Project Definition Document (PDD):

Pneumatically Energized Auto-throttled Pump Operated for a Developmental Upper-stage (PEAPOD)

University of Colorado, Department of Aerospace Engineering Sciences ASEN 4018

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I. Problem or Need

As technology continues to advance and commercial space travel becomes more prevalent and accessible, there is an increasing need for reliable, reusable, and cheaper rocket engines; it is one of the industry's driving factors. SpaceX is seen to be a pioneer in the use of these reusable systems. By reusing their boosters SpaceX has decreased the cost of launches. Another benefit of using reusable technologies is their turnaround time between launches. This type of reliability and usability is an important factor in the advent of upcoming commercial space travel. Special Aerospace Services (SAS) is looking to develop new advanced space propulsion systems that provide an alternative to the commonly used turbo-pump rocket engines [6]. They hope to implement a low mass and efficient rocket engine for use on a micro-lander or on the upper stage of a rocket. SAS, therefore is looking to design a reusable pneumatic, helium powered pump, that can pump two hypergolic propellants simultaneously.

The purpose of this project is to research, design, manufacture and verify a rocket engine propellant pump that can pump two hypergolic fuels simultaneously. For the purposes of our study we are to design a prototype that is capable of displaying the piston pump engine functionality, as well as verify its use for rocket propellants. The pump is required to use high pressure helium, greater than 500 psi, be throttle capable between 10% – 100%, and have a digitally controlled throttling system. The pump should be able to supply a propellent rate of 3 kg/s for at least 120 seconds (Level 1 Success). For the purposes of this project, the materials used may not be completely compatible with volatile rocket propellants, but should be capable of providing a verification for pump testing. The configuration should also be able to interface with SAS's current testing infrastructure. The overall system is to demonstrate that a reusable, reliable, digitally controlled, helium powered piston pump engine is efficient and can be digitally throttle-able.

The experimental tests will focus on the functionality of the pump. These tests are to verify the ability to throttle a rocket, show the system can be digitally controlled, and be able to pump 3 kg/s of propellant for at least 120 seconds. These tests will be verified through SAS's water flow testing rig. These tests will also help estimate the re-usability of the system, its efficiency and create a maintenance envelope for the pump.

In addition, to the physical testing we will also be creating virtual models to examine: pump efficiency, throttle-ability, fluid dynamics and the like. These models will examine the feasibility of our system to use hypergolic fuels and to be able to pump fluids at TBD volumetric rates.

All things considered, a successful digitally controlled, pneumatic piston pump engine should provide a viable solution to a lighter, more efficient rocket than current pressure fed systems. Overall the piston pump engine is a proof of concept that must meet the specific objectives and critical project elements described below.

II. Previous Work

The first liquid-fueled rocket engine was first designed by Robert Goddard who pioneered the field of rocket science. Since Goddard, scientists have continued to improve on his liquid fueled design, reaching the epitome of thrust and power through NASA's launch programs. Modern day liquid rocket engines have always needed pumps to transfer the propellant to the engine. One common method is the use of centrifugal turbopumps because they are lightweight and can handle large volumetric flows. Many engines have used turbopumps successfully for liquid propellants in rocket engines and as a fuel pump in many jet engines [8] [1]. However, companies are now looking into the use of piston pumps for rocket engines due to their predicted reliability and mass restraints [1]. Positive displacement pumps, like piston pumps, are popular primarily in the automotive industry and have been used in some jet engines, though many of the larger engines use turbopumps. Smaller planes utilize piston engines and are more likely to use a positive displacement pump or a gravity feed system. XCOR Aerospace has successfully used a piston pump for a liquid rocket engine (Kerosene-LOX) in test fires [3] [5] [4]. The benefit to piston pumps is that they are easy to manufacture, work best for high-pressure applications, and are reliable [1].

A historical trend for piston pump engines has been to raise the chamber pressure, in order to increase specific impulse. The specific impulse depends on the chamber pressure, nozzle area ratio and application. Again Goddard started with chamber pressure pressure between 50 - 100 psi. This was later improve with a pump fed system in 1939 which allow the pressure to be raise up to 350 psi. Through the 1940's it was found that using a pressurized feed system, just like we are using in our project, increased the pressure to 500-1000 psi. The reason behind increasing chamber pressure is it allows higher nozzle area ratio, for higher performance. It also allows the thrust chamber to be smaller thus saving on volume restraints. Disadvantages for increasing chamber pressure is that according to gas laws, pressure increases linearly with temperature, thus making the gas chamber difficult to cool down.

There are two main types of pump: centrifugal pump and positive displacement pump. Centrifugal pumps are the type of pump that has one or more impellers. These types of pump are useful to for low viscosity liquids, with high flow rates from .32 kilograms per second to 12000 kilograms per second. A common type of centrifugal pump use in aerospace is a turbine pump; which instead of using an impeller with vanes it has blades similar to turbine. The turbine pump is often used in thin, clear liquids and is very compact. A disadvantage is that it is only used for low volumetric flows (.06 kilograms per second to

12 kilograms per second) and the pressures from 22 - 520 psi. The other major type of pump is positive displacement pump. A positive displacement pump does not have impellers, but relies on either pumping or rotating parts to directly push the liquid until enough pressure is reached. These types of pump are used for high viscosity fluids and can accommodate slow flow rates from .006 kilograms per second to 1000 kilograms per second. A type of positive displacement pump is a piston pump which is very common in car engines. Piston pumps are a type of reciprocating positive displacement pump that requires high pressure between 50-5000 psi and lubricant. The mass flow of these type of engines is generally 0.3 - 44 kilograms per second.

Our goal for this project is to design a positive displacement pump, possibly similar to XCOR's. However, it must simultaneously deliver both fuels at the necessary pressures. Most fuel systems use two pumps: one for each propellant on either side of the engine. Combining these two pumps into one housing may reduce the weight and volume which is beneficial for system integration.

Our design is going to be novel because we are pumping two propellants simultaneously. For actual positive displacement pump design, automotive and jet engine piston pumps will be consulted, so that we can adapt the technology for our propulsive system. If a turbo pump is used, there is a large array of documentation for its use in numerous liquid rockets.

III. Specific Objectives

The objective of this project is to develop a prototype helium-powered pneumatic pump for a liquid propellant rocket engine. This pump must be able to pump two liquid propellants at the same time (nominally hypergolic fuels and oxidizers) at a full throttle outlet pressure of 625-700 psi. Additionally, the pump must be controlled by a digital throttle and achieve independent throttling of the propellant outlet pressures and mass flow rates to achieve a simulated engine thrust level of 10% to 100% of full throttle. Safe operation of this pump will be demonstrated using water-flow testing.

Level	Functional Requirements	Performance Requirements
1	• A pneumatically powered, digitally throttleable pump system shall be designed and manufactured. • This pump shall be capable of independently and simultaneously pumping two propellants without mixing and shall be capable of safe operation and shut down.	• The pump shall be designed to maintain a 625-700 ± 100 psi outlet pressure and a mass flow rate of propellants on the order of 3 kg/s during operation. • The pump shall be designed with a structural and operational factor of safety of 2.5. • A test of the pump shall be conducted in which the pump is operated at the required full throttle pressure and flow rate for no less than 120 seconds.
2	• The pump shall be designed such that the throttling of each propellant component can be controlled independently.	• The pump shall be designed to be throttleable such that the outlet pressure and mass flow rate achieve a simulated engine thrust from 10-100%. • The 0% to 100% startup ramp rate shall be no more than 2 seconds. • The pump shall be demonstrated to operate for no less than 500 seconds.
3	• The pump shall be fully compatible with all client-specified hypergolic propellants.	• The 0% to 100% startup ramp rate shall be no more than 1 second. • The pump shall be tested with fluids of similar viscosity as the client-specified propellants.

IV. Functional Requirements

This pump shall pump two fuels of volatile nature simultaneously, requiring a dual-pump system to maintain fuel separation and safety. Throttling requirements demand that regulators be used to control the fuel flow and gas flow into and out of the pump.

A functional block diagram is shown in figure 1, detailing the components this group is expected to produce and the elements that will be provided for testing. A CONOPS diagram is also displayed below showing how our system will be verified and how it fits into the big picture.

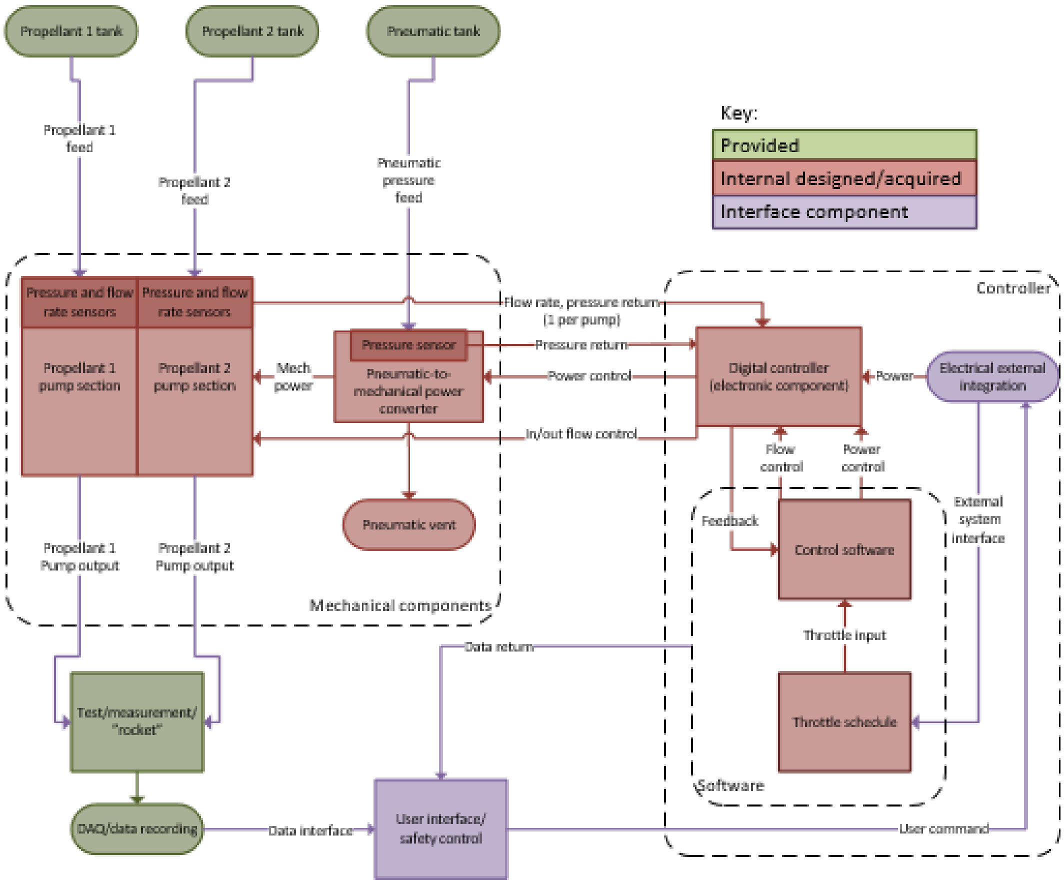

Figure 1: Functional Block Diagram

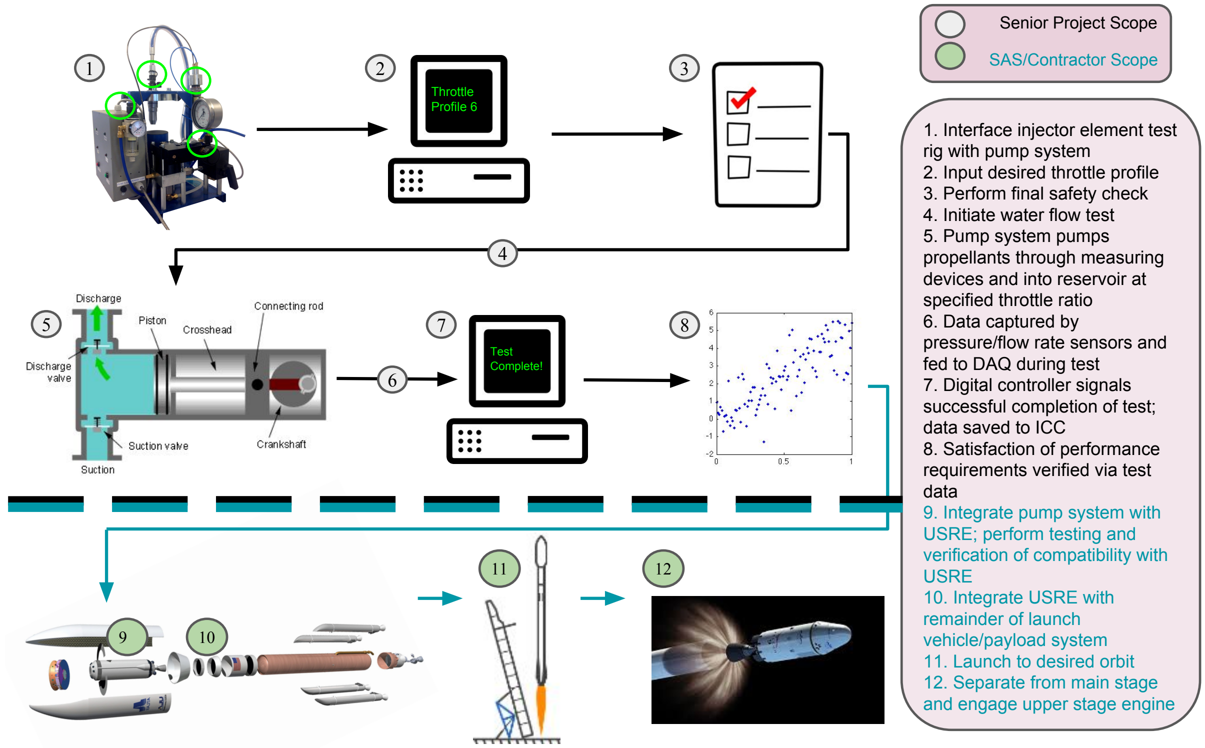

Figure 2: Concept of Operations

V. Critical Project Elements

A. Developing The Knowledge and Skills to Design and Manufacture a Pump System

The biggest challenge all project members will face, as the project evolves, will be developing the knowledge and skills required to successfully design the various parts of the pump assembly. The team has not worked with pump machinery before this project, and thus we will have a difficult time predicting issues that could drive critical path and budget increases. This will require extensive time commitments from all team members as well as seeking outside help from experts. Therefore, in the limited time available to complete this project, developing all these skills and contacts will be a major logistical challenge for all members. It will also be critical to develop the manufacturing knowledge which includes understanding material requirements, costs, tolerances, and lead times. Manufacturing will be imperitive in the successful demonstration of the pump. The development and mastery of these skills will allow the project design and manufacturing to correctly fulfill the clients needs.

B. Developing Throttling Capabilities (10 - 100%)

The pump system shall integrate software and hardware elements to achieve throttle-ability through the range of 10% to 100%. Developing, unit-testing and integrating this control system could pose serious engineering, logistical and systems level problems.

C. Safely Pumping Two Propellants

The pump shall be designed to pump two different test liquids. The fluids shall be individually throttleable. Furthermore, in order to demonstrate hypergolic capability the pump system shall not allow any mixing of the two fluids in any of its elements. A failure to maintain the separation of hypergolic fuels in a pump would cause the propellants to ignite, destroying the pump and potentially causing injury or loss of hardware. Thus, any observed mixing of the two fluids at any point in the pump will be considered a failure of the system.

D. Safe Operation of the Pump System

Safeties must be put in place to preserve personnel safety and the pump must be designed to minimize or preclude damage to the SAS provided test stand. Developing and proving the safety measures that are to be put in place could require a lot of thought and effort and could drive critical path because the safeties must be in place and proven before testing can occur.

E. Interfacing with SAS Testing Rig

The pump system shall be designed to interface with SAS testing rig. This critical element will require that the pump be designed to interface with the provided test stand. Additionally, scheduling of test stand time must be managed carefully to ensure that our group is able to get time on the client-provided test stand, as well as thorough logistical plan to get time on the client provided test stand.

VI. Team Skills and Interests

Table 1: Team skills and interests needed to complete critical project elements

Critical Project Element	Team Skills and Interests
Developing The Knowledge and Skills to Design and Manufacture a Pump System	Mechanics, fluid dynamics, systems materials, manufacturing
Developing Throttling Capabilities (10 - 100%))	Software, electronics, testing, controls/embedded systems
Safely Pumping Two Propellants	Structures, mechanics, materials, manufacturing
Safe Operation of the Pump System	Mechanics, testing, safety
Interfacing with SAS Testing Rig	Electronics, Testing, Mechanics, Structures

VII. Resources

Table 2: Resources needed to complete critical objectives

Critical Project Element	Resources/Source
Developing The Knowledge and Skills to Design and Manufacture a Pump System	Time for reiterations, materials, CAD software manufacturing machinery, money
Developing Throttling Capabilities (10 - 100%)	Electronics, modeling software (e.g Simulink), Time for reiterations, test rig
Safely Pumping Two Propellants	Measurement and material testing equipment, CAD software
Safe Operation of the Pump System	Modeling software, CAD software, time for approval and reiterations
Interfacing with SAS Testing Rig	Test stand provided by SAS, time for problem solving, money for fuels

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