Product Design Specifications Report

Liquid Propellant Engine:

Test Stand Integration and Testing

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1 Purpose

This document is intended to act as a guide for the development and testing of the Liquid Propellant Engine Test Stand. The Project Design Specification (PDS) will be used as the meter stick by which to ensure that all customer requirements are met and that the project is on track.

2 Project Background

Portland State Aerospace Society (PSAS) is a collection of students, citizen-engineers and industry mentors with a long history of developing low-cost, open-source rocket hardware and avionics systems. In 2018 PSAS joined the Base 11 Space Challenge (Base 11), a competition for student university groups to produce and launch a liquid-propelled single stage rocket to 100km. In line with PSAS' vision statement, the challenge acts as an additional incentive to build and launch the next PSAS launch vehicle, Launch Vehicle 4 (LV4). Prior to the design and construction of LV4, the rocket's liquid bi-propellant rocket engine must be tested.

PSAS is preparing to test a 2.2 kN regeneratively cooled bipropellant (liquid oxygen and isopropanol) rocket engine. This engine design has a number of innovative features including fully parametric CAD design using Python and SolidWorks, direct metal laser sintering (DMLS) production by i3D manufacturing, augmented spark torch ignition and pintle injection.

The Liquid Propellent Engine Test Stand was originally produced by a Portland State University capstone team in 2015. The team designed, analyzed, and constructed the frame of the test stand and set in path many of the construction elements. Since the frame was constructed, the stand has been awaiting final integration and installation of some subsystems including propellant and cryogenic plumbing as well as the engine mounting & interfacing.

PSAS has asked our team to complete the construction of the test stand and test the 2.2kN engine. Upon completion, the test stand will continue to serve the organization by testing the liquid-oxygen electric feed system, cryogenic composite oxidizer and propellant tanks, and the next generation 8kN rocket engine. Our work will synergize with the efforts of previous capstone teams to prototype the technology for LV4 and to compete in the Base 11 Space Challenge.

3 Mission Statement

The proposed project is to integrate, test, and analyze our prototype engine. An analysis of the first static test fire is scheduled to be accomplished in the spring of 2019.

We will integrate and test the previously designed engine and validate its performance metrics including thrust, cooling capabilities, and chamber pressures. Engine testing will be conducted in a reproducible manner according to a written standard operating procedure which will emphasize safe operation. Other procedures for interacting with authorities, safety, and testing site hazard analysis will be written and used during this project. The captured data from the static fires and the analysis methods will be published under an open-source license.

The test stand needs to stand up to the rigors of testing a rocket engine while also incorporating safety and data acquisition capabilities. Furthermore, it needs to have the ability to be used with multiple sizes of engines, although only the 2.2kN engine will be tested in the Spring of 2019.

An analysis will be conducted to determine engine performance. Data will be acquired through a Data Acquisition system (DAQ) working under the Test Stand Automation & Regulation system (TSAR). TSAR will act primarily as a safety and management tool to provide safeguards for both human and system operations. Upon completion of initial testing, the data acquired will be compared against the engine's theoretical performance characteristics. Analysis tools include Solidworks, Python programs such as Jupyter Notebooks, and GitHub for collaboration. The data analysis will determine the viability of testing the future generation 8kN engine. The analysis will also prepare PSAS for integration of the liquid engine into the flight-ready control system of future rocket designs to be used in the Base 11 Challenge.

Standard Operating Procedures will be formalized to meet or exceed industry standards as to mitigate risk towards personnel, equipment, and property. All documentation will be created in accordance with relevant industry standards and best practices determined useful by PSAS. All documentation will contain sufficient detail, background information, and operational description to enable a smooth transfer of knowledge to new project members.

4 Top Level Project Plan

Project completion will include integration, testing, and analysis of the 2.2kN engine. The project outcomes will be an analysis of the first static test fire, which is scheduled to be accomplished in the spring of 2019, along with the other project deliverables listed below:

- Post-processing 3D printed engine
- Jig creation, precision machining, and CT scanning analysis
- Integrated assembly (including structures, electronic ground support equipment, and plumbing)
- Control and data acquisition software and design documentation

- Operational, and transport procedures
- Failure Effects Mode Analysis (FMEA), House of quality, and system safety analysis
- Leak, hydro, and system proof testing buy-offs
- Integrated cold-flow test data, including the engine injector
- Hot fire test data for the 1.0 version 3D printed engine

Timeline

Month	**Tasks / Milestones**
December	Pintle test, Igniter test, Piping and layout, Hardware skills workshop
January	CAD Design updates, Preliminary design review, BoM & order - AN & flange hardware, Cryogenic piping, and hardware
February	Mount Hardware & Construction, Finalize the Standard Operating Procedure and Project Documentation, Critical Design Review
March	Site Preparation, Practice & Safety Training
April	Static fire, Data & Safety analysis
May	Second Chance: Static fire, Data & Safety analysis
June	Report Compilation

Figure 1: Project Timeline

5 Customers and Stakeholders

Portland State Aerospace Society - Andrew Greenberg Capstone Advisor - Mark Weislogel Capstone Class - Sung Yi / Faryar Base 11 Oregon Space Grant Consortium - Catherine Lanier

5.1 Customer Interviews and Feedback

Customer feedback per project customer. The main bullet is the project customer and the sub-bullets are the requirements.

PSAS: Interview Question: What kind of documentation do we need?

- Create a formal failure mode and effect analysis document

- Create a Standard Operating Procedure Manual
- Create a post-firing analysis of engine with suggestions
- Create a background, research, and theory of operation document
- Create training materials
- Create documents for system maintenance
- Create documents for test site management
- Create documents for the transportation of the test stand and propellants
- Create a SolidWorks CAD model of test stand assembly
- Regularly send all technical documents and files to Github
- All other tests stand administrative files to be stored on PSAS shared google drive
- Create a bill of materials

Interview Question: What safety standards must be met?

- Safety procedures are known and followed
- Participation in any mandatory safety training
- Human interaction withstand during test must be minimized
- No person(s) is to approach the test stand while the system is pressurized
- Redundant systems must be implemented to prevent accidental pressurization of the system

Interview Question: What will be needed for the system?

- Isopropyl alcohol will be the fuel
- Liquid oxygen will be the oxidizer
- Nitrogen gas will be the pressurant
- Data acquisition equipment from TSAR
- 2.2 kN engine from PSAS
- Fully constructed test stand

Interview Question: What data will we need to acquire?

- Engine chamber pressure
- Fuel mass flow rate
- Propellant mass flow rate
- Injector spray angle

Capstone Adviser: Interview Question: What are your goals for meetings?

- Bi-weekly meetings to discuss project and progress

Capstone Class: Interview Question: What documents must be submitted?

- Create a Project design specification report

6 Product Design Specifications (PDS)

Customer Need	Primary Category	Secondary Category	Variable	High	Low	Desired
PSAS						
Formal Failure Modes and Effects Analysis (FMEA)	Document	Safety	FMEA	1	0	1
Deliverable Document: Safety S.O.P.	Document	Safety		1	0	1
Deliverable Document: Operations S.O.P.	Document	Document		1	0	1
Deliverable Document: Post Firing Analysis of Engine with suggestions for 8kN engine	Document	Analysis		1	0	1
Safety Procedures Known and Followed	Safety	Safety		1	0	1
Fuel: Isopropyl alcohol	System			1	0	1
Oxidizer: Liquid Oxygen	System			1	0	1
Pressurant: Nitrogen (gas)	System			1	0	1
Incorporation of PSAS Supplied DAQ (From TSAR)	System	Safety		1	0	1
Test Engine: 2.2kN engine supplied by PSAS	Hardware	System		1	0	1
Participation in any mandated safety Training (multiple customers)	Safety			1	0	1
Minimum human interaction with the test stand during operation	Safety	System		1	0	1
No Person(s) are to approach Test Stand while system is pressurized	Safety	System		1	0	1
Redundant system to prevent accidental pressurization of System	Safety	System		1	0	1
Funds available from PSAS should not exceed $2,000 without prior approval	Budget		Money	2000	0	2000
Deliverable Document: Background, Research, & Theory of Operation	Document			1	0	1
Deliverable Document: Training Materials	Document			1	0	1
Deliverable Document: System Maintenance	Document			1	0	1
Deliverable Document: Test Site Management	Document			1	0	1
Deliverable Document: Transportation of Test Stand & propellants	Document			1	0	1
Deliverable files: Full Solidworks CAD model of Test Stand Assembly	Document			1	0	1
Software: All technical documents and files are to be regularly pushed to git	Document			1	0	1
Software: All other test stand administrative files to be stored on PSAS Shared google drive	Document			1	0	1
Deliverable Document: Bill of Materials	Document			1	0	1
Fully Constructed Test Stand (or whatever is left of it)	Hardware	System		1	0	1
Engine Chamber Pressure	System		Pressure	375	325	350
Fuel Mass Flow Rate	System		lbm/sec	unk	unk	1.16
Propellant Mass Flow Rate	System		lbm/sec	unk	unk	0.09
Injector spray angle	System		degree	unk	unk	45
Capstone Advisor						
Bi-Weekly meeting to discuss project and progress	Administrata					
Capstone Class						
Deliverable Document: Project Design Specifications	Document					

Figure 2: Project Design Specifications

7 House of Quality

Relative Weight	Customer Importance	Customer Requirements	Portable	Weight	Size	Maximum Pressure	Fuel Capacity	Pressurant Capacity	Replication	Temperature	Spray Angle	Layout
			Functional Requirements									
		Direction of Improvement	▲	□	□	▲	□	▼	▼	▲	▼	▲
9%	7	Formal Failure Modes and Effects Analysis (FMEA)							□			□
12%	9	Deliverable Document: Safety S.O.P., Operations S.O.P, Post Firing Analysis			▽	■				▽		■
12%	9	Safety Procedures Known and Followed		■		■	□		□			
12%	9	Fuel: Isopropyl alchohal		▽			■			▽	■	
12%	9	Oxidizer: Liquid Oxygen		□						▽	■	
1%	1	Pressurant: Nitrogen (gas)	▽					■				
8%	6	Incorporation of PSAS Supplied DAQ (From TSAR)										□
12%	9	Test Engine: 2.2kN engine supplied by PSAS	□	▽	□							
12%	9	Participation in any mandated safety Training (multiple customers)							▽			
8%	6	Human interaction with stand during test to be minimized							▽			
12%	9	No Person(s) are to approach Test Stand while system is pressurized							■			
12%	9	Redundant system to prevent accidental pressurization of System				■		▽		□		
5%	4	Funds available from PSAS should not exceed $2,000 without prior approval							□			
4%	3	Deliverable Document: Background, Research, & Theory of Operation, Training Materials...										□
3%	2	Deliverable files: Full Solidworks CAD model of Test Stand Assembly										■
5%	4	Software: All technical documents and files are to be regularly pushed to git										■
5%	4	Software: All other test stand adminstrative files to be stored on PSAS Shared google drive										■
3%	2	Deliverable Document: Bill of Materials										
12%	9	Fully Constructed Test Stand (or whatever is left of it)		■	■	■	□	□				
8%	6	Engine Chamber Pressure				■				▽		
8%	6	Fuel Mass Flow Rate								▽		
8%	6	Propellant Mass Flow Rate	▽	▽	■	■						
		Sum (Importance x Relationship)	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####
		Relative Weight	3%	15%	4%	19%	13%	1%	7%	3%	19%	14%
		Our Product										

Figure 3: House of Quality

8 Conclusion

A 2.2kN engine supplied by the Portland State Aerospace Society is to be tested using the Liquid Propellant Engine Test Stand. The capstone team is tasked with the integration of some subsystems and components including the engine into the test stand. The team is further tasked with executing a static fire of the stand to acquire engine performance data.

The most important requirements of this project are those related to safety. The team expects to apply significant effort in the creation, practice, and delivery of safety documentation. PSAS requires the highest level of safety and care to be maintained through all phases of integration and operation.

A particularly difficult requirement is the minimization of human interaction. Fuel and oxidizer loading will have minimum human interaction with the test stand. Implementing computerized systems will be an educational experience for the team. It may pose a hurdle as the team has little to no experience with robotic systems.

The team is excited to learn from the integration and static firing of the engine. We anticipate several hurdles in this project but are excited to meet challenges with creative designs and to meet the requirements of PSAS and MCECS Capstone.