Project 106(B) Integration of Turbine Operational Parameters into Aerothermal System Analyses

The Pennsylvania State University

Project Lead Investigator

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- P.I.: Prof. Reid Berdanier
- FAA Award Number: 13-C-AJFE-PSU-129
- Period of Performance: January 21, 2025, to September 30, 2026
- Task:
  1. Define program and baseline measurements

Project Funding Level

The Federal Aviation Administration (FAA) has provided $200,000 of funding to date. In-kind cost-sharing of $200,000 has been provided by Penn State and Siemens.

Investigation Team

Prof. Reid A. Berdanier, All Tasks
Asst. Res. Prof. Matthew Meier, (staff scientist), All Tasks
Assoc. Res. Prof. Michael Barringer, (staff scientist), Task 1
Justin Brumberg, (staff scientist), Task 1
Tom Houck (project manager), Task 1
Jeremiah Bunch, (laboratory technician), Task 1
Matthew Stuber, (graduate student), Task 1

Project Overview

Gas turbine engines will continue to be the propulsion power plant of choice for large single- and twin-aisle aircraft in the foreseeable future because of their high power and energy density capabilities. However, these engines produce 90% of today's carbon dioxide (CO_2) emissions in the aviation sector. While turbine engines are ubiquitous in propulsion, many of the advances that have been made stem from improvements component efficiencies rather than system level approaches that quantify the interrelations of engine operations. These operational impacts are particularly important as new architectures are designed. One key component where there is a lack of information to improve operational models to predict thermal efficiency trends is the turbine where the complexities of leakages and cooling make this challenging. The goal of this task is to acquire data from the test turbine in Penn State's Steady Thermal Aero Research Turbine (START) Lab under carefully controlled conditions to build a library of specific operational impacts on thermal efficiencies and then integrate this library of data into the modeling tools of the Georgia Institute of Technology (GT) Aerospace Systems Design Laboratory (ASDL). This effort will result in accurate operational trade-offs with cooled turbines whereby the modeling tools can be widely used by the industry to assess sustainability concepts.

Key to being able to identify new turbine architectures is to understand thermal efficiency losses that result from blade cooling, tip clearances, purge flows, manufacturing variability, and stage gaps. Missing, however, are data on each specific loss mechanism under carefully controlled and well-documented turbine operations. There are reasons for this lack of data: there are few test facilities that can independently control turbine operational parameters and even fewer facilities that are able to make highly accurate thermodynamic efficiency measurements. The START Lab not only has developed a measurement capability that provide highly accurate stage efficiency measurements but also has the ability to independently vary turbine airfoil cooling flowrates, locations of where this coolant in injected back into the main hot gas path (i.e., trailing edge, blade tip, etc.) blade tip gaps, inlet temperature and turbulence profiles, underplatform sealing flowrates needed to minimize hot gas ingestion, airfoil manufacturing methods, and gap sizes between the vane and blade. All of these operational features significantly impact thermal efficiencies as has already been shown through preliminary measurements taken in the START Lab. Through National Aeronautics and Space Administration (NASA) University Leadership Initiative (ULI) collaborations, the START Lab and ASDL have identified a gap in data available that benchmark thermodynamic efficiency losses of specific features. This proposed project entails the use of several available test turbines including the START Lab's National Experimental Turbine (NExT) to do detailed efficiency measurements by controlling specific turbine operational features.

GT-ASDL will collaborate on creating an aero- thermodynamic model of a high-pressure turbine capable of integrating the operational parameters library from the START lab. This endeavor aims to develop detailed design algorithms, systems of equations, and Numerical Propulsion System Simulation (NPSS) code to calculate the necessary turbine operational parameters for a given cycle while interfacing with the experimentally determined library. The approach will be refined using an example engine model based on a state-of-the-art engine for calibration purposes. Additionally, several other "future" cycle models will be developed to assess the significance of incorporating these impacts in future sustainable aircraft studies. These future cycles will be selected to align with past and future FAA studies, such as the International Civil Aviation Organization (ICAO) Long Term Aspirational Goal (LTAG) analysis or other pertinent research. Following the development of the approach and integration of the operational parameter library from the START lab, a "before and after" benchmark study will be conducted to demonstrate the impact of the work across the spectrum of included cycle models.

Task 1 – Define Program and Baseline Measurements

The Pennsylvania State University

Objective

The objective of this task is to utilize NExT geometry to measure performance metrics such as stage efficiency. The turbine will be operated over a range of test conditions sweeping up to three separate cooling flow rates independently. In this way, the relative merit of each cooling flow can be independently evaluated for system-level modeling. Detailed measurements of efficiency-driving parameters such as blade tip clearances will also be monitored during the test program to serve as primary variables in the modeling approaches developed at ASDL. Measurements conducted at Penn State will be processed and curated by the START team prior to sharing data packages with GT-ASDL. The measured data, along with knowledge of the detailed geometry definition pertaining to the NExT turbine, will be packaged into system-level analysis approaches developed at ASDL and create a baseline reference case.

Research Approach

Define program and baseline measurements

The START team initiated this program by upgrading the hardware and software for START Lab inlet and exit traverse instrumentation systems to improve thermal efficiency measurement capabilities. Inlet radial traverse systems were equipped with backshaft quadrature encoders for accurate spanwise positioning of probes. With the new encoders, the START Lab can resolve spatial measurements within 0.001-in. Motor control hardware and software upgrades for the inlet radial traverse systems were completed to replace end-of-life third-party control systems with off-the-shelf motor control hardware and custom in-house software. The new hardware and a view of the control system software are depicted in Figure 1. With the new software upgrades, multiple traverses can be run simultaneously which will increase measurement accuracy through larger sample sizes. In addition, the new software updates make START Lab inlet traverses versatile to support a suite of flow measurements which will be employed through the upcoming test campaign for this ASCENT Project 106B project.

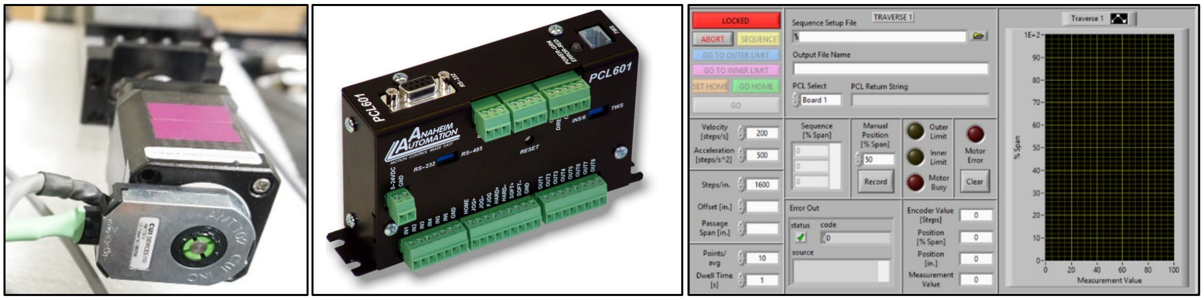

Figure 1. Left: Backshaft encoder on radial traverse. Middle: Off the shelf Anaheim Automation stepper motor controller. Right: Custom, in-house radial traverse control software.

The START Lab exit traverse, which is used to collect total pressure and total temperature measurements across the full 360-degree annulus at the turbine's exit plane, was upgraded with new hardware for improved sensor cable management. New winding ring guide rails were designed, manufactured, and installed to decrease the probability of sensor cables interfering with traverse movement and halting operation. The new hardware and cable routing are shown in Figure 2. The new guide rails restrict the motion of the cables, preventing them from crossing into different groves which would create interference with the outer diameter of the traverse cavity. Without the modifications, this interference could have resulted in damage to the traverse or a stoppage in test operations. These hardware improvements will improve the efficiency of test operations and result in more data acquisition during the ASCENT Project 106B test program.

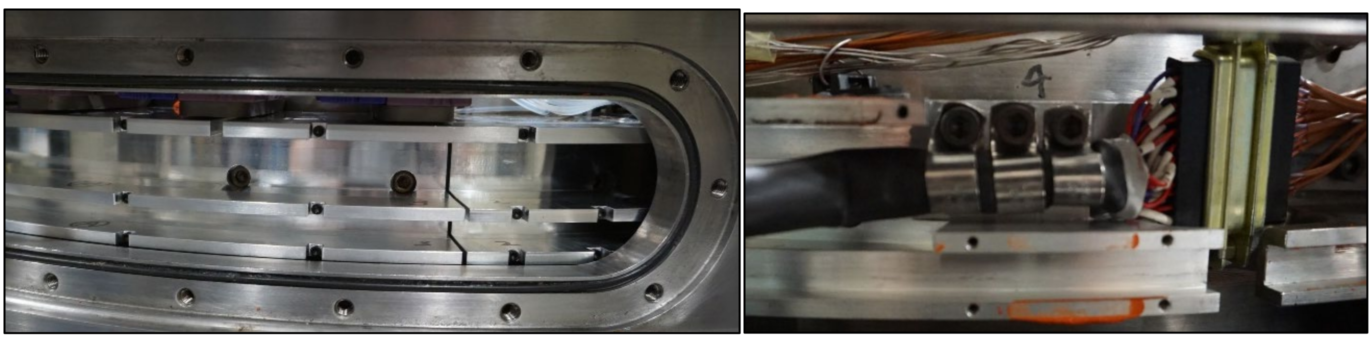

Figure 2. Left: Exit traverse winding right with new guide rails installed. Right: Thermocouple sensor cable showing how the cable is situated in the traverse groove during normal operation.

A preliminary test matrix was developed in reporting period quarter (Q)2 for the ASCENT Project 106B test campaign. Three primary turbine operating parameters (vane trailing edge flow, cavity purge flow, and blade cooling flow) have been identified as the primary variables in this test matrix. This will be optimized through collaboration with the GT team to identify additional or different parameters which will be addressed to provide model inputs. Test matrix development will continue through the next reporting period.

The START team is actively working with the Penn State Office of Research Administration Services to establish a data use agreement (DUA). This DUA will provide the legal framework for sharing test data and relevant geometric parameters of the NExT test article with the GT-ASDL team. The initial draft of this document is complete and under review. This DUA will allow the START team to share the required turbine design parameters for NExT with ASDL to incorporate into their turbine meanline model. Penn State is awaiting feedback on the document from GT, and then data transmission can begin. This process is illustrated in Figure 3.

Figure 3. Flow chart representation of the data use agreement for sharing National Experimental Turbine (NExT) design parameters with Aerospace Systems Design Laboratory (ASDL).

A separate test program was conducted which included efficiency data acquisition. Examples of several measured efficiency trends due to turbine cooling flow rate are illustrated in Figure 4. This data acquisition process was leveraged to optimize the post-processing format which will be used in the ASCENT Project 106B test program. The optimization will ensure a streamlined transfer of processed data to the GT-ASDL team for incorporation into their meanline model. Data was leveraged to refine the test matrix for the upcoming ASCENT Project 106B test program. Various turbine operational parameters (blade cooling flow rate, vane trailing edge flow rate, and tip clearance) were adjusted to determine which would have the largest influence on stage efficiency. This information has been used by the START team to refine the test matrix to represent a series of test points which will provide the largest value to the gas turbine community through this ASCENT Project 106B test campaign.

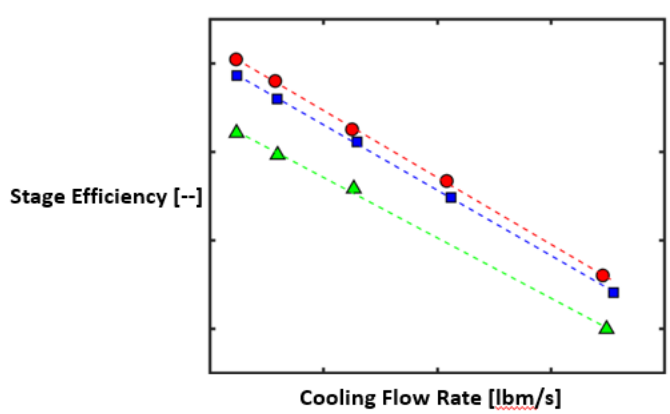

Figure 4. Example turbine efficiency trends acquired during a separate test program. These data were used to optimize the data processing format.

The START team finalized the test matrix that will yield the efficiency data pertaining to ASCENT Project 106B in reporting period Q4, and it is graphically outlined in Figure 5. This test matrix is designed to provide detailed datasets to develop turbine stage efficiency trends based on varied vane trailing edge (VTE), cavity purge, and blade cooling flow rates. Previous test program learnings were leveraged to determine stage operational parameters which resulted in significant influence on stage efficiency, and this led to the selection of these parameters. These data will be of great importance to aircraft engine designers, as each of these test matrix parameters are critical to the design of a new turbine stage.

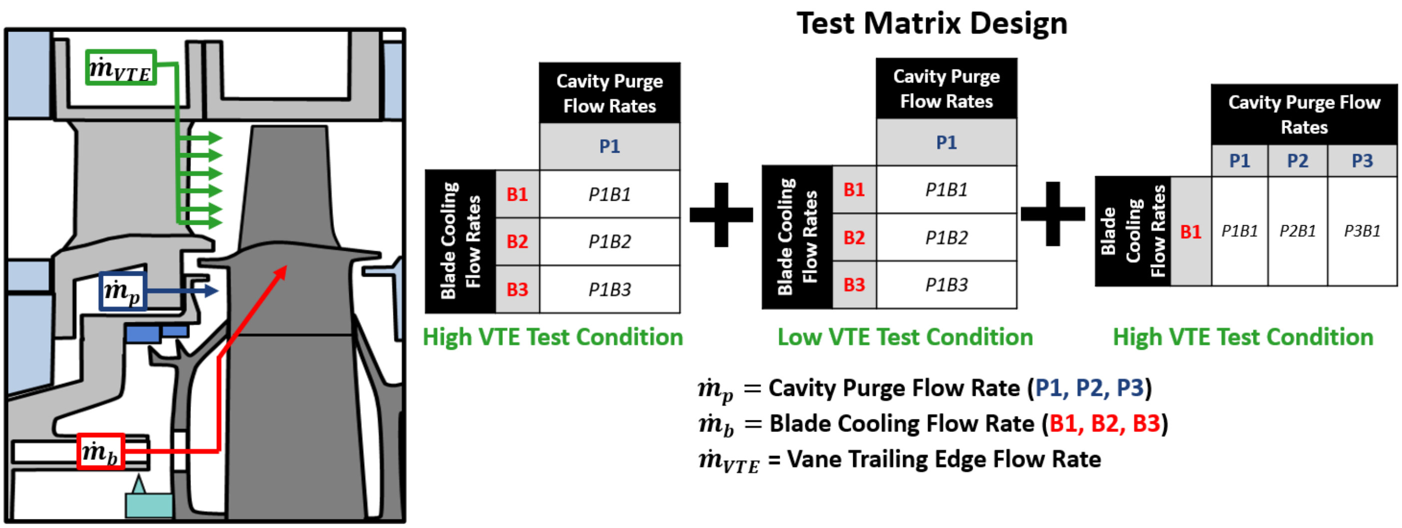

Figure 5. Test matrix for ASCENT Project 106B turbine efficiency testing.

This test program started at the end of this annual reporting period and will continue through the majority of the next quarter. Efficiency data will be processed to determine stage efficiency sensitivities, which will be shared with the GT-ASDL team for incorporation in their model. Initial data will be shared with the GT team when the aforementioned DUA is executed by both research teams.

Milestones

Milestone	Due date	Estimated date of completion	Actual date of completion	Status
Workplan	2/21/2025	2/21/2025	2/21/2025	Completed
COE meeting 1	5/31/2025	5/31/2025	5/7/2025	Completed
COE meeting 2	10/31/2025	10/31/2025	10/14 – 10/16/2025	Completed
Annual report	12/31/2025	12/31/2025		
Project closeout	9/30/2026	9/30/2026		

Major Accomplishments

- Executed a kickoff meeting with all individuals from the Penn State, GT, and FAA teams.
- Shared a presentation at the annual ASCENT meeting to share project status with the entire community.
- Completed final test hardware preparations and started the test campaign near the end of the annual reporting period.

Publications

None.

Outreach Efforts

The results reported in this document have been shared internally with the project team (Penn State and GT-ASDL) and will eventually result in a publication when testing is complete. Initial project goals were reviewed through an industry-government-academic partnership review meeting associated with the National Experimental Turbine in November 2024. Participants included the Department of Energy—National Energy Technology Laboratory, Office of Naval Research, Air Force Research Laboratory, National Aeronautics and Space Administration, Pratt & Whitney, Solar Turbines, Siemens

Energy, Honeywell Aerospace, and Agilis Engineering. Project updates and program goals were shared with Pratt & Whitney during a bi-annual industry-academic Center of Excellence partnership meeting in December 2024 and June 2025. In May 2025, updates on the overall ASCENT Project 106 program were shared during the annual ASCENT meeting and during a dedicated discussion as part of a bi-annual industry-academic Center of Excellence relationship. Additionally, goals and results were shared in a dedicated discussion in January 2025 and September 2025 as part of a bi-annual industry-academic Center of Excellence relationship with Solar Turbines.

Awards

None.

Student Involvement

An early career graduate student (Matthew Stuber) has been leading the efforts to optimize the data processing format, and he is now leading the effort to execute the test campaign. This has led to leadership development of this student through data analysis, meeting presentation skills, and team communication. Additional support has also been provided by a new graduate student (Dan Strobel) starting in August 2025.

Plans for Next Period

- Continue to coordinate & optimize the data delivery process and format for the GT-ASDL modeling tools.
- Complete the test program during the next reporting period, which will enable data analysis to proceed toward developing efficiency sensitivities to turbine operational parameters.

Disclaimer

This research was funded by the FAA Office of Environment and Energy through ASCENT, the FAA Center of Excellence for Alternative Jet Fuels and the Environment, Project 106B through FAA Award Number 13-C-AJFE-PSU-129 under the supervision of Pierre Mulgrave. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the FAA.