ME302: 2024-25-II COURSE PROJECT REPORT

FUTURE WORK

Based on our analysis of the facility capabilities and current research trends in turbomachinery, we propose ten experimental research studies that could be conducted in the modified facility. These studies require modifications only to the test section and upstream diffuser while leveraging the existing closed-loop testing infrastructure.

1. Turbulence Effects on Component Performance

Research Focus: Investigate how different levels of inlet turbulence intensity and length scales affect the performance of turbomachinery components.

Implementation: The test section would be modified to include interchangeable turbulence generators capable of producing controlled turbulence intensities (5-30%) and length scales (1-30% of axial chord). High-frequency response instrumentation would measure pressure fluctuations and flow structures.

Technological Advancement: Research by QuEST Global has shown that efficiency drops with higher flow length scales and turbulence intensity, with length scale effects being more predominant at high turbulence intensities[1]. Their studies indicated that an inlet length scale variation by 10 times could impact aerodynamic efficiency by ~0.5% to 4%. Recent research published in ASME Journal of Turbomachinery demonstrated that combustor turbulence increases profile loss and endwall loss in turbine cascades by 37% and 47%, respectively[2]. Our research would expand on these findings by providing detailed measurements of how turbulence parameters affect boundary layer development, separation behavior, and overall component performance.

Potential Beneficiaries: Companies like General Electric, Rolls-Royce, and Pratt & Whitney would benefit from this research as it would help them design more efficient and robust turbomachinery components that can operate effectively under various inlet conditions, particularly at the turbine-combustor interface where turbulence levels are highest.

2. Advanced Cooling Techniques for Turbine Components

Research Focus: Evaluate novel cooling configurations for high-temperature turbine components.

Implementation: The test section would be redesigned to accommodate scaled models of turbine blades with various internal cooling passages and film cooling hole arrangements. Temperature-sensitive paint or infrared thermography would visualize cooling effectiveness.

Technological Advancement: As noted by the U.S. Department of Energy's National Energy Technology Laboratory, effective internal and external cooling of airfoils is key to maintaining component life for efficient gas turbines[3]. Modern turbine designs are operating with inlet temperatures higher than 1900 K, which is achieved by actively cooling turbine components. Our research would investigate advanced cooling concepts such as impingement cooling, film cooling, transpiration cooling, and pin fin cooling to determine their relative effectiveness.

Potential Beneficiaries: Aerospace companies (Boeing, Airbus), defense contractors (Lockheed Martin), and power generation companies (Siemens, Mitsubishi) would be interested in this research for developing turbine components that can operate at higher temperatures for improved cycle efficiency while maintaining acceptable component life.

3. Surface Roughness Effects on Aerodynamic Performance

Research Focus: Quantify how surface roughness and simulated fouling affect the performance of turbomachinery components over time.

Implementation: The test section would accommodate components with controlled surface roughness patterns and simulated fouling deposits. Performance degradation would be measured under various operating conditions.

Technological Advancement: Research from the University of Melbourne has shown that the performance of gas turbines can be affected when blade surfaces become rough due to fouling or erosion, with efficiency of components dropping up to 10%[4]. Additional studies have demonstrated that roughness effects have different impacts depending on Reynolds number - at low Reynolds numbers, roughness can reduce or eliminate laminar separation bubbles, thus reducing loss, whereas at high Reynolds numbers, roughness increases boundary layer losses[5].

Potential Beneficiaries: Companies operating gas turbines in harsh environments (Saudi Aramco, ExxonMobil, Shell) and maintenance service providers (Sulzer, MHI, Wood Group) would benefit from improved prediction of performance degradation and optimized maintenance intervals.

4. Boundary Layer Control Techniques for Performance Enhancement

Research Focus: Investigate active and passive boundary layer control methods to improve turbomachinery component performance.

Implementation: The test section would be modified to incorporate various boundary layer control devices such as vortex generators, synthetic jets, or plasma actuators. Detailed flow measurements would quantify their effectiveness in preventing separation and reducing losses.

Technological Advancement: Boundary layer control techniques have shown promise in reducing losses in turbomachinery, particularly in low-pressure turbines where separation can be a significant issue. Recent research has explored plasma actuators for film cooling enhancement, with demonstrated cooling improvements of up to 15%[6].

Potential Beneficiaries: Aircraft engine manufacturers (GE Aviation, Safran), automotive turbocharger companies (BorgWarner, Garrett Motion), and industrial compressor manufacturers (Atlas Copco, Ingersoll Rand) would benefit from technologies that could improve component efficiency and operating range.

5. Unsteady Flow Interactions in Multi-stage Turbomachinery

Research Focus: Examine how unsteady flow structures propagate between turbomachinery stages and affect overall performance.

Implementation: A simplified multi-stage turbomachinery setup would be installed in the test section with high-speed instrumentation to capture time-resolved flow data. Phase-locked measurements would correlate unsteady phenomena between stages.

Technological Advancement: Understanding unsteady flow interactions is critical for improving the performance of multi-stage turbomachinery. Recent computational studies have made progress in this area, but experimental validation is needed, particularly for complex flow phenomena like wake-blade interactions and potential field effects.

Potential Beneficiaries: Companies developing multi-stage compressors and turbines (Siemens Energy, MAN Energy Solutions, Kawasaki Heavy Industries) would gain insights into stage matching and unsteady flow management, potentially leading to more efficient designs.

6. Noise Generation and Mitigation in Turbomachinery

Research Focus: Investigate the mechanisms of noise generation in turbomachinery components and evaluate mitigation strategies.

Implementation: The test section would be acoustically treated, and microphone arrays would be installed to measure noise generation. Various noise reduction concepts would be tested, including modified blade geometries and acoustic treatments.

Technological Advancement: Noise reduction is becoming increasingly important for both aerospace and power generation applications. Research in this area would help identify the primary sources of noise in turbomachinery and develop effective mitigation strategies.

Potential Beneficiaries: Aircraft engine manufacturers (Rolls-Royce, Pratt & Whitney, CFM International) facing increasingly stringent noise regulations would benefit from technologies that reduce engine noise while maintaining performance.

7. Flow Instabilities at Off-Design Conditions

Research Focus: Characterize flow instabilities (surge, rotating stall, etc.) that occur when turbomachinery operates away from design conditions.

Implementation: The test section would be equipped with fast-response instrumentation capable of detecting precursors to instabilities. Various control strategies would be tested to extend stable operating range.

Technological Advancement: Improving the stability of turbomachinery at off-design conditions is critical for applications with variable operating requirements. This research would help identify early warning signs of instabilities and develop effective control strategies.

Potential Beneficiaries: Companies developing compressors for variable operating conditions (Solar Turbines, Elliott Group, Howden) would benefit from improved understanding of instability mechanisms and methods to prevent them, leading to more reliable operation.

8. Secondary Flow Control in Turbine Passages

Research Focus: Investigate methods to control secondary flows (passage vortices, tip leakage flows) that contribute significantly to losses in turbines.

Implementation: The test section would house scaled turbine passages with various secondary flow control features. Detailed flow visualization and pressure measurements would quantify their effectiveness.

Technological Advancement: Secondary flows can account for up to 30% of total losses in turbines. Research in this area would help identify effective methods for controlling these flows and reducing associated losses.

Potential Beneficiaries: Power generation companies (GE Power, Mitsubishi Power, Ansaldo Energia) would benefit from technologies that reduce secondary flow losses, directly improving turbine efficiency and power output.

9. Novel Sealing Technologies for Turbomachinery

Research Focus: Evaluate advanced sealing concepts for reducing leakage flows in turbomachinery, which directly impacts efficiency.

Implementation: The test section would be modified to test various seal designs under realistic pressure differentials and rotational speeds. Leakage flow rates would be precisely measured to quantify seal effectiveness.

Technological Advancement: Leakage flows can significantly reduce turbomachinery efficiency. This research would evaluate novel sealing technologies that could minimize these losses while maintaining durability and reliability.

Potential Beneficiaries: Companies developing high-efficiency turbomachinery (Doosan Heavy Industries, Toshiba Energy Systems, Baker Hughes) would benefit from improved sealing technologies that minimize internal leakages and improve overall cycle efficiency.

10. Additive Manufacturing Effects on Flow Performance

Research Focus: Compare the aerodynamic performance of conventionally manufactured versus additively manufactured (3D printed) turbomachinery components.

Implementation: Identical geometry components would be produced through different manufacturing methods and tested under identical conditions to measure performance differences due to surface roughness, dimensional accuracy, and internal feature fidelity.

Technological Advancement: Additive manufacturing is increasingly being used to produce complex turbomachinery components. Research by various groups has shown that surface roughness in compressor and turbine blades is a significant factor causing performance deterioration in gas turbines[7]. This research would provide valuable insights into how manufacturing methods affect aerodynamic performance.

Potential Beneficiaries: Additive manufacturing companies (EOS, 3D Systems), aerospace manufacturers (SpaceX, Blue Origin), and industrial gas turbine manufacturers would benefit from understanding the aerodynamic implications of this increasingly popular manufacturing method, enabling more informed decisions about when and how to apply these technologies.

Each of these research directions represents a valuable opportunity to advance turbomachinery technology while leveraging the capabilities of the existing closed-loop testing facility. The modifications required are limited to the test section and upstream diffuser, making these studies feasible within the constraints specified in the project.

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1. https://quest-global.es/wp-content/uploads/2021/06/Studies-on-Impact-of-Inlet-Viscosity-Ratio-Decay-Rate-Length-Scales-in-a-Cooled-Turbine-Stage.pdf
2. https://asmedigitalcollection.asme.org/turbomachinery/article/142/9/091009/1084739/The-Impact-of-Combustor-Turbulence-on-Turbine-Loss
3. https://www.osti.gov/servlets/purl/1571231
4. https://energy.unimelb.edu.au/about-us/news/news-archive/extreme-scale-simulations-of-roughness-effects-on-compressor-and-turbine-performance-and-heat-transfer
5. https://asmedigitalcollection.asme.org/turbomachinery/article/136/6/061008/378392/The-Effect-of-Surface-Roughness-on-Efficiency-of
6. https://en.wikipedia.org/wiki/Turbine_blade
7. https://journal.gpps.global/The-effect-of-volute-surface-roughness-on-the-performance-of-automotive-turbocharger,76145,0,2.html