Turbo-prop Add-on to Jet Engine to Generate 500 W of DC Electrical Power

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Introduction

The U.S. Air Force Research Laboratory's APOP is sponsoring an intercollegiate competition that gives undergraduate students the opportunity to modify a JetCat P80-SE gas turbine engine and gain experience with propulsion systems. This year's task is to develop an appendage device to the JetCat turbojet that is capable of extracting 500 Watts of DC electrical power at 24 Volts while maintaining as much of the stock thrust as possible. Currently most aircraft use small auxiliary jet engines to produce energy. This energy is then used to power onboard systems in an aircraft. The aim of our project is to combine these separate processes into one. The results and recommendations of our design process for the given task are listed in the sections to follow.

Figure 1: JetCat P80SE jet engine

Background

For our design we are taking a similar but somewhat different approach to the traditional turboprop design. We are harnessing the exhaust gases from the gas turbine and using them to drive a power turbine. Then using gear reduction we will use the torque created by the power turbine to drive a propeller. This is how we plan to maintain the stock thrust. Attached to the propeller shaft we have a timing belt which will drive an alternator. This is how we will be deriving our 500W of electrical power

Figure 2: Turbo-prop design assembly

Design Criteria

There are three design criteria required for the APOP competition.

- Generate 500W of electrical power from a P80-SE at 125,000 RPM
- Maintain as much of the stock thrust of the engine
- Fit within the confines of the box shown in the figure below.

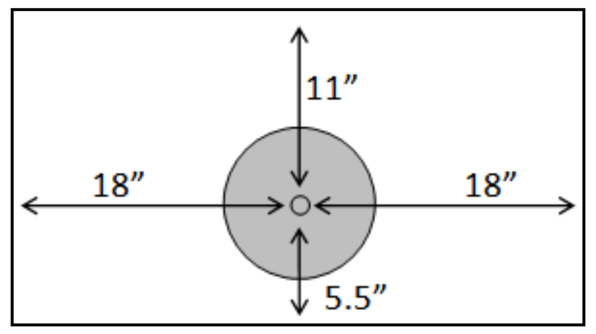
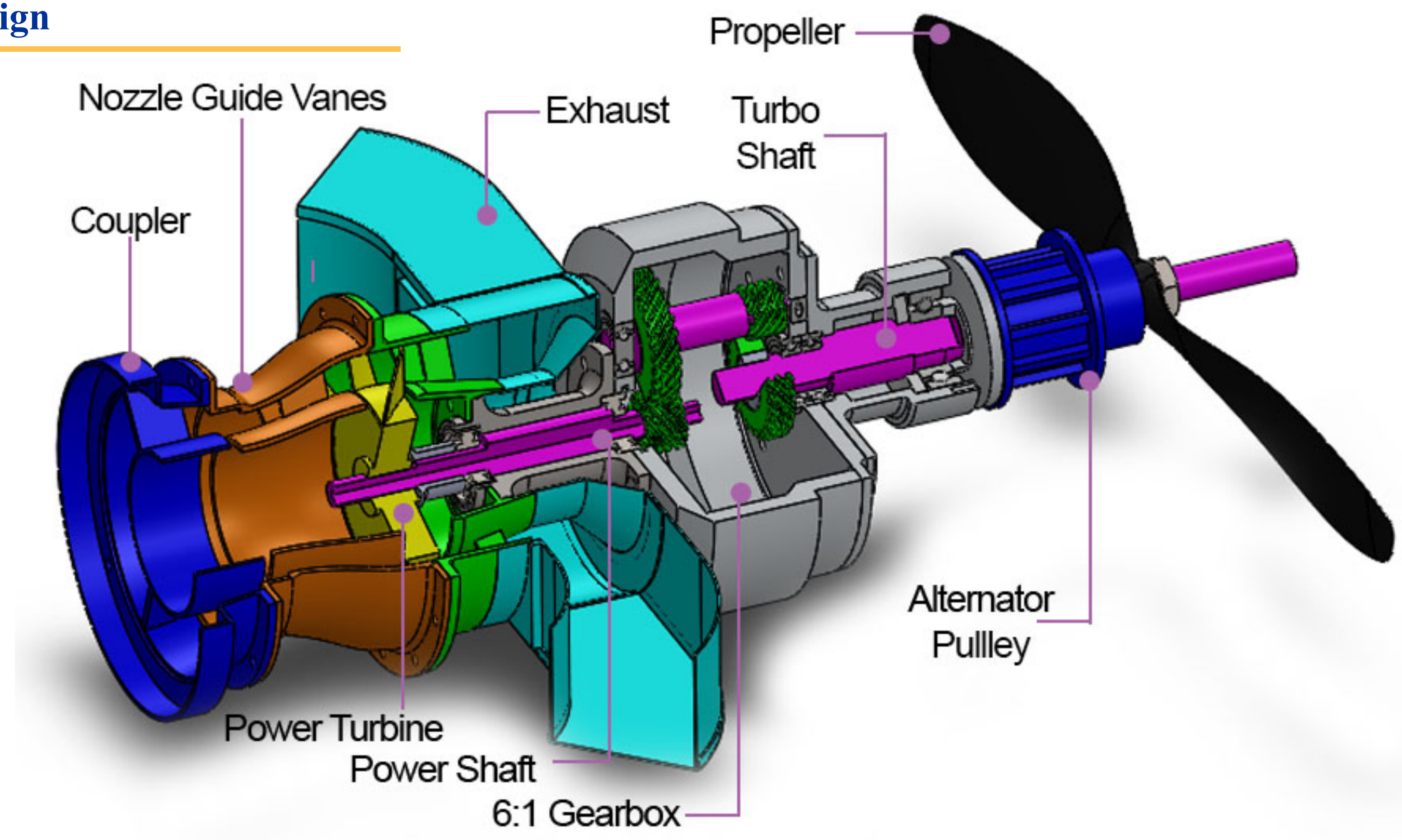


Figure 3: Design envelop constrain for APOP competition

Final Design



P80-SE Performance Characterization

To size the turbo-prop add-on and determine its performance the following unknown parameters of the P80-SE was needed

- Exit velocity
- Exit Mach number
- Exit mass flow rate

Static and stagnation pressure at the jet engines turbine exit was measured. The dynamic pressure was derived and used to calculate exit velocity and mass flow rate of the P80-SE.

66.5mm Diameter

72mm Diameter

85.2mm Diameter

The three figures above depict the different size power turbines that were available to us. From our mass flow analysis we determined that the 72mm Wren turbine was the most fitting for our application. Our performance chacterization results are tabulated below.

Parameter	Value
Max RPM	125000
Max Thrust	96.31 N
Nozzle exit velocity	319.35 m/s
Exit Mach number	0.5455
Exit mass flow rate	0.3771 kg/s

Table 1: JetCat P80-SE exit performance parameters at max. rpm

Power Turbine Analysis

Turbine blade angles and velocity triangles theory was used to determine the speed of the power turbine and subsequently the propellers speed.

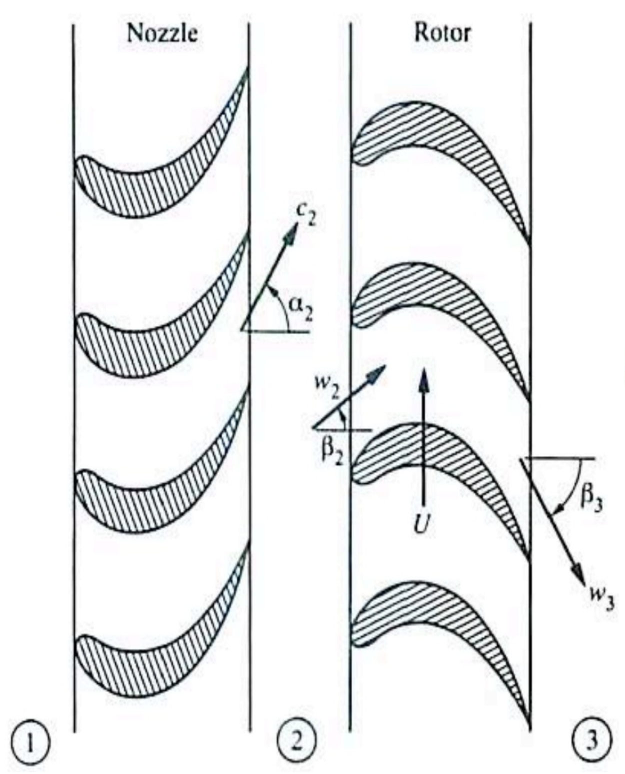


Figure 5: Turbine Rotor Stator Diagram

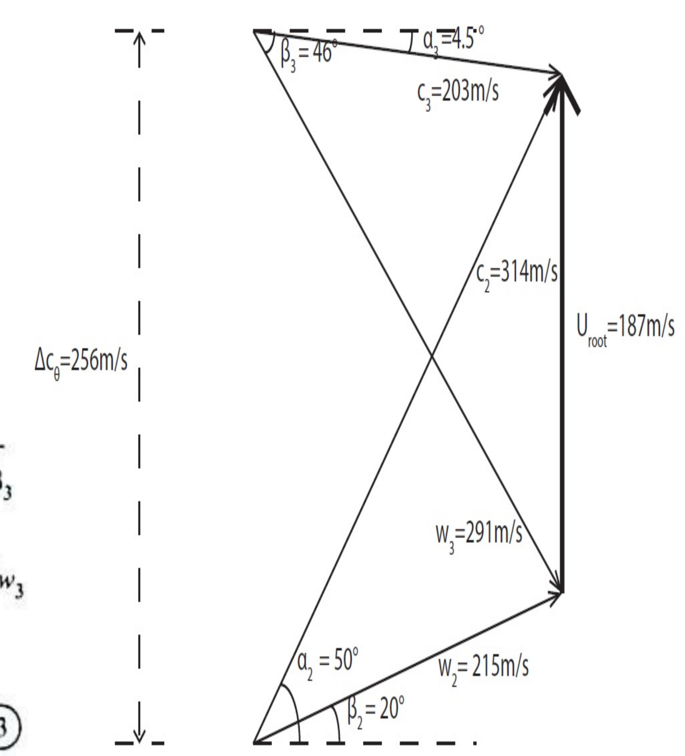


Figure 6: Turbine measured blade angles and derived velocity triangles

Measurement	Value
Constant axial velocity	200 m/s
Turbine blade's root velocity	187 m/s
Turbine wheel RPM	80,000
Propeller RPM	13,500

Table 2: Calculated values for power turbine performance

Propeller Analysis

Figure 6: 10x8 G/F Series Propeller

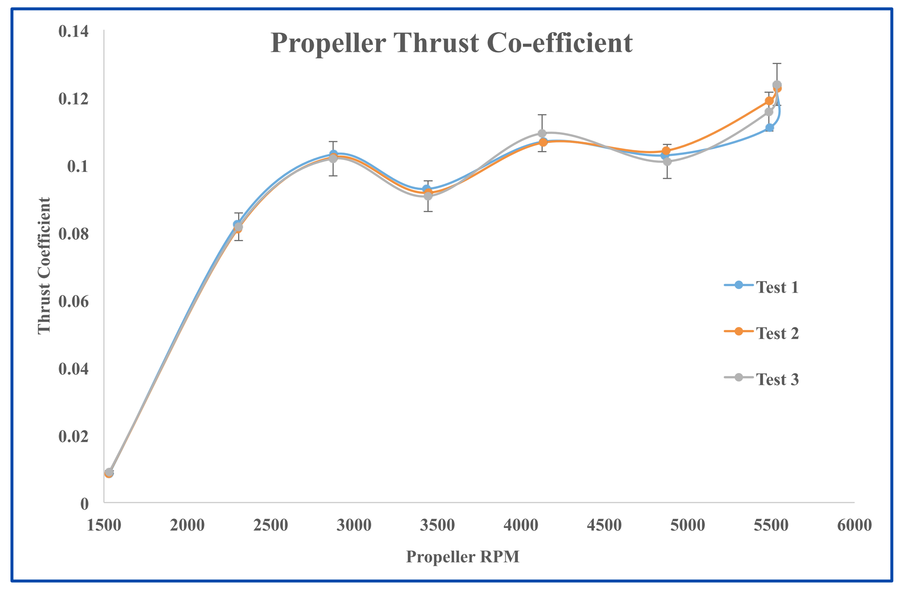


Figure 7: 10x8 G/F Series Propeller Thrust Analysis

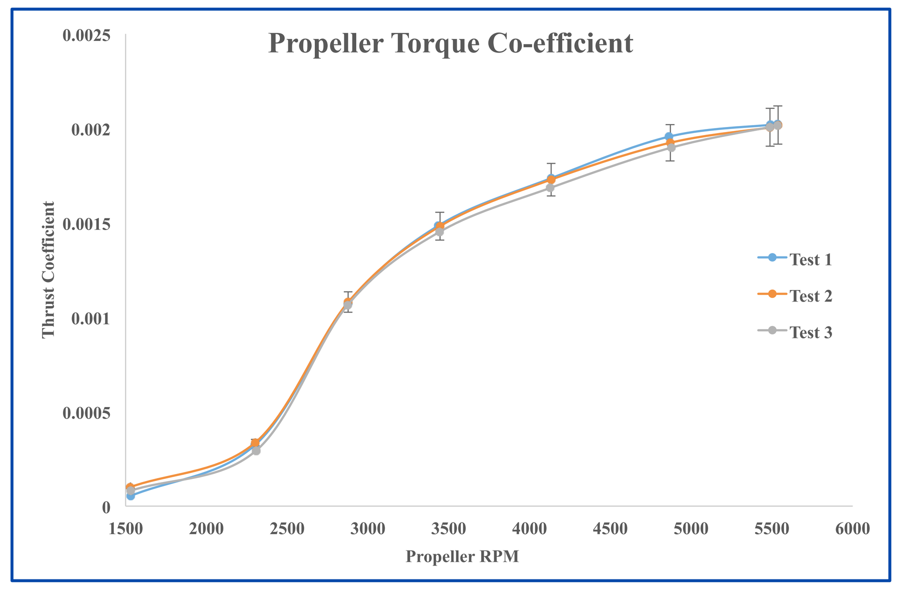


Figure 8: 10x8 G/F Series Propeller Torque Analysis

At 13500 RPM, the 10x8 G/F Series propeller should generate the following parameters:

- 15.11 N of Thrust
- 67.47 mN*m of Torque

Conclusion

The turbo-pro at on will use the jet engine as a gas generator. It uses a propeller to increase mass flow to generate thrust. The gear box will convert the high RPM low torque to low RPM high torque. By characterizing the performance of the jet engine and other components of the turbo-pro we managed to accordingly size the add-on. Further from our theoretical analysis we expect to be generating a between 350-450 Watts just under our desired value. From the alternator specifications we need the propeller shaft to run at 15,000 RPM and we are expecting to run at 13,500 RPM.

Future Work

The following work is still required before we deliver the add-on to APOP.

- Test turbo-prop mechanism without gas generator
- Test turbo-prop mechanism with gas generator
- Design, build and implement gear box lubrication system
- Measure electrical power generated by add-on
- Consider more than one propeller