PLASMA TORCH POWER CONTROL FOR SCRAMJET APPLICATION

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Abstract

Plasma torches have proven reliable methods of ignition and flame-holding for supersonic combustion applications. The Hy-V Scramjet Flight Experiment plans to use an 800W plasma torch for ignition of hydrogen fuel in a Mach 2 flow—a "first" in a free-flight scramjet experiment. Torch power will be controlled by a proportional feedback system monitoring feedstock pressure, fuel pressure, and a combustion-chamber infrared flame sensor. Original designs are required for the hardware and control system of the plasma torch operating under these conditions. This paper will discuss the design and construction of a battery power source and controller to achieve and sustain supersonic combustion.

1. Introduction

The Hy-V Scramjet Flight Experiment is an educational and research program with plans to test a dual-mode scramjet in free-flight. Launched atop a sounding rocket from NASA Wallops Flight Facility, the scramjet will be accelerated to Mach 5 then released into free-flight 90,000ft over the Atlantic Ocean. The project is a collaborative effort between the five Virginia Space Grant Consortium Universities, NASA, and various partners in industry.

1.1 Dual-Mode Scramjet

Subsonic combustion, supersonic combustion, and the transition between modes each pose a unique set of combustor design challenges. In subsonic mode, the flowpath must have a physical or thermal throat upstream of the combustor whereby flow coming into the throat is supersonic and flow leaving the throat is subsonic. In supersonic mode however, the absence of any throat is necessary to stop the formation of a normal shock and sonic point. Although variable geometry presents a possibility to choke and unchoke the flow, it would severely increase design complexity and weight[1]. Therefore, thermal choking—and thus mode—will be controlled by means of increasing or decreasing the fuel-air ratio. A robust means of igniting the fuel-air mixture is required to ensure and sustain combustion over the large variation of equivalence ratios and flow temperatures expected. Current designs include a plasma-torch igniter specifically for this purpose.

1.2 Plasma Torch

Plasma torches have been extensively tested at Virginia Tech as a method of ignition and flame-holding in scramjets[2,3,4]. The plasma torch to be used in the Hy-V scramjet is a modification of the VTPT-3, developed by Scott Gallimore. Seen in Figure 1, the torch consists of a copper anode and a hafnium-tipped cathode, isolated from each other by a 4 micrometer gap. Nitrogen feedstock gas is fed through this gap into the combustion chamber. When sufficient voltage is placed across the torch, dielectric breakdown occurs within the nitrogen and plasma is formed. Injection of the plasma into the fuel-air mixture is a robust means of ignition and flame-holding.

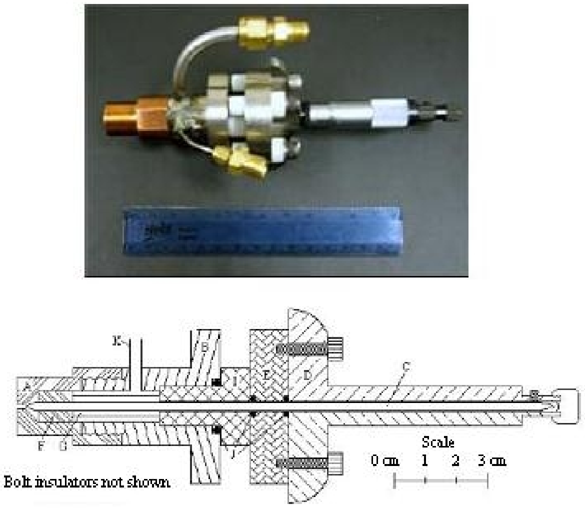

Figure 1. Photograph and schematic of VTPT-3 Plasma Torch[4]. (A: Anode, B: Torch Body, C: Cathode, D: Micrometer Drive, E: Cathode Bracket, F: Flow Swirler, G: Support Rod, H: Bolt Jackets, I: Body Insulator, J: O-Rings, K: Feedstock Lines)

1.3 Power Control

Design voltage and power waveforms—as well as dynamic fluctuations in the combustor—require that the torch power be actively controlled during powered flight. Sample power waveforms can be seen in Figure 2. Tests have confirmed that pulsing the torch power with a 50% duty cycle can decrease battery consumption while still maintaining operational characteristics[4]. Future work will determine the exact power waveform to be used during launch and its implication on battery life.

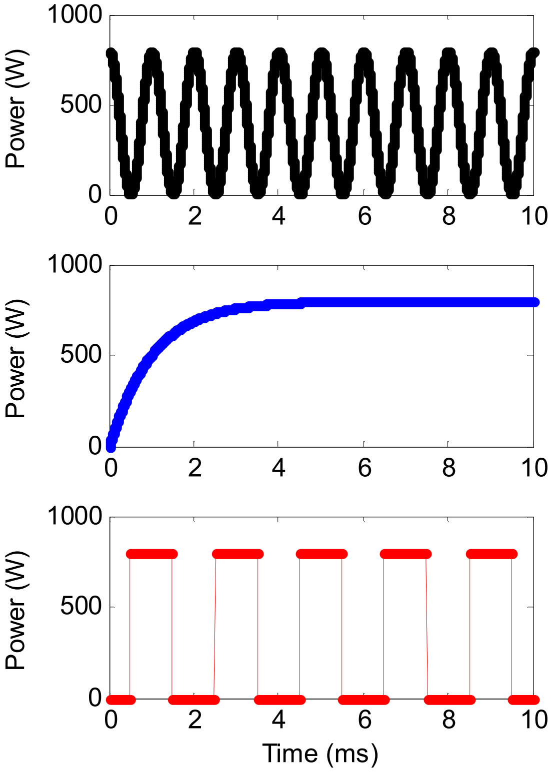

Figure 2. Candidate power waveforms for the torch control system. Sinusoidal(a) and square(c) waveforms have proven increased battery life without sacrificing combustion quality.

Active control of the torch power will be maintained by an embedded microcontroller with feedback from nitrogen feedstock pressure, hydrogen fuel pressure, and an infrared flame-sensor in the combustion chamber. To minimize design complexity while still providing robust control, the controller will operate with proportional feedback loops. Ground testing will provide an experimental database from which controller gains will be computed.

2. Design

An original design is needed to supply and control plasma-torch power during a sounding rocket launch. Hardware and software must combine to form a seamless solution to the design problem.

2.1 Hardware

A hardware design schematic can be found in Figure A at the end of this report. The following sections describe the setup in more detail.

2.1.1 Microcontroller

A Gumstix® Connex 200xm microcontroller will serve as the control system's central processing unit. Seen in Figure 3, the board is 4 in x 1 in. A 200MHz ARM processor allows for control at very high sampling rates, necessary because of the system's short characteristic timescale. A Gumstix® Breakout GS Expansion board will allow the microcontroller to output virtually any desired digital signal in TTL serial or RS-232 encoding. A digital-to-analog converter will then accept the generated digital signal and create a driver analog signal. An amplifier will step up the analog signal to the desired amplitude.

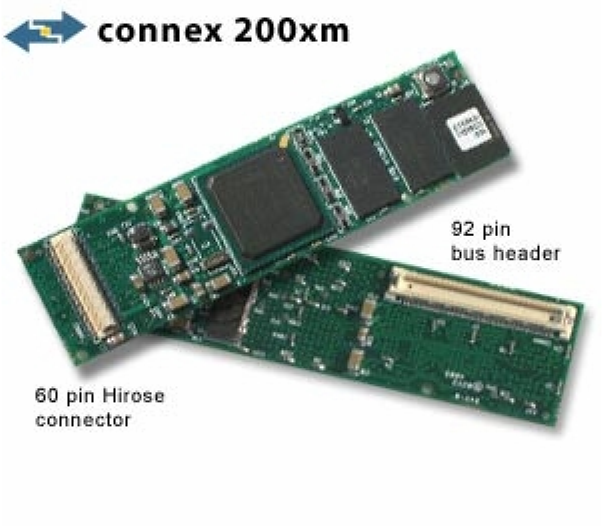

Figure 3. Gumstix® Connex Microcontroller.

2.1.2 Battery Power

FlightPower® EVO20 3s1p Lithium-Polymer batteries—seen in Figure 4—will be used as the primary torch power supply. Lithium-polymer technology allows for a battery package that only weighs about 300g yet delivers 800W continuously with bursts of up to 2000W. A 3700mAh capacity provides for at least 160s of full-on power—three times the minimum required by the design.

When over-drawn or damaged, lithium-polymer batteries have been known to overheat and catch fire[5]—an unacceptable failure mode inside a rocket. Consequently, battery power will be managed by a commercial voltage regulator able to shut off the power supply if conditions become necessary.

Figure 4. FlightPower® Lithium Polymer Batteries.

2.13 Other Hardware

Two pressure sensors and an infrared-flame sensor will be used to provide the controller with feedback about the current state of the system. If necessary, additional amplifiers will scale the sensor output voltages to amplitudes acceptable by the analog-to-digital converter.

2.2 Software

The Gumstix controllers are preloaded with a custom flavor of the Linux operating system. This allows for rapid development and easy maintenance of the microcontroller's run-time code. Using KDevelop and Gumstix

SDK, software has been written in high-level C-language to control the hardware described above. Further work will explore the ability of The MathWorks Simulink® to model the system and output C-source code for compilation directly in KDevelop.

2.3 Sequencing

The correct time sequencing of events is critical to the safe operation of the scramjet and its subsystems. A functional diagram of the controller start-up sequence can be seen in Figure B at the end of this report. As the rocket reaches apogee, the main guidance computer will send a signal to the rocket nosecone releasing explosive bolts, causing the nosecone to separate. The torch controller will accept this signal and pause for twenty milliseconds to allow for the transient flow in the scramjet inlet to "start". Once steady-state flow has been reached, a feedstock gas valve will be opened. After confirmation of the feedstock flow from the embedded pressure sensor, the controller will begin outputting the power waveform. The torch should begin injecting plasma into the combustor. After confirmation of the torch plume from the infrared-flame sensor, the fuel valve will be opened and supersonic combustion will ensue. At this point, the controller will enter a loop during which it will accept feedback from the infrared flame sensor and adjust the torch power so as to keep the flame lit. If the infrared sensor detects a flame-out situation, the controller will check fuel supply via the second pressure sensor and, if necessary, temporarily boost torch power to maximum.

3. Future Work

Future work will focus on system fabrication and flight certification. Current plans indicate the scramjet payload will be launched atop a Terrier Mk12-Improved Orion Sounding Rocket. This provides for a 350lb payload of 14in diameter to be launched to the necessary altitude and Mach number. During the launch, ascent, and experiment phases, the controller will have to accept various inertial, vibrational, and thermal loading. The NASA Wallops launch team has years of experience designing and certifying rocket hardware. Further specifications will be obtained at the Mission Initiation Conference, the next step in the Wallops Mission Life Cycle.

4. Conclusions

Supersonic combustion in the Hy-V Scramjet Flight Experiment will be initiated and sustained by a plasma-torch igniter. Original designs of hardware and software are needed to control the torch power and maintain combustion. A proportional feedback controller has been designed to accomplish these tasks. Plans include fabrication and flight-certification to meet the timeline of a 2009 launch.

Acknowledgements

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Figures

The following figures are presented out-of-text to allow for two-column span.

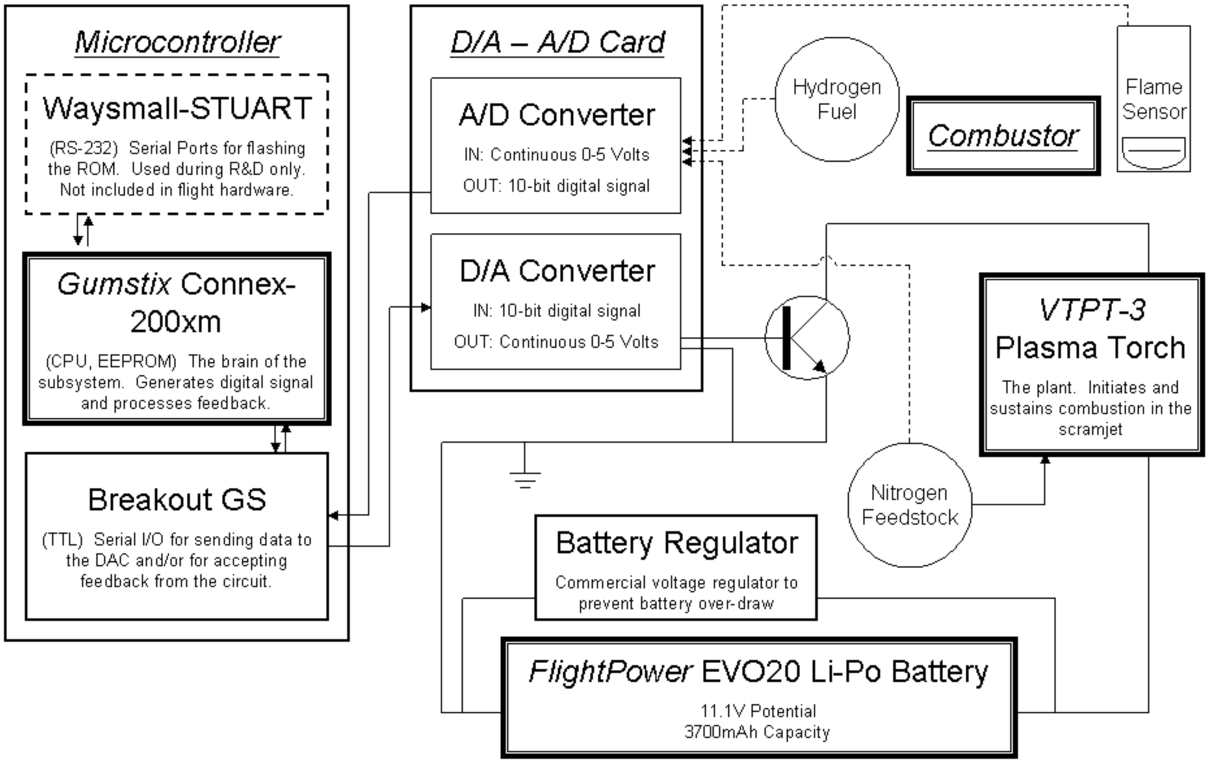

Figure A. Hardware schematic of the plasma torch power control system.

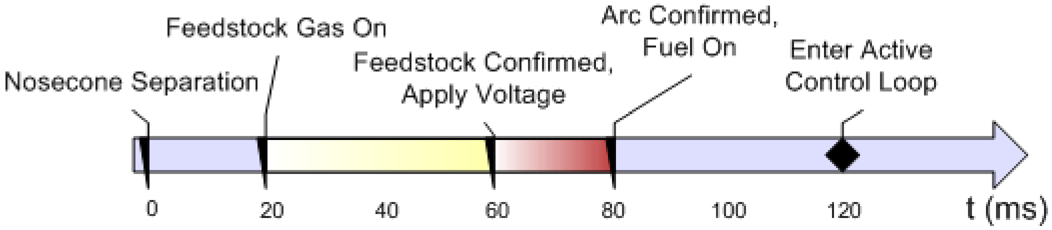

Figure B. Plasma torch controller time sequence.