Aerospace Propulsion Outreach Program (APOP): Reverse Thrust Technology

VARIABLE-PITCH PROPELLER REVERSER (ViPeR)

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Project Objectives

The US Air Force Research Laboratory's Aerospace Propulsion Outreach Program sponsors an annual intercollegiate turbojet engine modification competition. The 2023-24 project requires teams to develop and demonstrate a thrust reversal solution for a stock JetCat P100RX engine.

Jet engine thrust reversal, an extreme case of thrust vectoring, improves aircraft maneuverability and enables short distance take-off and landings.

Key solution design criteria include:

- Achieve reverse thrust (RT) > 40% of baseline thrust (BT)
- Complete reverse thrust system actuation within 5 seconds
- Maximize baseline thrust-to-weight ratio
- Ensure compliance with system hardware volume constraints
- System operation from >20ft from engine

Solution Development

Alternative solution designs considered:

- Clamshell, umbrella, pivoting exhaust tube, rotating exhaust tube, whale tail, direct-drive propeller

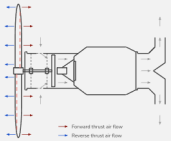


Selected design:

- Generate BT and RT via cold-side turbine-driven propeller
- Neutralize engine thrust via hot-side whale tail exhaust system

Solution design evaluation:

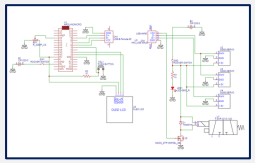
- + : Low mechanical component heat exposure
- + : High RT/BT potential
- + : Simple actuation
- -- : Weight considerations
- -- : High complexity
- -- : Substantial impact on engine operation



Electronic Hardware

Propeller Pitch System

- Propeller pitch is controlled by three servo motors, which are controlled by an Arduino
- Due to servo motor arrangement, two signals are necessary for propeller pitch adjustment



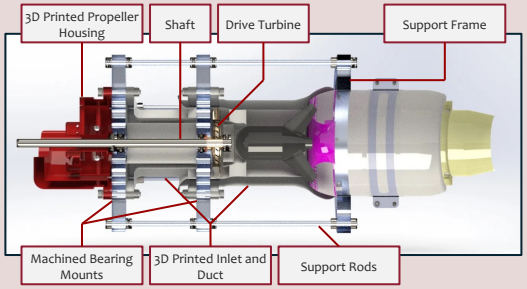
Compressed Air System

- Pneumatic valve system to increase engine intake airflow controlled with an Arduino via a binary signal

Control Mechanism

- USB connection allows for propeller pitch (via potentiometer) and compress air release (via button) from distance via a control box

Solution Design Part I (Cold-side)





Propeller Thrust Generation

Air enters the compressor of the engine via the 3D printed duct inlet. Air flow passes guide vanes and spins a drive turbine connected to a shaft. The shaft is fixed onto a propeller on the front side of the system, that will then spin and generate thrust, with its direction dependent on the blade pitch angle.

Reverse Thrust Mechanism

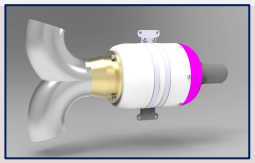
A swashplate is attached to rotor blades. Adjusting the position of three servo motors in a coordinated fashion moves the swashplate upwards and downwards on the shaft, in turn, pitching the blades to generate forward or reverse thrust. Blade symmetry and servo motor position range allows for a theoretical 100% reverse thrust to forward thrust ratio.



Key Features

- Propeller hub system attached to main titanium shaft via coupling
- Interchangeable and 360mm and 175mm propeller blades
- Necessary weight distribution achieved via support rod attachment to support frame
- Shaft alignment achieved via precise assembly of aluminum bearing mounts and support rods
- Valve system between turbine and compressor inlet to increase mass flow of air entering engine

Solution Design Part II (Hot-side)



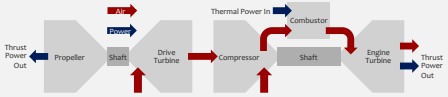
Exhaust Gas Neutralization

Our manufactured hot side system neutralizes the engine thrust through an exhaust pipe. The exhaust tubes direct the exhaust gas 90 degrees in the plane perpendicular to the axis along which reverse thrust is being generated, thus eliminating contribution to thrust in both forward and reverse arrangements.

The thrust is redirected in both the positive and negative direction to avoid an excessive amount of force on the engine in a particular direction.

Since the diameter of the system is constant throughout, the flow is directed evenly in all directions. Two exhaust pipes, made out of stainless steel with a uniform 56mm diameter, were cut in half and welded together to create the whole exhaust system. The system fits on the mid-section of the nozzle and is fixed with a set of screws in even intervals.

Modelling, Analysis and Validation



Thermodynamic Modelling

The JetCat P100RX was modeled in python using ideal-gas air and heat capacity calculation methods. To improve model accuracy, parameters were adjusted to better reflect our engine's thrust output performance.

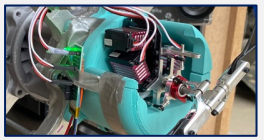
Due to the pressure drop across the frontside inlet and the drive turbine, air flow entering the engine is restricted. This leads to un-combusted fuel in the combustor, causing the engine to run at higher temperatures. Work required to drive the turbine and propeller must be accounted for to maintain a closed thermodynamic system. Engine thrust (as opposed to propeller thrust) is unimportant for our solution, though the diversion mechanism will further raise engine temperature.

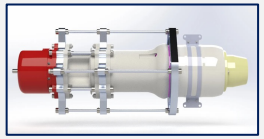
Testing and Validation

The team adopted an iterative approach to testing by completing individual system-level tests for early-stage hardware, software and design concept validation prior to full system assembly. Tests completed include:

- Propeller pitch actuation test
- Turbine-shaft-propeller system alignment test
- Valve system actuation test
- Weight distribution and support system robustness
- Exhaust gas diversion test







Future Work and Conclusion

Future Work

Future iterations of the solution design should prioritize the following:

- Improvement of duct inlet to reduce pressure drop pre-drive turbine
- Robust variable air intake flaps to increase air mass flow into engine
- Weight reduction via material selection and mechanical design
- Integrate electronic hardware onto engine system
- Maximize baseline thrust by adjusting hot-side exhaust gas diversion angle via tradeoff with reverse thrust ratio

Conclusion

- ViPeR leverages intake airflow to drive a propeller via a turbine-shaft system on the cold-side of the engine to reduce thermal constraints. Variable-pitch control of rotor blades allow for the generation of thrust in both the forward and reverse directions. This is combined with a hot-side airflow diversion exhaust system to negate engine thrust.