OSGC Undergraduate Team Experience Award Program Proposal
for the

# PSAS Liquid Propellant Rocket Engine Electric Feed System


**Project lead: Jorden Roland**
17390 SE 82nd Dr, Clackamas OR
(503) 421-5214, jroland@pdx.edu

**Faculty advisor: Andrew Greenberg**
PSU ECE Department, 1900 SW 4th Ave suite 160, Portland, OR, 97201
(503) 708-771, adg@ece.pdx.edu



Supporting Team Members:
Johnny C. Froehlich, James Luce, Rawand Rasheed,
Michelle Shang, Johnathan Talik


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# 1. Project Description

## Background

Portland Space Aerospace Society (PSAS) is a student aerospace engineering group at Portland State University with the mission of building low-cost, open source rockets that feature some of the most sophisticated amateur rocket avionics systems in the world. Our long-term goal is to put a tiny satellite into orbit. Our current project, LV4, attempts to design and build a rocket which can fly to altitudes of over 100 kilometers. To reach these altitudes, LV4 requires a liquid fuel engine currently being prototyped as a liquid oxygen and ethanol bipropellant rocket engine.

## The Electric Feed System

Since the 1940s, turbo-pumps have been the industry standard for generating the required pressure head in most professional Liquid Fuelled Engine rockets. The extremely large rockets used by industry to deliver significant amounts of mass to orbit make turbine driven pumps the most efficient means of delivering the required chamber pressures. Groups in amateur rocketry, however, do not typically have access to the budgets or infrastructure required to develop turbo-pumps. These groups usually opt for the simpler method known as "blowdown pressurization" in the fuel/oxidizer tanks. Unfortunately, this requires tanks rated for very high pressures (in excess of 1500 psi in some cases). Tanks rated to these pressures are extremely heavy, which is detrimental to the mass ratio of the rocket.

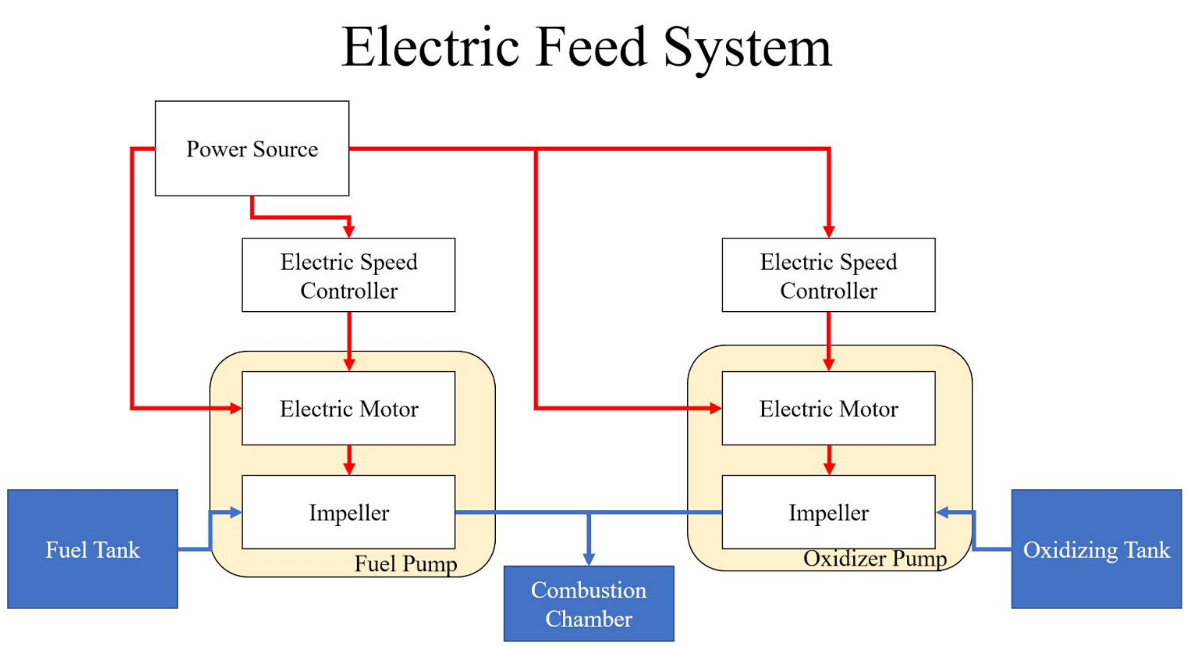


*Figure 1: Block diagram of the Electric Feed System*

Figure 1 illustrates our proposed solution to address propellant pressurization by using an *electric feed system (EFS)*. The electric feed system has the potential to greatly reduce the weight of the rocket over other methods of propellant delivery. Rutherford Engine designer P. Rachov states, “the proposed [electric feed] system results lighter than the pressurized gas system according as the combustion chamber pressure increases.”[1]

We propose using a commercial off-the-shelf (COTS) electric motor and motor control system with a custom-designed 3D printed pump. Our system will dramatically reduce the required pressure of the fuel tanks. By reducing the pressure requirement of the propellant tanks, we can reduce the mass of the structure required to hold the propellant tanks at high pressure. When comparing an EFS to other forms of fuel injection, a 2013 research paper lead by D. Spiller states that EFS offers a great advantage over gas-pressure feed systems in terms of inert mass.[2] Spiller also claims there may be possible advantages when comparing EFS to turbo-pump by providing a reduction in the weight of the rocket. In addition to our group, a second capstone group will be working in parallel to design fuel tanks using lightweight carbon fiber materials. The combination of lightweight material and reduced pressure requirements will decrease the mass ratio of the rocket. This innovative design will create the potential to attain vertical distances far beyond the typical range of a typical amateur rocket.

We have completed preliminary pump sizing calculations demonstrating the theoretical feasibility of an EFS to generate the required inlet pressure to deliver propellant to the existing Liquid Fuelled Engine (LFE). [7]

## Project Objective

The objective of the EFS project is to design, build, and test an electric feed system using COTS parts and in-house manufacturing for the PSAS LV4 liquid fueled rocket engine prototype by June 6, 2017.

This project will be executed as a senior capstone by a group of mechanical engineering students at Portland State University. The deliverables of this project will include:

- Feasibility analysis of the feed system using software simulation
- Selection of optimal COTS electric motor
- Design and manufacture of custom pump
- Construction of a functional prototype
- Performance testing of the prototype using regular and cryogenic liquids

## Methodology

A large cache of professional papers on liquid fuel rocket propulsion has been assembled for reference. We will also utilize access to professional mentoring from the Air National Guard (for LOX handling procedures), and industry expert contacts at SpaceX, Spaceflight Ind, NASA, Orbital ATK, and Blue Origin.

Github will be used for team version control on documents, models, and programs for public access and final uploading of the required customer documents. This will include the LOX handling, SOP procedures, reproducibility, technical documentation, design tools, and comparison studies. Jupyter notebooks will be the main tool for iterative design development as one of the main customer requirement deliverables. Statistical analysis of data will be done using R. Solidworks CAD software will be used for mechanical design. In addition, simulation of the system will be created using software such as Abaqus, Star-CCM, Matlab, etc.

Further available resources include access to prototyping labs at Portland State University, access to donated metal, professional machining labor, DMLS 3D printing, and the Liquid Fuelled Engine Test Stand (LFETS) currently being worked on by another PSAS team. Testing will take place at a site outside of Clackamas, Oregon.

## Proposed Timeline of Deliverables

| **Date** | **Deliverable** | **Objectives** |
|---|---|---|
| Jan 15, 2017 | Pump Sizing Requirements (Design Outputs) | Determine number of stages, pump rotational speed, pump impeller tip speeds, impeller entrance and exit diameters, pump efficiency, shaft power required to drive pump. |
| Jan 22, 2017 | Initial COTS components selection | Individual team members finalize and present 5-10 candidate OTS tech (Bearings, Motor, inverter,). |
| Jan 29, 2017 | Feasibility Study of COTS Parts | |
| Feb 1, 2017 | Non-Functional prototype | Determine feasibility of form, flow loop, bench size and orientation. |
| Feb 26, 2017 | Submit Purchasing Request For COTS | |
| April 2, 2017 | Subsystem testing | Assembly and validation of subsystems and COTS components |
| April 23, 2017 | Functional prototype | Assembly of subsystems |
| April 25, 2017 | Initial testing | Static checks, dynamic checks (cold test), validation runs. |
| May 7, 2017 | Post processing, alternative comparisons | Validation for final prototype go-ahead |
| May 21, 2017 | Final prototype | |
| May 28, 2017 | Final Prototype cold testing | Final Prototype cold testing |

## 2. Synergy

Our mentor, Andrew Greenberg, is the founder and faculty advisor to PSAS, and adjunct professor of electrical engineering at Portland State University. Mr. Greenberg's work at PSU specifically focuses on interdisciplinary engineering education. Due to his experience in aerospace research and advising interdisciplinary groups, Mr. Greenberg is an ideal mentor for the EFS project.

The development of an EFS for the LV4 rocket provides all participating students with the opportunity to enhance their knowledge and skills in aerospace engineering, including fluid mechanics, heat transfer, mechanical design, power systems, and design of turbomachinery.

Development of the EFS will also add to the PSAS objective of furthering amateur and university-based rocketry technology. Specifically, electric feed systems are a relatively new technology made possible by recent advancements in battery and motor technology. These feed systems have been explored and developed by only a handful of groups around the world. It is therefore critical to develop a low-budget EFS in order to help pave the way for future development of feed systems by PSAS, and other ametuer rocket groups around the world.

This year, three PSAS teams will be synergistically solving system challenges presented by a liquid propulsion system. In addition to the electric feed system, one capstone team will be developing a composite cryogenic fuel tank. Another PSAS-lead team will be developing a test stand for the testing of a pressure-fed liquid fuel engine, building on previous PSAS projects, including a 2016 capstone team which developed a 3D printed rocket engine[5]. Future capstone teams will integrate these projects into one robust system. The liquid propulsion system presents challenges that promote a collaborative learning experience. Multiple teams work in parallel to develop and integrate the rocket engine, electric feed system, and composite fuel tanks. Future capstone teams will then be tasked with producing a flight ready system from these integrated systems.

## 3. Aerospace Relevancy

The broad purpose of the project is to continue PSAS's ongoing study of possible methods to achieving low cost, open source access to space. The EFS explores ideas on expanding the envelope of amateur rockets to include the insertion of small payloads into orbit. A feed system for liquid propellant rocket engines based on electric pumps and powered by high performance batteries has recently been shown on theoretical bases to offer a definitive advantage with respect to gas pressure feed systems in terms of inert mass, and under some circumstances even with respect to turbopump systems, i.e., the classical feed systems for such engines.[1]

Development of Electric Feed Systems is currently underway with Rocket Lab's Rutherford Engine. This year, they will launch the first rocket using an EFS for fuel injection.[6] PSAS's EFS research will further the pursuit of this technology and push accessibility.

Finally, Electric feed systems are directly applicable to first stages of microsatellite launchers, such as NASA's Venture-class launch vehicles that are currently being sponsored by the Human Exploration and Operations (HEO) directorate, and Space Mission Directorate (SMD).

# 4. Budget

The budget outlined below includes commercial off-the-shelf components, materials, labor, services need to develop and test an electric feed system for PSAS. This budget is preliminary, since a majority of the design work is to be completed in the following months. It includes both current and future

| Item | | Description | Vendor | Amount | Matching |
|---|---|---|---|---|---|
| **System Components** | | | | | |
| 1 | Motor | Brushless DC motor to power pump, Qty. 2 | HackerMotor | $1,000 | |
| 2 | Controller | Electric Speed Controller to control the motor speed, Qty. 2 | Amain | $500 | |
| 3 | Power Supply | Power supply for testing components and full system tests | Miller Electric | $2,500 | |
| 4 | Electrical Components | Wiring, connections, soldering, etc | Various Vendors | $400 | |
| 5 | Plumbing | off-the-shelf components | Various Vendors | $500 | |
| 6 | Impeller | Requested: 3D printed impeller. 3 impellers for testing. | 3Di Manufacturing | | $4,000 |
| 7 | Mechanical Components | Bearings, seals, nuts, bolts, etc. | Various vendors | $1,000 | |
| 8 | Pump Casing | Materials and labor for manufacturing the pump casing, Qty. 2 | Machine Sciences | | $2,000 |
| **Testing** | | | | | |
| 9 | 2kW Generator | For remote testing in clackamas | DeWalt | $1,000 | |
| 10 | Hydraulic Oil | 45 gallons of hydraulic oil for for flow testing | Sinopec | $450 | |
| 11 | Hydraulic Oil tanks | Stores hydraulic oil | ULINE | $100 | |
| 12 | Liquid Nitrogen | 45 gallon of liquid nitrogen for 3 cryo tests at 25 seconds each | PSU Bio Dept | $1500 | |
| 13 | Liquid Nitrogen storage | Cryogenic dewar for 40L of liquid nitrogen | Taylor-Wharton | | $1,4000 |
| 14 | Liquid Nitrogen handling | Personal protection equipment for handling | PSU Bio Dept | $100 | |
| 15 | Test site travel | gas/rentals for travel to testing location in Clackamas | Uhaul | $2000 | |

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|---|---|---|---|---|---|
| **Misc** | | | | | |
| | 2017 Crowdfunding | Funds already raised during 2016-2017 PSAS crowdfunding effort. | | | $10,000 |
| | | | | | |
| | **Total** | | | **$7,900** | **$17,400** |

# 5. Citations


[1] Rachov, P., Tacca, H., Lentini, D. Electric Feed Systems for Liquid Propellant Rocket Engines. 2010. Research Report.

[2] Spiller, D., Stabile, A., Lentini, D. Design and Testing of a Demonstrator Electric-Pump Feed System for. Liquid Propellant Rocket Engine. Aerotecnica Missili & Spazio, Journal of Aerospace Science, Technology and Systems, 2013.

[3] NASA, Pline. A. (2016, July). About the Human Exploration and Operations Mission Directorate. https://www.nasa.gov/directorates/heo/about.html

[4] Portland State Aerospace Society http://psas.pdx.edu/

[5] Tucker, J., Dib T., Ricey T., Schmidt E., Travis K., Viggianoz B. Development of a Small Bipropellant Rocket Engine Utilizing Additive Manufacturing Processes. https://github.com/psas/liquid-engine-capstone-2015/blob/master/AIAA%20Space%20Proceedings/AIAA_Space_2016_Proceedings__LFRE_.pdf

[6] Rocketlabs https://www.rocketlabusa.com/latest/rutherford-engine-qualified-for-flight/

[7] Schmidt E. Electric Feed System Pump Size Estimates. https://github.com/psas/electric-feed-system/blob/master/Analysis/electric_pump_calcs/pump_sizing.ipynb

**JORDEN'S RESUME (ONE PAGE)**

## Team Members

1. **Jorden Roland:** jroland@pdx.edu
    - (see resume above)
2. **Johnny C. Froehlich:** froeh@pdx.edu
    - John Froehlich is a senior in mechanical engineering at Portland State University. John completed an internship at NASA Goddard in 2015 where he helped to design an experiment that studies the behavior of fluids subject to low-gravity conditions. John's work also includes microfluidic research in the Dryden Drop Tower lab at Portland State University. John was also a mentor in the PSU Invention Bootcamp program, a 4-week engineering program in partnership with The Lemelson Foundation, Impact Entrepreneurs, and Oregon Mesa. Where he provided day-to-day guidance/assistance in teaching the basic skills needed for rapid prototype development to Oregon high schoolers.
3. **James Luce:** jaluce@pdx.edu
    - James Luce is a senior in mechanical engineering at Portland State University. James completed an internship at NASA Marshall Space Flight Center, in 2016, which focused on finite element analysis for thermal and launch loads in rocket motors. His work also includes undergraduate research at PSU Dryden Drop Tower lab on microgravity capillary fluidics experiments and data analysis for ISS experiments. James also served as product/project management at Trulia et al from 2004-2013, where he performed research, feature prioritization, logistics and project planning.
4. **Rawand Rasheed:** Rawand@pdx.edu
    - Rawand Rasheed is a senior in mechanical engineering at Portland State University. He is a first generation Kurdish American and the president and co-founder of the Kurdish Youth Organization. He is also an officer and co-founder of ASME: Engineers for Global Development at PSU. His experience includes undergraduate Research at WET Lab, design engineering at Sulzer Pumps, and mechanical engineering at Intel: STTD R&D Pathfinding Lab. Rawand is also the recipient of the Daimler Mechatronics scholarship for 2016-2017, and has completed an internship at Daimler focusing in the integration of electrical and mechanical systems in powertrain engineering.
5. **Mimi Shang:** mshang@pdx.edu
    - Mimi Shang is a senior in Mechanical Engineering at Portland State University. She is a first generation Chinese American, and is fluent in Mandarin Chinese and Spanish. She is also president of the Society of Women Engineers Portland State University section. As a queer woman of color in engineering, she passionately

advocates for women in STEM by organizing mentorship with an all girls high school robotics team, and sending her section to regional networking conferences. Mimi is also the recipient of the Daimler Mechatronics scholarship for 2015-2017. She has completed two internships at Daimler focusing in the integration of electrical and mechanical systems. Currently, she is working with the Greenroof Research Lab at Portland State University to develop open source, low cost sensor platforms for monitoring building air quality.

6. **Johnathan Talik:** JTalik@pdx.edu
    - John Talik is a Senior Mechanical Engineering Student at Portland State University. John has been working at Nike Inc. as a Design Engineering Intern since June 2015 where he has been involved in design, development, and manufacturing of products related to Nike Air. His experience also extends to PSU's Undergraduate Research and Mentoring Program (URMP), working under Professor Raul Cal in the Wind Energy and Turbulence lab. John was also team lead of the Viking Motorsports Composite Team in 2015/14. John interned in at Kroger in 2014 as the Energy Engineering Intern, determining the avoided energy savings from multiple projects and retrofits. From 2012-2016, John was apart of Portland State's Div. 1 Track and Cross Country teams, leading as Team Captain for his final 2 years.

## Demographics Summary

17% women, no minorities, and no veterans.

**ANDREW’S SUPPORT LETTER (1 PAGE)**