# Brayton Cycle Model Report

## Introduction

This report describes a Python-based **Air-Standard Brayton Cycle with irreversibility** simulation.

This cycle is widely used in gas turbine engines. The program calculates state conditions, work, heat transfer, efficiency, and power output based on user-provided initial conditions.

## The Air-Standard Brayton Cycle with irreversibility

Diagram of a diagram of a heat exchanger

AI-generated content may be incorrect.A diagram of a triangle with arrows and points

AI-generated content may be incorrect.

Figure 1 Air-Standard Brayton Cycle including irreversibility of compression and expansion processes (Moran, Shapiro, Boettner, & Bailey, 2014)

The standard-air Brayton cycle with irreversibility consists of four main stages:

* **Compression**: Ambient air is compressed in the compressor, increasing pressure and temperature. This compression is non-isentropic.
* **Isobaric Heat Addition**: The compressed air absorbs heat in the combustion chamber, raising its temperature.
* **Expansion**: The hot, high-pressure air expands through the turbine, producing work output. This expansion is non-isentropic.
* **Isobaric Heat Rejection**: The remaining heat is expelled, returning the air to its initial state.

Assumptions of the Air-Standard Brayton Cycle with irreversibility

An idealization often used in the study of open gas turbine power plants is that of an air-standard analysis. In an air-standard analysis two assumptions are always made (Moran, Shapiro, Boettner, & Bailey, 2014):

* The working fluid is air, which behaves as an ideal gas.
* The temperature rise that would be brought about by combustion is accomplished by a heat transfer from an external source.
* Irreversibility of compression and expansion processes are considered.
* Frictional pressure drops in heat exchangers are not considered.

Engineering Model (Moran, Shapiro, Boettner, & Bailey, 2014)

* Each component is analyzed as a control volume at steady state.
* The compressor and turbine are adiabatic.
* There are no pressure drops for flow through the heat exchangers.
* Kinetic and potential energy effects are negligible.
* The working fluid is air modeled as an ideal gas.

## Model architecture

In this section, the **Brayton Cycle Model Architecture Diagram** is presented to provide a visual representation of the thermodynamic processes involved in the cycle.

A diagram of a flowchart

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Figure 2 Brayton Cycle model architecture (author)

## Code Structure

The code is organized into modular functions sourced from different imported modules:

* initial\_conditions:
  + Defines pressure (P1, P2, P3, P4), temperature (T1, T3), and volumetric flow rate.
* fluid\_properties:
  + get\_cp\_cv: Retrieves specific heat values (Cp and Cv) from ideal\_gas\_properties database.
* general\_functions:
  + compression\_ratio: Calculates pressure compression ratio.
  + volumetric\_to\_mass\_flow\_rate: Converts volumetric to mass flow rate.
* thermodynamic\_processes:
  + isentropic\_compression: Computes temperature T2 and compressor work.
  + isobaric\_heat\_addition: Computes heat input Qin across constant pressure.
  + isentropic\_expansion: Computes temperature T4 and turbine work Wt.
  + isobaric\_heat\_rejection: Computes heat rejection Qout.

## Thermodynamic Process Breakdown

The code implements four key thermodynamic processes:

1. **Isentropic Compression**
   * Uses compression ratio (rc) and initial temperature (T1) to compute final temperature (T2) and compressor work input (Wc).
   * Requires specific heat capacity at constant pressure (cp) for property calculations.
   * Takes gamma (γ) as an input to apply entropy relations in the isentropic process.
2. **Isobaric Heat Addition**
   * Uses initial temperature (T2) and final temperature (T3) to compute the heat added (Qin) during the isobaric heating phase.
   * Requires specific heat capacity at constant pressure (cp) for property calculations.
   * Returns Qin, representing the heat input for subsequent turbine stages.
3. **Isentropic Expansion**
   * Uses initial pressure (P3) and final pressure (P4) along with initial temperature (T3) to compute the final temperature (T4) after expansion.
   * Requires specific heat capacity at constant pressure (cp) for property calculations.
   * Takes gamma (γ) as an input to apply entropy relations in the isentropic process.
   * Computes work output (Wt) generated by the turbine.
4. **Isobaric Heat Rejection**
   * Uses initial temperature (T1) and final temperature (T4) to compute the heat rejected (Qout) during the isobaric cooling phase.
   * Requires specific heat capacity at constant pressure (cp) for property calculations.
   * Returns Qout, representing the expelled heat for further thermodynamic analysis.

## Performance Metrics

The simulation determines key cycle performance metrics (Moran, Shapiro, Boettner, & Bailey, 2014):

* **Net Work Output:**
  + Wnet\_work\_based = Wt - Wc (direct work output calculation).
  + Wnet\_heat\_based = Qin + Qout (energy balance method).
* **Efficiency Calculation:**
  + efficiency = Wnet\_work\_based / Qin
* **Power Output:**
  + power\_output = Wnet\_work\_based \* m\_dot
* **Back Work Ratio (BWR):**
  + bwr = Wc / Wt

## Results & Improvements

The code systematically computes and prints:

* **Stage-wise temperatures, work values, and heat transfer values**.
* **Net power output and efficiency**.

Possible Enhancements:

* **Error Handling:** Improve missing temperature checks with fallback values.
* **Modularization:** Simplify repeated calls to get\_cp\_cv() with a helper function.
* **Graphical Output:** Implement **Matplotlib** to visualize efficiency trends.

## Conclusion

This Brayton Cycle model efficiently simulates gas turbine performance and provides insights into thermodynamic properties. With minor refinements, it can serve as a robust tool for cycle analysis.