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COMPARATIVE SIMULATION ANALYSIS OF AEROSTATIC THRUST BEARING AND ORIFICE-TYPE AEROSTATIC THRUST BEARING

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Article Info

Abstract

This research presents a comprehensive numerical simulation study comparing the performance of porous-type and orifice-type aerostatic thrust bearings using ANSYS Fluent. Detailed 3D CAD models were developed to reflect realistic geometries, followed by high-quality meshing and parameterized simulations under varying air film thicknesses, restrictor configurations, and supply pressures. The study evaluates key performance metrics including axial load capacity, stiffness, and mass flow rate across both bearing types. Results show that porous-type bearings offer more uniform pressure distribution and better stiffness characteristics at lower film thicknesses, making them suitable for precision applications. Orifice-type bearings, on the other hand, demonstrated faster pressure buildup but higher air consumption, indicating lower energy efficiency. A mesh independence study ensured numerical accuracy, while comparative analysis highlighted the tradeoffs between performance stability and energy usage. This simulation-based investigation provides valuable insights into optimal bearing selection and design for high-precision mechanical systems.

Keywords: *Aerostatic thrust bearing; Computational Fluid Dynamic Study; Dynamic Stiffness and Damping; Mass Flow Rate; Precision Engineering.*

1. Introduction

Aerostatic thrust bearings are a category of gas-lubricated bearings that utilize an externally supplied, high-pressure gas most commonly air to generate a supporting film between two surfaces that do not make physical contact. In contrast to hydrodynamic or rolling-element bearings that depend on relative motion to create a load-bearing film, aerostatic bearings use an external pressure source and a flow restrictor to sustain a constant air film even when stationary.

Aerostatic thrust bearings offer several notable advantages, including minimal friction losses, exceptional rotational accuracy, and wear-free operation, as they do not rely on traditional oil-based lubrication. These characteristics make them highly suitable for demanding, high-precision environments. As a result, they are commonly used in ultra-precision applications such as high-speed CNC spindles, semiconductor manufacturing equipment, coordinate measuring machines (CMMs), aerospace gyroscopes, and systems requiring precise micro-machining or optical alignment.

Aerostatic bearings operate by introducing compressed air into the gap between two surfaces through a flow-restricting element. This restrictor, which may be porous or orifice-based, controls the airflow and generates pressure within the gap, creating a thin air film that supports the applied load without direct surface contact. The primary components of this system include the thrust or bearing surface, the restrictor, and an external source of pressurized air. The performance of the bearing, particularly its load capacity and stiffness, is strongly influenced by several factors. These include the air supply pressure, the type and configuration of the restrictor, the thickness of the air film, and the overall geometry of the bearing. Optimizing these parameters is essential for achieving efficient and stable operation

Restrictors are critical components in aerostatic bearings, as they play a defining role in regulating pressure and ensuring the stability of the air film that supports the load. The type and configuration of the restrictor directly influence the bearing's performance characteristics, such as load capacity, stiffness, and air consumption. Aerostatic bearings are generally classified into two main types based on the restrictor design: orifice-type and porous-type aerostatic bearings. Each type offers distinct advantages and limitations in terms of pressure distribution, flow control, and operational efficiency. This study specifically focuses on evaluating and comparing the performance of these two bearing configurations in thrust bearing applications, where axial load support and stability are critical for reliable operation.

Orifice-type aerostatic thrust bearings function by incorporating a series of precisely machined micro-holes, or orifices, distributed across the bearing surface. These orifices act as flow restrictors, controlling the entry of compressed air into the bearing gap and establishing a stable pressure field that supports axial loads. The performance of these bearings is heavily influenced by the number, size, and spatial distribution of the orifices, as these factors directly affect stiffness, pressure uniformity, and overall flow behavior.

One of the main advantages of orifice-type bearings is their relatively simple and cost-effective manufacturing process. Additionally, they allow for easier control of airflow through individual orifices and can deliver high stiffness when properly optimized. However, these bearings also present some limitations. Due to the small diameter of the orifices, there is a higher risk of clogging, which can disrupt performance. In some cases, non-uniform airflow may lead to uneven pressure zones across the bearing surface. Moreover, achieving consistent and optimal performance in aerostatic thrust bearings requires high-precision machining and a superior surface finish to maintain uniform air film thickness and minimize flow disturbances. Even slight deviations in geometry or surface texture can lead to performance degradation, such as uneven pressure distribution or reduced load capacity.

A porous-type aerostatic thrust bearing is a high-precision, non-contact bearing that evenly distributes compressed air across its surface using a porous restrictor material, such as ceramics or sintered bronze. A thin, even layer of air is formed between the moving surface and the bearing when pressurized air is introduced and passes through the restrictor's interconnected pores. By removing direct contact and supporting axial loads, this air film lowers wear and friction. This bearing type's uniform pressure distribution, which offers high stiffness and exceptional stability, particularly in static applications, is one of its main advantages. Additionally, the porous structure aids in controlling air flow without creating pressure spikes or turbulence. To maintain performance, though, a clean air supply and high manufacturing precision are needed.

The problems that are needed to identify and address are the challenges encountered during the simulation and modeling of aerostatic thrust bearings and orifice-type aerostatic thrust bearings. Specifically, the study will focus on issues such as mesh generation for complex geometries, convergence problems in CFD simulations, sensitivity to boundary conditions, and the accurate representation of air compressibility and flow characteristics. By systematically analyzing these challenges, the research aims to develop robust simulation methodologies that ensure accurate and reliable comparisons of load-bearing capacity, stiffness, and mass flow rate between the two bearing types. The findings will provide insights into overcoming modeling limitations and improving the fidelity of simulation-based design optimization for aerostatic thrust bearings in precision engineering applications.

The objective is to create an accurate 3D CAD model of both porous-type and orifice-type aerostatic thrust bearings that closely match real-world designs. These models included important details like the placement of orifices and porous zones to make sure that the simulations would be accurate in terms of structure and size. We looked at three important performance metrics axial load capacity, stiffness, and mass flow rate to see how stable and efficient each type of bearing was. The maximum vertical force that can be supported without physical contact is called the axial load capacity. The stiffness of the system shows how resistant it is to movement, and the mass flow rate shows how much air it uses and how energy-efficient it is. We performed a full parametric analysis to find out how changes in design and operation affect performance. The study looked at how changes in air film thickness, porous material thickness, and supply pressure affected pressure distribution, load support, and stiffness in the porous-type bearing. In the same way, we looked at how changes in air film thickness, orifice diameter, and supply pressure affected the flow behavior, load-carrying ability, and system stability of the orifice-type bearing. This all-encompassing approach made it possible to compare both bearing configurations in a wide range of operating conditions.

Aerostatic thrust bearings (ATBs) use a thin film of high-pressure gas to support loads between stationary and moving surfaces. They offer benefits like high precision, speed, and durability. ATBs are commonly used in spindles, precision machines, turbines, and drilling tools. With rising demand for accurate and efficient machining, improving ATB performance has become a key focus. This includes enhancing load capacity, stiffness, and stability [1].

In 2020, Muhammad Punhal Sahto investigates and compares the static characteristics specifically load-carrying capacity (LCC) and stiffness of three types of aerostatic thrust bearings: porous, orifice, and multiple orifice restrictors. The authors utilized computational fluid dynamics (CFD) simulations based on Navier-Stokes equations, along with experimental validation for porous bearings, to analyze how material and geometrical parameters influence bearing performance. Key findings indicate that multiple orifice restrictors generally offer superior LCC, especially at smaller air film thicknesses, while porous restrictors often provide greater stiffness [2].

In 2019, Qiang Gao carried out research that provides a comprehensive state-of-the-art review of aerostatic bearings, which are essential components in precision engineering applications due to their ability to support moving parts with a pressurized air film. The authors detail the historical development and widespread adoption of these bearings across various industries, highlighting their advantages in terms of motion accuracy, low friction, and minimal pollution compared to traditional options. The core focus of the paper is on the analytical and computational methods used for designing and optimizing aerostatic bearing performance, including discussions on static and dynamic characteristics, and challenges like micro-vibration. Ultimately, the paper aims to present a systematic overview of current research and future trends, emphasizing the need for a deeper understanding of underlying design principles to further enhance their capabilities [3].

In 2022. Authored by Yuntang Li from China Jiliang University, the research proposes an aerostatic thrust bearing incorporating both multi-orifice and porous material restrictors**.** The authors utilize Computational Fluid Dynamic (CFD) simulation to evaluate the bearing's Load Carrying Capacity (LCC) and stiffness**,** analyzing how various parameters affect its performance. Findings indicate that the compound restrictor design significantly enhances LCC and stiffness compared to bearings using only one type of restrictor, while also offering improved stability. The article concludes by suggesting optimal parameters to enhance the bearing's overall effectiveness [4].

In 2025, Guoda Chen and Zhaoshou Chen from Zhejiang University of Technology, propose this new bearing design to improve the stiffness and active control of aerostatic bearings, which are crucial for ultra-precision machinery. Unlike traditional fixed-orifice bearings, the VOR bearing uses an elastic structure to adjust the throttling area. The research includes fluid-solid coupling models, simulations, and experimental validation with a prototype, demonstrating significant performance enhancements and enabling active control capabilities for such bearings [5].

In 2025, Jiang Zheng introduces a novel analytical model for aerostatic thrust bearings, focusing on improving the accuracy of performance prediction. The authors address the common issue of overestimating bearing capacity and stiffness by proposing to use the average pressure within the area surrounded by the orifice, rather than the traditional pressure behind the orifice, for calculations. Through computational dynamics (CFD) simulations and experimental validation, the study explores how various structural parameters and gas supply pressure influence this average pressure. The research culminates in an approximate expression for the average pressure coefficient, which provides a more precise and efficient tool for the engineering design of rectangular aerostatic thrust bearings, particularly for high-precision applications like lithography machines [6].

In 2021, Muhammad Punhal Sahto investigates the dynamic performance of aerostatic thrust bearings, specifically focusing on how different orifice designs partial porous multiple orifice and porous types impact their stiffness and stability under vibration. The authors employ Computational Fluid Dynamics

(CFD) simulations using FLUENT software to analyze the intricate fluid flow and pressure distribution within these bearings. Key findings highlight that while the number of orifices mainly affects static load capacity, the radius and height of these orifices significantly influence dynamic stiffness and damping characteristics, crucial for the bearings overall stability and performance, especially across various perturbation frequencies [7].

In 2023, Puliang Yu research investigates novel aerostatic bearings featuring a primary and secondary orifice restrictor (PSOR), designed to address the challenge of simultaneously enhancing load-carrying capability (LCC) and mitigating undesirable nano-vibrations in ultra-precision manufacturing equipment. The study employs both numerical simulations, specifically large eddy simulation (LES) for analyzing turbulent flows, and experimental validation to examine how varying the diameter of the secondary orifices impacts the bearing's static and dynamic performance. A key finding reveals that optimizing the secondary orifice diameter can significantly improve LCC and reduce nano-vibrations, providing insights into the complex formation and interaction mechanisms of turbulent vortices within these systems. Ultimately, the paper demonstrates the effectiveness of the PSOR design in enhancing the stability and performance of aerostatic bearings [8].

In 2021, Qiang Gao introduces an efficient Finite Element Method (FEM) based modeling technique for analyzing the performance of aerostatic thrust bearings. The core innovation lies in its ability to account for the fluid-structure interaction (FSI) phenomenon, where the deformation of the solid bearing structure due to air pressure significantly impacts its performance. Unlike previous computationally intensive methods, this new approach reduces calculation time dramatically by using FEM for both the bearing and thrust plate models, alongside a refined discharge coefficient model. The research aims to provide a highly accurate and efficient design tool for aerostatic thrust bearings in applications where precision and performance are critical [9].

In 2022, Yangong Wu introduces and validates a simplified calculation method for predicting the static performance of aerostatic journal bearings equipped with multiple orifice-type restrictors. The authors highlight this method's utility for fast calculation and engineering design, directly linking structural and performance parameters through nonlinear equations. Unlike more complex numerical approaches like Computational Fluid Dynamics (CFD), which are time-consuming, this simplified method offers a more intuitive and efficient way to analyze bearing performance, making it highly valuable for the early stages of engineering design. The study verifies its accuracy against CFD data using real-world spindle examples, showing a less than 10% deviation in load-carrying capacity (LCC), and also investigates the influence of a key parameter, on bearing characteristics like stiffness and mass flow rate [10].

In 2025, Tayeb Trari investigates the performance of aerostatic thrust bearings under high rotational speeds, focusing on how different orifice chamber geometries and air film thicknesses impact pressure distribution, load capacity, and stiffness. Using a three-dimensional CFD model, the study numerically analyzes the fluid dynamics within the bearing, validating its findings against experimental data. The authors conclude that chamber geometry significantly influences lubrication effectiveness and that load capacity generally decreases with increasing rotational speed and air film thickness. The paper ultimately aims to optimize aerostatic bearing design for enhanced operational stability and performance [11].

In 2025, Lu Zheng introduces a novel compound restrictor aerostatic bearing system that significantly improves upon conventional designs. The paper, published in Tribology International, details the design, analysis, and implementation of a bearing that integrates orifice, radial groove, and circumferential groove restrictors. Through numerical simulations and experimental validation, the authors demonstrate that this new design enhances load capacity by over 51% and stiffness by more than 55%, while also mitigating issues like vortex-induced micro-vibrations and improving stability. The findings highlight a promising advancement for ultra-precision instruments requiring high stability and load-bearing capabilities, addressing limitations of existing aerostatic bearing technologies [12].

In 2025, Li Yifei introduces the shape optimization of aerostatic bearings to enhance their dynamic performance and operational stability. The authors investigate how the air pocket's design influences harmful phenomena like micro-vibration and pneumatic hammering, linking these two factors such as vortex flow and supersonic regions within the bearing's air film. A key aspect of their optimization involves maximizing the displacement impedance, which signifies the bearing's ability to resist external dynamic loads. Ultimately, the study aims to achieve a balanced design that improves both static and dynamic characteristics, recommending a cylindrical pocket with a tapered inlet as the optimal configuration for enhanced performance [13].

In 2022, Hui Zhuang introduce a more accurate dynamic modeling approach for aerostatic thrust bearings, particularly addressing the challenge of frequency-dependent stiffness and damping in their air film. This improved model and aims to provide a reliable method for vibration analysis in these bearing systems, which are crucial components in various mechanical equipment, by considering how different frequencies of external forces influence the air film's behavior [14].

In 2025, Siyu Gao investigates the performance of micro-hole high-speed aerostatic thrust bearings using the finite element method (FEM). It highlights the advantages of micro-hole designs over traditional orifice restrictors, such as improved load capacity, stiffness, and stability. The study examines various factors affecting performance, including restrictor types, micro-hole layouts, structural parameters, and the impact of centrifugal deformation at high rotational speeds. The methodology involves solving the Reynolds equation and validating the computational models against experimental data, providing a theoretical foundation for designing high-speed aerostatic spindles [15].

In 2023, Bivash Chakraborty and Dr. Prasun Chakraborti, conducted a state-of-the-art review of advancements and research in this field, emphasizing the growing reliance on computational methods for optimization. Ultimately, the paper analyzes future research directions and development trends, highlighting the importance of these bearings in tools requiring extreme precision, such as lathes and CMMs, due to their ability to minimize errors and production time [16].

In 2021, Abdurrahim Dal and Tuncay Karaçay investigates the impact of manufacturing errors or foreign materials, specifically partially blocked orifices, on the performance of aerostatic journal bearings. The authors utilized a numerical model to analyze airflow and predict changes in the bearing's force and stiffness due to varying blockage ratios and positions. This study highlights how such blockages can significantly alter the system's performance, either positively or negatively, depending on the specific conditions [17].

In 2022, Gouda Chen investigate how single-orifice blockage (SOB) and double-orifice blockage (DOB) impact bearing performance, including air film pressure distribution, load capacity, and tilting moment.

Their study combines theoretical analysis and experimental verification, ultimately proposing a method to predict orifice blockage based on the bearing's tilting direction and angle [18].

In 2011, Guido Belforte investigated how a circumferential groove impacts pressure distribution, air consumption, and stiffness in these bearings, which are crucial for precision movements and high-speed rotations. They conducted experimental measurements and numerical simulations, validating their computational model against real-world data. The study highlights the importance of the supply holes' discharge coefficient, even with grooves, contributing to the understanding and design of advanced air bearing technology [19].

In 2024, Ning Gou, Kai Cheng, and Dehong Huo, comprehensively review the historical progression and current advancements in the design and analysis of aerostatic bearings, highlighting their benefits in precision engineering. The article identifies ongoing challenges in air-bearing development and discusses future research directions and applications. It functions as a critical review of the field, supported by an extensive list of references [20].

In 2018, Verstraaten investigated the stiffness and load-carrying capacity of both flat and indented air bearings, concluding that indented designs offered superior advantages in both areas. The study utilized custom meshing software to accurately represent the air bearing geometry, with simulations performed using Open FOAM [21].

In 2005, J. P. Khatait aimed to create a simple design methodology and analytical tools for these bearings, moving beyond overly complex existing formulations. They achieved this by conducting an analytical study, performing Computational Fluid Dynamics (CFD) simulations, and constructing an experimental setup to validate their theoretical findings. The research highlights the impact of parameters like orifice diameter, supply pressure, and bearing diameter on load capacity and stiffness, ultimately providing a practical framework for designing high-performance, cost-effective aerostatic bearings [22].

In 2024, Lei An, research investigates how structural parameters, such as orifice diameter and bearing clearance, influence the dynamic properties of these bearings, particularly at high speeds. The authors employed a coupled numerical solution combining equations for gas film pressure, spindle motion, and flow balance, revealing that changes in these parameters lead to various periodic and quasi-periodic motions within the system. Ultimately, this study aims to contribute to the optimization of aerostatic journal bearing design for enhanced performance [23].

In 2024, Karan Singh Jamwal, investigate the impact of surface roughness on both thrust and journal bearings. Their work includes experimental determination of how different finishing methods—machining, grinding, and magnetorheological finishing—affect load capacity. The study highlights the importance of surface finish in enhancing the overall functional efficiency of these critical components in various industries [24].

In 2016, Cui Hailong, propose a two-way fluid-structure interaction numerical simulation model based on fluid and solid mechanics. Their research focuses on optimizing the bearing's design parameters to enhance load capacity, stiffness, and dynamic stability by mitigating gas redundancy. Experimental validation confirms the accuracy of their numerical simulation methods and the effectiveness of their optimization approach in significantly improving the aerostatic spindle's performance [25].

In 2020, Yueqing Zheng, Guangwei Yang, Hailong Cui, and Yu Hou, focuses on enhancing the stiffness of aerostatic bearings. The authors propose a novel multi-orifice series restrictor to improve restriction effects, thereby increasing bearing stiffness, and they validate their findings numerically and experimentally. The publication details indicate it was first published online in January 2020 and includes access options, citation information, and related research articles [26].

In 2021, Ashutosh Patel and Pramod Kumar from the Indian Institute of Science, Bangalore, numerically evaluates the load capacity and stiffness of a six-feed hole orifice type aerostatic thrust bearing using ANSYS FLUENT code. It investigates the optimum orifice location, the effect of orifice geometry, and the impact of clearance height and rotational speed on bearing performance. The document also provides publication details such as ISBN, ISSN, and pricing for access, alongside language options for the conference proceedings [27].

In 2005, Chyang Renn and Jia-Feng Yang, highlights a discrepancy between conventional models and actual gas flow characteristics in these systems. Through CFD simulations and experiments, the authors demonstrate that the mass flow-rate through orifice-type restrictors differs significantly from that through an ideal nozzle, suggesting the need for their new, more precise model to enhance the design and modeling of gas-lubricated aerostatic bearings [28].

2. Methodology

2.1 Research Approach

The study is based on a quantitative simulation-based approach, relying on finite volume method (FVM)-based CFD techniques. Instead of relying on physical experimentation, this numerical method offers cost-effective and accurate predictions of performance parameters under various operating conditions.

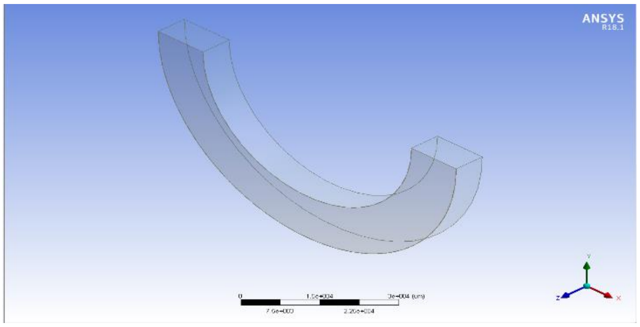
Characteristics of the Approach: Comparative performance analysis under identical operating conditions, Steady-state laminar flow simulations, Parametric studies for sensitivity analysis, Controlled and idealized environmental modeling, Axisymmetric and full 3D simulations for realism and accuracy.

2.2 Modeling and Geometry Creation

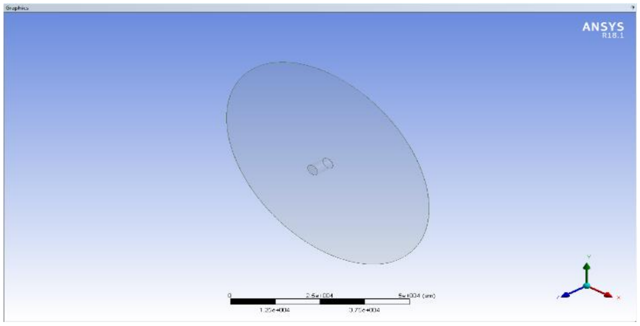
The design models for both the porous-type and orifice-type aerostatic thrust bearings were carefully developed using ANSYS, ensuring high geometrical precision and adherence to real-world design specifications. The porous-type aerostatic thrust bearing includes a porous restrictor positioned between the plenum chamber and the bearing surface. This configuration promotes a uniform pressure distribution across the bearing surface and helps reduce flow instability, which is crucial for maintaining consistent load support. Depending on the level of detail required, this bearing can be modeled either as an axisymmetric geometry to simplify the analysis and reduce computational cost, or as a full 3D model to capture more complex flow behaviors and structural details.

On the other hand, the orifice-type aerostatic thrust bearing consists of single small orifices, around the bearing surface. This orifice act as precise flow restrictors, allowing compressed air to enter the gap between the bearing and the moving surface through a central plenum. The flat bearing surface and symmetrical orifice arrangement contribute to a balanced pressure distribution.

For both bearing types the important design parameters we used are air film thickness (evaluated at different values from 4.5 to 23.5 µm), orifice diameters (commonly 3 mm, 4mm, 5mm, 6mm), and porous restrictor thickness (e.g., 8mm, 7mm, 5mm, 4 mm). These parameters were selected to reflect realistic operating conditions and to enable a detailed investigation into how geometrical and structural changes influence the performance characteristics of each bearing type. The modelling of both porous and orifice-type aerostatic thrust bearing is shown in Figure 1.



(a) Porous



(b) Orifice

Figure 1. Model and geometry of porous and orifice-type aerostatic thrust bearing

2.2.1 Reynolds Equation for Compressible Air Flow

Used to describe the pressure distribution in the air film of the bearing as governed by Eq. (1).

$$\frac{\partial}{\partial x}\left(\frac{\rho h^3}{12\mu}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\rho h^3}{12\mu}\frac{\partial p}{\partial y}\right)=\frac{\partial(\rho h)}{\partial t} \quad (1)$$

The key parameters include air density (ρ), air film thickness (h), dynamic viscosity (µ), pressure (p), and time (t). These variables are fundamental in governing the behavior of the air film and influence the bearing's load-carrying capacity, pressure distribution, and overall performance under varying operating conditions.

2.2.2 Mass Flow Rate Equation

The mass flow rate through the orifice-type restrictor is determined using Eq. (2).

$$\text{m} = C_d A_o p_0 \sqrt{\frac{2\gamma}{RT(\gamma-1)}\left[\left(\frac{p}{p_0}\right)^{\frac{2}{\gamma}} - \left(\frac{p}{p_0}\right)^{\frac{\gamma+1}{\gamma}}\right]} \quad (2)$$

In the analysis of orifice-type aerostatic thrust bearings, important parameters include the mass flow rate (ṁ), discharge coefficient (C_d), orifice area (A_o), supply pressure (p_0), and film pressure (p). Additionally, the specific heat ratio of air (γ) and the gas constant ® are essential for describing the compressible airflow through the orifices, which directly affects the pressure distribution and performance of the bearing system.

2.2.3 Load Capacity Equation

The vertical load supported by the air film is calculated using Eq. (3).

$$W = \iint p(x, y)\, dx\, dy \quad (3)$$

The load capacity (W) of an aerostatic thrust bearing is determined by the pressure distribution p(x, y) over the bearing surface. This distribution influences the bearing's ability to support external loads uniformly and stably.

3.2.4 Stiffness Equation

The static stiffness of the bearing is defined by Eq. (4).

$$K = \frac{\Delta W}{\Delta h} \quad (4)$$

Stiffness (K) in an aerostatic thrust bearing is defined as the ratio of the change in load (Δh) to the corresponding change in air film thickness (Δh). It indicates the bearing's resistance to deflection under varying load conditions and is a key factor in its dynamic stability.

3.2.5 Non-Dimensional Reynolds Equation

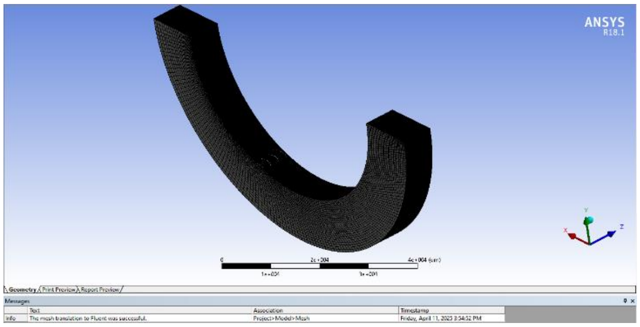
For numerical simulations, the non-dimensional Reynolds equation is employed to simplify the governing calculations, as given in Eq. (5).

$$\frac{\partial}{\partial \bar{x}}\left(\bar{h}^3 \frac{\partial \bar{p}}{\partial \bar{x}}\right) + \frac{\partial}{\partial \bar{y}}\left(\bar{h}^3 \frac{\partial \bar{p}}{\partial \bar{y}}\right) = 12\frac{\partial(\bar{p}\bar{h})}{\partial \bar{t}} \quad (5)$$

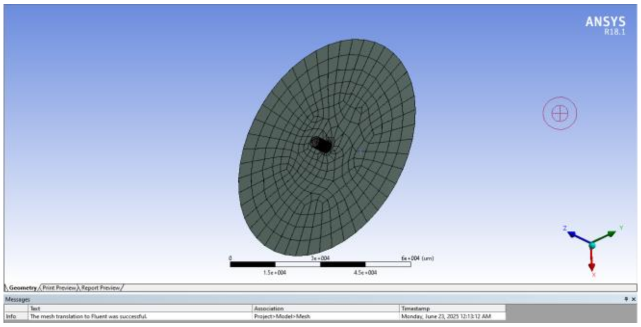
This non-dimensional form of the Reynolds equation is commonly used in numerical simulations to simplify computations and enhance generality. The barred terms represent normalized variables, allowing easier comparison across different operating conditions.

2.3 Meshing

A fine and high-quality mesh was generated using the ANSYS Meshing Tool to ensure accurate simulation results and numerical stability. Depending on the complexity of the geometry, either a structured or unstructured mesh was employed. Special attention was given to critical regions such as the narrow air film gap, orifice holes, and porous restrictor areas, where a finer mesh was applied to capture sharp gradients in pressure and velocity. To accurately resolve boundary layer effects and improve solution accuracy near solid surfaces, inflation layers were introduced adjacent to the walls. Additionally, a mesh independence study was performed by incrementally refining the mesh density and analyzing the simulation results. The process was continued until further mesh refinement resulted in negligible changes in output parameters, confirming the mesh quality was sufficient for reliable simulation as shown in Figure 2.



(c) Porous

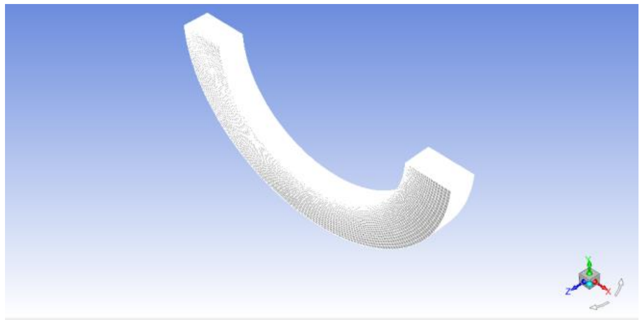


(d) Orifice

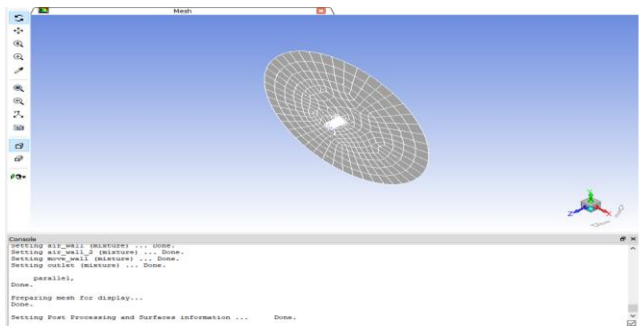
Figure 1. Mesh model of aerostatic thrust bearing

2.4 Simulation Setup in ANSYS Fluent

Boundary conditions were applied such that the inlet pressure varied from 0.3 bar to 0.6 bar, while the outlet pressure was fixed at atmospheric pressure (1 bar) to simulate realistic discharge conditions. For the porous-type aerostatic thrust bearing**,** the porous region was defined using Darcy's Law, incorporating appropriate permeability and porosity values to model the resistance to flow within the material accurately. In the case of the orifice-type bearing, the orifice restrictors were either modeled using their actual geometric representation or by applying flow resistance models that replicate the pressure drop across the orifice accurately. This approach ensured a reliable simulation of the flow characteristics and performance parameters in both types of aerostatic thrust bearings as shown in Figure 3.



(e) Porous



(f) Orifice

Figure 3. Simulation setup of aerostatic thrust bearing

2.5 Parametric Study

In this study, three key parameters were systematically varied for each type of aerostatic thrust bearing to evaluate their impact on performance. For the porous-type bearing, the parameters included air film thickness ranging from 4.5 µm to 23.5 µm, porous layer thicknesses of 8 mm,7 mm, 5 mm, and 4 mm, and supply pressures of 0.3, 0.5, and 0.6 bar. Similarly, the orifice-type bearing was tested with the same range of air film thicknesses, orifice diameters of 3 mm, 4 mm, 5 mm, and 6 mm, and orifice height is 6mm and the same supply pressure levels. Each parameter variation was analyzed independently through simulations to identify performance trends and comparative behavior.

2.6 Output Parameters and Data Extraction

Post-simulation, the following parameters were extracted and analyzed: Here in post-simulation, the key performance parameters were extracted and analyzed, including pressure distribution through 2D contour and profile plots within the bearing gap, load-bearing capacity by integrating the pressure over the bearing surface area, stiffness from the slope of the load versus air film thickness curve, and mass flow rate measured at the outlet boundary. Post-processing tools like ANSYS CFD-Post and Microsoft Excel were used to visualize results.

2.7 Performance Comparison and Analysis

Results from both types of bearings were compared on the basis of static pressure profiles - Load-bearing capacity at different pressures and film thicknesses variation in stiffness with design parameters mass flow efficiency and energy losses

The results were interpreted to identify which bearing type offers better performance under varied design and operating parameters. Comparative graphs and trend analyses helped highlight the pros and cons of each design.

2.8 Tools and Software Used

The tools and software employed in this study and their corresponding purposes are presented in Table 1.

Table 1. Tools and Software Used

Tool	Purpose
ANSYS Design Modeler	Geometry modeling
ANSYS Meshing	Grid generation
ANSYS Fluent	CFD simulations
ANSYS CFD-Post	Post-processing and contour plots
Excel	Data analysis and graphing

This structured and comprehensive methodology ensures accurate simulation outcomes and a fair comparison between porous and orifice-based aerostatic thrust bearings.

3. Results and Discussion

3.1 Aerostatic Thrust Bearing (Porous-Type)

3.1.1 Load-Bearing Capacity

The porous-type aerostatic thrust bearing exhibits a relatively uniform pressure distribution across the bearing surface due to the even diffusion of air through the porous restrictor. This allows the bearing to generate a smooth and consistent load-carrying capacity.

As shown in Figure 4, 5 and 6 (0.3, 0.5 and 0.6 MPa) at 0.3 MPa, the load is lower across all film thickness values due to the limited supply pressure. However, when the pressure is increased to 0.5 MPa and 0.6 MPa, there is a significant improvement in the load capacity. This is because a higher-pressure gradient drives more air through the porous layer, increasing the force generated in the air film gap.

Furthermore, the results indicate that a reduction in the air film thickness significantly increases the load-carrying capability of the bearing. This is because a thinner air film allows for a steeper pressure gradient and minimizes the escape paths for air, effectively concentrating the pressure within a smaller volume. The resulting high-pressure zone provides greater support against the applied load. This inverse relationship between air film thickness and load capacity is in strong agreement with the theoretical principles governing aerostatic bearing behavior.

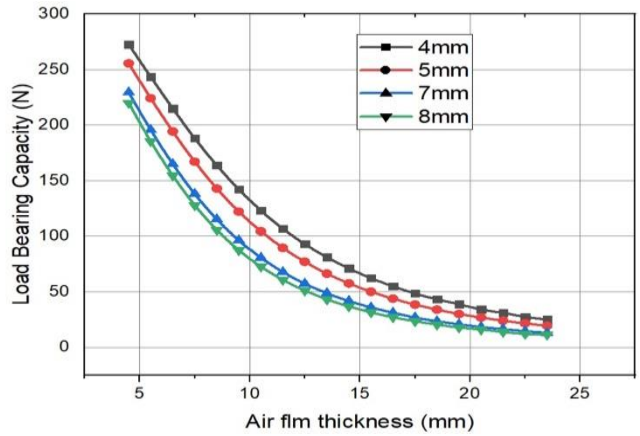


Figure 4. Load bearing capacity at 0.3 MPa

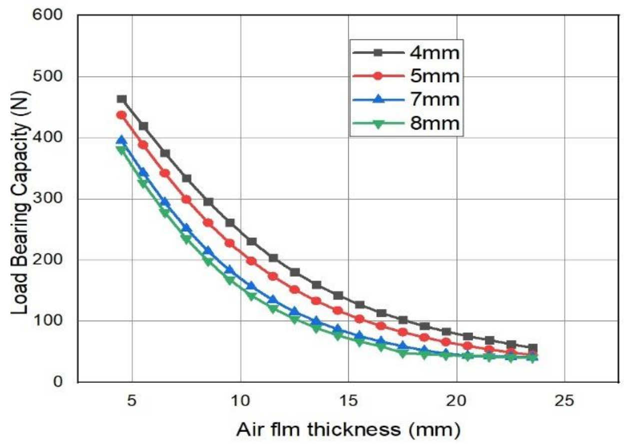


Figure 5. Load bearing capacity at 0.5 MPa

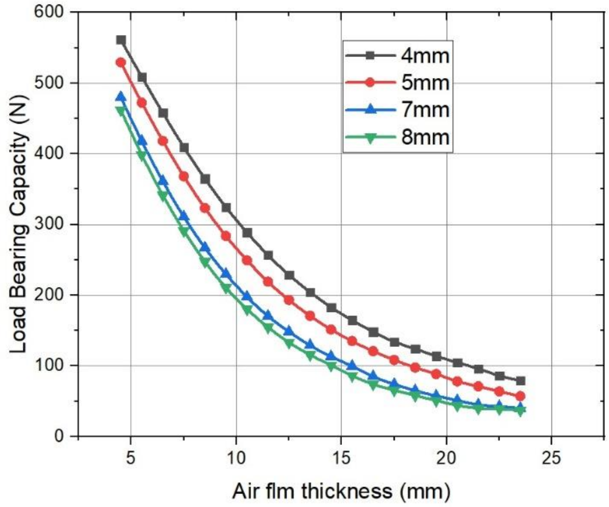


Figure 6. Load bearing capacity at 0.6 MPa

3.1.2 Stiffness

Stiffness is a key performance metric, particularly in precision applications. It is defined as the change in load per unit change in air film thickness. As shown in graph stiffness is highest at lower film thicknesses, where the compressibility of the air film is minimal and the pressure support is more concentrated.

At 0.3 MPa, the stiffness is relatively lower compared to higher pressure inputs. As the supply pressure increases to 0.5 MPa and 0.6 MPa as shown in Figure 7, 8 and 9, the stiffness improves substantially due to enhanced air pressure support and reduced deformation potential in the air gap. Overall, porous-type bearings demonstrate stable and predictable stiffness characteristics, especially under low film thickness, making them ideal for applications requiring precise axial positioning and vibration damping**.**

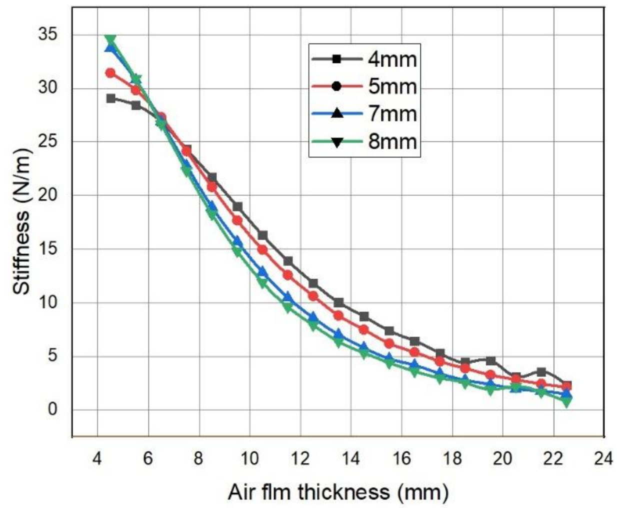


Figure 7. Stiffness at 0.3 MPa

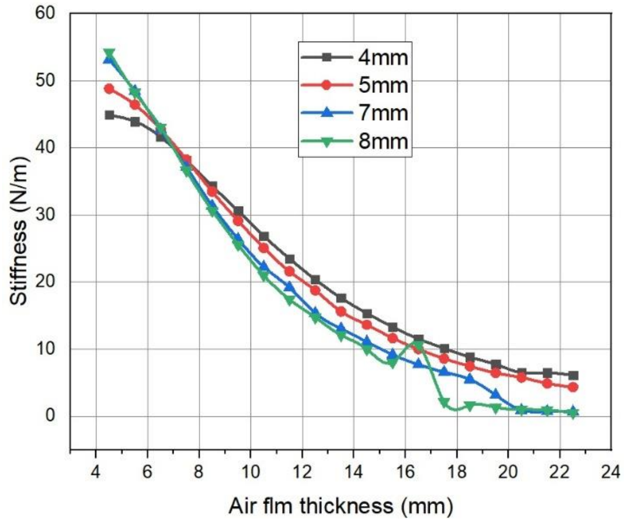


Figure 8. Stiffness at 0.5 MPa

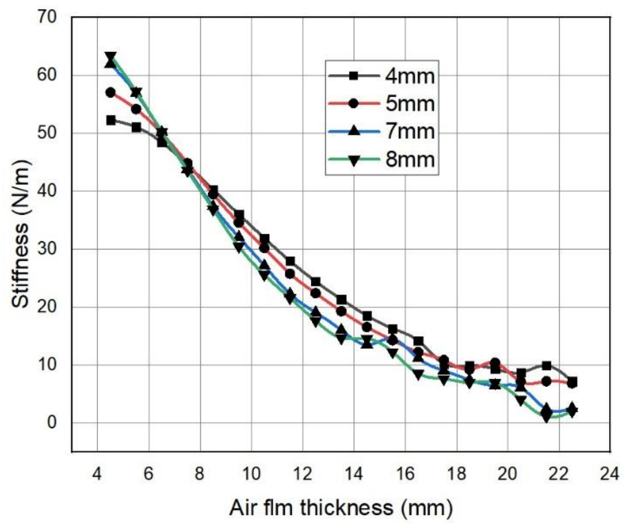


Figure 9. Stiffness at 0.6 MPa

3.1.3 Mass Flow Rate

Mass flow rate is a critical factor in determining the energy efficiency of a gas-lubricated system. In the case of porous-type bearings as shown in Figure 10, 11 and 12 (0.3, 0.5 and 0.6 MPa), where Graph illustrate that the mass flow rate increases with both higher supply pressure and larger film thickness.

This is due to the reduced flow resistance in the porous media at higher pressures and wider air gaps. However, compared to orifice-type designs (discussed later), the porous-type bearing has a much smoother and lower rate of air consumption, which makes it energy-efficient and quieter.

This consistent performance confirms the porous restrictor's ability to regulate airflow evenly and limit unnecessary loss of compressed air, which is particularly important in cleanroom or energy-sensitive applications.

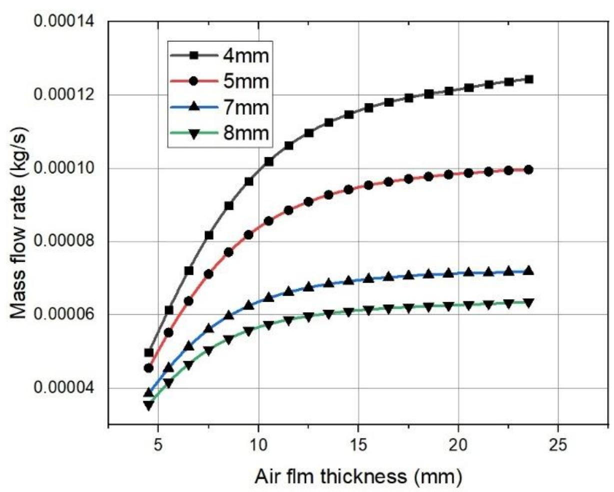


Figure 10. Mass flow rate at 0.3 MPa

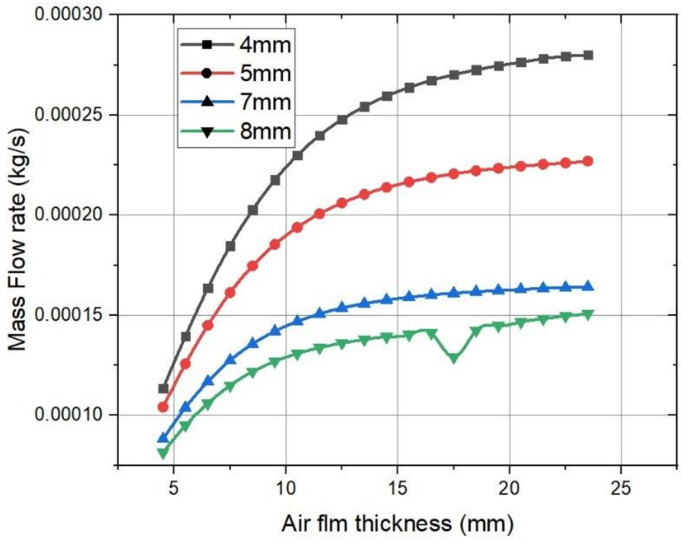


Figure 11. Mass flow rate at 0.5 MPa

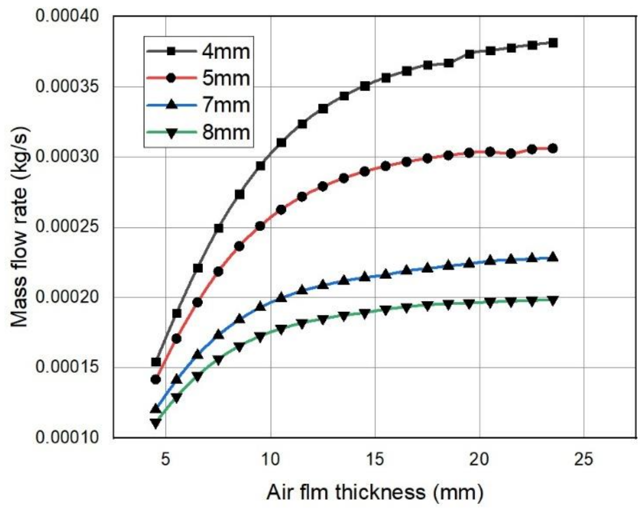


Figure 12. Mass flow rate at 0.6 MPa

3.2 Orifice-Type Aerostatic Thrust Bearing

3.2.1 Load-Bearing Capacity

The orifice-type aerostatic thrust bearing uses a number of micro-drilled holes to introduce air into the bearing gap. Unlike porous-type bearings, this design produces localized pressure zones around each orifice, which are evident in the pressure distribution plots.

As shown in Figure 13, 14 and 15 (0.3, 0.5 and 0.6 MPa) where Graphs shows that at low film thickness and high pressure (0.6 MPa), the orifice-type bearing achieves a load capacity comparable to the porous type. However, due to the concentration of pressure near the orifices and less uniform support in the remaining areas, the total load capacity is slightly lower and less consistent.

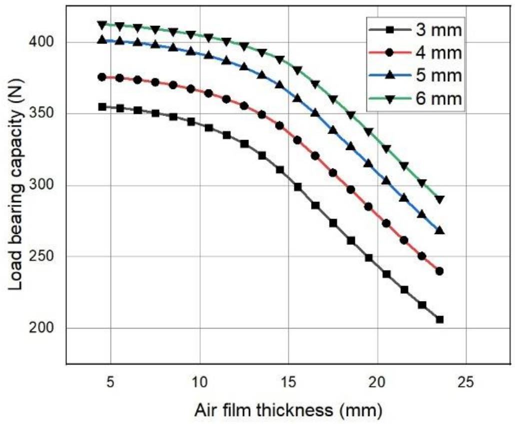


Figure 13. Load bearing capacity at 0.3 MPa

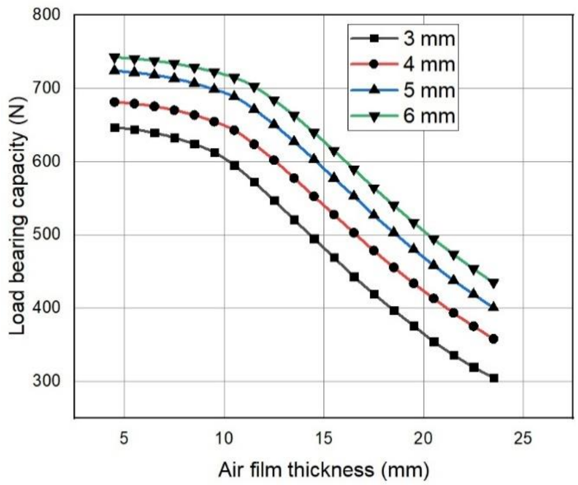


Figure 14. Load bearing capacity at 0.5 MPa

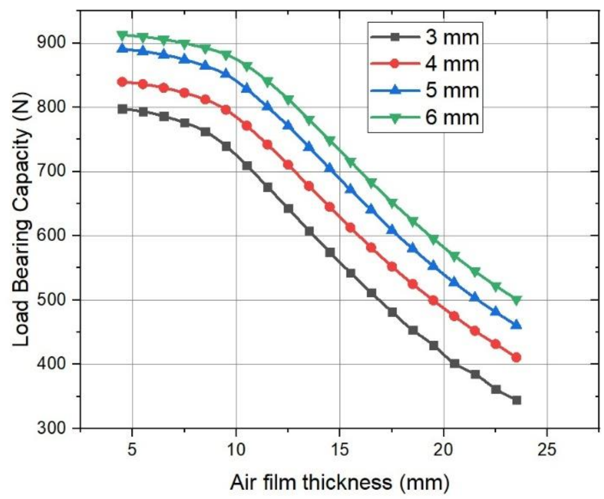


Figure 15. Load bearing capacity at 0.6 MPa

3.2.2 Stiffness

Stiffness results as shown in Figure 16, 17 and 18 (0.3, 0.5 and 0.6 MPa) for the orifice-type bearing are shown in graphs. The stiffness varies significantly with orifice diameter and supply pressure. At lower film thickness, the stiffness is relatively high, but due to uneven air pressure distribution, it does not follow a smooth trend as in the porous-type bearing. This type of design often exhibits non-linear stiffness behavior, particularly at mid-range film thicknesses where the pressure recovery within the bearing gap becomes insufficient to maintain stable support. As the film thickness varies, the load capacity and stiffness can fluctuate unpredictably, making it less ideal for applications requiring consistent performance across a broad operating range. However, the orifice-type aerostatic bearing can still perform effectively in applications where the operating conditions remain close to a specific design point, allowing it to deliver reliable performance within a narrow range of parameters.

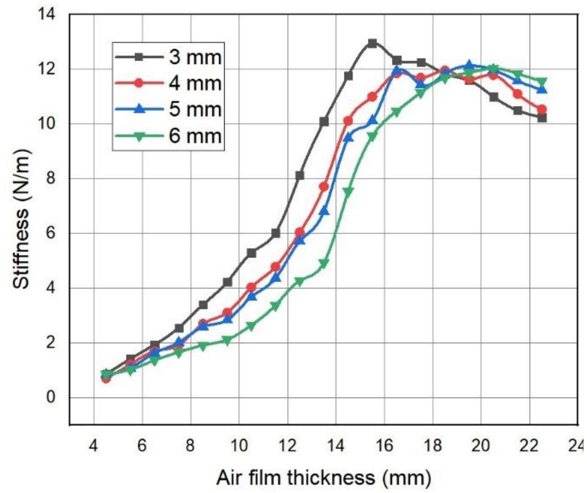


Figure 16. Stiffness at 0.3 MPa

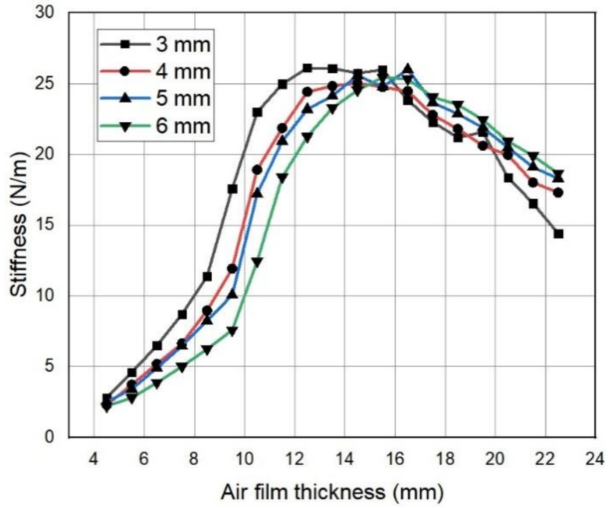


Figure 17. Stiffness at 0.5 MPa

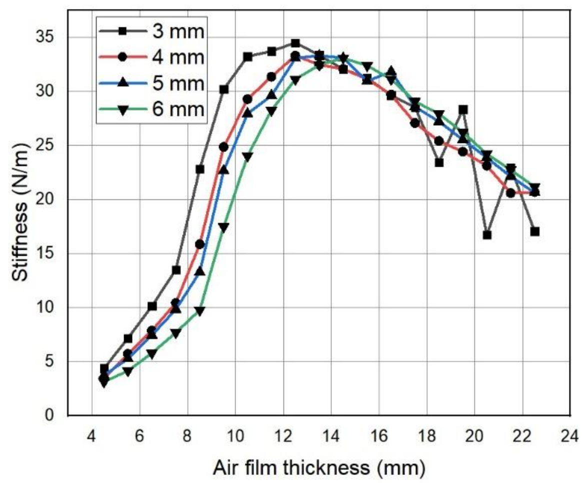


Figure 18. Stiffness at 0.6 MPa

3.2.3 Mass Flow Rate

Orifice-type bearings as shown in Figure 19, 20 and 21 (0.3, 0.5 and 0.6 MPa) generally exhibit higher mass flow rates than porous-type bearings at all pressures and film thicknesses. This is due to the direct flow paths through the orifices with minimal resistance, unlike the flow-limiting behavior of porous materials.

While this configuration allows for a quicker buildup of pressure within the bearing gap, it also comes with certain trade-offs. The concentrated air injection through discrete orifices results in increased air flow rates, which, although beneficial for rapid stabilization, can significantly reduce energy efficiency. Consequently, orifice-type designs often demand higher compressor power and lead to increased gas consumption, especially in continuous or high-load operations, making them less suitable for applications where energy efficiency and operating costs are critical concerns.

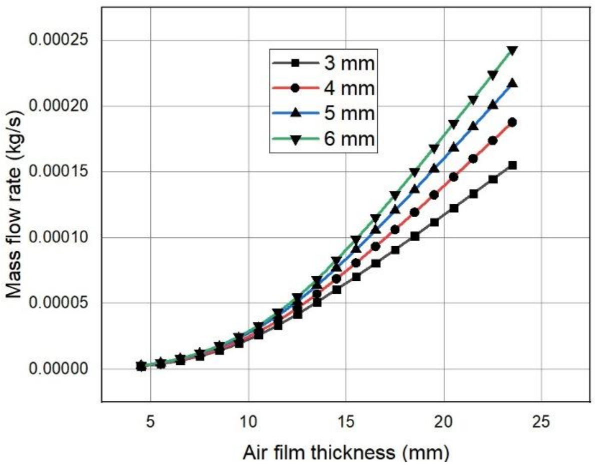


Figure 19. Mass flow rate at 0.3 MPa

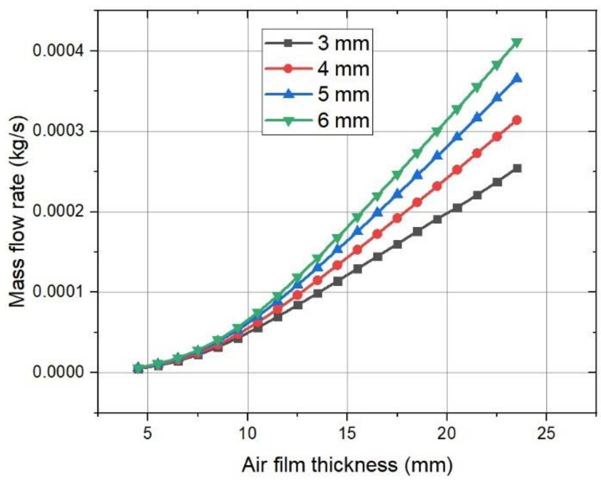


Figure 20. Mass flow rate at 0.5

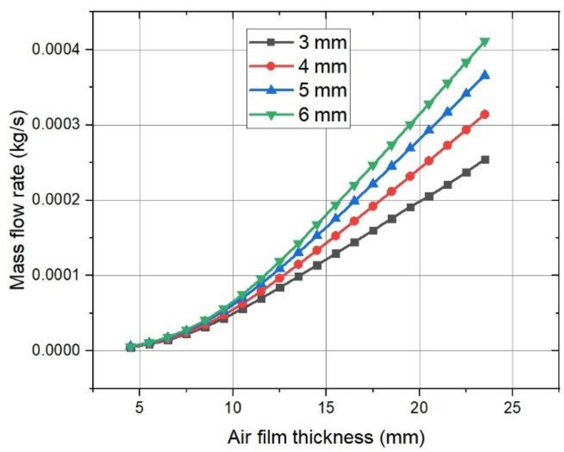


Figure 21. Mass flow rate at 0.6 MPa

3.3 Comparative Discussion

The result of the findings clearly demonstrates the performance trade-offs between aerostatic thrust bearings of the porous and orifice types. Because they can disperse air evenly through the porous restrictor, porous-type bearings continuously offer a higher and more consistent load-carrying capacity under a variety of operating conditions. While orifice-type bearings have non-linear stiffness characteristics that are extremely sensitive to variations in geometry and operating parameters, porous-type bearings behave in a more stable and predictable manner. The analysis also shows that orifice-type bearings have higher mass flow rates because they use a lot more air than their porous counterparts. Particularly in applications where energy conservation is crucial, like long-duration or battery-powered systems, this increased air consumption may lead to decreased operational efficiency.

4. Conclusion

A comparison of aerostatic thrust bearings of the porous and orifice types reveals a number of significant performance variations. A more uniform pressure distribution is guaranteed by the porous-type bearing, which helps to maintain a constant load-carrying capacity at different air film thicknesses and inlet pressures. On the other hand, under ideal circumstances, the orifice-type bearing frequently achieves higher maximum loads because it is more sensitive to changes in orifice size and supply pressure. Because air is delivered through individual orifices that create localized pressure concentrations, the orifice-type bearing usually shows higher stiffness values when evaluated, especially at lower air film thicknesses and larger orifice diameters. The porous bearing, however, maintains a steadier mass flow rate thanks to its uniform permeability, while the orifice-type tends to show more variation depending on design and input parameters. Both bearing types demonstrate a reduction in load capacity as the air film thickness increases, which is in line with theoretical principles. Nonetheless, the porous bearing offers smoother performance transitions, indicating enhanced operational stability in dynamic or fluctuating environments.

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