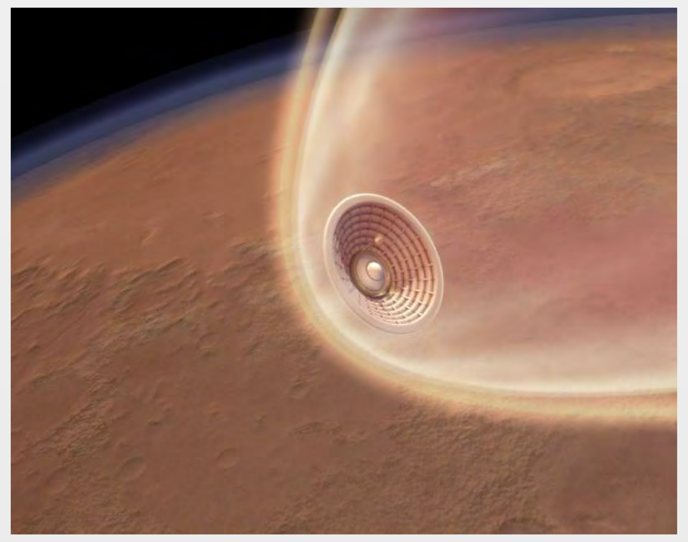
MINIATURE SUPERSONIC ROCKET

Goal is Mars: Alex Burrows Junyan He Chaebin Kim Ben Wood
Advisors: Dr. Kuan Chen Donovan Chipman

Department of MECHANICAL ENGINEERING
THE UNIVERSITY OF UTAH

Introduction



Supersonic retropropulsion is a promising way for space-shuttles to decelerate when reentering the Earth or during Mars landing. The goal of our project is to simulate the physics of supersonic retropropulsion by visualizing and recording the flow effect (shock wave) and measuring the parameters such as pressure, velocity and thrust.

Purpose

Due to the high cost of conducting full scale experiments, this field is seldom touched by university researchers. The miniature rocket project provides a new perspective to study this complex phenomenon: reproduce the results using a small scale experimental setup.

Problem Statement

This project was ongoing from last year and 3 main problems need to be solved: short running time, humidity, and manual operation. This year, the improved version of set up needs to be designed and constructed to have longer running time and contain minimum moisture condensation. The new setup will also be highly automated, requiring minimal human effort.

Design

Metrics	Design Value	Achieved value
Experiment run time	10s	14s
Moisture condensation (Binary)	NO	NO
Wind tunnel flow velocity	Mach 1.5	Average Mach 1.61 Max Mach 1.78
Thrust of the nozzle	60N	38N
Cost of raw materials	<$500	$451

Larger tank capacity
- Six 60-gallon storage tanks + one 80 gallon expansion tank

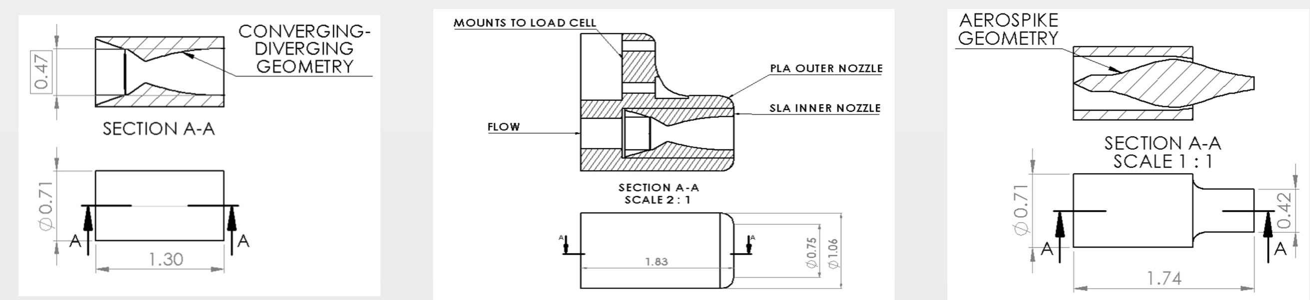
Removal moisture in the air
- A filter and desiccant air dryer were installed

New nozzle manufacturing method
- Inner geometry printed with SLA printer, highly accurate and smooth finish
- Outer shell printed with PLA, high strength

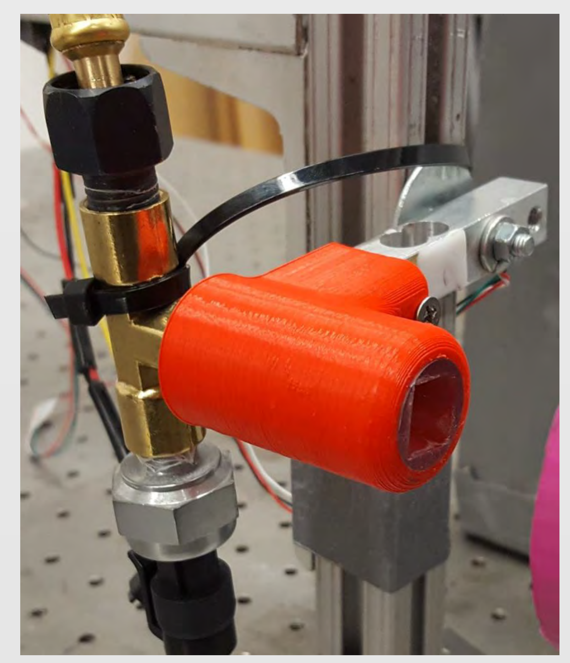
Integrated data collection / experiment control system
- Temperature, pressure, humidity, thrust are measured
- A LCD screen displays the current time during recording
- A master switch controls the start/stop of the experiment

Nozzle Redesign

Two nozzle profiles, one converging-diverging (Left) and one aerospike (Right) were designed and manufactured.



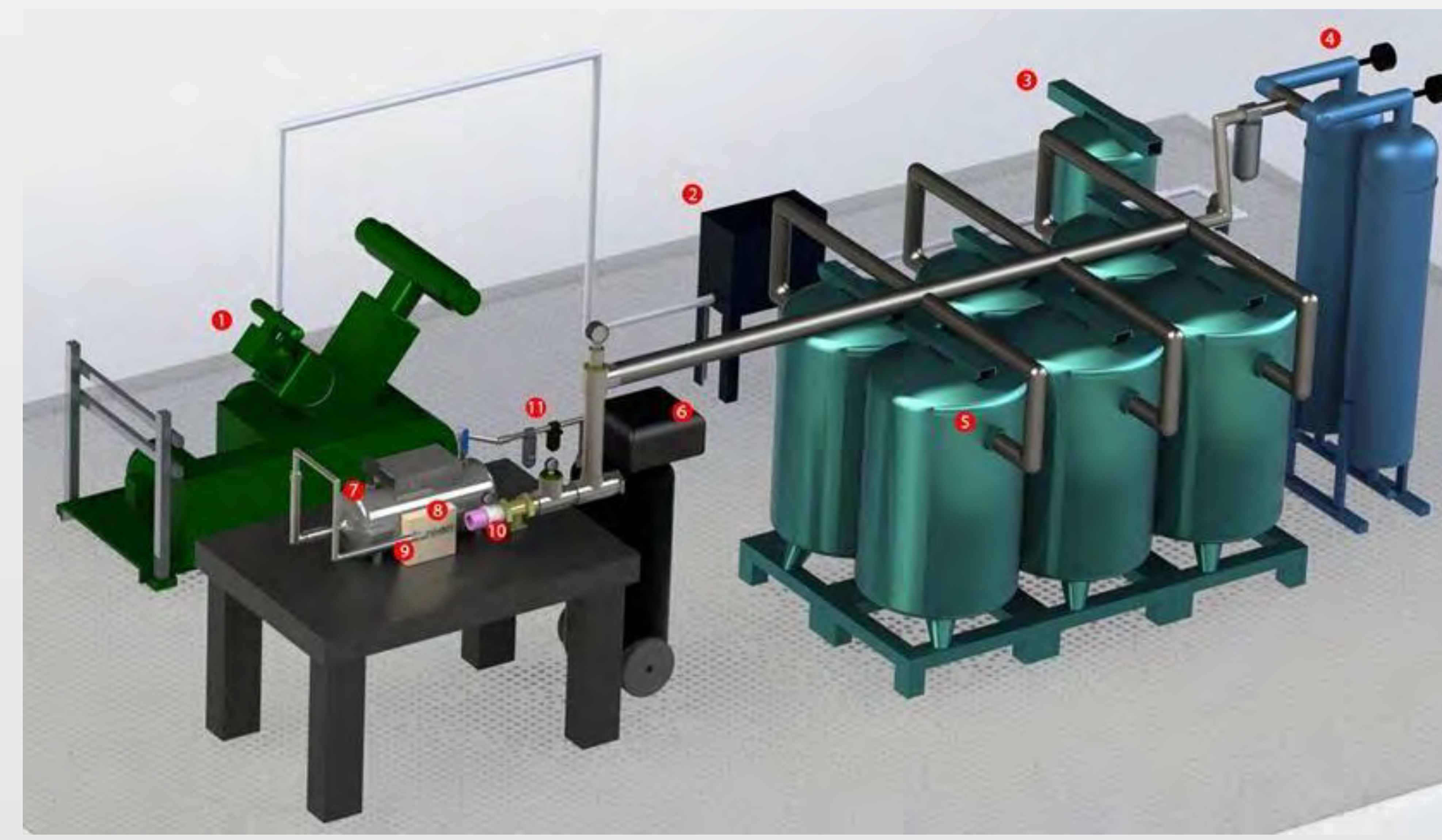
A finite-element analysis was performed on the nozzle and we found that stereolithography(SLA) printed nozzles are not strong enough to withstand pressure and thrust. However, SLA prints geometry accurately and has minimum surface roughness. Our solution:
- Print the internal geometry with SLA printer
- Print a PLA outer shell to cover the inner one



The internal piece has shape of a cylinder. Therefore, one can freely change the internal geometry to make different types of nozzles but can still fit in the same outer shell.

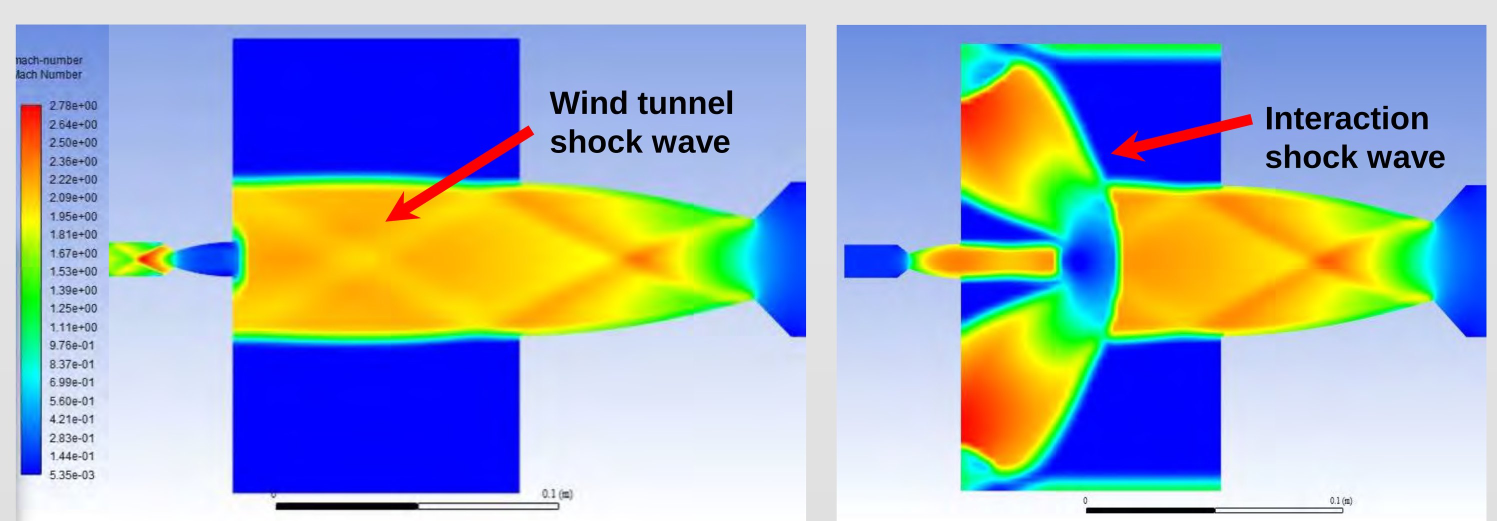
The composite design held up to the applied pressure and thrust of the system. It provides both the strength and accuracy needed using the advantages of both print materials.

Model Rendering



1. Compressor
2. After-cooler
3. Expansion tank
4. Air-dryer
5. Storage tanks
6. Compressor for nozzle
7. Storage tank for nozzle
8. Projector screen
9. Nozzle
10. Wind tunnel
11. Nozzle air-dryer

CFD Simulation

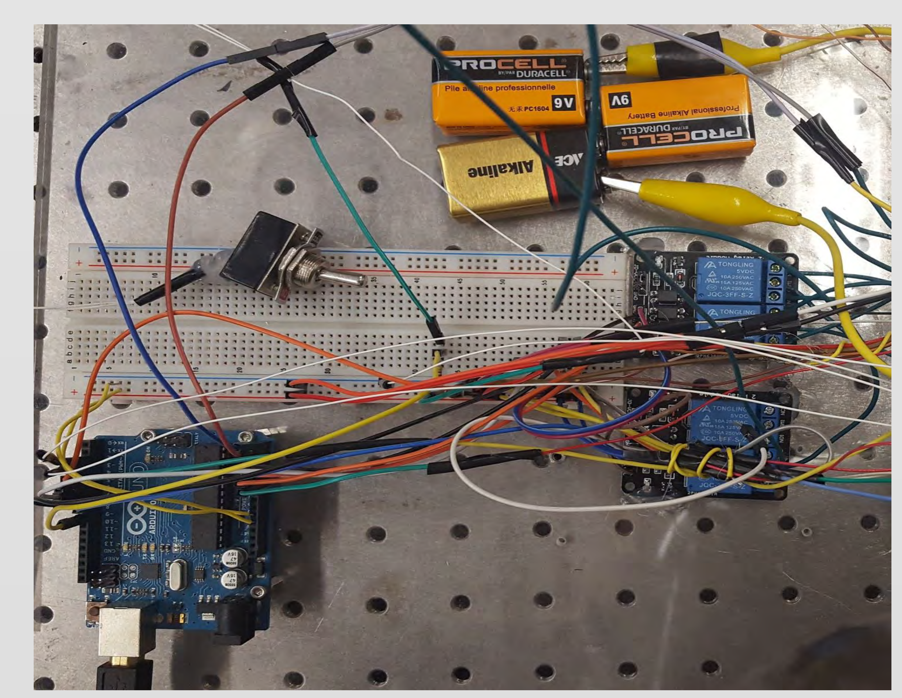


CFD simulations were done on the converging-diverging nozzle to evaluate its interaction with the wind tunnel. On the left shows the Mach number plot of a simulation where the internal pressure of the nozzle was set to 0. On the right shows the same plot for a simulation where the internal pressure of the nozzle was set to 145 psi, the applied pressure in the experiment.

Looking at the left plot, one can clearly see the shock wave of the wind tunnel. Comparing the two plots, one can see that when the nozzle was turned on, the shockwave due to the supersonic retropropulsion is clearly visible. The simulated result also matches closely with what was observed in the experiment.

A simulation on the aerospike nozzle was also conducted. However, due to the miscalculation in the cross-section, the opening is too small for the mass flow-rate of the system. Therefore, the flow coming out from the nozzle is minimum and the shock wave can hardly be detected. The optimization of the aerospike nozzle is left as an unfinished task for the following team.

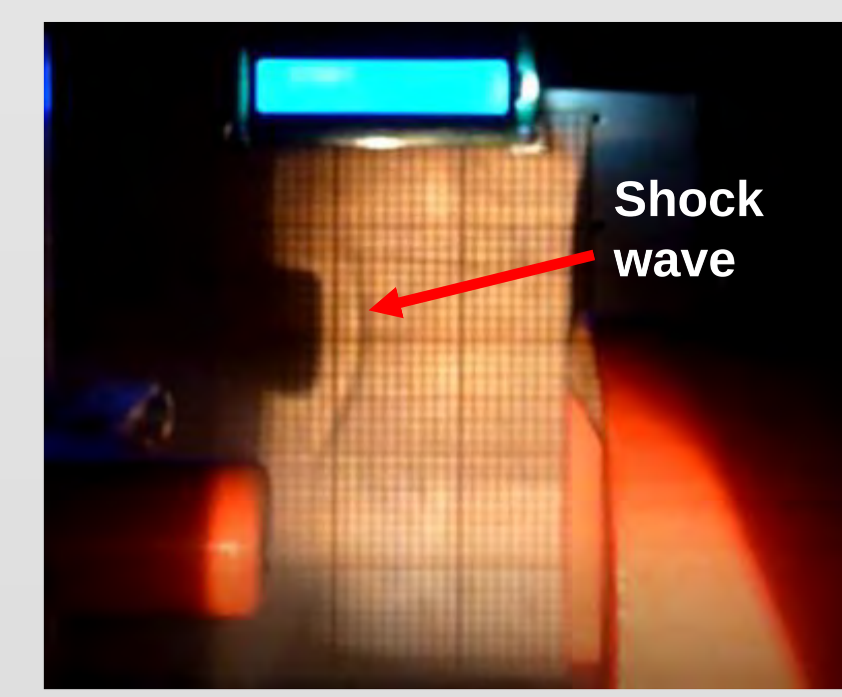
Control System



An Arduino-based integrated data acquisition and control system was built. A master switch controls the start/end of the experiment and electric/pneumatic actuators ensure the fast response of the system. Data from all sensors are sent to the Arduino, where they are post processed. The Arduino then prints the data to the screen.

Testing revealed that all valves open/close within 0.8s of the action of the master switch. The Arduino collects sensor data at 5Hz and load cell reading at 1Hz. This meets the need of our customers.

Shock Wave



One important metric of this project is the visualization of the shockwave. In this project, a projector is used to cast a shadow of the shockwave on the screen.

With the increased and more sustained flow from the wind tunnel, the shock wave becomes much more pronounced. It is also worth noting that no moisture comes out from the wind tunnel, proving that our air-dryer system is effective. A comparison to the CFD shock wave results show close agreement between our simulation and experiment observations.