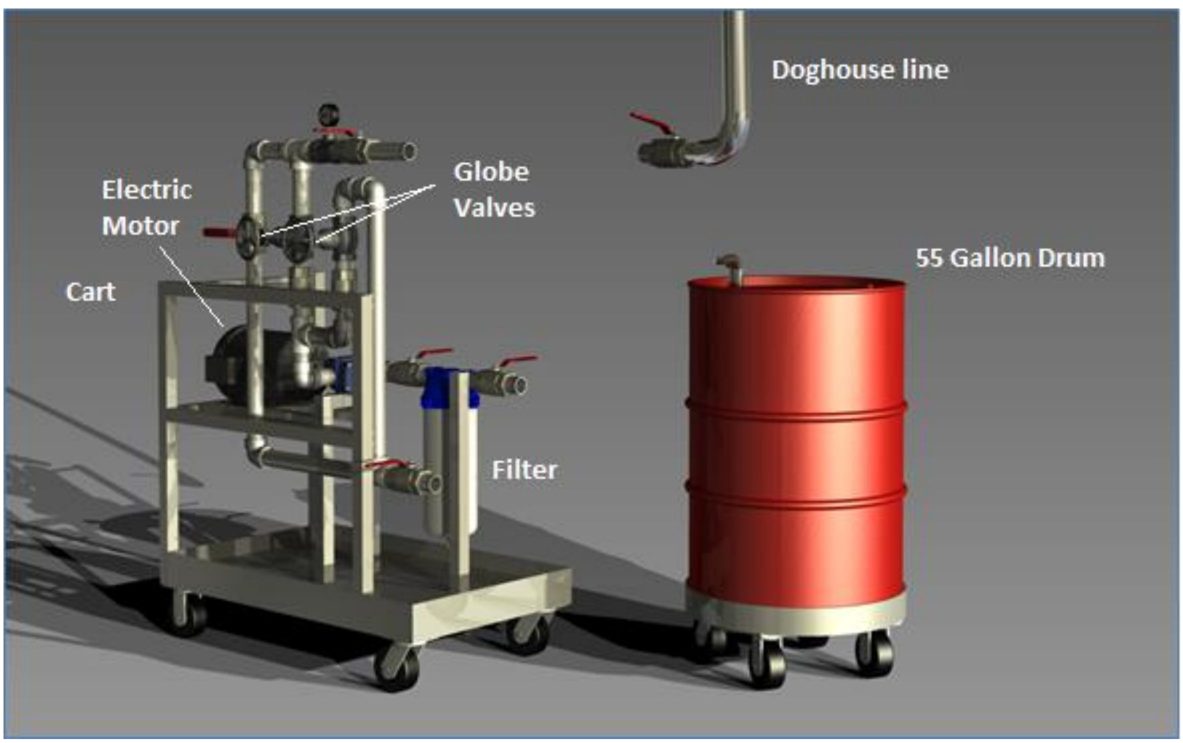

Figure 3 - Mobile Inhibiting System Render with Doghouse Line

3.1 Pump Selection

A major component in the inhibiting system is the pump. This is the device responsible for transferring the inhibitor fluid into the engine fuel system. When selecting the pump, the first decision we made is what will be the driving force for the pump. For our project, an electric driven gear pump and an air powered fluid pump were viable options to use for our specific design. This section discusses each type of pump and the selection of the pump can be seen in Section 3.1.3.

3.1.1 Gear Pump

A gear pump consists of a housing containing a set of gears. This pump uses the meshing of gears to pump the fluid by displacement. A motor is attached to the input shaft of the pump which drives one of the two gears. As this shaft rotates, the gears rotate transferring the fluid in one direction. There are two common types of gear pump: internal and external. The internal gear pump has one gear inside an internal gear. As the two gears un-mesh, a space opens up allowing the fluid to enter. This fluid is transferred around the crescent and forced out the outlet of the pump as the gears begin to mesh together. The external gear pump consists of two similar gears with power to only one gear. As the gears un-mesh, it creates a vacuum on the inlet side which pulls the fluid into the pump. Much like the internal gear pump, the fluid is trapped in the teeth of the gears. The fluid is trapped on the outside of the gears against the housing and force through the outlet as the gears mesh. Figure 4 is a cut away view of an internal gear pump and Figure 5 is a cut away view of an external gear pump.

Figure 4 – Internal Gear Pump [4]

Figure 5 - External Gear Pump [5]

A gear pump is an effective way to transfer viscous fluids at temperature ranges from -40°C to 121°C. This is necessary since our fluid to be pumped has a viscosity of 2446 mm/s at a temperature of -40°C, and this pump is expected to work in temperatures as low as -30°C. Gear pumps have a simple design with a minimal number of moving parts. A gear pump is also the type of pump that is used in the StandardAero Plant 6 engine inhibiting system. The required components for the pumping system include a filter, electric motor, pump, and necessary lines. This is a simple system which can be implemented with a bleed line to help regulate the pressure in the lines.

Our team chose the Haight 8US stainless steel gear pump to further explore as a possible pump for our system. This is an internal gear pump, and the 3D CAD model can be seen in Figure 6.

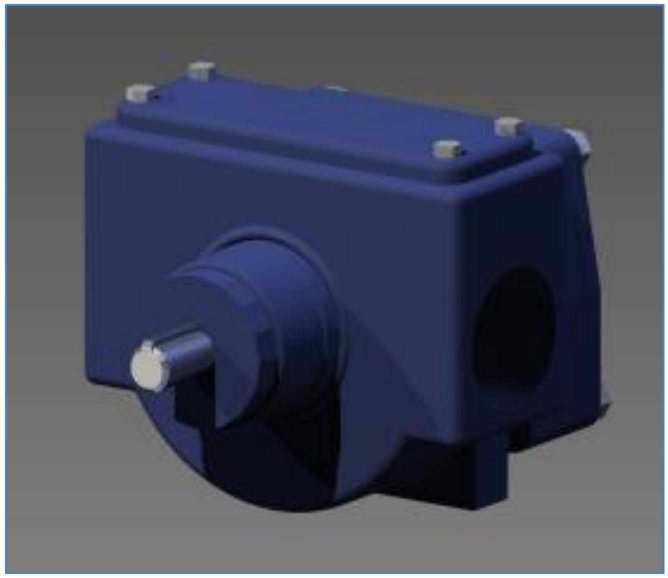

Figure 6 - Autodesk External Gear Pump Render

This pump is capable of flowing 8 gpm at an outlet pressure of 250 psi. Based on the pump curve seen in Figure 7 and research into electric motors, the flow rate of 5 gpm can be achieved when attached to a 2 hp electric motor rotating at 1200 rpm.

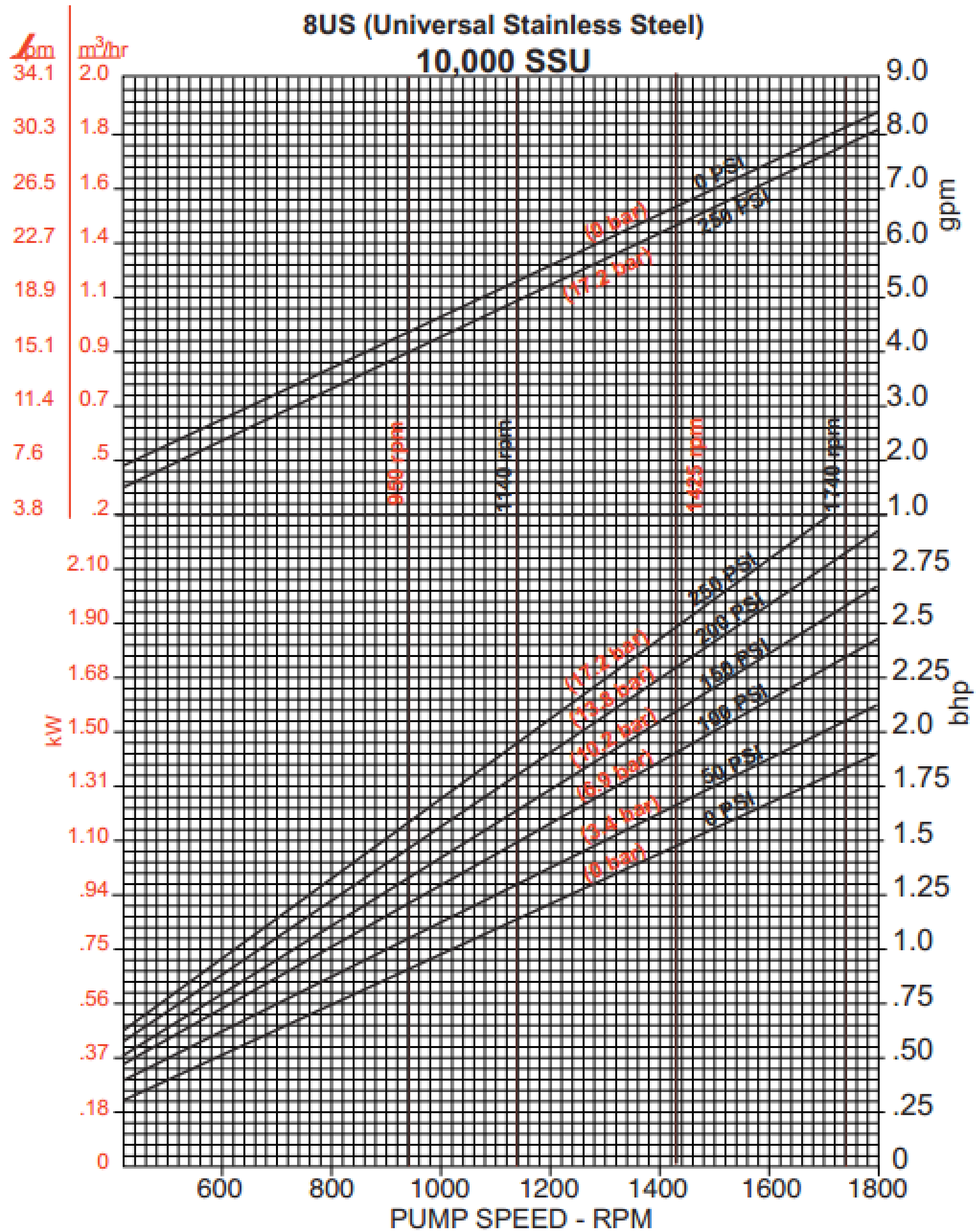

Figure 7 - Haight 8US Pump Curve

This 5 gpm flow rate was selected by our team as we feel it will provide sufficient flow to minimize the time to inhibit an engine while it minimizes loses from increased velocities. This pump is made from stainless steel which allows this pump to resist corrosion, which will allow the pump to have a long lifespan. If this pump is exposed to rain or snow, the elements will not have any effect on the performance of the pump.

3.1.2 Pneumatic Fluid Pump

A pneumatic fluid pump is a different type of pump used to pump a fluid; the main difference between this and a gear pump is what drives the pump. A gear pump is driven by an electric motor while the pneumatic pump is air driven. Located inside the pump is a reciprocating piston. The large surface area is exposed to a low pressure air which acts directly on a smaller surface area piston pushing on the fluid. This area difference increases the pressure to the same ratio of area between the two pistons. As the air acts on the piston, fluid is forced through the outlet of the pump. Air pressure is then applied on the other side, creating the reciprocating movement of the piston and allowing the pump to transfer the fluid. The pump will cycle continuously as pressure is built up. Once the desired pressure is reached, the pump will cut out until the pressure drops. Check valve are placed in the pump to eliminate fluid flowing backwards through the pump. Figure 8 shows the cutaway view highlighting a specific section of the pump. Each section is responsible for the successful operation of the pump.

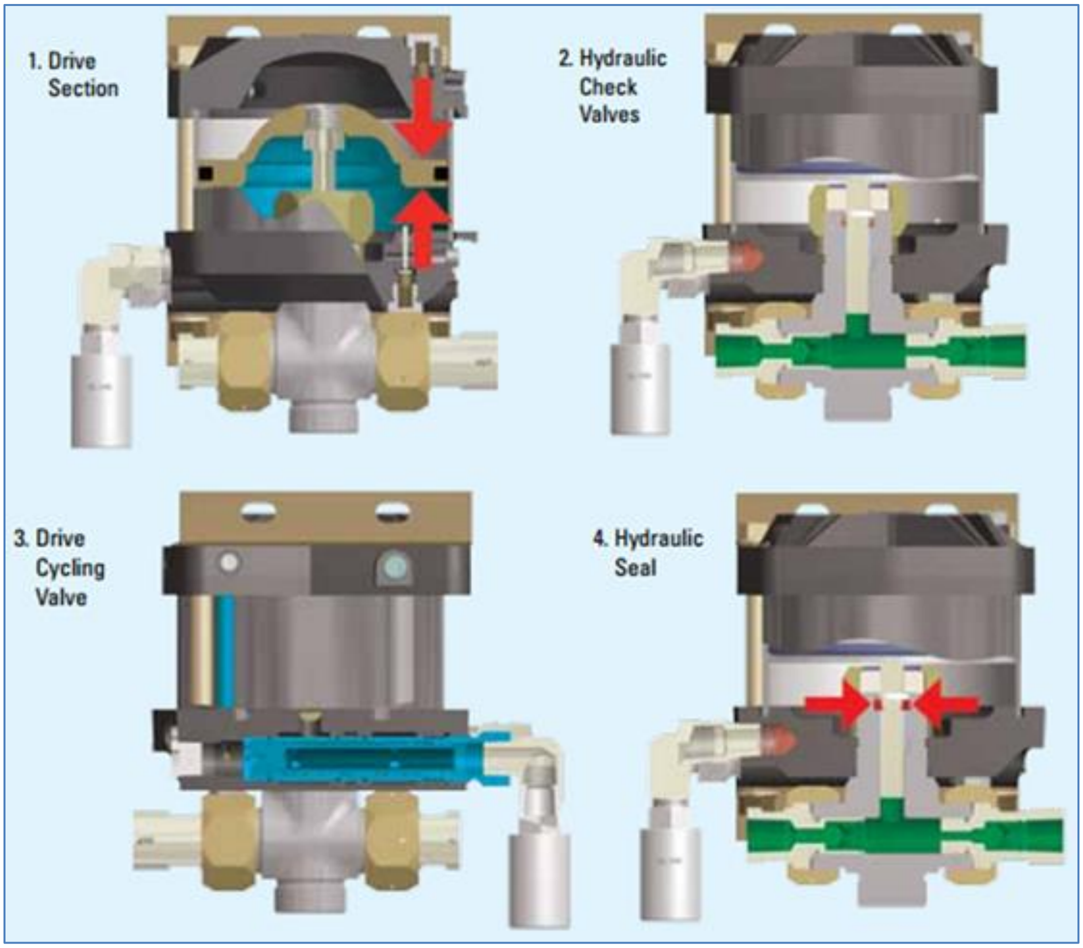

Figure 8 - Pneumatic Pump [6]

Due to the design of this pump, very high pressures of the fluid can be achieved even with a low air pressure. The combination of a larger ratio and the use of additional pistons can generate pressures as high as 100 000 psi. The use of a pneumatic pump will be a consideration as this is the type of pump used in the GE engine inhibitng system. A supply of air is required with air as the driving force of the pump. This air line must also be equipped with an inline dryer, lubricator and filter. The pump will have an inlet line and outlet line for the fluid, as well as a fluid filter just like the gear pump. Figure 9 depicts the general arrangement of a pneumatic fluid pump.

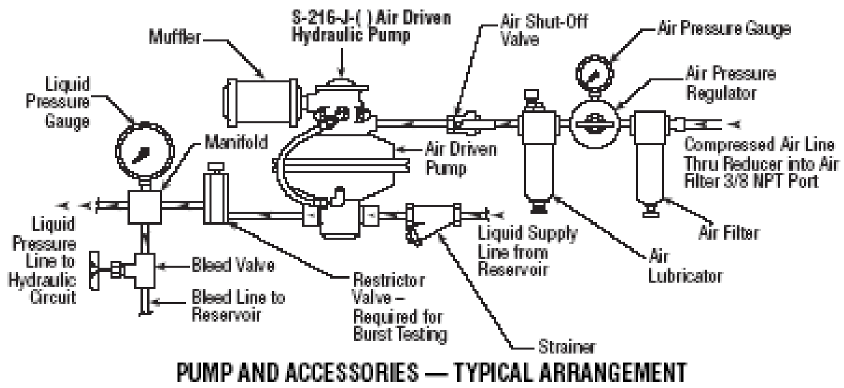

Figure 9 - Pneumatic Pump Arrangement [7]

Our team chose the Haskel ATV-4 pneumatic pump to further explore as a possible pump for our system. This pump can be seen in Figure 10 .

Figure 10 - Haskel ATV-4 Pneumatic Pump [8]

3.1.3 Comparison between Gear and Pneumatic Pumps

Our system must operate in cold temperature so the pump must have an operating range down to -30°C. The gear pump is capable of cold temperatures while the pneumatic pump is not. Seals can be installed in the pneumatic pump to allow it to safely operate in colder temperatures, but this will increase the cost of the pump. Additionally, moving the system from indoors to outdoors can create a possible issue with the pneumatic pumps during winter months. Any possible moisture in the air system can potentially freeze up, preventing the pump to operate.

The ability to regulate pressure is important since we do not want to have so high of a pressure that it can possibly damage engine fuel system components. We also do not want the pressure too low as it won't break the cracking pressure of the engine, and inhibitor fluid will not flow into the fuel system. Both styles of pumps can be regulated using a similar approach. The pump will be turned on, pumping fluid until it has reached its desired pressure. A regulator is located after the pump and is designed to bleed off the fluid once the pressure is reached. This fluid bled off with flow in a line back to the reservoir. This regulator will allow continued running of the pump without burning it out.

Due to the simplicity and overall size of a gear pump, the Haight 8US stainless steel gear pump is the pump our team decided to implement into our design.

As seen previously in Figure 7, the pump curve shows the required horsepower versus the rotational speed. Using this plot, we were able to determine that our electric motor to power the pump must have a power output of 2 hp. Since the rotational speed the pump is required to rotate to achieve the desired 5 gpm is 1200 rpm, we had to choose a motor to spin at this rate. A NEMA 184T electric motor, which can be seen in Figure 11, was selected to drive our pump.

Figure 11 - NEMA 184T [9]

This motor is fully enclosed allowing it to be used in a more harsh condition when compared to a more conventional open motor. This will prevent dust, snow, and any other contaminants from entering the motor. This enclosed design will ensure the pump will function properly if exposed to the harsh winter elements. Since our selected electric motor matches the required speed of the gear pump, the electric motor can be directly attached to the gear pump. A coupling hub is attached to the output shaft of the motor and another attached to the shaft of the pump. A urethane isolator is placed between the couplers to reduce vibration transmission and can allow a certain amount of misalignment between the motor to the pump. This coupler combination will provide a smooth transition of power delivery. The metal coupler and urethane isolator can be seen in Figure 12 and Figure 13, respectively.

Figure 12 - Urethane Spider Coupler [10]

Figure 13 - Coupling Hub [11]

3.2 Piping and Instrumentation

The design of the piping system was done by first indicating the necessary valves and fitting for optimum operation of the inhibiting system and the layout and the orientation of the pipes themselves for both the connections inside the inhibiting system's cart and also the design of a pipe line to connect the system from the ground to the Doghouse. The piping system consists of three lines: a primary feed line running through the filter and pump and directly upwards to a pressure gauge and exit, a flow bypass line that tees off directly after the pump to regulate flow, and a backflow bypass line that tees off before the pressure gauge to provide pressure relief and drainage when the inhibiting process is completed. The latter two lines serve as return lines and return unused inhibitor fluid back to the barrel, preventing waste or spills. The piping system also provides two globe valves to regulate flow and pressure when needed, four ball valves to open and close the primary and return lines, and two check valves to prevent any backflow from the return lines to flood into the primary line during use. Three hoses are used in this system: one at each end of the primary line to supply the engine with inhibitor fluid, and one for the return line to lead back into the barrel.

3.2.1 Pipe, Fitting, and Valve Selection

The preferred material for the pipes, valves, and fittings is 316 stainless steel for its ability to resist corrosion and handle the high pressures within the system. The pipe, valves, and fittings also follow National Standard Threading (NST) for compatibility. The pipes used in the inhibiting system are Schedule 80, or thick walled, NST threaded piping and are seamless to provide unrestricted flow. The pipe also meets ASTM A733, ASTM A312, and ANSI/ASME B1.20.1 industry standards. To ensure the quality of the pipes and to avoid extensive shipping costs, the required pipes were selected from the North American supplier, McMaster Carr®.

The valves and fittings were selected to minimize pressure losses, while improve the safe operation of the system by providing high pressure use. The valves and fittings are all rated for safe use with water, oil, air, and chemical/petroleum products. The fittings utilized for the system consist of only elbows and tees and couplings for simplicity, and all the fittings are rated for high pressure operation up to 1000 psi, are NST threaded, and conform to ASTM A182 and ANSI/ASME B16.11 standards.

The valve selection consists of ball valves, globe valves, and check valves. The ball valves shown in Figure 14 are used to open and close each line during operation and to isolate components for maintenance purposes. They provide unrestricted flow when open, feature Polytetrafluoroethylene (PTFE) seals, and are rated up to 1000 psi.

Figure 14 - High Pressure Ball Valve [12]

The globe valves shown in Figure 15 are used to balance the primary and bypass lines in order to reach the desired output pressure for various types of engines. These valves are rated to 1975 psi.

Figure 15 - Super High Pressure Globe Valve [13]

The check valves shown in Figure 16 are one way valves to prevent backflow during operation and setup, and require a minimum cracking pressure of 3.6 psi to open. The check valves also feature PTFE seals and are rated up to 400 psi.

Figure 16 - Medium Pressure Check Valve [14]

An NIST certified pressure gauge, shown in Figure 17, is used to identify the output pressure inside the primary flow line, and provide monitoring for any irregularities during operation. The gauge is liquid filled to provide greater accuracy in conditions where vibration is present. The gauge itself is vertically mounted and the connection to the pressure gauge comprises of a reducing tee and a reducing coupler to attach the ¼" end of the gauge to the 1-1/2" pipe at the exit.

Figure 17 - A Liquid Filled Pressure Gauge [15]

Again, to avoid expensive shipping rates and ensure the compatibility of all the design components, we selected the required fittings, valves, and instrumentation from McMaster Carr®.

3.2.2 *Pipe, Valve and Instrumentation Layout*

The overall pipe layout is primarily designed for optimal flow of the line feeding the engine (via the Doghouse or directly) and was obtained through trial and error, while considering safety and ease of assembly and maintenance, until the optimal configuration was found. The primary direction of fluid flow from the supply contains a minimal number of bends to reduce minor losses. The regulating and backflow bypass lines branch off the primary feed line, as minor losses in these return lines do not affect the pressure at the exit of the primary line. These return lines are also located below the primary line because any head losses in these lines do not affect performance. The layout is also relatively simple. Minimal bends and avoiding awkward placements of tee fittings for the return lines result in a layout where all the lines are very easy to distinguish and easy to access in case maintenance is required. A simplified Piping and Instrumentation Diagram (P&ID) provides a visual representation of the pipe layout and flow direction, and is shown in Figure 18.

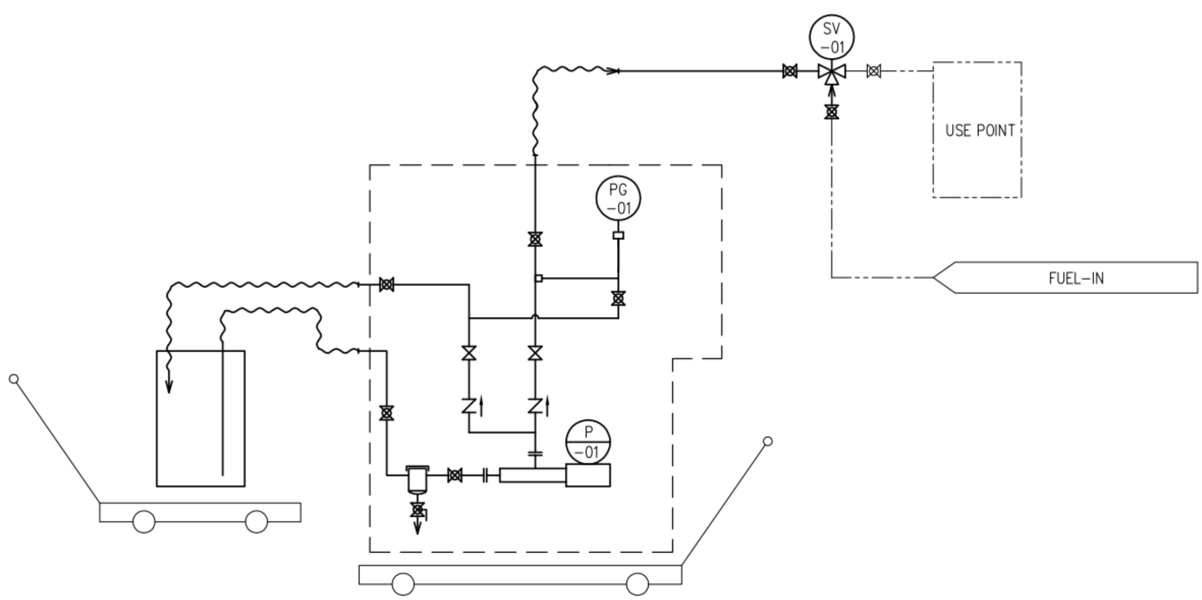

Figure 18 - Simplified System P&ID

The location of the valves and instrumentation ensures accessibility and ease of use where possible. The two regulating valves are parallel and aligned with each other for consistency, and are within arm's reach when the operator is standing. The shutoff valve for the backflow bypass line is also in line and level with the regulating valves, again for consistency and easy access. The check valves are located immediately below and before the regulating valves and are easy to access in case of maintenance or replacement. The shutoff valve and pressure gauge for the exit of the primary line are located directly above the regulating and check valves. This places the pressure gauge closer to the operator's line of sight and prevents excessive bending or crouching to accurately read the gauge. Only the shutoff valves for the supply and return lines are located near the base of the cart. This could not be avoided mainly due to space constraints of the cart, as well as to minimize the amount of pipe fittings and the length of piping used. However, they still remain easily accessible for maintenance or replacement. An additional ball valve is placed in between the oil filter and gear pump, and only serves as an isolation valve if maintenance is required for either component.

3.2.3 Doghouse Pipeline for Hot Slush

In order to meet the need of hot slush functionality, a stationary pipeline was required to connect the mobile inhibiting system to the Doghouse. The system is connected to this pipeline with a 1-1/2" flexible hose that couples to an isolating ball valve as shown earlier in Figure 14. The pipeline itself consists of 65 feet of 2-1/2" pipe. The 2-1/2" pipe diameter was determined through iteration; minimizing the pressure losses throughout the application of the system, while avoiding large diameters as much as possible to prevent any choke of the flow through pipe area changes, especially in flows from large to small diameter pipes. The pipeline has a coupling point near the bottom of the ground level and is opened and closed with a high pressure ball valve. The end of the pipeline that extends to the top and into the Doghouse ties into the existing fuel supply line via a 2 way/1 position automated valve and 3 way/2 automated position valve. The automated valve has not been selected as it requires automation and access to GE's control system information for implementation, and this is outside the scope of the report. Further recommendations regarding the Doghouse implementation is included in Section 5.0.

3.3 Mobile Cart

The purpose of the cart is to provide the mobility required by the TRDC while still being relatively small. The cart is designed in tandem with the piping layout to ensure that it too promotes simplicity and accessibility of the system's components while still being able to maneuver during winter conditions. The cart measures 3-1/2'x2'x5', and therefore will be able to fit through a standard exterior door opening. It is constructed of primarily 1-1/2" square general-use steel tubing, as shown in Figure 19, with a .083" wall thickness, and .075" thick general use steel sheet. Our team chose steel because it is economical, readily available, easy to weld, and provides suitable mechanical properties for our application.

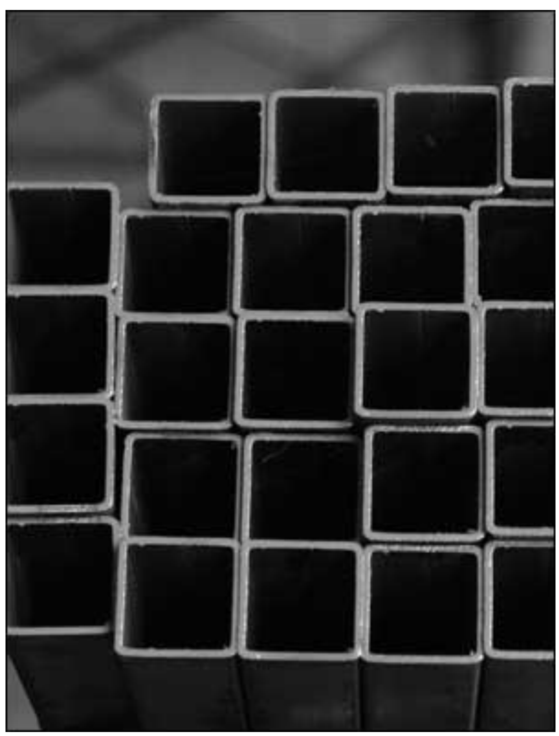

Figure 19 - Square Steel Mechanical Tubing [16]

The square tubing is welded to create a sturdy frame where all the components can be mounted. The steel sheet is used primarily for the floor to act as a spill pan in case of any oil leaks. A handle is made of 1” diameter steel tubing and is placed 3’ off the ground so the arms of the standing operator are not too high or low. The entire steel frame is painted to protect the cart from corrosion, as general use steel does not provide the same level of corrosion resistance as the 316 stainless steel used for the piping system. Four 8” air ride casters, shown in Figure 20, are used in each corner of the cart to provide enough height to comfortable traverse through up to 4” of snow if needed. The rear casters are rigid, while the front casters swivel to allow for steering.

Figure 20 - 8" Air Ride Caster with Swivel [17]

Also, the cart utilizes aluminum strut channels, shown in Figure 21, to provide flexible mounting options for the pipes. These strut channels are the same method of securing the pipe as done with the inhibiting system in Plant 6 as seen in Figure 2. One is located on the floor of the cart, oriented as a vertical channel to hold the pipes leading from the inhibitor fluid barrel to the filter. Another two channels are placed lengthwise on the top and middle steel bars at the output side of the cart to hold the exit and backflow return lines. Strut mount clamps slide and anchor into the strut channel and hold the pipes in place. The strut channels are bolted onto the frame and floor of the cart, as aluminum cannot normally be welded to steel.

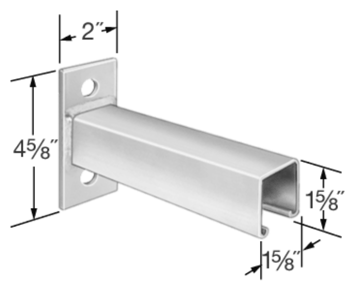

Figure 21 - Aluminum Strut Channel with Bracket [18]

The cart used to transport the barrel of inhibitor fluid is a readily available four wheeled dolly cart from McMaster Carr® to avoid added material of manufacturing cost. An example of a drum dolly cart is shown in Figure 22.

Figure 22 - Drum Dolly Cart [19]

3.4 General Operation

The operation of the inhibiting system is relatively simple. However, there are slight variations in the operating procedure for hot slush and cold slush methods. The procedure for each inhibiting method is as follows

3.4.1 Hot Slush

Note that the following instructions begin before performing engine testing in order to prepare the system to function in tandem with the Doghouse. Also, the ball valve located between the pump and filter must *always* be left in the open position, as this valve only serves as an isolation valve for maintenance purposes.

1. Ensure that all the ball valves are closed, all the globe valves are open, and that power switch for the pump motor is in the off position.
2. Position the cart to the coupling point of at the base of the Doghouse. Ensure the ball valve at the coupling point is closed before attaching the output hose to the coupling point.
3. Attach the hoses with the supply and return fittings to the barrel of inhibitor fluid.
4. Open the ball valves for the supply and return line.
5. Open the ball valve at the coupling point but leave the cart's output ball closed.
6. Turn on the pump and allow the system to reach the desired pressure by balancing the two globe valves. Excess fluid should return back to the barrel via the return line hose.
    a. If the Doghouse line requires priming (pre-filling) before testing, then the output valve can be opened. The pump is run until the Doghouse line is primed. Skip to step 10 and repeat the all steps for the hot slush procedure.
    b. If the Doghouse line is already primed, turn off the pump and close the cart's output valve and allow engine testing to start and complete, then continue to step 7.

7. When testing of the engine is complete, turn on the pump and open the cart's output valve to supply the Doghouse with inhibitor fluid. The automated valves implemented in the Doghouse line can be switched from fuel supply to inhibitor fluid supply.
8. Monitor the pressure of the cart's output until the inhibiting process is complete. Time will vary depending on the engine size (approximately 5 minutes).
9. Once the engine has been inhibited, the automated valves in the Doghouse line are closed.
10. Close the cart's output valve, and turn off the pump.
11. Close the ball valve at the Doghouse line coupling point.
12. Open the backflow bypass valve to drain the excess fluid. The output hose can be disconnected at this time. An airline can be attached to the output end to further purge the return line.
13. Once the return lines are purged, the ball valves for the supply and return are closed.
14. The supply and return hoses can now be removed from the barrel. The supply hose may experience minor spillage due to left over fluid in the hose.
15. Ensure all ball valves are now closed.

3.4.2 Cold Slush

As with the hot slush procedure, please note that the ball valve located between the pump and filter must ALWAYS be left in the open position, as this valve only serves as an isolation valve for maintenance purposes.

1. Ensure that all the ball valves are closed, all the globe valves are open, and that power switch for the pump motor is in the off position.
2. Position the cart beside the engine for inhibiting. Ensure the proper coupling fittings are used for the engine.

3. Attach the hoses with the supply and return fittings to the barrel of inhibitor fluid.
4. Open the ball valves for the supply and return line, but ensure the return line ball valve and cart output ball valve is closed.
5. Turn on the pump and allow the system to reach the desired pressure by balancing the two globe valves. Excess fluid should return back to the barrel via the return line hose. The desired output pressure depends largely on engine size, with cracking pressures up to 160 psi.
6. Once the desired output pressure is reached, open the cart's output valve and allow the inhibitor fluid to fill the engine.
7. Monitor the pressure of the cart's output until the inhibiting process is complete. Watch for any irregularities and adjust the output pressure by balancing the two globe valves as need. Time will vary depending on the engine size (approximately 5 minutes).
8. Once the engine has been inhibited, close the cart's output valve, and turn off the pump.
9. Open the backflow bypass valve to drain the excess fluid. The output hose can be disconnected at this time. An airline can be attached to the output end to further purge the return line.
10. Once the return lines are purged, the ball valves for the supply and return are closed.
11. The supply and return hoses can now be removed from the barrel. The supply hose may experience minor spillage due to left over fluid in the hose.
12. Ensure all ball valves are now closed.

4.0 Product Evaluation

The engine inhibiting system is evaluated in this section to ensure the performance of our suggested design. Our design is evaluated based on the expected performance, risks associated with operation, and compliance with client's needs. Each part of the evaluation is described in more detail.

4.1 Performance Analysis

The performance of the system is analyzed in this section based on the pressure requirements for inhibiting the engine, constraints and limitations associated with the project, and meeting customer specified needs. The initial step of the performance analysis is the calculations for head losses regarding the proposed design. Throughout this project we considered the safe performance of the system while designing different components of the inhibiting system. The safety features are discussed in more details in section 4.1.2.

4.1.1 Calculation of Total Head Losses

The calculation of losses is dependent on determining some parameters regarding the flow of the inhibiting fuel in the pipes and the specifications provided by the customer.

For the calculations in this section, we have only considered the flow of the fluid in the main flow line, from pump discharge to the point of connection to the engine feed line in the Doghouse. The suggested piping for this application consists of 9 feet of 1-1/2" flexible pipe to be attached to the system outlet, 50 feet of 2-1/2" pipe designed to connect the system from ground to the dog-house, and an additional 15 feet to connect this pipe to the tie-in point. The diameters of these different sections of the piping system vary and we will therefore calculate the head losses separately for each section. We selected stainless steel pipes for the purpose of this project because of their good corrosion resistance and strength properties. For optimum performance of the system, the diameters of the pipes were selected by the team by iteration of standard size stainless steel pipe diameters, and evaluating the performance outcome of the system for each iteration.

The flow rate was calculated for the largest engine expected to be tested at the facility, GE9X. As specified by the customer, inhibiting the GE9X requires about 100 liters of fluid and is expected to be performed in about 5 minutes. Therefore, the volumetric flow rate is obtained as Q=3.33E-4 m^3/s and the proposed design is required to maintain this rate throughout the operation of the system in each part of the piping system. This value can be used to obtain the required velocity of the fluid in the pipes using the following relation:

$$V = \frac{Q}{A} = \frac{4Q}{\pi D^2} \qquad \text{Eq. 1}$$

In the above equation the cross sectional area of the pipe is represented by A, velocity by V, and D is the diameter of the pipe. The velocity of the fluid will be different throughout the application as the diameters of the pipes vary in different locations. The velocity in each pipe line is presented in TABLE III.

TABLE III - FLOW VELOCITIES FOR 1.5" AND 2.5" PIPE

Pipe Diameter, D_i [in]	Pipe Diameter, D_i [m]	Area, A_i [m^2]	Velocity in Pipe, V_i [m/s]
1.5	0.0381	0.00114	0.2924
2.5	0.0635	0.00317	0.1053

The flow pattern related to the flow of inhibitor fluid inside the pipes can be predicted for different pipe diameters by Reynold's number. This dimensionless parameter is calculated from Equation 2. To calculate this value, the kinematic viscosity of the fluid was calculated at -30°C. To do so, the relationship between temperature and kinematic viscosity was obtained for a fluid with similar properties to those of ROYCO 481. The properties of this fluid, Aeroshell turbine oil 3 were obtained from the website of the manufacturing company Shell® [20]. The relationship between temperature and kinematic viscosity for Aeroshell turbine oil 3 was then applied to the known functional range of ROYCO 481, as shown in Figure 23. The values for kinematic viscosities of ROYCO 481 corresponding to the functional range of the fluid obtained from manufacturer's website.

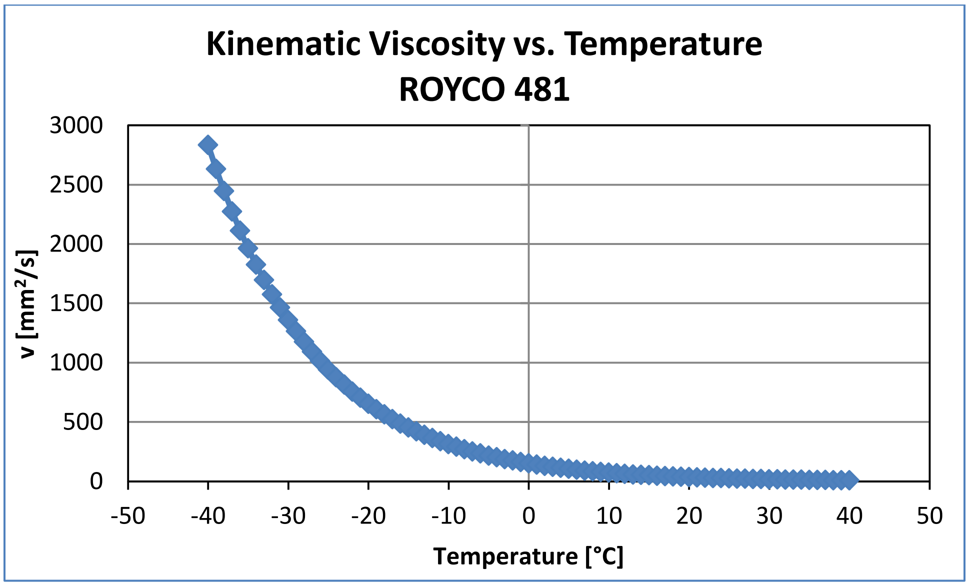

Figure 23: Relationship of Temperature and Kinematic Viscosity for ROYCO 481

This results in a kinematic viscosity of ν=1400 mm^2/s at -30°C. Similarity of Aeroshell turbine oil 3 with ROYCO 481 is a result of the two fluids having mineral oil as base oil. However, it should be noted that while the properties of Aeroshell turbine oil 3 appear to be similar to those of ROYCO 481, this fluid is not classified as a 1010 grade oil, and therefore, we recommend the customer to repeat this analysis, once additional information about the viscosity of ROYCO 481 at different temperatures is obtained. The Reynold's number is calculated for the operational range of the fluid using Equation 2, in which the kinematic viscosity of the fluid is presented as ν:

$$Re = \frac{VD}{\nu} \qquad \text{Eq. 2}$$

The Reynolds number can be used to obtain the friction factor for the flow of fluid though the pipe. To calculate the friction factor for laminar flow of the fluid in different regions of the pipe system, the Churchill equation is used as follows [21]:

$$f = 8\left[(\frac{8}{Re})^{12} + \frac{1}{(\theta_1 + \theta_2)^{1.5}}\right]^{1/12} \qquad \text{Eq. 3}$$

where,

$$\theta_1 = \left[-2.457 * ln\left[\left(\frac{7}{Re}\right)^{0.9} + 0.27\frac{\varepsilon}{D}\right]\right]^{16} \qquad \text{Eq. 3.1}$$

and

$$\theta_2 = (\frac{37530}{Re})^{16} \qquad \text{Eq. 3.2}$$

In Equation 3.1, the roughness of the inner surface of the pipe is denoted by ε, which is given as 0.045 mm for stainless steel [22].

Since the hot slush process requires elevation of the fluid to 50 feet, the hydraulic head is calculated for this function, and a pressure regulating valve is designed in the system to account for the pressure required for the cold slush process. The major head losses, in the operation of the system for the hot slush process, are due to friction in the pipes and are calculated using the following equation [23]:

$$H_l = f\frac{L}{D}\frac{V^2}{2g} \qquad \text{Eq. 4}$$

The minor head losses are caused by variations in geometry in which fluid is travelling. Entrance to pipe, fittings and valves are all assumed to add to the value of minor head loss. The general equation for calculating minor losses is as follows [23]:

$$H_{lm} = K\frac{V^2}{2g} = f\frac{L_e}{D}\frac{V^2}{2g} \quad \text{Eq. 5}$$

The flow of the inhibitor fluid is subjected to a sudden expansion in area from the flexible pipe to the stationary pipeline. The coefficient of expansion is obtained from Figure 24.

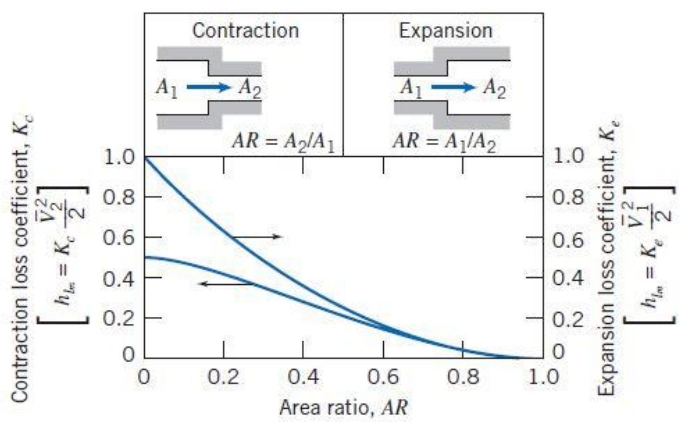

Figure 24 - Contraction and Expansion Loss Coefficients [23]

The area ratio AR is calculated as $AR = A_1/A_2 = {D_1}^2/{D_2}^2 = 0.36$ for D_1=1.5 inches and D_2=2.5 inches. Therefore, an expansion factor of K_e=0.4 is used in the calculation of minor losses corresponding to this expansion.

The losses due to the flow of the fluid though valves and fittings are accounted for by including the equivalent length of these components. These values are provided in TABLE IV.

TABLE IV – DIMENSIONLESS EQUIVALENT LENGTH OF COMPONENTS

Component	Equivalent Length, L_e/D
Globe Valve	340
Ball Valve	3
Check Valve	135
90° Standard Elbow	30
Standard Tee	20

The minor head losses are calculated for the main flow in the 1-1/2" diameter pipe using Equation 6. In this portion of piping, the fluid flows through one ball valve, one globe valve, one check valve, two 90° standard elbows, two standard tees, and an expansion in area. Therefore, the minor losses in this section of the system can be calculated as follows:

$$H_{lm} = K_e * \frac{{V_1}^2}{2g} + f\frac{V^2}{2g}\left[\frac{L_e}{D}_{Ball\ Valve} + \frac{L_e}{D}_{Globe\ Valve} + \frac{L_e}{D}_{Check\ Valve} + 2\frac{L_e}{D}_{elbow} + 2\frac{L_e}{D}_{tee}\right] \qquad \text{Eq. 6}$$

The flow of the fluid in the 2-1/2" diameter pipeline is subjected to minor losses due to at least two 90° standard elbows, and one standard tee. The quantity of valves and different types of them depends on the valves currently used in the "dog-house". Also, the additional distance from the tie point to the engine is neglected, yet a factor of safety of 15% is considered to account for the valves and fittings and assumptions in calculations. The minor losses in the 2-1/2" pipe are calculated as follows:

$$H_{lm} = f\frac{{V_2}^2}{2g}\left[2\frac{L_e}{D}_{elbow} + \frac{L_e}{D}_{tee}\right] \qquad \text{Eq. 7}$$

Total hydraulic (Head) losses are calculated using Equation 8 [23]:

$$H_{lT} = H_l + H_{lm} \qquad \text{Eq. 8}$$

As discussed before, a factor of safety of 15% will be added to the total head loss of the entire piping system to account for unknown fittings and assumptions in calculations. The total head losses can then be converted to pressure loss, in units of Pascals, using Equation 9:

$$\Delta P = \rho g H \qquad \text{Eq. 9}$$

In the above equation ρ is the density of the fluid. The density of ROYCO 481 at the functional range of this fluid was not made available to us by the manufacturer of the product. Knowing that the base of this fluid is mineral oil, and that the majority of the fluid consists of the base oil, we assume that the density of the fluid is similar to the density of mineral oil. At 15°C mineral oil has a density of 875 kg/m^3, and in most cases the density of mineral oil at other temperatures can be calculated by a coefficient 0.00065/°C [24]. However this approximation is correct for a certain temperature range and therefore we recommend the customer to repeat the calculations for head losses once they have information about kinematic viscosity and density of the fluid at the desired temperatures. Using the named relation, the density is estimated to have a value of 862 kg/m^3 at 37.8°C, and 901 kg/m^3 at -30°C.

The results associated with head loss calculations for the two ends of the operational range of the working fluid are provided in the following tables. TABLE V shows the calculation results for the portion of piping with D_1=1-1/2" and TABLE VI shows the results for D_2=2-1/2":

TABLE V – CALCULATION RESULTS FOR FLEXIBLE 1-1/2” PIPE

Temperature [°C]	37.8	-30
Kinematic Viscosity, ν [m^2/s]	1.02E-05	0.0014
Reynolds Number, Re	1097.483	7.957
Friction Factor, f	0.058315	8.043
Major Head Losses, H_l [m]	0.018293	2.523
Minor Head Losses, H_{lm} [m]	0.148598	20.258
Total Head Losses, H_{lt} [m]	0.166891	22.781

TABLE VI – CALCULATION RESULTS FOR 2-1/2” PIPE

Temperature [°C]	37.8	-30
Kinematic Viscosity, ν [m^2/s]	1.02E-05	0.0014
Reynolds Number, Re	658.4899	4.774
Friction Factor, f	0.097192	13.406
Major Head Losses, H_l [m]	0.017123	2.362
Minor Head Losses, H_{lm} [m]	0.00439	0.606
Total Head Losses, H_{lt} [m]	0.021513	2.967

Therefore, the total head losses throughout the application are calculated by combining the total head losses of each section. The total head losses with 15% safety factor and the equivalent pressure losses in the pipes are presented in TABLE VII:

TABLE VII – TOTAL PRESSURE LOSSES FOR THE DESIGN

Temperature [°C]	37.8	-30
Head Losses for Design, H_{lt} [m]	0.188	25.748
Head Losses with 15% Safety Factor [m]	0.217	29.610
Equivalent Pressure Losses, ΔP [Psi]	0.266	37.942

However, the required pressure at the engine entrance, i.e. the required cracking pressure, is 160 psi, as specified by the customer. Therefore, for the pump to provide a 160 psi pressure at the engine, a discharge pressure of about 200 psi is required from the pump.

It should be noted that the calculations in this sections are done by using fluid properties that are roughly estimated, due to unavailability of information for the selected inhibitor fluid, ROYCO 481. As a result, the relationship between temperature and kinematic viscosity for ROYCO 481 might be different in reality, than what is shown in this section. Since the inhibitor fluid is very viscous at low temperatures, the effects of uncertainties in kinematic viscosity calculations, affect the calculated pressure difference in operations at low temperatures. The system is expected to perform in temperatures as low as -30°C; therefore as discussed above, we recommend the customer re-calculate the pressure requirements once more accurate information about viscosity and density of the fluid at the desired temperatures is obtained. The pressure losses will be lower at higher temperatures, and therefore the size of the pump and pipes could vary once these losses are known for the lowest operational temperature, -30°C. Recommendations and suggested solutions are discussed in more detail in Section 5.0, closing remarks and recommendations.

4.1.2 Safety

The inhibiting system meets the operational safety regulations provided to the team by the customer throughout the course of this project. This section includes an overview of these regulations, and the corresponding design features of the inhibiting system, which help in satisfying the regulations. The safety regulations for this design are described in more detail in Appendix B.

As specified by the customer, no spillage of oil is allowed in the facility. To prevent any leakage of inhibitor fluid we implemented trays on the carts for both the system and reservoir. We also designed fittings and diameters to be the right size to avoid any additional connections. Also, bypass flows were designed in the system layout to ensure the safe disposal of the fluid inside the pipes in the case of system shut off. Valves, fittings and pipes were selected to withstand the operational pressures and temperatures to avoid any corresponding failures.

The inhibitor fluid is received from the supplier in 55 gallon drums and those same drums are used as the reservoir for the final design. At the time of storage the drum's plug is used to seal it and due to the mobility of system, the pumping and reservoir carts can be easily moved and stored in a dry location. During the operation of the inhibiting system the components are electrically grounded through the pump motor and the transfer of the fluid is due to the suction effect of the pump. Therefore the regulations for safe storage and handling of the fluid provided by the product's material safety data sheet (MSDS), which are discussed in Appendix B, were accounted for throughout the design of the inhibiting system.

For safe performance of the system, a factor of safety of 15% was designed in the head loss calculations. Additionally, a more powerful pump than required is selected to ensure the safe performance of the system and thorough coverage of the engine fuel system's components. This was done to account for the pressure losses regarding any sudden change in the area when the fluid flows through the pipe line to the smaller diameter pipes.

4.2 Risk Management and Assessment

A Failure Modes and Effects Analysis was used to identify ways in which the engine inhibiting system could fail and provided an estimated risk priority number (RPN) associated with each identified failure mode. Each failure mode has an action plan or recommendation to mitigate the risk of failure, which is seen by a decrease in the RPN. The components of the engine inhibiting system were analyzed in TABLE VIII and TABLE X, for the current RPN of the design. While the effects of implementing the actions/recommendations on the new RPN are shown in TABLE IX and TABLE XI.

TABLE VIII – CAUSES AND EFFECTS FOR PUMP MOTOR, PUMP AND FILTER FOR INHIBITING SYSTEM

Process Step/ Input (X)	Potential Failure Mode	Potential Effect	Sev.	Potential Causes	Freq.	Current Controls	Det.	RPN
Pump Motor	over heating	loss of performance requiring replacement	8	motor overworked (operating above or below design temperatures)	2	bypass loop (high pressure)	3	48
	seized motor	inoperable motor	8	environmental conditions (outdoor)	3	none	6	144
	electrical short	inoperable motor	8	internal components become wet (outdoor)	3	none	6	144
Pump	overheating	damaged seals	8	pump overworked (thick fluid causing high friction)	2	bypass loop (high pressure)	6	96
		seized pump	8	pump overworked (thick fluid causing high friction)	1	bypass loop (high pressure)	6	48
		run dry	8	pump on when not hooked up to reservoir	2	bypass loop (high pressure)	4	64
	cavitation	excessive pump wear	6	large pressure drop across pump	2	bypass loop (high pressure)	6	72
Filter	collapsed filter	blocking fluid flow	8	high differential pressure across filter	3	bypass loop (high pressure)	6	144
	punctured filter	not filtering all fluid	6	poor quality or defect in filter	2	replace according to maintenance schedule	8	96
	plugged filter	blocking fluid flow	8	heavily contaminated fluid	2	bypass loop (high pressure)	6	96
			8	filter not changed according to maintenance schedule	4	bypass loop (high pressure)	6	192

TABLE IX – RECOMMENDATIONS FOR PUMP MOTOR, PUMP AND FILTER FOR INHIBITING SYSTEM

Process Step/ Input (X)	Potential Failure Mode	Potential Effect	Actions /Recommendations	Results After Action			
				Sev.	Freq.	Det.	New RPN
Pump Motor	over heating	loss of performance requiring replacement	temperature sensors on critical components of the motor connected to a motor shut off switch.	8	1	1	8
	seized motor	inoperable motor	install protective cover for motor/cart	8	1	6	48
	electrical short	inoperable motor	install protective cover for motor/cart	8	1	6	48
Pump	overheating	damaged seals	temperature sensors on critical components of the pump connected to a motor shut off switch.	8	1	1	8
		seized pump	temperature sensors on critical components of the pump connected to a motor shut off switch.	8	1	1	8
		run dry	manual or automatic fuse breaker to shut-off pump if demanding high amps	8	1	2	16
	cavitation	excessive pump wear	monitor pressure before and after pump	6	1	1	6
Filter	collapsed filter	blocking fluid flow	add differential pressure gauge (shows if filter is clear or plugged)	8	1	1	8
	punctured filter	not filtering all fluid	add differential pressure gauge (shows min. pressure difference across filter)	6	1	1	6
	plugged filter	blocking fluid flow	add differential pressure gauge (shows if filter is clear or plugged)	8	1	1	8
			add differential pressure gauge (shows if filter is clear or plugged)	8	1	1	8

TABLE X – CAUSE AND EFFECTS FOR RESEVOIR, VALVES, HOSES & FITTINGS AND CART FOR INHIBITING SYSTEM

Process Step/ Input (X)	Potential Failure Mode	Potential Effect	Sev.	Potential Causes	Freq.	Current Controls	Det.	RPN
Reservoir	leaks fluid	environmental hazard	9	connections not properly tightened	2	visual	2	36
			9	spill from transferring hoses between empty to full reservoir	5	shut-off valves to reduce disconnect spills	2	90
Valve	leaking	environmental hazard	9	worn seals (O-rings)	2	visual	2	36
			9	connections not properly tightened	3	visual	2	54
	stuck open or closed	high line pressures (prevents bypass)	8	valve residue build up (increasing friction)	2	none	4	64
3-Way Valve	leaking	environmental hazard	9	worn seals (O-rings)	2	visual	2	36
			9	connections not properly tightened	3	visual	2	54
	stuck open or closed	oil or fuel back tracking through other inlets	6	valve residue build up (increasing friction)	2	none	6	72
		high line pressures (prevents bypass)	8	valve residue build up (increasing friction)	2	none	4	64
Hoses/ Connections	leaking	environmental hazard	9	worn seals (O-rings)	2	visual	2	36
			9	connections not properly tightened	3	visual	2	54
			9	hole in hose	2	visual	2	36
Cart	seized/ broken wheel	not easily mobile	6	wheel bearing seize due to outdoor elements	2	visual	1	12
			6	damaged by other equipment/ improper use	3	visual	1	18

TABLE XI – RECOMMENDATIONS FOR RESERVOIR, VALVES, HOSES & FITTINGS AND CART FOR INHIBITING SYSTEM

Process Step/ Input (X)	Potential Failure Mode	Potential Effect	Actions /Recommendations	Results After Action			
				Sev.	Freq.	Det.	New RPN
Reservoir	leaks fluid	environmental hazard	reservoir dolly has raised lip to contain spills	5	1	1	5
			reservoir dolly and cart have raised lip on base to contain spills	5	2	1	10
Valve	leaking	environmental hazard	inspect valve before system operation	9	2	1	18
			inspect valve before system operation	9	2	1	18
	stuck open or closed	high line pressures (prevents bypass)	cycle valves open and closed before operation	8	1	1	8
3-Way Valve	leaking	environmental hazard	inspect valve before system operation	9	2	1	18
			inspect valve before system operation	9	2	1	18
	stuck open or closed	oil or fuel back tracking through other inlets	add one-way valve to inlets of oil and fuel lines before 3-way valve	2	2	6	24
		high line pressures (prevents bypass)	cycle valves open and closed before operation	8	1	1	8
Hoses/ Connections	leaking	environmental hazard	inspect hose connections before system operation	9	2	1	18
			inspect hose connections before system operation	9	2	1	18
			inspect hose connections before system operation	9	2	1	18
Cart	seized/ broken wheel	not easily mobile	extra set of wheels (ex. 6 wheels on cart) able to function with one or two broken wheels	1	1	2	2
			extra set of wheels (ex. 6 wheels on cart) able to function with one or two broken wheels	1	1	2	2

The FMEA identified a plugged filter to have the highest RPN of 192, which, after following the recommendation of installing a differential pressure gauge, could be reduced to an RPN of 8. The differential pressure gauge would allow for an easy visual while the pump is running to determine if the filter is performing well (in the green) or requires replacement (in the red); an image of the gauge is shown in Figure 25.

Figure 25 - Differential Pressure Gauge for Filter [25]

The next three highest RPN were all the same at 144, which were for collapsed filter, seized pump motor, and electrical short in the pump motor. The collapsed filter would reduce fluid flow similar to a plugged or dirty filter; therefore by installing a differential pressure gauge you would be able to determine if the filter needed to be replaced and upon replacement would be able to determine if the filter had collapsed or was just plugged with debris. By installing the differential pressure gauge, two of the highest RPN's (192 and 144) can be mitigated to an estimated RPN of 8 each. Likewise, the next two highest RPN's can be mitigated with a similar solution. The pump motor seizing or having an electrical short can both be caused by exposure to outdoor elements such as rain or snow.

Therefore, a recommendation for both is to install a cover for either the electric motor or the entire cart to reduce the frequency of these two failure modes from occurring by protecting the components of the engine inhibiting system from the outdoor elements. Implementing this recommendation would mitigate the RPN from 144 to an RPN of 48 for both the pump motor seizing and shorting electrically.

4.3 Meeting Client Needs

The main purpose of the designed engine inhibiting system is to meet the clients' needs as best as possible. Our team met with the client throughout the duration of the design project in order to refine and prioritize the most important needs and how the needs will be met by the design. A brief summary of how the designed engine inhibiting system meets the clients' needs follows.

The mobility of the engine inhibiting system was achieved by having all of the components, such as the pump, filter, pump motor, and bypass valves, all fixed to a portable cart with 8" Air Ride castors. Therefore, the engine inhibiting system is easily able to move from the base of the Doghouse to the Preparation building to perform hot and cold slush, respectively.

The compatibility of the engine inhibiting system with various types and sizes of aviation engines was achieved by designing the system for the largest engine fuel capacity (GE 9X engine). Also, by connecting the inhibiting line to the existing fuel supply line our team was able to avoid having different fuel line connection fittings for each engine. The reservoir for the engine inhibiting system was designed to accommodate enough inhibitor fluid to inhibit two of the largest engines being tested at the facility, which is the GE 9X.

The engine inhibiting system is also compatible with 1010 or Royco 481 inhibitor fluid by having the system components made from stainless steel so they would not react with or contaminate the inhibitor fluid.

The engine inhibiting system can perform the hot slush process by supplying the engine with inhibitor fluid while the engine is mounted on the test frame. The engine inhibiting system can also perform the cold slush process by moving the cart and reservoir to the engine in the Preparation building. The system is also easy to setup and operate, as there is only one line to connect the engine inhibiting system to the engine either via the Doghouse (hot slush) or directly to the engine (cold slush), and minimal valves to operate without losing functionality.

The winter climate and varying weather conditions of Winnipeg, MB were used to design the engine inhibiting system to ensure that the pump would be powerful enough to pump the inhibitor fluid to the engine even when the fluid is at temperatures of -30C. The engine inhibiting system was also designed to operate in heavy precipitation or even blizzard conditions to meet when the client could require an engine to be inhibited.

The engine inhibiting system was also designed to follow environmental and safety regulations of both GE and federal government, related to aircraft engine testing, preservation, storage and to testing and storage facilities. The engine inhibiting system must be able to adhere to the governing safety regulations in order to be used at the facility.

The engine inhibiting system is easy to maintain, as the only maintenance is to change the filter and to perform a quick inspection of components. As for the aesthetic appeal, the design was made compact and portable with effort put into making the design look as visually pleasing as possible without investing a lot of time as the client had placed a low importance to aesthetics.

5.0 Closing Remarks and Recommendations

Based on our analysis, our team's engine inhibiting system satisfies the client's needs for cold weather performance, ease of maintenance, user friendliness, system flexibility, and mobility. For the hot slush process, we are able to provide the maximum design fluid pressure of 160 psi at the Doghouse in air temperatures down to -30°C. For the cold slush process, the globe valves allow pressure and flow regulation to suit a wide range of engines tested at the facility, as well as future models. The layout of the piping allows easy access to all the components of the system for use and maintenance. The system's cart implementation allows the system to be easily moved between the test site and Preparation building, even with snow up to 4" on the ground, and the height and width of the cart will fit through standard exterior door openings.

The Doghouse implementation is largely outside the scope of this report as it is too large to perform a proper analysis based on project time constraints and currently limited information from GE. However, our team has some recommendations on how to approach the implementation.

The primary issue with the Doghouse line is that it is exposed to the elements, and although 316 stainless steel is resistant to corrosion, it does not insulate the inhibitor fluid from cold winter temperatures. Cold fluid temperature for Royco 481 causes a large spike in viscosity. This explains the large pressure head losses in the pipe, as the calculations for pressures losses assume a fluid temperature of -30°C, the coldest air temperature at which the TRDC would be willing to perform tests outdoors. Heating the Doghouse line can be done by wrapping the entire line with heating tape and insulating it to bring viscosity of the inhibitor fluid to an acceptable value where pressure losses are much more acceptable. This can allow for a reduction of the pipe diameter of the pipeline as well as a size reduction of the system pump if required.

Another issue with the Doghouse line is the automation of the control valves inside the Doghouse. During testing, personnel are prohibited inside or around the Doghouse, making manual control impossible. Therefore, our team recommends automated valves at the tie-in point consisting of pneumatic or oil-safe solenoid valves. A 2-way/1-postion valve will be used for isolation, and a 3-way/2 position valve will be used to switch from fuel to inhibitor fluid supply. It also important to note that our team does not know at this time if a separate bypass return or pressure relief line is required since a piping and instrumentation diagram for the Doghouse cannot be provided at the present time due to legal concerns, so that should also be left for consideration.

Our team also recommends having the coupling point for the Doghouse line on the other side of the test area walls by extending the line horizontally through the wall. This is primarily for safety concerns as having the engine inhibiting system near the wind generator at the TRDC is a hazard if not anchored to the ground, and again, operators are prohibited inside the test area during engine testing. The added pressure losses caused by extending the Doghouse line can be avoided or neglected if the Doghouse line is heated to reduce the fluid viscosity within the pipe.

Overall, our team has designed a suitable inhibiting system that satisfies the design criteria determined at the start of the project, and more importantly, provides the TRDC with the much needed engine inhibiting functionality that the site requires. With the ability to inhibit aircraft engines on site, the TRDC can store engines on site for longer periods of time. Ultimately, this allows the TRDC to perform multiple test cycles on various engines, reduces site downtime, and allows the facility to operate all year long.

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Appendix A

Conceptual Design and Selection Process

Table of Contents

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A. Concept Selection

This section outlines the concept brainstorming, screening, and selection processes used by our team when developing all initial and secondary conceptual designs. Before our team started the concept selection we first weighed the criteria that each concept would be compared against.

A.1 Concept Criteria Weighting

Our team analyzed the concept criteria to develop a weighting for each criteria. This was done in order to distinguish more important criteria from the other criteria. Our team members individually used a criteria weighting matrix to evaluate and weigh all of the criteria against each other and then all of the individual weights were averaged to achieve the final criteria weights to use in the concept screening process. Our team reviewed and revised the first concept criteria weighting due to some minor changes to the clients' importance of specific needs, such as mobility. An example of one team member's individual concept criteria weighting matrix, as well as the weights evaluated by each team member and the average weighting are shown in TABLE I. Once all of the concept criteria were weighted, the weighted criteria were used in the preliminary concept scoring.

TABLE I - CRITERIA WEIGHING MATRIX

Criteria		Mobility	Cold Weather Performance	System Flexibility	User Friendliness	Ease of Maintenance	Cost
		A	B	C	D	E	F
A	Mobility	-	B	A	D	A	F
B	Cold Weather Performance	-	-	B	B	B	B
C	System Flexibility	-	-	-	D	E	F
D	User Friendliness	-	-	-	-	D	F
E	Ease of Maintenance	-	-	-	-	-	F
F	Cost	-	-	-	-	-	-
	Total Hits - Steve	2	5	0	3	1	4
	Weightings	0.133	0.333	0.000	0.200	0.067	0.267
	Total Hits - Sadegh	1	5	4	2	3	0
	Weightings	0.067	0.333	0.267	0.133	0.200	0.000
	Total Hits - Mike	3	4	2	4	1	1
	Weightings	0.200	0.267	0.133	0.267	0.067	0.067
	Total Hits - Clarence	3	3	2	2	2	3
	Weightings	0.200	0.200	0.133	0.133	0.133	0.200
	Average Weightings	0.150	0.285	0.125	0.185	0.120	0.135

A.2 Preliminary Concepts

The preliminary concepts were generated initially through individual brainstorming, and then refined through design team discussion. Our team developed six main concepts (A-F) and a few sub-concepts, for a total of thirteen concepts to be evaluated in the concept scoring matrix to follow the concept descriptions.

A.2.1 Concept A – Utility Trailer

Concept A, shown in Figure 1, is a trailer based system that can be pulled behind a vehicle with a trailer hitch.

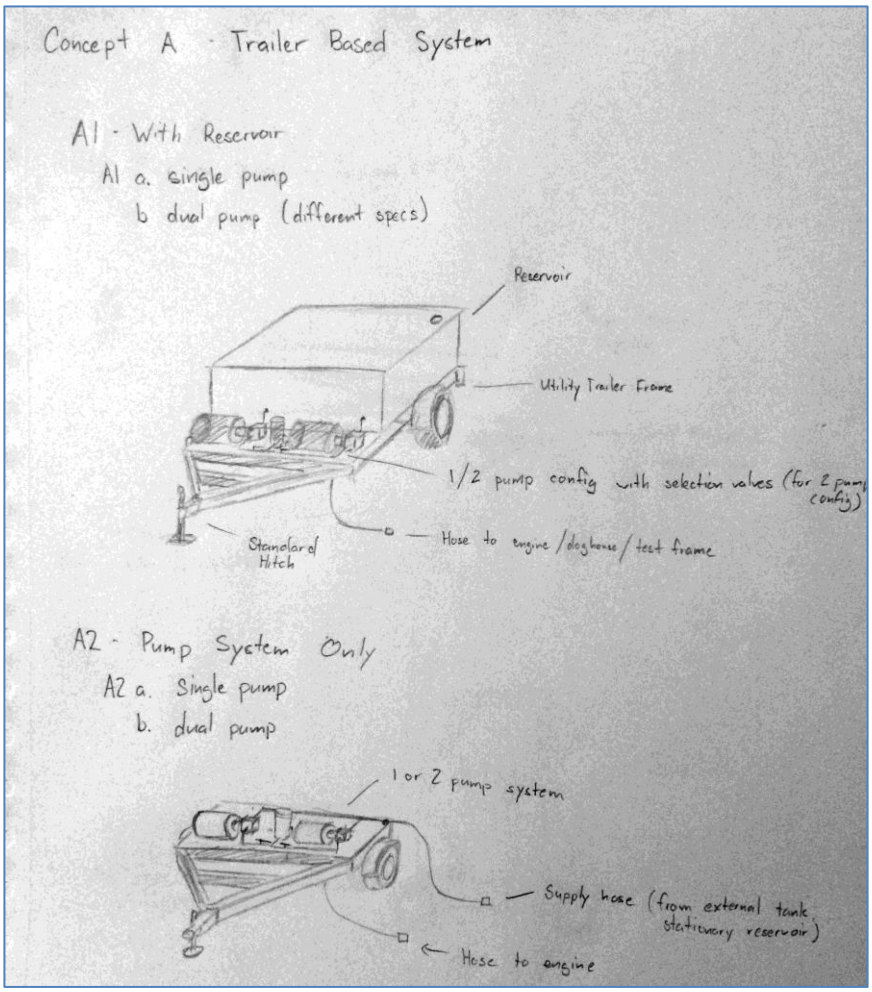

Figure 1 - Concept A – Utility Trailer

Concept A1a has the following key features:

- Fully portable engine inhibiting system
    - Reservoir on the utility trailer frame as well as the required pump system
    - Requires vehicle with trailer hitch to move between locations
- Single pump configuration (capable of supplying hot or cold slush operating pressures)
- Hose to supply inhibitor fluid to engine via the Doghouse or thrust frame (hot slush) or directly to engine for cold slush in Preparation building

Concept A1b has the following key features

- Fully portable engine inhibiting system
    - Reservoir on the utility trailer frame as well as the required pump system
    - Requires vehicle with trailer hitch to move between locations
- Two pump configuration
    - One pump capable of supplying hot slush operating pressures
    - One pump capable of supplying cold slush operating pressures
- Hose to supply inhibitor fluid to engine via the Doghouse or thrust frame (hot slush) or directly to engine for cold slush in Preparation building

Concept A2a has the following key features:

- Semi portable engine inhibiting system
    - Required pump system on the utility trailer frame
    - Requires vehicle with trailer hitch to move between locations
- Reservoir at a fixed location
    - May require two reservoirs (one for Preparation building and one for base of thrust frame)

- Requires hose to connect reservoir to pump

- Single pump configuration (capable of supplying hot or cold slush operating pressures)
- Hose to supply inhibitor fluid to engine via the Doghouse or thrust frame for hot slush or directly to engine for cold slush in Preparation building

Concept A2b has the following key features

- Semi portable engine inhibiting system
  - Required pump system on the utility trailer frame
  - Requires vehicle with trailer hitch to move between locations
- Reservoir at a fixed location
  - May require two reservoirs (one for Preparation building and one for base of thrust frame)
  - Requires hose to connect reservoir to pump
- Two pump configuration
  - One pump capable of supplying hot slush operating pressures
  - One pump capable of supplying cold slush operating pressures
- Hose to supply inhibitor fluid to engine via the Doghouse or thrust frame for hot slush or directly to engine for cold slush in Preparation building

A.2.2 Concept B – Scissor Lift or Forklift

Concept B, shown in Figure 2, uses either a cargo loader/scissor lift (B1) or a forklift (B2) to carry/lift the engine inhibiting system to a desirable height to reduce the pump head, hence requiring a smaller pump to inhibit the engine.

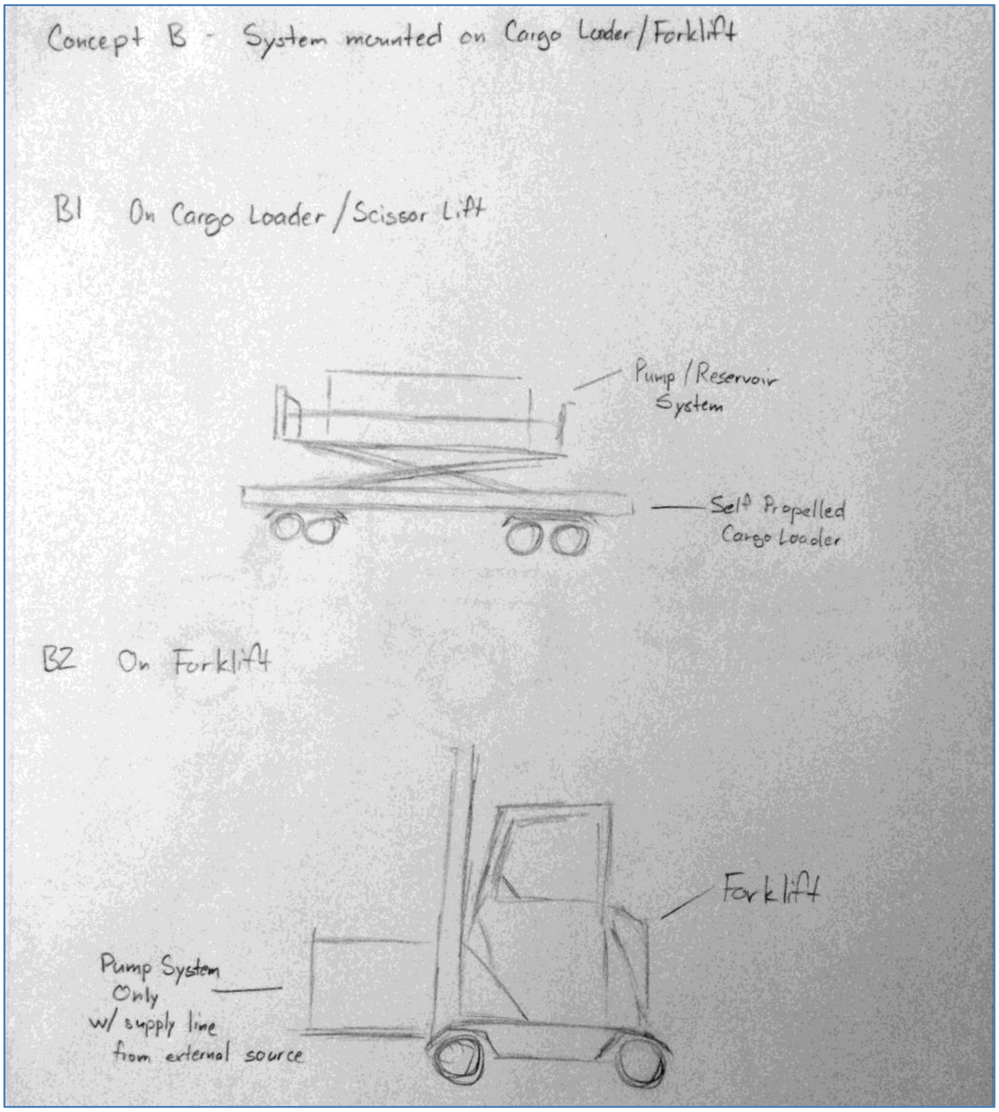

Figure 2 - Concept B1 – Scissor Lift, Concept B2 – Forklift

Concept B1 has the following key features:

- Self-propelled cargo loader or scissor lift allows for easy movement of engine inhibiting system between thrust frame and Preparation building
- Adjustable height of engine inhibiting system reduces pump head
    - Therefore a smaller and more economical pump
- Small reservoir with engine inhibiting system

Concept B2 has the following key features:

- Self-propelled Forklift
    - Ease of movement between thrust frame and Preparation building
    - Requires certified operator
- Adjustable height of engine inhibiting system reduces pump head
    - Therefore a smaller and more economical pump
- Small reservoir with engine inhibiting system

A.2.3 Concept C – Pick-up Truck

Concept C, shown in Figure 3, has the engine inhibiting system fixed in the bed of a pick-up truck.

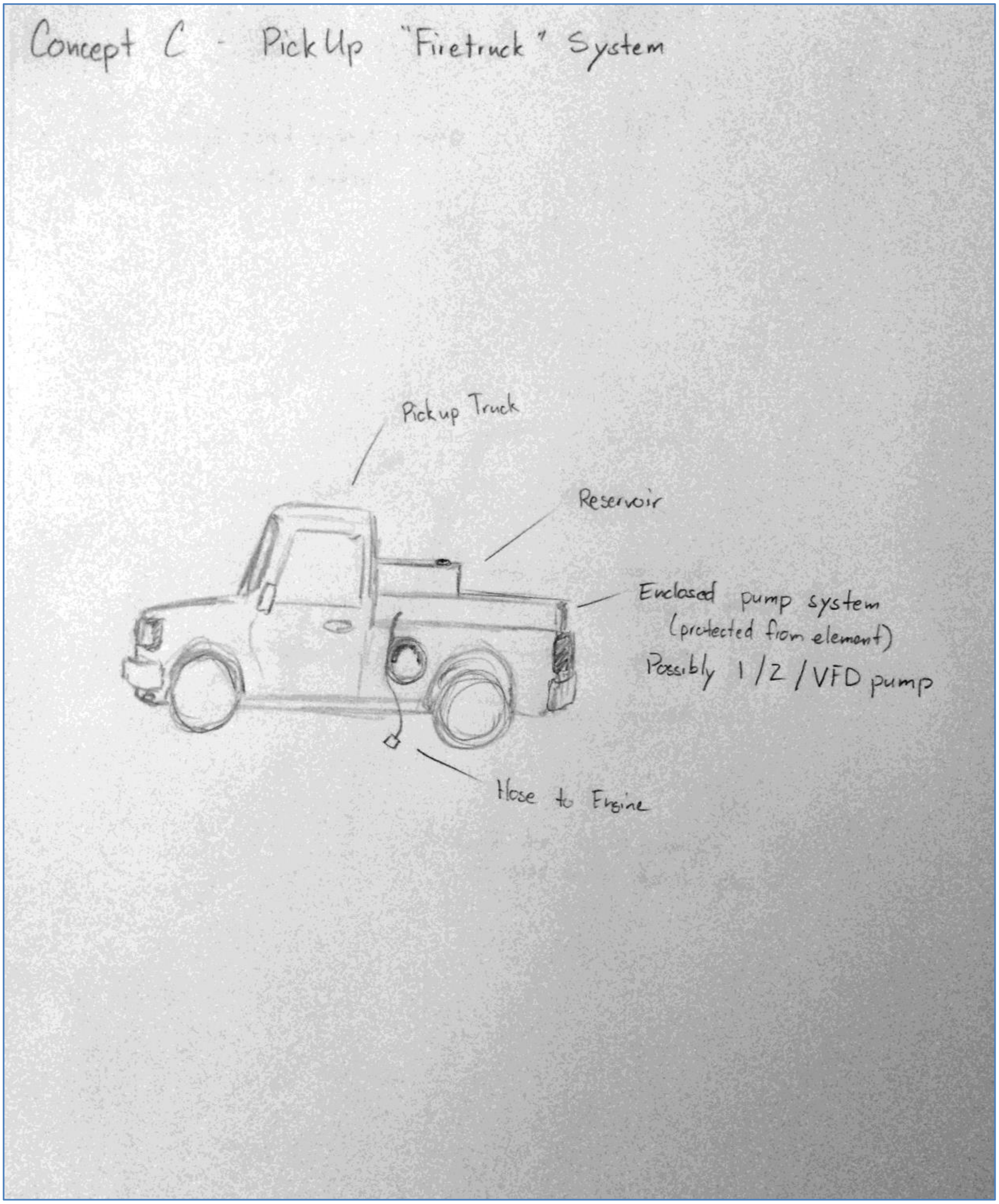

Figure 3 - Concept C – Pick-up Truck

The key features of **Concept C** are as follows:

- Fully portable engine inhibiting system
- Reservoir attached to the back of the truck bed
  - Fairly easy to refill reservoir
- Cover on truck bed to protect engine inhibiting system from elements
- Multiple pump options
  - Single pump capable of supplying hot and cold slush operating pressures
  - Two pumps – one pump each capable of supplying hot or cold slush operating pressures
  - VFD pump – adjustable to hot or cold slush operating pressures
- Supply hose to engine for inhibitor fluid
  - Attached to connector hose from base of Doghouse to engine (hot slush)
  - Connected directly to engine (cold slush)

A.2.4 Concept D – Hand Cart

Concept D, shown in Figure 4, uses a hand cart (similar to a pressure washer cart) to transport the engine inhibiting system.

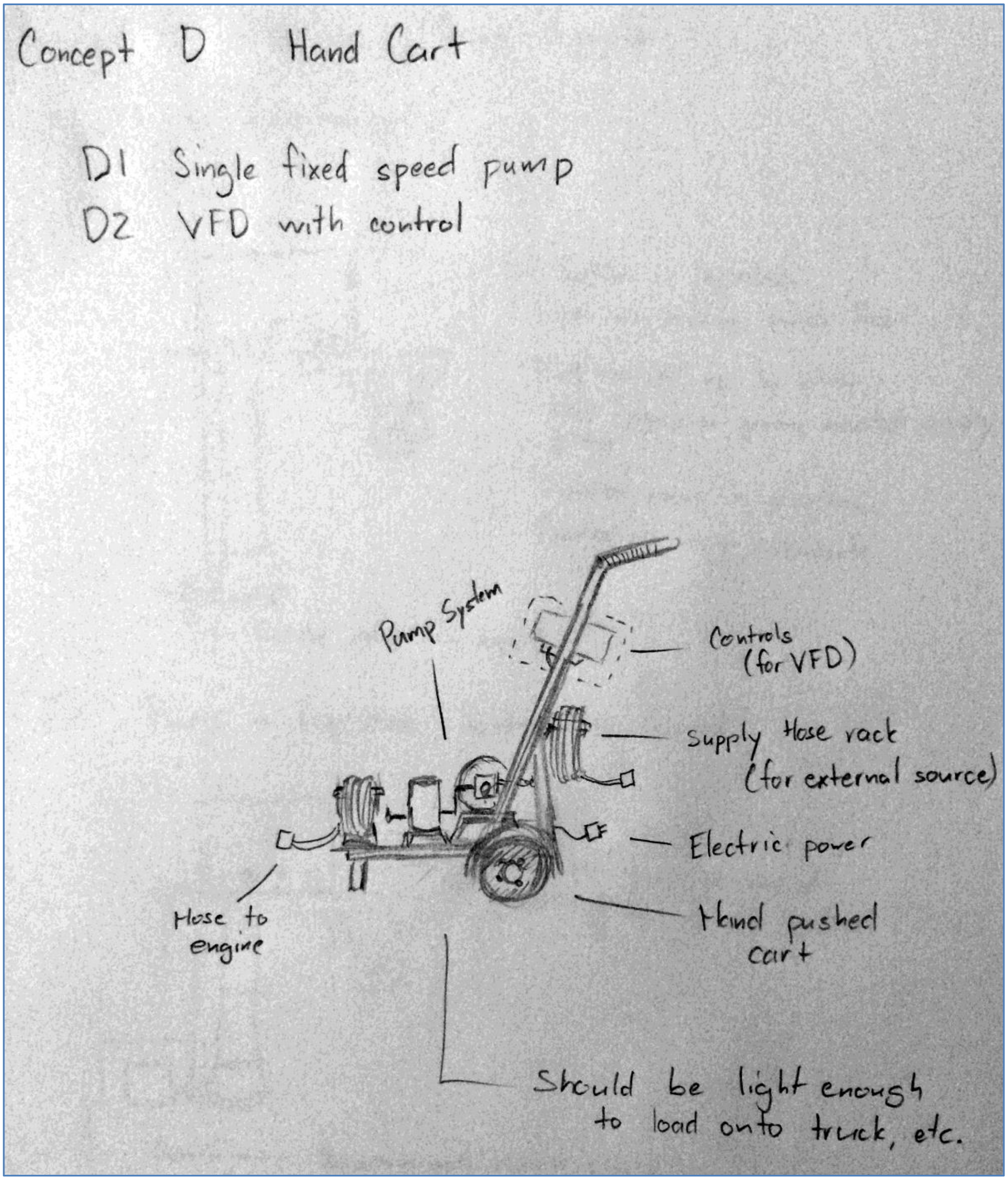

Figure 4 - Concept D – Hand Cart

Concept D1 has the following key features:

- Semi portable engine inhibiting system
- Reservoir is in a fixed location that engine inhibiting system connects to
- Single pump capable of supplying hot and cold slush operating pressures
- Supply hose to engine for inhibitor fluid
    - Supply hose attached to connector hose from base of the Doghouse to engine (hot slush)
    - Supply hose connected directly to engine (cold slush)

Concept D2 has the following key features:

- Semi portable engine inhibiting system
- Reservoir is in a fixed location that engine inhibiting system connects to
- VFD pump capable of supplying hot and cold slush operating pressures
- VFD controls mounted between handles of cart
- Supply hose to engine for inhibitor fluid
    - Supply hose attached to connector hose from base of the Doghouse to engine (hot slush)
    - Supply hose connected directly to engine (cold slush)

A.2.5 Concept E – Stationary/ Semi-Modular

Concept E, uses the Doghouse to house some or the entire engine inhibiting system components, as seen in Figure 5.

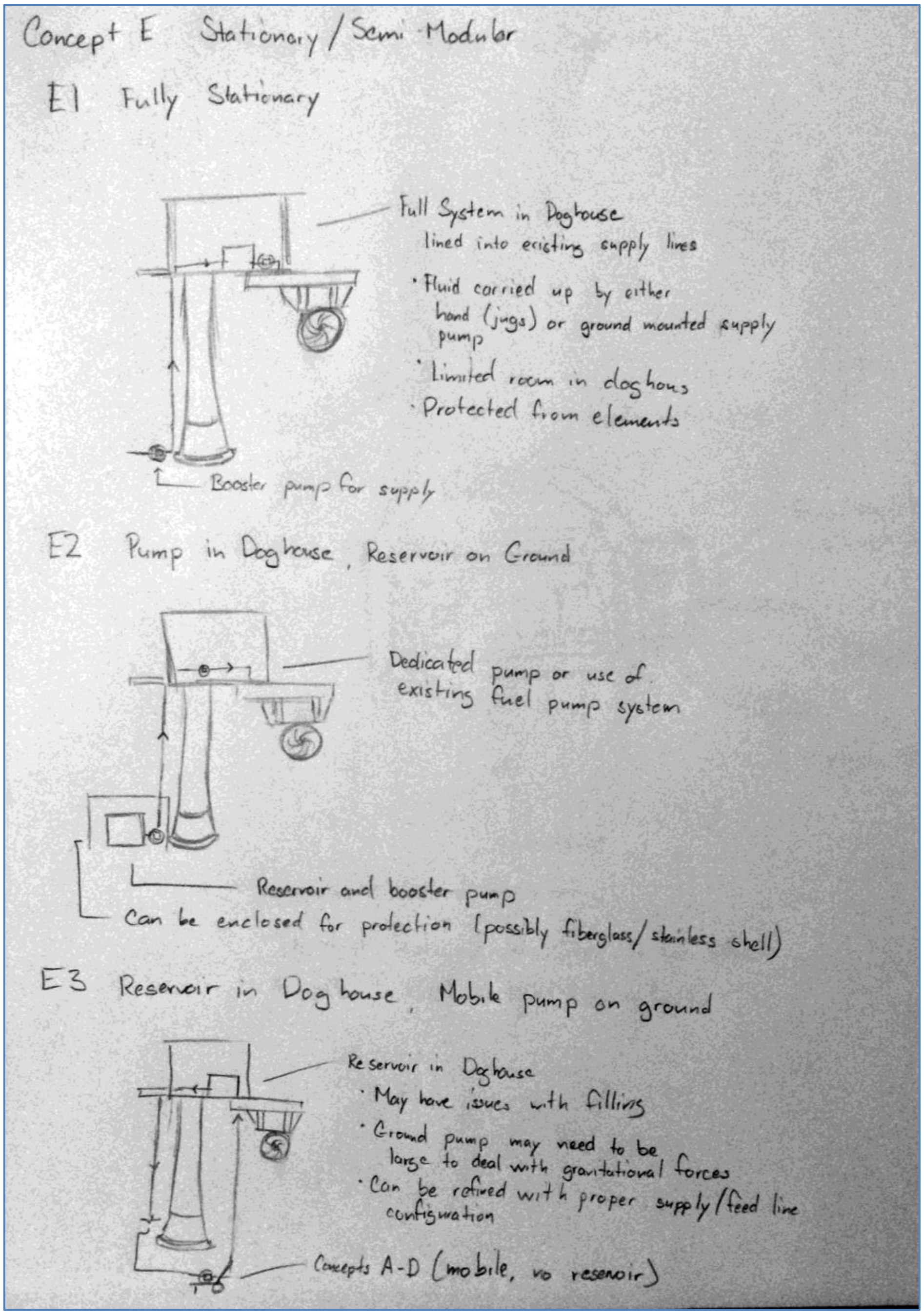

Figure 5 - Concept E – Stationary/Semi-Modular

Concept E1 has the following key features:

- Full system in Doghouse and connected to existing fuel supply lines
    - Engine inhibiting system protected from elements in the Doghouse
- Reservoir located in the Doghouse
    - Inhibitor fluid either pumped to fill reservoir in Doghouse or manually carried by hand in small containers (e.g. 5 Liter jugs)
- Optional booster pump on ground level to fill reservoir
- Limited by space in the Doghouse (already occupied by other equipment)

Concept E2 has the following key features:

- Dedicated inhibitor fluid pump in the Doghouse and connected to existing fuel supply lines
    - Engine inhibiting system pump protected from elements in Doghouse
    - Less space required in Doghouse (only need space for pump)
- Reservoir located on ground level
    - Inhibitor fluid pumped by dedicated pump in the Doghouse with option for supplemental booster pump
    - Enclosure to protect reservoir and optional booster pump from elements

Concept E3 has the following key features:

- No pump system; requires one of concepts A-D or F for pump system
- Reservoir located in the Doghouse
    - Inhibitor fluid either pumped to fill reservoir in Doghouse or manually carried by hand in small containers (e.g. 5 Liter jugs)
    - Reservoir in Doghouse to help counter act pump head

A.2.6 Concept F – Handheld System

Concept F, shown in Figure 6, features a portable pump that can be carried by hand (dependent on weight of selected components) and connects to a reservoir and to the engine.

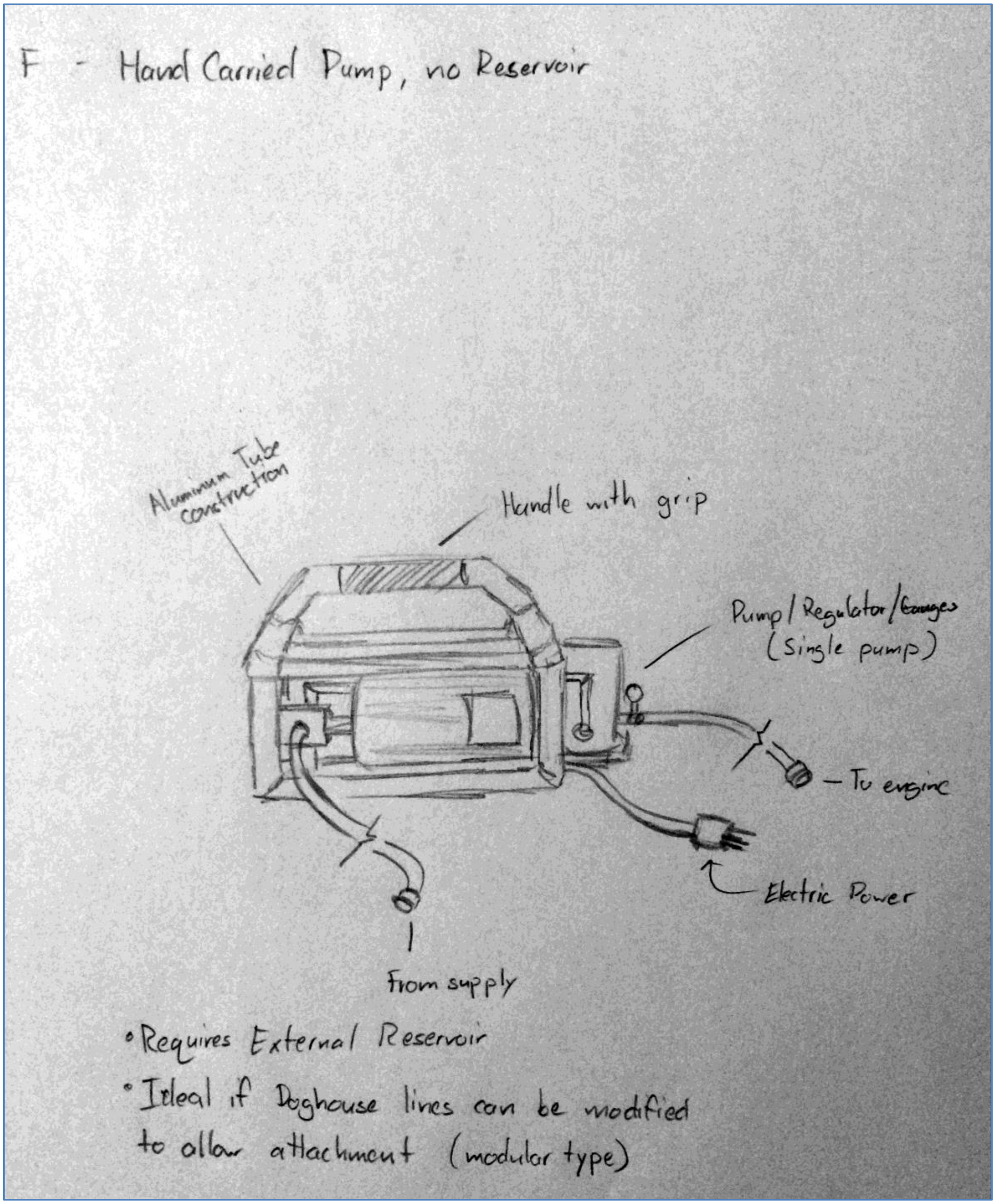

Figure 6 – Concept F – Handheld System

The key features of **Concept F** are as follows:

- Can be transported by one person (mobile)
  - Able to perform hot slush at Doghouse or cold slush in Preparation building
- Requires an external reservoir to supply inhibitor fluid to engine
- Weight is a limiting factor to transport by hand
  - System components need to be lightweight
- Requires extra hoses:
  - To connect to the reservoir
  - To connect to the engine

A.2.7 Preliminary Concept Scoring

The concepts with some main similarities are labeled with the same letter for ease of reference and scoring/screening. Our team scored the concepts individually to achieve an unbiased opinion (to avoid agreement between each member based on one member's scoring) and then averaged the individual results to determine the top scoring concepts. TABLE II shows a sample of one team member's scoring along with every team members overall scoring and the overall average score of each concept. From TABLE II, the design team was able to eliminate concepts A through C.

TABLE II - INITIAL CONCEPT SCREENING

Weight	Selection Criteria	Control	Concepts												
		0	A1a	A1b	A2a	A2b	B1	B2	C	D1	D2	E1	E2	E3	F
0.150	Mobility	2	0	0	1	1	2	2	2	2	2	1	1	0	1
0.285	Cold Weather Performance	0	1	1	1	1	1	1	1	1	1	2	2	1	1
0.125	System Flexibility	2	0	1	0	1	1	1	1	1	2	0	1	1	1
0.185	User Friendliness	2	2	1	1	0	0	0	1	1	1	2	2	1	2
0.120	Ease of Maintenance	2	1	1	0	0	1	1	1	1	1	1	1	1	2
0.135	Cost	2	0	1	0	1	1	2	2	1	0	0	0	0	1
Overall Score - Steve		0.33	0.54	0.34	0.62	0.43	0.46	0.32	0.51	1.15	1.14	0.91	1.04	0.48	1.31
Overall Score - Sadegh		0.33	0.18	0.31	0.29	0.42	0.43	0.12	0.71	0.29	0.13	0.80	0.71	0.68	0.32
Overall Score - Mike		0.33	0.21	0.21	0.05	0.05	0.32	0.32	0.32	1.41	1.27	1.20	1.32	1.07	1.53
Overall Score - Clarence		0.33	0.50	0.49	0.37	0.36	0.33	0.32	0.61	1.59	1.14	1.03	0.65	1.16	1.47
Average Overall Score		**0.33**	**0.25**	**0.23**	**0.33**	**0.31**	**0.38**	**0.21**	**0.54**	**1.11**	**0.92**	**0.99**	**0.93**	**0.85**	**1.16**

The weighting and scoring legend, as shown in TABLE III, presents the corresponding score for each weight used in evaluating each concept for all stages of concept refinement. Before scoring the secondary concepts, the team optimized concepts D, E, and F by integrating and fusing the strongest attributes of specific concepts together.

TABLE III - SCORING LEGEND FOR TABLE II

Weight	Score
Very Strong	2
Strong	1
Neutral	0
Weak	1
Very Weak	2

A.3 Secondary Concept Analysis

The top scoring preliminary concepts (D, E, and F) were analyzed in greater detail to find strengths and areas of improvement for each concept.

A.3.1 Preliminary Concept D Analysis

The hand cart concept scored very well in the preliminary concept scoring, but was still optimized by combining it with concept E2 to replace the fixed pump beside the reservoir. The optimization will allow for the mobility of the cart to perform cold slush in the Preparation building while maintaining the ability to perform hot slush at the thrust frame.

A.3.2 Preliminary Concept E Analysis

Concept E1 was optimized by removing the booster pump for filling the reservoir and relying on carrying jugs of inhibitor fluid up to the Doghouse instead. Removal of the booster pump will decrease the cost of the system but in turn reduce user friendliness by requiring manual labour to carry the inhibitor fluid up to the Doghouse. Another optimization to Concept E1 is the addition of the cold slush hoses that run from the pump in the Doghouse down to ground level to inhibit an engine not mounted to the thrust frame.

A.3.3 Preliminary Concept F Analysis

Our team found, after referral to the engine inhibiting system used at Plant Six (configuration and key components), that concept F would not be worth pursing, as the engine inhibiting system components would be too heavy and awkward to easily transport by a handheld system. In addition to the awkwardness of the handheld system, inlet and outlet hoses would need to be transported by hand as well.

A.4 Integration and Fusion of Preliminary Concepts

The analysis of Concept D, E, and F lead to the generation of three concepts (Concept E1+, E2, and E2+D) composed of key attributes from the top scoring preliminary concepts, shown in Figure 7.

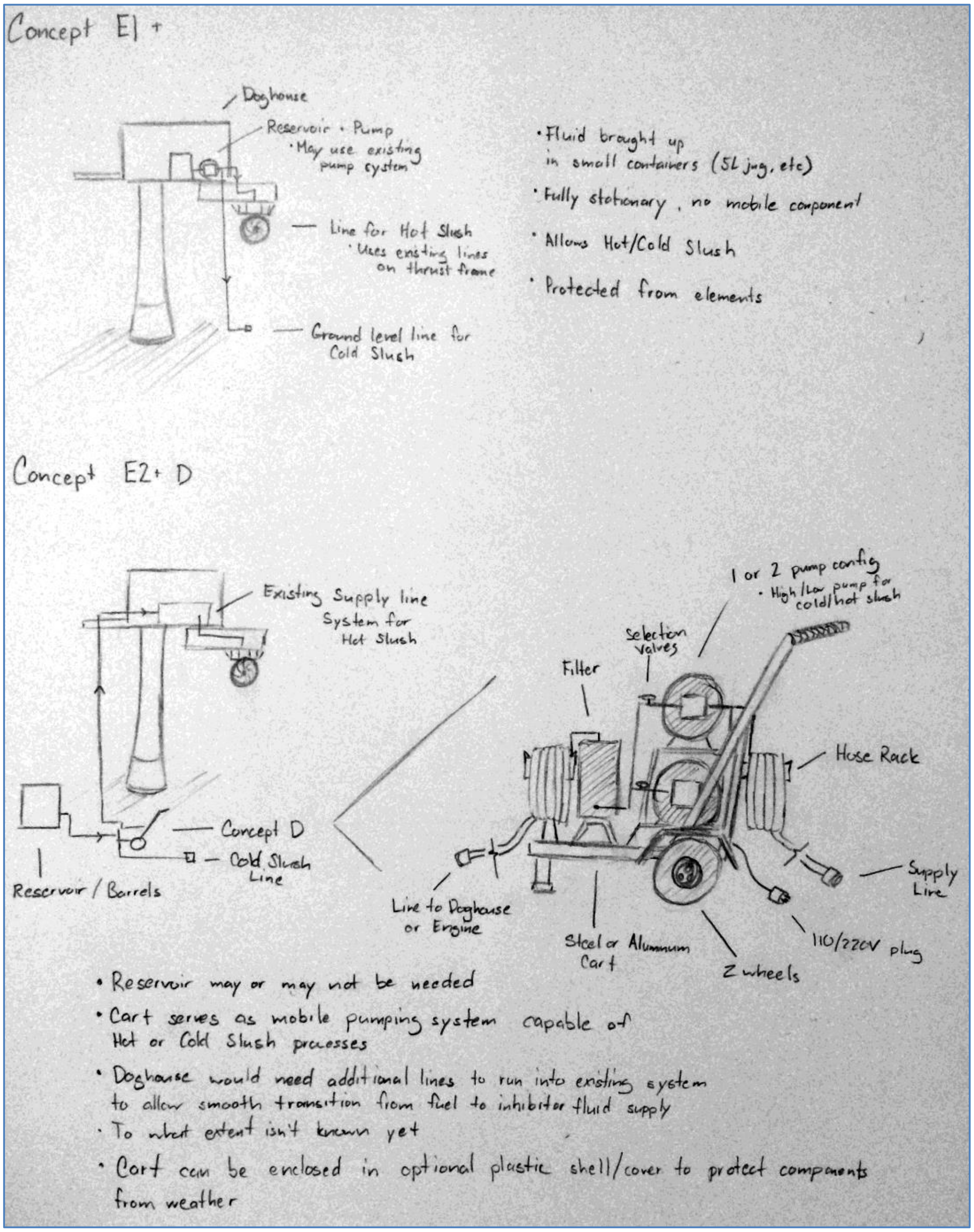

Figure 7 - Refined Concepts after Initial Screening

Concept E1+ - Fixed to Doghouse

- May use existing pump system (fuel pump)
- Uses existing lines/hoses on thrust frame for inhibiting engine via hot slush process
- New ground line/hose run from the Doghouse to ground for inhibiting engine via cold slush process
- Inhibitor fluid transported to the Doghouse by small containers (5 liter jug)
- Fully stationary (no mobile components)
- Allows for hot and cold slush processes
- Engine inhibiting system protected from elements (located in the Doghouse)

Concept E2 – System in Doghouse, Reservoir on Ground

- Dedicated pump in the Doghouse or optional use of existing fuel pump to supply inhibitor fluid to hot slush engine
- Reservoir located on ground level for easy refilling
- Booster pump needed to pump inhibitor fluid to the Doghouse
- Optional enclosure for reservoir and booster pump to protect from elements

Concept E2+D – Hand Cart with Mobile Reservoir

- Reservoir may or may not be needed (option for barrel inhibitor fluid comes in to be used as reservoir)
- Cart serves as mobile pumping system for hot or cold slush processes
- The Doghouse would need additional lines/hoses to run into existing system to allow smooth transition from fuel to inhibitor fluid supply
- Cart can be enclosed in removable shell/cover to protect components from elements
- Electrical plug may need to be installed at base of the Doghouse to power electrical pump on cart
- Optional number of pumps (1 or 2 pumps for different applications)

A.5 Secondary Concepts Scoring and Selection

The three concepts generated were then scored by each individual team member in the same fashion as in the preliminary concept scoring, where the individual overall concept scores are averaged to determine the highest scoring concept, as seen in TABLE IV.

TABLE IV - SECONDARY CONCEPT SCREENING

Weight	Selection Criteria	Control	Concepts		
		0	E1+	E2	E2+D
0.150	**Mobility**	2	0	1	2
0.285	**Cold Weather Performance**	0	2	2	1
0.125	**System Flexibility**	2	1	1	2
0.185	**User Friendliness**	2	1	1	1
0.120	**Ease of Maintenance**	2	1	2	2
0.135	**Cost**	2	2	2	1
Overall Score - Steve		0.330	1.270	0.990	1.395
Overall Score - Sadegh		0.330	0.920	0.890	0.910
Overall Score - Mike		0.330	1.035	0.835	1.145
Overall Score - Clarence		0.330	0.970	1.090	1.260
Average Overall Score		**0.33**	**1.05**	**0.95**	**1.18**

The Hand Cart with Mobile Reservoir (E2+D) was the highest scoring concept, which can be seen from TABLE IV. This concept *very strongly* meets the following selection criteria: mobility, system flexibility, and ease of maintenance, while *strongly* meeting cold weather performance, user friendliness, and cost. The Hand Cart with Mobile Reservoir Concept (E2+D) best meets the customer's needs and project objectives and is therefore analyzed in the detailed design section of the report.

Appendix B

Project Scheduling

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B. Project Scheduling

Our team has implemented a Work Breakdown Structure (WBS) and Gantt chart to provide visual aids for tracking the progress of the design project. The WBS, which can be found in the Appendix as Figure B1, divides the entire project into three phases: Project Definition, Conceptual Design, and Detailed Design. Each phase is further divided into small work packages that represent specific milestones and deliverables. Each of the three phases and their respective work packages are then placed on a Gantt chart, presented in Figure B2, to visually represent the progress of the project over the three month span given to our team. The due dates of each phase correspond to the completion of the phase's major deliverable, such as technical reports and oral presentations, and are set by our team's course instructor. Smaller work packages and milestones are given estimated internal due dates that may or may not be met depending on the pace of our team's progress and unforeseeable events such as illness.

Our team's incorporation of proper project scheduling aids us in ensure we can plan our internal deadlines to comfortably meet all external deadlines, and adjust our pace of work depending on the level of progress our team reaches at any point of time during the duration of the project. A detailed WBS and Gantt chart will also help our client understand our team's scheduling expectations regarding the design project and give insight to our client of time periods where communication and collaboration are most necessary.

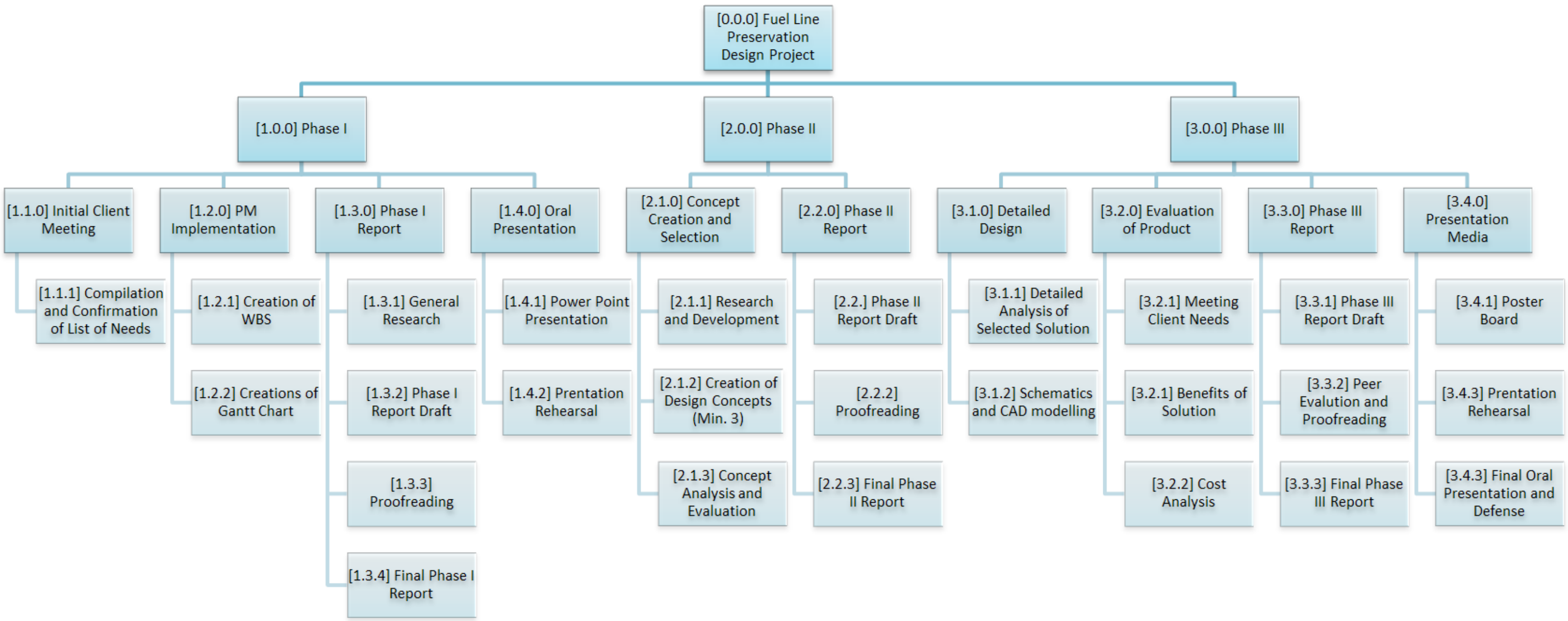
[0.0.0] Fuel Line Preservation Design Project
[1.0.0] Phase I
[2.0.0] Phase II
[3.0.0] Phase III
[1.1.0] Initial Client Meeting
[1.2.0] PM Implementation
[1.3.0] Phase I Report
[1.4.0] Oral Presentation
[2.1.0] Concept Creation and Selection
[2.2.0] Phase II Report
[3.1.0] Detailed Design
[3.2.0] Evaluation of Product
[3.3.0] Phase III Report
[3.4.0] Presentation Media
[1.1.1] Compilation and Confirmation of List of Needs
[1.2.1] Creation of WBS
[1.2.2] Creations of Gantt Chart
[1.3.1] General Research
[1.3.2] Phase I Report Draft
[1.3.3] Proofreading
[1.3.4] Final Phase I Report
[1.4.1] Power Point Presentation
[1.4.2] Prentation Rehearsal
[2.1.1] Research and Development
[2.1.2] Creation of Design Concepts (Min. 3)
[2.1.3] Concept Analysis and Evaluation
[2.2.] Phase II Report Draft
[2.2.2] Proofreading
[2.2.3] Final Phase II Report
[3.1.1] Detailed Analysis of Selected Solution
[3.1.2] Schematics and CAD modelling
[3.2.1] Meeting Client Needs
[3.2.1] Benefits of Solution
[3.2.2] Cost Analysis
[3.3.1] Phase III Report Draft
[3.3.2] Peer Evalution and Proofreading
[3.3.3] Final Phase III Report
[3.4.1] Poster Board
[3.4.3] Prentation Rehearsal
[3.4.3] Final Oral Presentation and Defense

Figure 1 - WBS

Task Name	Duration	Start	Finish
[1.0.0] Phase I	**15 days**	**Mon 9/15/14**	**Fri 10/3/14**
[2.0.0] Phase II	**15 days**	**Mon 10/6/14**	**Fri 10/24/14**
[2.1.0] Concept Creation and Selection	**10 days**	**Mon 10/6/14**	**Fri 10/17/14**
[2.1.1] Research	10 days	Mon 10/6/14	Fri 10/17/14
[2.1.2] Concept Design	7 days	Mon 10/6/14	Tue 10/14/14
[2.1.3] Concept Evaluation	3 days	Wed 10/15/14	Fri 10/17/14
[2.2.0] Phase II Report	**5 days**	**Mon 10/20/14**	**Fri 10/24/14**
[2.2.1] Report Draft	3 days	Mon 10/20/14	Wed 10/22/14
[2.2.2] Proofreading	0 days	Thu 10/23/14	Thu 10/23/14
[2.2.3] Final Draft	2 days	Thu 10/23/14	Fri 10/24/14
[3.0.0] Phase III	**27 days**	**Mon 10/27/14**	**Tue 12/2/14**
[3.1.0] Detailed Design	**14 days**	**Mon 10/27/14**	**Thu 11/13/14**
[3.1.1] Detailed Analysis	14 days	Mon 10/27/14	Thu 11/13/14
[3.1.2] CAD Modelling	14 days	Mon 10/27/14	Thu 11/13/14
[3.2.0] Evaluation of Product	**7 days**	**Fri 11/14/14**	**Mon 11/24/14**
[3.2.1] Client Needs	7 days	Fri 11/14/14	Mon 11/24/14
[3.2.2] Benefit Analysis	5 days	Tue 11/18/14	Mon 11/24/14
[3.2.3] Cost Analysis	5 days	Tue 11/18/14	Mon 11/24/14
[3.3.0] Phase III Report	**6 days**	**Tue 11/25/14**	**Tue 12/2/14**
[3.3.1] Report Draft	2 days	Tue 11/25/14	Wed 11/26/14
[3.3.2] Proofreading	2 days	Thu 11/27/14	Fri 11/28/14
[3.3.3] Final Draft	2 days	Mon 12/1/14	Tue 12/2/14
[3.4.0] Presentation Media	**6 days**	**Tue 11/25/14**	**Tue 12/2/14**
[3.4.1] Poster	3 days	Tue 11/25/14	Thu 11/27/14
[3.4.2] Rehearsal	2 days	Fri 11/28/14	Mon 12/1/14
[3.4.3] Final Oral Presentation	0 days	Tue 12/2/14	Tue 12/2/14

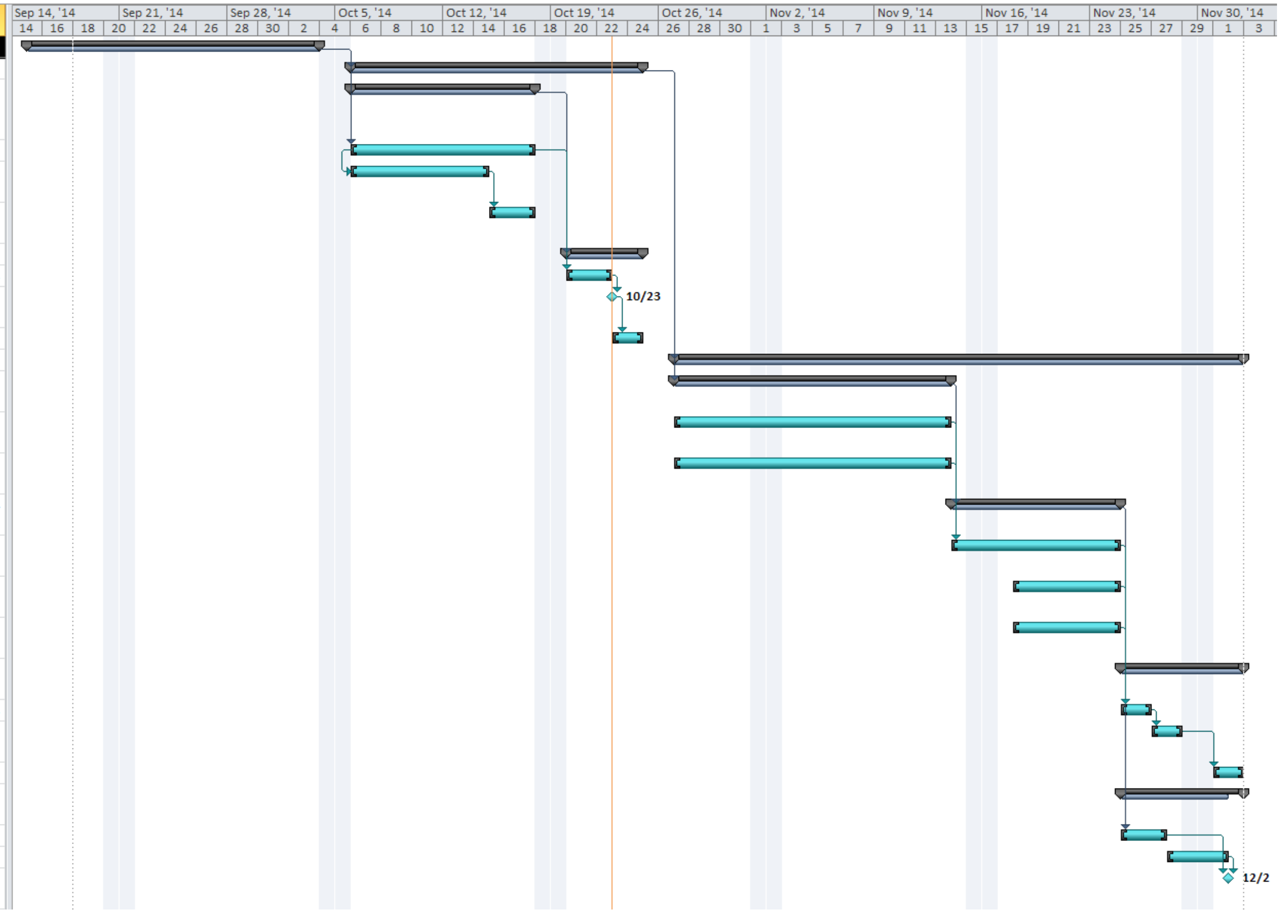

Figure 2 - Gantt Chart

Appendix C

Cost Overview

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C. Cost Overview

During the three month span of the project, the TRDC made clear with subsequent meetings that they are more concerned with the need for inhibiting functionality on site and less concerned with a low cost solution or payback period. Therefore, our team adjusted the initial list of customer needs to put much less emphasis on the overall cost of the project, as our customer does not require a detailed cost analysis. However, our team has compiled a bill of materials, shown in TABLE I, and cost breakdown, shown in TABLE II, for the inhibiting system to provide an estimated cost of the final design. Most parts are sourced from McMaster Carr® for convenience. Any parts that are source elsewhere are noted with square brackets in the product descriptions.

TABLE I: BILL OF MATERIALS

Part Number	Part Name	Description	Quantity	Unit of Measure	Price per Unit
		Piping System			
4443K618	316 SS Threaded Pipe Fitting - Elbow	High-Pressure 316 Stainless Steel Threaded Pipe Fitting, 1-1/2 Pipe Size, 90 Degree Elbow	10	Each	$125.87
4443K648	316 SS Threaded Pipe Fitting - Tee	High-Pressure 316 Stainless Steel Threaded Pipe Fitting, 1-1/2 Pipe Size, Tee	3	Each	$157.20
4452K448	316 SS Threaded Pipe Fitting - Coupling	Type 316 Stainless Steel Threaded Pipe Fitting, 1-1/2 Pipe Size, Coupling, 1000 PSI	3	Each	$39.90
4443K782	316 SS Threaded Pipe Fitting - 1-1/2 x 1 Reducing	High-Pressure 316 Stainless Steel Threaded Pipe Fitting, 1-1/2 x 1 Pipe Size, Reducing Coupling	2	Each	$69.88

Part Number	Part Name	Description	Quantity	Unit of Measure	Price per Unit
4627K331	Iron Threaded Pipe Fitting - Tee Reducing	Medium-Pressure Black Malleable Iron Threaded Fitting, 1-1/2 x 1 x 1-1/2 Pipe Size, Inline Reducing Tee	1	Each	$41.64
50925K261	SS Threaded Pipe Nipple - Hex Reducing	Compact Extreme-Pressure Steel Threaded Fitting, 1 x 3/4 Pipe Size, 2-3/32" Length, Hex Nipple	1	Each	$8.04
4452K813	316 SS Threaded Pipe Fitting - Coupling Reducing	Type 316 Stainless Steel Threaded Pipe Fitting, 3/4 x 1/4 Pipe Size, Reducing Coupling, 1000 PSI	1	Each	$16.18
4475K128	316 SS Threaded Pipe Nipple Schedule 80 2"	Thick-Wall 316/316L Stainless Steel Threaded Pipe Nipple, 1-1/2 Pipe Size x 2" Length	15	Each	$19.24
4475K48	317 SS Threaded Pipe Nipple Schedule 80 3"	Thick-Wall 316/316L Stainless Steel Threaded Pipe Nipple, 1-1/2 Pipe Size x 3" Length	2	Each	$26.91
4475K58	318 SS Threaded Pipe Nipple Schedule 80 4"	Thick-Wall 316/316L Stainless Steel Threaded Pipe Nipple, 1-1/2 Pipe Size x 4" Length	1	Each	$35.53
4475K68	319 SS Threaded Pipe Nipple Schedule 80 5"	Thick-Wall 316/316L Stainless Steel Threaded Pipe Nipple, 1-1/2 Pipe Size x 5" Length	1	Each	$43.21
4475K78	320 SS Threaded Pipe Nipple Schedule 80 6"	Thick-Wall 316/316L Stainless Steel Threaded Pipe Nipple, 1-1/2 Pipe Size x 6" Length	3	Each	$50.85
	316 SS Unthreaded Pipe Schedule 80	Thick-Wall 316/316L Stainless Steel Unthreaded Pipe, Both Ends, 1-1/2" Pipe Size [Supplier TBD]	77	Per Foot	$0.00

Part Number	Part Name	Description	Quantity	Unit of Measure	Price per Unit
3902K11	SS Gauge with NIST Certificate	High Accuracy Liquid-Filled Stainless Steel Gauge, NIST Certificate, 2-1/2" Dial, 1/4 NPT Bottom	1	Each	$187.49
47885K77	316 SS Check Valve 400 psi	Stainless Steel Check Valve, PTFE Seal, Medium-Pressure, 1-1/2 NPT Female	2	Each	$301.85
46495K25	316 SS Ball Valve 1000 psi	Type 316 Stainless Steel Ball Valve with Lever and Unrestricted Flow, 1-1/2" Pipe Size	5	Each	$119.18
4737K57	Super High Pressure Steel Globe Valve 1975 psi	Super-High-Pressure Steel Globe Valve, 1-1/2" NPT Female	2	Each	$252.54
54675K44	Chemical Hose for 1-1/2" Pipe with 316 Fitting	High-Temperature Chemical Hose, 1-1/2 NPT Male 316 Stainless Steel Fittings, 350 PSI, Up to 100'	3	Each	$256.30
6136K441	Base Mount NEMA 184T, 2hp, 1200 RPM	Three-Phase 208-230/460 VAC @ 60 Hz Motor, Totally Enclosed Fan-Cooled (TEFC) Enclosure With Automatic Overload Protection	1	Each	$898.63
	Haight 8US Universal Stainless Internal Gear Pump	Haight 8US Universal Stainless Internal Gear Pump [Gekko Inc.]	1	Each	$3,851.82
PVVF61	Parker Velcon VF-61/62 Filtration Housing	Max. Operating Pressure: 150 psi, Inlet/Outlet connection: 1-1/2” NPT [JMEsales]	1	Each	$351.54
3HPZ5	Jaw Coupling Hub	Jaw Cplg Hub, Bore Dia .500 In, Size JCC36 [Grainger]	1	Each	$125.25

Part Number	Part Name	Description	Quantity	Unit of Measure	Price per Unit
30UP46	Jaw Coupling Hub	Jaw Coupling Hub, 1-1/8in., Aluminum [Grainger]	1	Each	$134.20
3HRF1	Jaw Coupling Insert	Urethane Spider, Tq 165 In-Lbs, JC26/MJC41 [Grainger]	1	Each	$17.40
		Pipe Mounting and Insulation			
3188T53	316 SS Strut Channel with Bracket	Strut Channel with Mounting Plate, Solid, 1-5/8" x 1-5/8", Type 316 Stainless Steel, 1-1/2' Length	1	Each	$49.39
33085T758	316 SS Strut Channel Slotted	Stainless Steel Strut Channel, Slotted, 1-5/8" x 1-5/8", Type 316, 2' Length	3	Each	$33.04
3656T88	Plastic Strut Mount Clamp for Insulated Tube	Strut-Mount Clamp for Insulated Tubing for 1-1/2" Outside Diameter, Black Plastic	8	Each	$5.91
54325K139	1/2" Pipe Insulation - 6'	Low Temperature Polyethylene Foam Pipe Insulation, Self-Seal, 1/2" Thick, 2" Insulation ID, 6' Long, Black	24	Each	$11.25
9619K34	1/2" Pipe Insulation - Elbow Fitting	Low Temperature Polyethylene Pipe Insulation Fitting, 90 Degree Elbow, 1/2" Thick, 2-1/8" Insulation ID	10	Each	$6.17
9619K74	1/2" Pipe Insulation - Tee Fitting	Low Temperature Polyethylene Pipe Insulation Fitting, Tee, 1/2" Thick, 2-1/8" Insulation ID	4	Each	$7.30

Part Number	Part Name	Description	Quantity	Unit of Measure	Price per Unit
4530K183	White Latex Paint - 1 quart	White Latex Paint for Pipe Insulation Outdoor Use	2	Each	$21.11
4463K211	Contact Adhesive - 1 pint	Contact Adhesive for Pipe Insulation	1	Each	$14.34
Cart Materials					
6527K234	Steel Square Tube 1-1/2" .083"	Low-Carbon Steel Square Tube, 1-1/2" Wide, 1-1/2" High, .083" Wall Thickness, 6'	2	Each	$33.64
6527K234	Steel Square Tube 1-1/2" .083"	Low-Carbon Steel Square Tube, 1-1/2" Wide, 1-1/2" High, .083" Wall Thickness, 3'	13	Each	$20.18
6527K234	Steel Square Tube 1-1/2" .083"	Low-Carbon Steel Square Tube, 1-1/2" Wide, 1-1/2" High, .083" Wall Thickness, 1'	2	Each	$11.10
6544K57	Steel 24"x 36" Sheet .075"	General Purpose Low-Carbon Steel, Sheet, .075" Thick, 24" x 36"	2	Each	$64.95
7767T231	Steel Tube 1" - 3'	Low-Carbon Steel Tubing, 1" OD, .870" ID, .065" Wall Thickness	1	Each	$6.71
53795T15	8" Air Ride Caster - Rigid	Heavy Duty Air-Ride Caster, Rigid, 8" x 2.8"/2.5-4 Single Wheel, 330 lb Capacity	2	Each	$77.64

Part Number	Part Name	Description	Quantity	Unit of Measure	Price per Unit
53795T11	8" Air Ride Caster - Swivel	Heavy Duty Air-Ride Caster, Swivel, 8" x 2.8"/2.50-4 Single Wheel, 330 lb Capacity	2	Each	$119.45
270S26X145	Tremclad Semi Gloss Black	Tremclad Rust Preventive Paint, 946mL [HOME DEPOT]	2	Each	$14.47
92865A765	9/16"-12 Steel Cap Screw	Medium-Strength Grade 5 Zinc-Plated Steel Cap Screw, 9/16"-12 Fully Threaded, 2" Long, Pkg of 10	2	Each	$9.34
93827A250	9/16"-12 Steel Hex Nut	Zinc Aluminum Coated Steel Hex Nut, Grade 8, 9/16"-12 Thread Size, 7/8" Wide, 31/64" High, Pkg of 25	1	Each	$11.65
90107A106	9/16" 316 SS Flat Washer	Type 316 Stainless Steel Flat Washer, 9/16" Screw Size, 0.578" ID, 1.062" OD, Pkg of 50	1	Each	$9.48
Doghouse Coupling Point					
4452K588	315 SS Threaded Piping Fitting Reducing 2x1-1/2"	Type 316 Stainless Steel Threaded Pipe Fitting, 2 x 1-1/2 Pipe Size, Reducing Coupling, 1000 PSI	1	Each	$82.34
4452K661	316 SS Threaded Piping Fitting Reducing 2-1/2x2"	Type 316 Stainless Steel Threaded Pipe Fitting, 2-1/2 x 2 Pipe Size, Reducing Coupling, 1000 PSI	1	Each	$190.58
46495K25	316 SS Ball Valve 1000 psi	Type 316 Stainless Steel Ball Valve with Lever and Unrestricted Flow, 1-1/2" Pipe Size	1	Each	$119.18

TABLE II: TOTAL COST BREAKDOWN

System Component	Cost
Piping System	$10,669.24
Pipe Mounting and Insulation	$613.25
Cart Materials	$884.08
Doghouse Coupling Point	$392.10
Total (Parts only)	**$12,558.67**

Appendix D

Standards and Research Results

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D. Standards and Research Results

This section includes regulations, standards, and safety concerns that were considered in throughout the design of the engine inhibiting system. The standards presented in this section have been updated throughout the report, as we obtained more information about the scope of the project from the customers. The selection of industry certified equipment from suppliers was considered by the team throughout the final phase of the project, and industry standards were considered in design of the system.

D.1 Standards

In this project, our team follows a set of environmental, safety, and operational standards that correspond to both the GE TRDC test facility and our design for a jet engine fuel system preservation assembly.

For our design to operate in the TRDC facility, it must follow the environment and safety regulations that ensure safe operation in TRDC facility. Through verbal communication with the customer, it was brought to our team’s attention that the design cannot result in any spillage of preservation fluid on the plant floor or inside the preparation building in the facility. Another regulatory restriction specified to our team by the customer is that when tests are in progress, no one is allowed on the test floor, and existence of foreign objects is restricted.

The standards associated with our team’s inhibitor system design are broken down into different categories based on the components of the final design. These standards and their relevance to this project are briefly described below. The final design components and their compliance with their corresponding standards are provided in Section 3.2.1. Two major categories of standards that our team covers in this report involve fluid storage and fluid distribution.

D.1.1 Preservation Fluid

The specifications for inhibitor fluids used in engine fuel system preservation are provided in MIL-PRF-6081D Amendment 1. These specifications include properties of two grades of lubricating oil including 1005 and 1010 grades [1]. Based on the client's requirements, the inhibiting system must be compatible with 1010 grade lubricating oil. ROYCO® 481 corrosion preventative compound, meets the requirements stated in MIL-PRF-6081D Amendment 1 and is selected as the inhibitor fluid for our design [2]. The safety regulations and standards associated with the use of this fluid are provided in the Material Safety Data Sheet (MSDS) for ROYCO® 481. These standards will be considered for usage and handling of the fluid and also in the design of the different components of the inhibiting system. The fluid storage system for our design needs to follow the specifications provided in the ROYCO® 481 MSDS. The following include major regulations for storage and handling of the preservation fluid according to the supplier [3].

Container is required to be tightly closed in a dry and well-ventilated place when not in use.

Pressure should not be used for emptying the drums.

All equipment used in the transfer operation of the fluid need to be electrically grounded.

D.1.2 Fluid Distribution

One of the components that must be carefully considered is the pump system of the design. The operation of the pump system is to move the fluid from the reservoir to the engine. The full scale of the operation, such as the desired discharge pressure, type of pump, and the location at which the pump will be placed, is covered in Section 3.2. The standards that the pump must follow depend on the pump type, application and project constraints.

The inhibitor fluid is transferred in the final design through a series of pipes, hoses and fittings. The size and material of these components are discussed in detail in Section 3.2. The main pipe line which connects the system to the dog house structure is located beside the thrust frame and is subjected to extreme weather conditions during winter. However, the inhibiting system and the reservoir however are stored in doors and are only used outdoors when hot slush process is being performed.

The selection of valves for the assembly is discussed in Section 3.2. Some relevant standards that must be considered for selection of valves are mentioned in this section of the appendix.

The quality of operation of the inhibiting system is ensured by selecting standard certified components. The selected components of the final design follow the following set of standards:

ASTM A733 [4]

This standard covers the requirements for welded and seamless austenitic stainless steel pipe nipples in standard steel pipe sizes. As stated in the main report body in Section 3.2.1, the selected nipples in the piping system follow this standard.

ASTM A312 [5]

Standard qualifications for seamless, straight-seam welded and cold worked welded austenitic stainless steel pipe, used in high temperature or corrosive applications, are described in this document. As mentioned in Section 3.2.1, the piping components of the final design follow the specifications provided in this document.

ASTM A182 [6]

Information in this standard are related to forged or rolled alloy and stainless steel piping components for operation in pressure systems. As described in Section 3.2.1, the final selected fittings and valves of the piping of the final design follow this standard.

ANSI/ASME B1.20.1 [7]

This standard covers the specifications for unified screw threads and pipe threads. The threaded piping components of the system follow the specifications provided in this standard.

ANSI/ASME B16.11 [8]

The information provided in this standard cover the ratings, tolerances, marking and requirements for socket-welding and threaded forged fittings. As mentioned in Section 3.2.1, the specifications included in this standard are followed by the corresponding piping components.

D.2. Research Results

Aside from abiding to all relevant codes and standards, in order to develop concepts that meet our customer needs, our team first created a list of concepts individually. Each member was tasked to brainstorm as many concepts as possible and search for any existing solutions that can possibly be modified to fit the client's needs. Our team did not limit ourselves to any methods as long as it was a realistic and feasible design. During this development process, we had to stay with the client's needs and their requests that were established over multiple facility visits. After our team's first client meeting, it was apparent the client preferred a mobile design concept. As a group, our team wanted to work towards alternative methods from the ideas of the client as well as pursue variations of their initial ideas. After our second client meeting, the client needs were altered, resulting in greater design flexibility. This change allowed some traits of certain concepts to be desired. Our team then compiled a list containing all of the different concepts created by each member. This list of concepts was then subject to screening which can be seen in the Appendix A. After presenting the concepts to the customer, they informed us that mobility of the engine inhibiting system is actually a preferred feature in the design. Therefore, the team focused on optimizing the concepts that satisfied this criterion. The final suggestion is presented in Section 3.0 complies with the client needs as discussed in Section 1.3.

References

[1] Lubricating Specialties Company, "TECHNOLUBE TURBO 1010 MIL-PRF-6081 GRADE 1010", [Online]. Available: http://www.lsc-online.com/technolube-turbo-1010-mil-prf-6081-grade-1010/. [Accessed 25 09 2014].

[2] Anderol Specialty Lubricants, "Royco 481 Corrosion Preventative Compound for Aircraft Turbine Engines", [Online]. Available: http://www.anderol.com/deployedfiles/ChemturaV8/Anderol-en-US/Products/Royco%20481%20Datasheet.pdf. [Accessed 19 10 2014].

[3] Anderol Specialty Lubricants, "Material Safety Data Sheet ROYCO 481", 30 05 2005. [Online]. Available: http://www.e-aircraftsupply.com/MSDS/Royco-481.pdf. [Accessed 19 10 2014].

[4] ASTM International, “ASTM A733-13, Standard Specification for Welded and Seamless Carbon Steel and Austenitic Stainless Steel Pipe Nipples”, 2013 [Online]. Available: http://www.astm.org/Standards/A733.htm. [Accessed 20 11 2014].

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