P17101: Design and Characterization of a 1kW Arcjet Thruster Tabletop Technology Demonstrator

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***Abstract*—A tabletop prototype of an arcjet electrothermal propulsion system was developed to supplement ongoing exploratory spacecraft development conducted by RIT Space Exploration (SPEX). The arcjet thruster demonstrates the degree of practicality in implementing electrothermal propulsion systems. The arcjet assembly generates an electrical arc across the thruster nozzle's throat, ionizing argon propellant in order to achieve a greater specific impulse compared to cold gas propulsion.**

NOMENCLATURE

$\dot{m}$	Gas mass flow rate	
A	Cross-sectional area of nozzle	
F	Thrust	
g_0	Standard acceleration due to gravity	$9.81\,\mathrm{m\,s^{-2}}$
I_{sp}	Specific impulse	
p	Gas pressure	
v	Gas flow velocity	

I. INTRODUCTION

RIT Space Exploration (SPEX) provided a hypothetical use-case to serve as the foundation for this exploration into satellite propulsion. SPEX's hypothetical mission objective is to design a communicaitons satellite that is capable of maintaining a polar geostationary orbit for 10 years.

In practice, satellites in Earth orbit for long-duration missions in excess of 5–25 years encounter perturbations to their trajectories over time from residual atmospheric and orbital particles, or from variations in Earth's gravity field. These spacecraft perform short station-keeping maneuvers periodically to compensate for drift and orbital decay.

An electrothermal rocket engine is method of propulsion by which an inert gas stored at ambient temperature (cold gas) is released from a pressurized vessel or driven by a pump and heated electrically before being expelled out of a nozzle. Two proven methods of electrothermal propulsion are *resistojets*, which use conventional heat exchangers to heat the propellant, and *arcjets*, which pass the propellant through an electrical arc to heat the gas.

Electrothermal propulsion is advantageous over conventional chemical or cold-gas rockets for use by long-life satellites since the engines may be small in size, have no moving parts, and are more efficient at the expense of thrust. While resistojets and arcjets require more elecrical power than chemical rockets, for example, the electrical energy may be recovered over time by photovoltaic panels, for example, whereas propellant fuel is a finite resource for these spacecraft.

A tabletop prototype thruster was designed and tested to explore the feasibility of this type of system with less strict requirements compared to the limitations of building a flight-worthy system. A tabletop version does not require integration with a spacecraft, and mass and spatial limitations are relaxed.

II. DESIGN METHODOLOGY

In low power ($1\,\mathrm{kW}$) applications, an arcjet offers up to 200% gains in efficiency over a resistojet thruster [1]. Figure 1 identifies the typical use cases and performance characteristics of arcjets compared to various other types of electrothermal thrusters. Arcjets achieve a greater specific impulse compared to resistojets but produce less thrust. Thus a maneuver would take a longer amount of time using an arcjet but would consume less propellant overall for the same maneuver as compared to a resistojet.

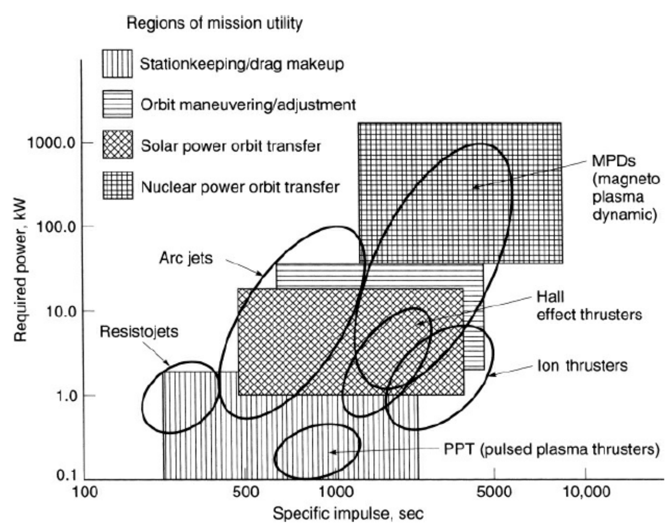

Fig. 1. Types of electrothermal propulsion with respect to typical performance and mission utility. In the $1\,\mathrm{kW}$ range, arcjets typically have a higher specific impulse than resistojets. (Sutton 2010)

A. Gas Dynamics

The ideal propellant for arcjet engines is one which can be stored easily, has a low atomic mass, and favorable thermodynamic conditions during heating and expansion. NASA

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identifies Hydrogen (H_2), Ammonia (NH_3), and Hydrazine (N_2H_3) as ideal propellants for arcjets [2]. Unfortunately, these gases are toxic or difficult to handle on a university campus. Nitrogen (N_2) is an easy-to-handle alternative that has relatively favorable ionization and thermodynamic characteristics, and has been used in similar low-power arcjet demonstrations [3], [4].

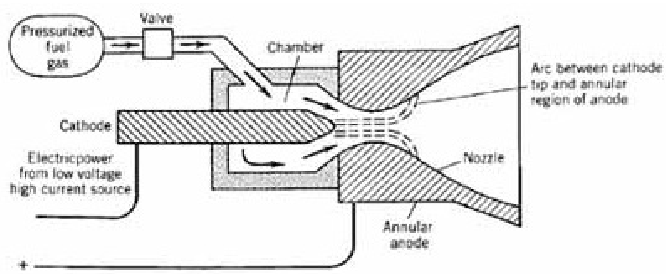

Fig. 2. A cross sectional view of a typical arcjet shows the expected flowpath of propellant and the expected region of the electric current arc. The propellant is ionized and heated by the arc then expanded through the nozzle. (NASA GRC 1992)

Gas enters the chamber and is ionized and heated by a high-current arc that extends from the cathode to the throat of the anodic nozzle to form a plasma. In the ideal case, the plasma reaches sonic speed in the throat and is supersonically accelerated as it expands through the nozzle.

Thrust is a function of the momentum of the flow exiting the nozzle.

$$F = \dot{m}v_e + (p_e - p_b)A_e \tag{1}$$

where F is thrust, v is flow velocity, A is nozzle cross sectional area, and subscripts e denotes parameters at the nozzle exit and p_b denotes ambient backpressure.

B. Power Conditioning

The electrical arc used to add energy to the gas is generated and sustained by the Power Conditioning Unit (PCU). The PCU consists of high-voltage (HV) and high-current (HC) modes. The HV side of the circuit initiates the arc, then the PCU switches to the HC "side" of the circuit to sustain a high-current arc. This architecture is similar to a plasma torch and has been demonstrated in similar tabletop systems [5]. When the arc jumps between the cathode and anode across the flowpath, it closes the HC portion of the circuit. This current induces a redd switch to open, turning off the HV side of the PCU.@

C. Test Signal Amplification

III. System Overview

A. Thruster Design

B. Power Conditioning Unit

IV. Testing

A. Test Stand

B. Data Acquisition

C. Safety Measures

V. Results

VI. Conclusions and Recommendations

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