



# Pump-Fed Reaction Control Systems

*For Lunar Lander Applications*

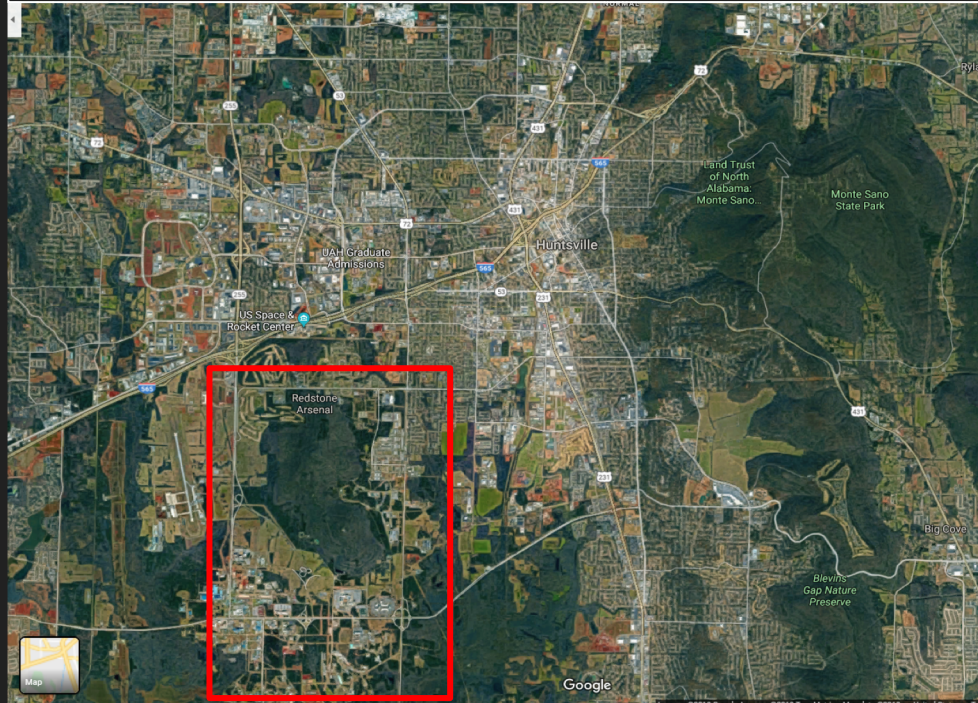
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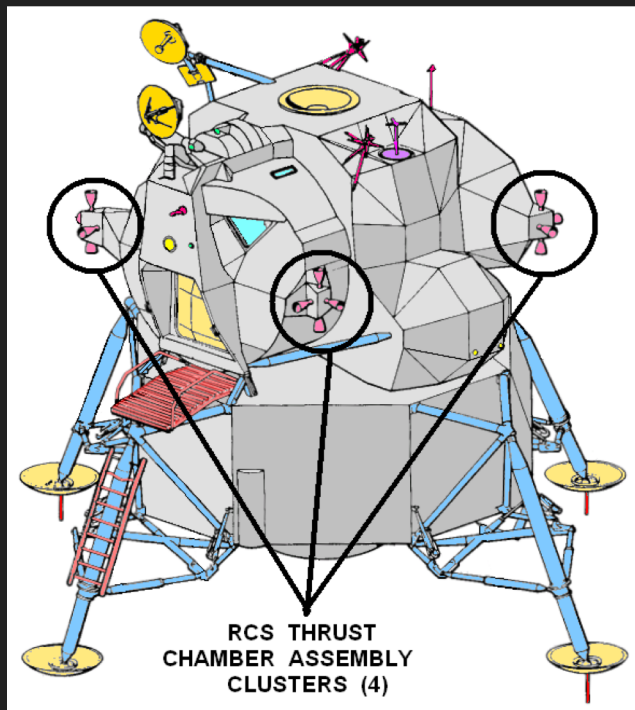


## Redstone Arsenal - Huntsville Alabama





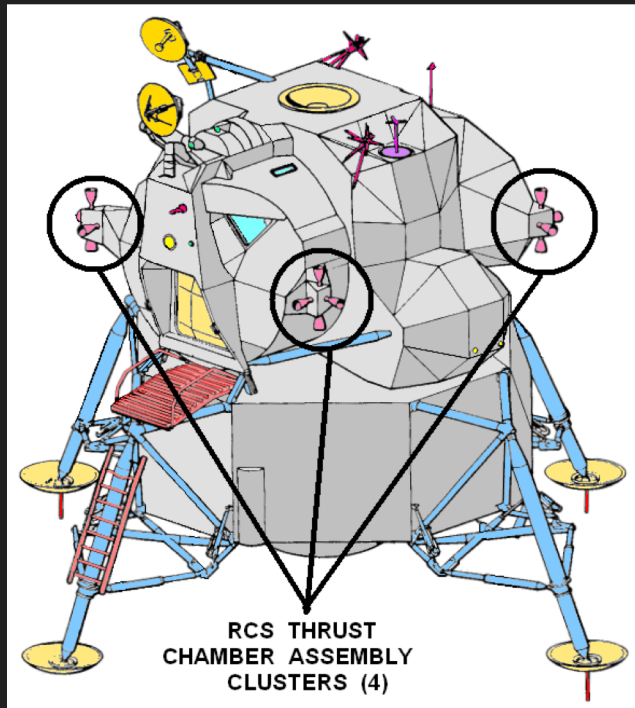
# RCS Systems in Lunar Landers



- Used to make corrections in vehicle orientation
- Historically in “thruster clusters” of three or more nozzles
- Hypergolic propellants as in Apollo missions for quick bursts
- Working Principle: Take in error signal from gyroscope or inclinometer, open corresponding valves to correct



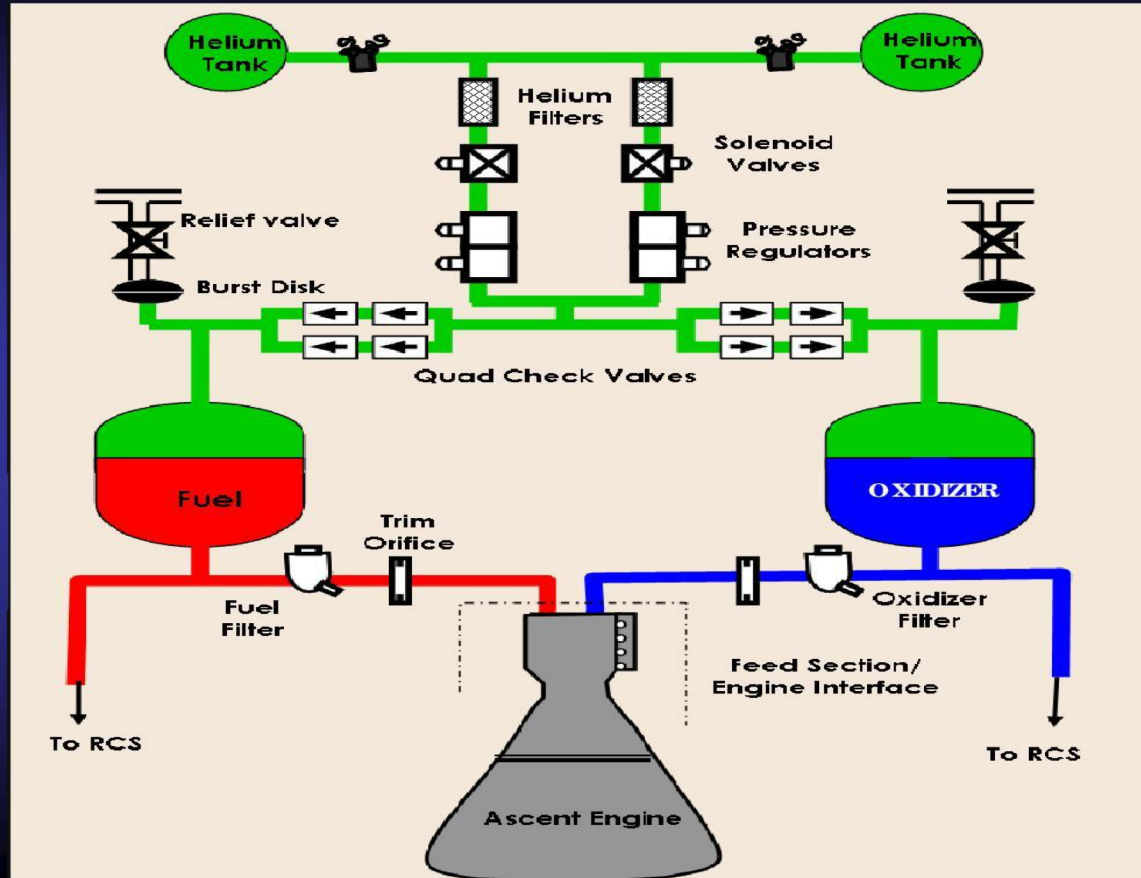
# RCS Systems in Lunar Landers



- Traditionally use helium tanks and associated hardware to pressurize propellants
- Many heavy regulators required to maintain sufficient pressure at thruster inlets during firing sequences

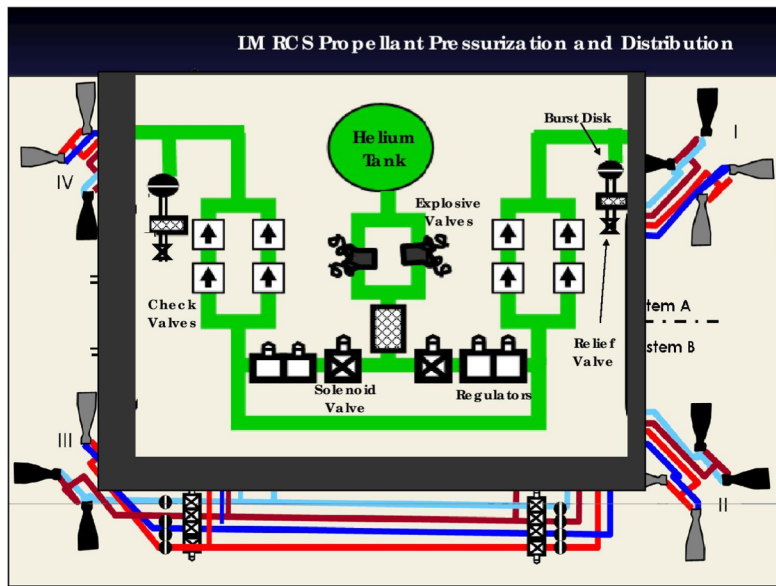


# APS Engine Propellant Pressurization and Flow





# RCS Systems in Lunar Landers



- Pump-fed design instead of high-pressure tanks
- Potential to save weight by using lower pressure tanks with thinner walls, possibly also eliminate helium pressurization
- Pressure can be regulated with just one back pressure regulator and by varying pump speed
- Saving weight means larger payloads for long-term and permanent lunar missions



# Considerations for Pump-Fed Test System

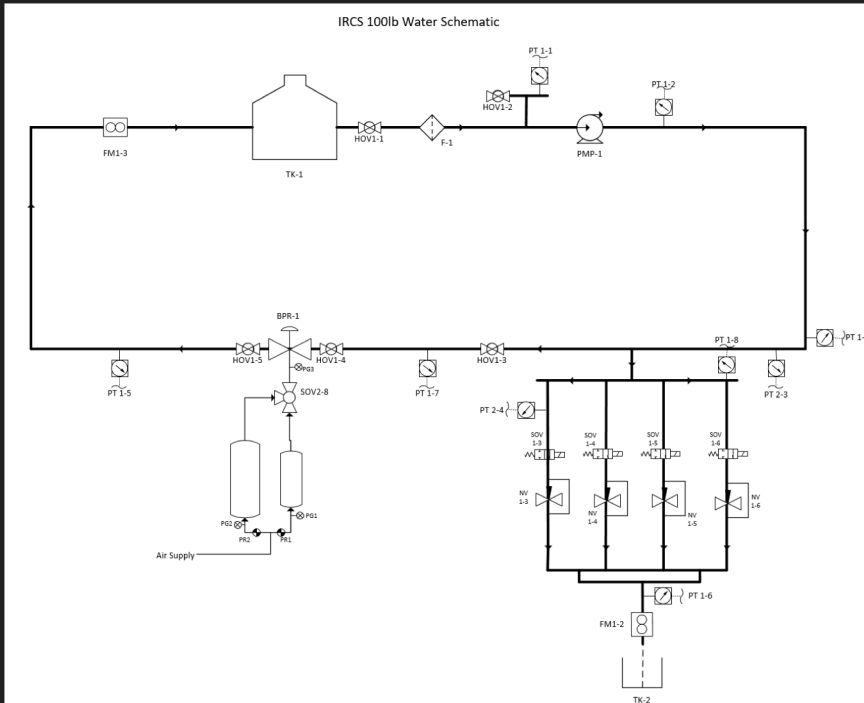
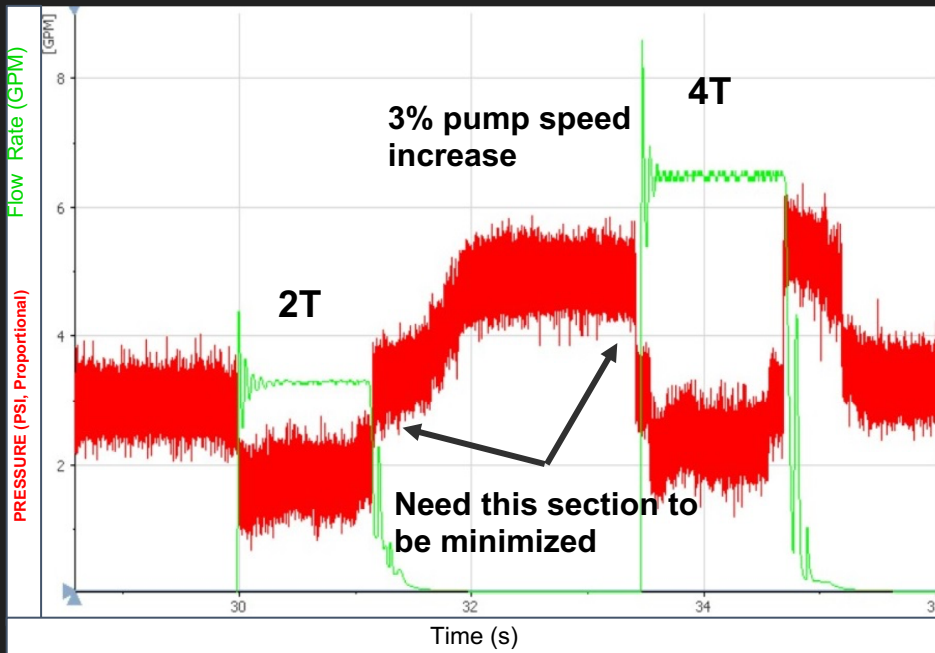


Figure: Four-Thruster Water Test Article

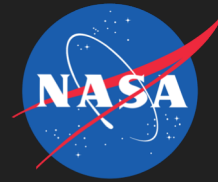
- Constant pressure is paramount, regardless of thruster activity
- Opening thruster valves results in significant pressure slumps
- Back pressure regulator and variable pump speed to modulate pressure



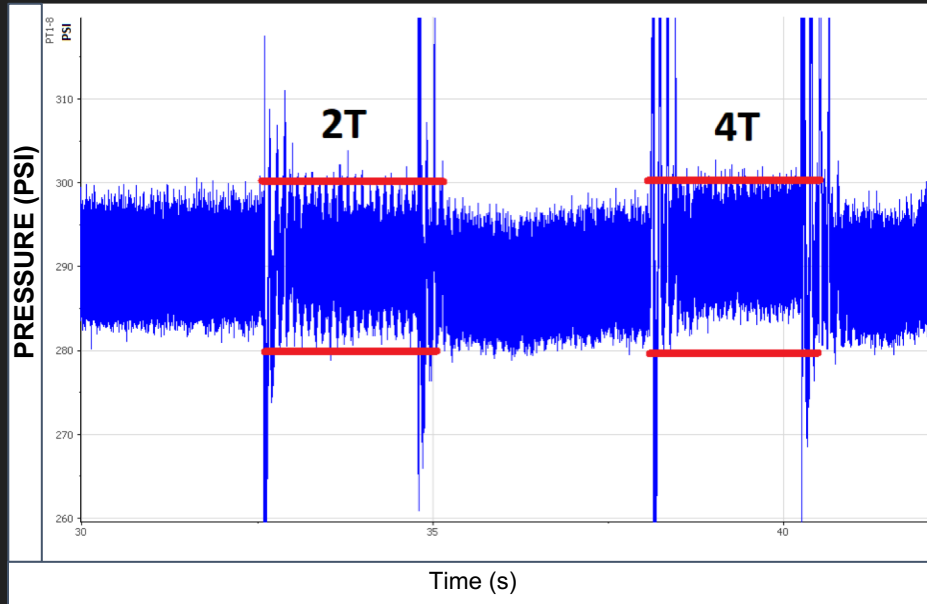
# Considerations for Pump-Fed Test Article



- Began testing with a water pump system
- When orientation error signal is received:
  - Increase speed of pump (increase proportional to number of thrusters) while opening thruster valves (or just before)
  - From graph, pump clearly taking too long to ramp up, but quickly ramping = pressure spikes
  - Not off to a great start..



# Considerations for Pump-Fed Test Article



- Now that looks better
- How were the two previous problems mitigated?

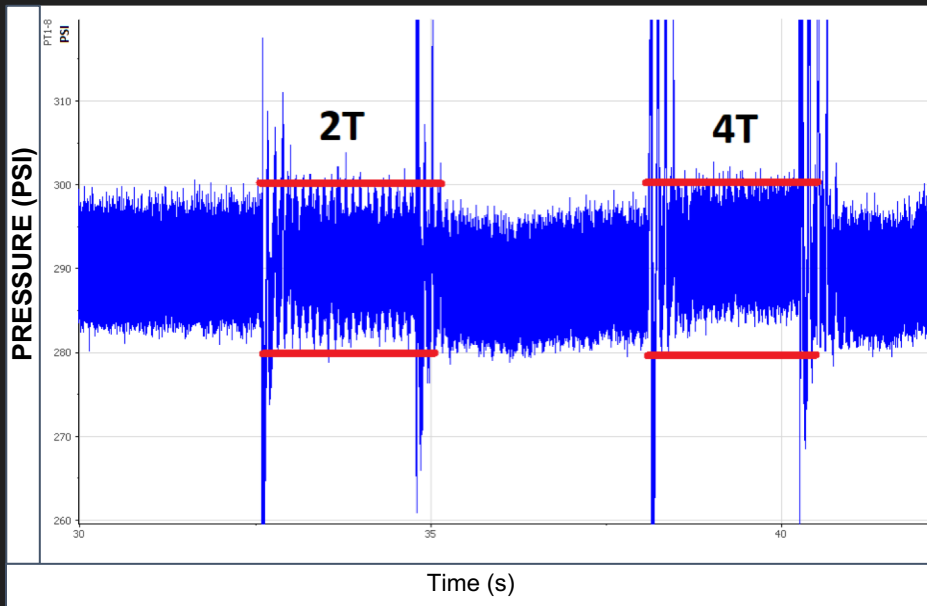


 100  100 THE INTERNET 100  100 

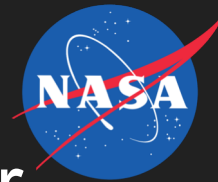




# Considerations for Pump-Fed Test Article

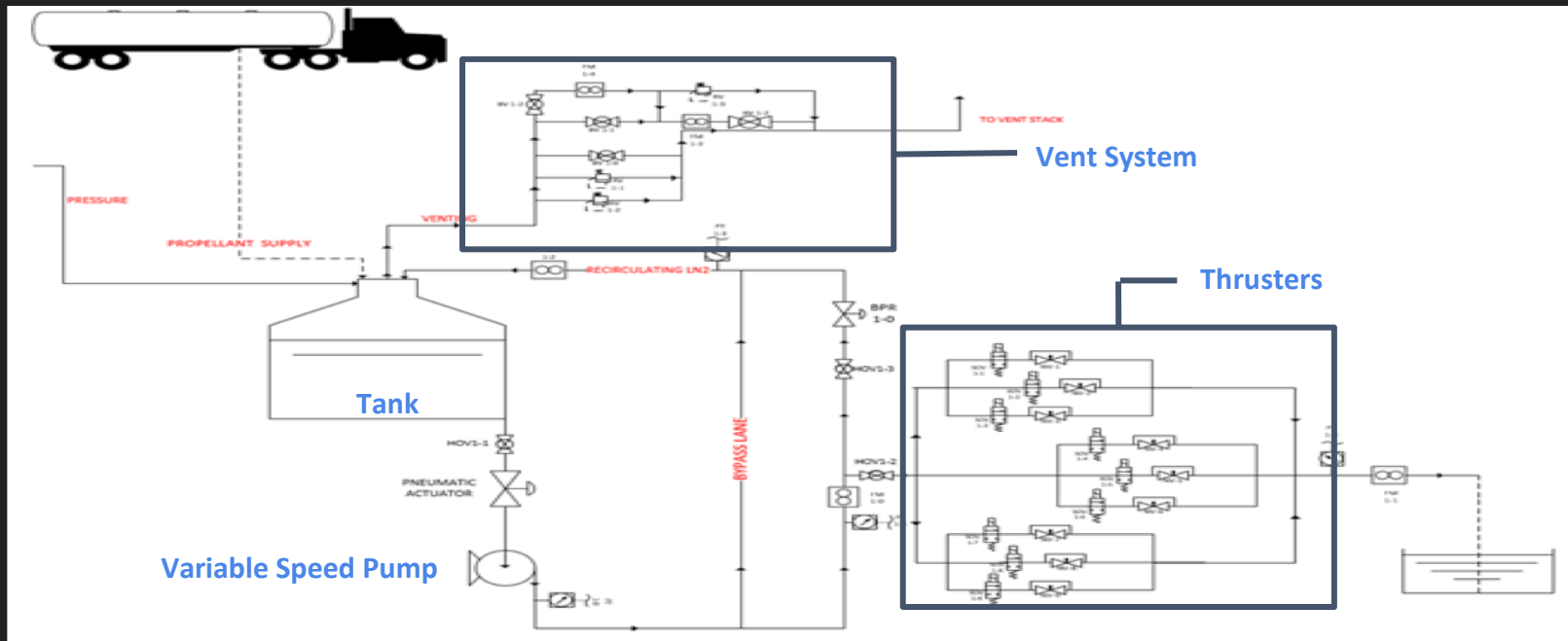


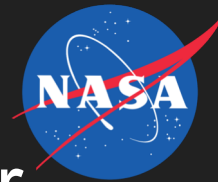
- Set pump to very quickly ramp as soon as the valve is opened
- Again increase speed proportionally with number of thrusters
- Simultaneously (or even slightly ahead of time) decrease BPR setting to bleed off extra during pressure spike



# Hands on at Marshall Space Flight Center

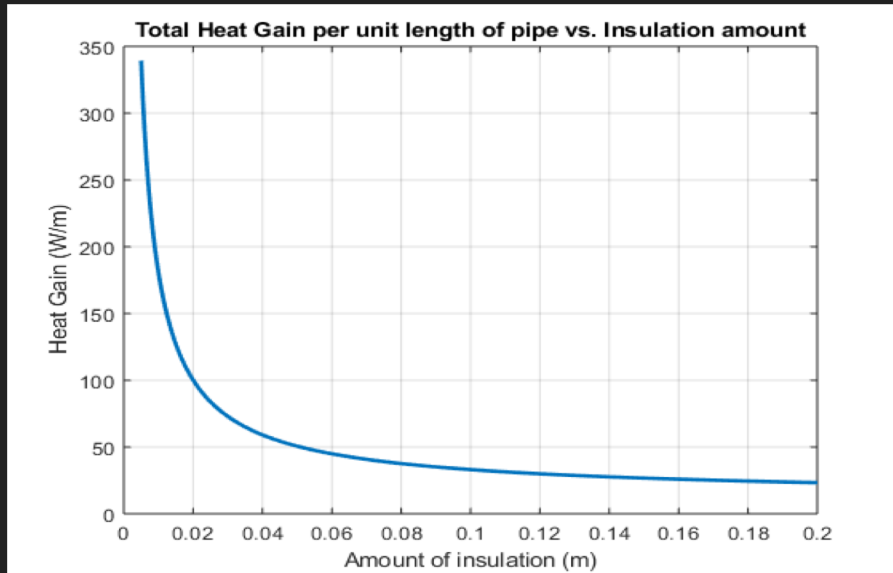
## Moving to Cryogenic Liquid Nitrogen System



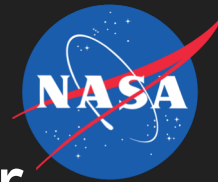


# Hands on at Marshall Space Flight Center

## Moving to Liquid Nitrogen System

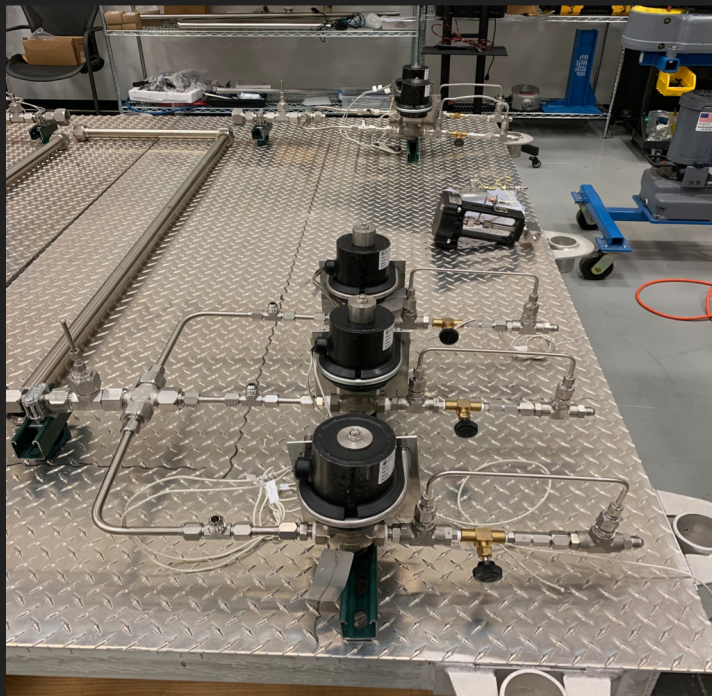


- Start by sizing pipes, 1" OD fits our flow rates
- Must be sure we can insulate reasonably
- Based on this graph we determined that 3cm of insulation would provide acceptable heat losses through pipes



# Hands on at Marshall Space Flight Center

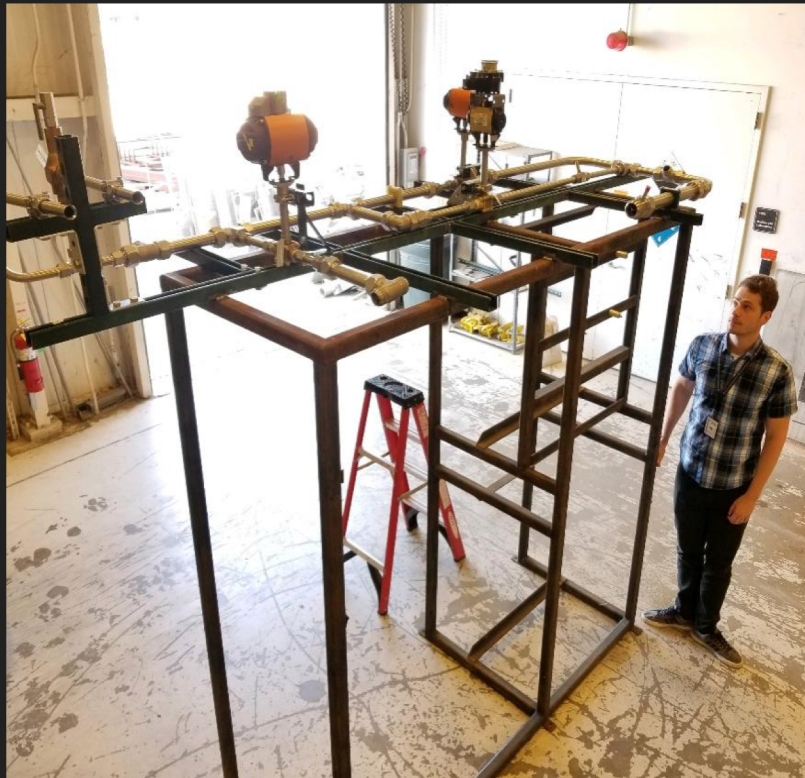
## Moving to Liquid Nitrogen System



- Now know we need a ventilation system
- Learned to cut, bend, flare, fit, and seal tubing
- Spent over half of internship constructing ventilation system
- Refined skill in machining, designing, and 3D printing



# Hands on at Marshall Space Flight Center



- Designed and fabricated iron frame to elevate vent system
- Welded frame together, installed valves and fittings (half finished in picture)
- After finishing vent system, ended internship with miscellaneous fabrication projects for solid rocket team



# Hands on at Marshall Space Flight Center







# Thank You!

And a special thank you to Oregon Space Grant Consortium for funding this internship

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