# Ammonia Vent of the External Active Thermal Control System (EATCS) Radiator #3 Flow Path #2 on the International Space Station (ISS)

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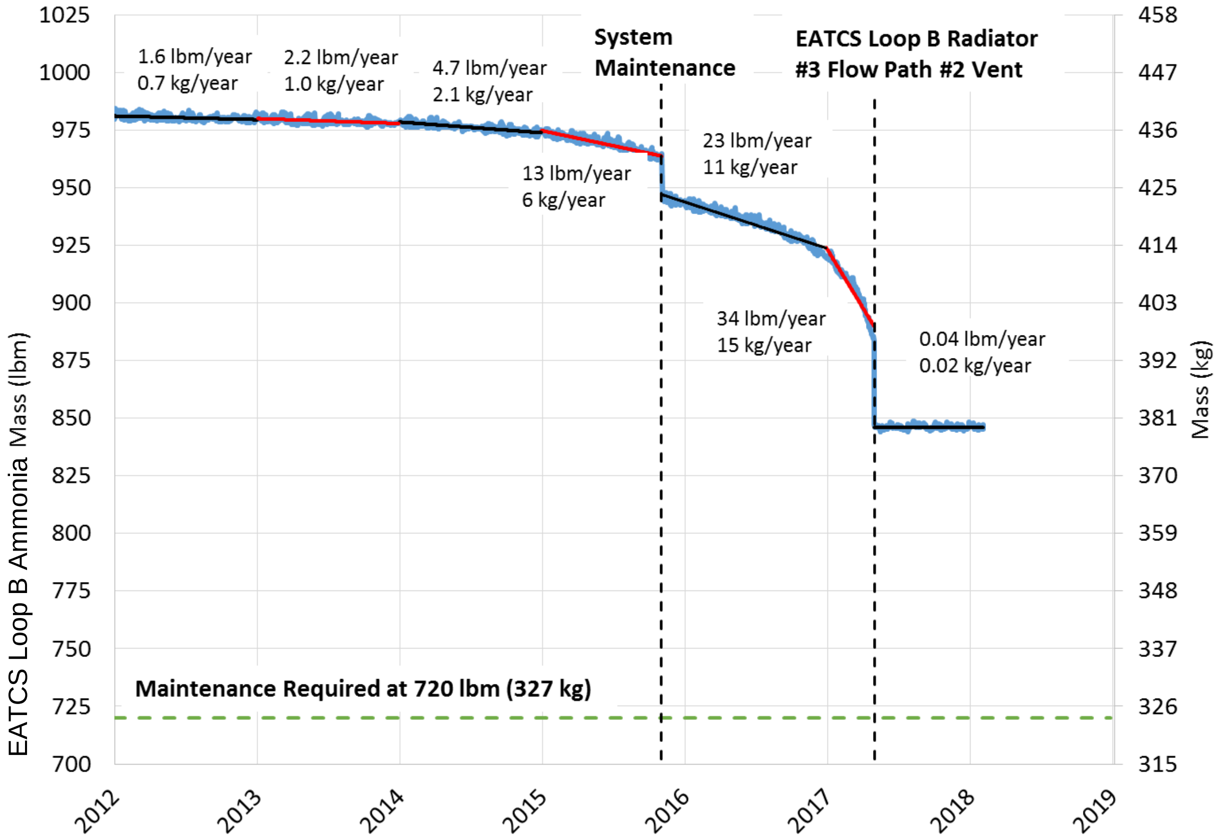
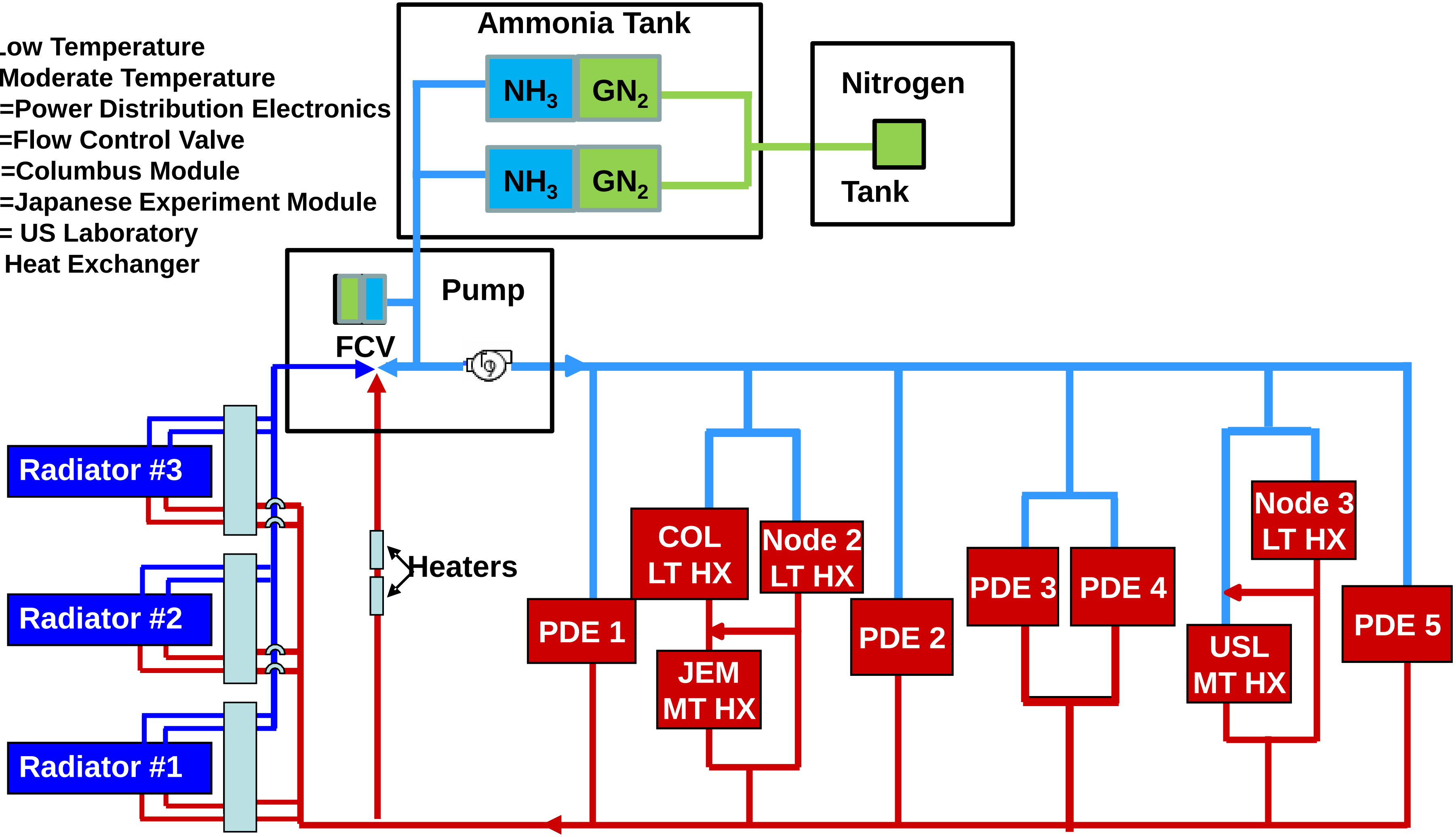
# Background

- The External Active Thermal Control System (EATCS) provides active cooling for all pressurized modules and the main Power Distribution Electronics (PDE) on the International Space Station (ISS)
  - 2 EATCS loops (Loop A and Loop B) each of which includes 3 deployable radiators
  - Each deployable radiator contains 2 flow paths to provide heat rejection
- Telemetry monitoring identified a coolant (liquid ammonia) leak in EATCS Loop B
- Robotic External Leak Locator (RELL) scans found higher concentrations of vaporous ammonia near the EATCS Loop B Radiator #3 Flow Path #2
- On May 3, 2017, the EATCS Loop B Radiator #3 Flow Path #2 was isolated and vented
- As of the data to date, the ammonia leak has ceased
- The purpose of this presentation is to discuss the analysis for venting the EATCS Loop B Radiator #3 Flow Path #2



# EATCS Overview

**Key:**
**LT=Low Temperature**
**MT=Moderate Temperature**
**PDE=Power Distribution Electronics**
**FCV=Flow Control Valve**
**COL=Columbus Module**
**JEM=Japanese Experiment Module**
**USL= US Laboratory**
**HX= Heat Exchanger**




**EATCS Loop B Simplified Schematic**

# International Space Station (ISS)

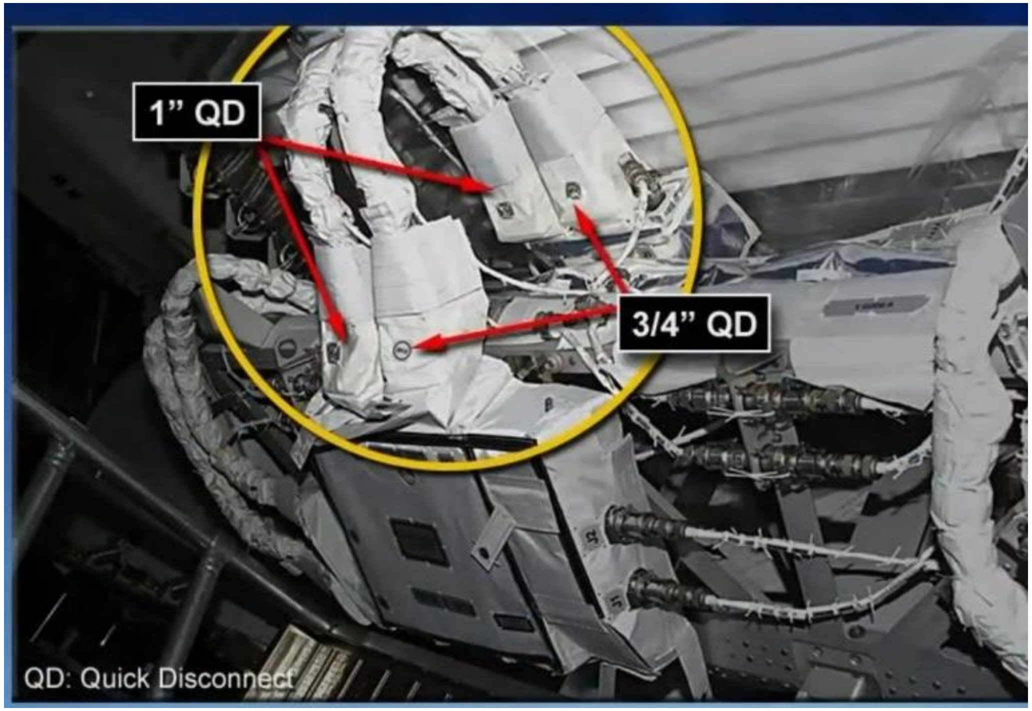
EATCS Loop B

**International Space Station**

**http://zombie.wikia.com/wiki/The_International_Space_Station_(ISS)**

# Venting Analysis Problem Definition

- Ammonia venting analysis is performed to determine:
  - Time to empty the flow path
  - Thrust imposed on the ISS
- The plan was to isolate the ammonia from the EATCS Loop B Radiator #3 Flow Path #2 from the rest of the EATCS, then vent the isolated volume to space
- Any residual ammonia left in the radiator could cause hydrostatic lockup (no compliance) resulting in potential hardware damage
- Furthermore, excessive thrust could cause the ISS to lose attitude control
- Flight controllers and engineers in the Mission Control Center (MCC) used this data to develop operational procedures and safety measures to perform the vent

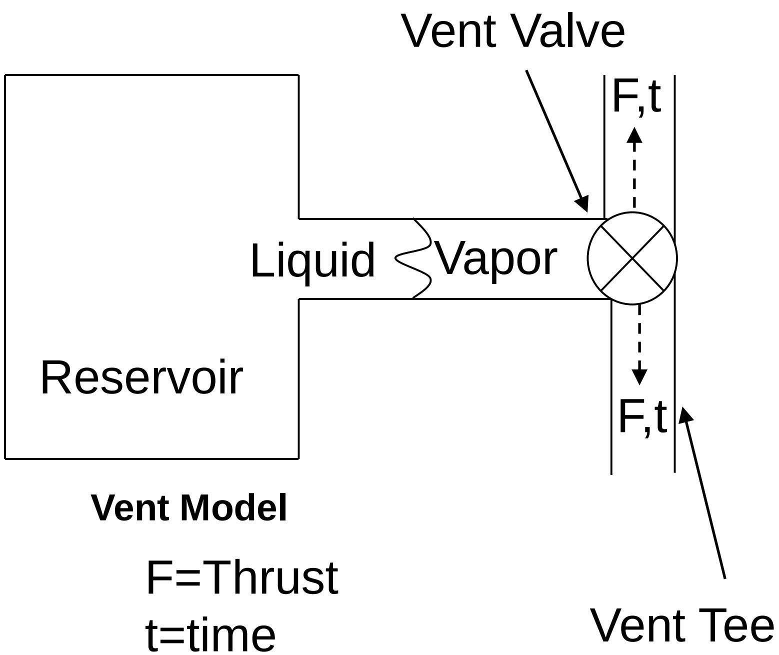



**Radiator Beam Valve Module**

http://spaceflight101.com/iss/iss-us-eva-49-preview/

# Modeling

- Mathematical model in Excel
- Radiator flow path was modeled as a lumped reservoir
  - Used the worst case temperatures to represent the entire Radiator Flow Path (~ 1 $ft^3$)
- Ammonia vents through a small pipe without friction directly to space and choked at the exit
  - Radiator Flow Path is vented through a Tee
- Reservoir is initially a liquid
- The vent begins as a isothermal process until the system reaches saturation (2-phase)
- Once the reservoir reaches saturation, the vent continues via isentropic expansion
  - No heat transfer
  - Pressure decreases the temperature decreases to maintain constant entropy
- Thrust and time to vent can be calculated

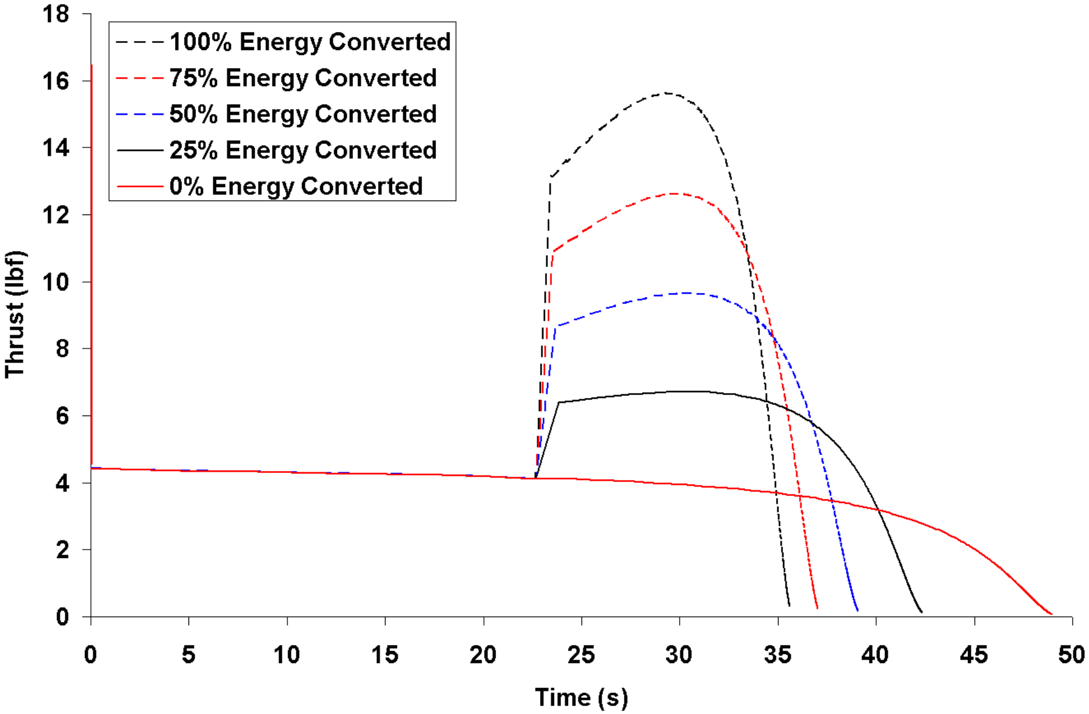



**Vent Model**

F=Thrust
t=time

# Additional Calculation for Thrust

- Liquid vents begin at a quality of 0 and throughout the vent the void fraction increases until it eventually reaches a quality of 1, this produces two independent venting regimes.
- Void Fractions < 0.5
  - Liquid vent is driven by mechanical energy (pressure)
- Void Fractions > 0.5
  - Liquid vent is driven by both mechanical energy (pressure) and thermal (temperature) energy
    - liquid vent reaches the “dispersed flow” two phase regime and the liquid slugs are accelerated by the compressible gas bubbles



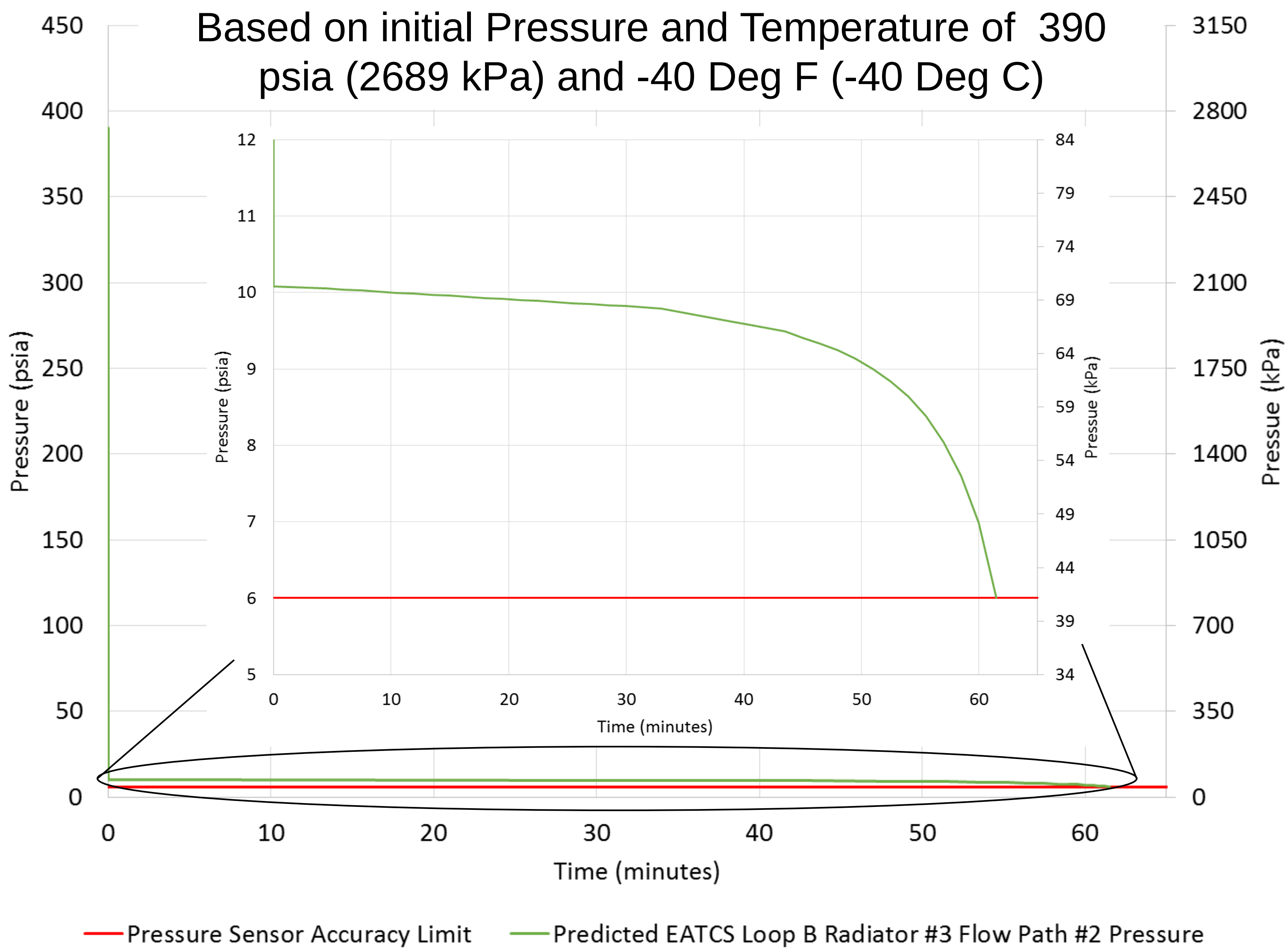
# Assumptions

- Initial EATCS Loop B Radiator #3 Flow Path #2 pressure was based on the maximum operating pressure requirement of 390 psia (2689 kPa)

- Initial EATCS Loop B Radiator #3 Flow Path #2 temperatures for time to vent and thrust were based on the worst case coldest and hottest operational temperatures observed on-orbit over the past 2 years
  - Coldest temperature ~ -40 Deg F (-40 Deg C) drives maximum vent duration
  - Hottest temperature ~ 55 Deg F (13 Deg C) drives maximum thrust

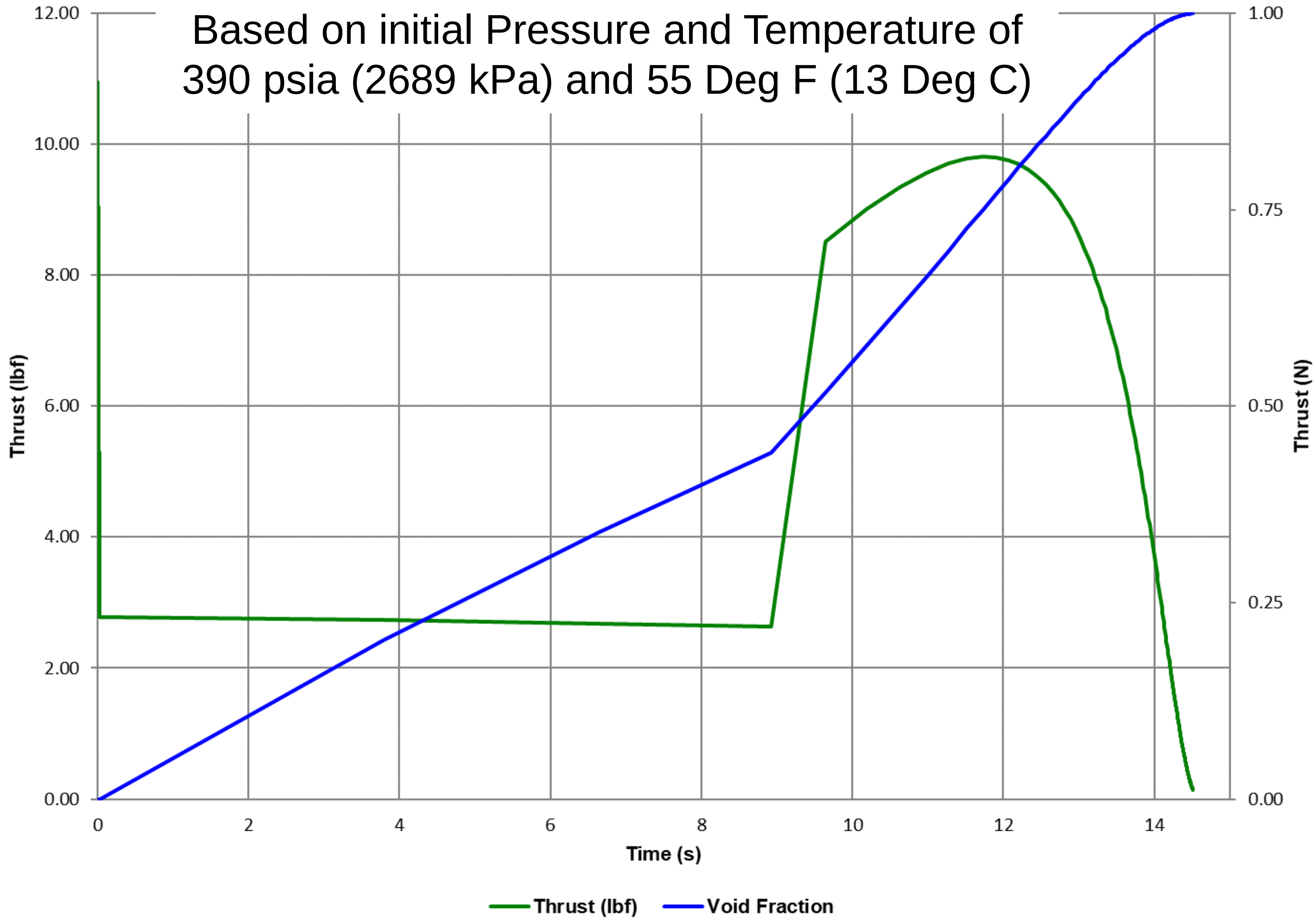
- Telemetry sensor error and temperature and pressure swings due to orbital environmental changes are neglected

# Analysis Results




**EATCS Loop B Radiator #3 Flow Path #2 Pressure vs Time Plot**

# Analysis Results




**EATCS Loop B Radiator #3 Flow Path #2 Thrust vs Time Plot**

# On-Orbit Operation Recommendations

- Summary
  - Worst case time to empty the EATCS Loop B Radiator #3 Flow Path #2 was ~ 60 minutes
  - The predicted maximum thrusts were ~ 11 lbf (49 N) at the start of the vent and ~10 lbf (45 N) after the system reaches saturation

- Recommendation
  - For vent times,
    - ATCS recommended leaving the EATCS Loop B Radiator #3 Flow Path #2 in the vent position for no less than 24 hours to ensure all the ammonia is evacuated
  - For thrust,
    - Recommend using Russian Thrusters to maintain ISS Attitude Control

# Comparison to On-Orbit Operations

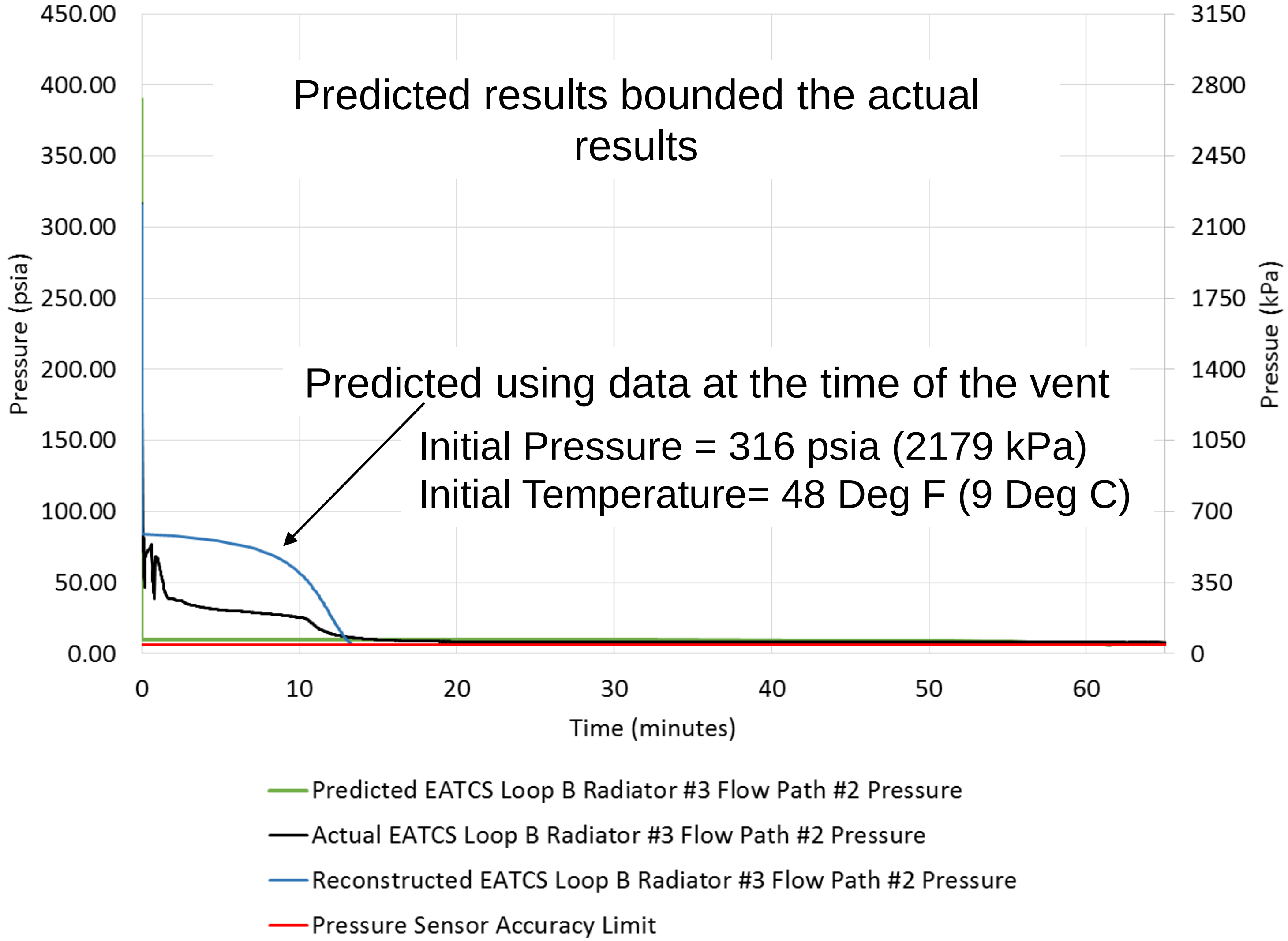



**Figure 9: Predicted vs Actual EATCS Loop B Radiator #3 Flow Path #2 Pressures**

# Vent Video

- EATCS Loop B Radiator #3 Flow Path # 2 Vent Video available via YouTube
  - https://youtu.be/PJzjs4EI22k?list=PL4Bmr2TXQTcQnxXpZ7BkGk_t0IhTByrDy

# Summary

- Predictive analysis determined the worst case time to empty the EATCS Loop B Radiator #3 Flow Path #2 was ~ 60 minutes
- Telemetry indicated that the system reached saturation almost instantaneously and took ~ 20 minutes to empty the EATCS Loop B Radiator #3 Flow Path #2
- Using telemetry from the day of the vent, analysis determined the time to empty the EATCS Loop B Radiator #3 Flow Path #2 would be ~13 minutes
- The original predictive analysis used worst case inputs and assumptions which bounded the actual results
- The maximum thrust initial time of the vent and during 2-phase were ~ 11 lbf (49 N) and ~10 lbf (45 N)
- Telemetry is not available to correlate actual thrust with the predicted maximum thrusts
- However, by using Russian Thrusters for ISS attitude control, attitude control telemetry indicated the flight attitude was maintained

# Backup

# Acknowledgments


- Would like to acknowledge the outstanding work of the Flight Operations Directorate (FOD) and Mission Evaluation Room (MER) engineering teams
  - Particularly the following:
    - The Boeing Company - Houston Active Thermal Control (ATCS) and Passive Thermal Control Systems (PTCS) team
    - FOD - Station Power, Articulation, Thermal, and Analysis (SPARTAN) group
    - NASA – Johnson Space Center (JSC) Active Thermal Control System (ATCS) team