HASP Student Payload Application 2007

Payload Class: Large
Group Name: Aerospike

Investigation of a Single Stage to Orbit (SSTO) Rocket Engine Nozzle

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Abstract

The *Aerospike Nozzle* team consists of LSU ME undergraduate students who are active members of the LSU AIAA Student Chapter. The team proposes to design and test an optimized aerospike nozzle, a type of Altitude Compensating Nozzle (ACN), that can be used by Single Stage to Orbit (SSTO) Rocket Engines. Because the structural boundary between the core nozzle flow and the surrounding ambient atmosphere is eliminated with aerospike nozzles, they may result in increased engine performance by enabling efficient pressure relaxation between the core flow and ambient air. As such, they are attractive for use with Single Stage to Orbit Rocket Engines that experience a wide range of ambient pressure. Moreover, tests made by the Aerospike Nozzle team for HASP 2006 does indeed indicate that the aerospike does perform more consistently at a large range of back pressures as compared to a typical converging-diverging nozzle[1]. A large payload (up to 10kg) is requested on the HASP for simultaneously testing an optimized aerospike nozzle against a conventional nozzle at various altitutudes. We will first study the exhaust flow-field behind an aerospike nozzle using both analytical and computational techniques, and will identify an optimal aerospike shape for the altitude range of 0–120,000 ft that is available to HASP. There are many unresolved problems associated with the design and optimization of aerospike type ACNs which make the proposed project both interesting and challenging.

1 Introduction & Payload Description

The LSU *Aerospike Nozzle* team proposes to design an optimize an aerospike type of Altitude Compensating Nozzle (ACN) that will be experimentally tested at various altitudes on the High Altitude Student Platform (HASP).

Nozzles are critical components of jet and rocket engines that enable the functioning gases in these devices, a source of high available energy, to produce large thrusts by expanding to high velocities. The gas expansion process within the nozzle is largely controlled by the ambient pressure (or *back pressure*) of the surrounding air, p_b, which is directly proportional to the nozzles altitude. In theory, the optimal thrust for a given jet or rocket engine occurs when the nozzle exit pressure, p_e, equals p_b. With other design variables fixed (mainly the combustion chamber pressure), there exists only one area ratio of nozzle exit area, A_e, to throat area, A_t, at a given altitude for optimal expansion. Given that rockets do not generally travel at a fixed altitude, the ability to achieve optimal expansion during flight is effectively impossible without the use of dynamically adaptive nozzles, whose complex design and relatively high cost prohibit widespread use.

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[1] Kornuta, J.A., "Performance Comparison of the Aerospike & de Laval Nozzles".

This observation is particularly relevant to *Single Stage to Oribit (SSTO)* rocket engines, which experience large altitude variations and are intended for single use operations. The proposed project will address a fundamental problem in rocket engine nozzle design: that is, how to handle the mismatch in desired exit areas at different speeds, altitudes, and thrust settings.

The three broad classes of rocket engine nozzles commonly used in practice include cone, bell, and annular plug nozzles. Because the shape of conventional cone and bell type nozzles is fixed in reference to a particular design point, optimal expansion is achieved only for the design point's specified back pressure. At low altitudes where the ambient pressure is higher than the design point pressure p_e (obtained by analyzing the isentropic flow case), the nozzle flow becomes overexpanded, resulting in the formation of irreversible shock waves and, consequently, inefficiencies. For such cases, the nozzle exit must be reduced in area to achieve optimal expansion. Conversely, at high altitudes where the back pressure is less than the design point pressure, the nozzle flow is underexpanded, resulting in the formation of strong, irreversible expansion waves that also cause inefficiencies. For such cases, the nozzle exit must be enlarged to achieve optimal expansion [Figure 1].

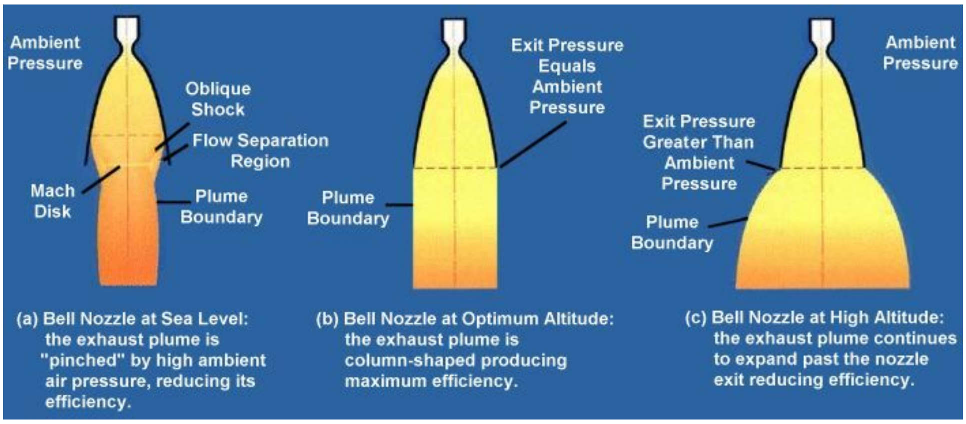

Figure 1: C-D nozzle flow pattern at different back pressures [Rocketdyne, 1999]

One solution to this fundamental problem is the implementation of an *Altitude Compensating Nozzle (ACN)*, whose design allows the ambient pressure p_b to actually dictate the flow pattern exiting the nozzle. The *Aerospike Nozzle* team will design, optimize, and fabricate different nozzle configurations that can be tested on HASP. Tests made by the Aerospike Nozzle team for HASP 2006 does indeed indicate that the aerospike does perform more consistently at a large range of back pressures as compared to a typical converging-diverging nozzle. As such, these nozzles are extremely attractive for *Single Stage to Space (SSTO)* rocket engines. This year the Aerospike team will focus on fabricating more precise miniature nozzles, implementing more efficient thrust stands, and simplifying the design of the data acquisition & control system. As a result, we hope to attain more accurate and conclusive data, as well as ensure optimal nozzle performance.

The exhaust flow of an annular aerospike nozzle, as shown in Figure 2, is directed radially inward toward the nozzle axis; this configuration is unlike that of a bell nozzle where the flow expands away from the axis along a diverging nozzle wall. A free boundary exists between the expanding core flow and ambient air, enabling pressure relaxation to occur with minimal losses. Consequently, expansion of the core flow is controlled by the external environment resulting in nearly optimal nozzle performance over a wide range of altitudes [Figure 3].

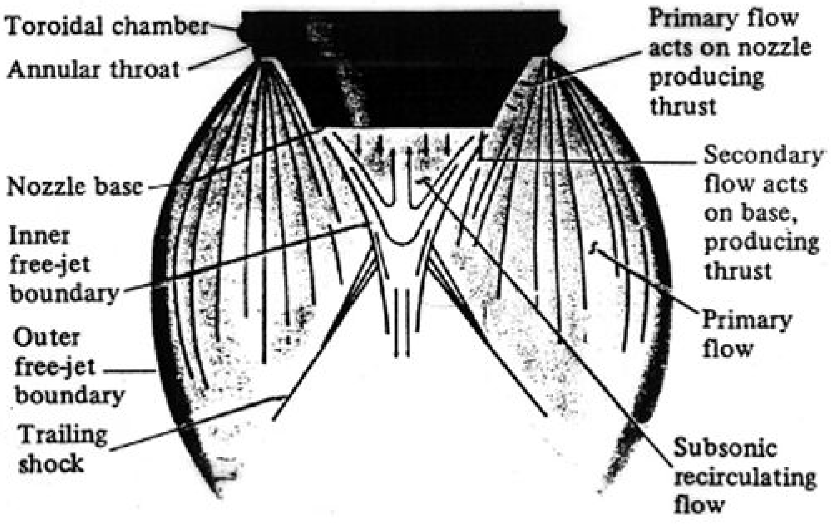

Figure 2: Aerospike flow characteristics [Hill and Peterson, 1992]

We will first study the exhaust flow field through an aerospike nozzle using both analytical and computational fluid dynamics (CFD) techniques and will optimize the shape of the aerospike for the altitude range that is available to HASP. Having experience designing miniature thrust stands and a data acquisition/control system for HASP in 2006, our team is confident that we can design and build an even better experiment that will yield useful and accurate data.

The main objective of the proposed experiment is to test multiple nozzle configurations at different altitude ranges. The payload will consist of two **miniature** nozzles that will be powered by compressed **nitrogen**. One optimized aerospike design and one conventional bell shaped nozzle will be built and tested. The nozzles will be connected to a single compressed air source, and the flow of gas will

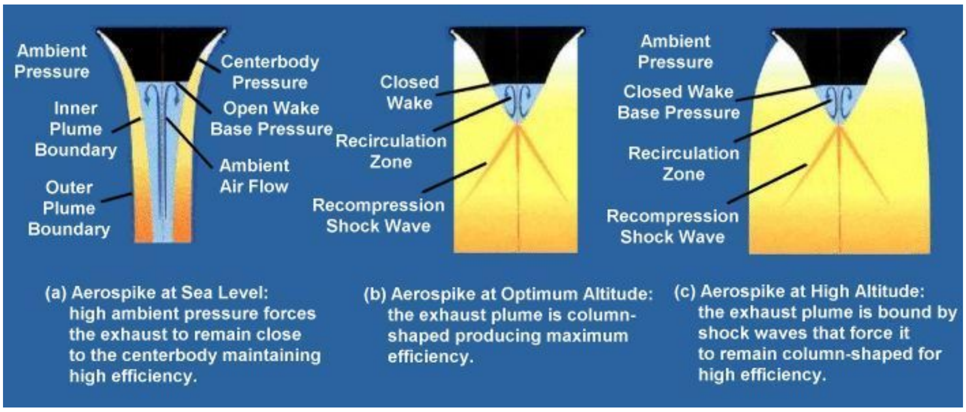

Figure 3: Aerospike nozzle flow pattern at different back pressures [Rocketdyne 1999]

be controlled by two standard solenoid valves. As the balloon gradually climbs to maximum altitude, the valves will periodically discharge a small, fixed amount of gas from the tank through the nozzles. The resulting thrust force will then be measured by compression type load cells. Various performance coefficients will be computed from the collected data and compared to theoretical predictions. We plan on performing at least 40 test shots for each nozzle as the balloon climbs from ground level to 120,000 ft.

2 Team Structure & Management

The team consists of LSU ME students who are active members of the LSU AIAA Student Chapter. For 75 years, the American Institute of Aeronautics and Astronautics (AIAA), has been the principal society of the aerospace engineer and scientist. The purpose of this organization is "*to advance the arts, sciences, and technology of aeronautics and astronautics, and to promote the professionalism of those engaged in these pursuits.*" The following students will participate in the project:

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Overseeing all operations of this project will be two faculty advisors, Dr. Shengmin Guo and Dr. Keith Gonthier of the Louisiana State University Mechanical Engineering Department.

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Carla Guzzardo will be in charge of thermal considerations as well as nozzle fabrication. Edward Scheuermann and Ian Walsdorf will be responsible for thrust stand design and transducer integration. Jeff Kornuta will be in charge of system integration as well as the data acquisition and control system. We expect to have at least four student members and one faculty advisor of this team work on this project over the summer of 2007 and participate in the flight operations in September at Ft. Sumner, NM.

3 Payload Specifications

Our team will be seeking a **large payload** interface from the HASP project. The exact footprint will be designed to satisfy the specification. The payload will utilize a single compressed nitrogen source to provide gas to two solenoid valves and two miniature nozzles. The thrust generated by different nozzles at various ambient pressures and temperatures will be recorded and analyzed using an array of electronic transducers and microcomputer powered by a BASIC Stamp series of microcontroller. Based on preliminary calculations and experiments performed during HASP 2006, each nozzle should produce **no more than 200 grams** of net thrust. The pulsed air jet will last for approximately 1 second for each test. **This small pulsed force should not cause any noticeable disturbances to the balloon.**

We will record all information with an on-board data acquisition system powered by a BASIC Stamp microcontroller. The data acquisition will record various parameters such as each nozzle's thrust force, atmospheric pressure and temperature, and air supply temperature and pressure. The weight budget for this project will remain under 10 kg for the large interface. This mass will include the nozzle systems, compressed air tank, and sensors. We expect most of the system mass will result from the compressed air tank. We are confident that the payload size constraints will not be a limiting factor for our design.

Procedures will be established to implement our design with the HASP payload. The primary focus of this project will be to first design, optimize, and fabricate the nozzle systems to be tested, and to then make certain that our system will remain functional when merged with the HASP payload. We would like to incorporate our design as easily as possible with the HASP system so that it does not interfere with other payloads. This task will be conducted with safety as a priority.

4 Payload View

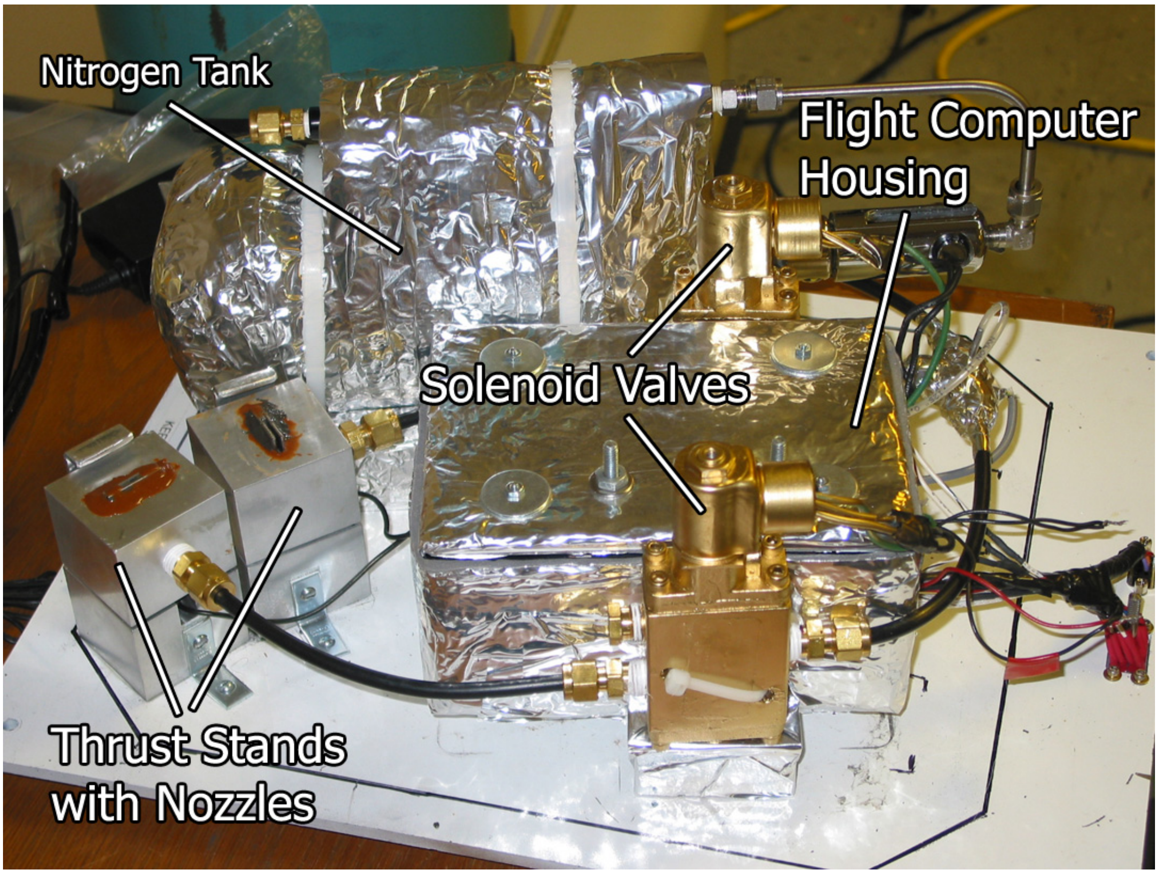

Figure 4: Team Aerospike payload for HASP 2006 as a payload example.

5. Budget:

Materials and supplies:	$ 4,000
Travel:	$ 2,000
Student wages:	$ 4,000
Total:	$10,000