Title

Numerical Analysis of Brayton Cycle Performance Using Temperature-Dependent Specific Heat

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Independent Research Project

Abstract

Gas turbine cycle analysis is usually performed using the assumption of constant specific heat. However, modern gas turbines operate at very high turbine inlet temperatures where thermodynamic properties vary significantly with temperature. This project investigates how temperature dependent specific heat influences the predicted performance of the Brayton cycle. A numerical model was developed in MATLAB to compare two approaches:
(1) conventional constant specific heat analysis and
(2) variable specific heat analysis using NASA polynomial thermodynamic data.

The compressor and turbine exit temperatures were obtained by solving the entropy balance equations numerically. The model evaluated net work output, thermal efficiency, back work ratio, and optimum pressure ratio over a range of pressure ratios and turbine inlet temperatures representative of modern gas turbine engines.

The results show that the constant specific heat assumption over-predicts both efficiency and work output, especially at high turbine inlet temperatures. The variable specific heat model produces more realistic behaviour and shifts the optimum operating pressure ratio. The study demonstrates that temperature-dependent thermodynamic modelling is necessary for accurate preliminary gas turbine performance prediction.

1. Introduction

Gas turbines are widely used in aircraft propulsion and power generation because of their high power to weight ratio and operational flexibility. The performance of these engines is fundamentally based on the Brayton cycle, which models compression, heat addition, expansion, and heat rejection processes.

Traditional Brayton cycle analysis assumes that air behaves as an ideal gas with constant specific heat. This simplifies calculations and provides acceptable accuracy at low temperatures. However, modern gas turbines operate at turbine inlet temperatures above 1500 K, where thermodynamic properties vary strongly with temperature.

When temperature effects are ignored, cycle analysis becomes overly optimistic. The compressor work is underestimated and turbine expansion effectiveness is overestimated. As a result, performance predictions such as efficiency and optimum pressure ratio may be inaccurate.

The purpose of this project is to investigate the effect of temperature dependent specific heat on Brayton cycle performance and to quantify the modelling error caused by the constant specific heat assumption.

1.1 Objectives

This study aims to:

1. Develop a MATLAB-based numerical model of the Brayton cycle
2. Implement temperature dependent specific heat using NASA polynomial relations
3. Determine compressor and turbine exit temperatures by solving entropy balance equations numerically
4. Evaluate key performance parameters, including net work output, thermal efficiency, back work ratio, and optimum pressure ratio
5. Perform a parametric study over a range of compressor pressure ratios and turbine inlet temperatures

6. Compare the results obtained using constant specific heat and variable specific heat models
7. Quantify the performance prediction error introduced by the constant specific heat assumption

2. Methodology

Two thermodynamic models were created:

A. Baseline Model

Assumes:

- Ideal gas
- Constant specific heat
- Analytical isentropic relations

This represents the classical Brayton cycle analysis used in textbooks.

B. Advanced Model

Uses:

- temperature dependent specific heat Cp(T)
- NASA polynomial thermodynamic data
- entropy balance equations
- numerical integration
- iterative root finding solution

Because Cp varies with temperature, exit temperatures cannot be calculated analytically. Therefore, the compressor and turbine temperatures were solved numerically using entropy equations. MATLAB numerical integration and nonlinear solvers were used to determine the thermodynamic state points and calculate cycle performance.

3. Performance Parameters

The following parameters were evaluated:

1.) **Net Work Output**

2.) **Thermal Efficiency**
3.) **Back Work Ratio**
4.) **Optimum Pressure Ratio**
5.) **Error**

4. Results and Discussion

The numerical results show consistent trends for all turbine inlet temperatures.

Net work increases with pressure ratio initially.
2. After a certain point, compressor work dominates.
3. A maximum work output occurs at an optimum pressure ratio.

When temperature-dependent specific heat is included:

1. Net work output decreases
2. Thermal efficiency decreases
3. Back work ratio increases
4. Optimum pressure ratio shifts

This occurs because at high temperature the specific heat of air increases. More energy is required to compress the air, and turbine expansion becomes less effective. Therefore, the constant specific heat model produces overly optimistic predictions.

5. Engineering Meaning

The results show that constant property thermodynamic analysis is acceptable only for low temperature gas turbines. For modern engines operating above 1500 K, temperature dependent modelling is required for accurate preliminary design.

If constant Cp analysis is used in engine design:

1. compressor size may be underestimated
2. fuel consumption may be underestimated

3. operating pressure ratio may be incorrect

Therefore variable Cp modelling should be used before performing detailed CFD or turbomachinery design.

6. Conclusion

This project investigated the influence of temperature dependent specific heat on Brayton cycle performance using a MATLAB numerical model. Two approaches were compared: the conventional constant specific heat analysis and a variable specific heat model based on NASA polynomial thermodynamic data.

The results showed that the constant specific heat assumption over-predicts both thermal efficiency and net work output, especially at high turbine inlet temperatures. When temperature dependent properties were included, the predicted compressor work increased, turbine expansion effectiveness decreased, and the back work ratio became higher. In addition, the optimum pressure ratio shifted from the value predicted by the constant specific heat model. These findings demonstrate that simplified Brayton cycle analysis can lead to unrealistic performance predictions for modern high temperature gas turbines.

Therefore, temperature dependent thermodynamic modelling is necessary for accurate preliminary gas turbine performance evaluation. The developed numerical model provides a more realistic representation of engine behaviour and can serve as a useful preliminary step before detailed turbomachinery design or computational fluid dynamics analysis.

This project provided a strong foundation in numerical thermodynamic modelling and gas turbine performance analysis. It also encouraged further interest in higher fidelity propulsion modelling methods, such as mean-line turbomachinery analysis and computational fluid dynamics, which are important for modern aircraft engine development.