Design, Modeling, and Construction of a Compact Gas Turbine Prototype for Educational and Experimental Applications

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Abstract: *This study presents the design, modeling, and construction of a compact gas turbine prototype. The main goal is to combine theoretical thermodynamic analysis with practical mechanical realization, enabling visualization and study of the performance of a micro-gas turbine system for educational and research purposes. The design phase was carried out in SolidWorks, where each turbine component, including the compressor, combustion chamber, turbine, etc., were individually modeled to ensure dimensional accuracy and fit during assembly. The 3D model served as the basis for the production and assembly of the real parts of the prototype, built with machined metal components and mounted on a customized steel frame. The combustion and exhaust system was designed to ensure controlled fuel flow and safe ignition conditions, while the shaft was supported on precision bearings to minimize vibration and friction losses. The physical realization, combined with CAD modeling and thermodynamic cycle analysis, provides an excellent platform for studying the thermodynamics of the Brayton cycle, energy conversion efficiency, and heat transfer mechanisms in compact turbines. The study shows that interdisciplinary collaboration between mechanical design, thermodynamics, and practical realization can lead to the construction of a functional prototype for educational and research purposes, which can serve as a basis for experimental testing and further developments in the field of gas microturbines. Future work will include the integration of sensors for real-time data collection and the comparison of experimental performance with theoretical predictions.*

Keywords*: GAS TURBINE, MICROTURBINE, SOLIDWORKS MODELING, THERMODYNAMIC CYCLE, EDUCATION.*

1. Introduction

Gas turbines represent one of the most efficient and versatile thermomechanical systems for power generation, characterized by continuous-flow combustion, high power-to-weight ratio, and modular scalability [1]. In recent years, micro-gas turbines (MGTs) have gained considerable attention for educational, research, and distributed generation applications due to their compact size, fuel flexibility, and relatively simple architecture compared to large-scale industrial turbines [2–3]. Their ability to clearly demonstrate the Brayton thermodynamic cycle makes them ideal platforms for laboratory teaching and experimental studies in thermodynamics, heat transfer, and turbomachinery.

The development of physical prototypes for academic use offers several advantages, as it allows students and researchers to visualize and measure real thermodynamic processes, including compression, combustion, and expansion, beyond the idealized models of textbooks [4], [5]. It also provides a practical understanding of engineering trade-offs such as pressure losses, combustion stability, rotor alignment, lubrication requirements, and thermal stresses that are often difficult to convey through theory alone. Combining modeling tools (CAD, CFD) with experimental platforms enhances conceptual understanding and strengthens engineering problem-solving skills [6], [7].

This study presents the complete workflow for the design, modeling, and construction of a compact gas turbine prototype intended for educational and research purposes. The design phase was performed using SolidWorks, enabling detailed modeling of each subsystem, compressor, combustor, turbine, compressor-turbine assembly, injector, lubrication lines, and structural frame, ensuring dimensional compliance and manufacturability. CAD-based design served as the basis for machining individual metal components and assembling them into a functional prototype, a methodology aligned with modern micro-turbine development practices reported in recent research [2], [7].

Emphasis was placed on the design of the combustion chamber and fuel injection system to achieve controlled ignition and stable flame behavior, in accordance with recommended practices in micro-scale combustor design [1], [3]. In parallel, the mechanical assembly focused on minimizing vibration and friction losses through the selection of precision bearings and careful shaft alignment, an essential requirement for small-scale turbine stability and efficiency [9].

The completed prototype provides a valuable platform to observe the real-world behavior of the Brayton cycle, studying energy conversion efficiency and examining heat transfer mechanisms in compact turbines. In addition, it opens possibilities for future instruments with temperature, pressure, and velocity sensors, enabling a direct comparison between theoretical predictions and experimental performance.

2. Methodology

The design of the compact gas turbine prototype followed an integrated workflow that combined thermodynamic analysis, CAD modeling, and practical manufacturability considerations [8]. The goal was to create a functional system that accurately represents the Brayton cycle, while remaining simple enough for educational and research use.

2.1 CAD Modeling in SolidWorks

All components including the compressor, combustor, turbine, shaft, bearings, lubrication lines, and frame were individually modeled in SolidWorks to ensure accurate dimensions, clearances, and assembly compatibility. The CAD model also allowed visualization of airflow paths and mechanical alignment, consistent with common micro-gas turbine design practices [9].

2.2 Component Design

Compressor: A turbocharged radial impeller was used due to its compact size and suitable pressure ratio, consistent with approaches seen in similar prototypes [3].

Combustion Chamber: Designed with primary and dilution holes for stable flame anchoring and uniform temperature distribution, following established micro-combustor guidelines [1].

Turbine and Shaft: A single-shaft configuration was adopted, with precision bearings to minimize vibration and friction losses, essential for small-scale turbine operation [4].

2.3 Structural Integration

A custom steel frame was designed to support all components, ensuring rigidity, proper alignment, and secure routing of fuel and lubrication lines. The CAD assembly served as the blueprint for the machining and assembly of the physical prototype.

The figure below shows the rotor assembly of a micro-gas turbine, consisting of a single shaft supporting the radial compressor wheel (green) on one side and the radial turbine wheel (blue) on the other. The assembly includes bearing supports, spacers, and retaining discs that ensure proper axial alignment and smooth rotation at high speeds. This configuration enables efficient energy transfer between the turbine and compressor while maintaining mechanical stability.

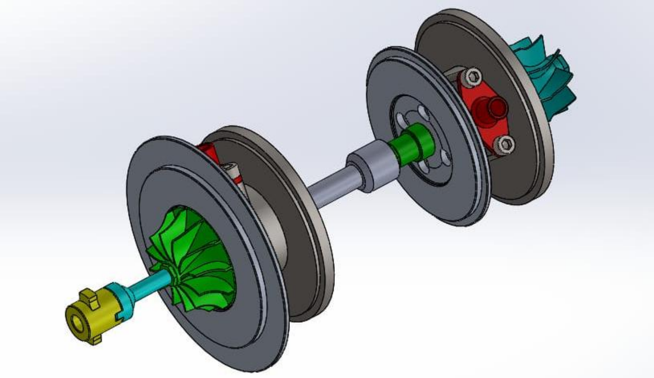

Fig. 1 *Exploded view of the micro gas turbine rotor assembly.*

The combustion chamber assembly of the micro gas turbine, featuring the cylindrical perforated liner (green), the outer casing, and the integrated fuel injector positioned at the upstream end. The design ensures proper air–fuel mixing, flame stabilization, and smooth flow transition between the compressor outlet and turbine inlet.

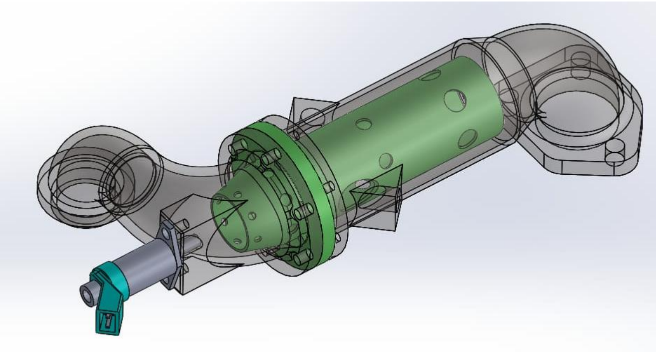

Fig. 2 *CAD model of the combustion chamber assembly.*

The figure below shows the integrated assembly of the compressor, combustion chamber and turbine section.

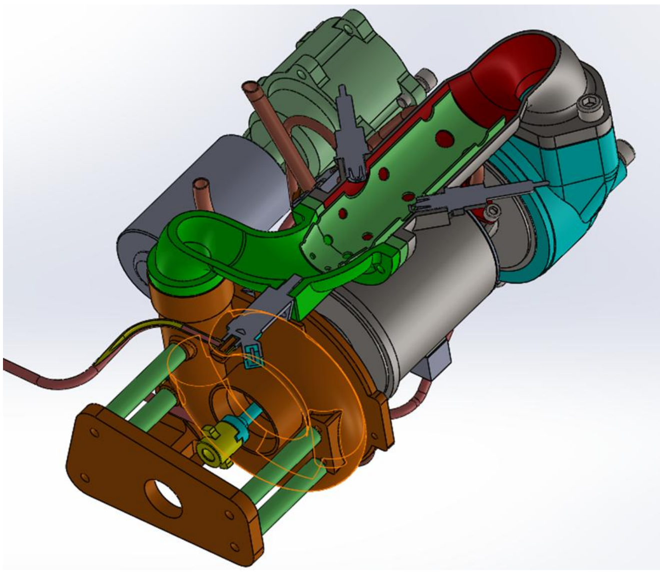

Fig. 3 *Detailed CAD assembly of the micro gas turbine core.*

The combustor (green and red) is positioned between the compressor outlet and the turbine inlet, with air guide channels ensuring smooth flow into the combustor and towards the turbine wheel.

The model illustrates the interaction between the major components of the micro gas turbine, including the compressor, the transition duct and combustion chamber, the turbine scroll, and the central shaft housing. The perforated combustor liner and the internal air-routing geometry are designed to promote controlled air–fuel mixing and stable combustion. Downstream, the turbine housing channels the high-temperature gases toward the turbine wheel, ensuring efficient energy transfer to the rotating assembly. Overall, the configuration demonstrates the complete gas-path sequence of the system, from compression, to combustion, and finally to expansion through the turbine stage.

The images present the integrated lubrication and fuel-supply system of the micro gas turbine prototype. The assembly incorporates the oil pump, fuel pump, lubrication lines, oil reservoir, and the coiled heat-exchanger tubing arranged around the turbine core. The routing of the lines is designed to provide continuous lubrication to the shaft bearings and to ensure a stable and uninterrupted fuel supply to the injector. The extended tube bundle operates as a compact heat exchanger, dissipating thermal loads and maintaining the oil temperature within safe operating limits, an essential requirement for reliable long-duration turbine operation.

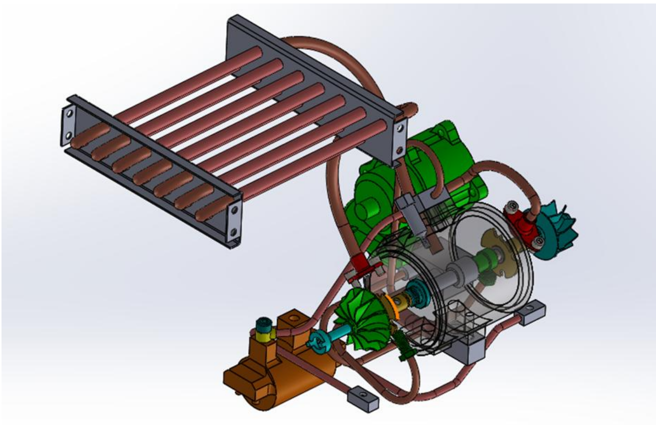

Fig. 4 *CAD representation of the lubrication and fuel-line system of the micro gas turbine.*

The model also includes the fuel-injector subsystem, comprising the injector nozzle, the pressurized fuel line, and the connected fuel tank. This configuration delivers a controlled and consistent fuel flow to the combustion chamber, supporting stable ignition and sustained combustion throughout turbine operation.

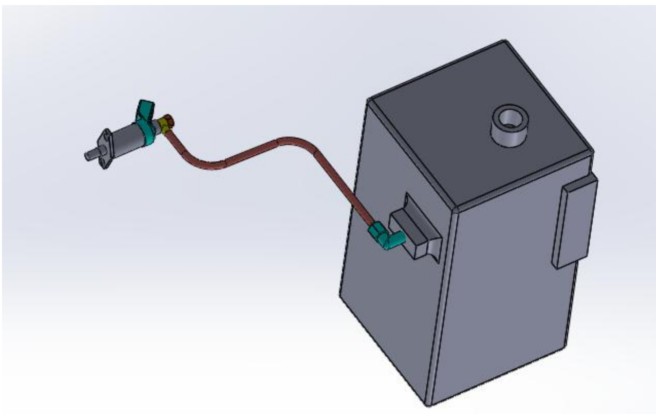

Fig. 5. *CAD representation of the injector and fuel-tank connection.*

The injector nozzle is linked to the main fuel tank through a rigid copper fuel line equipped with fittings for leak-free operation. This subsystem ensures precise fuel delivery to the combustor, enabling controlled atomization and efficient mixing with compressed air during turbine operation.

The presented figures show the complete micro gas turbine prototype, assembled within a rigid steel support frame. The system integrates all subsystems required for autonomous turbine operation, including the compressor, combustor, turbine core, lubrication unit, fuel supply, and thermal management components.

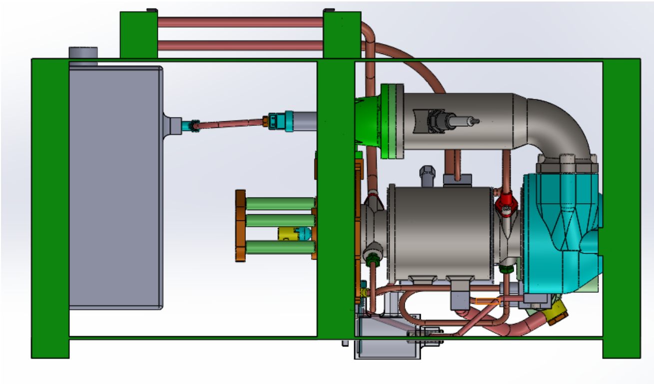

Fig. 6 *Side-view CAD assembly of the complete micro gas turbine prototype.*

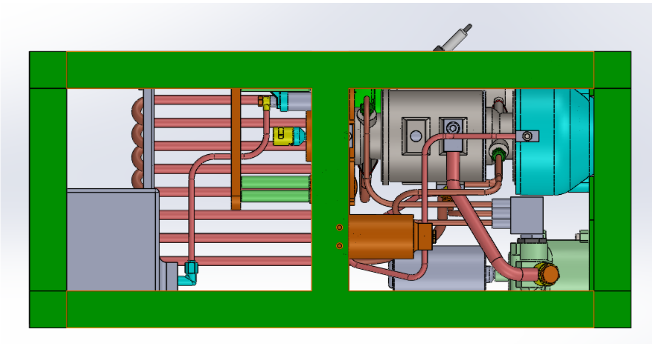

Fig. 7 *Upper-view CAD assembly of the complete micro gas turbine prototype.*

The layout displays the integration of the main turbine core compressor, combustor, and turbine with the auxiliary systems housed within a rigid steel frame. The combustion chamber is centrally positioned, while the fuel line, lubrication circuit, and cooling tubes are routed around the core for efficient distribution. On the right side, the fuel tank is mounted externally for easy access and refilling. The arrangement highlights the compact packaging of all functional subsystems necessary for stable turbine operation.

3. Thermodynamic Analysis

The prototype was analyzed using an ideal Brayton cycle model to obtain reference values for compressor outlet temperature, turbine work, specific work output, and cycle efficiency.

To support both design and teaching, a MATLAB model and GUI dedicated to the Brayton cycle were developed [10]. The GUI (integrated into MATLAB App Designer) allows the user to enter key parameters, such as compressor pressure ratio, inlet temperature and pressure, turbine inlet temperature, mass flow rate, and isentropic efficiencies and instantly calculates the state points, thermal efficiency, specific work, and heat transfer rates. The program automatically generates the corresponding P–v and T–s diagrams of the gas turbine cycle.

In future work, the same interface will be used to compare theoretical predictions with experimental data from the physical prototype, providing a direct link between the analytical theory of the Brayton cycle and the measured performance of the gas microturbine.

4. Prototype Fabrication and Assembly

The fabrication of the micro gas turbine prototype followed a structured, component-based manufacturing approach to ensure accuracy and safe assembly. All major parts, compressor housing, turbine scroll, shaft supports, and the combustion chamber were produced using CNC machining to maintain tight tolerances required for high-speed operation. Metallic components such as the combustor liner, fuel injector mounts, and bearing housing were manufactured from heat-resistant steel and aluminum alloys, selected for their strength-to-weight ratio and thermal stability.

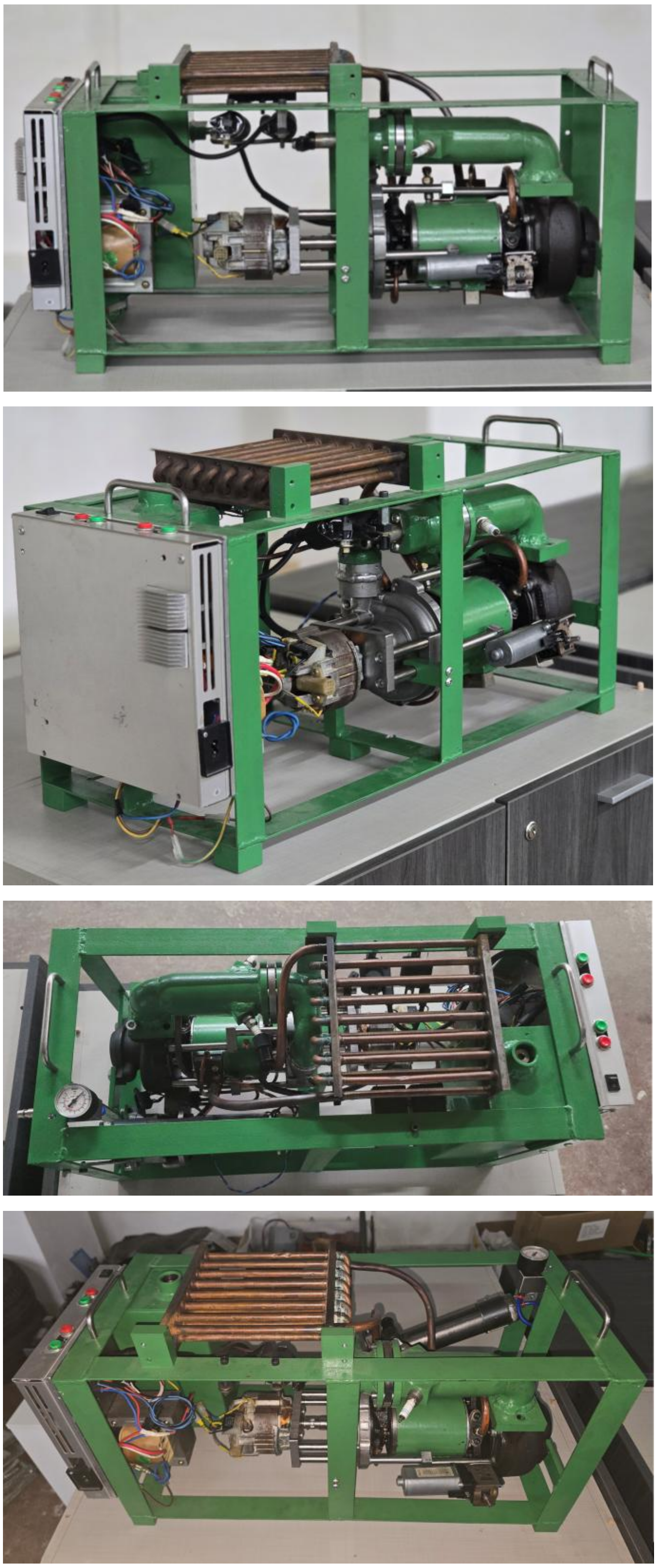

Fig. 8 *Fully assembled micro gas turbine prototype mounted on its steel support frame.*

The figure below shows the electrical control panel of the micro gas turbine prototype, which houses the switches, indicators, and power connections required for safe system operation. The panel includes ignition controls, pump activation switches, and status lights that allow the operator to monitor and control the turbine during startup and testing.

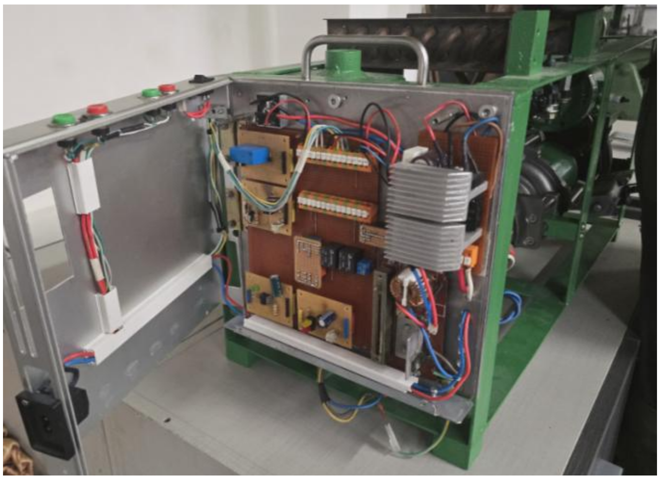

Fig. 5 *Electrical control panel for the micro gas turbine prototype.*

The panel integrates ignition circuitry, power distribution, emergency shutoff, and control switches for auxiliary components such as the fuel and lubrication pumps. Indicators provide real-time status feedback, enabling safe and controlled turbine startup, monitoring, and shutdown.

5. Future Work

The next development stage involves equipping the prototype with a comprehensive sensor suite to enable real-time monitoring and data acquisition. Planned instrumentation includes thermocouples at compressor exit, combustor inlet/outlet, and turbine exit; pressure transducers at key flow locations; rotor speed sensors; and flow meters for fuel and lubrication circuits. These measurements will provide a detailed picture of system performance and will be integrated into a digital data-logging interface for controlled experimental operation.

The experimental data collected will be compared directly with predictions from the MATLAB Brayton-cycle model and GUI developed during this study. Key comparisons will include compressor outlet temperature, turbine expansion ratio, thermal efficiency, specific work output, and overall mass-flow behavior. Discrepancies between theoretical and measured values will be analyzed to refine the numerical model and adjust assumptions such as component efficiencies, heat losses, and real-gas effects. This comparison will not only validate the design methodology but also guide iterative improvements to the turbine prototype and its analytical model.

6. Conclusion

This work successfully demonstrates the complete development of a compact micro-gas turbine prototype, from CAD modeling and thermodynamic analysis to fabrication and assembly.

The SolidWorks-based design was accurately translated into a real, functional prototype, confirming the reliability of the modeling process and the proper integration of key subsystems such as the compressor, combustor, turbine, lubrication system, and fuel system. Preliminary mechanical checks verified smooth rotor operation, effective lubrication, and consistent combustor performance, indicating that the prototype is structurally sound and ready for controlled testing.

Beyond its technical value, this prototype has significant educational significance. It provides students and practitioners with a rare opportunity to directly observe the Brayton cycle, understand the interactions of turbine components, and relate theoretical thermodynamics to real mechanical behavior. The accompanying MATLAB Brayton cycle GUI further enhances learning by allowing users to simulate operating conditions and compare them with future experimental results.

Overall, the prototype provides a powerful practical platform for teaching, experimentation, and research in thermal engineering, increasing understanding of gas turbines and supporting future innovations in micro-generation and power systems.

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8. References

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