A Preliminary Design Analysis of High Altitude Testing Facilities

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Introduction

Rocket nozzles are designed to operate in the upper atmosphere where air pressure is significantly lower than at ground level. High expansion ratio rocket nozzles are used to optimize thrust levels at these high altitudes. In a standard ground test, the exhaust plumb is overexpanded due to the high ambient air pressure. High-altitude testing (HAT) facilities are able to simulate high atmosphere conditions by systematically lowering the air pressure around the nozzle exit by use of the exhaust plumb itself, diffusers, and ejectors. A HAT facility can simulate altitudes of up to 100,000ft while the engine is running at full capacity. These low pressures are obtained by utilizing the momentum from the exhaust plumb, as well as any ejectors that are employed, to pull air out of the testing section of the apparatus. There are different types of blowdown style HAT facilities, ones with no ejectors, and ones with one or many.

Table 1: Types of HAT Configurations

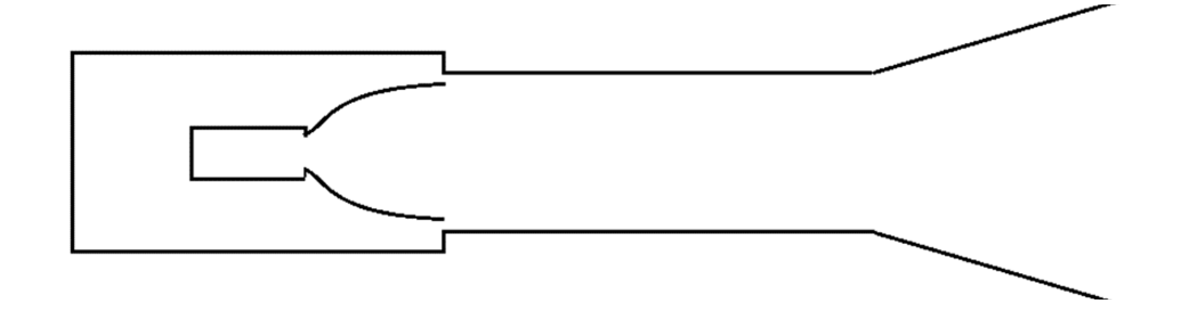
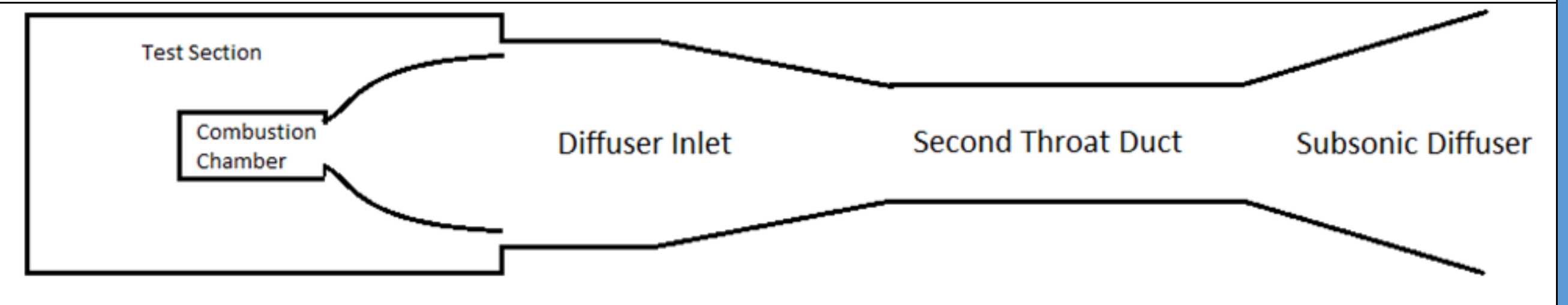
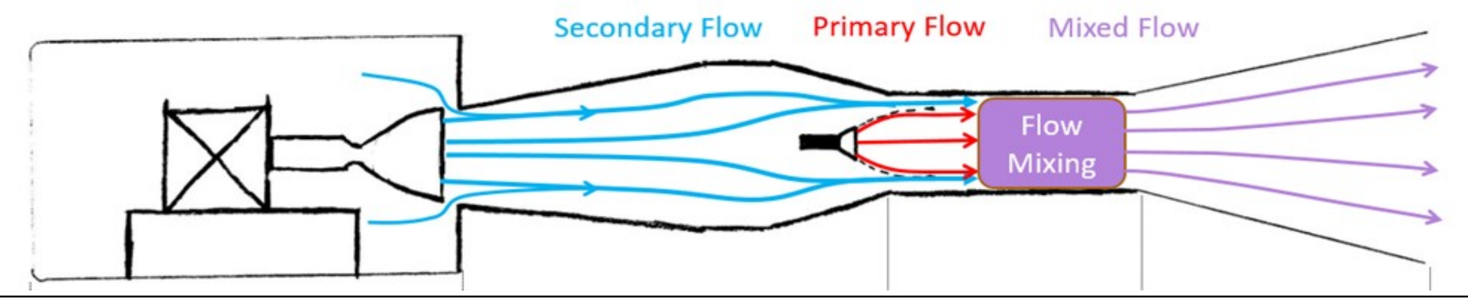
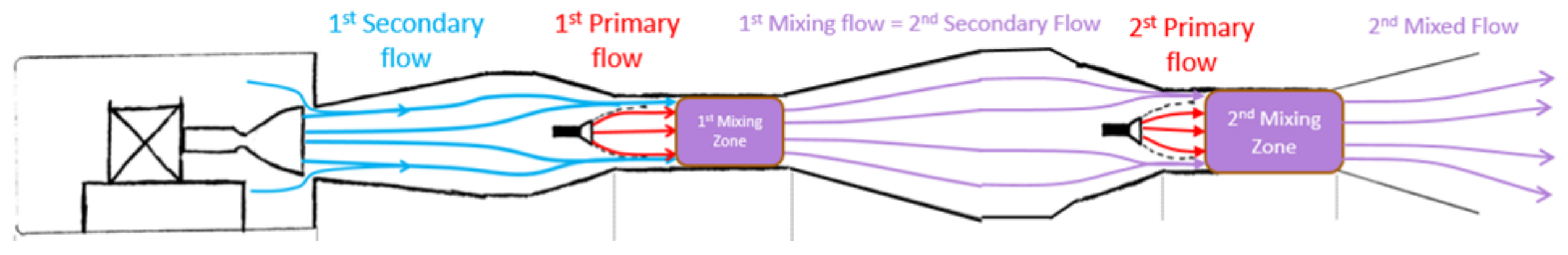
Constant-Area Exhaust Diffuser (CAED)	
Second-Throat Exhaust Diffuser (STED)	
Single-Stage Ejector Diffuser (SSED)	
Two-Stage Ejector Diffuser (TSED)	

Table 1 tabulates the four main types of blow-down style HAT facilities. The first two only utilize the momentum of the exhaust plumb to induce the low pressures, while the latter two utilize high pressure ejectors to create back pressure assisting the exhaust flow.

Approach

Analytical and numerical methods exist that are capable of approximating the flow-field inside of each type of HAT facility. An analytical method will be employed first for each design, followed by a numerical confirmation of the results with ANSYS FLUENT CFD software. If there are discrepancies in the results, models will be altered and analysis will be iterated until consistent results are found.

Methodology

Five different analytical models are used to predict how a flow-field will change within each type of HAT facility, more so for the CAED and STED facilities because they lack the complexity of ejectors and their resulting flow-field.

Table 2: List of Utilized Analytical Models

Model	Description
Normal Shock Model	Commonly used to determine the minimum second throat size to allow optimum flow. Simplest of the five models.
Momentum Model	Accounts for skin friction within the second throat.
Weighted Shock Model	Estimates the flow-field of diffusers with diffuser inlet to nozzle exit ratios of less than 1.5
Isentropic Compression Model	Estimates flow-field of diffusers with inlet to nozzle exit ratios of greater than 1.7
Three-Zone Model	A combination of the weighted shocks model and the isentropic compression model

After analysis of the flow-field with a combination of the previously stated models, numerical analysis will validate the results using the Shear Stress Transport (SST) model utilizing the k-epsilon models in the free stream and the k-omega models near the boundaries. Many iterations of these analyses are performed with slightly different geometric parameters and pressures so as to provide a large set of data to analyze.

Preliminary Findings

Analytical methods are solved using MATLAB, though some tweaking still needs to be done to match the analytical solutions to the numerical ones. The following are a few preliminary conclusions that can be made. The size of the test chamber does not affect steady state operation, only the transient from startup. The area of the second throat is the leading factor in how the facility will perform, also the diameter of the diffuser inlet. The CAED and STED facilities are the simplest, but more inefficient and less effective than the SSED and TSED facilities.

Preliminary Conclusions

Much more work is still needed to gather reliable data. Fixing errors in the Matlab code, applying finer meshing in the FLUENT simulations, and more thorough data analyses still need to be performed to draw accurate conclusions. The ultimate goal is to create an optimized design for the Embry-Riddle community to fabricate and use to test high expansion ratio rocket nozzles.

Future Directions

Furthering current analysis of steady state flow regimes will remain priority. Investigation into transient flow regimes between startup and steady state operation will be the next step. Determining parameters that affect facility operation and how they affect it will be investigated and thoroughly documented. Knowledge of various fluid flow types and regimes will also be practiced and applied.

Acknowledgements

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