**Flight Ready Electric Feed System**

Portland State University

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Team Lead

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**Date of Submission: November 02, 2018**

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### **Product Description**

The Flight Ready Electric Feed System (EFS) is an electronically driven cryogenic bi-propellant pump system to be designed for the Portland State Aerospace Society (PSAS) Launch Vehicle No. 4 (LV4). LV4 is the prototype for a 100 km rocket design that is part of the Base 11 Space Challenge university rocketry competition. The EFS has been proposed by PSAS in order to make the use of the most lightweight, low-pressure composite propellent flight tanks possible. As opposed to utilizing a more traditional high pressure 'blow down" system, an EFS will be used to provide the necessary pressure to pump the propellants into the engine.

#### **Pump Design**

The pump design will utilize a shared electric drive shaft that will be used to power a pair of pumps, each of which is to be optimized for the required pressure of two independent propellants. The pump design will be flight ready, utilizing a space and weight efficient casing enclosing twin chambers to separately increase the pressure of Isopropyl Alcohol and Liquid Oxygen. The pump will be powered by an onboard battery pack, providing DC current to an electric inverter. AC converted current will power the brushless motor driving the shaft, controlling the rotation of both impellers within the pumping system. As the system provides rotational energy, the pressure of the incoming propellants will increase from 45 PSI to 500 PSI as they undergo energy transfer from the impellers of each pump.

Additionally, the pump design will need to address the dramatic differences in density and viscosity between Isopropyl Alcohol and Liquid Oxygen. Both fluids must have the same momentum when they come into contact inside the engine. The two propellants must have the correct resultant deflection angle after contact, which is crucial to achieve the optimum burn rate and greatest possible thrust.

**Manufacturing Process**

The manufacturing process will begin with 3D rendering in SolidWorks to create the shape of the housing. A machinable prototype needs to have two separated pressure chambers centered along a single axis. The housing will be split into two sections with the case split parallel to the center axis. A functional design will be followed by ANSYS vibrational and thermal analysis to check for structural integrity. Once the design has been analytically verified, it will be fabricated using CNC machining.

**Material Selection**

The corrosive properties of liquid oxygen will be the primary parameter limiting the materials selected to be used on the pump. 304 Stainless steel is the most common metal alloy used for liquid oxygen components, and its availability makes it a logical candidate for material selection. In addition, research will be performed on the feasibility of using alternative materials that may be more cost effective and easier to machine, such as aluminum alloys.

#### **Testing**

Tolerance testing will begin as soon as a completed machined part. All dimensions will be compared against the CAD model for machining accuracy and precision. Once measurements have been verified, leak testing can begin. While in flight, the pump will be subjected to massive g-forces and vibrations. So, it is imperative that the system withstands any cause for leaks. To ensure this, the pump will be assembled and filled with water up to 1000 PSI to pressure test for any leaks in the system. Additional leak testing will be done using Helium gas to ensure a closed system. After leak testing, the pump will undergo performance testing to ensure proper spin characteristics from both impellers. Checking for excessive vibration, frictional loss, and off-axis rotation will be critical for pump efficiency.

#### **Key Milestones and Deliverables (Nov 15, 2018 - June 7, 2019)**

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| --- | --- |
| **Week** | **Milestone Description** |
| 1 - 3 | Research and locate budget line items to optimize spending. Discus pump design process to dictate the purchase sequence. |
| 4 - 6 | Finalize design for preliminary prototyping with 3D printing and mock testing |
| 7 - 10 | Integrate Control system with proven test design |
| 11 - 15 | Coordinate Electric Feed System design with Engine Test Stand and Airframe |
| 16 - 20 | Begin manufacturing process for steel housing, plumbing, and airframe fixture |
| 21 - 22 | Testing cryogenic compatibility, fluid leak, and durability to cycle usage |
| 23 - 25 | Department testing with Test Stand and Airframe |
| 26 - 27 | Finalize Electric Feed System Design |
| 28 - 30 | Organize project material for finalized report and presentation |

#### **Scholarly Aspects and Educational Objectives**

The EFS will give participants relevant experience working on an interdisciplinary student project merging students from business, mechanical engineering, electrical engineering, and computer science. Students will have the opportunity to collaborate and design these vital components to make the LV4 a reality. Further, of the 5 students on the proposal, 3 will be receiving credit for the pump design as part of their senior year Capstone project in mechanical engineering.

Finally, Portland State Aerospace Society will benefit from the educational objective of having all research, CAD, and results for this project published as open source. Although designed for PSAS' entry into the Base 11 Space Challenge, the pump system will be able to be used by many other student teams.

#### **Expected Outcomes**

Upon completion, the desired deliverable will be a functioning, electronically controlled pump tested and verified for flight. Crucially, the pump and associated system components must be compatible with liquid oxygen and isopropyl alcohol. The end product must ensure absolute separation of the different fluids at all points within the system; cross-contamination of fluids will be considered a design failure, in addition to posing safety risks. The final EFS produced must be capable of withstanding a minimumof ten engine test fires without significant overhaul. However, surpassing ten test fires is preferred. The pump and its related systems should be embedded with sensors for required data collection, as this testing data is also a deliverable.

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### **Synergy**

#### **Team-Advisor Collaborative Learning**

Dr. Mark Weislogel is a professor at Portland State University who specializes in transport of fluids within a variety of systems and devices. He spent 10 years working for NASA as a microgravity researcher and further developed methods that improved the transport of fluids. An EFS is a sensitive fluid transfer system that will benefit tremendously using Professor Weislogel as a mentor. There will be a number of difficult fluid parameters this system will need to overcome such as massive g-force from acceleration, vibrational disturbances, and cryogenic conditions. Mark has expertise in working with all the difficult fluid conditions this project will undergo. Efficient and effective solutions will come from the collaboration of the dedicated students working on this EFS and the experience of Professor Weislogel.

#### **Leveraging Opportunities for Funding and Further Research**

The ideal outcome of this project is to advance the capabilities of PSAS and further research into liquid propellant rockets. PSAS is taking part in the Base 11 Space Challenge and competing to be the first University to reach 100 km altitude in flight. Having a working liquid propellant rocket will greatly progress the capabilities of PSAS. The EFS is a critical component to add to our list of successful partnering projects such as the composite fuel tanks, carbon fiber airframe, 3D printed liquid fuel rocket engine and test stand.

Advancing PSAS as an aerospace club gives us leverage in recruiting excellent future members and students as they see what PSAS has accomplished; participation in which prepares students for careers in aerospace-related disciplines. With PSAS’s open source files, students from around the world can inform themselves about the accomplishments within the organization as they review previous projects.

Finally, the results of this project will be submitted for publication in the AIAA SPACE Conference in September of 2019.

### **Aerospace Relevancy**

Successful implementation of an EFS for use with cryogenic fluid will be highly beneficial to the aerospace industry. The use of an EFS in place of traditional pressurized tanks or turbopumps make high altitude launches more cost-effective, particularly at the amateur level of rocketry. A light-weight EFS design will create an incredible opportunity for students to take their experience to companies looking to implement this new technology in application.

In support of NASA’s Space Technology Mission Directorate, an EFS will advance broadly applicable, transformational technology to infuse solutions into applications for which there are multiple customers. Current technology limits the efficiency of electric pumps due to the weight of the battery pack. This weight causes them to be less efficient than a turbopump systems, but still more efficient than solid propellant motors or pressure fed engines. Pump systems do excel in being simple to control and manufacture. As technology improves, battery packs will become more energy dense allowing electric pump systems to increase in usability for industrial applications. Working with electric pump design while in undergraduate studies will keep students ahead in this advancing technology.

### **Budget**

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| **Item** | **Description** | **Vendor** | **Award Amount** | **1.5:1 Cost Share** |
| **Cost Share** | | | | |
| PI Salary | Dr. Mark Weislogel will commit 0.29 months during the academic year. | Portland State University |  | $4,000 |
| PI Fringe Benefits | Estimated at 49% during the academic year. | Portland State University |  | $2,156 |
| **Award Budget** | | | | |
| 304 SS Steel | Raw material used to machine pump housing | McMaster-Carr | $800 |  |
| Tooling | Pump House machine tooling | Western Precision Products Inc | $1,400 |  |
| 6061 Aluminum | Raw Material to create EFS Airframe Structure | McMaster-Carr | $200 |  |
| 304 SS Steel | ¼” x 24” TGP Precision Shaft | Metals Depot | $10 |  |
| Impeller | Rotational Impellers for propellants | Shapeways | $200 |  |
| ISO Plumbing | Various plumbing fittings for alcohol | Home Depot | $100 |  |
| LOX Plumbing | Various LOX compatible fittings | AcmeCryo | $300 |  |
| Aluminum Piping | ½” Aluminum piping for plumbing | Metals Depot | $100 |  |
| Seals | Metal C-Ring Internal Pressure Face Seals | Parker | $30 |  |
| Liquid Oxygen | 40 Gallons of LOX for testing | Airgas | $200 |  |
| Liquid Nitrogen | 40 Gallons of LN for cryo testing | Airgas | $200 |  |
| Electric Motor | Brushless Motor for shaft drive | Hobbyking | $150 |  |
| Heat Sink | Heat Sink for Brushless motor | Amazon | $25 |  |
| Arduino | Arduino to Controlling pump | Amazon | $50 |  |
| Sensing Equipment | Pressure Transducers and flow meters for fluid monitoring | Omega | $500 |  |
| **Total Direct Costs** |  |  | $4,265 | $6,556 |
| Total Indirect Costs |  | 48.50% | $2,069 | $3,180 |
| **Total Project Costs** |  |  | **$6,334** | **$9,736** |
| **Cost Share Ratio** | 1.537 |  |  |  |

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### **Team Lead Resume**

**Julio Garcia**

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[jugarcia@pdx.edu](mailto:jugarcia@pdx.edu)

**EDUCATION**

**Bachelors of Science in Mechanical Engineering** (Sept 2017 - June 2019)

*Portland State University, Portland OR*

**Course Highlights:**

Thermodynamics, Fluid Mechanics, Heat Transfer, Mechanical Analysis, System Dynamics and Vibrations, Controls, Finite Element Analysis, Technical Report Writing.

**Associates of Science** (Sept 2014 - Dec 2016)

*Portland Community College, Portland OR*

**Course Highlights:**

Physics with Calculus, Strength in Materials, Manufacturing Processes, Statics, Dynamics.

**SOFTWARE AND COMPUTER SKILLS**

* ABAQUS and ANSYS for FEA, thermal, and vibrational analysis
* Matlab for Controls Simulations
* Rstudio for Statistical Analysis

**EXPERIENCE**

**Student Member**

*Portland State Aerospace Society* (Sept 2017 - Present)

* Fabrication and Modification of Liquid Engine Test Stand
* Machining of Teflon vibration management components for Fuel & LOX Tanks
* Composite Airframe layup training.

**Maintenance Fabrication**

*Bullseye Glass Co*(Jan 2014 - Present)

* Weld and machine custom tools for glass casting
* Build and maintain glass furnaces for operations
* Repair supporting equipment throughout the facility such as ducting and controls

### **Team Member Listing and Experience Profiles**

Group Demographics

Female Students: 2/5 (40%)

Underrepresented Minority Students: 3/5 (60%)

Veterans: 0/5 (0%)

Shayli Elrod:(Mechanical Engineering Undergraduate, PSU)

PSAS member with design process experience. Demonstrates consistent performance while working closely with sponsor and meeting deadlines. Extensive history in data analysis and data entry. Proficient in technical writing, dimensional tolerancing, and SOLIDWORKS.

Timothy Finn: (Business Administration and Supply and Logistics Management Undergraduate, PSU). Experience with multiple data analysis platforms (Tableau, R, Excel, etc). Past research laboratory experience, and grant writing/poster presentation experience. 10+ years retail management experience.

Julio Garcia: (Mechanical Engineering Undergraduate, PSU)

PSAS Liquid Propulsion Team member, past project: Liquid Rocket Engine Test Stand Fabrication. Experience with Machining, Fabrication, Controls, FEA, SolidWorks, ABAQUS, and Matlab.

Amber Stroh: (Business Administration and Community Health Education Undergraduate, PSU)

PSAS member, experience with R data analysis software, past project experience in program plan development for a grant proposal.

Phil Wahl: (Mechanical Engineering Undergraduate, PSU)

PSAS Liquid Propulsion Team member with relevant work experience in the pump industry. Experience with project-specific FEA and design software (ANSYS, Solidworks, etc), proficiency in various coding languages (Matlab, Python, VBA, R, etc). Past project experience in cryogenic component design. Educational focus is thermal-fluid sciences, as applied to engineering.