Journal of Emerging Technologies and Industrial Applications
Vol. 3 No. 2 (2024) pp. 1-7
e-ISSN: 2948-507X

Journal homepage: https://jetia.mbot.org.my/index.php/jetia/index

Development of a Thrust Measurement Device System for Micro-Gas Turbine

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Abstract: This study focuses on developing a specialized system model for thrust measurement in micro-gas turbines, addressing the need to modify conventional techniques to accommodate their unique design, size, and operational characteristics. The primary objective of this paper is to develop and design a reliable and practical thrust measurement device system that accurately simulates the forces exerted by a micro-gas turbine on a specific material, with a focus on ensuring trustworthiness and usability. By completing a thorough literature review and using an appropriate methodology, this project intends to construct a thrust measurement system, design a related model, and successfully implement and integrate the simulation results. As a result, a reliable and practical device system model for measuring micro gas turbines was developed and designed, and through Solidworks CAD simulation tests, we found that malleable cast iron is the most ideal material due to its ideal results among applied materials. The research not only contributes to the field of aeronautical engineering by developing new avenues for micro-gas turbine technology research, and innovation, but also highlights the need for further advancements, including the integration of high-quality weighing sensors, robust mounts and suspensions, reliable signal conditioning, comprehensive calibration and validation procedures, robust data acquisition systems, and prioritization of safety considerations throughout the design process.

Received 20 February 2024; Accepted 15 May 2024; Available online 26 June 2024

Keywords: Micro-Gas Turbine, Thrust Measurement Device System, Solidworks CAD

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1. Introduction

Micro gas turbines have gained significant attention in recent years due to their compact size and powerful performance, making them a practical choice for various sectors, including unmanned aerial vehicles (UAVs) and micro jet engines. As the demand for affordable micro-turbojet engines increases, accurate thrust measurement becomes essential for testing and performance assessment. However, conventional thrust measuring techniques used for larger engines are ineffective for micro gas turbines due to their small size, fast rotating speeds, and limited space for instrumentation.

The objective of this technical paper is to address the challenges associated with thrust measurement in micro gas turbines and develop a specialized thrust measurement device system tailored specifically for these engines. This multidisciplinary project incorporates instrumentation design, material selection, and safety considerations to ensure the system's reliability and compatibility with micro gas turbine operations. The absence of a reliable thrust measuring device system poses significant limitations in the development and widespread adoption of micro gas turbine technology. Without a standard and verified thrust measurement system, it is challenging to compare performance data, conduct reliable research, and establish effective management strategies. Therefore, the development of a thrust measurement device system for micro gas turbines is crucial to unlock the full potential of these engines and enable enhanced performance and operational effectiveness in various applications.

The research significance of this project lies in its potential to address a critical need in the field of micro gas turbines. By developing a thrust measuring device system specifically tailored for these engines, the project aims to enhance operational effectiveness, facilitate performance evaluation and optimization, and open up new opportunities for small-scale power production in various sectors.

This paper aims to design a thrust measurement device system model for micro gas turbines and utilize it for simulation. The objectives include the development of a reliable and practical device system for thrust performance measurement, the extraction and analysis of simulation data for the applied materials, and the determination of optimal materials that satisfy the design requirements. Overall, the successful development of the thrust measurement device system for micro gas turbines will advance the science of micro gas turbine technology and contribute to the broader understanding of thrust dynamics. It has the potential to revolutionize the capabilities and applications of micro gas turbines, leading to improved performance, enhanced design iterations, and the creation of new opportunities for small-scale power production in multiple industries.

2. Introduction

2.1 Review of Micro-Gas Turbine

Micro-gas turbines consist of an assembly of a compressor, a combustion chamber, and a turbine, as illustrated in the simplified design of Figure 1. This arrangement is similar to that of small, medium, and large-scale gas turbines [1]. Micro-gas turbines can operate with or without recuperation, where a regenerator is used to pre-heat the air supply to the turbine, thereby improving efficiency by recovering heat from the exhaust system. The utilization of a regenerator can raise the overall cycle efficiency significantly, up to 30%. Micro-gas turbines without heat recovery typically have an average net efficiency of 17%. [2]

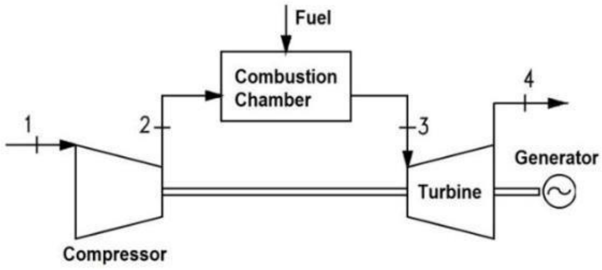

Fig. 1 - Gas turbine system scheme of a simple open cycle [1]

2.2 Thrust Measurement Test Bench

The micro-turbojet engine thrust measuring system includes a test bench, load cell, data acquisition modules, and a computer. The test bench employs a suspended test. An S-type sensor, such as the CFBLSM-100Kg model, is used as the load cell to convert thrust changes into electrical signals. The ADAM-4018 and ADAM-4520 data acquisition modules are utilized to convert the electrical signals into digital form and transmit them to the computer. The software, developed using VC++ and LabVIEW, enables real-time monitoring and data processing of the engine thrust. [3]

The schematic of the test bench, as shown in Figure 2, consists of a fixed frame, lever, roller, and sliders. The lower end of the lever is connected to the micro-turbine engine via a clamp, and a roller attached to the top end of the lever is wedged between two sliders that can only move horizontally along guide rails. The load cells are connected to the sliders to measure the forces generated by the engine. [4]

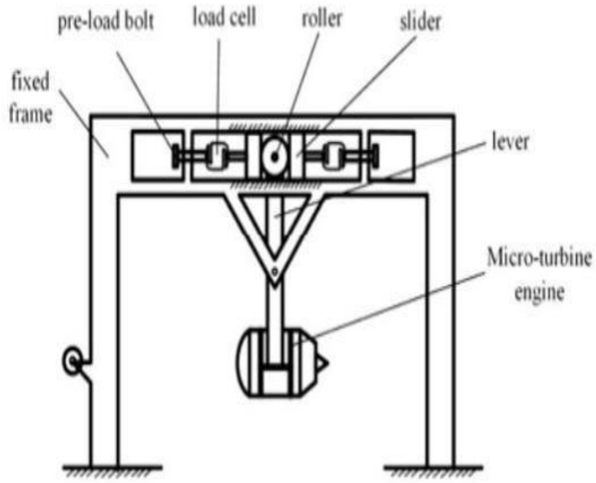

Fig. 2 - Schematic of the Test Bench. [4]

2.3 **Trust Stand**

The thrust stand comprises a thruster support plate, in situ levelling and calibration systems, non-contact displacement measuring systems, and data collecting systems. The frame is constructed using a skeletal structure, support legs, a hanger frame, and adjustment plates to ensure precise positioning. A linear capacitive displacement sensor (LCDS) with a resolution of 0.1 mm is used to detect the displacement caused by the deformation of the leaf spring. The LCDS output signal ranges from 0 to 5V, and a data acquisition system is employed to collect the thrust data [5].

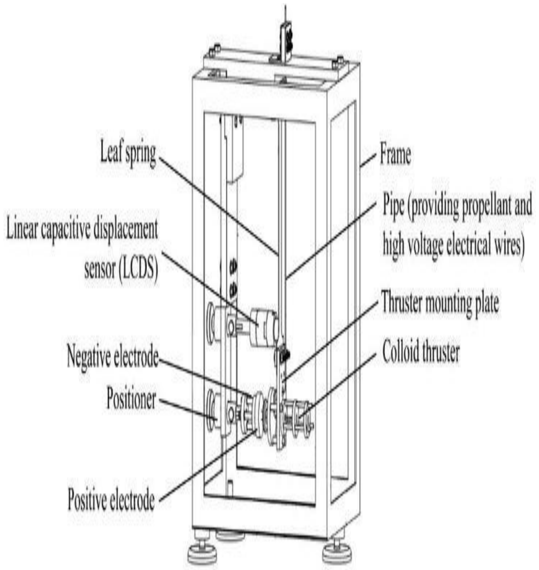

Fig. 3 - Schematic of the Thrust Stand [5]

2.3.1 **Review of the Thrust Measurement Principle and Precision**

Thrust stands at various academic institutions and in the industry have had their principles, ranges, and precision examined as shown in Table 1.

Table 1 - Principles, Ranges, and Precision

Author	Principle	Range	Precision
[6]	Torsional balance	10 µN-2 mN	~ ±2%
[7]	Torsional balance	88.8 nN, 734 nN	±11%
[8]	Torsional balance	5-30 µN	0.03 µN
[9]	Torsional balance or pendulum	1-100 µN	1 µN, 1 µNs
[10]	Torsional balance	1-100 µN	0.1 µN
[11]	Torsional balance	2-45 µN	5-14%
[12]	Torsional balance	0.1-500 µN	0.025 µN
[13]	Torsional balance	4.4 µN-22 mN	25%
[14]	Torsional pendulum	260 µNs	1%
[15]	Torsional balance	1-100 µN	<3%

3. **Methodology**

The flowcharts illustrate the development and planning process of a thrust-measuring device system for a micro gas turbine. The flowchart outlines the general procedure for conducting comprehensive research and preparing the project report. It provides an overview of the various stages involved in the project, including data collection, analysis, and documentation. The flowchart also depicts the timeline for the completion of the project, divided into two parts: PSM 1 and PSM 2, which represent different phases of the final year project. These flowcharts provide a visual representation of the research and reporting process for the thrust measuring device system project.

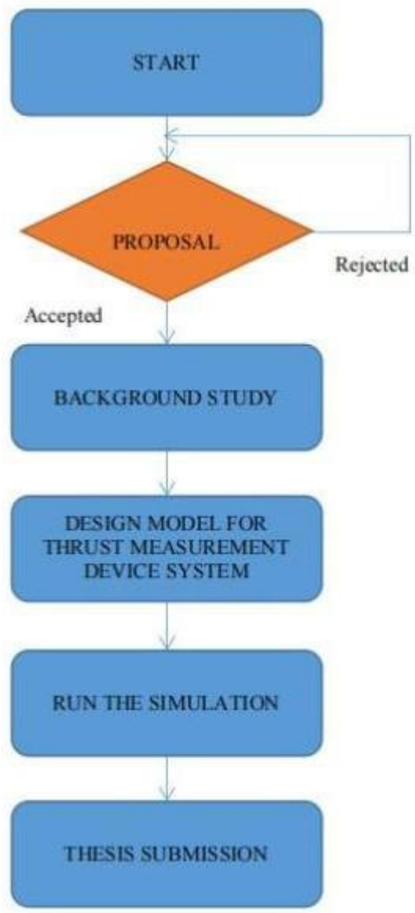

Fig. 4 - Flowchart diagram of the study

3.1 **Thrust Measurement Device System Model Designing Software**

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The software used for designing the model of the thrust measurement device system is Solidworks. SolidWorks is a computer-aided design (CAD) software that enables users to create and design 3D models of objects and products. It offers a range of tools and capabilities for building intricate 3D models, including drawing, extruding, rotating, and sweeping. In the design process, the current thrust measuring system is assessed, and the SolidWorks software is utilized to create 3D models that meet the project's requirements.

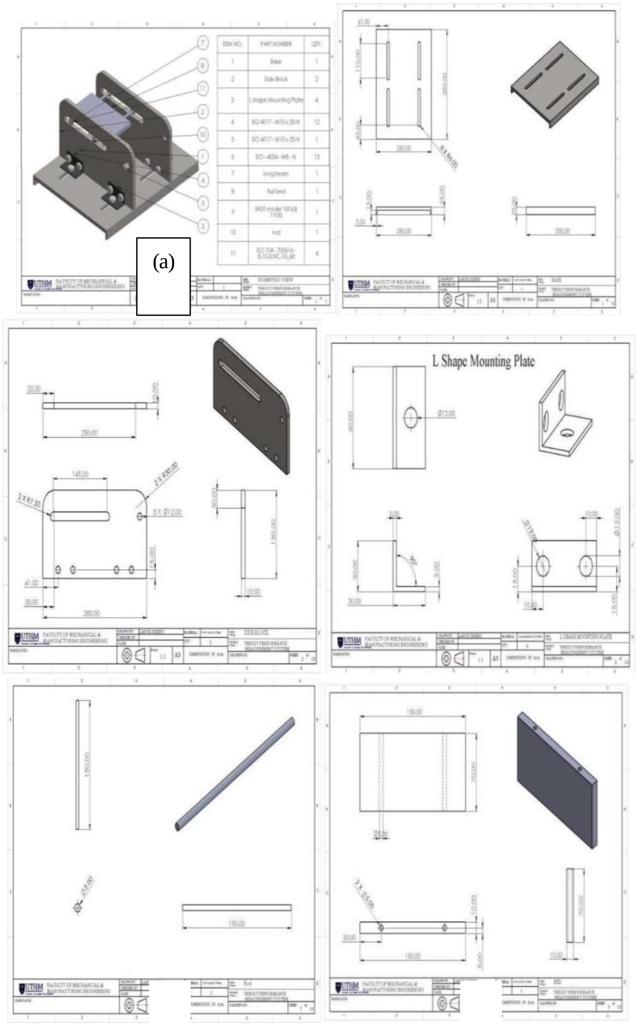

Fig. 5 - (a) BOM diagram of the model, (b) Base, (c) Side block, (d) L Shape Mounting Plate, (e) Rod, (f) Flat Bed

3.2 Run the Simulation

The software used to run the simulation is Solidworks. Simulation is performed to test the material specifications and determine the optimal material for constructing a model that provides stability and high safety levels. The simulation includes static analysis, which involves conducting stress, strain, and displacement tests to gather relevant data.

3.2.1 **Stess Test**

A stress test is performed as part of the static simulation to assess the structural integrity and behavior of the design or component under different loading scenarios. It involves applying specific loads to the model and analyzing the resulting stresses and deformations. The stress test helps determine how the design can support and distribute the applied loads without experiencing time-dependent effects. It aids in evaluating safety criteria, identifying potential weak areas, and optimizing the design for optimal performance and strength.

3.2.2 **Strain Test**

A strain test is conducted in static simulation to evaluate the deformation and strain properties of the design or component under applied loads. It predicts how the material of the design will deform and stretch in response to the specified loading conditions. The strain test provides essential information about deformation patterns, maximum strain values, and potential failure points or regions of excessive deformation. This data is crucial for ensuring that the design can withstand the anticipated loads and meet the required performance criteria.

3.2.3 **Displacement Test**

A displacement test is a specific type of study performed in static simulation to analyze the displacements or movements of the design or component under applied stresses. The goal is to determine the extent to which the design will deform and shift under the specified loading conditions. The displacement test provides valuable information about the overall deformation and movement of the design, aiding in understanding its response to applied forces and identifying potential interference issues or clearance requirements.

4. Results and Discussion

4.1 Part Layout

The finalize model once assemble with the parts is shown in Figure 5. On the other hand Table 2 Shows the part and its function.

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Table 2 - Part and its function

Part	Function
Base	Provides physical support
Side block	Attach with holder
L shape mounting plate	Make side block attach firmly with base.
Flat Bed	Provides a flat surface on which to place a micro gas turbine model
Rod	Function as support for the flat bed and share the load received
Ball bearing (ISO 1224 - 171015)	To connect two machine members that move relative to one another in such a manner that the frictional resistance to motion is minimal
Hex Bolt Grade AB ISO 4017	To fasten and assemble parts from within aligned unthreaded holes
Grae C ISO 4034	Used in conjunction with a mating bolt to fasten multiple parts together.

4.2 Model Design

In this part, the designed model is shown in Figure 6 below in different views.

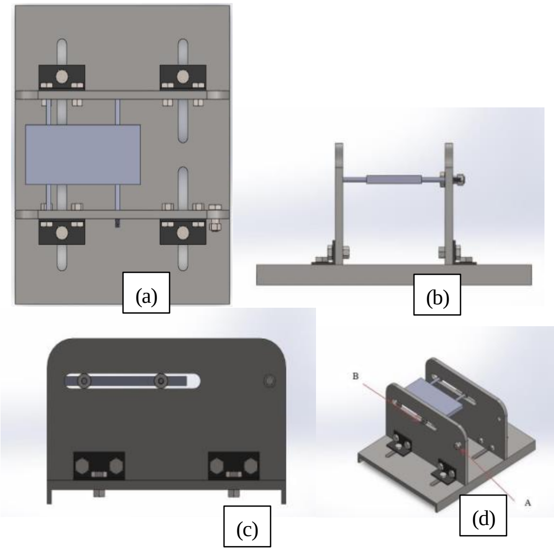

Fig. 6 - (a) Top View, (b) Front View, (c) Side View, (d) Isometric View

The final design of the thrust measurement device system includes a two-sided block attached to the base, supported by an L-shaped mounting plate. The main bed is suspended between the blocks using poles and ball bearings to minimize friction. A portable electronic scale is used to measure the thrust, with one end connected to point A and the other end connected to point B. As the micro gas turbine advances, the displacement change at point B is detected by the electronic scale, providing an accurate reading of the thrust generated.

4.3 Material Test Results

The selection of materials for this project involved thorough testing to ensure their suitability, compliance with specifications, and safety when subjected to the weight and forces of the micro gas turbine. The materials considered were plain carbon steel, cast alloy steel, malleable cast iron, and 1060 aluminum alloy. To evaluate their performance, static simulation was conducted on a built-in model. The simulation included stress tests, strain tests, and displacement tests, all subjected to a constant applied force of 137 Newton.

4.3.1 Results of Stress Test

After conducting the stress test in the simulation, the results were analyzed and presented in Figure 7. The findings indicate that malleable cast iron exhibited the highest yield strength among the tested materials, with a value of 2.725e+08 N/m2. It was followed by cast alloy steel, plain carbon steel, and 1060 aluminium alloy, which had the lowest yield strength. In terms of stress levels, malleable cast iron demonstrated the highest resistance to deformation and the ability to sustain applied loads without failure. These results highlight the superior strength and load-bearing capabilities of malleable cast iron compared to the other materials in the study.

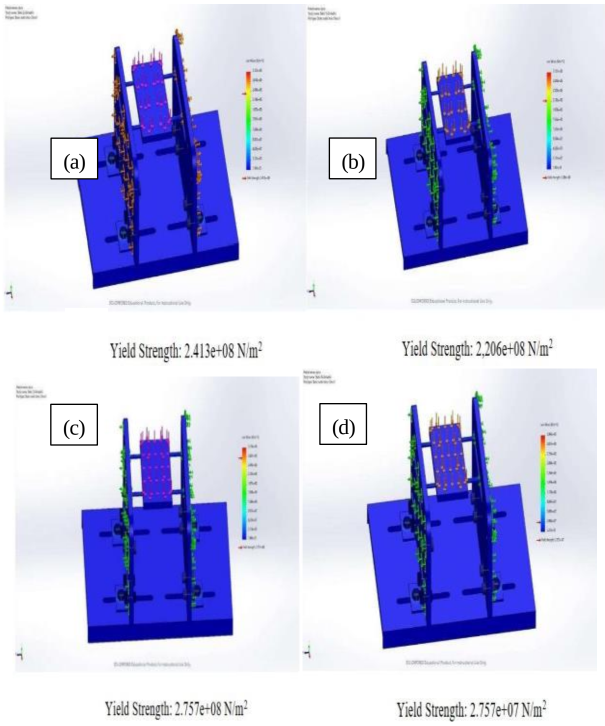

Fig. 7 - (a) Plain Carbon Steel, (b) Cast Alloy Steel, (c) Malleable Cast Iron, (d) 1060 Aluminium Alloy

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4.3.2 **Results of Strain Test**

Upon completing the simulation, a strain test was conducted to evaluate the behavior of the materials. High levels of equivalent strain indicate that a material is approaching failure or exhibiting unstable behavior, potentially leading to deformation or breakage. According to Figure 8, plain carbon steel exhibited the lowest equivalent strain value at 9.552e-04, followed by cast alloy steel and malleable cast iron. The highest equivalent strain was observed in 1060 aluminium alloy. This suggests that 1060 aluminium alloy reached its failure threshold and displayed indications of instability more rapidly compared to the other tested materials. The results highlight the relative strengths and limitations of each material in terms of their ability to withstand strain and deformation.

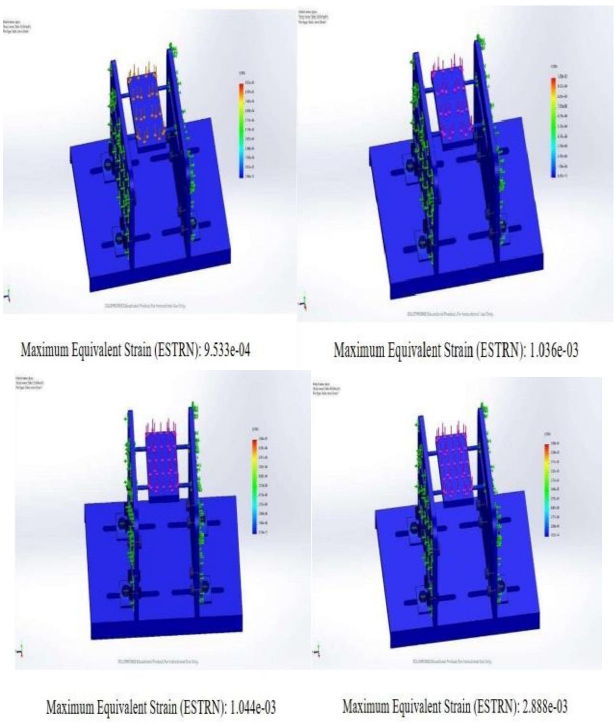

Fig. 8 - (a) Plain Carbon Steel, (b) Cast Alloy Steel, (c) Malleable Cast Iron, (d) 1060 Aluminium Alloy

4.3.3 **Results of Displacement Test**

Upon completion of the simulation, the results of a displacement test were obtained to assess the flexibility and deformation capabilities of the materials. A higher displacement value suggests that a material is more flexible and can undergo significant deformation when subjected to applied stresses. According to Figure 9, the displacement of 1060 aluminium alloy was the highest, measuring 2.454e- 02 mm. It was followed by the displacements of cast alloy steel, malleable cast iron, and plain carbon steel, which had lower displacements. The 1060 aluminium alloy reached its failure threshold and exhibited signs of instability at a faster rate compared to the other tested materials. Since the 1060 aluminium alloy experienced the highest displacement during the test, it can be inferred that it underwent the greatest amount of deformation or displacement compared to the other materials under similar conditions. This indicates that the 1060 aluminium alloy has a higher degree of flexibility and can sustain considerable deformation.

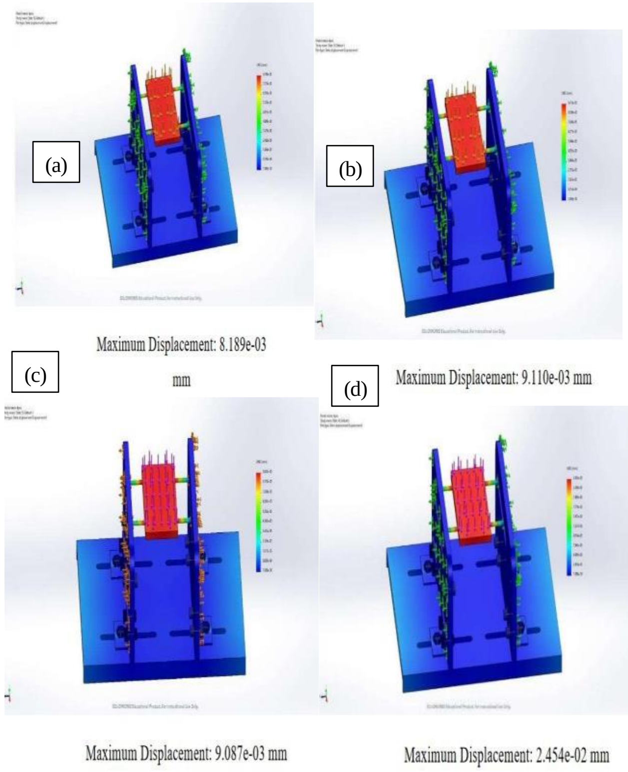

Fig. 9 - (a) Plain Carbon Steel, (b) Cast Alloy Steel, (c) Malleable Cast Iron, (d) 1060 Aluminium Alloy

4.4 **Summary Results**

Table 3 provides a comparison of the yield strength, maximum equivalent strain, and maximum displacement for the four tested materials. The ideal material for the model parameter characteristics would have high yield strength, low equivalent strain, and low displacement. Among the tested materials, malleable cast iron exhibited the highest yield strength, moderate equivalent strain, and second-lowest displacement. While it did not meet the most ideal parameter requirements, malleable cast iron demonstrated the most comprehensive performance compared to the other materials tested.

Table 3 - Comparison of static simulation test result

Material	Yield Strength (N/m^2)	Maximum Equivalent Strain	Maximum Displacement (mm)
Plain Carbon Steel	2.206e+08	9.552e04	8.199e-03
Cast Alloy Steel	2.413e+08	1.036e-03	9.110e-03
Malleable Cast Iron	2.757e+08	1.044e-03	9.087e-03
1060 Aluminium Alloy	2.757e+07	2.888e-03	2.454e-02

5. Conclusion

In conclusion, the project focuses on the development of a reliable and practical thrust measurement device system for micro gas turbines. The use of malleable cast iron as the material for crucial components enhances the system's safety, robustness, and durability. Through careful design analysis and material selection, the resulting system provides real-time measurements while withstanding the demands of its operational environment.

However, there are still opportunities for further development and improved performance. Recommendations include utilizing malleable cast iron for key components, integrating a high-quality load cell, designing a sturdy mounting and suspension mechanism, implementing reliable signal conditioning, conducting thorough calibration and validation procedures, ensuring seamless system integration and compatibility, incorporating a robust data acquisition system, and prioritizing safety throughout the design process.

Overall, the creation of this thrust-measuring device system significantly advances our knowledge and utilization of small-scale propulsion systems. It opens up new avenues for research, development, and innovation in the field of micro gas turbine technology, contributing to advancements in aeronautical engineering.

Acknowledgement

The authors would like to thank the Ministry of Education Malaysia for supporting this research under the Fundamental Research Grant Scheme No. FRGS/1/2019/TK10/UTHM/02/7 Vot K218, GPPS U749 and partially sponsored by Universiti Tun Hussein Onn Malaysia.

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