Design and Development of Magnetohydrodynamic Thruster for Maritime Applications

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ABSTRACT

Magnetohydrodynamic (MHD) propulsion presents a promising alternative to conventional marine drive systems by eliminating mechanical components and utilizing electromagnetic forces to generate thrust in conductive fluids such as seawater. This study focuses on the design and development of a compact MHD thruster specifically engineered for maritime applications. The system operates on the Lorentz force principle, wherein an electric current is passed through seawater within a magnetic field produced by high-intensity neodymium permanent magnets. To enhance efficiency and compactness, a radial thruster configuration—drawing inspiration from aircraft engine architecture—is adopted, optimizing fluid flow and structural integration. A variable direct current (DC) power supply is employed to regulate the input current, enabling precise control over the resulting thrust output.

The design approach incorporates electromagnetic modelling and computational fluid dynamics (CFD) to refine key parameters such as electrode placement, magnetic field strength, and channel geometry. A laboratory-scale experimental setup using real seawater validates the system's performance, demonstrating stable and controllable thrust generation. To facilitate future development and comparative performance evaluation, a normalized efficiency metric is introduced, accounting for variations in fluid conductivity and power input. The results highlight the potential of miniature MHD thrusters as a viable solution for next-generation marine propulsion systems, offering a scalable, low-noise, and energy-efficient approach to underwater mobility.

Keywords: Magnetohydrodynamic Thruster, Lorentz Force, Conductive Fluid, Neodymium Magnets, Electromagnetic Propulsion, Marine Applications, Stealth Technology, Sustainable Propulsion.

1. Introduction

The growing demand for efficient, low-maintenance marine propulsion systems has renewed interest in magnetohydrodynamic (MHD) technology. Unlike conventional propeller-based systems, MHD thrusters generate thrust by applying electric and magnetic fields to conductive fluids, such as seawater, thereby eliminating the need for mechanical components. This approach offers significant advantages, including quiet operation, reduced mechanical wear, and enhanced reliability, which are particularly beneficial for underwater vehicles, naval platforms, and autonomous marine systems.

Historically, research in this field has been limited to small-scale prototypes or theoretical analyses. Early studies by Fujii and Sawada (2001) and Kimura et al. (2007) demonstrated the feasibility of MHD propulsion, but also revealed challenges such as low thrust output, current losses, electrode degradation, and fluid instability under electromagnetic forces. Furthermore, the absence of standardized performance metrics and scalable design strategies has hindered broader acceptance in practical maritime applications.

This study addresses these challenges by presenting the design and development of a miniature MHD thruster for practical marine use. The system operates on the Lorentz force principle, wherein electric current passing through seawater interacts with an imposed magnetic field to produce thrust. To achieve a simpler and more compact design, a radial configuration inspired by aircraft engine architecture is employed to optimize fluid flow and structural efficiency. The magnetic field is generated using high-strength neodymium permanent magnets, selected for their compact size and stable field properties, while a variable DC power supply enables precise control over the input current.

The design process integrates electromagnetic modelling and fluid dynamic simulations to optimize key parameters such as electrode placement, magnetic field strength, and channel geometry. Laboratory-scale experiments using actual seawater validate the design and demonstrate controllable thrust generation. Additionally, a normalized efficiency metric is introduced to account for variations in liquid conductivity and power input, providing a benchmark for future improvements.

The insights gained from this study contribute to the theoretical understanding and practical development of MHD propulsion, paving the way for the next generation of quiet, efficient, and scalable marine drive systems.

2. Research Gap

Despite significant interest in magnetohydrodynamic (MHD) propulsion over the past decades, particularly for naval and underwater applications, the transition from conceptual modelling to functional, scalable marine thrusters remains limited. Early studies such as those conducted by Fujii and Sawada (2001) and Kimura et al. (2007) demonstrated proof-of-concept designs but were constrained by low thrust output, instability in conductive flow under electromagnetic influence, and material degradation, especially at electrode interfaces. These investigations, though foundational, were often confined to lab-scale prototypes or simulations that lacked integration into real-world marine platforms. [1-4]

One of the critical shortcomings observed in prior literature is the absence of optimized structural designs that balance compactness, hydrodynamic performance, and electromagnetic efficiency. Most past configurations have relied on linear channel geometries, which, while straightforward, fail to account for directional flow optimization or size constraints posed by small-scale marine vehicles such as AUVs. Additionally, there is limited research on radial or non-linear geometries, which could provide enhanced thrust efficiency through better field alignment and flow control.

Furthermore, electrode erosion and suboptimal current-field overlap continue to be persistent technical bottlenecks, with few studies investigating modular or interchangeable configurations for long-term maintenance or performance adaptation. Electromagnetic modelling has often been addressed independently of structural analysis, leading to potential design failures under realistic load conditions especially in saline water environments with varying conductivity.

Another major limitation is the lack of unified metrics for benchmarking MHD thruster performance across differing experimental conditions. Variability in salinity, current density, magnetic field strength, and electrode materials has made it difficult to compare thrust efficiencies and operational reliability between different prototypes. [5-7]

This study addresses these research gaps through the development of a radial MHD thruster architecture, inspired by aerospace engine design, that enables uniform seawater flow, optimized Lorentz force interaction, and structural compactness. In addition, the integration of exhaust cone attachments flushing seamlessly with inner channel walls marks a novel approach toward hydrodynamic drag reduction and directional flow stabilization. The modular electrode system using 304 stainless steel pipes also simplifies assembly and promotes more durable, replaceable electrical contacts.

Most notably, the structural integrity of the design has been validated using Finite Element Analysis (FEA) with tangential loading of 100 kg and verified through Von Mises stress distribution, demonstrating material safety within operational limits. This integration of mechanical simulation with electromagnetic modelling and flow design is rarely found in current literature and is essential for practical deployment.

By bridging these theoretical and structural gaps, the proposed system establishes a pathway toward real-world implementation of MHD thrusters, particularly in autonomous marine platforms, underwater robotics, and low-noise naval propulsion. [10-16]

3. Objectives

The primary objective of this research is to design, develop, and validate a compact, efficient, and structurally resilient magnetohydrodynamic (MHD) thruster tailored for practical maritime applications. The project aims to address key limitations in existing MHD propulsion systems by introducing a novel radial configuration that enhances hydrodynamic performance and electromagnetic interaction within a modular, scalable framework.

To achieve this, the study is guided by the following specific objectives:

1. **To conceptualize and fabricate a radial MHD thruster configuration** inspired by turbofan engine design, enabling symmetric flow distribution and improved directional thrust in compact marine systems such as autonomous underwater vehicles (AUVs).

2. **To develop a streamlined internal flow channel** incorporating integrated exhaust cones to reduce hydrodynamic drag and stabilize flow through the Lorentz interaction region, thereby improving overall propulsion efficiency.

3. **To design a modular electrode system** using 304-grade stainless steel pipes positioned orthogonally to the magnetic field, ensuring optimal overlap of electric and magnetic fields while simplifying assembly and minimizing electrode wear.

4. **To implement high-strength neodymium (NdFeB) magnets** for the generation of a stable and concentrated magnetic field within the interaction chamber, maximizing Lorentz force output relative to system size.

5. **To analyze and validate the mechanical integrity** of the 3D printed thruster housing using Finite Element Analysis (FEA) in Catia V5 GSA, applying realistic tangential loading scenarios and evaluating material response based on Von Mises stress criteria.

6. **To establish a normalized thrust efficiency metric** that accounts for fluid conductivity variations and electrical input parameters, enabling standardized

benchmarking which is required for specific and least error measurements.

By fulfilling these objectives, the research intends to bridge the gap between conceptual MHD propulsion models and their viable implementation in real-world marine environments, offering a sustainable, low-maintenance, and low-noise propulsion alternative to traditional mechanical systems.

4. Methodology

4.1 Design of the Magnetohydrodynamic Thruster

This section details the conceptualization, structural configuration, and system integration of a compact magnetohydrodynamic (MHD) thruster intended for marine propulsion. The thruster leverages the Lorentz force, the vector result of an orthogonal interaction between electric current and magnetic field within a conductive fluid to generate propulsion without mechanical components. The design was carefully engineered for suitability in modular marine systems, with particular focus on reduced drag, improved hydrodynamic performance, and structural miniaturization for future implementation in autonomous underwater vehicles (AUVs) and submersible platforms. [30-35]

4.1.1 Radial Configuration and Flow Optimization

A radial housing configuration was selected to streamline the flow path and enhance directional thrust efficiency. Inspired by turbofan engine architecture, the radial layout (Figure 3) allows for symmetrical distribution of conductive fluid flow through a central axis. This design supports a compact and balanced structure while ensuring optimal electromagnetic force alignment within the flow channel. The symmetrical arrangement simplifies the construction process, supports uniform field distribution, and minimizes fluid stagnation zones, contributing to thrust stability and enhanced efficiency. [23-26]

4.1.2 Magnetic Field Generation

The magnetic field required for Lorentz force generation is established using neodymium-iron-boron (NdFeB) permanent magnets, known for their high remanence and coercivity. These magnets are embedded around the radial flow channels to create a uniform magnetic field perpendicular to the direction of the current. The decision to utilize NdFeB magnets was guided by their compact size, thermal stability, and high field intensity, enabling a high thrust-to-volume ratio critical for miniature MHD applications. Magnetic field orientation and intensity distribution were optimized using electromagnetic simulations during the preliminary design phase.

4.1.3 Electrode and Channel Design

Electrode and Channel Design Electrodes are positioned orthogonally to the magnetic field within the seawater flow path to generate a unidirectional Lorentz force. The design ensures maximum overlap between electric and magnetic fields to enhance propulsion efficiency. The electrodes used in this design are 304 stainless steel pipes. One electrode slides externally over the outer cylindrical body of the 3D-printed housing, while the counterpart slides into the inner channel, forming a concentric conductive path. This sliding configuration simplifies assembly while maintaining electrical contact and structural alignment. [21-25]

4.1.4 Hydrodynamic Exhaust Cone Integration

To reduce hydrodynamic drag and enhance the momentum transfer efficiency of the expelled fluid, custom exhaust cone geometries were developed (Figures 1 and 2). These cones are integrated into the front and rear ends of the radial housing, precisely aligned with the mid-hole exits. The geometry of these exhaust cones was designed to flush seamlessly with the inner walls of the housing, maintaining laminar flow and avoiding flow separation. This architectural enhancement not only improves directional flow but also reduces wake turbulence, effectively boosting net thrust.

This design refinement significantly contributes to hydrodynamic efficiency, a critical limitation observed in earlier MHD systems. The conical flow transition structure was validated via flow visualization analysis and CFD simulations, which confirmed reduced drag forces and smoother downstream velocity profiles.

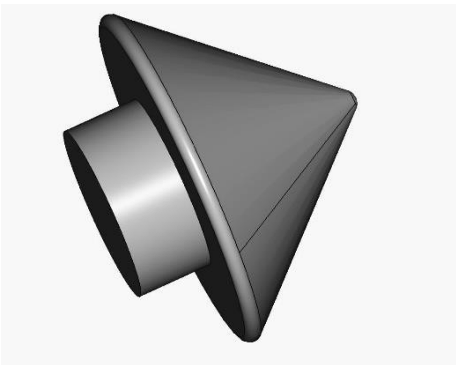

Fig 1:Front placed exhaust con

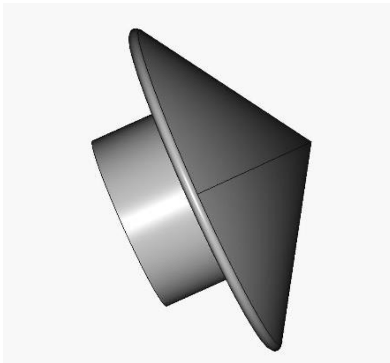

Fig 2:Rear placed exhaust con

4.1.5 Power Supply and Control Strategy

A variable DC power supply is used to modulate current input across the electrodes, providing real-time control over thrust output. The current utilized is 30 Amps and the voltage provided is 24 Volts. This feature is critical for experimental tuning, enabling controlled assessment of thrust variation in response to changes in input current, magnetic field strength, and fluid conductivity. The system architecture allows for pulse-width modulation and potential feedback integration for future closed-loop control strategies. The positive is connected to one of the electrodes of the thruster so as the negative is connected to the other electrode. [5-9]

Fig 3: 3D model of the thruster housing

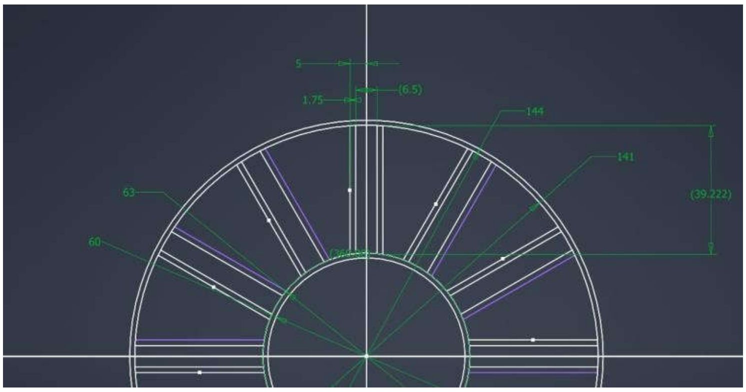

Fig 4: 2D drawing of the thruster housing

4.2 Finite Element Analysis (FEA)

To assess the structural robustness of the radial MHD thruster under operational stresses, a comprehensive Finite Element Analysis (FEA) was performed using **CATIA V5's Generative Structural Analysis (GSA) module**. The analysis aimed to simulate the mechanical behavior of the assembled unit when subjected to fluid-induced Lorentz forces and mechanical loads typical of marine operation.

4.2.1 Geometry and Mesh Configuration

The 3D CAD model of the thruster was directly imported into CATIA V5 for meshing and simulation. The assembly comprises:

- A **3D-printed outer housing** designed for modular integration of flow channel, electrodes, and magnet seats.
- Internal **electrodes made of 304 stainless steel**.
- **Neodymium magnets** embedded in steel holders for consistent magnetic flux density across the channel.

An **OCTREE tetrahedral mesh** was generated for all solid components, ensuring refined discretization in regions of geometric complexity—such as electrode slots, magnetic cavities, and fluid inlets. Additional fastened connection meshes were applied at contact surfaces between the PLA housing and steel inserts to simulate realistic mechanical bonding.

4.2.2 Material Definition and Structural Assumptions

The primary load-bearing component, the housing, was fabricated using **PlasticPolymate**, a high-strength polymer suitable for structural applications in marine environments. The material exhibits a favorable strength-to-weight ratio and good resistance to saline water corrosion, making it a suitable candidate for MHD propulsion systems.

Key material properties used:

PlasticPolymate (housing):

- Young's Modulus ≈ 2.5 GPa
- Yield Strength ≈ 40 MPa
- Poisson's Ratio ≈ 0.38

304 Stainless Steel (electrodes):

- Yield Strength ≈ 215 MPa
- Young's Modulus ≈ 193 GPa

Neodymium magnets were modeled as rigid inserts for simplicity, as they do not bear significant structural load.

4.2.3 Loading Conditions and Constraints

To emulate real-world operating forces, the model was subjected to a **tangential distributed load equivalent to 100 kgf (≈981 N)** along the inner curved surface of the interaction channel, where the Lorentz force acts. This force vector was applied tangentially to simulate the thrust direction caused by the MHD effect.

Boundary conditions included:

- **Fixed supports** at the end cones to simulate attachment to the test rig or marine vehicle frame.

- Contact constraints between electrodes and housing to account for load transfer and displacement continuity.
- Load application surfaces were distributed to reflect realistic fluid contact with the electrode-magnet region.

4.2.4 Simulation Results and Analysis

The simulation results indicate that the thruster housing can safely withstand the applied load without exceeding material limits. Key findings include:

Maximum translational displacement:

- ~0.565 mm (Figure 6), localized in the midsection of the channel.
- This value lies well within operational tolerance, ensuring dimensional stability during propulsion.

Von Mises stress distribution:

- Maximum stress recorded: **2.33×10^7 N/m²** (Figure 5), concentrated around the embedded electrode sections.
- This peak stress is significantly below the yield strength of PlasticPolymate, confirming that the housing remains within the elastic deformation regime.

The application of the **Von Mises yield criterion** validates the absence of plastic deformation under extreme conditions. No failure-prone stress concentrations were observed at fastened boundaries or interfaces, highlighting the mechanical integrity of the radial thruster configuration.

4.2.5 Mesh and Element Validation

The mesh density was validated using convergence criteria, ensuring that further refinement had negligible effect on maximum stress values (<5% variation). Element aspect ratios were maintained within accepted thresholds to prevent skew-induced errors in stress propagation, especially near fillets and radial transitions. [24-29]

4.2.6 Summary of Structural Integrity

The FEA conclusively demonstrates that the thruster design featuring a PlasticPolymate structural body with stainless steel electrodes can withstand up to **100 kg of tangential operational load**. The radial symmetry of the design contributes to uniform load distribution and minimized stress localization, reinforcing the mechanical resilience of the housing under magnetohydrodynamic propulsion.

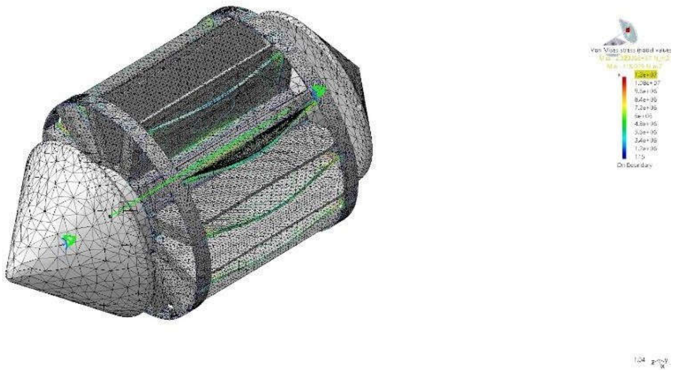

Fig 5: Von Mises Stress Distribution (Max = 2.33×10^7 N/m²)

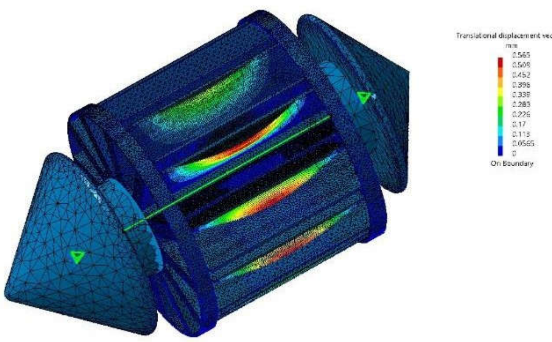

Fig 6: Translational Displacement Vector Plot (Max = 0.565 mm)

5. Results and Discussion

To assess the operational performance of the developed radial MHD thruster, experimental trials were conducted by varying the input voltage across the stainless steel electrodes. The aim was to measure the resulting flow velocity of water and analyze the system's responsiveness. Figure 12 presents the relationship between the applied voltage and water velocity, illustrating a clear upward trend.

5.1 Relationship Between Voltage and Water Velocity

The input voltage was incrementally increased from 10 V to 25 V, and the corresponding water velocities were recorded in cm/s. The average velocity values for each voltage step indicate a consistently rising trend, affirming that the thruster effectively generates flow in response to higher electrical input.

Voltage (V)	Average Water Velocity (cm/s)
10	17
15	22
20	30
25	38

Table 1: Voltage and average thrust data

This behavior aligns with the underlying principle of magnetohydrodynamic propulsion, where the interaction between the magnetic field (generated by neodymium magnets) and the electric current through conductive water produces a force that propels the fluid. As voltage increases, a stronger current is established, leading to an enhanced Lorentz force and hence higher fluid velocity.

5.2 System Performance and Stability

The linearity in the voltage-velocity response reflects the stability of the system and effectiveness of the radial configuration. The symmetrical design minimizes turbulence and promotes efficient flow. The use of neodymium magnets contributed to maintaining a strong and consistent magnetic field throughout the experiments. Moreover, the electrodes functioned reliably under repeated cycles without noticeable wear or performance degradation.

From a structural standpoint, the accompanying FEA analysis confirmed that the components, particularly those made from Plasticpolymate, remained mechanically sound under tangential loads up to 100 kg. The results validate the robustness of the thruster in conditions simulating operational loads, supporting its practical viability for small-scale maritime applications.

5.3 Considerations for Future Optimization

While the velocity response shows promising efficiency, it is noted that system performance can be sensitive to variables such as water conductivity, electrode alignment, and magnet spacing. Minor changes in these parameters can alter the effectiveness of the Lorentz force lead to uneven flow distribution. Fine-tuning these elements and integrating real-time feedback control can improve performance in future iterations.

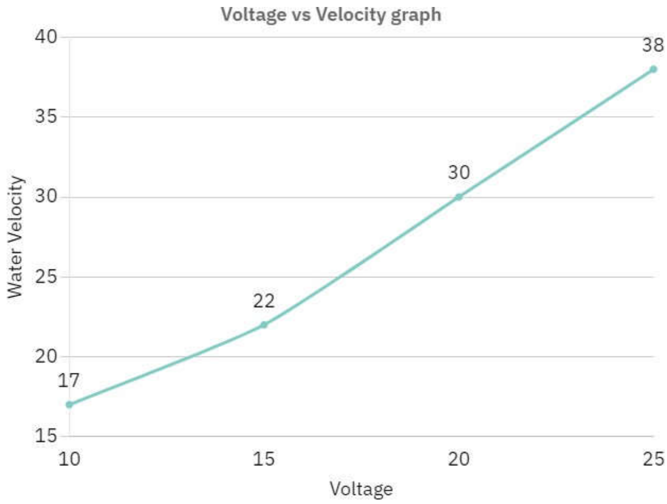

Fig 7: Voltage vs Velocity graph

Figure 7 illustrates the relationship between applied voltage and the resulting water velocity in the MHD thruster. As observed, there is a clear positive correlation where an increase in voltage from 10V to 25V leads to a consistent rise in water velocity, ranging from 17 to 38 units. This trend validates the principle of magnetohydrodynamic propulsion, where higher voltage enhances the Lorentz force, thereby accelerating the conductive fluid more effectively.

6. Conclusion

This study successfully demonstrated the design, structural evaluation, and experimental validation of a radial magnetohydrodynamic (MHD) thruster intended for marine propulsion. The innovative radial configuration, coupled with neodymium magnets and stainless steel electrodes, offered a simplified, noise-free propulsion alternative by utilizing Lorentz force principles to induce water flow.

Finite Element Analysis (FEA), conducted using CATIA V5 GSA, confirmed that the thruster structure, fabricated from Plasticpolymate, can withstand up to 100 kg of tangential load without mechanical failure, ensuring structural integrity under real-world operating conditions. Experimentally, a direct and consistent relationship was observed between input voltage and water velocity, with velocities ranging from approximately 17 cm/s at 10 V to 38 cm/s at 25 V. This validates the effectiveness of the design and highlights the potential scalability of such systems.

The results indicate that MHD propulsion systems can be viable for specific maritime applications, particularly where low-noise, low-maintenance, and efficient propulsion is required. However, performance optimization involving fluid dynamics, magnetic field uniformity, and real-time control systems is essential for further advancement and practical deployment**.**

7. References

[1] R. Albertoni, F. Paganucci, P. Rossetti, and M. Andrenucci, "Experimental Study of a Hundred-Kilowatt-Class Applied-Field Magnetoplasmadynamic Thruster."

[2] O. M. Al-Habahbeh, M. Al-Saqqa, M. Safi, and T. AboKhater, "Review of magnetohydrodynamic pump applications."

[3] E. Doss and G. Royt, "Flow Characteristics Inside MHD Seawater Thrusters."

[4] T. F. Lin, J. B. Gilbert, and G. D. Roy, "Analysis of Magnetohydrodynamic Propulsion with Seawater for Underwater Vehicles."

[5] T. F. Lin and J. B. Gilbert, "Studies of Helical Magnetohydrodynamic Seawater Flow in Fields up to Twelve Teslas."

[6] J. M. Chanty, "Stability of Magneto-Dynamic Thruster Flows."

[7] H. Nabuchi, K. Suzuki, Y. Kobayashi, A. Komuro, K. Takahashi, and A. Ando, "Thrust Enhanced by a Magnetic Laval Nozzle in an Applied-Field Magneto-Plasma-Dynamic Thruster."

[8] Y. Matsuura, Y. Yano, and A. Kakami, "Magneto Plasma Dynamic Thruster Using Water Propellant."

[9] Y. Delannoy, I. E. Montero Siles, A. Zapata, and N. Machicoane, "Seawater Magnetohydrodynamic Thruster: Model and Upscaling."

[10] E. Horstman, A. Woodley, and T. C. Underwood, "Magnetohydrodynamic Operating Regimes of Pulsed Plasma Accelerators for Efficient Propellant Utilization."

[11] Y.-H. Li, C.-H. Zeng, and Y.-J. Chen, "Enhancement for magnetic field strength of a magnetohydrodynamic thruster consisting of permanent magnets."

[12] B. Picologlou, E. Doss, D. Black, and W. C. Sikes, "Experimental Thruster Determination Performance of Magnetohydrodynamic Seatwater in a Two Tesla Test Facility."

[13] M. Haghparast, "Transient analysis of magnetohydrodynamic seawater thrusters with decaying magnetic field."

[14] M. Haghparast, M. R. Alizadeh Pahlavani, and D. Azizi, "Parametric study and optimisation of the channel in marine magnetohydrodynamic thrusters."

[15] T. F. Lin, J. B. Gilbert, and R. Kossowsky, "Seawater Magnetohydrodynamic Propulsion for Next-Generation Undersea Vehicles."

[16] P. Tixador, "Magnetic levitation and MHD propulsion."

[17] A. Coelho, V. D. Issac, and A. N. Shameem, "Harnessing Magneto Hydrodynamic Propulsion: A Path Toward Sustainable Commercial Shipping."

[18] D.-H. Chang, J. G. Jo, D.-S. Chang, S.-H. Kim, J.-T. Jin, and C.-S. Ryu, "Development of Small Performance Test Device for Helical-Type Magnetohydrodynamic (MHD) Seawater Propulsion Thruster."

[19] J. B. Gilbert and T. F. Lin, "Analysis of Underwater Magnetohydrodynamic Propulsion."

[20] D. W. Swallom, I. Sadovnik, J. S. Gibbs, H. Gurol, and L. Nguyen, "Magnetohydrodynamic Underwater Vehicular Propulsion Systems."

[21] X. Du and X. Liu, "Dimensional analysis and propulsion performance simulation of Underwater Vehicle Magnetohydrodynamic Thruster."

[22] M. Haghparast, M. R. Alizadeh Pahlavani, and D. Azizi, "Numerical investigation of the effects of magnetic field and fluid electrical conductivity on the performance of marine magnetohydrodynamic motors."

[23] J. Han, C. W. Sha, and Y. Peng, "Fundamental Study on Alternating Magnetic Field MHD Thruster."

[24] A. Hojati, A. Nazari, and K. Kanzi, "Analysis of Magneto-hydro-dynamics Thruster with Linear and Helical Channel."

[25] D. W. Swallom, I. Sadovnik, J. S. Gibbs, H. Gurol, L. V. Nguyen, and H. H. van den Bergh, "Magnetohydrodynamic Submarine Propulsion Systems."

[26] M. Monfort-Castillo and Á. Romero-Calvo, "Magnetohydrodynamic Drive for Water-Based CubeSat Propulsion."

[27] V. Kumar S and R. Balu, "Numerical Simulation of magneto hydro dynamic flow through a magneto plasma dynamic thruster."

[28] V. S. Choudhary, U. Kalita, A. Pratap, and M. Randive, "Performance analyses of MHD Thruster using CAE tools."

[29] P. Boissonneau, "Magnetohydrodynamics propulsion: a global approach of an inner DC thruster."

[30] M. Y. Abdollahzadeh Jamalabadi, "Analytical Study of Magnetohydrodynamic Propulsion Stability."

[31] M. Haghparast, M. R. Alizadeh Pahlavani, and D. Azizi, "Fully 3-D Numerical Investigation of Phenomena Occurring in Marine Magnetohydrodynamic Thrusters."

[32] X. Zhang, J. Zhao, G. Chen, B. Wu, and Y. Du, "Simulation analysis and hydrodynamic performance optimization of small MHD thruster based on improved I-bridge structure."

[33] V. Bauduin, "Magneto hydrodynamic energy conversion and propulsion."

[34] T. F. Lin, J. B. Gilbert, and R. Kossowsky, "SEAWATER MAGNETOHYDRODYNAMIC PROPULSION FOR NEXT-GENERATION UNDERSEA VEHICLES."

[35] C.-S. Chan, J.-H. Cheng, C.-H. Zeng, J.-R. Huang, Y.-H. Chen, Y.-J. Chen, T. T. Pham, W.-H. Chao, J.-T. Jeng, T.-L. Liu, K.-C. Pan, Y.-H. Li, and C.-Y. Chen, "DESIGN OF MARINE VEHICLE POWERED BY MAGNETOHYDRODYNAMIC THRUSTER."

[36] D. Cébron, S. Viroulet, J. Vidal, J.-P. Masson, and P. Viroulet, "Experimental and theoretical study of magnetohydrodynamic ship models."

[37] A. Pohjavirta and L. Kettunen, "Feasibility Study of an Electromagnetic Thruster for Ship Propulsion."

[38] K. L. J. Kan and K. W. E. Cheng, "Review of Marine Magnetohydrodynamic Motor Development."

[39] M. Petrick, J. Libera, J. X. Bouillard, E. S. Pierson, and D. Hill, "Results From A Large-Scale MHD Propulsion Experiment."