Reaction Control System for High Altitude Balloons

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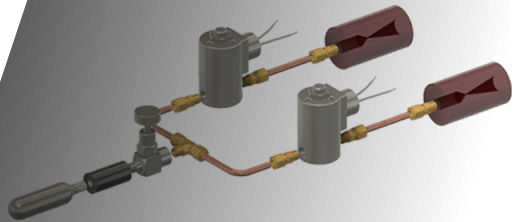


Introduction

- What is a high altitude balloon (HAB)?
- What is a reaction control system? (RCS)?
- Why collect data with HAB payloads? (HABPs)?

Motivation

- There are problems with HABPs!
  - Sporadic winds control and limit data acquisition
- Solution: integrate a reaction control system (RCS)

Options for RCSs

1. Reaction/Momentum wheels
2. Control moment gyroscope
3. Combustion thruster
4. Cold gas thruster

Gyroscopic Reaction Control Systems

Figure: Reaction wheels

Cold Gas Thruster Reaction Control Systems

Figure: ”Four of VACCO’s extremely robust, man-rated triad assemblies were used in each Space Shuttle MMU”

Phases

1. Characterizing a CGT
2. Integration the CGT into a HABP

Nozzles

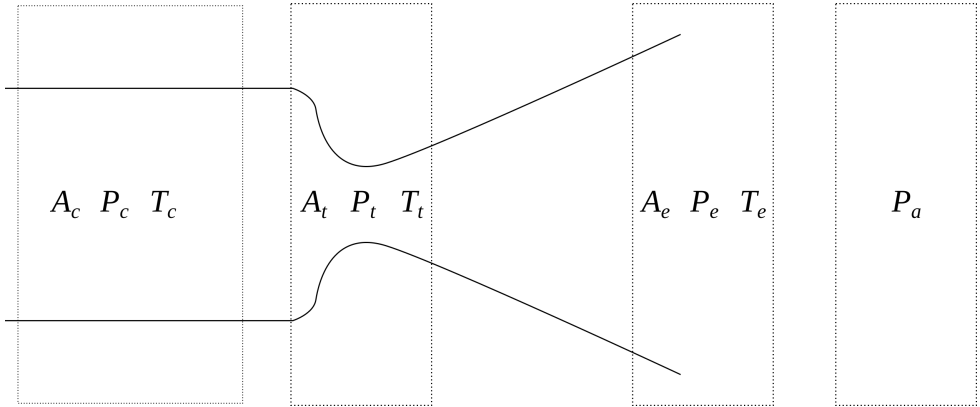


Figure: Basic nozzle design and some parameters.

Existing Nozzle Theory

$$\frac{A_t}{A_e} = \left(\frac{\gamma+1}{2}\right)^{\frac{1}{\gamma-1}} \left(\frac{P_c}{P_a}\right)^{\frac{1}{\gamma}} \sqrt{\left(\frac{\gamma+1}{\gamma-1}\right)\left[1-\left(\frac{P_c}{P_a}\right)^{\frac{\gamma-1}{\gamma}}\right]} \tag{1}$$

Optimum expansion ratio for nozzle

Nozzle Design

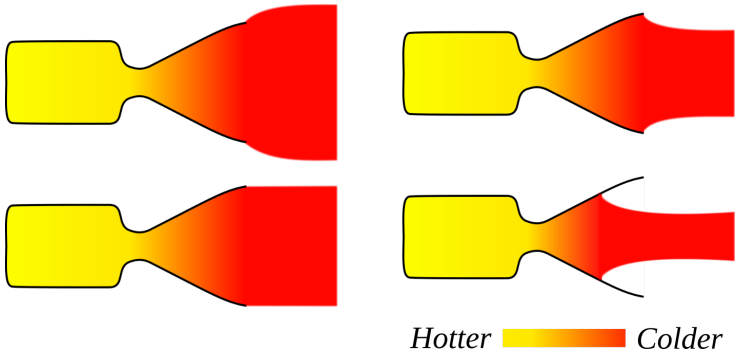


Figure: Nozzle expansion and temperature gradient visualized.

Specific Impulse

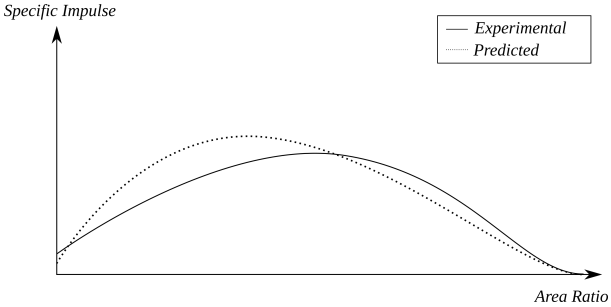
Definition of specific impulse:

$$I_{sp} = \frac{\textit{Thrust}}{\textit{rate of mass ejection}} \tag{2}$$

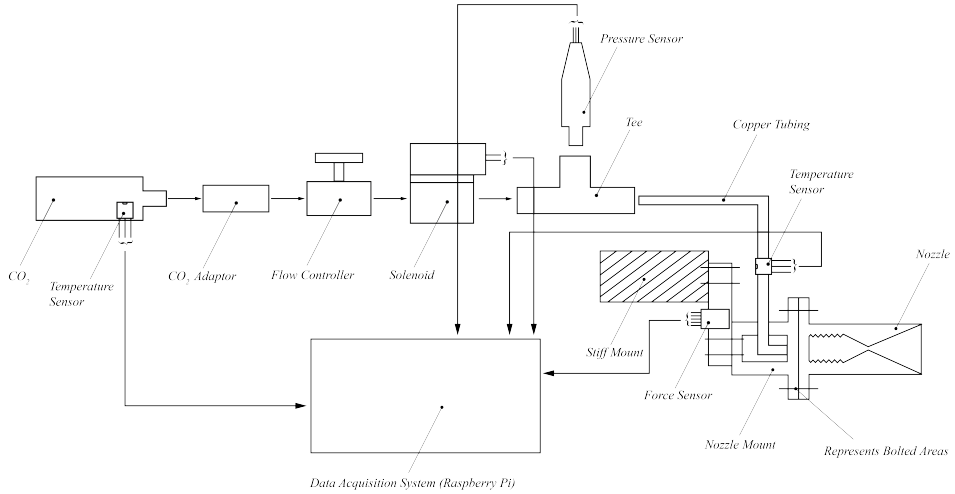
$$I_{sp} = \left(\frac{2\gamma G T_c}{(\gamma - 1) W} \left(1 - \left(\frac{T_e}{T_c} \right) \right)^{\frac{1}{2}} \right) + \left(\left(\frac{T_e}{T_c} \right)^{\frac{\gamma}{\gamma - 1}} \right) \epsilon \sqrt{\frac{P_c}{\gamma \rho_c}} \left(\frac{\gamma + 1}{2} \right)^{\frac{\gamma + 1}{2(\gamma - 1)}} \tag{3}$$

Derived specific impulse

Develop an Experiment



Develop an Experiment



Manufacturing

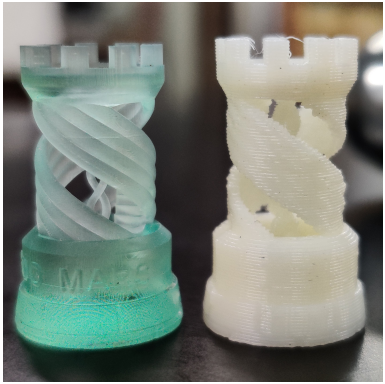


Figure: Left: ELEGOO MARS, Right: uPrint SE Plus

Manufacturing

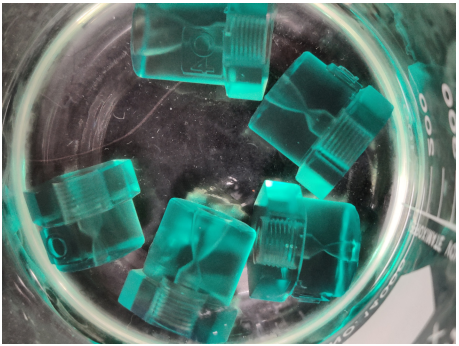
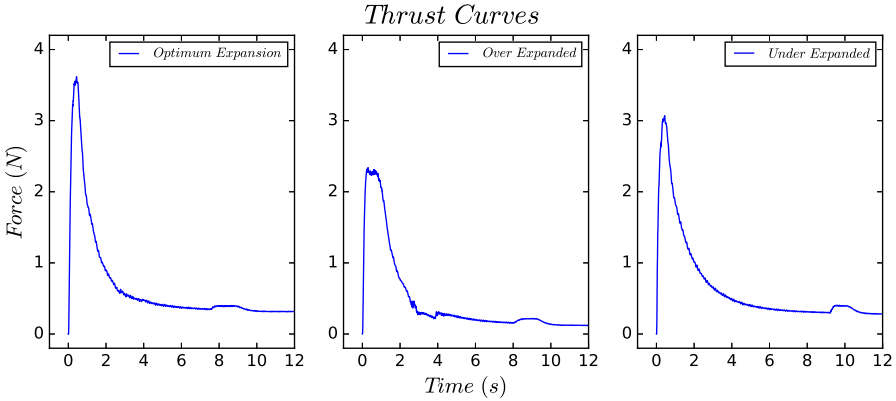


Figure: Nozzles bathing in isopropyl alcohol.

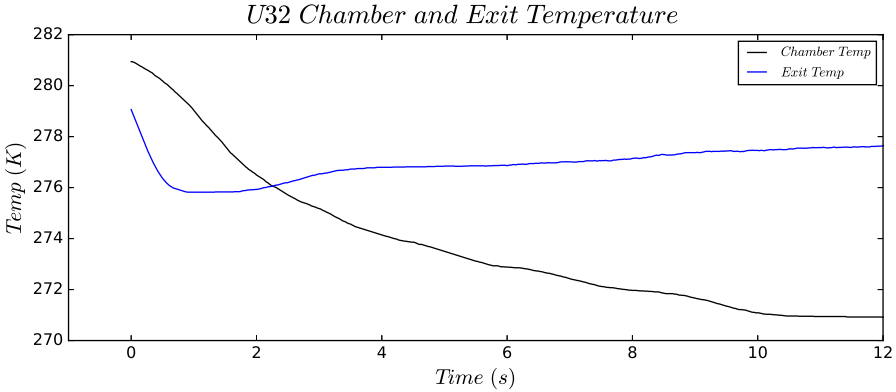
Data Collection



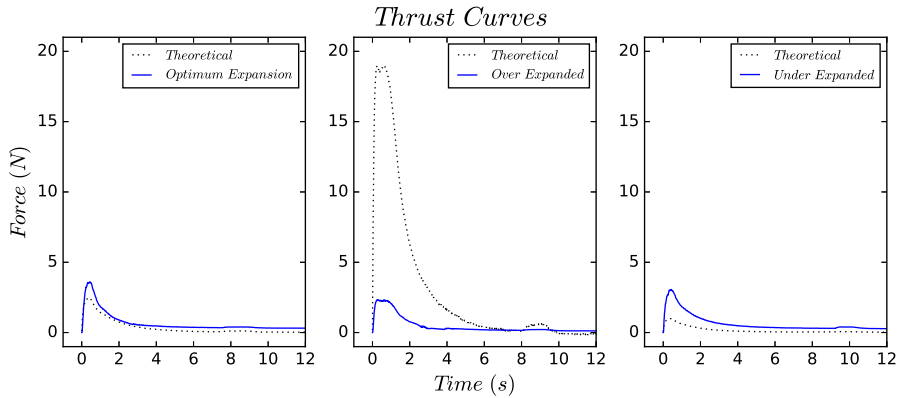
Analysis

$$F = A_t P_c \left(\sqrt{\frac{2\gamma^2}{\gamma - 1} \left(\frac{2}{\gamma + 1} \right)^{\frac{\gamma+1}{\gamma-1}} \left(1 - \frac{T_e}{T_c} \right)} + \left(\left(\frac{T_e}{T_c} \right)^{\frac{\gamma}{\gamma-1}} - \frac{P_a}{P_c} \right) \epsilon \right) \tag{4}$$

Analysis


U32 Chamber and Exit Temperature
Chamber Temp
Exit Temp
Temp (K)
Time (s)
282
280
278
276
274
272
270
0
2
4
6
8
10
12

Analysis


Thrust Curves
Theoretical
Optimum Expansion
Over Expanded
Under Expanded
Force (N)
Time (s)
0
5
10
15
20
0
2
4
6
8
10
12

Solutions

- Placing thermocouples in better locations
- Measure change in mass over time

Integration into a Payload

- After optimizing nozzle design, the design would be integrated into a HABP.
- More testing
  - Simulating windy conditions
  - Fuel storage ability, etc

Payload Integration

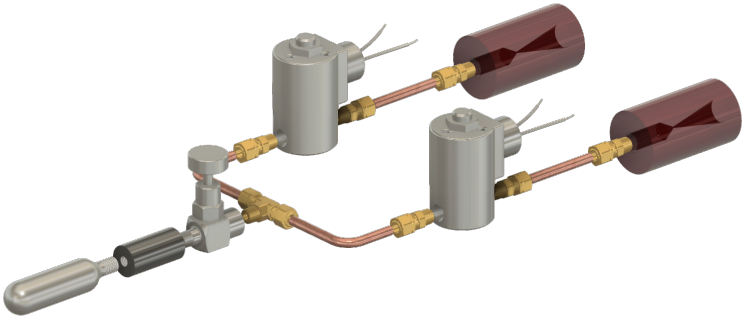


Figure: CAD Render of the plumbing system for my RCS.

Conclusion

1. Missing some information to complete characterization of the CGT
2. Solid foundation for future work
3. Integration into HABP
4. Flight on board a HAB

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