Cryogenic RCS Feedsystem Testing (CRFT)

Thermal/fluid modeling and analysis

Thermal and Fluids Analysis Workshop

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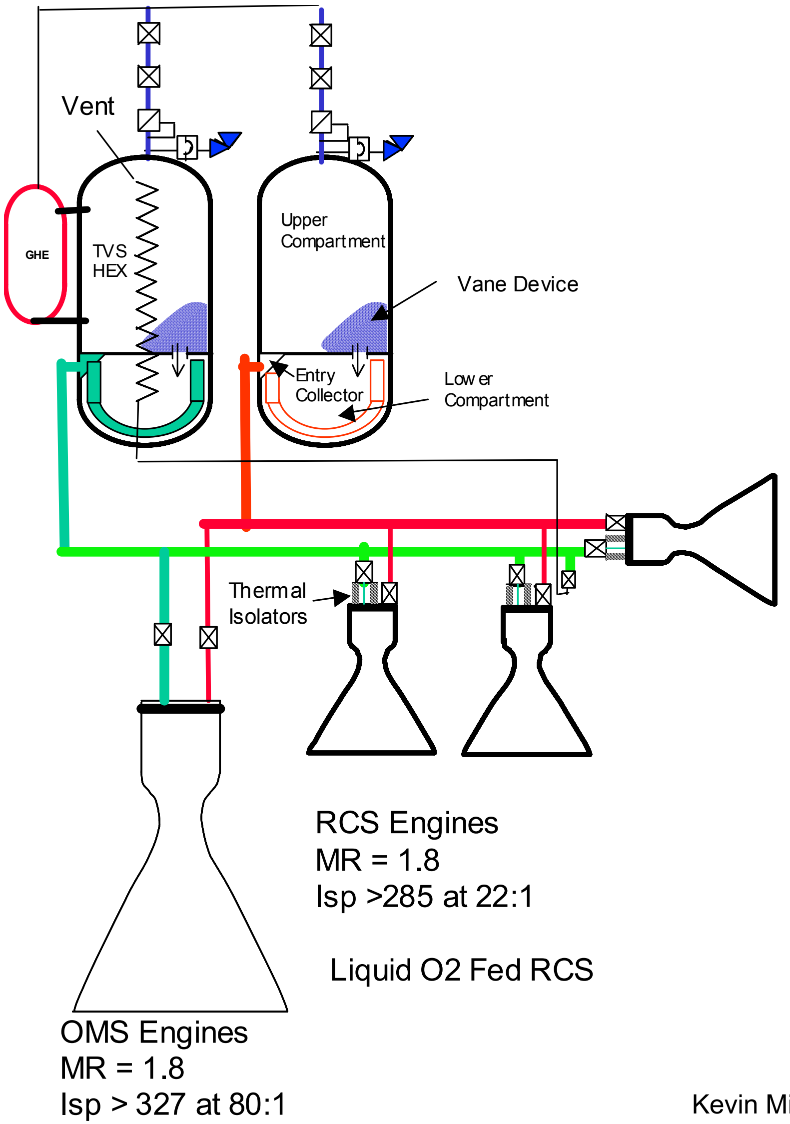
NT OMS/RCS Overview

- **NT OMS/RCS Basic System Design**
  - –Pressure-Fed System at 250 - 350 psia
    - LO2 and Ethanol
  - –Cryogenic RCS Feedsystem Principle of Operation
    - Subcooled Liquid Oxygen
    - Loaded at 14.7 psia and 163 R
    - Then Pressurized to 250 - 350 psia
    - Results in ~70 - 80 R subcooling
- **Test and Analysis Objective**
  - **– Demonstrate cryogenic RCS manifold under flight-like thermal conditions to observe effects of:**
    - Maintain Subcooled liquid at thruster inlet
    - Measure Heat soak-back from thruster injector plate
  - –Validate Sinda Fluint Model of cryogenic feedsystem
  - –Use Manifold design for WSTF tests



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CRFT Modeling and Analysis

- CRFT model used as analysis tool
  - examine effects of changes to test article
  - project LOX performance from LN_2 test data
- SINDA/FLUINT thermal and fluid model of test article started in Summer 2000
- Testing of feedsystem thermal performance began December of 2000
- Model was improved and correlated to test results
  - Full transient simulation of feedsystem may be performed with changes to key variables such as:
    - Valve control logic (temperature set points)
    - Supply tank pressure and temperature
    - Working fluid
  - Test data supported simplification of thermal model-(long model run-times were no longer a hindrance)
  - More variables were taken into account to make model resemble the as-tested feedsystem
  - Analyses of system reconfigurations were made

CRFT Modeling Objectives and Results

- Objectives / Results
  - Investigate Poor Performance of MLI wrapped feedline
    - High Interstitial pressure in MLI caused by high Chamber Pressure of 1 x 10-4 torr
    - Need to increase from 15 layers to 30 layers
    - MLI perhaps compressed too much
  - Investigate Thruster Thermal Isolator:
    - Need radiation shields in thruster thermal isolator

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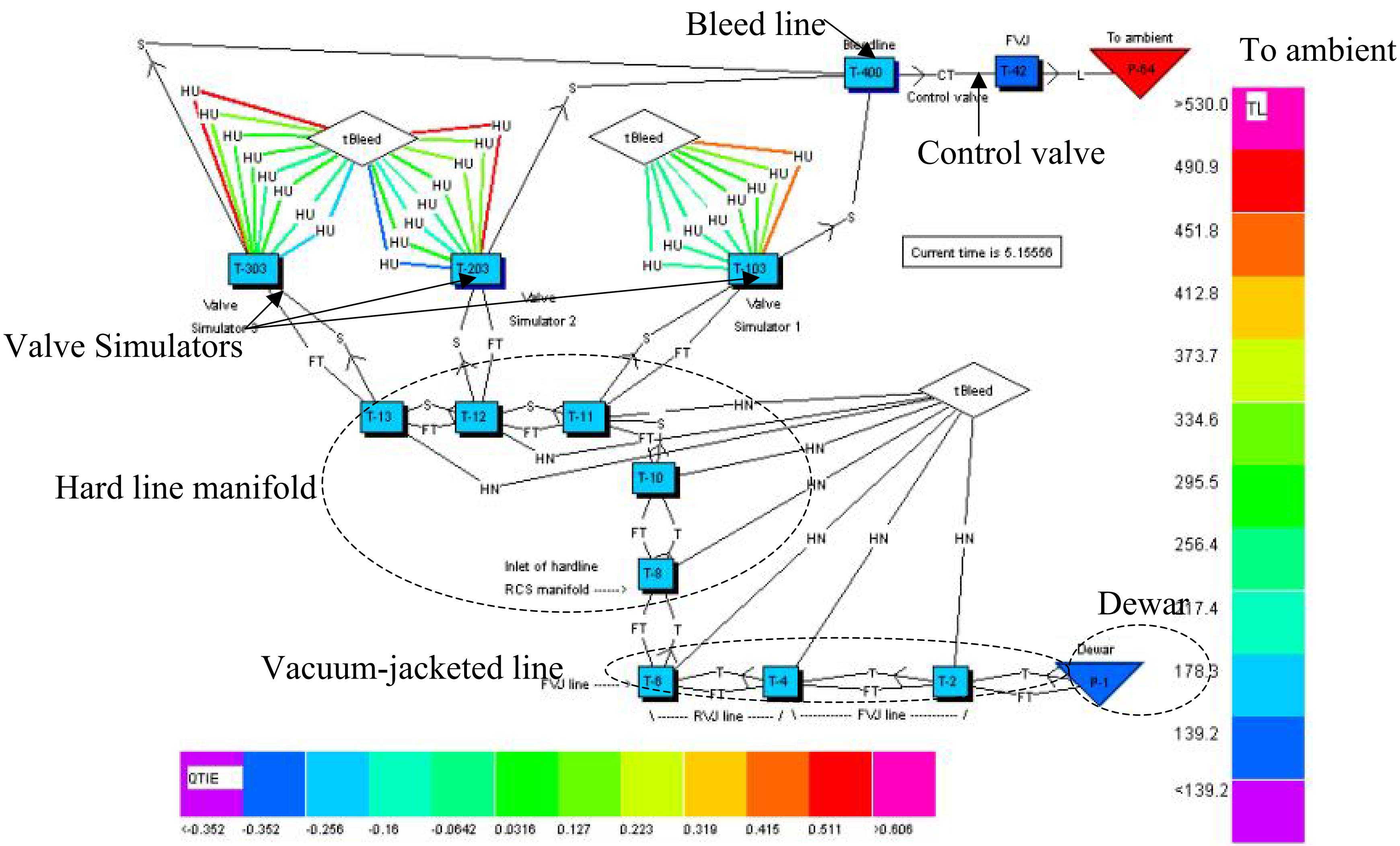
CRFT Fluid Model



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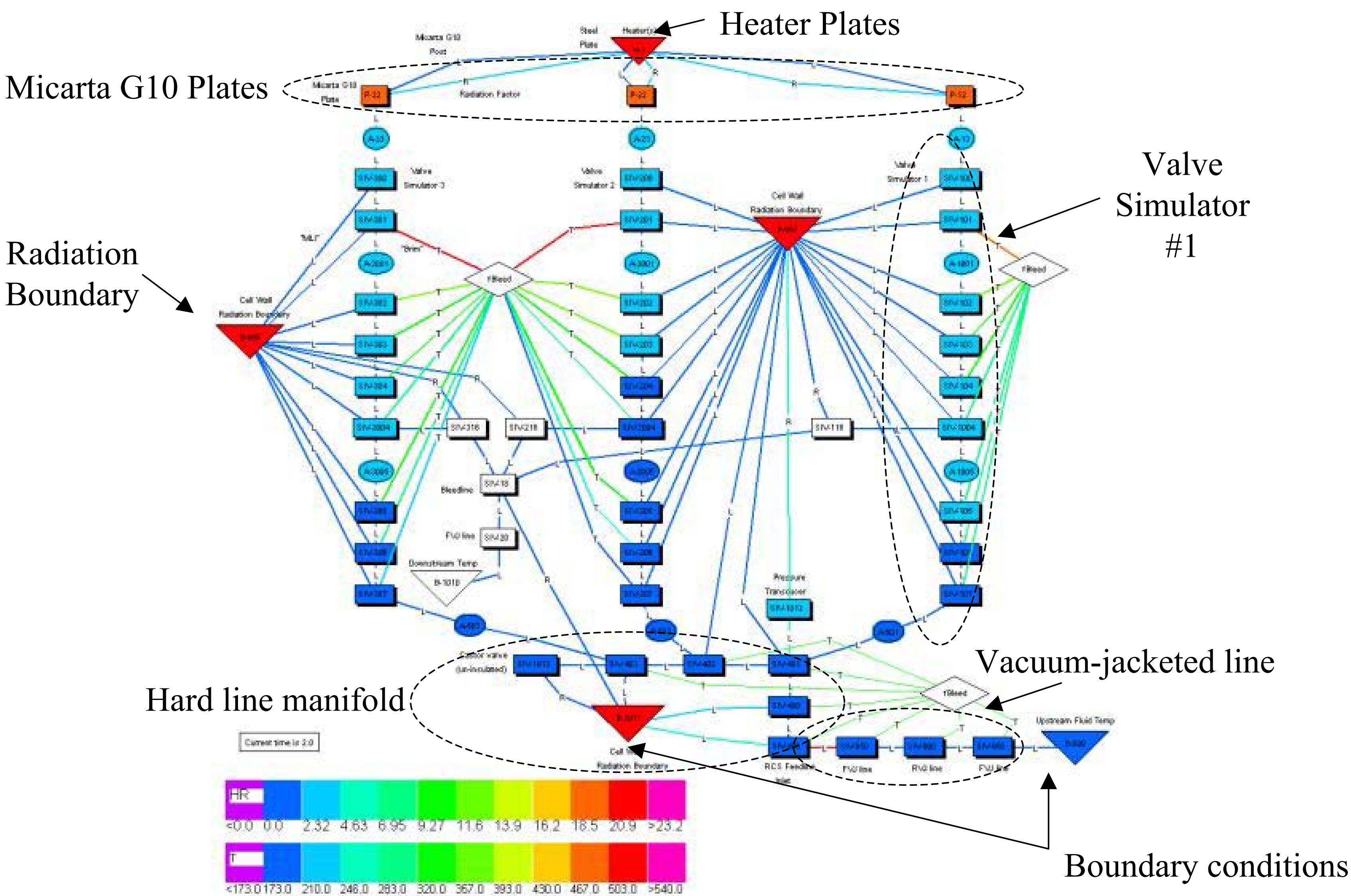
CRFT Thermal Model



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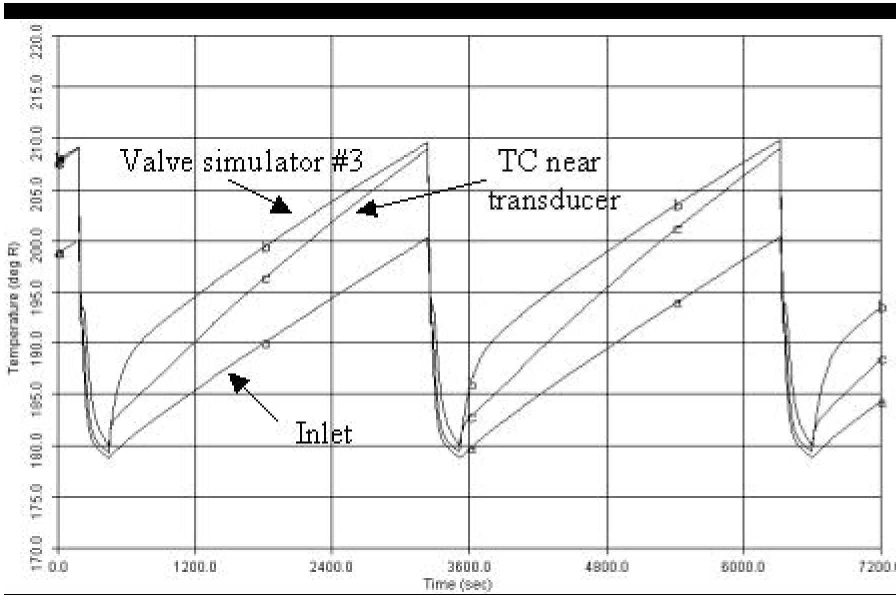
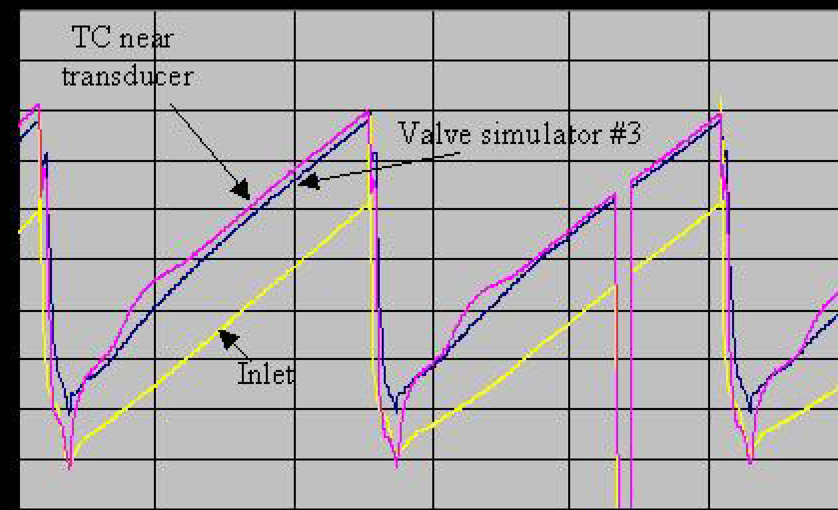
CRFT Model Matched to Test Data

Model



Test data



- Model matched to steady-state performance (heat-up/cool-down cycle)
- Temperature gradient established from injector plate (540 °R) to Micarta plate (470 °R)
- Flow rates and manifold pressures correlated to test data
- MLI conductivity values used at test chamber pressure (10^{-4} torr)
- Effects of un-insulated components and contact resistances added
- Boundary conditions (vaporization) in bleed line were difficult to model
- Two phase fluid modeled

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Thermodynamic Comparison of LN_2 and LOX

	LN_2	LOX
Sat. Temp. (at 14.7 psia)	139.2 °R	162.3 °R
Sat. Temp. (at 330 psia)	212.4 ° R	243.8 °R
Specific Heat (at 330 psia, 180 ° R)	0.533 Btu/lb-°R	0.410 Btu/lb-°R
Density	43.57 lb/ft^3	68.47 lb/ft3

Sources: Thermophysical Properties of Nitrogen, NBS, 1973
Thermodynamic and Related Properties of Oxygen, NBS, 1977

- Specific heat capacity of nitrogen 1.3 times greater than oxygen
- Density of oxygen 1.6 times greater than nitrogen

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Extrapolation by Analysis Shows Vent Rate of 1.6 lbm/hour for LO2 Feedsystem

Liquid Oxygen Projections

24-hr runs	nominal inlet conditions		"steady-state"		
High Setpoint 204 R	Cycles	Through-put	Heat-up	Cool-down	Interconnect temp
Low Setpoint (R)		(lbm/hrs)	(min:sec)	(min:sec)	max (deg R)
174	9	4.7	130:31	1:45	172-steady
184	24	2.4	45:19	0:18	174-rising
194	**46**	**1.6**	**22:14**	**0:07**	**175-rising**

- Liquid oxygen system analysis performed
- Initial conditions:
  - LOX lines sub-cooled to 163 °R
  - Supply tank maintained at 163 °R
  - Thermal gradient set up through valve simulators
- 24-hr run time
- Different temperature ranges tested
- Nominal system: MLI performance, thruster inlet conditions
- Flow out of vent line: 0.15 lbm/sec when cycled

- **Results**
  - Interconnect line temperature rise ~12 deg °R, at pressure this is still 70 °R of sub-cooling
  - Minimal bleed flow needed to maintain nominal thruster inlet conditions (below 204 °R)
  - Each conditioning method expels less than daily vernier through-put (roughly 130-160 lbs)
  - For normal operation of RCS system, venting or other active thermal control might not be required
  - Cryogenic feedsystem must demonstrate long periods of quiescent operation (docked to ISS)

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Conclusion / Forward Plan

- Basic Operation of Cryogenic Feedsystem demonstrated
  - Successfully Maintained sub-cooled bulk liquid in 110 ft VJ Line for long durations
    - 60 Hours Demonstrated under no flow (2 deg R per 3 hours)
- Several Improvements Require retest
- Extrapolation by Analysis for LO2 shows that 1.6 lbm/hour vent rate is possible which correlates to 4.8 lbms/hour for Shuttle sized vehicle
  - Maintains fluid between 163 R and 204 R
  - 4.8 lbms per hour is approx. equal to the average vernier flowrate of 4 - 7 lbm/hour
  - Hence, minimal venting will be required in flight

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