UNIVERSITY TURBINE SYSTEMS RESEARCH (UTSR) 2019 GAS TURBINE INDUSTRIAL FELLOWSHIP PROGRAM

Prepared by:
Karl Roush
B.S. Candidate, Aerospace Engineering
Georgia Institute of Technology

FINAL REPORT
UTSR Summer 2019 Fellowship

Prepared for:
Southwest Research Institute

August 2, 2019

SOUTHWEST RESEARCH INSTITUTE®
6220 Culebra Road
San Antonio, Texas 78238

UNIVERSITY TURBINE SYSTEMS RESEARCH (UTSR) 2019 GAS TURBINE INDUSTRIAL FELLOWSHIP PROGRAM

Prepared by:
Karl Roush
B.S. Candidate, Aerospace Engineering
Georgia Institute of Technology

FINAL REPORT
UTSR Summer 2019 Fellowship

Prepared for:
Southwest Research Institute

August 2, 2019

Approved:

Grant O. Musgrove
Manager, R&D
Propulsion & Energy Machinery

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

The UTSR Fellowship offers university students the opportunity to experience industrial gas turbine design and manufacturing environments. Southwest Research Institute® (SwRI®) manages and participates in this program. The Fellowship splits tasks among various sections of Division 18, Department 04. As such, this report will cover various tasks from NPSS (Numerical Propulsion System Simulation) analysis to hardware modifications.

2. VARIABLE CYCLE QUIET POWER ENGINE

The purpose of this project was to examine the viability of a variable cycle engine within a given mission profile. Essentially, the system includes a ducted fan allowing for optimum design of the propulsion system aerodynamics without sacrificing the aero performance of the compact fuel-to-electric system.

2.1 LITERATURE REVIEW

An initial literature review showed that mini UAVs (Unmanned Aerial Vehicles) preform best with electric and that larger "strategic" aircraft are better off with a combustion engine. However, the middle range ("tactical") are ideal candidates for a hybrid propulsion system.

An initial calculation based off of the TigerShark UAS system (500 lbs.) showed that a hybrid system could provide the requisite power at this size. This was then scaled up to the test aircraft which has a MTOW of about 3,000 lbs. The power requirements at this size are in line with current hybrid technology, though the specifics will vary based on mission profile.

Category	Mini	Tactical	Strategic
Altitude	Low	Low to medium	Medium to high
Endurance	Short (about an hour)	Medium (up to several hours)	Long (ranges from hours to days)
Range	Close-range	Limited to line-of-sight (approximately 300 kilometers or less) (about 186 miles)	Long range
Example	Raven 	Shadow 	Global Hawk 

Sources: CIA (information); DOD (photos).

Figure 1. CIA definitions of UAV sizes

2.2 LEARNING NPSS

At the start of the project, I was familiar with the use of NPSS and its syntax, but had only used it for the purpose of an engine cycle analysis. As such, the first month of the project was spent on understanding how the Mission Elements aspect of NPSS functioned. Since documentation on the use of these elements was lacking, I modified CDM05 to understand how it worked.

Additionally, David Ransom's VCQ engine model worked best with the NPSS IDE. Although easy to use, the IDE is under development so not all aspects are functional. It was, therefore, an additional project objective to provide feedback on the IDE.

The initial VCQ engine was not compatible with how NPSS handles mission analysis. This required re-writing the initial model, adding a PowerSetting and EngineInterface, while also restructuring the model into an assembly.

2.3 MODIFICATIONS AND CONCEPT

The example mission analysis was for a fighter aircraft. However, the UAV for this analysis is based off of a high lift/drag ratio, sail plane variant aircraft. Therefore, the airframe weights, payloads, and drag polars had to be generated for this specific instance. More details can be found in the project documentation.

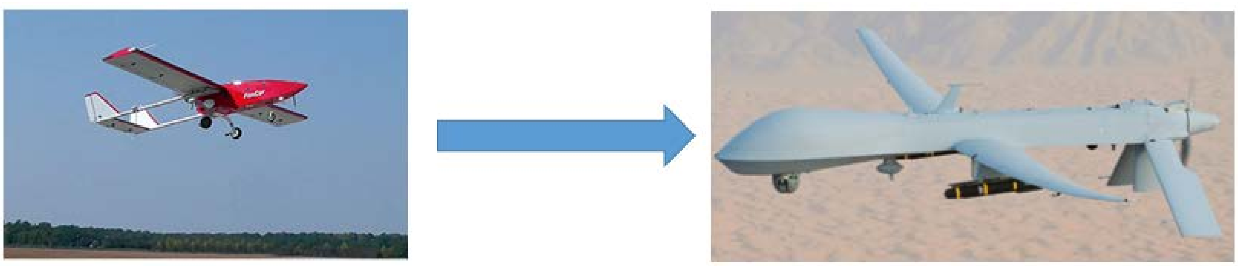

Figure 2. Modeling transition from small scale to midsize tactical UAV

The concept was to use the combustion powered engine for all points in the flight, except during a loiter segment. In this section, a battery is used. However, NPSS does not allow for variable cycle analysis, requiring the integration of two "different" engines for the mission. The second engine was essentially the same as the first, but without the combustor. Through the use of a Class Member Access Operator, the engines can be swapped during the loiter segment of the mission.

2.3.1 ADDING A BATTERY

For all intents and purposes, a battery can be modeled as an extra payload. Based on another literature review, a spreadsheet that calculates battery weight based on equivalent fuel weight or loiter time was generated.

This was implemented into the mission analysis via a separate function file. Essentially, the mission analysis runs with a combustion engine, then a hybrid case. After the first run, this function takes the amount of fuel burned during loiter and converts it to an appropriate battery weight for the second run.

2.3.2 ADJUSTING FUEL BURN

NPSS does not check whether or not the fuel burned during the mission is more than the fuel input at the start. As a consequence, it is possible that the analysis yields more fuel burned than is actually available. To avoid this issue, another separate function file is used. This function varies the fuel input at the start of the mission until it is greater than the fuel burned. It also allows the user to specify an excess fuel margin.

2.4 RESULTS

Based on the analysis, a hybrid cycle UAV would be the optimum choice for loiter times less than 1.5 hours. Beyond this point, the added battery weight requires more fuel for the mission than if it ran entirely on a combustion engine.

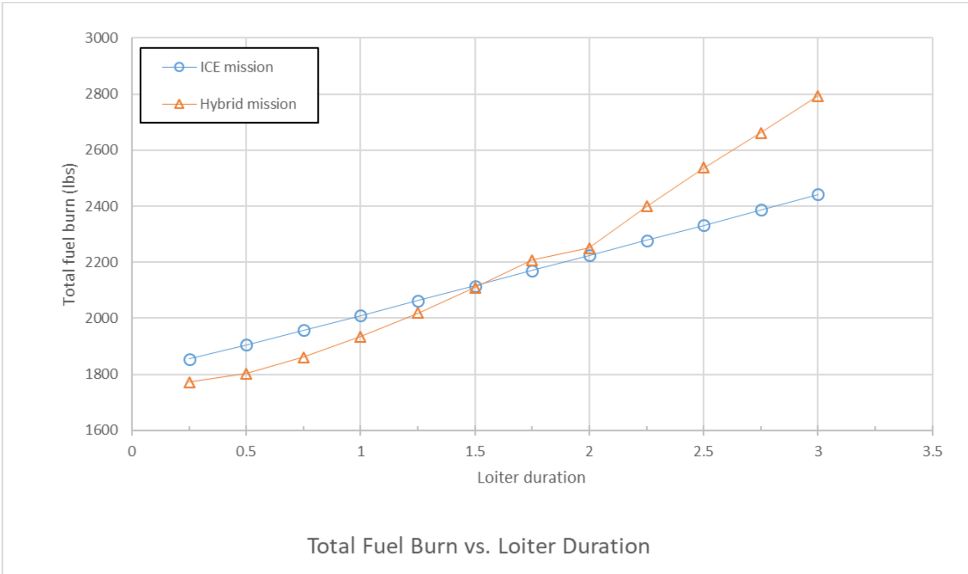

Figure 3. Battery and Fuel Weights for Given Loiter Time

2.5 CURRENT STATUS

The mission analysis shows that a mid-sized hybrid UAV based off of the VCQ engine design is feasible for short loiter times. A sensitivity analysis was carried out to determine numerous target areas to increase the range or loiter times, which are identified in the project files.

The next steps for this project would be to examine the weight reduction of a VCQ engine over a traditional hybrid system in addition to physically modelling the UAV.

3. LASER PIV SYSTEM

The goal of this project is to repurpose the Quantel Qsmart Twins laser for use in a particle image velocimetry (PIV) system.

3.1 FEASIBILITY

The PIV system must have a laser, related optics, timing-based control system, and a camera. The most critical aspect of the system is in the timing component. A literature review showed that a laser PIV system can be built at a reasonable price assuming certain timing and image requirements are met.

3.2 SYSTEM SETUP

After purchasing the required sheet forming optics, we determined that the current department camera could not be externally controlled and, therefore, could not be used in the system. A NIKON DSLR3500 was selected for its resolution, fast shutter speed, and capability to be externally controlled.

Initially, the laser cooling units were not with the actual laser, but were eventually located. Setting up the laser was relatively straight forward; it was simply bolted to a cart and connected to the cooling units.

When filling the cooling units and testing the pumps, two of the fuses blew in Cooler Unit 1. Quantel believes this to be a motherboard issue; they are checking their stock in the U.S. and France for a spare part. If they are unable to locate one, we will have to ship the cooling unit to the manufacturer for repairs. During this down time, a collection of safety and operating procedures were compiled.

Figure 4. Laser Mounted to Cart, Cooling Units Below

3.3 CURRENT STATUS

Due to the failure of Coolant Unit 1, we were unable to test the laser. However, all components are ready and assembled. The next steps would involve aligning the laser, hooking up an external controller, and then testing.

4. DRAG TEST RIG

The goal of this project was to rebuild the drag test rig and collect data from of a new set of samples.

4.1 PROGRESS

The rig was initially in storage, so a location for it had to be found. After relocating the rig, it was disassembled to remove the previous test article then re-assembled. The rig had several leaks, which were plugged. The lack of availability of pressure transducers set the project back about a month. Additionally, Division 18 IT restricted installs of REFPROP due to licensing issues.

4.2 CURRENT STATUS

The rig was run with both a set of flat plates and with plates surfaced with riblets. No data analysis has been carried out at this point, so that would be the next step for this project.

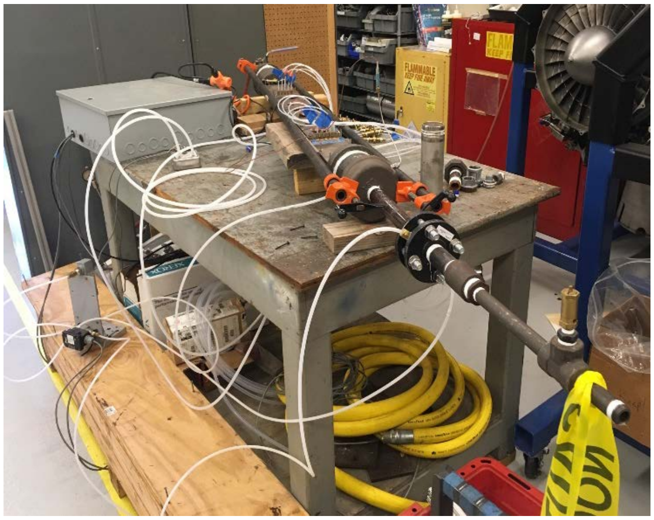

Figure 5. Current Drag Test Rig Setup

5. TITAN T62-32 INSTRUMENTATION

The goal of this project was to instrument the Titan T62 and run it with an attached generator.

5.1 SAFETY UPGRADES

After confirming that the engine ran as stock, the control panel was disassembled and disconnected from the engine. The wires were only several feet long, presenting a safety issue. This was resolved by splicing in a larger wire grouping extending it out to 15 ft. With these upgrades, the control panel could be separate from the engine cart.

5.2 GENERATOR INFORMATION

While we did have a manual for the engine, we did not have one for the generator. Finding documentation on the almost 50-year-old engine was rather difficult, but eventually one was sourced from a vendor. The same vendor supplied some information on connecting the generator to an output, which indicated a need to purchase a voltage regulator. All of these aspects should be considered for future project work.

5.3 CURRENT STATUS

In light of the missing equipment, the project goal was shifted to obtaining baseline data from the engine. In addition to collecting pressure and temperature data at compressor discharge, there will be several temperature probes mounted in the exhaust. However, the orifice plate (to measure air mass flow rate) is not rated to temperatures above 200°F, so the exhaust pipe is extended to allow for cooling.

Due to time constraints, the T62 was only able to be configured with instrumentation ports. There are ¼" thermocouple fittings in the exhaust and two ports at compressor discharge (one for temperature and the other for pressure). The next steps for this project would be to insert the thermocouples & pressure transduces, and carry out a test.

Figure 6. Current T62 Setup

6. NPSS UNIT CONVERSION

The goal of this project was to take an example of one of the Common Development Models and convert it to allow for SI unit input/output.

6.1 CHANGES

Within model files, NPSS support a "units" modification after value assignment. Although this is the most concise way of handling unit conversions, several methods were used as a demonstration. These were compiled in a short document, explaining how each works.

Units are handled differently in viewers through a separate @units modifier. However, in title blocks, the actual value of the variable is pulled so a mathematical operation for the conversion has to be performed. All of this was documented in the aforementioned explanation file.

6.2 CURRENT STATUS

This project was completed with regards to the requirements.

7. ACKNOWLEDGEMENTS

I would like to thank SwRI for choosing me for the 2019 UTSR Fellowship and investing in my education. I am very grateful for the introduction to a variety of research topics; something I appreciate as I am in the process of picking an area for my Master's thesis.

Throughout the fellowship, I felt like a valued member of the team and had the support of the entire group. I would especially like to extend my gratitude to Grant Musgrove, David Ransom and Tim Allison for integrating me into their sections. Also, to Jacob Delimont, Charles Krouse, Owen Pryor, Ellen Smith, Shane Coogan, and Dorothea Martinez for providing their assistance and guidance throughout the fellowship.