University of Colorado
Department of Aerospace Engineering Sciences
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Project Definition Document (PDD)

Methane Combustion and Control for a Mini Gas Turbine

Approvals

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Figure 1: Stock JetCat P90 RXi Turbine with Engine Control Unit

1.0 Problem or Need

The JetCat P90-RXi engine is a powerful miniature turbojet gas turbine, which currently runs on kerosene fuel. Methane, as opposed to kerosene, features lighter weights, easier combustion, increased cost effectiveness, and the production of more thrust per unit mass of fuel than kerosene. Thus, the mission of this team is to modify the engine to use gaseous methane as a fuel instead of kerosene, investigating the feasibility of methane as a fuel for a wider scope of mini turbojet engines.

The JetCat engine has six main components: the compressor, the combustion chamber, the ball bearing, the engine control unit (ECU), the fuel delivery system (FDS), and the turbine itself. Modifications to the turbine and the compressor fall outside of the scope of this project, and are not necessary to convert the turbine to run on gaseous methane.

The core intent of this project will focus on modeling, simulating, implementing, and integrating modifications to the ECU, the FDS, and the combustion chamber. The bearings will be not be modified, yet the modified engine will continue to use kerosene to lubricate the bearings as it currently does.

The ECU will be completely rebuilt, entirely discarding the previous ECU in favor of a newly designed and implemented new ECU with fully known functionality. An additional engine simulator code will be written as a companion program, fully simulating the engine running, generating simulated output signals, in order to facilitate testing the new ECU and FDS without running the engine. The FDS will be designed to interface with the modified engine, delivering and controlling gaseous methane output into the main combustion chamber.

The FDS will also be responsible for providing kerosene to lubricate the ball bearings. The combustion chamber will be modeled and designed to accommodate the burning of methane at high enough levels to maintain the thrust from the engine running on kerosene fuel.

The lowest level of success for this project will be validated as the new ECU fully integrated into the JetCat P-90RXi running on kerosene fuel, while still interfacing with a modeled combustion chamber and a modified FDS capable of delivering both methane fuel and kerosene lubrication using the engine simulator. Validation of the highest level of success of this project will come as a full test of the fully integrated NECU, FDS, and combustion chamber in the JetCat P90-RXi engine running methane fuel for TBD minutes at TBD max fuel rate without overheating.

2.0 Previous Work

Methane as a fuel in a turbine system for power production has existed for decades, beginning with models such as the GE Frame-3 generators still in use in many places today. These early models were capable of generating 11,923 kW continuous using only methane (natural gas) with an exhaust temperature of 542 °C (1). These generators and their successors are large scale (10s-100s of feet long) and primarily used in power plants.

The 2013-2014 University of Colorado senior design project COMET attempted to use the JetCat aircraft engine to produce power similar to the large turbine generators, but at a much smaller scale and using a kerosene-oil fuel (2). The team was able to extract power from as intended however the engine was not able to sustain such power generation for an extended amount of time. They were able to extract an average of 48 watts before the engine automatically shut down after about 6 seconds due to electrical and mechanical complications. The COMET project will be a valuable resource going forward.

Cryogenic methane as a fuel is currently under research in many fields, including the SpaceX Raptor program. This project is focused on creating reusable rocket engines powered by methane for future super-heavy launch missions in lieu of the current RP-1 kerosene fuel. The project was first proposed in 2009 and has been under development since 2011. Currently the program is undergoing component testing and does not have a public date of completion (5).

In 1973 NASA, in cooperation with General Electric, modified a J85-13 engine to run on gaseous methane. The engine took stored cryogenic methane, pumped it to supercritical pressures, and heated to the point of gasification before being pumped into the combustor. Modifications included replacing fuel manifold and injectors, mounting an overspeed tachometer, mounting a 28V DC motor to provide nozzle area control, and modification of the fuel control system. The engine was successfully tested with a demonstration where it was brought from idle to maximum rotor speed in 3.5 seconds. (4) However during testing the oil in an oil-to-methane heat exchanger froze at the fuel pump discharge. Although thrust data was not recorded for the converted engine, it was found that the system could replicate the RPM of the original engine. The J-85 engine is 45.4 inches long and 18.2 inches in diameter with a dry weight of 396 lbs and has an 8 stage axial compressor (3).

3.0 Specific Objectives

Table 1 defines the top level requirements for acceptable levels of success of this project. Level 1 represents the minimum acceptable level of success while level 4 represents the highest level of success.

Table 1: Methane Gas Engine level of success

Success Level	Project Element		
	ECU	Combustion Chamber	Fuel Delivery System (FDS)
Level 1	**ECU capable of interfacing with a simulated JetCat P90RXI engine running on kerosene fuel is designed and constructed.** -The ECU is capable of engine startup, shutdown, and operation at the idle state (40,000-50,000 rpm) -The ECU interfaces with the simulator and obtains and stores exhaust temperature and rpm data -The ECU will shut down the engine when receiving a simulated output in excess of TBD rpm (documented max). -The ECU will shut down the engine when receiving a simulated output in excess TBD ºC (documented max)	**Combustion chamber is modelled for JetCat P90RXI engine** -1D model is developed to determine the relationship between the temperature at the beginning of the combustion chamber and the temperature right before the turbine.	**Fuel Delivery System is designed to provide the correct amount of methane fuel and kerosene lubricant** -The correct relationship between methane fuel flow rate and throttle control is determined -The correct amount of kerosene to be provided to ball bearings is calculated -Required area of tubes is calculated -Required pressure for fuel delivery is calculated
Level 2	**ECU in Level interfaces with JetCat P90RXI engine running on kerosene fuel at idle state** -ECU operates fuel delivery system -The ECU reads and stores data from the rpm sensor -The ECU reads and stores exhaust temperature data from the thermocouple -ECU shuts down fuel delivery system when exhaust temperature exceeds TBD ºC or when rpm sensor outputs greater than TBD rpm	**Level 1 combustion chamber model is modified to support methane fuel** -1D model is used to modify existing combustion can to support adequate cooling of engine running on methane gas fuel	**Fuel Delivery system in level 1 is built and tested to provide fuel and separate methane fuel and lubricant** -Fuel delivery system is constructed and tested outside the engine -Fuel delivery system interfaces with ECU

Level 3	**ECU is modified and tested for JetCat P90 RXI engine running on methane gas fuel** -Simulated engine and ECU software are modified to support methane gas fuel -ECU capability is tested by running JetCat P90RXI engine with methane gas fuel	**Combustion chamber is integrated into JetCat P90RXI engine** -Component is integrated with engine -Engine is run with methane fuel for TBD minutes at TBD % max fuel rate without overheating	**Fuel delivery system is integrated into JetCat P90RXI engine** -Fuel Delivery System is integrated with engine - Methane flow rate gives equivalent burn energy to kerosene

4.0 Functional Requirements

Figure 2 provides a high level Concept of Operations (CONOPS), which including the major functional elements (RC Controller, ECU, Duel Delivery and Turbojet) of the methane gas turbine system. Figure 3 diagram provides a functional block diagram (FBD) showing how the methane gas turbine will be operated in the intended application

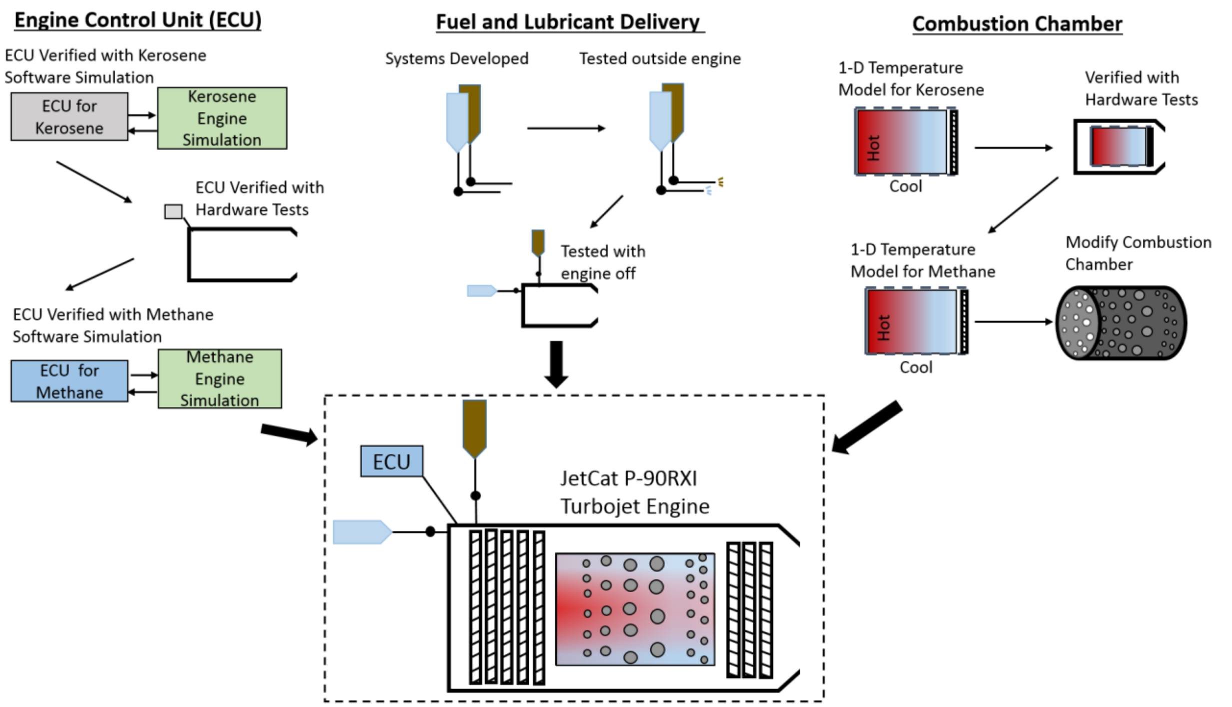

Figure 2: Concept of Operations (ConOps)

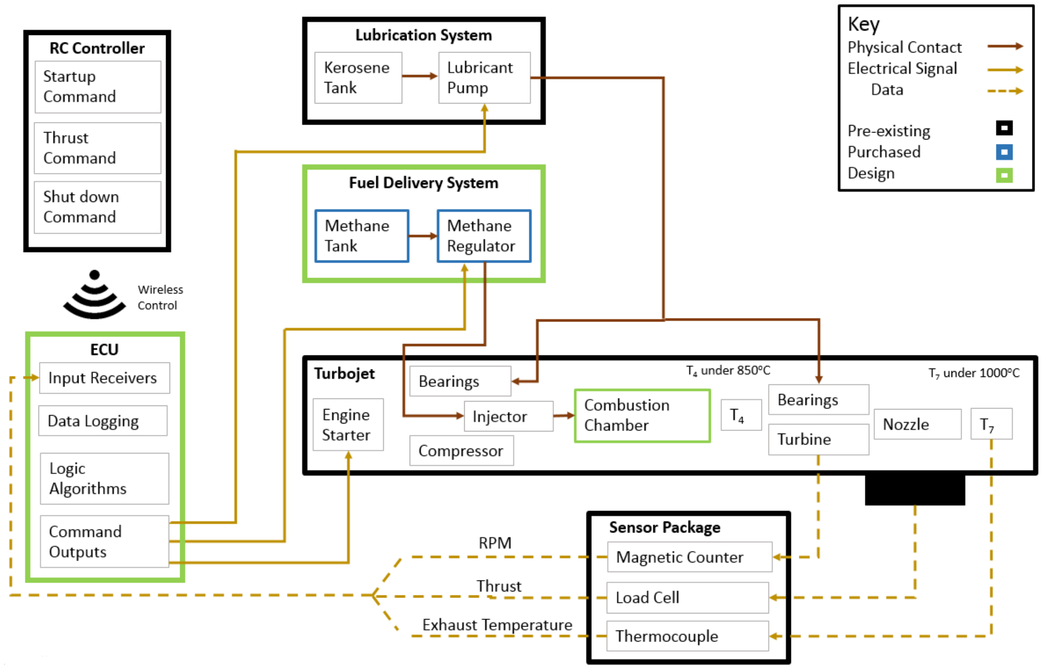

Figure 3: Functional Block Diagram (FBD)

5.0 Critical Project Elements

1. Hardware

1.1. **Electronic control unit (ECU):** A new engine control unit needs to be developed in order to make the switch to methane fuel. This will likely be a microcontroller that can interface with the exhaust gas temperature thermocouple, the RPM sensor and the fuel delivery system. The ECU will also need a way to output all of the data for storage and validation.

1.2. **Fuel delivery system:** In order to use methane as a fuel the fuel delivery system needs to be redesigned for gaseous methane while maintaining the flow of the JP-8/oil mixture that lubricates the bearings.

1.3. **Combustor can:** The combustor can needs to be redesigned to ensure the gas entering the turbine is adequately cool for the operation of the turbine stage.

2. Software

2.1. **ECU firmware:** The firmware needs to modulate the fuel flow rate based on exhaust gas temperature and RPM and make sure the desired thrust is reached without damaging the engine.

2.2. **Simulated engine:** A software simulation of the engine that is needed to verify the ECU. This should be run on a lab computer using existing hardware as the interface.

3. Models

3.1. **Combustion and cooling model:** Models the combustion and cooling of the combustion can when it is burning methane. This is needed to design the combustor can. This will either be a MATLab model or Solidworks and ANSYS available in the Visions lab.

3.2. **Engine operation model:** The model used to create the simulated engine. Calculates RPM and Exhaust gas temperature based on commanded fuel flow.

3.3. **Fuel delivery model:** Models the flow of the fuel within the injector in order to design an injector for methane operation. Made using pencil and paper or MATLab

4. Assets

4.1. **Boulder airport:** Boulder airport is the test location for the engine on the existing static test stand. Access shouldn't be a problem and the airport was fine with helping previous propulsion projects.

4.2. **Replacement engine:** It is possible that during testing an engine encounters a critical error and will need to be replaced. The cost of the replacement is around $2000.

4.3. **Replacement parts:** During the modification of the fuel delivery system the lubrication system will be modified which will endanger the bearings. In addition the bearings will need replacement after 25 hrs of total operation. It is likely that replacement bearings will be needed at some point in the project. The cost of bearing replacement is $500 and the time for a complete engine disassembly and reassembly.

6.0 Team Skills and Interests

Table 2: Team member skills and interests

Critical Project Element	Team Members	Associated skill
ECU	Corey Wilson Huikang Ma Crawford Leeds Nate Genrich	Software design – CSCI minor – systems background Microcontroller work – electronics and comms Hardware design – enrolled in Microavionics Experience with programming language Basic – microcontroller work
Combustion Chamber Design	Daniel Frazier Carlos Torres Chris Jirucha Abe Jorgenson Alex Truskowski	Thermo experience/interest – modeling experience Prev. completed 4013 – career interest Prev. completed 4013 – in communication with Prof. Daily from Mechanical Engineering dept. SolidWorks background – cycle analysis experience
Fuel Delivery System	Carlos Torres Nate Genrich Huikang Ma Chris Jirucha Daniel Frazier	Natural gas work – hardware/plumbing experience Work in Aerodynamics – PHYS minor Work in Aerodynamics – general interest Hardware modeling – flow meter internship Work in Aerodynamics – general interest

7.0 Resources

Table 3: Source and Resource for Critical Project Elements

Critical Project Elements	Resource/Source
ECU Hardware	Soldering station, electronic components and tools for assembly Source: Trudy Schwarz and Tim May
ECU Software	Basic development environment, consultation on controller algorithms Source: John Daily, Ryan Starkey and Air Force Advisor
Combustion Chamber	Access to Machine shop, specialized hole cutting equipment Source: Matt Rhode and Bobby Hodgkinson
Combustion chamber model	Consultation on equations for temperature distributions in the combustion chamber Source: John Daily, Ryan Starkey and Air Force Advisor
Fuel delivery system	Methane gas canisters, labs for methane storage, documentation/consultation on handling procedures, tubing to support methane flow. Source: Ryan Starkey, Matt Rhode and Bobby Hodgkinson
Test and Safety	Access to boulder airport to support engine testing. Consulting for JetCat P90RXI engine operation/testing procedures Source: Jeffrey Ellenoff, BACLab members and Boulder Airport
Storage	Support engine storage/rebuild Source: BACLab

8.0 References

(1) Brooks, Frank J. *GE Gas Turbine Performance Characteristics*. Tech. Schenectady, NY: GE Power Systems. Print.

(2) Contreras-Garcia, Julia, Emily Ehrle, Jonathan Lumpkin, Eric James, Matthew McClain, Megan O'Sullivan, Ben Woeste, and Kevin Wong. *COMET: Colorado Mini Engine Team Project Final Report*. 1 May 2014. Web.

(3) "The General Electric J85 Engine." *The General Electric J85 Engine*. 2 Feb. 2014. Web. 7 Sept. 2014.

(4) Goldsmith, J. S., and G. W. Bennet. *Hydrogen-Methane Fuel Control Systems for Turbojet Engines*. *Http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19740008380.pdf*. NASA. Web. 7 Sept. 2014.

(5) "SpaceX Advances Drive for Mars Rocket via Raptor Power." *NASASpaceFlight.com*. SpaceX, 7 Mar. 2014s. Web. 9 Sept. 2014.