University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

COMET: Colorado Mini Engine Team

Approvals

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Project Customers

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1.0 Problem or Need

Unmanned Aerial Vehicles (UAVs) are increasingly being used in military, civil, and scientific applications. Using batteries to power the onboard instrumentation is problematic due to issues of battery weight/volume, as well as issues with battery charge capacity [1]. Both of these issues restrict the number of sensors on board as well as the system endurance. A solution to this problem that is applicable to UAVs using mini-turbojet engines, such as the one shown in figure 1, is to generate the required power from the engine itself.

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Figure 1 – JetCat P-80SE Engine[2]

The goal of this project is to design and build a power extraction unit for a JetCat P-80 SE mini-turbojet engine that will generate 500 Watts of electrical power at 24VDC over TBD % of the engine's thrust range. Success of the project will see an increase in the utility of UAVs by creating an on board power source that does not have the limitations of battery power.

2.0 Previous Work

This design project pertains to the Air Force Research Laboratory's Aerospace Propulsion Outreach Program (APOP). APOP is a intercollegiate design showcase in which each year students modify existing P80-SE engines to aid the Air Force in different areas of propulsion related research. Currently in its fourth year, APOP has presented the challenge of designing, building, and testing a power extraction unit for the P80-SE from which 500W of electrical power will be extracted. Additionally, the Air Force requests that the power extraction unit has limited negative effects regarding the stock thrust and fuel consumption of the engine.

The novelty of this project comes from the combination of three parameters presented by APOP. First, the power extraction has to come from a gas turbine engine. Second, a large amount of power has to be extracted from a fairly small engine (and even more for future larger scale research). Third, the thrust, and fuel consumption parameter changes should be limited. A design that incorporates these parameters, as well as being light and reliable will render onboard aircraft batteries obsolete, thus reducing weight.

Research and implementation of engine power extraction has been demonstrated in the past. For example, a group of students at Purdue University teamed up with General Motors and developed a power extraction unit that ran on the temperature difference created by the car's hot exhaust gases. This method for power extraction utilizes thermoelectric materials otherwise known as thermoelectric generators (TEGs), which are solid-state electric converters that derive electrical energy from heat using the thermoelectric effect [1]; three of such effects are the Seebeck, Peltier, and Thomson effects. Although TEGs are a proven power extraction technique, and provide limited impact on the stock thrust and fuel consumption, there are some pitfalls. Only very recently have thermoelectric materials become efficient enough to be considered as a possible power extraction method, and they haven't been implemented on turbojet engines. This if this technique is utilized, modifications will need to be made in order to design within the Air Force's parameters.

In addition to thermoelectric generators, there are other practical methods to extract energy from the JetCat engine. However, these extraction methods are novel when it comes to aircraft engine, thus all risks and applications will be more thoroughly examined at a later date. One of these methods is to utilize a piezoelectric device [4]. A piezoelectric device is a device that usually contains ceramics or polymers that produce energy through the contracting and expanding of the material due to external environmental sources such as vibration. This electricity source could be practical for engine power extraction due to the vibrations produced by the engine and also the sound wave vibrations produced. However the power output of these devices is very low thus new designs will have to be implemented in order to satisfy the requirements.

Electrical power can also be harnessed from the shaft by linking the compressor to the turbine. However, there are major complications with this power extraction technique. Major manufacturing changes would have to be made to the engine to preserve the fuel injector lines and fuel tanks.

Power has also been produced from large amounts of flowing fluid such as a hose for a carwash[6]. A generator linking two hoses together produces electricity when turbines spin due to the flow of liquid over them and the pressure difference created by the fuel pump. This could be adapted to a smaller scale to harness the fuel flow into the JetCat engine. However the low volumetric fuel flow might cause only small amounts of power to be produced but could be more practical for large scale engines. Also the pressure drop and additional energy required to pump the fluid through the generator and turbine must be taken into account.

3.0 Specific Objectives

There are four levels of success defined for this project; the base level, level one, represents the minimum criteria for the project to have any element of success. Level one is defined by the requirements from the customer for the project, the US Air Force. As per project rules, the power extraction unit must generate 500 Watts of power at 24 Volts. The power extraction unit must produce this power after the engine has been running no longer than TBD seconds. The engine, including the power extraction unit, must be compatible with the existing test stand that will be used in the final test demonstration. This test stand will be provided by the US Air Force at WPAFB, where the system will be tested. Additional testing will also occur locally at Boulder Airport, but the test stand used for these tests may be modified to fit the power extraction unit.

The second level of success is to satisfy the level one conditions while also reducing thrust by no more than TBD and increasing specific fuel consumption by no more than TBD, compared to baseline tests for the unaltered JetCat P-80SE engine. Additionally, the power extraction unit will produce 500 W throughout the engine's operating range. Note: The thrust and specific fuel consumption parameters will be determined upon acquisition of additional scoring information from the customer, Lt Joseph Ausserer.

The third success level adds the goals of adding no more than the weight and volume to the engine than would be added by a battery pack that supplied equivalent power (500 W at 24 Volts). The final success level, level four, is for the power extraction unit to fulfill all lower level goals and for the power extraction unit to be entirely external to the JetCat engine. Internal modifications, such as tapping the main shaft of the engine, are allowed by the customer but the highest level of success is defined as the most modular solution. That is, the power extraction unit will not alter the interior of the engine or its operation. If this level of success is achieved, only the power extraction unit will need to be brought to the demonstration at WPAFB, otherwise the power extraction unit and the modified engine will both need to be transported.

The deliverables to the customer are the power extraction device, an explanation and poster describing the project, and a final design paper. The group must fly to Wright Patterson Air Force Base in Dayton Ohio to present the poster and demonstrate the power extraction device [8]. The senior projects course also has deliverables. Papers, presentations, and reviews occur over the course of the class, in addition to the operational power extraction unit.

4.0 Functional Requirements

The functional block diagram (FBD) is designed to visually show how the project will be tested and verified once it has been designed and built. This diagram starts with the JetCat engine and from this, energy is moved to the power extraction unit (PEU) and sensors built into the engine send information to a Data Acquisition or DAQ card. The power extraction unit is the only part of the system that will be built from scratch. The PEU takes the energy from the engine and will convert this into usable electricity that is sent to the DAQ, along with other measurements. The DAQ card and computer then takes all of the information provided from the PEU, the engine, ambient parameters, and other information and performs calculations to determine the specific fuel consumption, reduction in thrust, and the total electric power produced by the system.

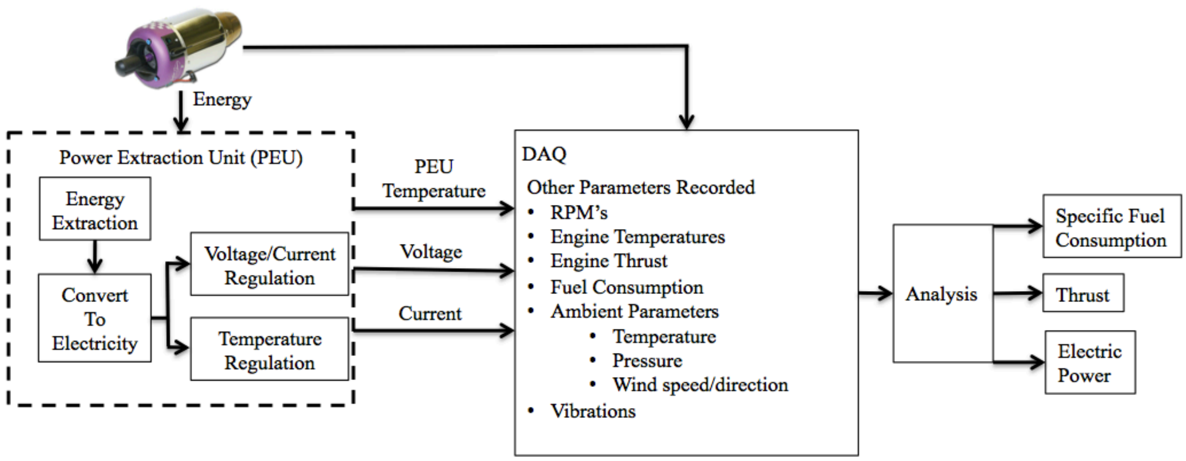

Figure 2. Functional Block Diagram

The CONOPS diagram in Figure 3 outlines the concept of operations for the COMET project. This Concept of Operations is based on the final system testing process that will verify the functionality of the Power Extraction Unit. This final test is also the normal operations process for the PEU in conjunction with the engine.

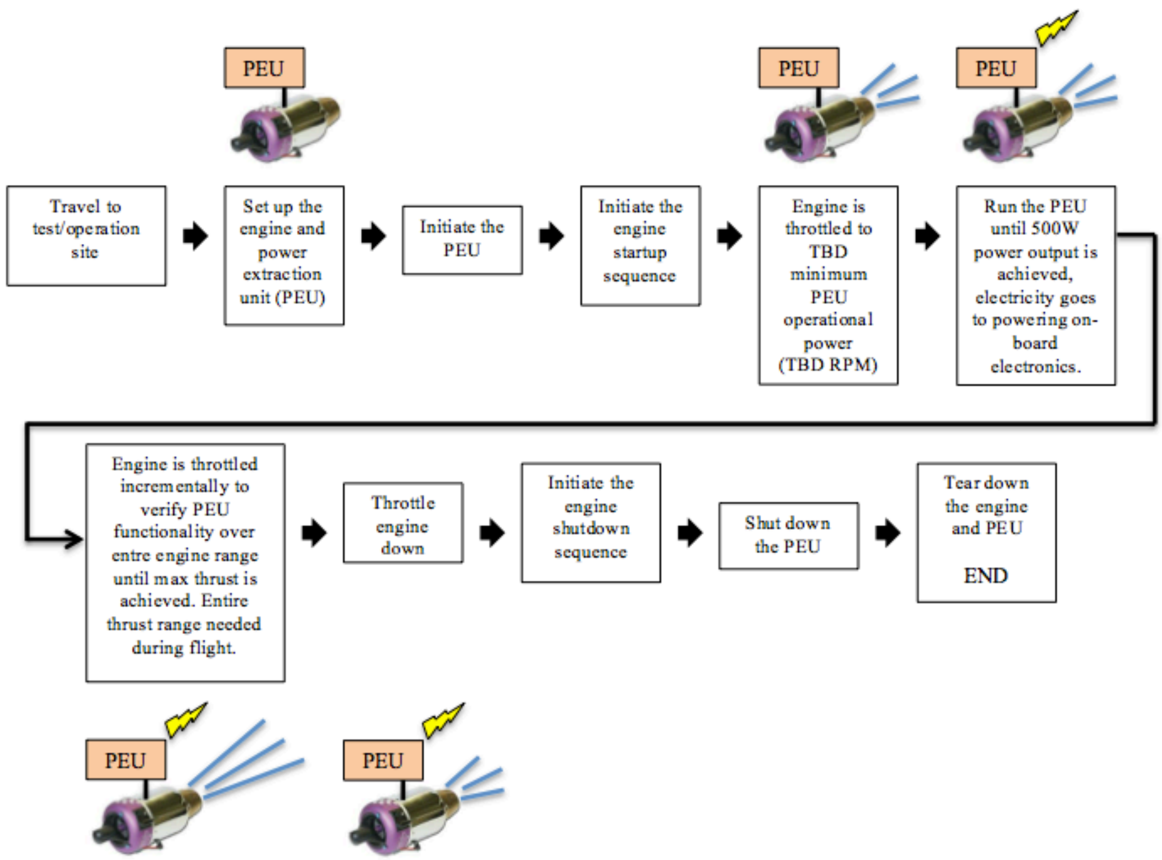

Figure 3. CONOPS Diagram

5.0 Critical Project Elements

Critical Project Elements	Reasoning
Engine Functionality	Since the project is centered around extracting 500W of power from the JetCat P-80SE engine, the most critical project element is functionality of the engine. The team will need to be able to become familiar with the operation of the engine so that this is not a problem while testing.
Thermal and Structures Environments	As the jet engine puts large amounts of stress on components from high heat (up to 690C) and fast rotation rates (35,000 - 125,000RPM), it will be necessary to design a structure that can integrate with the engine without introducing mechanical stress on the engine that could lead to engine failure.
Test Stand Customization	In order to successfully determine whether the project requirements have been met, it will be necessary to modify the existing test stand in order to interface with JetCat P-80SE as well as collect data on power output. This will involve construction of an adapter so that the engine can be secured as well as adding the capability to the existing DAQ to collect power output data.
Electrical Systems	Necessary in order to develop electrical systems to condition the generated power to the specifications of the requirements document. Also necessary in order to implement the testing of the engine performance.
Predictive Model Formulation	In order to determine the final design solution, a predictive model will need to be created that characterizes the amount of power available from the engine as well as the efficiency of the potential design solution in extracting this power.

6.0 Team Skills and Interests

Critical Project Elements	Team member(s) and associated skills/interests
Thermal	Ben – Very knowledgeable of thermodynamics and heat transfer Emily – Very knowledgeable of thermodynamics and heat transfer Eric – Experience in performing thermal analyses as a Thermal Systems intern at ULA
Structures	Emily – Very knowledgeable of structural component design as well as Solidworks experience Julia – SolidWorks, ProE, CATIA, MasterCAM, and Structural design experience. Matt – CATIA Modeling experience through summer internship along with experience in structural design.
Test Stand Customization	Emily- Learning LabView through job as lab assistant Matt – Testing and LabView/Simulink data acquisition Jon - Developed test stand for previous JetCat engine. LabView for interface Kevin – Testing and Integration team lead for Space Grant's HASP mission for fall 2010. Also, interned with Test and Data Integration

	team at United Launch Alliance summer 2012. Megan – Experience in product testing through Space Grant
Electrical Systems	Megan – Electrical manufacturing aka soldering, wire harnessing, assembly (interest in basic electrical system design) Jon – Electrical circuit development experience for robotics Eric – Experience in designing electrical systems for rockets along with sensor circuits.
Predictive Model Formulation	Emily- highly experienced in MATLAB Matt – Interested in MATLAB and Simulink Kevin – highly interested in CFD modeling and MATLAB Ben – Experienced in Simulink and MATLAB Eric – Highly experienced in MATLAB and Simulink

7.0 Resources

Critical Project Elements	**Team Resources**
Thermal	Ryan Starkey – Extensive experience working with jet engines. Will be able to assist the team in analyzing the thermal environment of the engine as well as suggest materials/parts able to withstand it.
Structures	ITLL SolidWorks enabled computers provide access to CAD modeling and Machine Shop access Have access and certifications that will enable the team to utilize these facilities for parts manufacturing. Aerospace Machine Shop Physics Machine Shop
Test Stand Customization	Boulder Municipal Airport – Will allow the team to use the airport as a safe testing facility for the engine. Test Stand/Sensors – Provided by Ryan Starkey in order to characterize the engine's performance.
Electrical Systems	Trudy Schwartz – Extensive experience and willing to help with any electrical design or manufacturing.

8.0 References

[1]Starkey, Ryan P. *ASEN4018-EngineProject_FA13*, University of Colorado, Boulder, Aug 2013, web. Accessed 9/4/13

[2] JetCat, USA. *P-80SE*. N.d. Photograph. http://www.jetcatusa.com/p80.html, 4250 Aerotech Center Way Bldg. G Paso Robles, CA 93446. Web

[3]"Thermoelectric Generator by TEG Power." *Thermoelectric Generator by TEG Power*. TEG Power, 2013. Web. 04 Sept. 2013. <http://tegpower.com/>.

[4]"PIEZOELECTRIC GENERATORS: APPLICATIONS." . APC International, LTD. Web. http://www.americanpiezo.com/piezo-theory/generators.html

[5]Dickinson, Boonsri. "How an Engine's Exhaust Can Generate Electricity." *SmartPlanet*. N.p., 24 Nov. 2010. Web. 04 Sept. 2013. <http://www.smartplanet.com/blog/science-scope/how-an-engines-exhaust-can-generate-electricity/5441>.

[6] "11 Innovative and Interesting Ways of Generating Power" Web. http://www.smashinglists.com/11-innovative-and-interesting-ways-to-generate-power/

[7] "Green Sidewalk Makes Electricity – One Footstep at a Time" Web. http://www.cnn.com/2011/10/13/tech/innovation/pavegen-kinetic-pavements (energy from walking/ could possibly be adapted into shaft, turbines, or compressors.

[8] APOP 2013-2014 Information and Rules (Rev. 1)