Aerospace Propulsion Outreach Program

Final Report

Raquel Coburn

Ziyi Jian

JP Miska

Travis Sundseth

2022-2023

Project Sponsor: United States Air Force

Faculty Advisor: Dr. David Blunck

Sponsor Mentor: James Mostek

Instructor: John Greeven

Oregon State University
College of Engineering

DISCLAIMER

ABSTRACT

The 2022-2023 Oregon State University APOP team has employed the Inlet Gas Generator to capture the power created by the JetCat P100-RX Microturbine Jet Engine. This redesign uses an inlet shroud made from 3-D printed PLA which encases an electric ducted fan (EDF). As the engine's rotors begin to accelerate, the blades in the EDF spin due to the air quickly traveling into the engine. The rotation of the EDF's blades is captured and transferred from AC to DC power through the implementation of a 3-phase full-bridge rectifier. A load, in the form of a DC car heater, is placed behind the rectifier in the system to drain the system of its excess power.

The thrust of the engine remained close to constant when the shroud was added to the intake, maintaining a value close to its original 94 Newtons. Because no changes were made to the rest of the engine, the thrust should remain practically unchanged when compared to the stock data. The power generated by the EDF has not reached the values assigned by the Air Force. Although the various EDF/shroud designs tested have spun at speeds of 6000 and 12,500 rpm with the 90 mm and 80 mm EDF respectively and produced over 5 volts of power, neither combination has generated more than 0.1 Watts of power. Because the EDF's are spinning at such high speeds and producing a significant voltage, some manipulation of the electrical circuit will be conducted to achieve higher power ratings. More testing and design iterations will take place prior to the Air Force meeting during April in order to optimize the inlet gas generator design.

ACKNOWLEDGEMENTS

The APOP team would like to thank John Greeven and Dr. Blunck for their ongoing support and mentorship throughout the duration of this project. These individuals have played a crucial role in the development and execution of this project. We would also like to thank the United States Air Force (USAF) for funding the APOP project. They made it possible for the APOP team to meet the requirements of the challenge presented by the USAF this year.We would also like to extend thanks to the non-capstone undergraduate students, Michael Lancaster and Andrew Burgess, who have played a crucial role in the success of this year's APOP team, and will continue the legacy of the team next year.

TABLE OF CONTENTS

Contents

1 BACKGROUND

The Aerospace Propulsion Outreach Program (APOP) is a student-led research project designed, funded, and run by the United States Air Force. The Air Force provides each university team with a JetCat P100-RX Microturbine Jet Engine. The project requires teams to undergo an extensive analysis of the engine in order to determine the best redesign concept to complete the objectives set by the Air Force in their Statement of Work. Each year the program tasks students with a new set of challenges that differ from the previous year. Various weights are assigned to each objective and teams will be scored in correspondence to these weights during the annual meeting at Wright-Patterson Air Force Base in Dayton, Ohio during the Spring. For the 2022-2023 school year, the Air Force assigned the following objectives with their corresponding weights:

- Maximize Thrust-To-Weight Ratio (30%)
- Generate 80 Watts of Power at Idle and 500 Watts of Power at Full Throttle (60%)
- Digital Twin Accuracy (10%)

Teams can manipulate any component that comes before or after the rotating assembly of the engine to meet these objectives. The fuel system cannot be modified for weight savings. The Digital Twin is a set of code(s) that should accurately predict the performance of the engine.

1.1 Project Scope

1.1.1 Purpose

APOP provides student engineers with the opportunity to not only learn about and work on a real, albeit, micro jet turbine, it also gives them the insight to see what working in the professional engineering field might be like. The process of working with a team to generate multiple redesign concepts, selecting one by applying tools like a House of Quality and Evaluation Matrix, reevaluating that initial redesign concept, and making iterations to it provides participating students with a good understanding of how their future projects will likely be in the professional field. Tracking, recording, and discussing the process with supervisors (both at OSU and the Air Force) can also be considered a precursor to what one may see at work after college.

1.1.2 Customers

The 2022-23 Oregon State University APOP team's primary customer is the United States Air Force. The Air Force, through the Air Force Research Laboratory (AFRL), set forth the tasks to solve and the funds to generate a solution to the problem. Not only is the Air Force looking for a solution to the objectives defined in the Statement of Work, but they are also looking for future employees to be hired on after graduation.

1.1.3 Stakeholders

The primary stakeholder of the project is the Oregon State APOP team. The project must be completed with sufficient effort and results in order to graduate with an engineering degree. Also, if the project is completed in an exemplary manner, members of the team may receive job offers from the Air Force afterwards.

Dr. David Blunck, the team's technical advisor is also a significant stakeholder. Dr. Blunck meets once per week to discuss the progress and the direction of the team, as well as serves as the mediator between the Air Force and the APOP team. To maintain connections within the Air Force and to ensure the continuation of the program, Dr. Blunck relies on the team's success at the Air Force meeting in April.

As previously discussed in Section 1.2.2, the Air Force has a stake in the success of the Oregon State APOP team because they rely on the team to generate new ideas and use the project to search out intelligent young engineers.

1.1.4 Previous Designs

Unlike other AIAA teams at Oregon State University, the Air Force changes the objectives of APOP on a yearly basis. While this keeps the project interesting and unique every year that Oregon State participates, it also means that the redesign concepts of previous teams are likely unusable by the current team. However, last year's team was tasked with maximizing the thrust-to-weight ratio of the engine. To do this, the 2021-22 Oregon State APOP team implemented additional fans, a compressor with enhanced geometry, and a modified outlet cone to increase the thrust. Unfortunately, some of these modifications only hindered the engine's performance and resulted in a failed start-up procedure in Ohio. Because a goal of the current team is to leave next year's team with a working engine in conjunction with the tasks set forth by the AFRL, employing the enhanced outlet cone geometry was the only redesign concept generated by the previous year's team that was considered for the current redesign.

2 DESIGN PROCESS

2.1 Team Charter

Before any concept generation took place, the 2022-23 Oregon State APOP team first put together a team charter to determine how the team would handle itself in order to get tasks done in a timely manner. The team charter also described how any disagreements or problems with the team would be handled. Once these procedures to mitigate future problems were determined, the team underwent a general brainstorming process. Multiple ideas were conceived and all members of the team proposed various design concepts that could potentially meet the criteria defined by the Air Force in their Statement of Work.

2.2 House of Quality

To judge the feasibility of each proposed design generated during the initial brainstorming step, the team created a House of Quality (see Appendix A) with multiple customer requirements as well as corresponding engineering specifications. Each customer requirement was assigned a weight out of 250 to specify which entries should be considered more important. Originally, the customer requirements and their corresponding weights were: power generation (100), device adjusts power generation (25), less fuel consumption (25), increased thrust power (35), reduced weight (25), available thrust is able to be utilized for work (15), aesthetically pleasing (5), device usable for longer duration without failing (5), device is able to start and sustain self under own power (5), and “digital twin” accurately models physical engine (10). These customer requirements were paired with engineering specifications that provided target values and tolerances. Most engineering specifications were based on the values provided by the Air Force in their Statement of Work, but some were given simple “yes/no” evaluations if there was no associated target value with the engineering specifications. The House of Quality has changed slightly since its inception due to gained experience by team members. These changes were made to provide more realistic expectations of the design’s performance and can be found in Appendix B. The three main customer requirements assigned by the Air Force remain in the House of Quality’s current iteration (albeit changed to better match the data obtained during trials), but the other customer requirements have been removed to create a set of streamlined objectives. Ensuring that the engine still runs with the addition of the inlet shroud and maintaining the engine’s functionality so that next year’s team has an engine at the beginning of Fall term were added to the House of Quality because the goals of the current team have changed over the last few months.

2.3 Evaluation Matrix

After the criteria for a successful redesign concept was defined with the team’s House of Quality, an Evaluation Matrix (see Appendix C) was created to grade each design. Each redesign concept was scored on the following criteria: material cost, manufacturing cost, reliability, modifications required, mass, fuel flow, and safety concerns. Each criteria (much like the House of Quality) was assigned a specific weight depending on its importance to the success of the project. Six design concepts were generated and applied to the evaluation matrix. Of the exhaust gas generator, bevel gear off-set, worm gear off-set, planetary gear direct drive, bevel gear off-set (internally attached), and direct drive generator, the direct drive generator scored highest in the evaluation matrix.

3 DESIGN PROPOSAL – First Term

Without a functioning engine to test the design concepts, the 2022-23 Oregon State APOP team made use of code and evaluation templates for the entirety of Fall term to find the best redesign solution for the project. Using MATLAB, members of the team designed multiple codes to analyze the anticipated performance of the engine with the various different redesign concepts. The codes and their corresponding graphs can be found in Appendix E.

3.1 Design Concept 1 - Direct Drive Generator

Using the evaluation matrix to influence our decision, the APOP team determined that the best redesign concept was the direct drive generator due to its reliability and minimal required modifications. Koford, a company that specializes in manufacturing high-quality, high-rpm motors, was to be used as a vendor for the applicable motor for the direct drive design. However, after further research was conducted, it was determined that the Koford motor would not meet the desired performance needed to achieve the assigned power output. Operating at a little over 100,000 rpm, the selected Koford motor would limit the engine's full throttle capabilities, running at a speed only ⅔ of the engine's maximum rpm rating provided by JetCat. Not only would the Koford motor reduce the speed at which the engine could operate, the torque seen at the coupler between the drive shaft and the motor's shaft would be too great for any commercial coupler to withstand. It may have been possible to special-order an industrial-grade coupler from a precision vendor, however the team determined that this would use up to much of the provided budget, and decided to move on from the direct drive generator design.

3.2 Design Concept 2 - Exhaust Gas Generator

Included in the evaluation matrix, the exhaust gas generator was the second design that the team attempted to use. This design would incorporate the use of the high-speed gas exiting the engine. A turbine would then be spun as the gas rushes through it, allowing for the possibility of generating and capturing the power it creates. To direct the flow of gas leaving the engine, a shroud made of heat-resistant material would encapsulate the generator to ensure that all the gas exiting the engine flows over the turbine blades. The generator itself would need to be enclosed in a superalloy or comparable ceramic material to ensure that the generator does not fail due to extreme temperatures seen in the exhaust gas [1]. Once again, this year's Oregon State APOP team determined that this heat-resistant generator casing would consume too much of the allotted budget, and the exhaust gas generator design was discarded.

4 Design Solution

After various iterations, the 2022-23 Oregon State University APOP team made the decision to generate power using an inlet gas generator. Unable to test the previous design concepts, the team has run test trials only with the inlet gas generator. Without comparison to other design concepts and only a little time left, the team will continue to optimize the inlet gas generator over the next month prior to our meeting with the Air Force in April in spite of the current inefficiencies of the design.

4.1 Description of Solution

The current redesign concept employs a similar train of thought as the exhaust gas generator; however, instead of using the exhaust gas to spin a turbine and generate power, the inlet gas generator uses an electric ducted fan (EDF) to produce power. Much like the exhaust gas generator, the EDF would be attached to the entry of a shroud, forcing the air entering the engine to first rush past the EDF's blades. This would in turn cause the EDF to spin and thus generate power. Because the air entering the engine is much cooler than the gas leaving the engine, special materials are not necessary for the inlet gas generator. The inlet shroud is 3-D printed out of PLA and the EDF is made out of plastic as well. Using a temperature sensor, it was determined that the inlet of the engine would not reach temperatures high enough to melt plastic. Multiple sizes of EDF's have been purchased and shrouds that correspond to the size of the EDF have been printed at a team member's home to test which size produces the most power.

The EDF is a three-phase AC motor. Multiple sizes of EDF's and shrouds have been tested to determine which combination would produce the most power. Attached to the inlet of the shroud, the EDF will begin spinning once the engine reaches a specific minimum rpm. As the EDF continues to speed up with the increased airflow through the engine, the three-phase motor generates an increasingly stronger current. The AC power created by the EDF is converted to the required DC power with the use of a full bridge rectifier [2]. The rectifier uses diodes to force the AC current to move only in the forward direction, transforming it to DC. A resistive load in the form of a variable DC car heater is placed after the full bridge rectifier to drain the system of all excess power.

4.2 Project Results

While the team is still planning to implement final design changes, and minor adjustments to the geometrical flow of the air flow through the inlet of the engine, we are projecting that the engine will decrease in thrust by roughly 2%, while current limitations and problems suggest a power generation of >30 watts of power. These values are a reflection of the team's issues stemming from the initial roadblock of having a non-functioning engine, rather than the efforts by the APOP members. Once the team received the new functional engine, members of the team attempted to complete a six-month project, in a 2 month timeline. While the overall goals of the project set forth by the AFRL were not met, the team was able to generate power through an unorthodox approach, and while the 500 watts is currently outside of the projected results, the team's advisor, Dr. Blunck is satisfied with the progress thus far.

5 LOOKING FORWARD

Since the final competition for this project is in April, the team will make any adjustments and minor changes to the overall design and implementation of power generation techniques that will be discussed in the coming week with a professor who is working on a similar power generation. The team is hopeful that he will be able to give us insight on the issues that he was able to overcome, and any suggestions he may have regarding how APOP can harness the power from the EDF.

Although the challenge set by the USAF is different each year, it is still necessary to ensure a smooth hand-off to next year's APOP team. A good hand-off would include the organization of any documents, supplies, equipment, or data collected by this year's team and previous teams, as well as a working engine that can be used by the next team.

In order to make sure next year's APOP team is able to get started on their project as soon as possible, the current APOP team will organize all equipment that will be used next year. This would include organizing all hardware, tools, 3D printed parts, electrical components, test stands etc. and consolidating them into a provided space in the Propulsion Lab. The team will also be responsible for improving upon the current test stand by creating a more user-friendly set up that includes permanent fixtures for the strain gauge, fuel pump, and necessary electrical components.

The current APOP team will also ensure that all documents on the team's Google Drive will be organized and easy to navigate. This will include creating a "Read Me" document detailing general information about APOP and contact information. The team will also include an operating guide for engine use, and a detailed document containing procedures such as start-up, shut-down, and operating limits of the engine, fuel mixing instructions, and safety information associated with the engine. A file containing data collected by past teams will also be included in the hand-off in case it may be helpful for future challenges set by the USAF.

The biggest issue that this year's team ran into was the quality of the hand-off from the previous team. A non-functional engine, and poorly managed documentation set the team back significantly and prevented them from reaching the full potential of their final design. Having experienced this, the team will prioritize handing off a working engine to next year's team so they can begin their project right away and hopefully accomplish all the requirements of their challenge.

Overall, the team will ensure that the hand-off is smooth and near-perfect so that next year's APOP team will not need to experience the struggles faced by this year's team. Sundseth and Coburn have elected to continue to work on the APOP project next term, and will be focusing heavily on meeting all of the deliverables described above, as well as improving any other aspects of the project transition that may arise.

6 CONCLUSIONS

6.1 General Project Processes/Guidelines

The 2022-23 Oregon State University APOP team has conducted a thorough analysis of the JetCat P100-RX engine, an extensive design process, and limited testing to determine the best method of meeting the objectives proposed by the Air Force. The team, prompted by the Oregon State Aerospace Capstone course led by John Greeven, first outlined the code of conduct and responsibilities of each member in our Team Charter. The Charter focused on creating protocols for how the team would settle disputes between team members and what actions should be taken if the team began to fall behind. After the charter was created, the team used a House of Quality and Evaluation Matrix to determine which engine redesign concept would best accomplish the goals of the team. The Air Force assigned three specific tasks to all university teams involved in the program: maximize the thrust-to-weight ratio, generate 80 watts of power at idle and 500 watts at full throttle, and create an accurate digital twin that would use computer software to predict the performance of the engine. Using these three conditions and others that included safety and cost as factors to consider, the House of Quality was built to provide engineering specifications that defined either a target value or a simple yes/no.

6.2 Safety/Environmental Considerations

For this project, safety is more of a concern than the environmental consequences caused by the redesigned engine. Unlike some of the other AIAA capstone teams who focus on creating aircrafts fueled by clean energy, the JetCat P100-RX runs on a mixture of kerosene and jet oil. However, although the engine is fueled by kerosene and consumes the fuel at a high rate, it is unlikely that the engine will cause any damage to the surrounding environment due to its small size. The greater concern for the team throughout the design process was undoubtedly safety. The JetCat P100-RX rotates at speeds greater than 150,000 rpm [3]. If something were to happen where a larger particle gets sucked into the engine and causes an internal explosion, the consequences could be quite serious to those in the direct vicinity. To mitigate risk of injury, a Safety Checklist (See Appendix E) was created to outline a consistent procedure for starting up the engine. Prior to every engine start up, the team has meticulously gone through and checked off each box of the safety checklist, ensuring that every team member is safe and that the engine runs smoothly.

The use of PLA for the inlet shroud was initially concerning to the team due to its relatively low melting point compared to the engine's extreme temperatures. Before adding the PLA shroud to the inlet of the engine, simple tests were conducted to determine whether the PLA would be sufficient for the project. Using a temperature sensor, the temperature at the inlet of the engine was measured to be just above 100 degrees fahrenheit. Because the melting point of PLA is 150-160 degrees celsius, it was determined that there would be no issues with using PLA to 3-D print the inlet shroud [4].

6.3 Testing

The tests conducted by the 2022-23 Oregon State APOP team have yielded disappointing results thus far. The thrust values have hardly changed with the addition of the inlet shroud to the engine, but the power generated by the EDF, worth 60% of the grade the team receives in April, has not yielded the best results. Although the electrical system looks to be generating a significant amount of voltage, the inlet gas generator has yet to produce more than a single watt of power. This is obviously a significant concern for the APOP team, and the following weeks will be spent learning more about the electrical circuitry of power generators. This knowledge will be applied to modifying the EDF/rectifier/DC load system to maximize the power generated by the inlet gas generator design.

6.4 Possible Iterations

The APOP team now has less than a month to get the engine to a point that it produces the optimized amount of power. Only minor design changes will be implemented at this point to achieve power generation optimization. Adding the exhaust cone designed by last year's team could be a possible change to the current design that might result in greater produced thrust. One of the goals of this year's team is to leave the engine as close to stock as possible for the benefit of next year's team; this goal will still be met if the alternate exhaust cone is used because it only requires the team to take off the current cone and replace it with the alternate. As more testing is conducted, the team will be able to determine which inlet shroud should be used with its corresponding EDF. So far, the team has only tested the 80 and 90 mm EDF's due to long 3-D print times and remeasuring certain tolerances. It is suspected that the best shroud design will be the 70 mm because it is closest in diameter to the actual inlet of the engine. Trials to test this hypothesis will occur this upcoming week.

7 REFERENCES

[1] mims. Feb 27, 2016. Stack Exchange. *What Material Is Used To Make The Hot Sections Of Jet Engines?* from https://aviation.stackexchange.com/questions/25645/what-material-is-used-to-make-the-hot-sections-of-jet-engines#:~:text=Then%20another%20slide%20show%20lists%20the%20materials%20as%3A,nickel%20alloy%208%20Exhaust%3A%20single%20crystal%20nickel%20alloy.

[2] Mar 6, 2023. Vedantu. *Bridge Rectifier*. from https://www.vedantu.com/physics/bridge-rectifier

[3] 2023. JetCat. *JetCat P100-RX Engine.* from https://www.jetcat.de/en/productdetails/produkte/jetcat/produkte/hobby/Engines/p100_rx

[4] Flynt, Joseph. Oct 4, 2021. 3D Insider. *What Is The Melting Point Of PLA.* from https://3dinsider.com/pla-melting-point/

8 APPENDICES

8.1 Appendix A: Original House of Quality

CR#	Customer Requirement	Weight (250 total)	Matching Engineering Specification	Targets with Tolerances
1	Power generation	100	Minimum generation of 80 watts at idle	(-10, +10) of desired minimum requirement
			Minimum generation of 500 watts at full throttle	(- 10 watt, + as much as possible)
2	Device adjusts power generation	25	Adjust rotational speed	yes/no(+/-)
			Drain unnecessary power	yes/no
3	less fuel consumption	25	Reduced fuel flow rate and burn	20 kg/hr (+0/- as low as possible)
4	Increased thrust power	35	Device produces enough thrust	yes/no
5	Reduced weight	25	Lighter materials	yes/no
			Hand held	yes/no
6	Available thrust is able to be utilized for work	15	Suitable transition from available energy to mechanical energy	yes/no
7	Aesthetically pleasing	5	Less wire clutter	yes/no
8	Device usable for longer duration without failing	5	Heat resistant materials	yes/no
9	Engine is able to start and sustain self under own power	5	Correct and efficient assembly	yes/no
10	“Digital twin” accurately models physical engine	10	Coding is accurate and working	+/- 10% of “real, measured value”

8.2 Appendix B: Updated House of Quality

Customer Description	Weight (300 total)	Matching engineering specification(s)	Targets with tolerances
Power generation	150	Minimum generation of 80 watts at idle	-30 Watts – max achievable power
		Minimum generation of 500 watts at full throttle	-300 Watts – max achievable power
		All power produced is drained by external sink	Yes/no (+/-)
Optimized Thrust-To Weight Ratio	75	Minimum thrust of 2N at idle	achievable thrust
		Minimum thrust of 100N at full throttle	-30 Newtons – max achievable thrust
		Minimum weight added to engine by shroud design	yes/no (+/-)
"Digital twin" accurately models physical engine	25	Code is accurate and working	+/- 10% of "real, measured value"
Engine runs with added shroud	15	Engine must overcome safety bypass feature	Yes/no (+/-)
Engine is usable for next year's team	35	Reassembly possible and engine still starts	Yes/no (+/-)

8.3 Appendix C: Evaluation Matrix

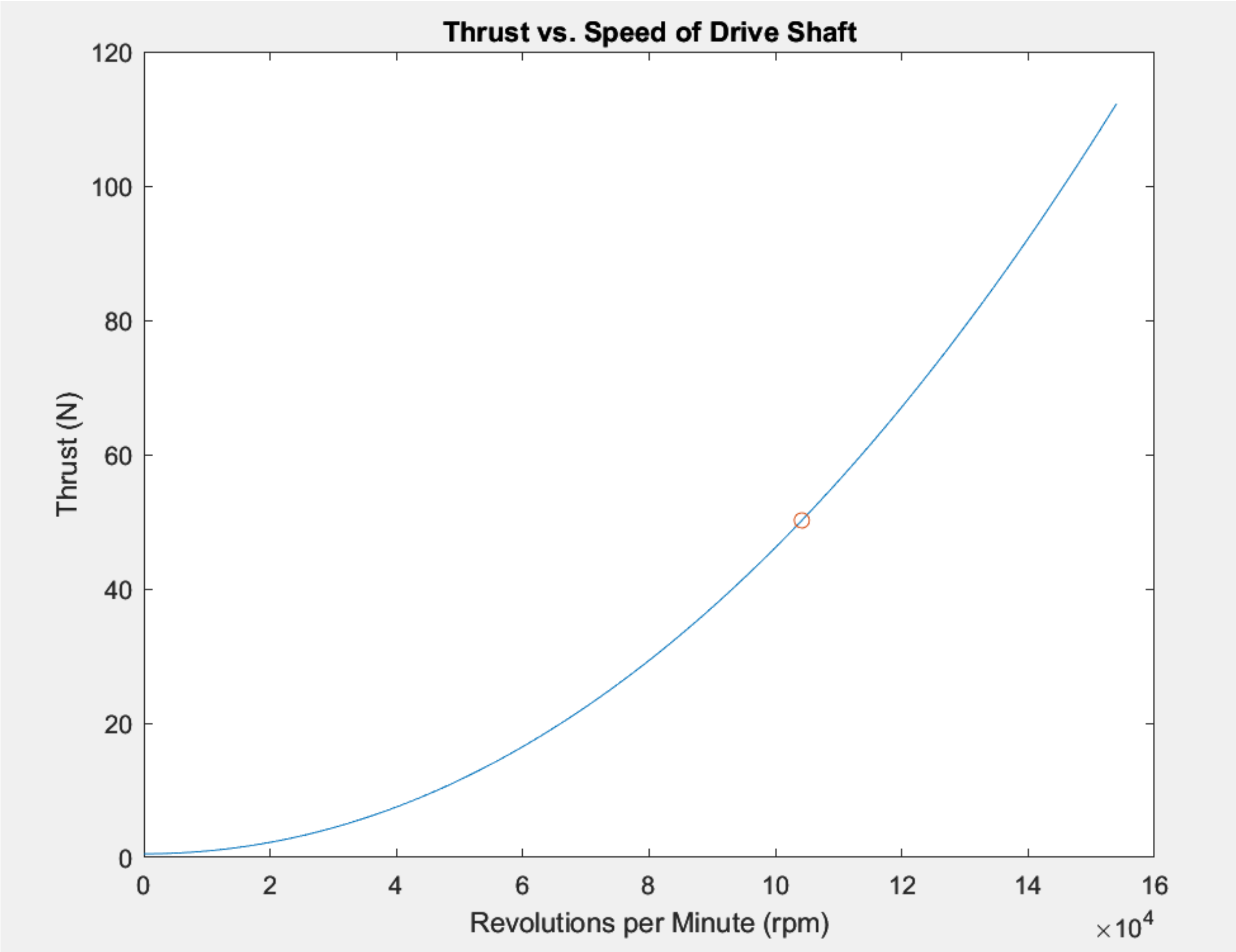
1. Material Cost	0.16	3	0.52
2. Manufacturing Cost	0.16	3	0.52
3. Reliability	0.11	4	1.44
4. Modifications Required	0.15	2	0.7
5. Mass	0.2	5	0
6. Fuel flow	0.1	1	0.9
7. Safety Concerns	0.12	1	0.88
Exhaust Gas Generator			4.96
1. Material Cost	0.16	2	0.68
2. Manufacturing Cost	0.16	4	0.36
3. Reliability	0.11	2	1.22
4. Modifications Required	0.15	3	0.55
5. Mass	0.2	2	0.6
6. Fuel flow	0.1	3	0.7
7. Safety Concerns	0.12	5	0.4
Bevel Gear Off-Set			4.51
1. Material Cost	0.16	2	0.68
2. Manufacturing Cost	0.16	4	0.36
3. Reliability	0.11	2	1.22
4. Modifications Required	0.15	3	0.55
5. Mass	0.2	2	0.6
6. Fuel flow	0.1	3	0.7
7. Safety Concerns	0.12	5	0.4
Worm Gear Off-Set			4.51

1. Material Cost	0.16	4	0.36
2. Manufacturing Cost	0.16	3	0.52
3. Reliability	0.11	3	1.33
4. Modifications Required	0.15	2	0.7
5. Mass	0.2	3	0.4
6. Fuel flow	0.1	3	0.7
7. Safety Concerns	0.12	2	0.76
Planetary Gear Direct Drive			4.77
1. Material Cost	0.16	4	0.36
2. Manufacturing Cost	0.16	5	0.2
3. Reliability	0.11	2	1.22
4. Modifications Required	0.15	5	0.25
5. Mass	0.2	2	0.6
6. Fuel flow	0.1	4	0.6
7. Safety Concerns	0.12	5	0.4
Bevel Gear Off-Set, Internally Attached			3.63
1. Material Cost	0.16	1	0.84
2. Manufacturing Cost	0.16	2	0.68
3. Reliability	0.11	4	1.44
4. Modifications Required	0.15	1	0.85
5. Mass	0.2	1	0.8
6. Fuel flow	0.1	4	0.6
7. Safety Concerns	0.12	3	0.64
Direct Drive Generator			5.85

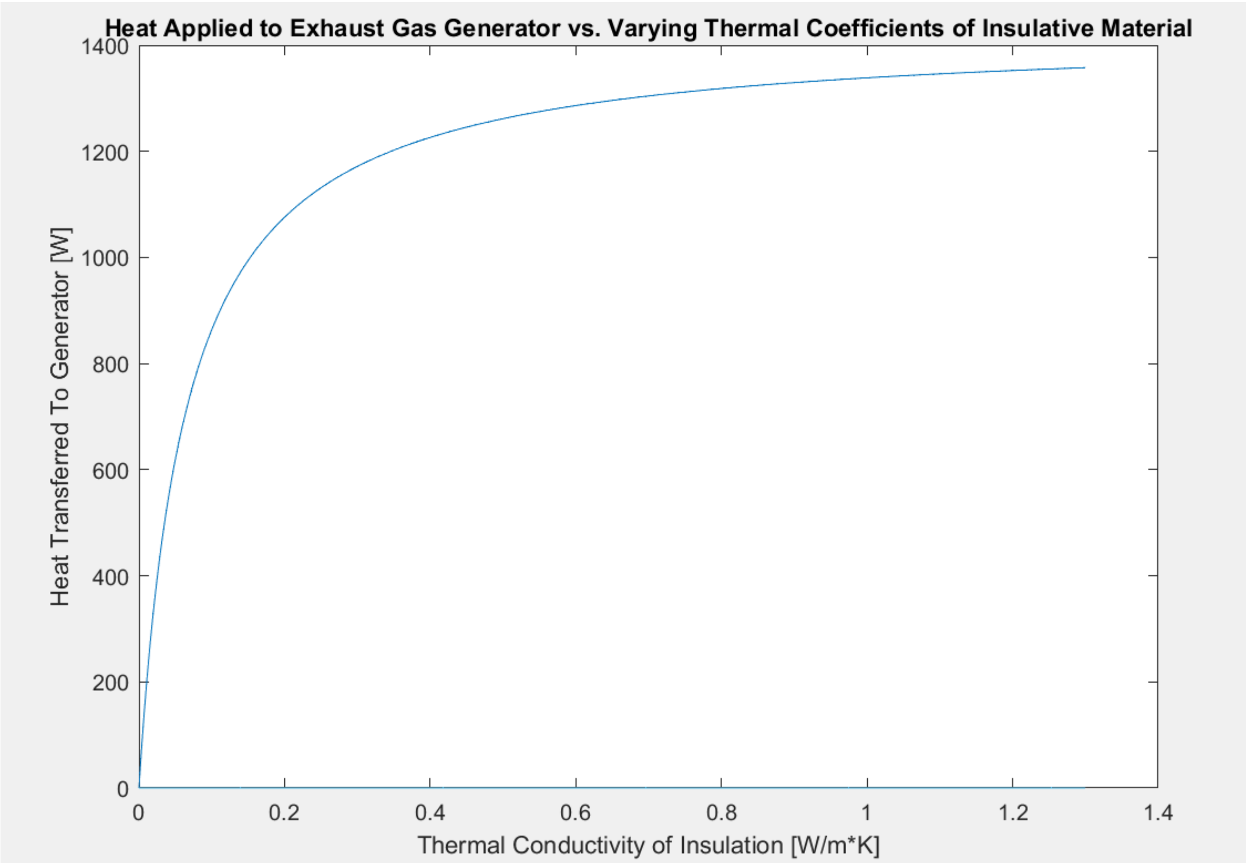
8.4 Appendix D: Test Data

	90mm		1450 kV	80mm		2400 kV
Time	Thrust of P100 [N]	RPM of Fan	Power Generation [W]	Thrust of P100 [N]	RPM of Fan	Power Generation [W]
0	0	0	0	0	0	0
10	1.5	0	0	2	0	0
20	6	0	0	2.7	0	0
30	6.5	0	0	6.9	0	0
40	20	0	0	7.1	0	0
50	43	0	0	32	0	0
60	65	0	0	63	0	0
70	91	6500	0.1	94	0	0
80	93	6530	0.1	96	12100	0.1
90	94	6500	0.1	98	12350	0.1
100	96	6490	0.1	96	12300	0.1
110	97	6500	0.1	96	12300	0.1
120	96	6500	0.1	97	12500	0.1
130	96	6500	0.1	97	12500	0.1
140	97	6500	0.1	96	12500	0.1
150	95	6500	0.1	97	12500	0.1
160	97	6500	0.1	97	12500	0.1
170	98	6500	0.1	98	12500	0.1
180	97	6500	0.1	97	12500	0.1

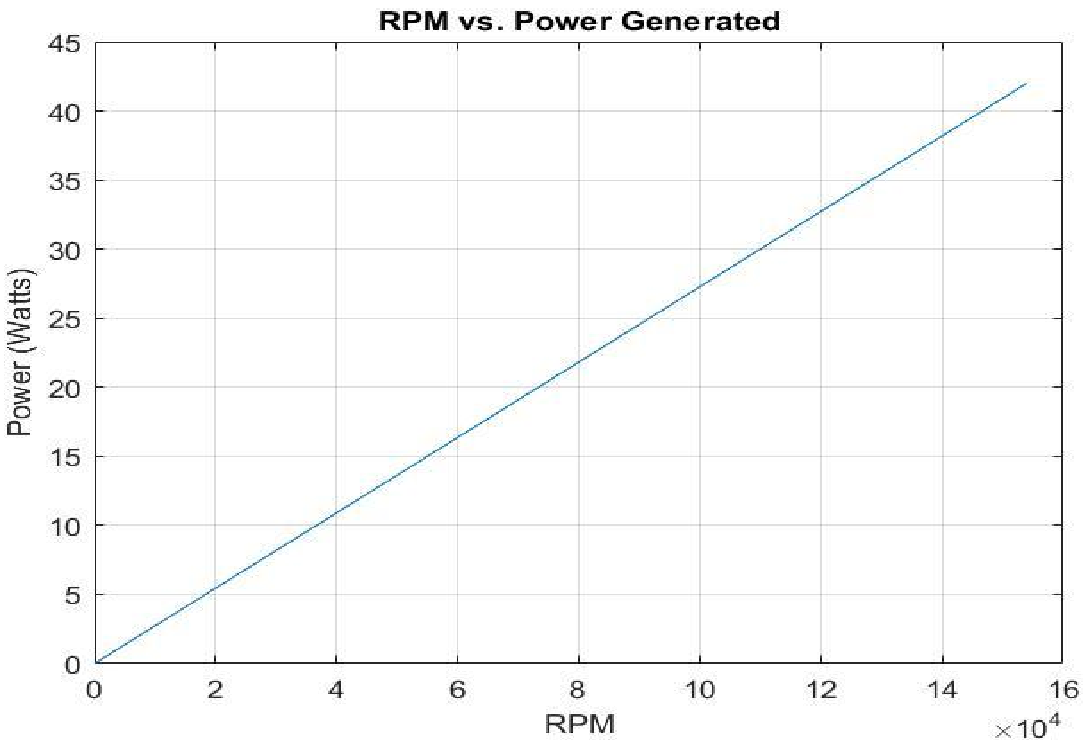
8.5 Appendix E: Direct Drive Generator Code Figure



8.6 Appendix F: Exhaust Gas Generator Code Figure



8.7 Appendix G: MATLAB Code and Related Figures



<u>Result from matlab command window:</u>

Thrust: 96.76 N
Mass Flow Rate In Front of Engine: 0.21 kg/s
RPM from the Motor: 5500.00 R/min
Power Generated by Motor: 575.96 W
>>

<u>Code used for Calculation:</u>

```
clc
% JetCat RX Turbine Engine Specifications
massFlowRate = 0.23; % kg/s
exhaustVelocity = 434.7222; % m/s
areaNozzle = 0.024; % m^2
```

```
pressureExhaust = 100000; % Pa
pressureAmbient = 101325; % Pa
temperature = 720; % K
pressureRatio = 2.9;

% Turbine Specifications
specificHeatAir = 1005; % J/kgK
temperatureAmbient = 300; % K
efficiency = 0.9; % 90% efficiency
time = 60; % seconds

% Calculate the thrust
gasConstant = 287; % J/kgK (universal gas constant for air)
specificHeatRatio = 1.4; % (specific heat ratio for air)
density = pressureAmbient / (gasConstant * temperature); % kg/m^3
throatArea = areaNozzle / sqrt(specificHeatRatio *
(2/(specificHeatRatio+1))^((specificHeatRatio+1)/(specificHeatRatio-1))); %
m^2
pressureThroat = pressureAmbient *
(2/(specificHeatRatio+1))^(specificHeatRatio/(specificHeatRatio-1)); % Pa
machThroat =
sqrt((2/(specificHeatRatio-1))*((pressureRatio)^((specificHeatRatio-1)/speci
ficHeatRatio)-1)); % Mach number at throat
velocityThroat = machThroat * sqrt(specificHeatRatio * gasConstant *
temperature); % Velocity at throat
thrust = massFlowRate * (exhaustVelocity - velocityThroat) +
(pressureExhaust - pressureAmbient) * areaNozzle;

% Calculate the mass flow rate in front of the engine
massFlowRateFront = massFlowRate * (pressureExhaust /
pressureAmbient) *
sqrt((specificHeatRatio+1)/(2*specificHeatRatio)*(pressureAmbient/pressur
eExhaust)^((specificHeatRatio-1)/specificHeatRatio));

% Motor Specifications
kvRating = 2200; % RPM/V
batteryVoltage = 0.1; % V
current = 100; % A
rpm = kvRating * batteryVoltage; % RPM
```

```
% Calculate the power generated by the motor
power = (2*pi/60) * rpm * current;

% Display results
fprintf('Thrust: %.2f N\n', thrust);
fprintf('Mass Flow Rate In Front of Engine: %.2f kg/s\n',
massFlowRateFront);
fprintf('RPM from the Motor: %.2f R/min\n', rpm);
fprintf('Power Generated by Motor: %.2f W\n', power);

% Motor specifications
KV_rating = 2200; % KV
battery = 6; % S
current = 100; % A
voltage = 25; % V
blade = 12;
motor_type = 'Brushless Inrunner';
rotation = 'Clockwise';
exit_diameter = 80; % mm
motor_weight = 300; % g

% Calculate the power generated by the motor
rpm = linspace(0, 154000, 1000); % range of RPM values to calculate
power = (rpm./KV_rating) .* (battery .* current .* 0.001); % power in Watts

% Plot the graph
figure;
plot(rpm, power);
title('RPM vs. Power Generated');
xlabel('RPM');
ylabel('Power (Watts)');
grid on;
```