Propulsion

Bradley Pitts
Propulsion Requirements

- **Safety**
  - Non-toxic byproducts
  - Non-touch hazard: -18C < T < 50C

- **Propellant**
  - Propellant supply sufficient to last at least 20 seconds

- **Control**
  - System must provide for 6 DOF
  - System must provide constant performance throughout flight duration

- **Thrust**
  - An acceleration of at least 0.16m/s²
- Liquid CO₂ system
- Solenoid valves provide actuation
- System as designed for the NAR:
• Bare minimum design
  – Focused on making the system operable
  – Did not worry about safety requirements
  – Did not worry about excess tubing/wiring
• Propulsion System Major Components
  – CO₂ Propellant Tank
  – Fixed Pressure Regulator - 850 psi to 70 psi
  – 7-Way Manifold
  – 6 Micro-solenoid Thruster Pairs
    • Solenoids
    • Nozzles
    • Spacers

• Other System Components
  – Tubing
  – 3-Way Manifolds
  – Electrical Connectors
  – Tank Cradle/Heat Sink
Prototype Components

- Thruster
- Mounted CO₂ tank
- Solenoid Valves
- Lexan Panel
- Tubing
- Electrical Connector
- Nozzles
- Spacer
- 7-Way Manifold
- Tank
- Cradle
- Regulator
- Connection Screw
- T-connector
- Structures
- Propulsion
- Metrology
- Power
- Avionics
- Comm
- Software
- Systems

Program Plan

Summary
• Thrust = \( M_\text{dot} \cdot V_{\text{exit}} + A_e (P_e - P_a) \)

• Four Regimes
  (Determined by ratio of \( P_{\text{upstream}}/P_{\text{downstream}} \)):
  - \( M_N = 1, M_V < 1 \)
  - \( M_N = 1, M_V = 1 \)
  - \( M_N < 1, M_V = 1 \)
  - \( M_N < 1, M_V < 1 \)

• Subsonic Flow: \( P_{\text{throat}} = P_{\text{downstream}} \)

• Sonic Flow: \( M = 1 \)
Analytic Model:
- Choose $P_o$, $A_v$
- Cycle through all $0 < M_v < 1$

\[
\frac{A_n}{A_v} = M_v \left( 1 + \frac{\gamma - 1}{2} \right) \left( 1 \frac{\gamma - 1}{2} M_v^2 \right)^{\frac{1}{2}}
\]

\[
\frac{F}{P_0 A_n} = (\gamma + 1) \left( \frac{2}{\gamma + 1} \right)^{\frac{\gamma}{2}} \left( 1 + \frac{\gamma - 1}{2} M_v^2 \right)^{\frac{\gamma}{2}} - \frac{P_a}{P_0}
\]
Propulsion Prototype Results

- Accomplishments
  - 6 DOF
  - Prototype Specs:
    - Thrust = 0.26 N
    - Lifetime: 20 sec ≤ t_L ≤ 1800 sec (30 min)
  - Actuated Firings through Avionics and Communication Systems

- Prototype Problems
  - Pressure leaks
  - Time needed to make system modifications
  - Liquid CO₂ build up downstream of regulator
  - No pressure safety features
  - Excess wiring/tubing
SPHERES  Propulsion Requirements Check

16.684 CDIO CDR Presentation

Objective

Motivation

Systems

Sub-systems
  - Structures
  - Propulsion
    - Metrology
    - Power
    - Avionics
    - Comm
    - Software
    - Systems

Program Plan

Summary

• Geometry
  – Ensures 6 DOF movement ✓

• Nozzle Design and Testing
  – Provides 0.26 N of thrust (< 0.272N)
  – Assures minimum lifetime of 20 sec ✓

• Analysis
  – Demonstrates that CO₂ toxicity is not an issue ✓
  – Demonstrates that performance is constant throughout flight duration ✓

• Testing
  – Demonstrates an acceleration of 0.11 m/s² (0.157 m/s² w/out test stand < 0.16 m/s²)
  – Reveals minimum tank temperature of -25° C (< -18° C )
Propulsion Modifications

- Solutions
  - Lee Co. MINSTAC tubing and connectors
  - Integration of purge, cut-off, and relief valves
  - Decreasing wiring/tubing tolerances
  - Connect DSP to Heat Sink