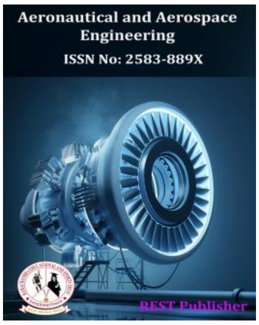
Aeronautical and Aerospace Engineering

Vol: 3(2), June 2025

REST Publisher; ISSN: 2583-889X (Online)

Website: http://restpublisher.com/journals/aae/

DOI: https://doi.org/10.46632/aae/3/2/4



Hybrid Hot and Cold Gas Micro Thruster for Rocket

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Abstract: *This study presents the design, numerical analysis, and performance evaluation of a titanium-based Hot Gas Thruster (HGT) system for small satellite propulsion. Operating with ethanol at 3,000,000 Pa inlet pressure, the thruster offers a non-combustive, low-risk alternative to traditional systems. Using CFD simulations, the internal flow dynamics, turbulence, and nozzle interactions are analyzed to assess efficiency and optimize performance. Results highlight the system's potential for precise, cost-effective, and safe maneuvering in small satellite applications.*

1. INTRODUCTION

The increasing demand for precise attitude control and orbital manoeuvring in small satellite platforms, such as Cuestas and Nan satellites, has accelerated the development of advanced micro propulsion systems. Among these, micro thrusters have emerged as a key enabling technology due to their compact form factor, low power consumption, and the ability to deliver fine impulse bits. Hybrid micro thrusters, which combine the advantages of both cold gas and thermal (hot gas) propulsion modes, offer a unique solution to balance simplicity, responsiveness, and performance. Cold gas propulsion systems are known for their structural simplicity, fast response times, and inherent safety, but they suffer from low specific impulse. By integrating both hot and cold gas modes into a single platform, hybrid micro thrusters can dynamically switch between high-thrust, high efficiency operation and low-power, rapid- response actuation.

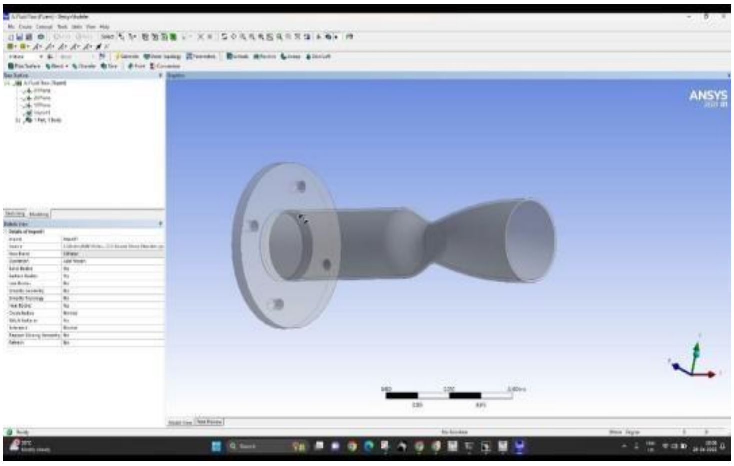

FIGURE 1.

2. PROBLEM STATEMENT

Small satellites need compact propulsion systems that balance simplicity and performance. Cold gas thrusters are safe but inefficient, while hot gas systems offer better thrust with added complexity. A hybrid thruster combining both modes can meet these needs, but challenges remain in heat management, material durability, and performance optimization. A focused numerical study is required to improve design and reliability under high-pressure, high-temperature conditions.

3. METHODOLOGY

The hybrid micro thruster system combines cold and hot gas propulsion to optimize performance and flexibility. Cold gas mode enables precise control using direct gas expulsion, while hot gas mode increases thrust through thermal heating. A microcontroller governs dual-path flow using solenoid valves, allowing seamless mode switching. The system includes a propellant tank, valves, heater or combustion chamber, and nozzle. Propellant selection, compact integration, and testing were conducted to evaluate thrust output and thermal behavior. The design targets efficient, scalable propulsion for small satellites, with focus on thermal management and reliable operation.

4. OVERVIEW OF HYBRID MICRO-THRUSTER

The hybrid micro thruster integrates cold and hot gas modes to offer both precise control and enhanced thrust for small satellites. Cold gas mode provides simple, low-thrust operation, while hot gas mode delivers higher performance through thermal energy input. Key features include a compact titanium design, dual-mode control via a microcontroller, integrated solenoid valves, and thermal management. The system is scalable, energy-efficient, and suitable for varied mission needs, balancing performance and reliability in a compact form.

5. DESIGN DIAGRAM AND CAD MODELING

The hybrid micro thruster system was designed using SolidWorks CAD software to ensure precision and optimize component integration. The CAD model includes the propellant tank, valves, heater/combustion chamber, and nozzle.

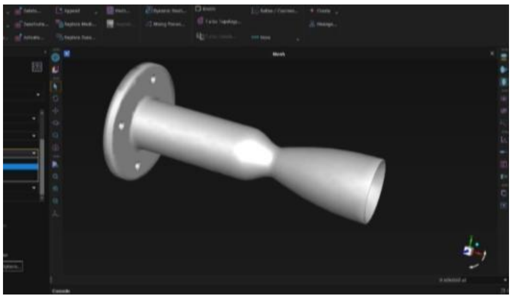

FIGURE. 2

6. APPLICATIONS OF HYBRID MICRO THRUSTERS

Hybrid micro thrusters, which integrate both cold and hot gas propulsion modes, provide significant advantages for various small satellite missions. In attitude control, they offer precise maneuvering capabilities, ideal for small spacecraft like Cube Sats. For orbital maneuvering, these thrusters facilitate station-keeping, orbital adjustments, and deorbiting with flexible thrust profiles. Additionally, hybrid systems support formation flying by maintaining precise relative positioning between satellites in a constellation. They also offer a promising solution for space debris removal, enabling controlled thrust for debris capture or repositioning. Finally, hybrid micro thrusters are suitable for deep space exploration, where small probes require both efficient thrust and precise control for interplanetary missions. The adaptability of hybrid micro thrusters makes them a versatile and reliable option for a Wide range of space applications.

FIGURE 3.

7. CONCLUSION

This study demonstrates the viability of a hot gas thruster using heated ethanol as a safe, non-ignition-based propulsion system for small satellites. The use of titanium ensures durability under high-pressure and temperature conditions, while heated ethanol provides controlled propulsion without combustion. Optimized nozzle design enhances thrust efficiency by effectively converting thermal energy into kinetic energy. Numerical investigations show favorable pressure and velocity distributions, confirming the system's potential for precise satellite maneuvers. Overall, the hybrid micro thruster offers a reliable, safe, and efficient propulsion solution for space missions.

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