Session Topic: Active Thermal/Fluids
Title: Ammonia Vent of the External Thermal Control System (EATCS) Radiator #3 Flow Path #2 on the International Space Station (ISS)
Author: Darnell Cowan

The External Active Thermal Control System (EATCS) provides cooling for all pressurized modules and the main Power Distribution Electronics (PDE) on the International Space Station (ISS). There are 2 EATCS loops (Loop A and Loop B) 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. Venting analysis is performed to determine the worst case time to empty the flow path and maximum thrusts imposed on the ISS. Flight controllers and engineers in the Mission Control Center (MCC) uses this data to develop operational procedures and perform the vent safely. It was predicted that the 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.

The vent was successfully performed 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 predictive analysis used worst case inputs and assumptions which bounded the actual results. 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.

TFAWS Active Thermal Paper Session

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

Darnell Cowan
NASA JSC ATCS

Presented By
Darnell Cowan

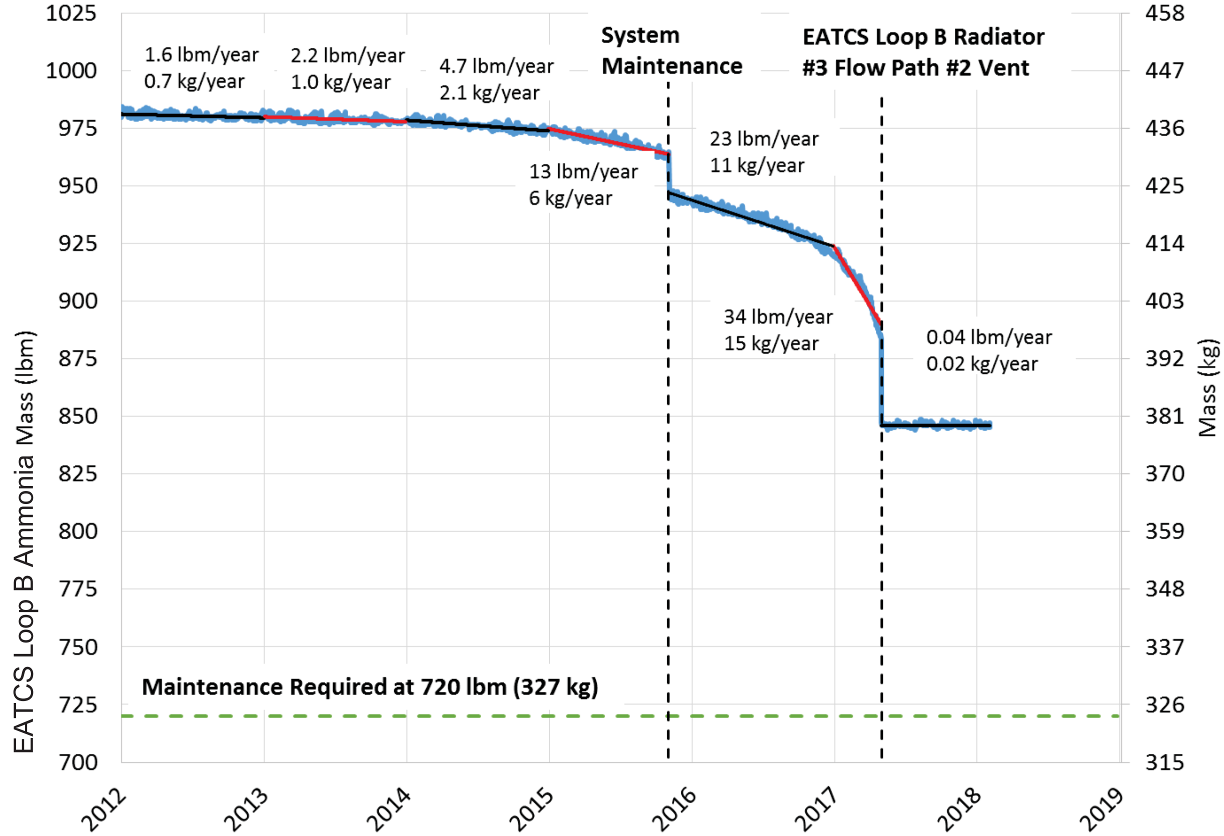
Thermal & Fluids Analysis Workshop
TFAWS 2018
August 20-24, 2018
NASA Johnson Space Center
Houston, TX

Overview

- Background
- EATCS Overview
- International Space Station
- Venting Analysis Problem Definition
- Modeling
- Assumptions
- Analysis Results
- On-Orbit Operations Recommendations
- Comparison to On-Orbit Operations
- Vent Video
- Summary
- Backup
  - Acknowledgments

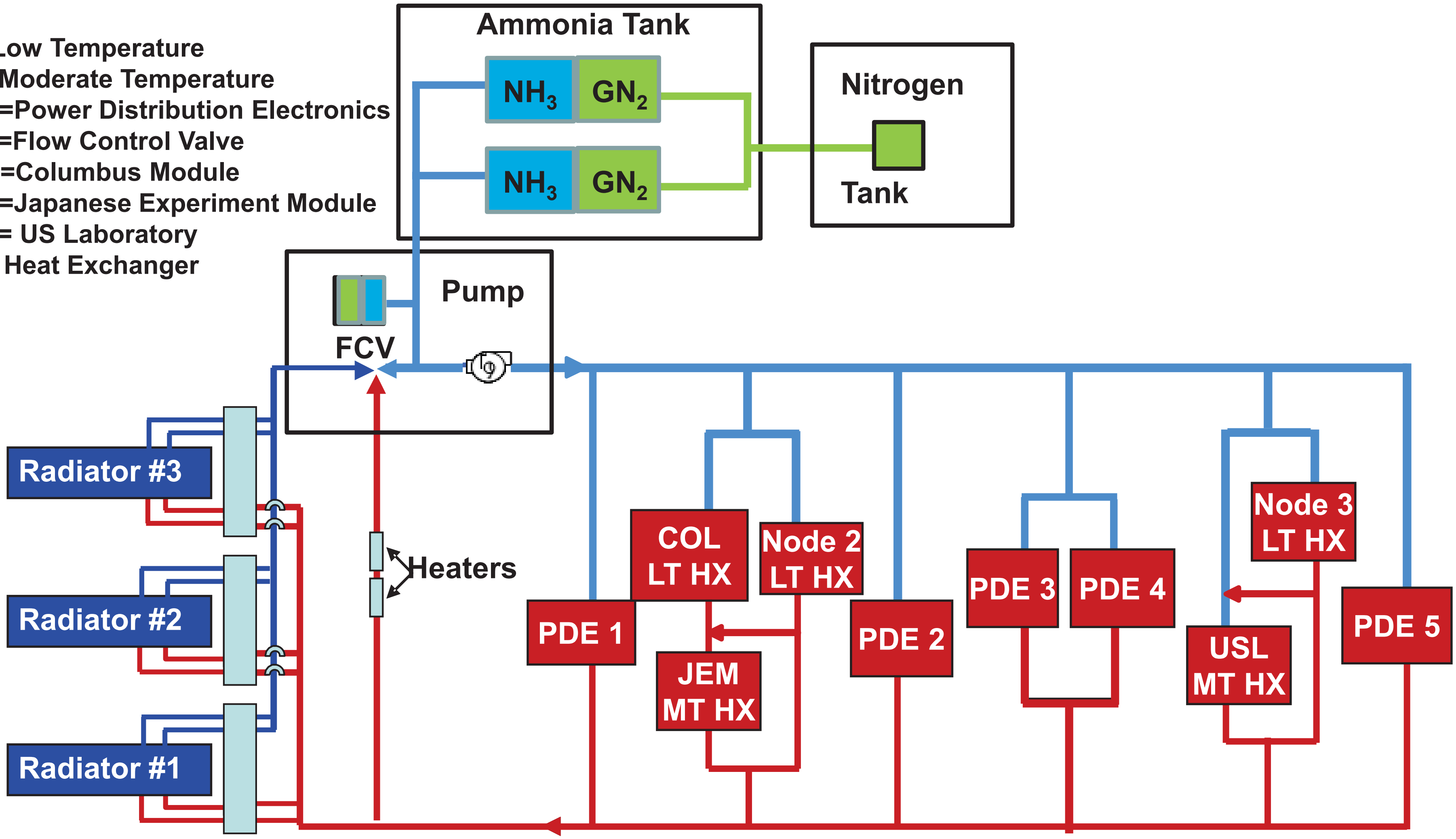
Background

- 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



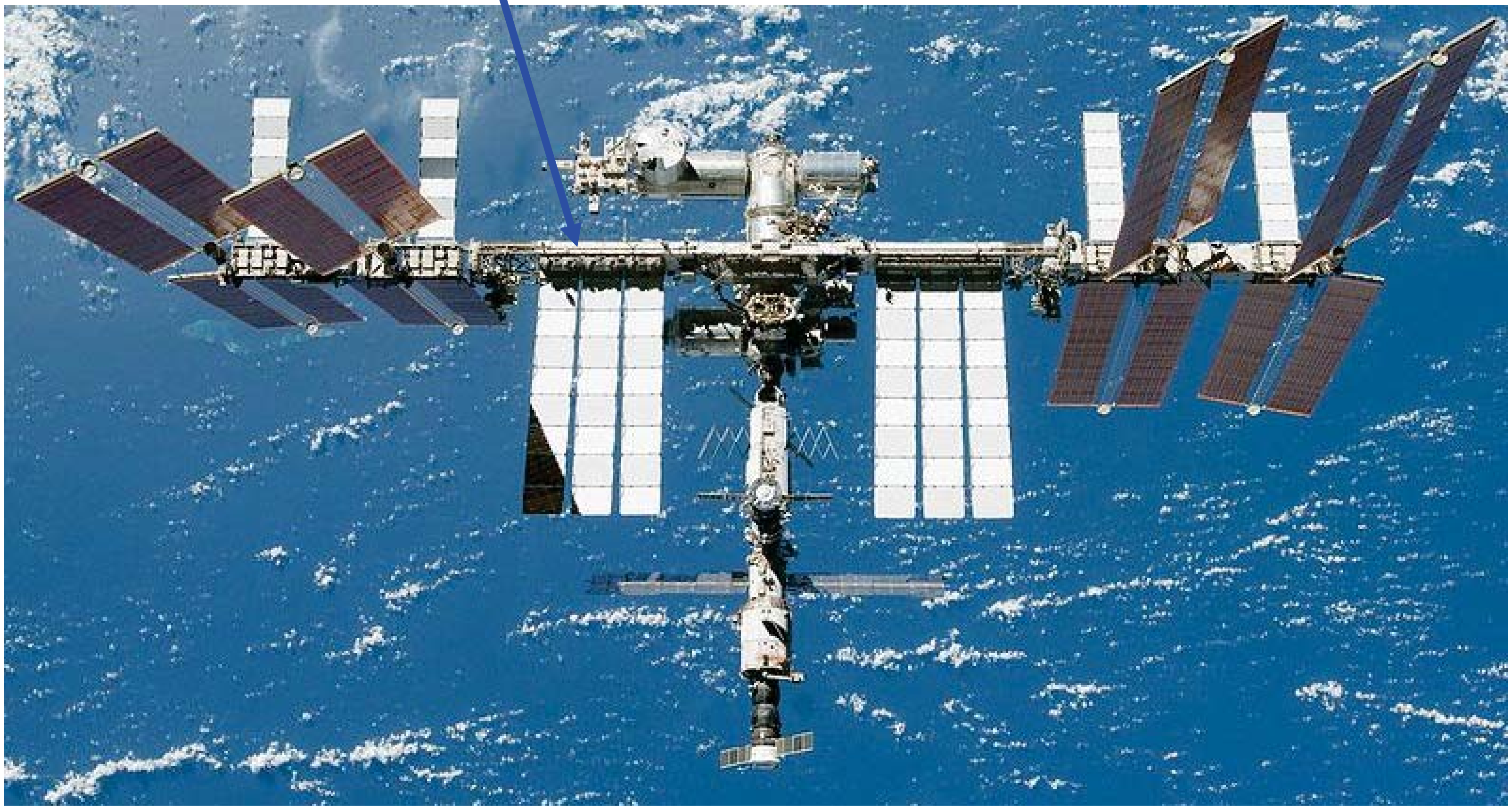
EATCS Overview

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

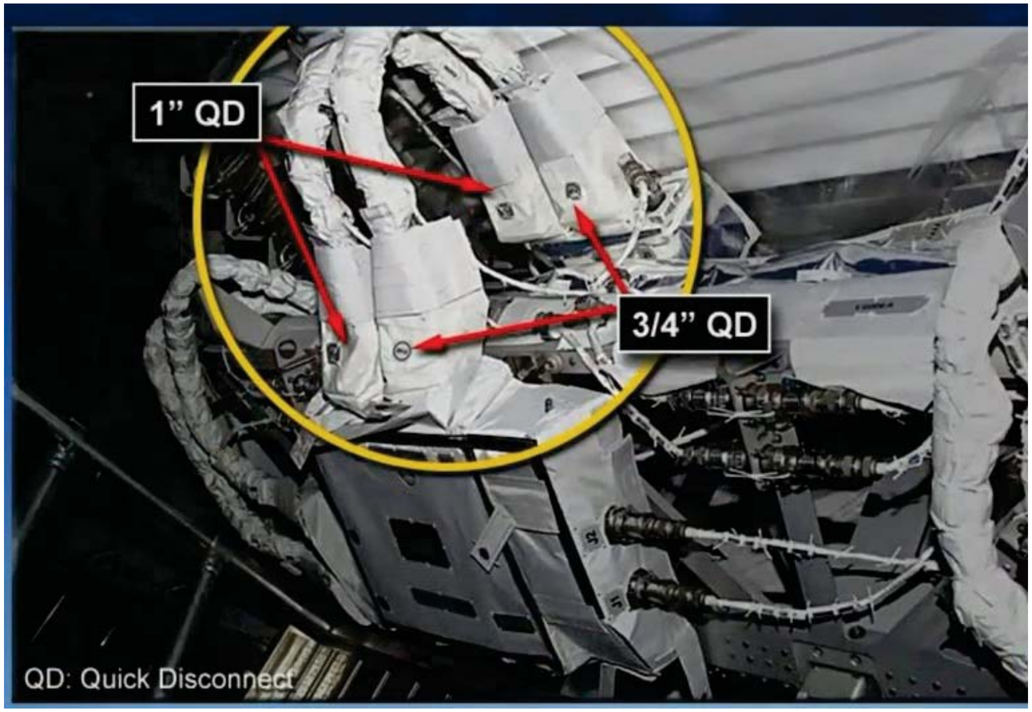
International Space Station (ISS)



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

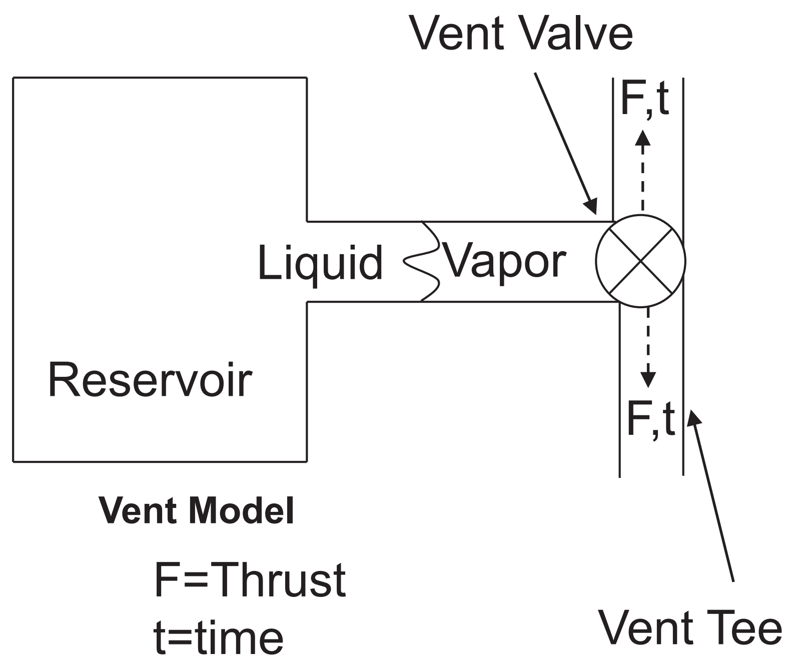


Radiator Beam Valve Module

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

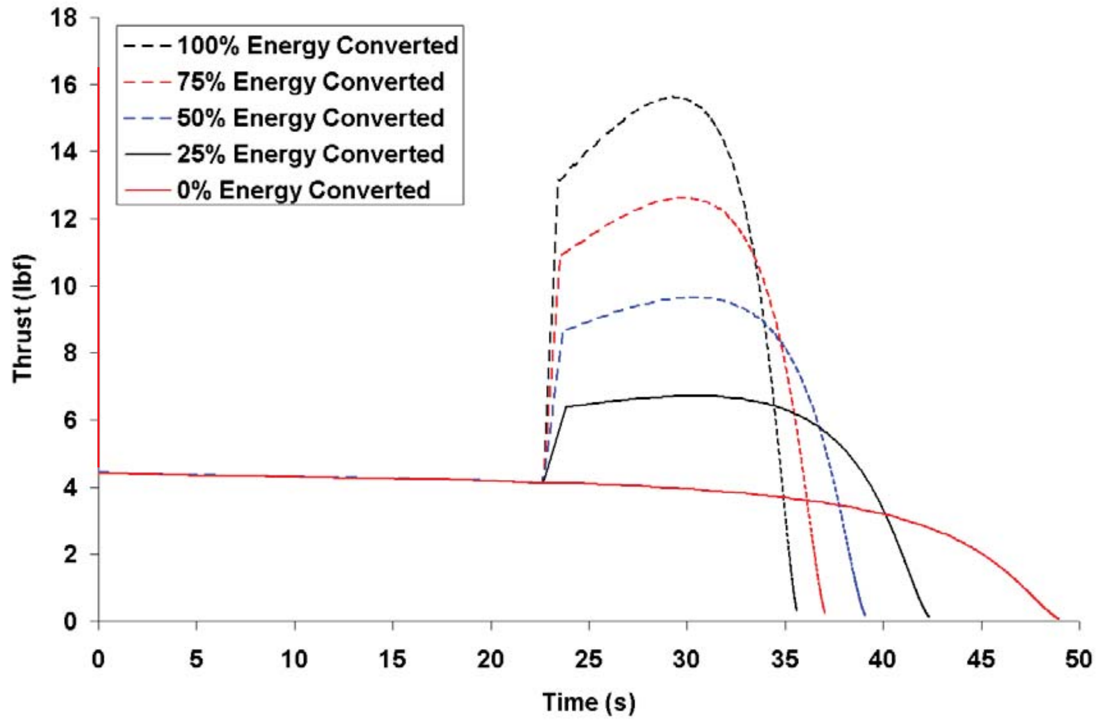
Modeling

- 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



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



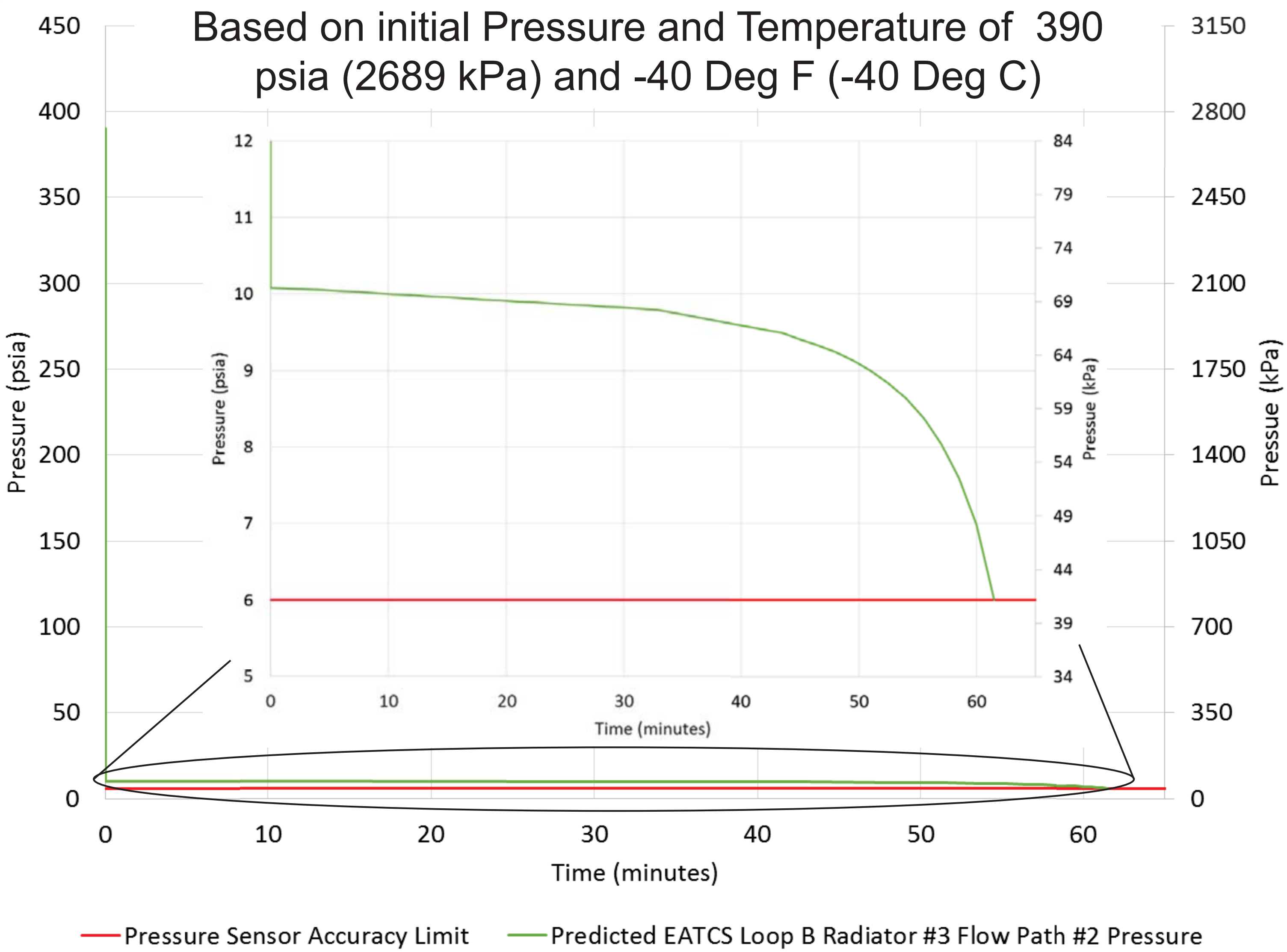
Assumptions

- 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

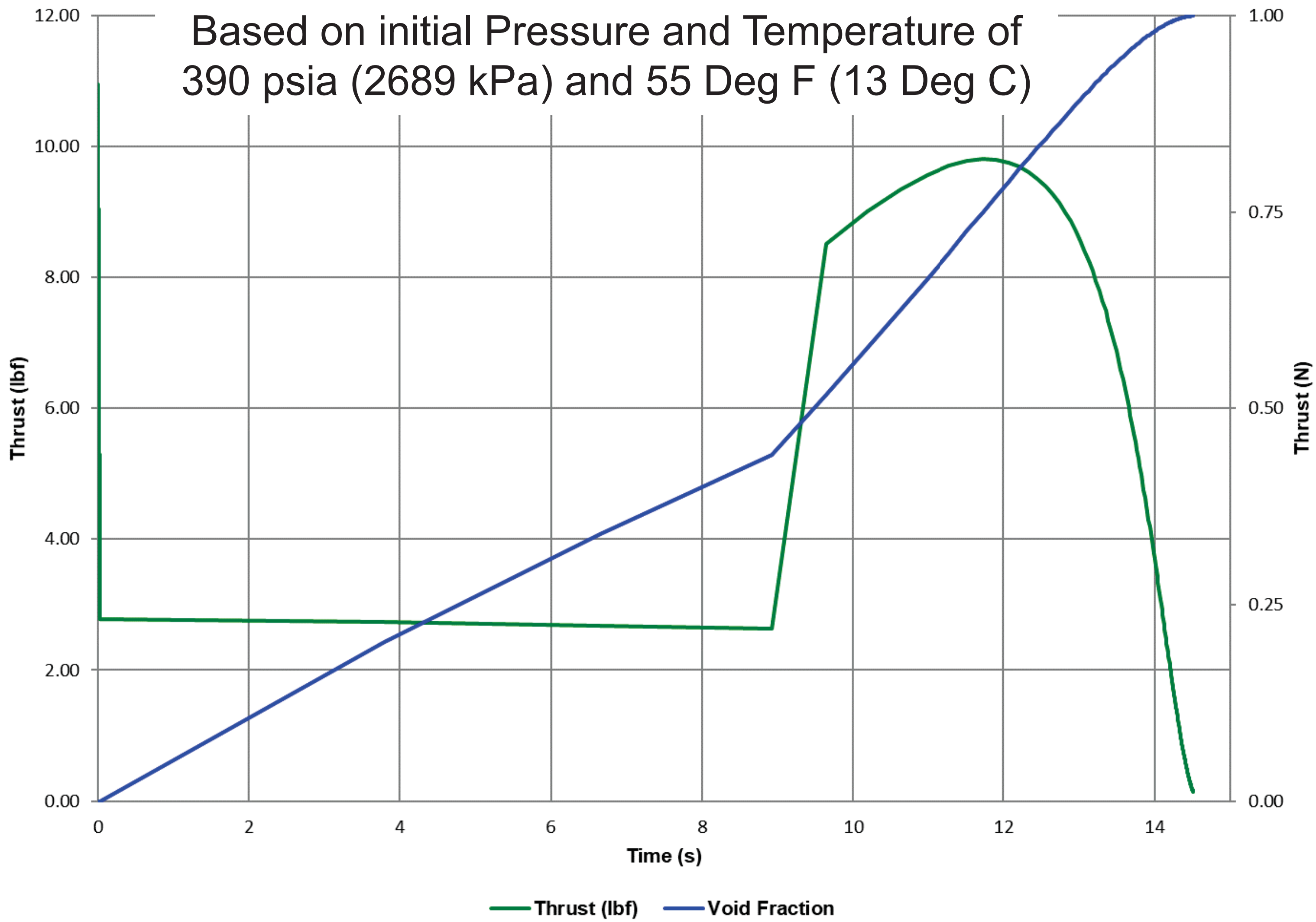
- Telemetry sensor error and temperature and pressure swings due to orbital environmental changes are neglected

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

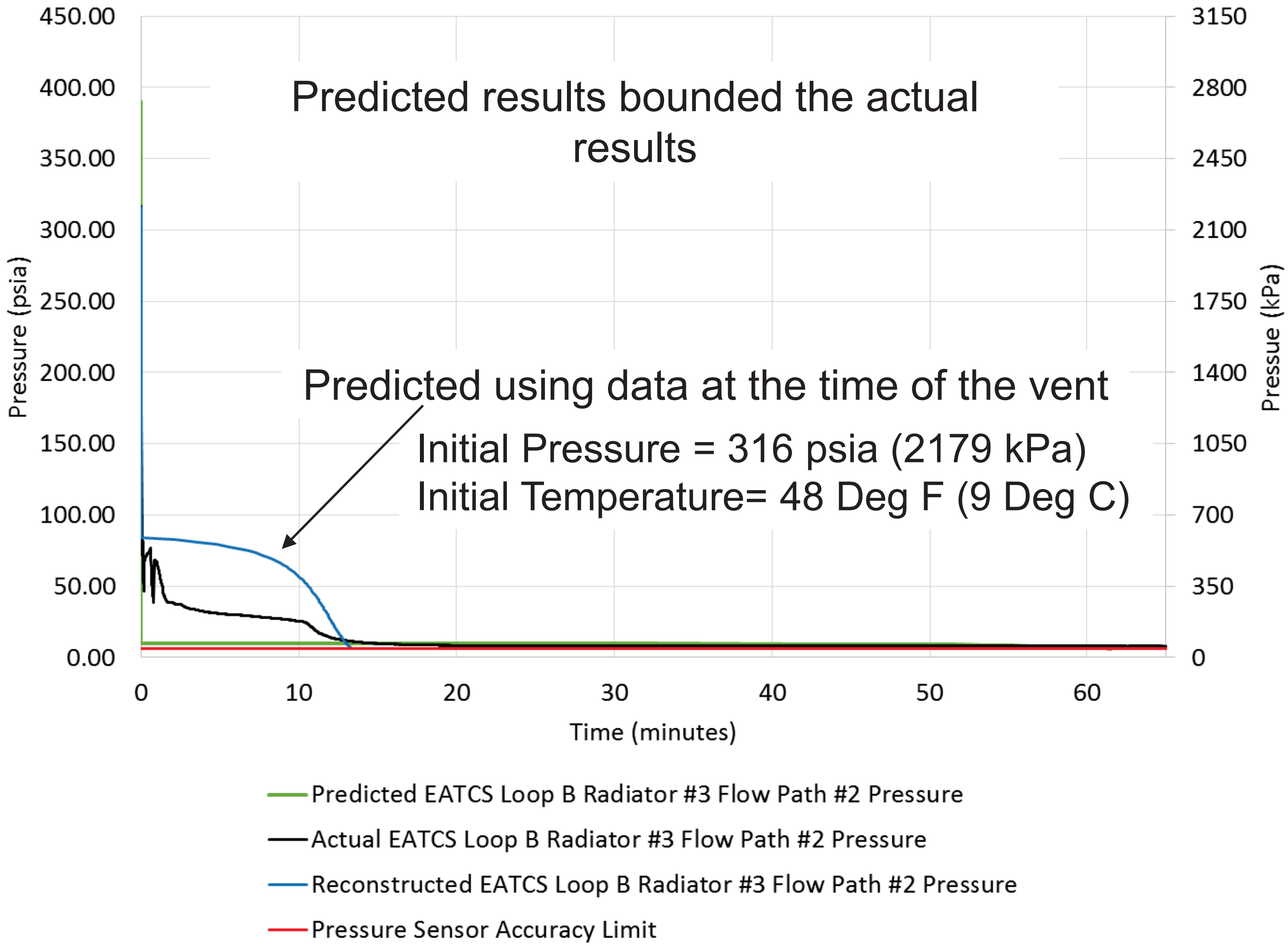


Figure 9: Predicted vs Actual EATCS Loop B Radiator #3 Flow Path #2 Pressures

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