

Overview of Engineering Design and Analysis at the NASA John C. Stennis Space Center

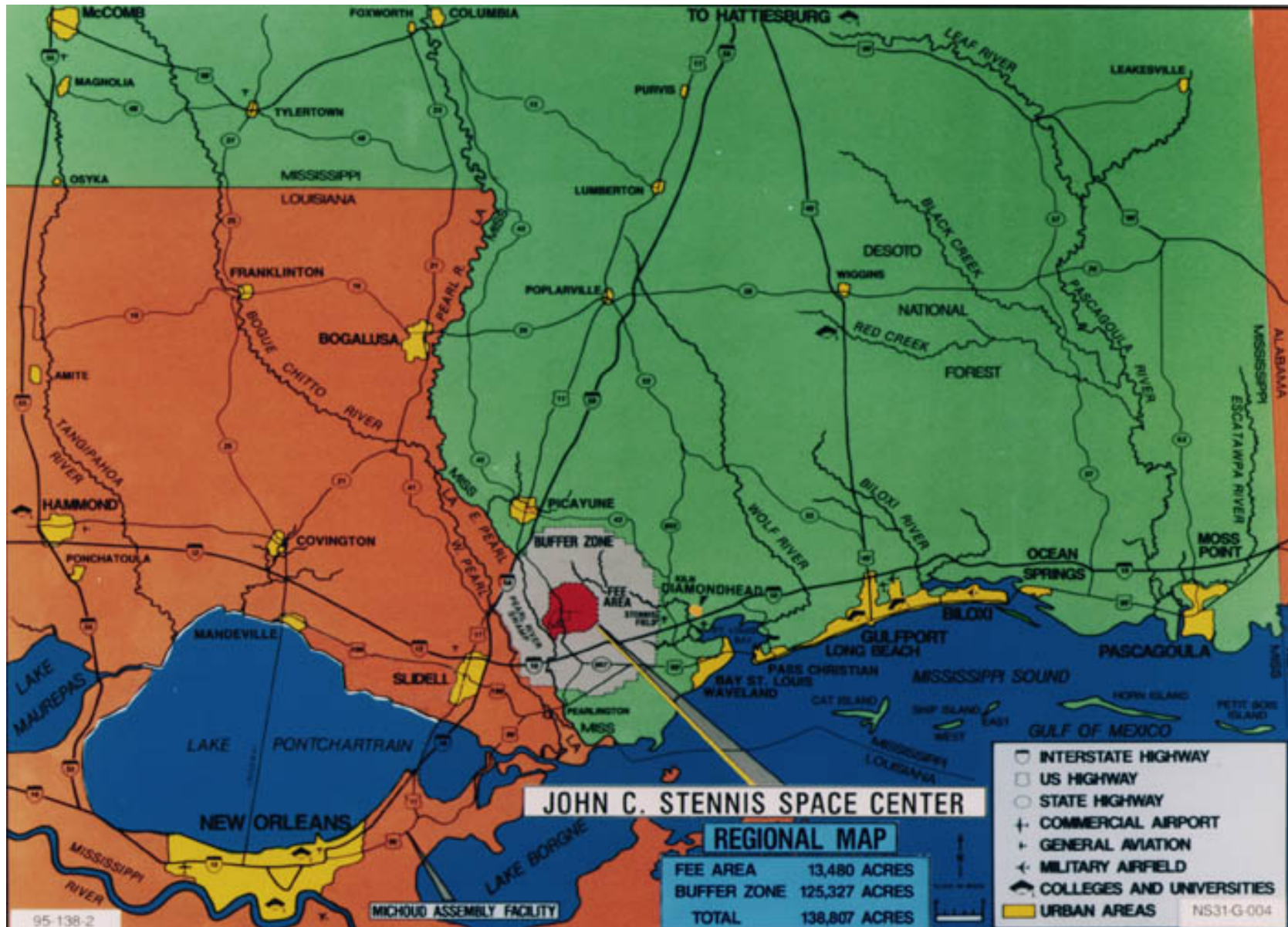


Jared Congiardo, Justin Junell, Richard Kirkpatrick and Harry Ryan
NASA, Stennis Space Center, MS, 39529, USA

Mississippi Engineering Society Winter Meeting
Jackson, MS
February 27, 2007



SSC Regional Map





Complete Suite of Test Capability and Expertise

E-1 Stand

High Press., Full Scale
Engine Components



A-1 ... Full Scale Engine Devt. & Cert ... **A-2**

E-2

High Press.
Mid-Scale
& Subscale



E-3

High Press.
Small-Scale
Subscale

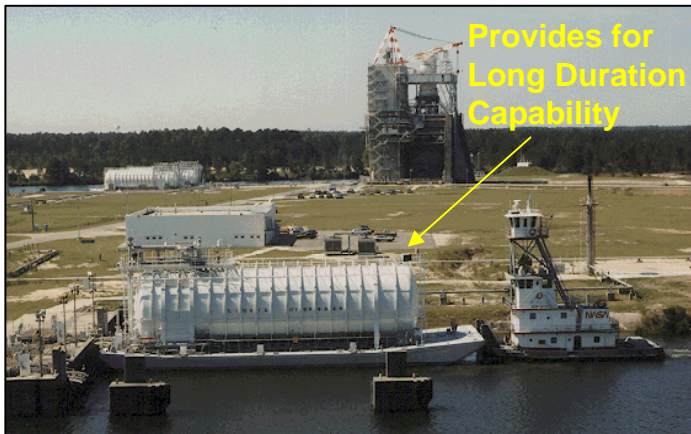


B-1/B-2 ... Full Scale Engine/Stage Devt. & Cert

Components ... Engines ... Stages



SSC Support Facilities



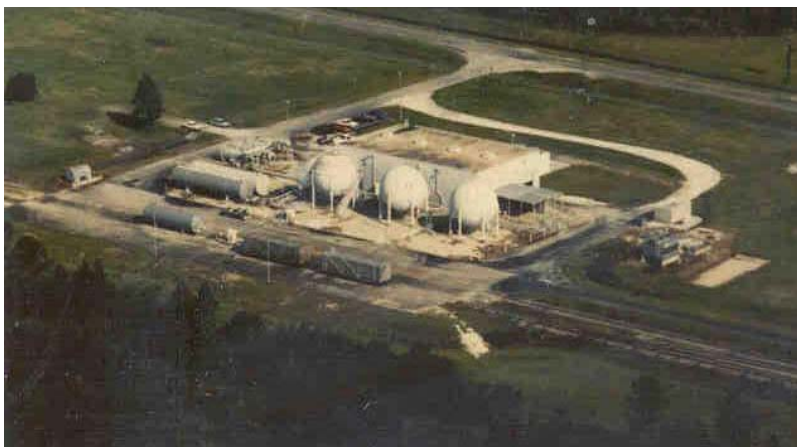
Cryogenic Propellant Storage Facility

Six (6) 100,000 Gallon LOX Barges
Three (3) 240,000 Gallon LH Barges



High Pressure Industrial Water (HPIW)

330,000 gpm Delivery System



High Pressure Gas Facility (HPGF)

(GN, GHe, GH, Air: ~ 3000 to 4000 psi)

Additional Support

- Laboratories
 - ✓ Gas and Material Analysis
 - ✓ Measurement Standards and Calibration
 - ✓ Environmental
- Shops
- Utilities

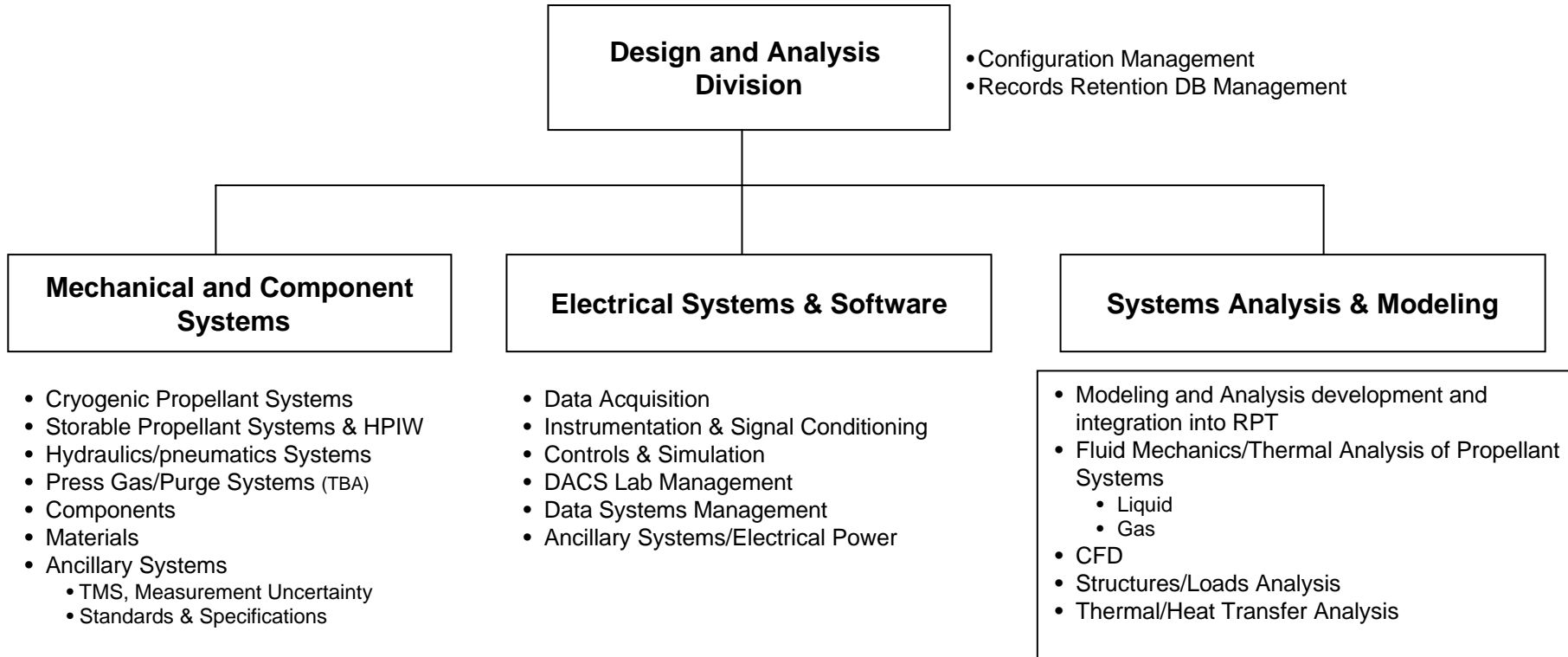


Propulsion Testing at the NASA John C. Stennis Space Center (SSC)

Video



NASA SSC Design & Analysis Division



Organization Goal:

- **Develop and maintain propulsion test systems and facilities engineering competencies**
 - Unique and focused technical knowledge across respective engineering disciplines applied to rocket propulsion testing. e.g.,
 - Materials selection and associated database management
 - Piping, electrical and data acquisition systems design for cryogenic, high flow, high pressure propellant supply regimes
 - Associated analytic modeling and systems analysis disciplines and techniques
 - Corresponding fluids structural, thermal and electrical engineering disciplines



Integrated Facility Simulation and Analysis

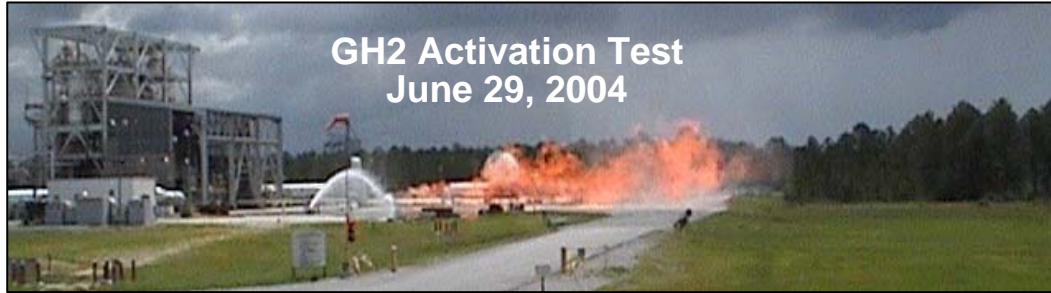
- To Support Propulsion Testing, SSC Has Developed & Implemented Analytic Modeling & Simulation Tools
 - Rocket Propulsion Test Analysis (RPTA) Model (FORTRAN) Used to Simulate Propulsion Test Facility Systems (e.g., LOX Run System)
 - ✓ Heritage of Model Dates to Pressurization and Propellant Systems Design Tasks for Space Shuttle and X-33
 - ✓ Model Adapted, Validated and Currently Used at SSC to Simulate Facility Pressurization and Propellant Systems
 - Computational Fluid Dynamics (CFD) Used for Select Propulsion Test Situations
 - Have Experienced Analysis Team that Routinely Solves Pressurization and Propellant System Problems
- Integrated Facility Simulation and Analysis Has Led to Substantial Project Cost and Schedule Savings



Integrated Facility Simulation and Analysis

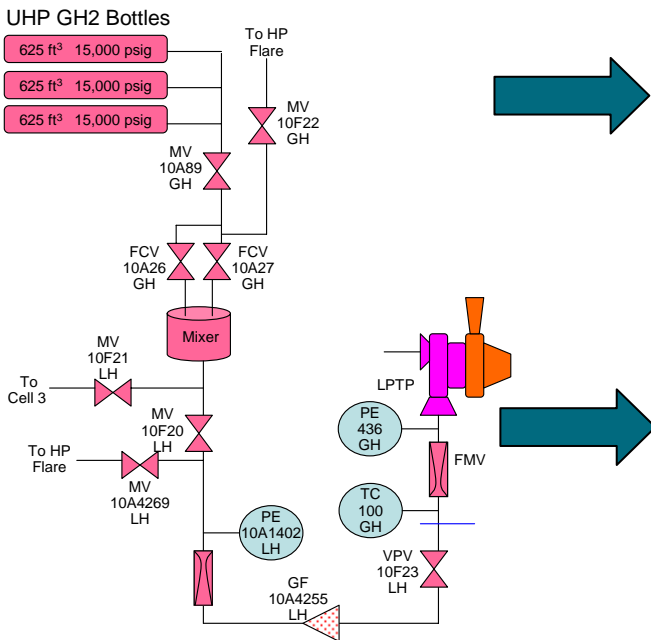
- Analytic Tools Available for Propulsion Test Facility Modeling & Analysis
- Comprehensive Propellant System Thermodynamic Modeling & Test Simulation

Integrated Performance Modeling Capabilities Substantially Improves Understanding & Knowledge of Test Systems Performance that has Translated to Efficient Test Facility Design, Activation & Test Operations

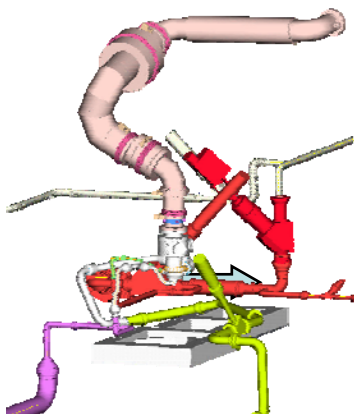


GH2 Activation Test
June 29, 2004

System Design



Modeling



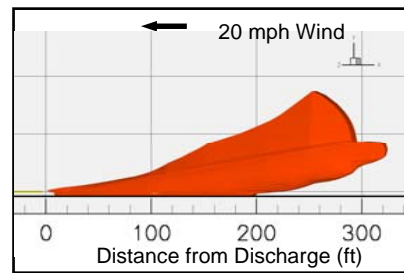
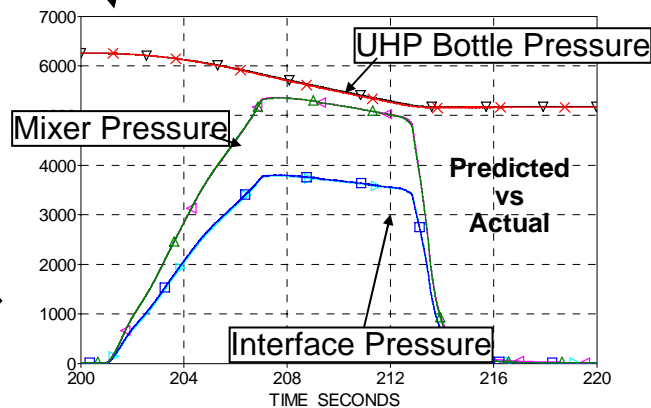
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Simulation of PI Control Loop in Allen Bradley PLC *****
IF (Time LT LoopStart + ScanTime) THEN
ELSE
RETURN
----- Set FCV Command
IF (PowerPara) THEN
CALL SPBaudScanTime_TFPPSP_TFPPStello_Rate
PCVPressSP = TFP((SPBaudScanTime))
END IF
CALL SPBaudScanTime_TFPPSP_TFPPStello_Rate
PropOut(2) = SP-PV
IntOut(2) = IntOut(2) + BiasOut
TotOut = IntOut(2) + BiasOut
A[100] = IntOut(2)
A[100] = BiasOut
IF (TotOut IE 0.0 OR TotOut GE 100.0) Then
TotOut = PropOut(2) + IntOut(1) + BiasOut
A[100] = IntOut(2)
Else
IntOut(1)=IntOut(2)
End IF

```

Fluid System Modeling

Test and Data Analysis



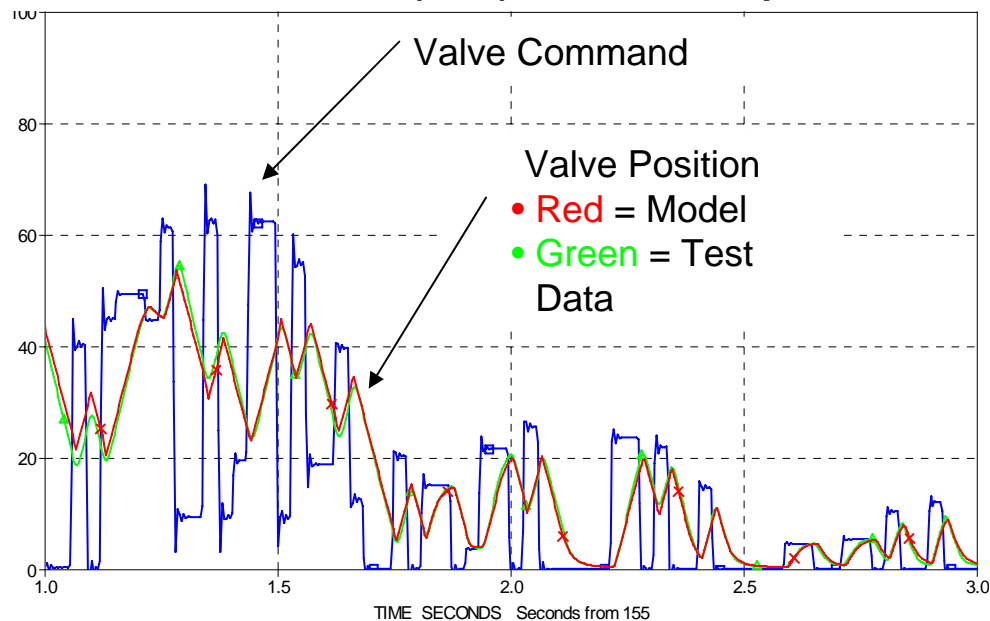
Advanced Capabilities in CFD Modeling & Analysis



Rocket Propulsion Test Analysis (RPTA) Model

- Temporal Transient Thermodynamic Modeling of Integrated Propellant Systems
- Thermodynamic Control Volume Solver Model Accurately Models High-Pressure Cryogenic Fluids and High-Pressure Gaseous Systems. Model Features Include:
 - High-Fidelity Pressure Control Valve (PCV) & Closed Loop Control System Model
- RPTA Model Validated Through Test Data Comparisons
 - IPD Fuel Turbopump, RS-84 Sub-Scale Pre-Burner, RS-83 Pre-Burner Cold Flows, SSME Flowliner Activation & IPD Engine System

Pressure Control Valve (PCV) Model Developed & Validated



A Significant Advantage of the RPTA Model is the Coupling of Control Logic (Electro-Mechanical Process) with Thermodynamic Processes



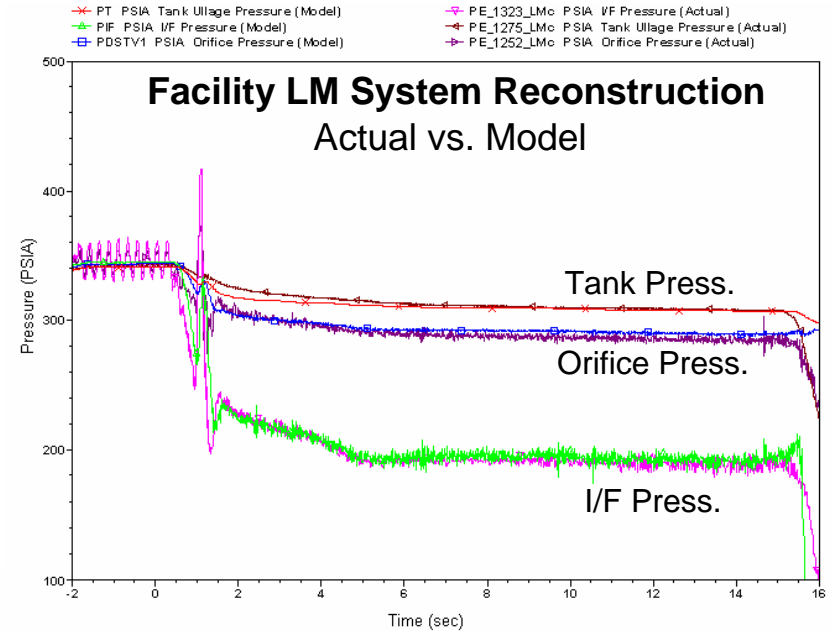
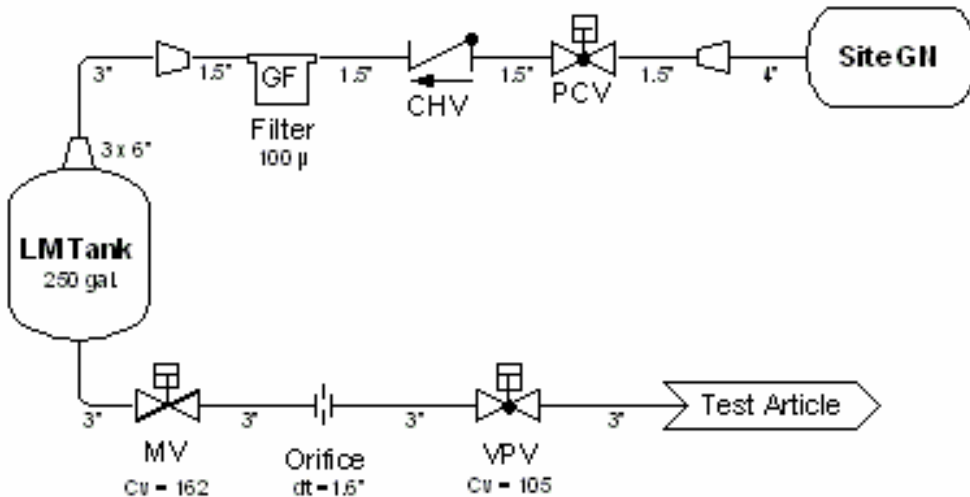
Recent LOX/Methane Testing at E-3

15 kbf Advent Engine Test Program – Nov 06

Facility Activated and Test Performed

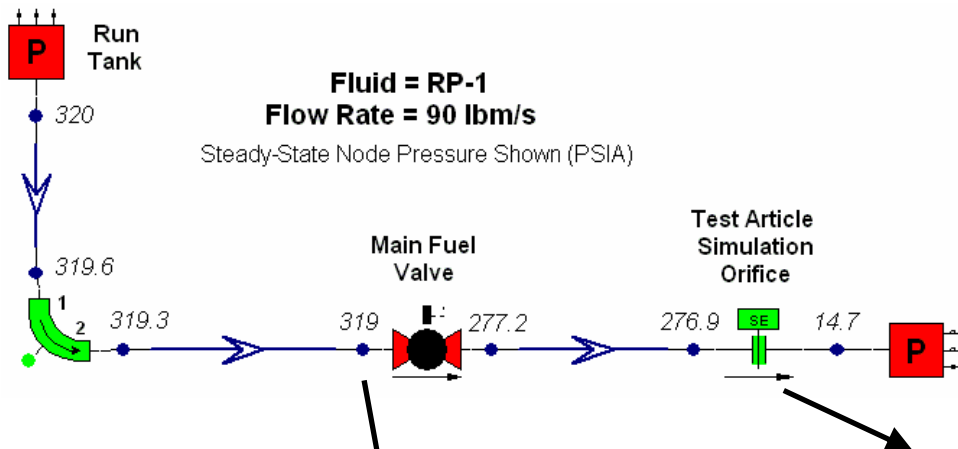
- Liquid Methane (LM) & Liquid Oxygen (LOX) Propellants Used
- Facility Model Results and Facility Test Activation Results Agree Well
- Test Capability: ~25 seconds

LM System Schematic

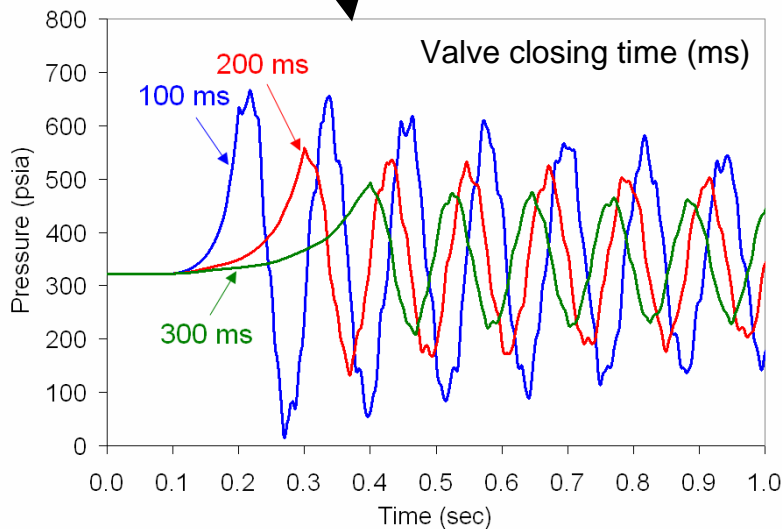




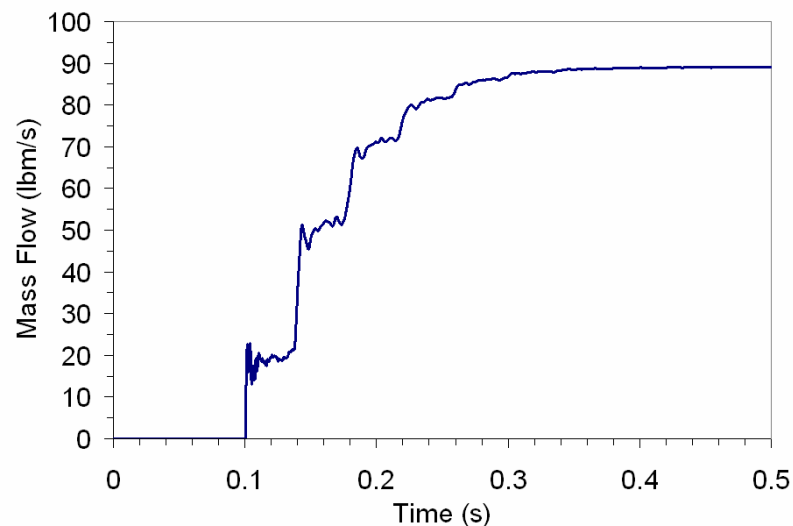
Comprehensive & Rapid Piping System Design & Analysis Capability



- Commercial Tools Employed to Augment Analysis
- Example: *FlowMaster* Piping System Analyzer
 - Allows for Steady-State or Transient Analysis, Compressible or Non-Compressible Flow
 - Includes Heat Transfer, Flow Balancing, Priming & Sizing Analysis



Water Hammer Effect Due to Rapid Closure of Main Fuel Valve



Propellant Flow to Test Article Due to Rapid Opening of Main Fuel Valve



Recent Project: Methane Technology Testbed Project (MTTP)

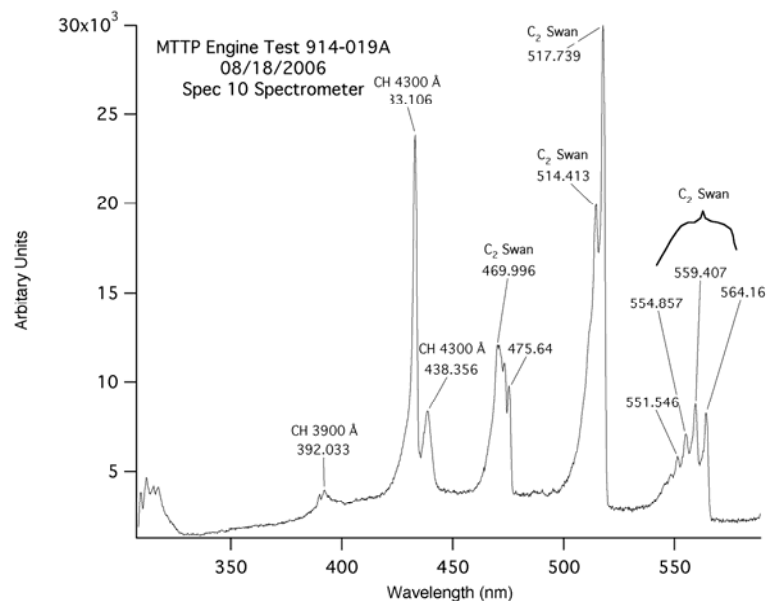
- MTTP provides portable, small-scale propulsion test capabilities
 - Can support gaseous methane, gaseous oxygen, liquid methane and kerosene-type propellants
 - Capable of supporting engines up to 1000-lbf thrust
- Tested 50-lbf thruster (right)
 - Plume diagnostics
 - Gained methane experience



Night firing of MTTP thruster



MTTP Test Skid



Exhaust spectrum for GOX/GM combustion



Recent Project: 14" Valve Test

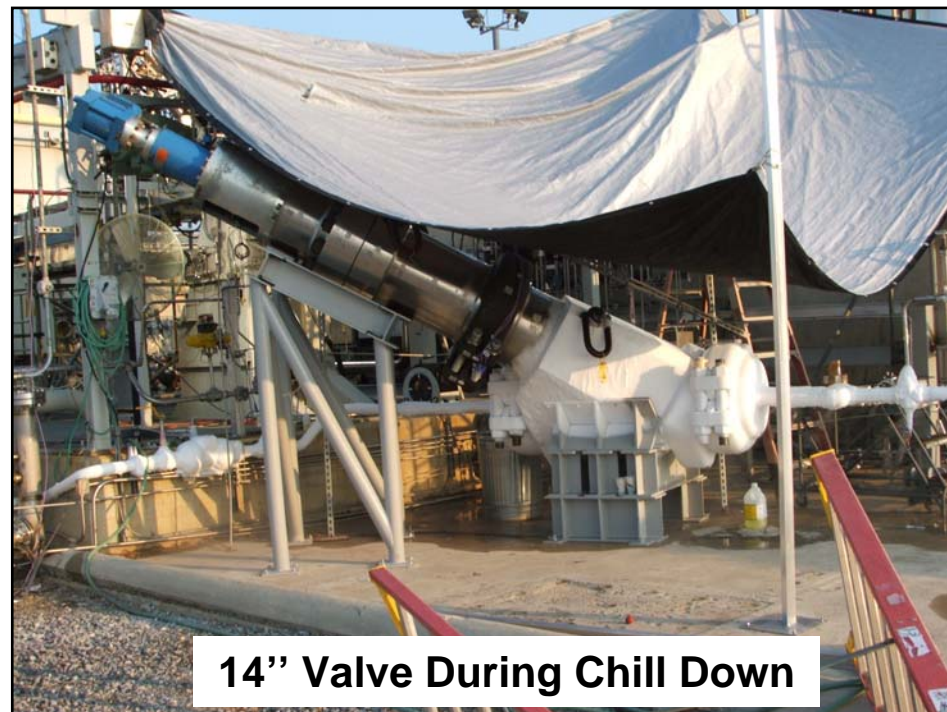
Description of Test Objectives

Test Objectives

- Collect Data Needed to Support a Decision to Install a 14" Valve (26,000 lb) on the E-1 Test Stand as the High Pressure (8,500 psi service) LOX Tank Isolation Valve
- Determine the Behavior of the Valve in Simulated Operating Conditions
- Determine the 14" Valve Bonnet and Body Steady State Temperatures

Test Details

- Conducted Valve Chill Down Test at the E-2 Test Stand
- Used Liquid Nitrogen (LN) to Chill Down the Valve
- Instrumented Valve with Multiple Thermocouples on the Valve Body and Stem
- During Chill Down Operations, the Valve was Cycled Multiple Times to Test Proper Valve Operation at Low Temperatures





14'' Valve Test Results

Picture of Frost Line After 23 Hours of Chilling

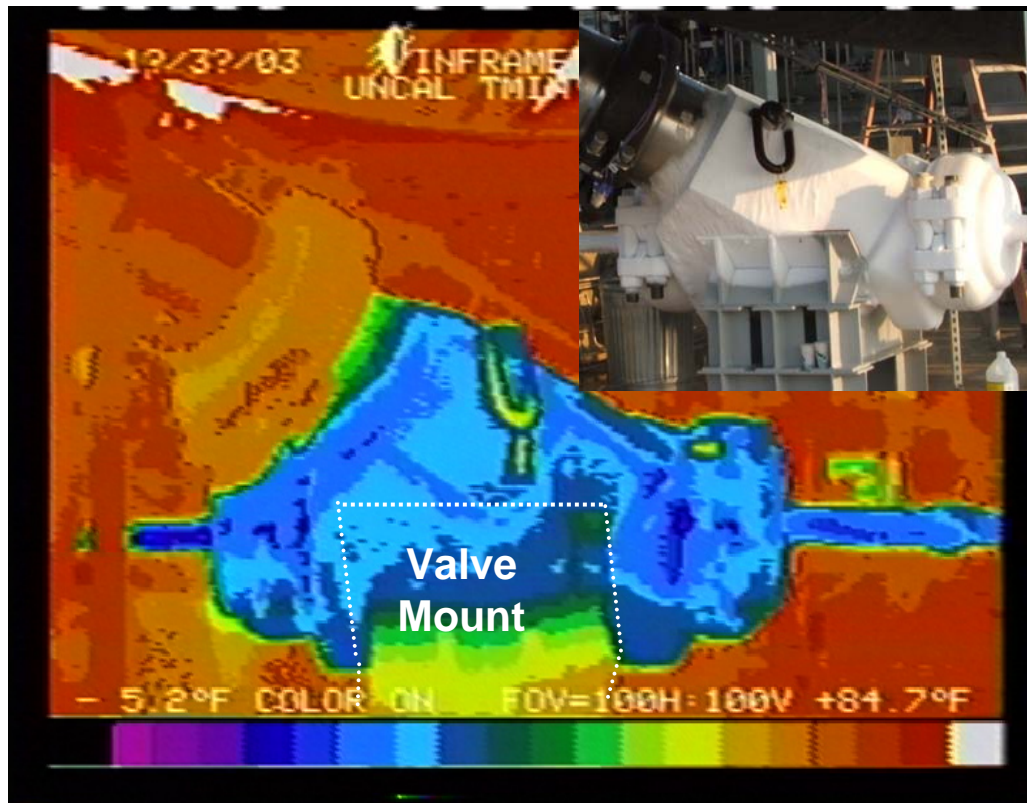


Test Results

- Test Lasted About 24 Hours
- About 6500 gal of LN Was Used for the Valve to Reach a Steady State Condition
- Boil Off Results Were Used to Calculate the Steady State Heat Load of the Valve

Analytical Accomplishments

- Identified Issue with Asymmetric Bonnet Wear at Cryogenic Temperatures
- Verified Analytical Predictions for the Heat Load of the Valve
 - Determined the Valve Heat Load
 - Determined the Valve Chill Down Time Constant
 - Test Results Will Be Used to Guide Bonnet Re-Design



↑
Thermal Image of Valve After Test



14" Valve

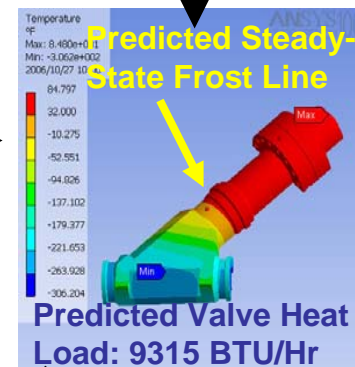
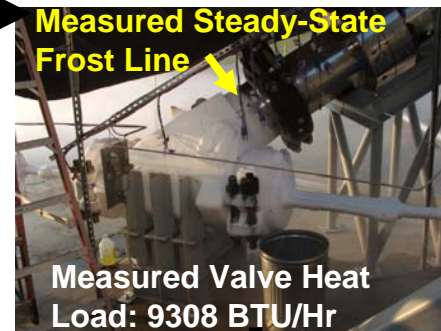
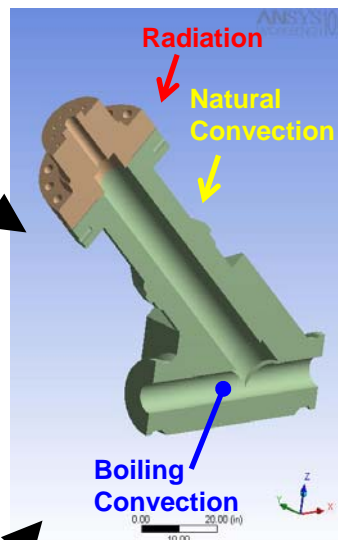
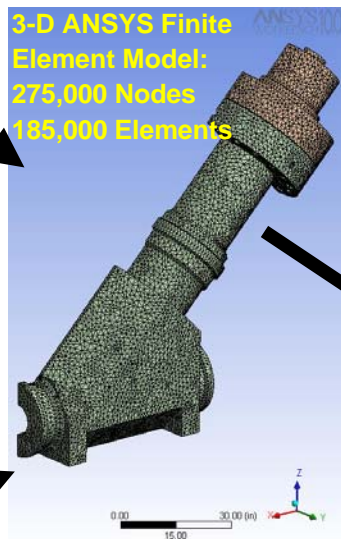
ANSYS Workbench Thermal Simulation

Geometry Description

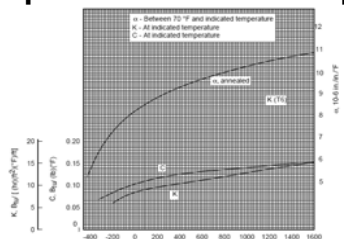
Analysis Model

Loads & Boundary Conditions

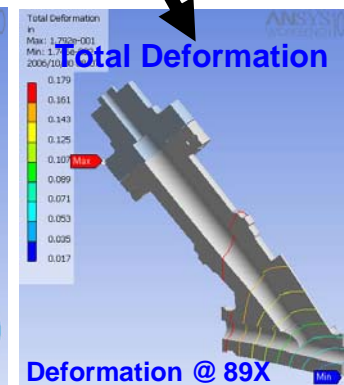
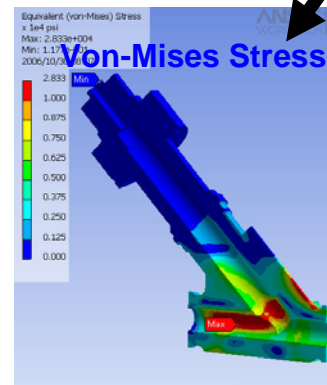
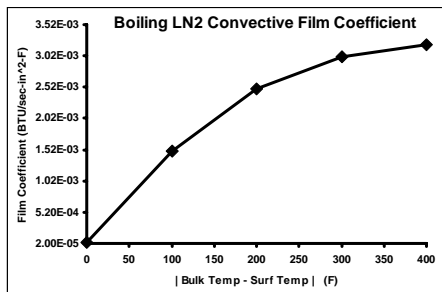
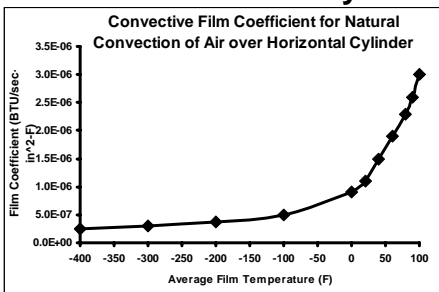
Validated Results



NIST / MIL-HDBK Temperature Dependent Material Properties



Empirically Based Temperature Dependent Boundary Condition Parameters





Computational Fluid Dynamics (CFD) Modeling

Employed CFD Code to Model E-1 High Pressure LOX Flow Capability

- CFD Investigations Indicate Pressurizing Gas Diffuser Flow Significantly Limits Flow Duration for High Flow Rate Cases

Analysis Boundary Conditions

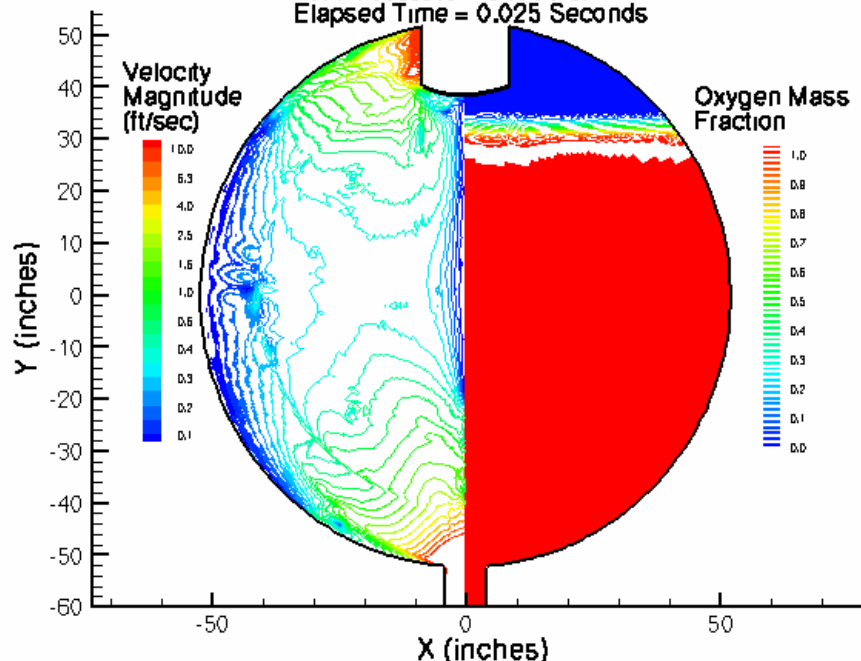
- HP LOX Tank at E-1 Test Stand
- Flow Case Assessed
 - 2500 lb/sec LOX Discharge Rate
 - 8400 psi Tank Pressure Maintained During Propellant Discharge

Results & Observations

- GN Convective Mixing with LOX Propellant is Substantial
 - Only 50% Loaded LOX is Useable (<~2% N₂ Concentration)
- LOX Propellant Supply at Assessed Flow Rate & Pressure Limited to Approximately 4 seconds (vs an Estimated 10 seconds Determined Using Nominal Facility Pressurizing Gas & Propellant Supply Limits)

HP LOX Tank Propellant Discharge Simulation

LOX Mass Flow Rate = 2500 lb/sec
LN₂ Mass Flow Rate = 1165 lb/sec
Tank Pressure = 8400 Psi
Elapsed Time = 0.025 Seconds

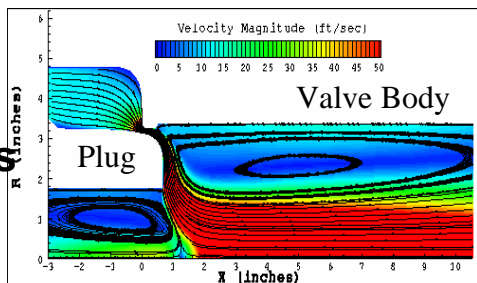




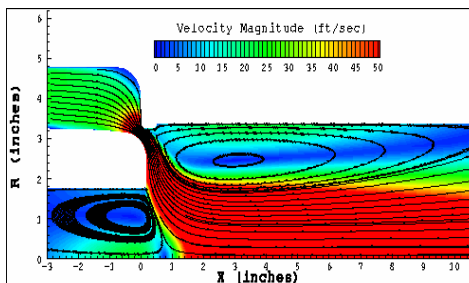
Computational Fluid Dynamics (CFD) Modeling

- Understanding a Valve's Flow Capacity (C_v) as a Function of Valve Stroke is Critical When Calculating the Propellant Flow Rates to a Test Article

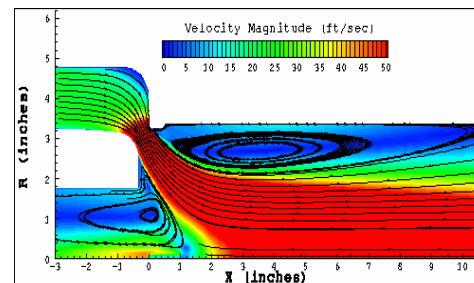
2.75" Stroke



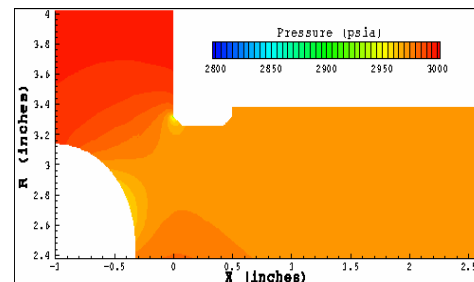
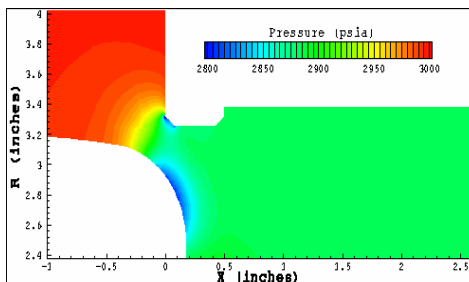
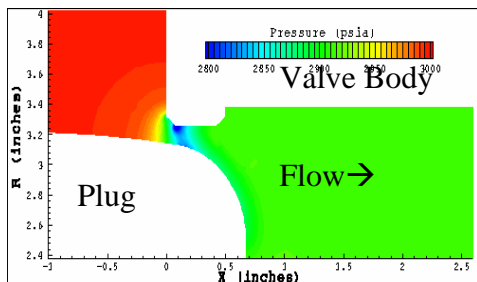
3.25" Stroke



3.75" Stroke

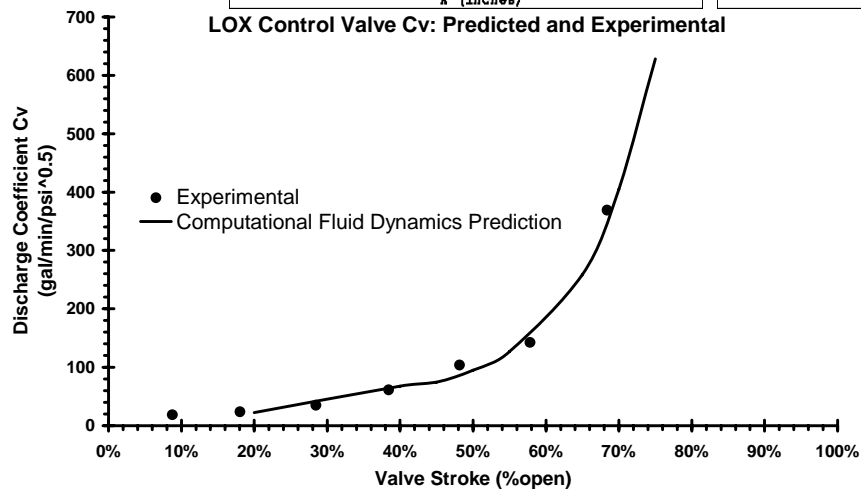


Velocity & Streamlines



Pressure

LOX Control Valve C_v : Predicted and Experimental



- CFD Used to Predict the Flow Field & C_v Curve for a Modified LOX Control Valve
- Yields a Good Understanding of How the Flow Field Changes as the Valve Opens & Affects C_v curve
- Analysis Reveals Areas Where Cavitation May Occur as Well as Areas of High Velocity That Are Important When the Working Fluid is LOX

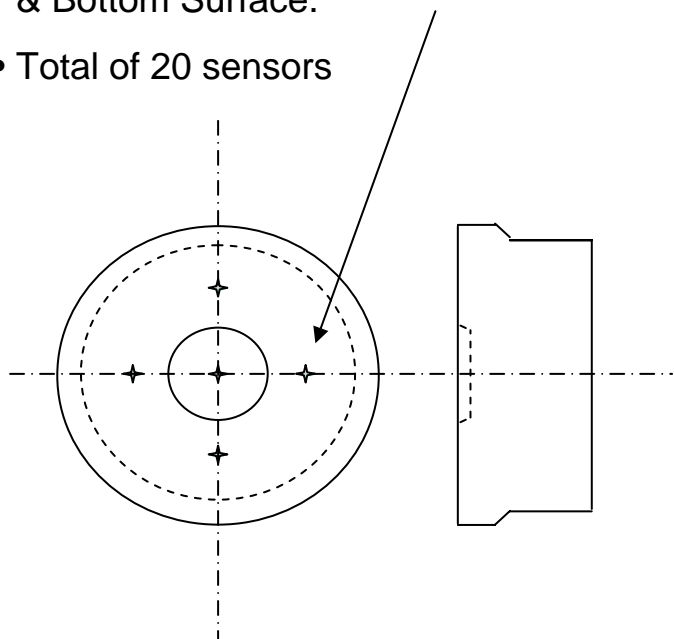


Thermal Fatigue Considerations

- The Goal of This Investigation Was to Simulate the Thermal Environment During Tank Chill Down and Apply What Was Learned in the Specimen Testing to Improve the Reliability of Analytical Model Calculations
- Performed Laboratory-Scale Testing

Test Specimen

- 5 Thermocouple & Strain Gage Pairs - 4 on 8" dia Spaced at 90°, 1 at Center. Typical on Both Top & Bottom Surface.
- Total of 20 sensors



Dye Penetration Testing

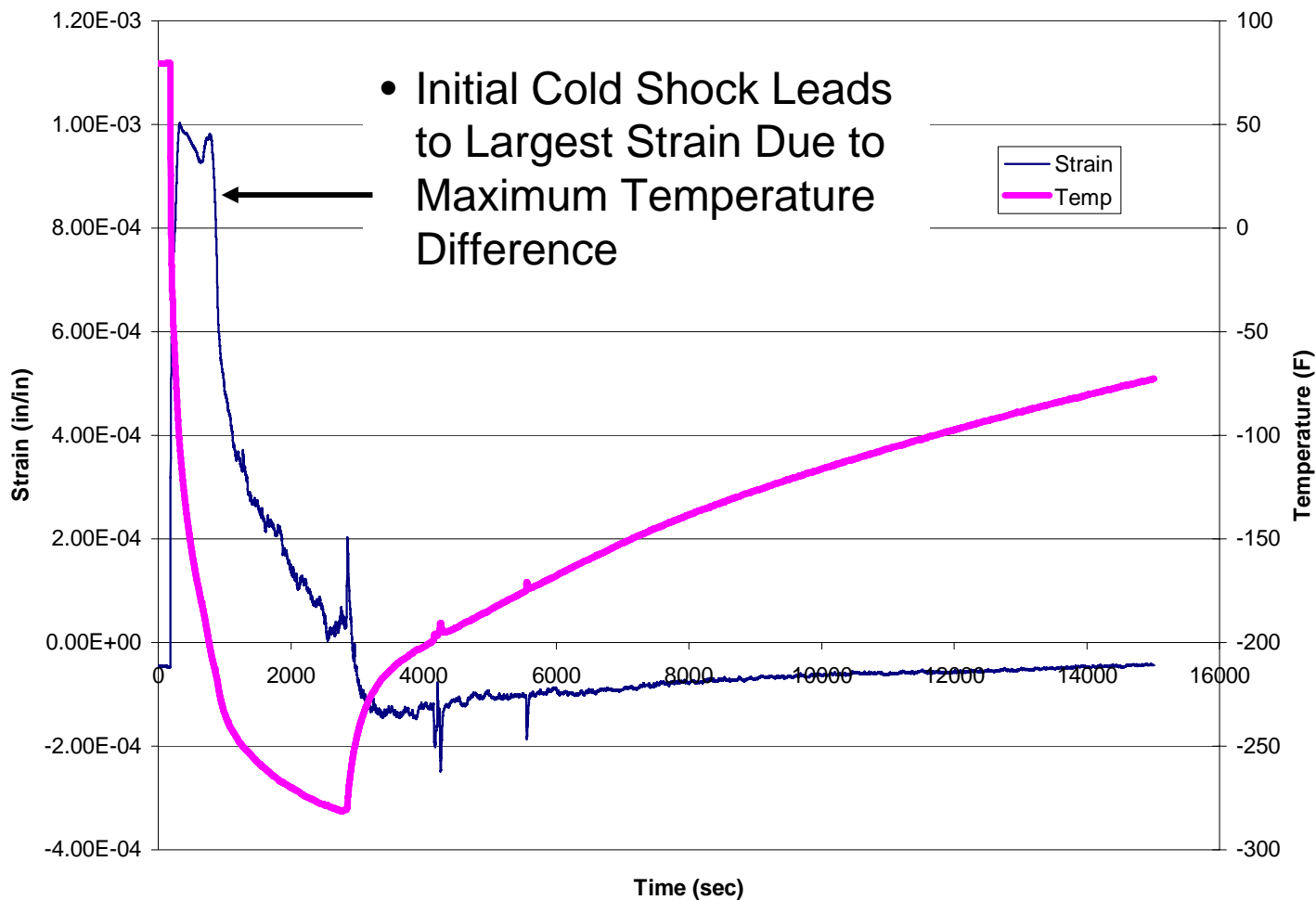
Test Procedure

- Subject Top of Test Specimen to LN
- Record Strain & Temperature Data
- NDE Dye Penetration Test Performed for Crack Detection
- Testing for Crack Initiation Made After Each Thermal Cycle for the First 15 Cycles
- Subject Test Specimen to Greater Than 100 Cycles



Thermal Fatigue Considerations

Top Center Temperature & Compensated Strain



Lab-Scale Specimen Exposed to LN



Summary

- SSC has Developed a Suite of Effective Analytic Modeling and Analysis Tools Providing High Fidelity Assessment of Test Stand Performance
 - Rocket Propulsion Test Analysis (RPTA) Model, a 1-D Propellant System Analyzer
 - CFD Applied to Select Propulsion Test Situations
 - Finite Element Analysis (ANSYS/CFX)
- Analytic Tools Exercised Regularly on a Variety of Propulsion Test Projects by Experienced Analysts
 - Active Test Facilities (1.0 to 1.5 Mlbf Thrust, 8500 psi LOX/LH/RP-1 Supply)
 - Active Test Projects (e.g., J-2X PPA, J-2X at PBS, TGV)
- We are Planning to Augment our Staff
 - Fluid Mechanics/Systems Modeling & Analysis
 - Thermal Analysis

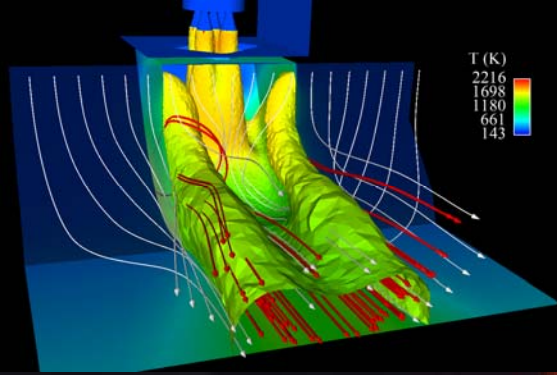
For Additional Information/Discussion Please Contact :

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Stennis Space Center Engineering and Test Directorate



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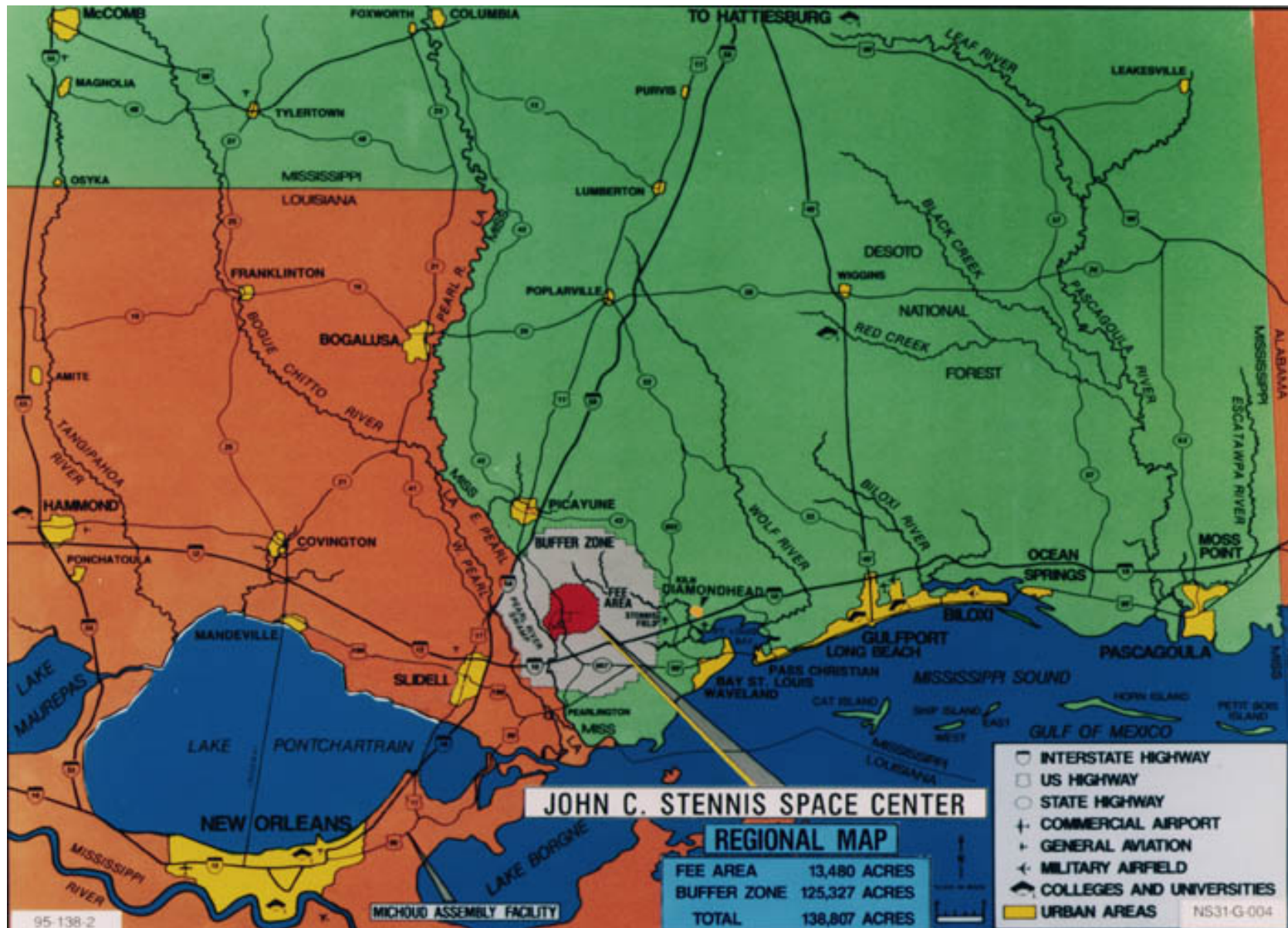
Arnold Association of Professional Societies (AAPS) Luncheon
Tullahoma, TN

January 21, 2009



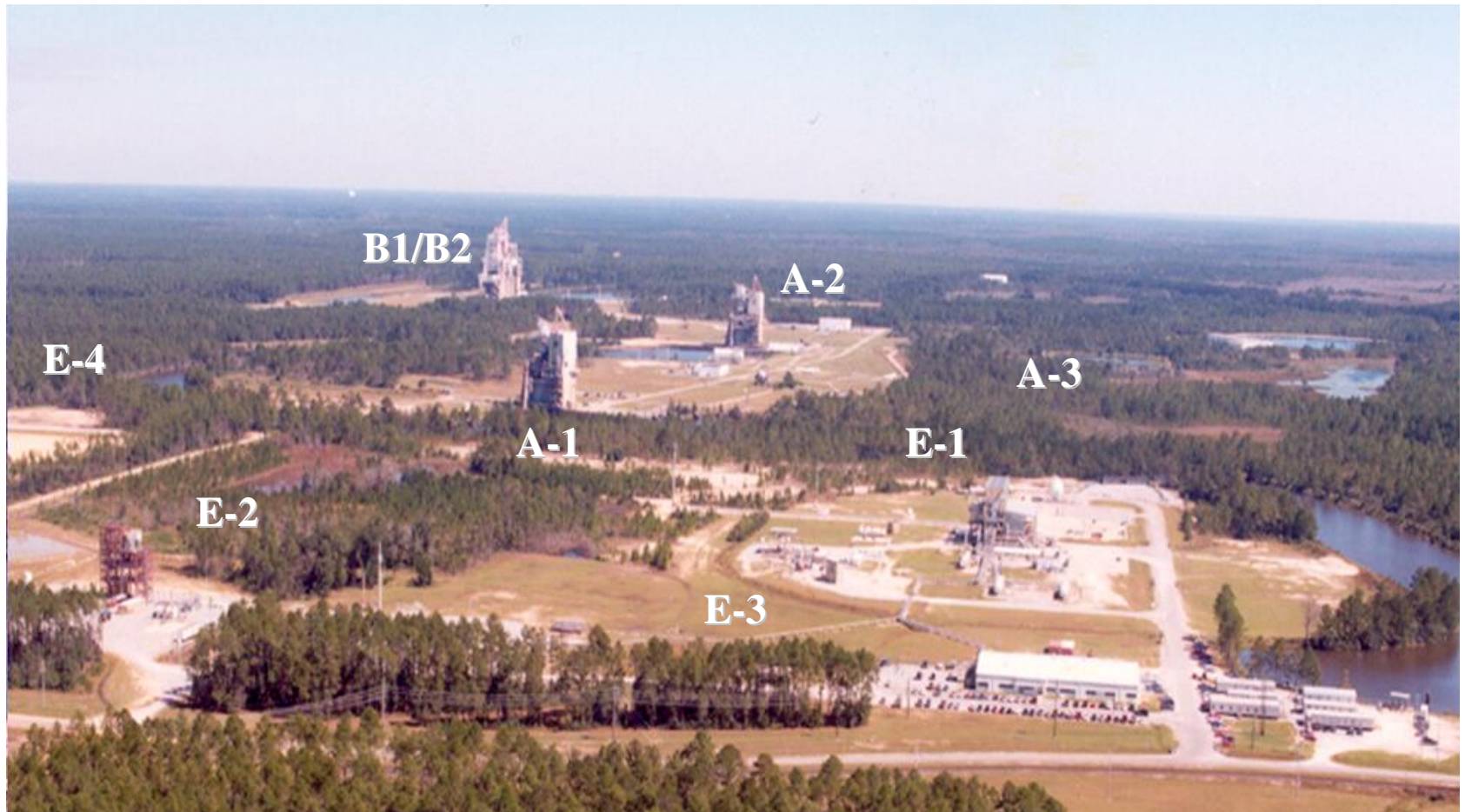


SSC Regional Map





Facilities & Operations



SSC's ETD (Engineering and Science Directorate) manages, develops, and operates SSC Rocket Propulsion Test (RPT) capabilities and facilities



Complete Suite of Test Capability and Expertise

E-1 Stand

High Press., Full Scale
Engine Components



A-1 ... Full Scale Engine Devt. & Cert ... **A-2**

E-2

High Press.
Mid-Scale
& Subscale



E-3

High Press.
Small-Scale
Subscale



B-1/B-2 ... Full Scale Engine/Stage Devt. & Cert

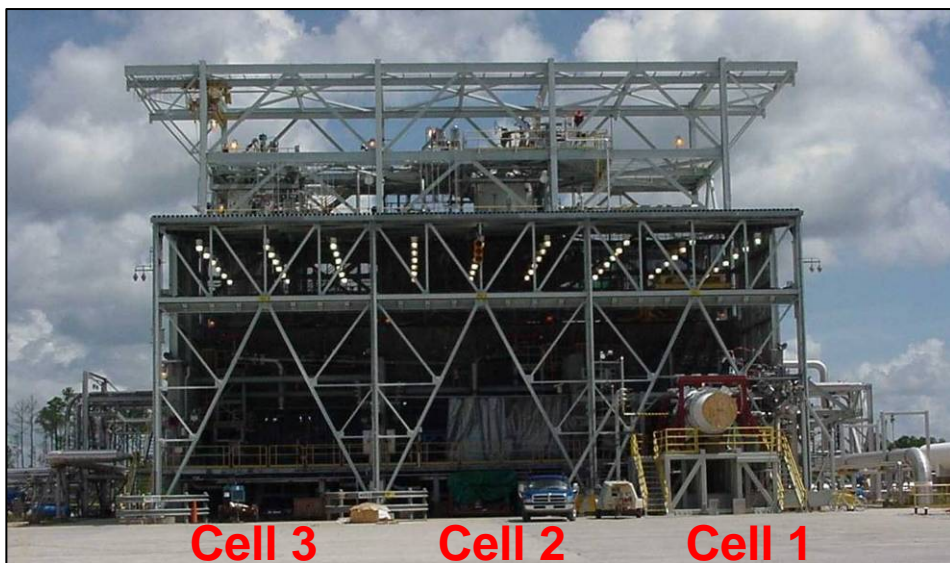
Components ... Engines ... Stages



NASA-SSC CFD Modeling Activities

NASA-SSC Test Facilities – E Complex

Component and Engine Testing (E-1)



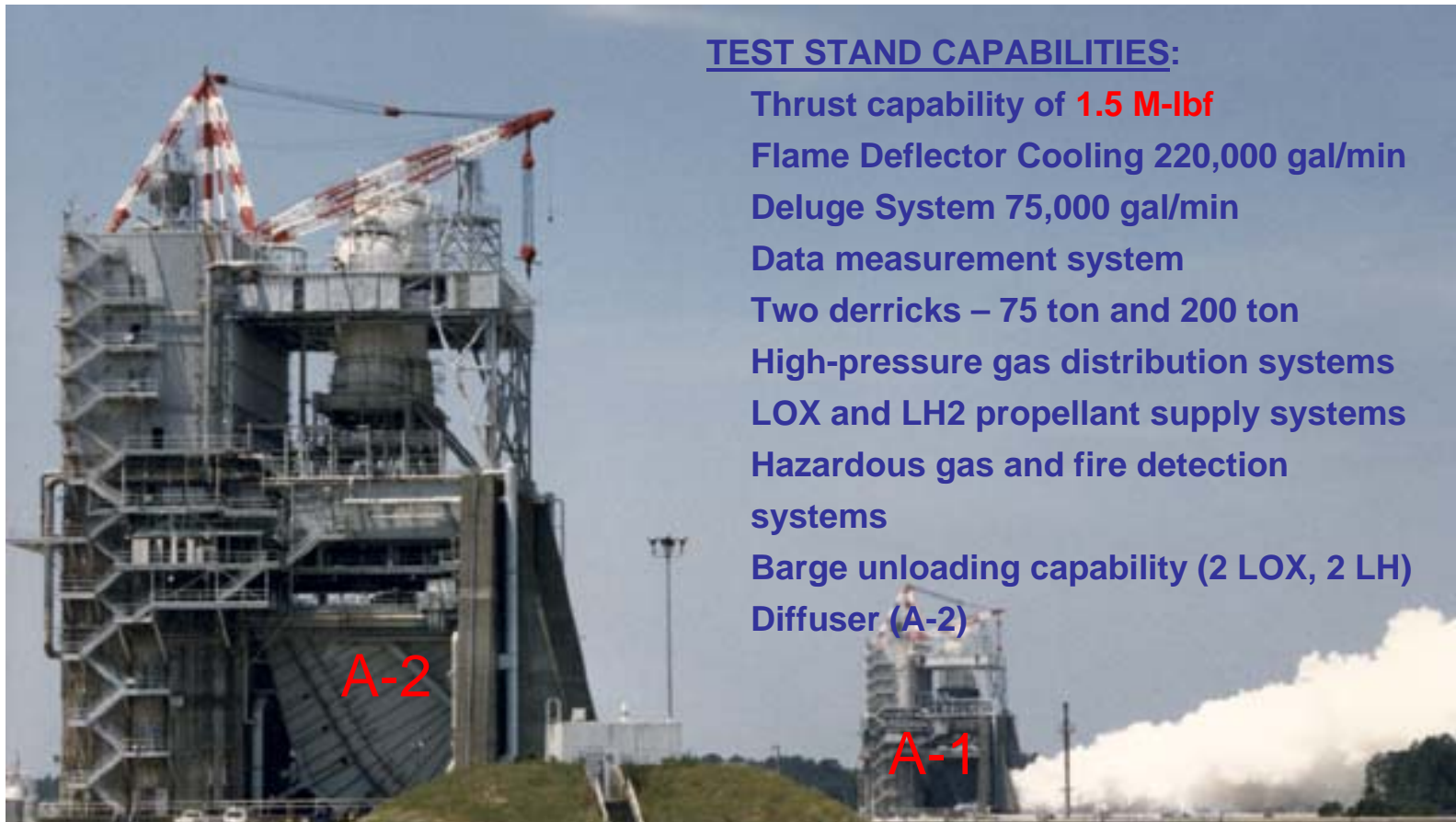
- High Pressure (Long Run) Capabilities
 - LOX/LH/RP ~ 8,500 psi
 - GN/GH ~ 15,000 psi
 - GHe ~ 10,000 psi
- State-of-the-Art DAC Systems
- E-1 Cell 1
 - Primarily Designed for Pressure-Fed LOX/LH/RP & Hybrid Test Articles
 - Thrust Loads up to **750K lb_f** (horiz.)
- E-1 Cell 2
 - Designed for LH Turbopump & Preburner Assembly Testing
 - Thrust Loads up to **60K lb_f**
- E-1 Cell 3
 - Designed for LOX Turbopump, Preburner Assembly & Engine Testing
 - Thrust Loads up to **750K lb_f**



NASA-SSC Test Facilities – A Complex

□ Full-scale Engine Development & Certification

- Saturn V 2nd Stage J-2 engine (1.15 M-lbf cluster of 5 LH₂/LOX J-2 engines)
- SSME (375 K-lb LH₂/LOX) development, flight acceptance, & 65kft altitude (A-2)
- X-33 Aerospike





NASA-SSC Test Facilities – B Complex

□ Vehicle Stage & Full-scale Engine Testing

- SATURN V (7.7 M-lbf cluster of 5 RP-1/LOX F-1 engines)
- SSME MPTA (1.1 M-lbf cluster of 3 LH₂/LOX SSME)
- Delta IV Common Booster Core (650 K-lbf LH₂/LOX RS-68 engine)

TEST STAND CAPABILITIES:

Thrust capability of **13 M-lbf**

Flame Deflector Cooling 330,000 gal/min

Deluge System 123,000 gal/min

Data measurement system

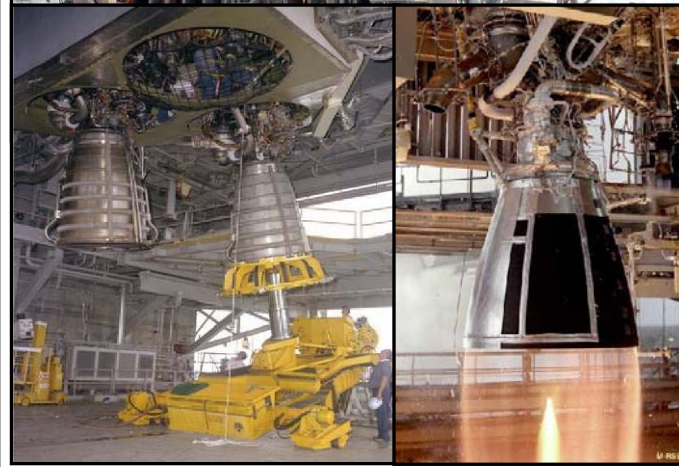
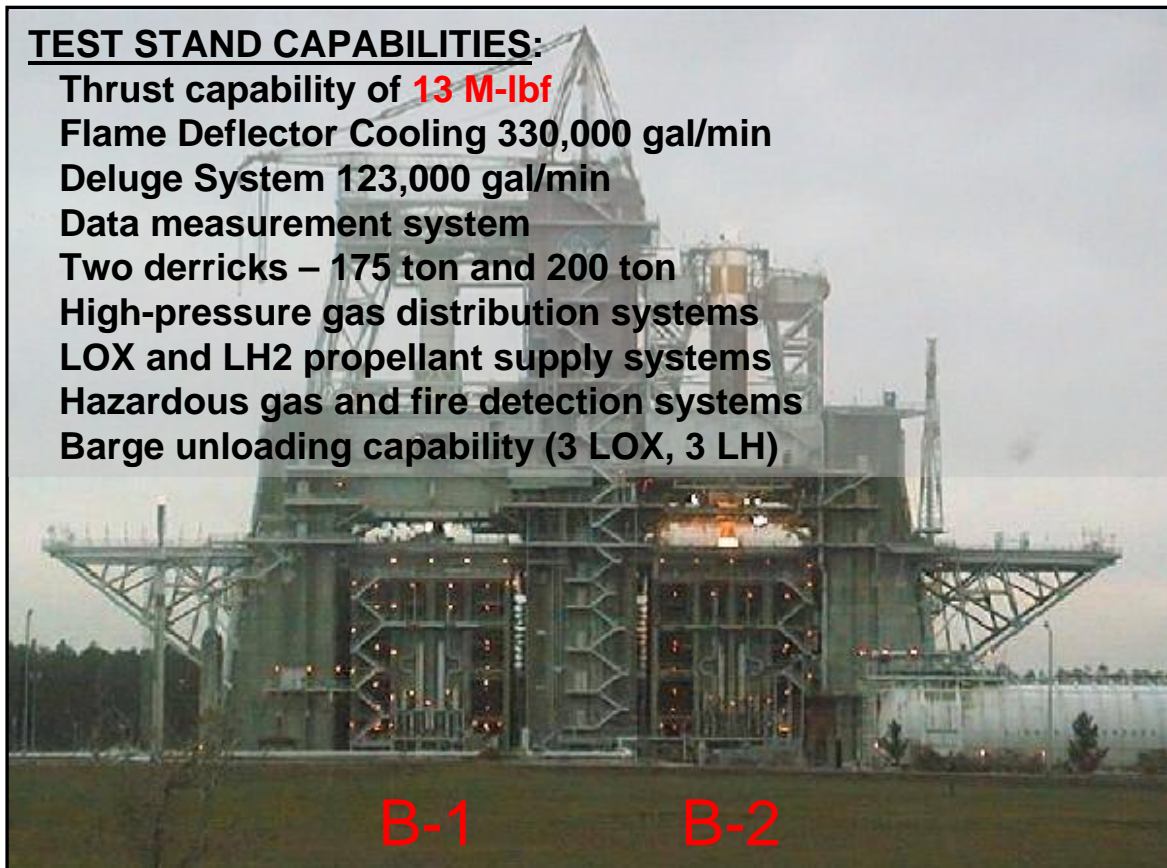
Two derricks – 175 ton and 200 ton

High-pressure gas distribution systems

LOX and LH₂ propellant supply systems

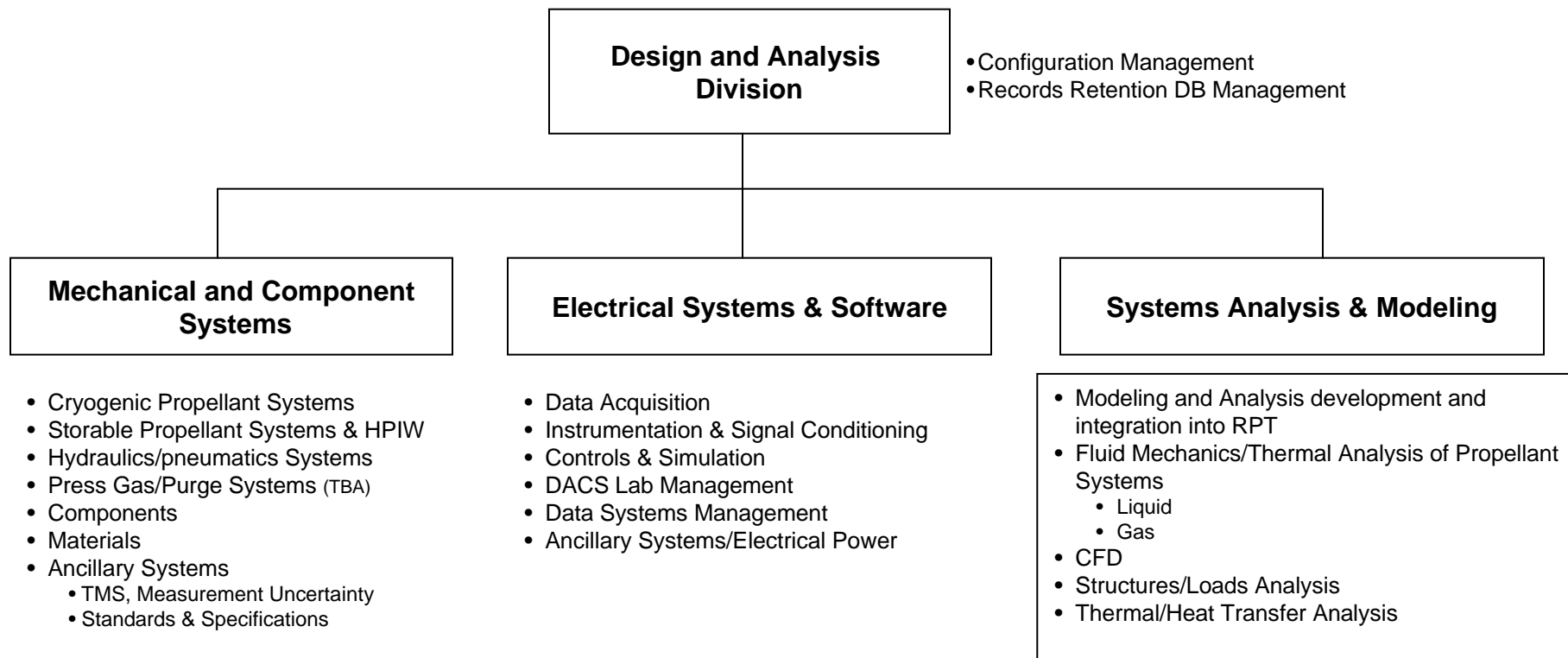
Hazardous gas and fire detection systems

Barge unloading capability (3 LOX, 3 LH)





NASA SSC Design & Analysis Division



Organization Goal:

- **Develop and maintain propulsion test systems and facilities engineering competencies**
 - Unique and focused technical knowledge across respective engineering disciplines applied to rocket propulsion testing. e.g.,
 - Materials selection and associated database management
 - Piping, electrical and data acquisition systems design for cryogenic, high flow, high pressure propellant supply regimes
 - Associated analytic modeling and systems analysis disciplines and techniques
 - Corresponding fluids structural, thermal and electrical engineering disciplines



Integrated Facility Simulation and Analysis

- To Support Propulsion Testing, SSC Has Developed & Implemented Analytic Modeling & Simulation Tools
 - Rocket Propulsion Test Analysis (RPTA) Model (FORTRAN) Used to Simulate Propulsion Test Facility Systems (e.g., LOX Run System)
 - ✓ Heritage of Model Dates to Pressurization and Propellant Systems Design Tasks for Space Shuttle and X-33
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 - Computational Fluid Dynamics (CFD) Used for Select Propulsion Test Situations
 - Have Experienced Analysis Team that Routinely Solves Pressurization and Propellant System Problems
- Integrated Facility Simulation and Analysis Has Led to Substantial Project Cost and Schedule Savings



D&A Capability Development

Strengthening Engineering Competencies

- Structural Analysis
- Control Systems design/development
- Thermal Analysis/Heat Transfer
- Fluid Mechanics specific to RPT



SSC Design & Analysis Division

- RPTA Model
- CFD Crunch/FDNS
- MathCad/Excel Models

Data Analysis Process Improvements

- Design & Data Management System
 - Record Retention System
 - Drawing Tree Development
 - Pro/E model MSK capability
 - A CM enhancement opportunity
- Wider access to analytic models
 - PSME Project
 - GUI
 - Server Access
- Internal Technical Reviews



Analysis Tool Suite Growth

- Structural Analysis
 - ANSYS/CFX
- Purge systems design and analysis
 - Flowmaster
- Structural Heat Transfer/Thermal Analysis
 - SINDA
- Piping system modal analysis
 - Autopipe

Comprehensive Test Site Engineering Support

- A,B & E Stand Modeling & Analysis
 - J-2X, A3, Subscale Sim, Steam Gen Projects
- Operations Support
 - Test stand activation & test
- Facility Operations Support, e.g.,
 - LO2 Barge Impeller Structural Margin Def.
 - A1/A2 LH2 Vent Duct Rupture Invest, and Resolution
 - HPGN system redesign
 - HP Air System Contamination
 - LH2 Sphere Bypass Design
 - UT inspection of B Stand HP Water Deluge Sys



Expanding Beyond SSC E-Complex

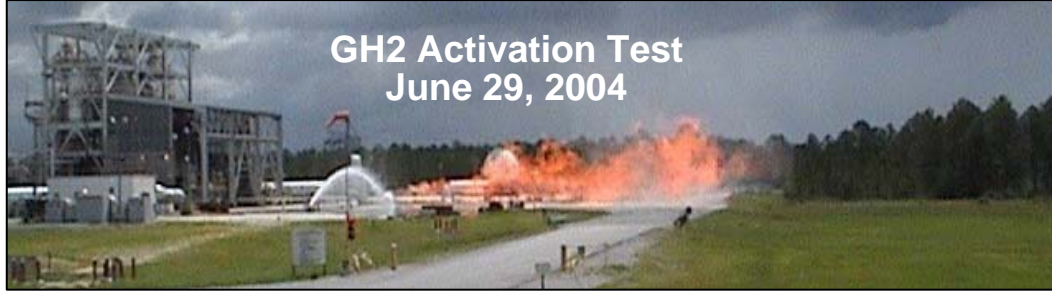
- Ares US Propellant Tank Operations Performance Analysis Support to MSFC
- PBS B2 Test Stand Design
- RS-68 Test vs Flight Performance
- LSAM (JSC) & CEV SBT (GRC/NESC)



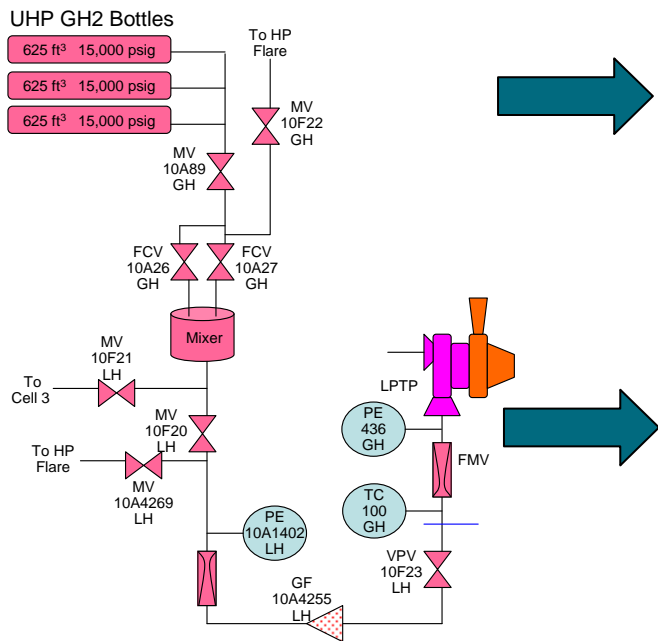
Integrated Facility Simulation and Analysis

- Analytic Tools Available for Propulsion Test Facility Modeling & Analysis
- Comprehensive Propellant System Thermodynamic Modeling & Test Simulation

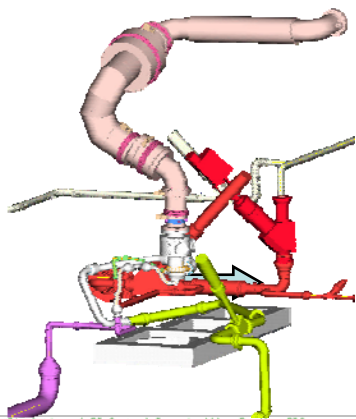
Integrated Performance Modeling Capabilities Substantially Improves Understanding & Knowledge of Test Systems Performance that has Translated to Efficient Test Facility Design, Activation & Test Operations



System Design



Modeling

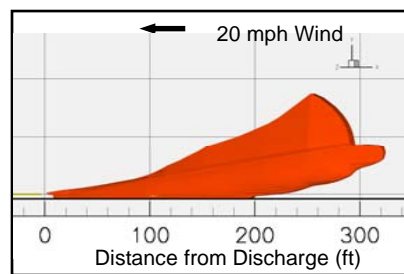
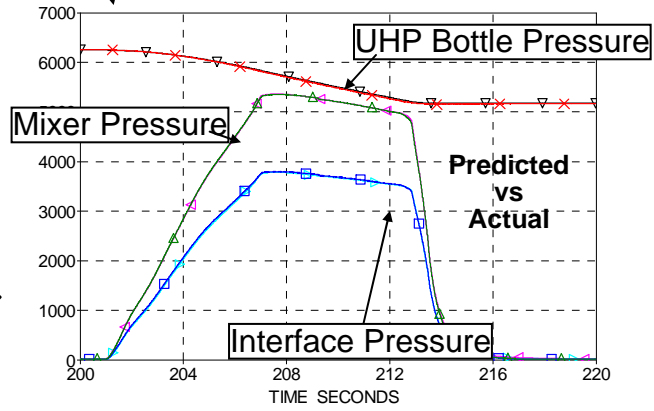


```

Simulation of PI Control Loop in Allen Bradley PLC *****
IF (Time LT LoopStart + ScanTime) THEN
ELSE
RETURN
----- Set FCV Command -----
IF (PCVAuto EQ 1) THEN
IF (PowerArea) THEN
CALL SPRead/ScanTime.TFPGP.TFPRateUp.Rate
PCVPressSP = TFP/(TFB*Rate)
END IF
CALL SPRead/ScanTime.TFPGP.TFPRateUp.E
TotOut = SP - PCVPressSP + PCVRateUp.E
A[100] = SP - PCVPressSP + PCVRateUp.E
A[100] = IntOut(1) + BiasOut
If (TotOut IE 0.0 OR TotOut GE 100.0) Then
TotOut = PropOut(2) + IntOut(1) + BiasOut
A[100] = IntOut(1)
Else
IntOut(1) = IntOut(2)
End If
  
```

Fluid System Modeling

Test and Data Analysis



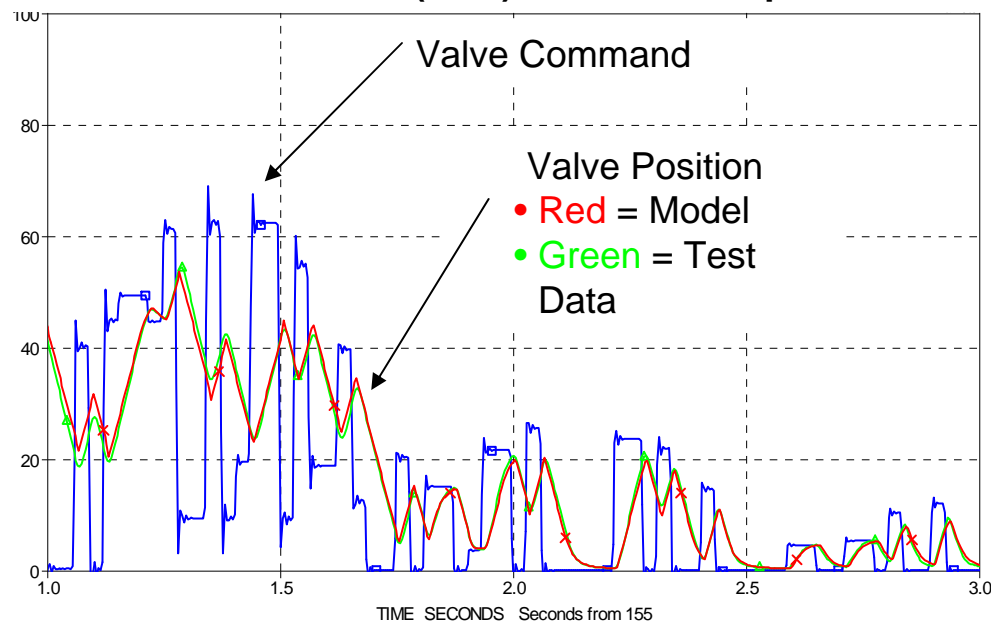
Advanced Capabilities in CFD Modeling & Analysis



Rocket Propulsion Test Analysis (RPTA) Model

- Temporal Transient Thermodynamic Modeling of Integrated Propellant Systems
- Thermodynamic Control Volume Solver Model Accurately Models High-Pressure Cryogenic Fluids and High-Pressure Gaseous Systems. Model Features Include:
 - High-Fidelity Pressure Control Valve (PCV) & Closed Loop Control System Model
- RPTA Model Validated Through Test Data Comparisons
 - IPD Fuel Turbopump, RS-84 Sub-Scale Pre-Burner, RS-83 Pre-Burner Cold Flows, SSME Flowliner Activation & IPD Engine System

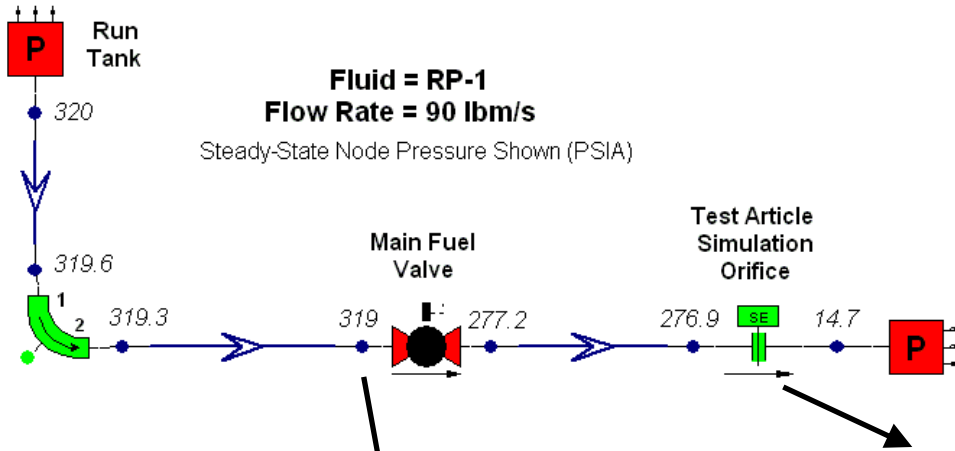
Pressure Control Valve (PCV) Model Developed & Validated



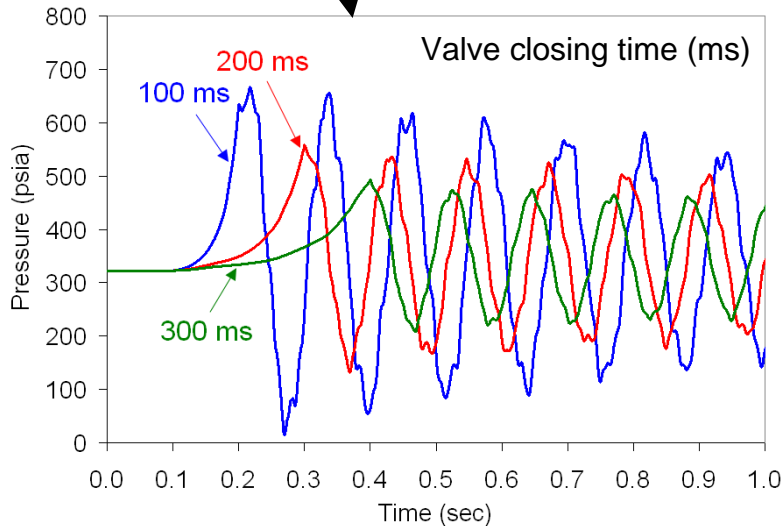
A Significant Advantage of the RPTA Model is the Coupling of Control Logic (Electro-Mechanical Process) with Thermodynamic Processes



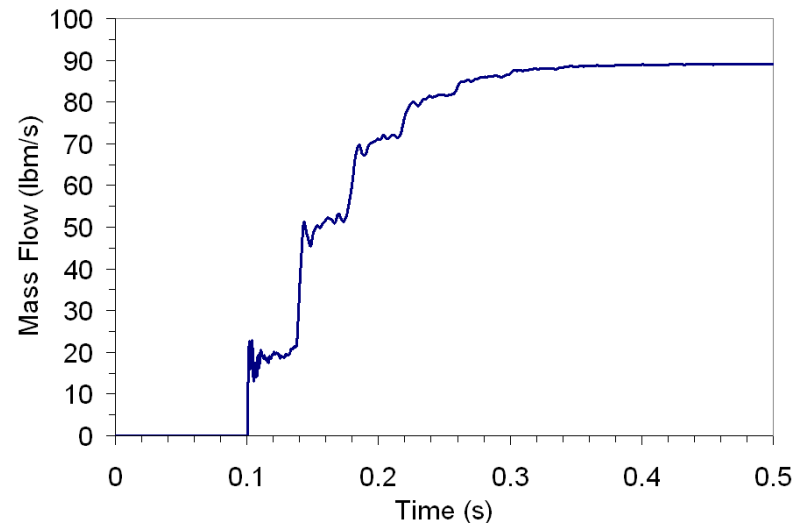
Comprehensive & Rapid Piping System Design & Analysis Capability



- Commercial Tools Employed to Augment Analysis
- Example: *FlowMaster* Piping System Analyzer
 - Allows for Steady-State or Transient Analysis, Compressible or Non-Compressible Flow
 - Includes Heat Transfer, Flow Balancing, Priming & Sizing Analysis



Water Hammer Effect Due to Rapid Closure of Main Fuel Valve



Propellant Flow to Test Article Due to Rapid Opening of Main Fuel Valve

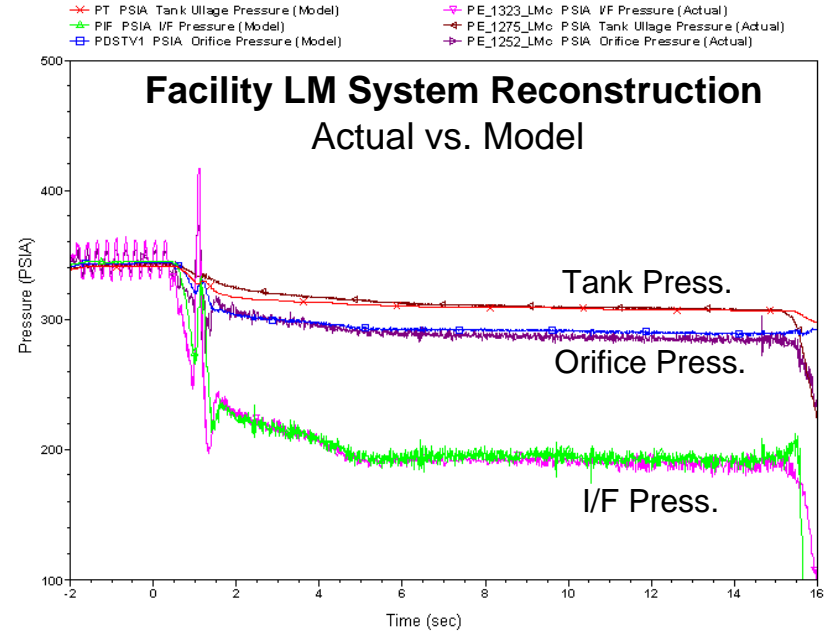


Recent LOX/Methane Testing at E-3

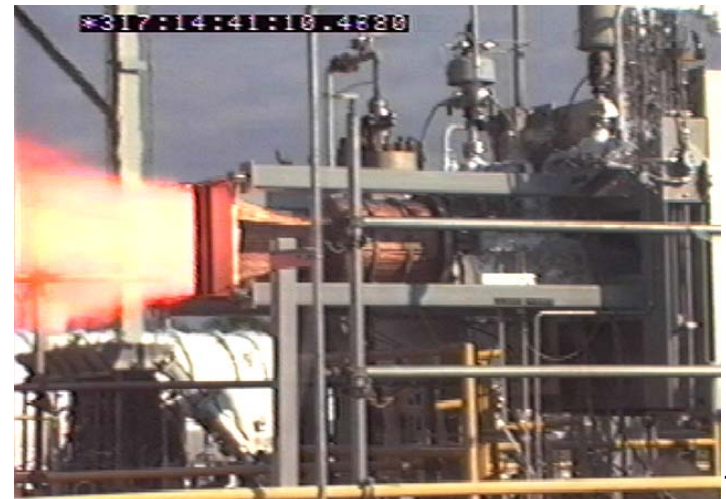
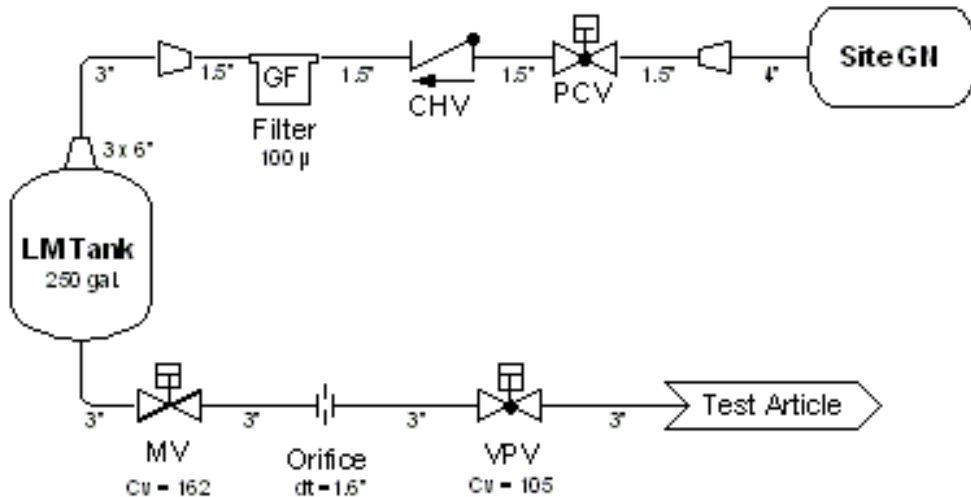
15 klbf Advent Engine Test Program – Nov 06

Facility Activated and Test Performed

- Liquid Methane (LM) & Liquid Oxygen (LOX) Propellants Used
- Facility Model Results and Facility Test Activation Results Agree Well
- Test Capability: ~25 seconds



LM System Schematic





14" Valve

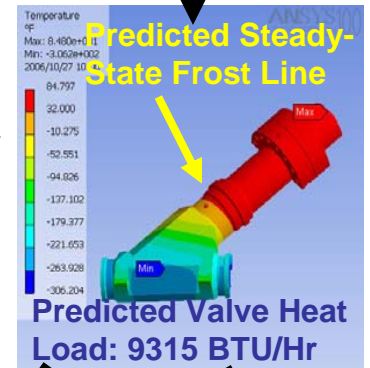
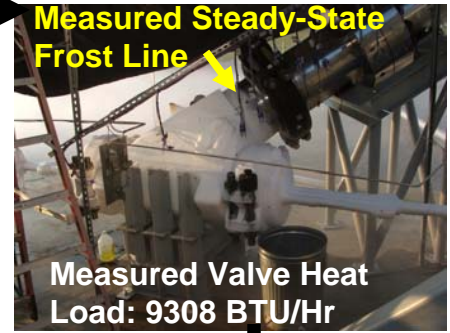
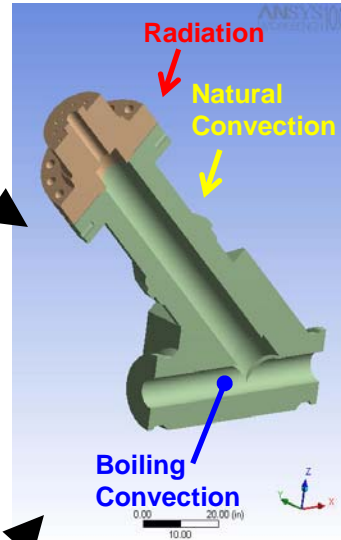
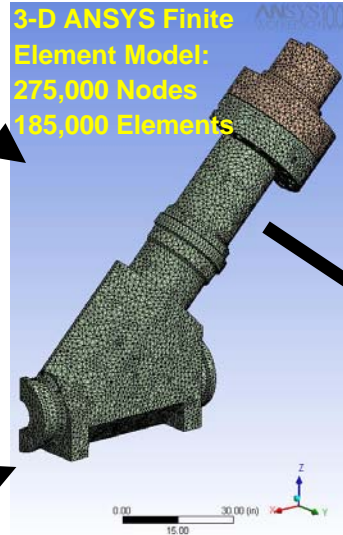
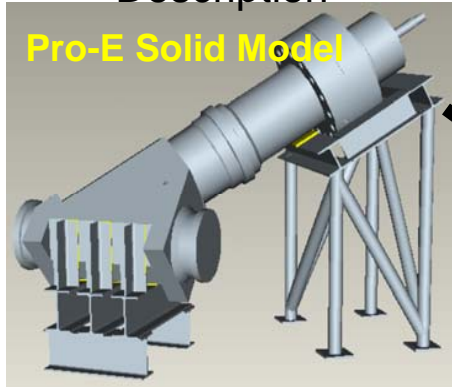
ANSYS Workbench Thermal Simulation

Geometry Description

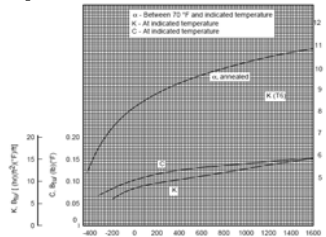
Analysis Model

Loads & Boundary Conditions

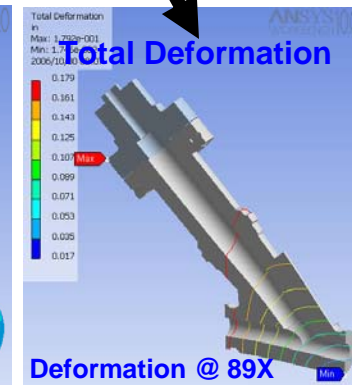
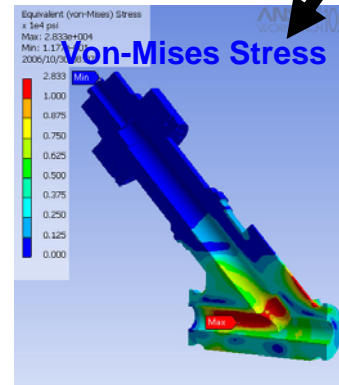
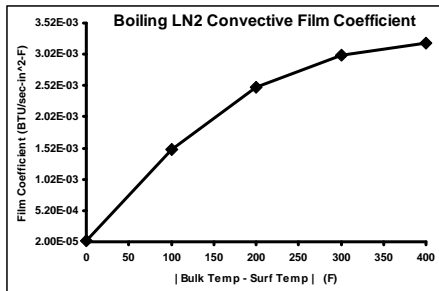
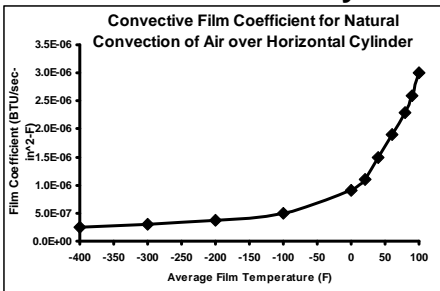
Validated Results



NIST / MIL-HDBK Temperature Dependent Material Properties



Empirically Based Temperature Dependent Boundary Condition Parameters





Computational Fluid Dynamics (CFD) Modeling

Employed CFD Code to Model E-1 High Pressure LOX Flow Capability

- CFD Investigations Indicate Pressurizing Gas Diffuser Flow Significantly Limits Flow Duration for High Flow Rate Cases

Analysis Boundary Conditions

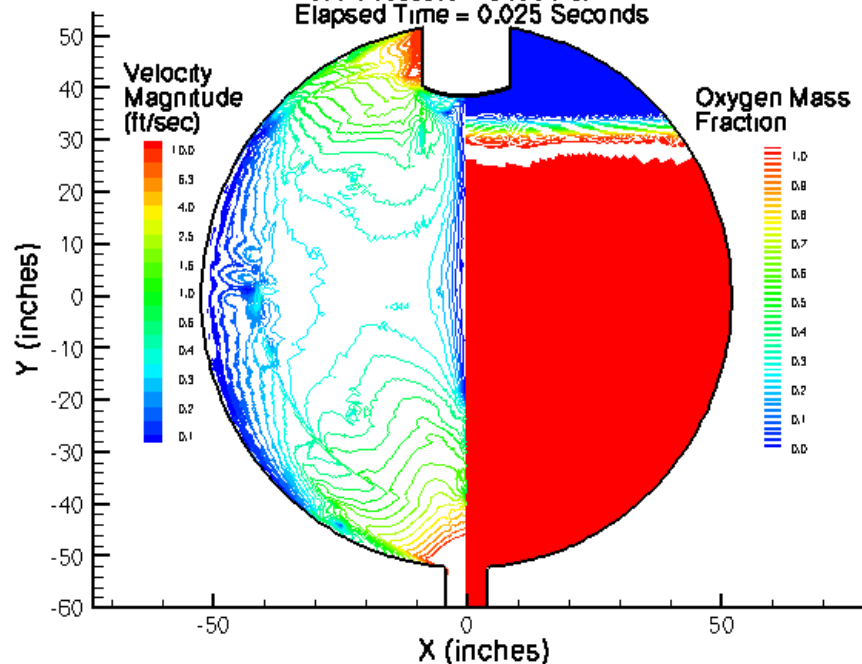
- HP LOX Tank at E-1 Test Stand
- Flow Case Assessed
 - 2500 lb/sec LOX Discharge Rate
 - 8400 psi Tank Pressure Maintained During Propellant Discharge

Results & Observations

- GN Convective Mixing with LOX Propellant is Substantial
 - Only 50% Loaded LOX is Useable (<~2% N₂ Concentration)
- LOX Propellant Supply at Assessed Flow Rate & Pressure Limited to Approximately 4 seconds (vs an Estimated 10 seconds Determined Using Nominal Facility Pressurizing Gas & Propellant Supply Limits)

HP LOX Tank Propellant Discharge Simulation

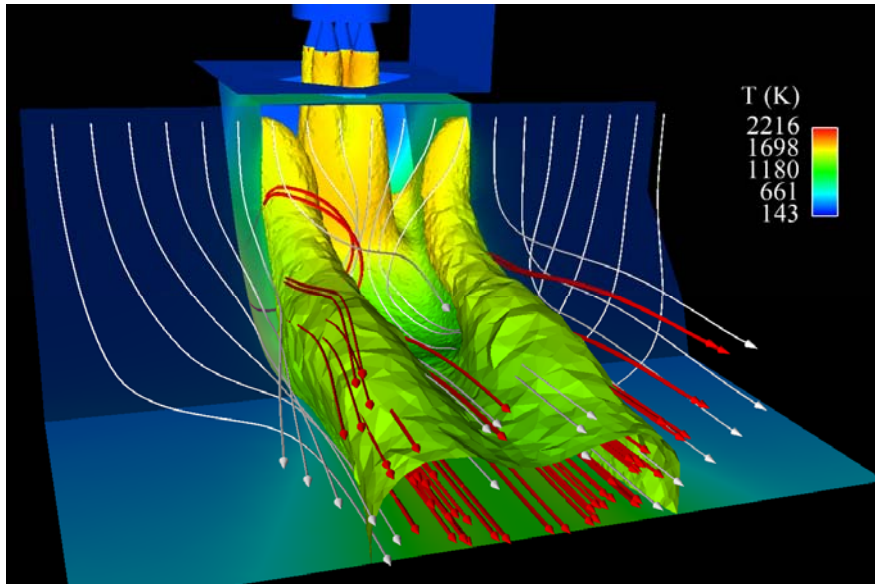
LOX Mass Flow Rate = 2500 lb/sec
LN₂ Mass Flow Rate = 1165 lb/sec
Tank Pressure = 8400 Psi
Elapsed Time = 0.025 Seconds





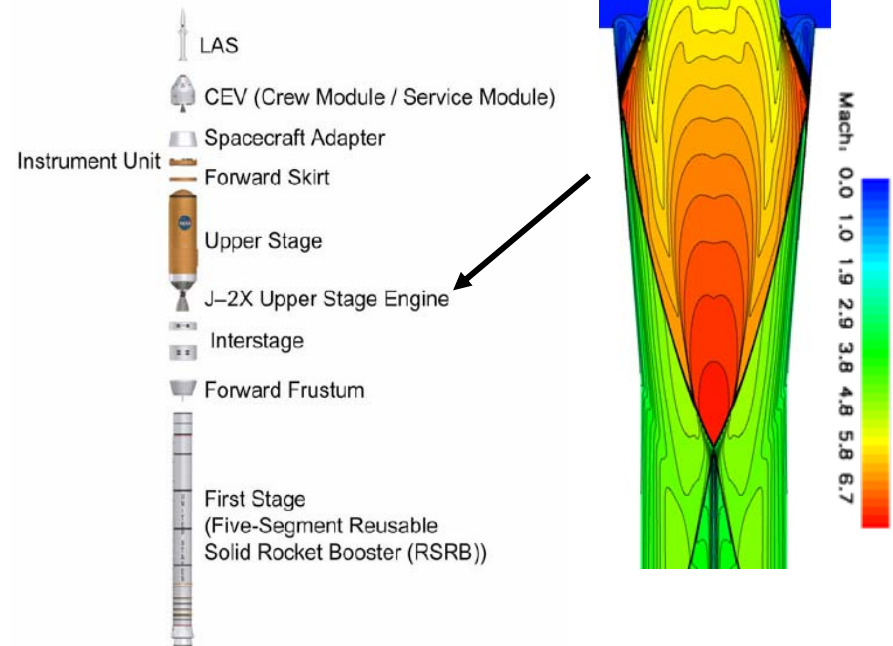
Advanced CFD Capability

- **Employ CFD Techniques to Support Propulsion Testing in the Following Areas:**
 - Cryogenic Propellant Delivery Systems (e.g., Run Tanks, Piping)
 - Cryogenic Control Devices (e.g., Valves)
 - Plume Modeling
- **Dedicated Computational Cluster (48 Dual Processors) at NASA SSC**



Computational Results of Conceptual Ares 5 Stage Test at SSC B-2 Test Stand

ARES I



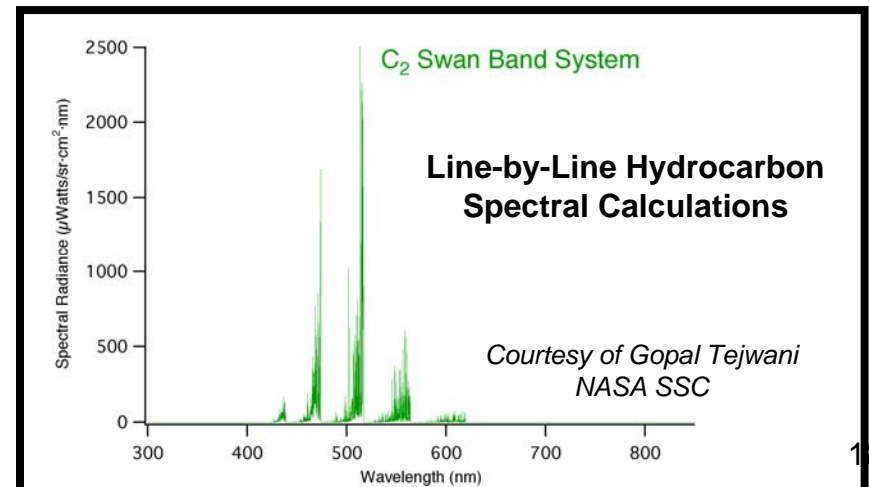
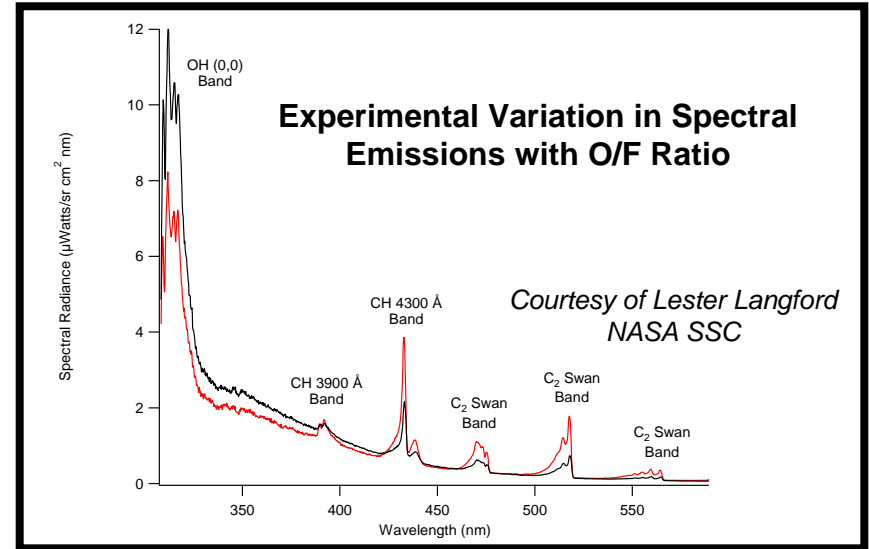
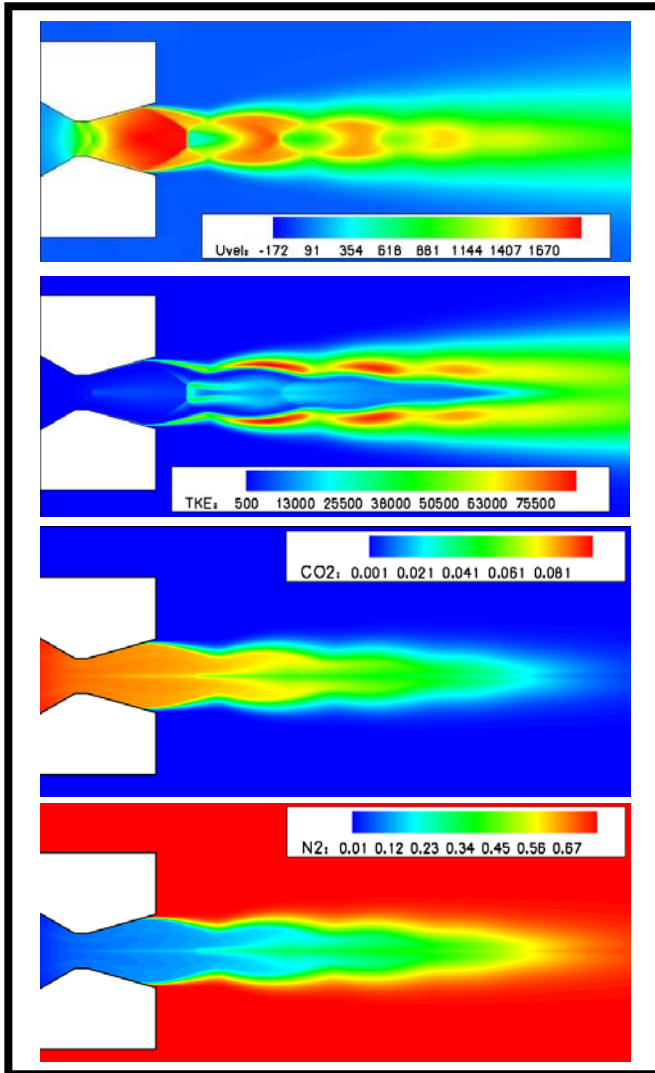
Computational Results of J-2X Altitude Diffuser Simulation (300 K-lbf)



NASA-SSC CFD Modeling Activities

MTTP Plume Simulations – CFD Model Validation

- CFD data was used to support parallel efforts in the experimental plume diagnostics and line-by-line spectral radiation analysis.





Summary

- SSC has Developed a Suite of Effective Analytic Modeling and Analysis Tools Providing High Fidelity Assessment of Test Stand Performance
 - Rocket Propulsion Test Analysis (RPTA) Model, a 1-D Propellant System Analyzer
 - CFD Applied to Select Propulsion Test Situations
 - Finite Element Analysis (ANSYS/CFX)
- Analytic Tools Exercised Regularly on a Variety of Propulsion Test Projects by Experienced Analysts
 - Active Test Facilities (1.0 to 1.5 Mlbf Thrust, 8500 psi LOX/LH/RP-1 Supply)
 - Active Test Projects (e.g., J-2X PPA & Engine, A-3, Chemical Steam Generator)

For Additional Information/Discussion Please Contact :

David Coote 228-688-1056, Email: David.J.Coote@nasa.gov

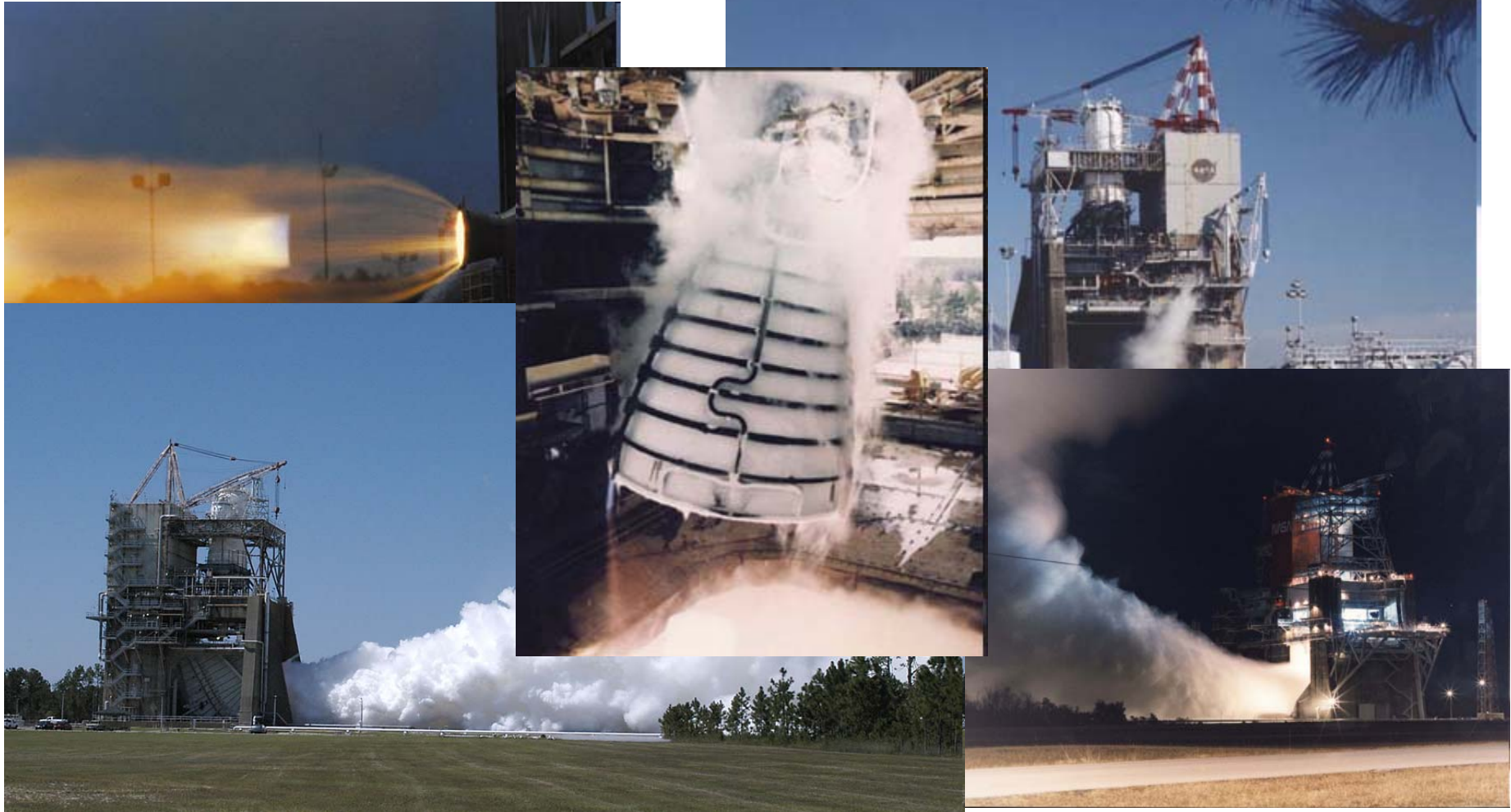
Harry Ryan 228-688-2757, Email: Harry.M.Ryan@nasa.gov



Liquid Propellant System Modeling



*NASA Stennis Space Center (SSC)
Engineering & Test Directorate (ETD)
Design & Analysis Division
January 21, 2009*





Liquid Propellant System Modeling

Summary



Background

- The Rocket Propulsion Test Analysis (RPTA) Model Is an Effective Analytic Modeling and Analysis Tool Providing High Fidelity Assessment of Propellant System Performance
 - RPTA Adapted From a Model Originally Developed for Shuttle & X-33 Propellant System Performance Analyses
 - RPTA Model Application :
 - Used Extensively for
 - SSC Propellant System Analysis (e.g., Test Project (e.g., J-2X PPA, A-3, Chemical Steam Generator (CSG)) Facility Development, Activation
 - Test and Facility Maintenance and Upgrades Investigations, Studies and Trades
 - Recently Used for Systems Sizing and Operations Performance Analysis of the LOX and LCH4 Tanks for the Lunar Surface Ascent Module Team Study (May 2007)
 - Currently Being Employed to Evaluate Propellant Load Operations and Performance of the Ares I LOX & LH Tank for MSFC Team (January 2009)
 - A Graphical User Interface (GUI) Developed for the RPTA Model to Allow Ease of Use of the Model

Benefits

- Propellant System Modeling Allows For A Timely & Cost-Effective Assessment of the Propellant System Performance
- Integrated Performance Modeling Capabilities Has Translated to Efficient Test Facility Design, Activation & Test Operations

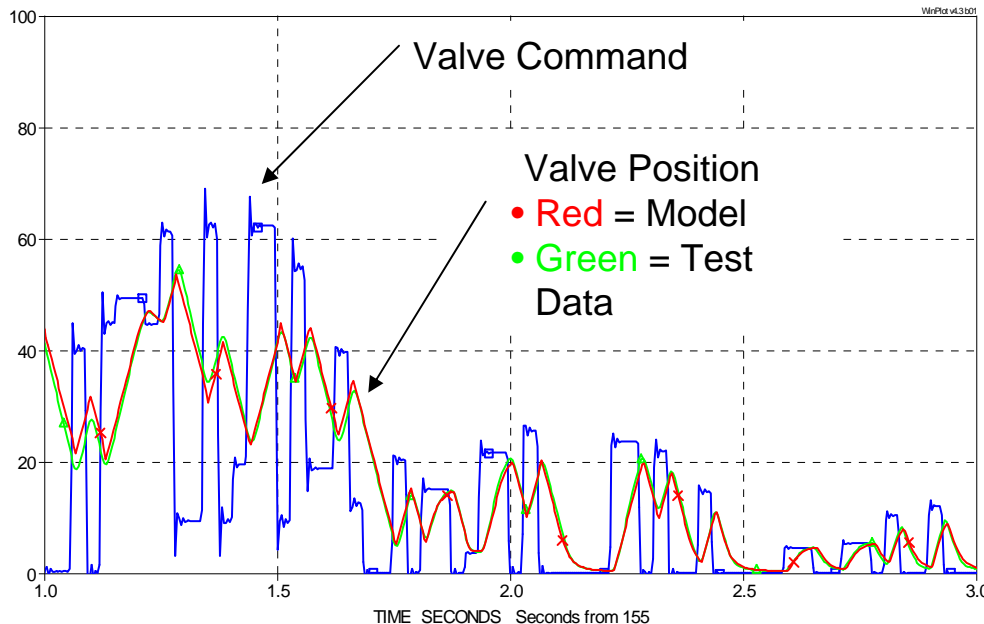


Rocket Propulsion Test Analysis (RPTA) Model



- Temporal Transient Thermodynamic Modeling of Integrated Propellant Systems
 - Thermodynamic Control Volume Solver Model Accurately Models Cryogenic and Storable Propellant and High-Pressure Gaseous Systems.
 - Includes High-Fidelity Pressure Control Valve (PCV) & Closed Loop Control System Algorithms
- Model Validated Through Numerous Test Data Reconstructions
 - J-2X PPA-1A, IPD Fuel Turbopump, RS-84 Sub-Scale Pre-Burner, RS-83 Pre-Burner Cold Flows, SSME Flowliner Activation & IPD Engine System

Pressure Control Valve (PCV) Model Developed & Validated



A Significant Feature of the RPTA Model is the Coupling of Control Logic (Electro-Mechanical Process) with Thermodynamic Processes



RPTA Model GUI Development



Background

- The RPTA Model provides focused and detailed analysis of a propellant system, from a single propellant tank to an integrated propellant system that includes
 - Propellant Tank
 - Facility Propellant Storage Tank
 - Pressurant Supply and System Control
 - Propellant Feed System
 - Test Article Simulation
- Requires a substantial amount of data defining boundary and initial conditions that requires esoteric knowledge of the model's data file structure and the model's code not required of the typical user
 - Following is a quick view of the model parameter data sets involved

RUNTABLES.dat - Notepad

File Edit Format View Help

```

99 | LP IPA T
99
1 1417 VTL vs. area of
99
1621 0 8
357 403
46
1641 0
19
17
99
2 1421 VT
99
1661 0
35
46
1681 0
19
17
99
3 1569 VT
99
1701 0
36
46
1721 0
10
87
99
4 1425 ##
99 ##
1741 5.
1751 0.
99
5 1429 ##
    
```

Tables.dat - Notepad

File Edit Format View Help

```

1305 3611. 10. 3621.
1309 3631 10 3641
    
```

tankmdf.dat - Notepad

File Edit Format View Help

```

77 TIME Sec Time (seconds from Start of Test)
203 ASU FT2 Tank cross-sectional area
204 AV IN2 Relief valve cDA
205 AW1 FT2 Area of wall inside tank - gas space
207 AWO FT2 Area of wall outside tank - gas spac
229 EING BTU Total energy in the gas
230 EINL BTU Total energy in the liquid
231 FMWTG f/m*mole Molecular weight of tank gas mixture
232 GAMTG non-dim Ratio of specific heats of tank gas
    
```

C:\E:\PSME\Releases\1.0.3\Files\RELEASED_MODEL_DIRECTORY\RPTA3\RPTA3.exe

```

ACC= 1.000 WDN = 0.000 EING= -0.336 TTG= 181.272 WGU= 0.000
WDRG= 0.000 UDL = 0.000 EINL= 3.137 WORK= 0.000 WDL= 0.000

T = 149.800 PT = 17.097 UTG= 476.132 TGE= 530.000 WTG= 136.753
PLL = 1.000 PTIN= 2.347 UTL= 4273.868 TTL= 164.989 WTL= 302559.000
ACC= 1.000 WDN = 0.000 EING= -0.333 TTG= 181.118 WGU= 0.000
WDRG= 0.000 UDL = 0.000 EINL= 3.540 WORK= 0.000 WDL= 0.000

T = 159.790 PT = 17.097 UTG= 476.134 TGE= 530.000 WTG= 136.878
PLL = 1.000 PTIN= 2.347 UTL= 4273.866 TTL= 164.989 WTL= 302558.875
ACC= 1.000 WDN = 0.000 EING= -0.314 TTG= 180.966 WGU= 0.000
WDRG= 0.000 UDL = 0.000 EINL= 3.731 WORK= 0.000 WDL= 0.000

winplotA3-CS

T = 169.780 PT = 17.097 UTG= 476.136 TGE= 530.000 WTG= 136.999
PLL = 1.000 PTIN= 2.347 UTL= 4273.864 TTL= 164.989 WTL= 302558.750
ACC= 1.000 WDN = 0.000 EING= -0.295 TTG= 180.818 WGU= 0.000
WDRG= 0.000 UDL = 0.000 EINL= 3.926 WORK= 0.000 WDL= 0.000
    
```

trajectory.csv - Notepad

File Edit Format View Help

```

TL,ACC,ALPHA,ALT,AX,AY,AZ,MACH,MRENG,PLL,WDOT,pcham,vxdot,wdfill
-100,1,-90,0,,,,,0,1,1,0,0,0,0
0,1,-90,0,,,,,0,1,1,0,0,0,0
5,1,-90,0,,,,,0,1,1,0,0,0,0
650,1,-90,0,,,,,0,1,1,0,0,0,0
650.1,1,-90,0,,,,,0,1,1,0,0,0,0
750,1,-90,0,,,,,0,1,1,0,0,0,0
    
```

```

ss of gas vented
ss of autogenous gas in ullage
ss of GN2 in ullage
ss of tank gas
ss of tank insulation - gas space
ss of tank insulation - liquid spa
ss of tank liquid
ss of tank liquid increase during
ss of tank metal
ss of tank metal - liquid space
gulated pressure supply to tank pcv
    
```

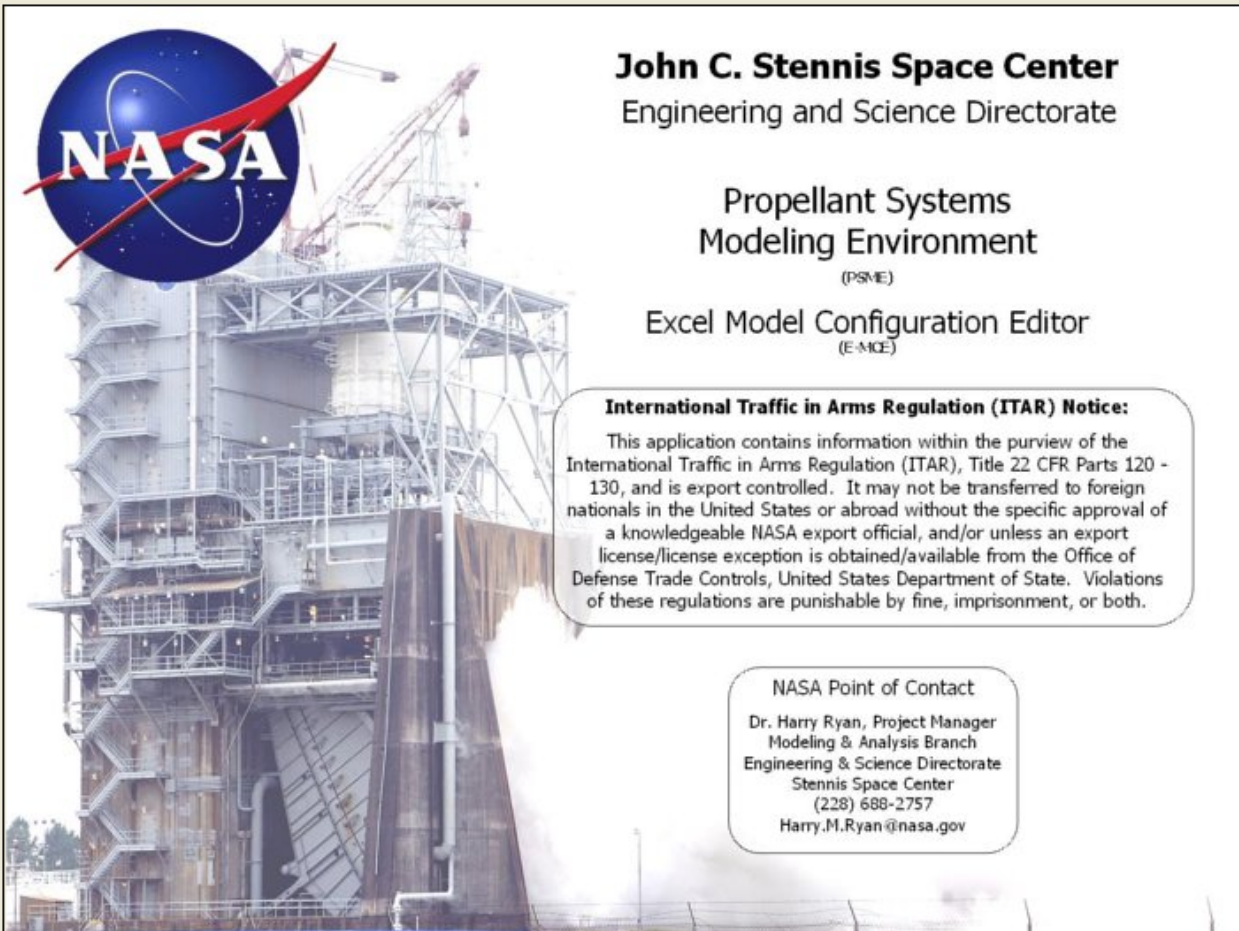



Propellant Systems Modeling Environment

PSME



ITAR Notice



John C. Stennis Space Center
Engineering and Science Directorate

**Propellant Systems
Modeling Environment**
(PSME)

Excel Model Configuration Editor
(E-MCE)

International Traffic in Arms Regulation (ITAR) Notice:
This application contains information within the purview of the International Traffic in Arms Regulation (ITAR), Title 22 CFR Parts 120 - 130, and is export controlled. It may not be transferred to foreign nationals in the United States or abroad without the specific approval of a knowledgeable NASA export official, and/or unless an export license/license exception is obtained/available from the Office of Defense Trade Controls, United States Department of State. Violations of these regulations are punishable by fine, imprisonment, or both.

NASA Point of Contact
Dr. Harry Ryan, Project Manager
Modeling & Analysis Branch
Engineering & Science Directorate
Stennis Space Center
(228) 688-2757
Harry.M.Ryan@nasa.gov

OK Cancel



GUI interface Significantly Simplifies Model Set-up



The screenshot displays a GUI interface for model set-up, divided into three main sections:

- Schematic (Top):** Shows a diagram of the system. On the left, four yellow rectangular "Pressurant Tanks" are connected to a horizontal "Pressurant Piping" manifold. This manifold is connected via a "Pressurant Control Valve" to a large cylindrical "Run Tank".
- Run Tank Data Table (Bottom Left):** A table providing initialization and configuration information for the Run Tank.

Initialization Information		
Tank Liquid Type	2	
Initial Run Tank Inner Wall Surface Temperature	530.0	R
Initial Run Tank Ullage Temperature	530.0	R
Initial Run Tank Ullage Volume	3250.0	ft3
Tank Pressure	15.0	psia
Temperature of Tank Liquid	163	R
Configuration Information		
Tank Baffle Area to Mass Ratio	0.0023	ft2/lb
Total Bubble Volume in Liquid	0.	ft3
Tank Stretch due to Pressure	0.	ft3/psi
Change in Volume due to Change in Tank Temp	0.	ft3/R
Total Tank Volume	3825.0	ft3
Nominal Tank Pressure	14.7	psia
Nominal Tank Temperature	530.0	R
Mass of Pressurant Gas in Ullage	30.0	lb
Constant for natural convection: ullage to liquid	0.09	
Constant for natural convection: ullage to wall	0.12	
Constant for forced convection: ullage to liquid	0.23	
Constant for forced convection: ullage to wall	10.	
Constant for natural convection: bulk liquid to surface	0.13	
Constant for natural convection: bulk liquid to wall	0.13	
Constant for forced convection: entering gas to diffuser	3.70	
Constant for forced convection: ullage to baffles	0.06	
Diffuser surface area	0.555	ft ²
Tank Runtime File Name	RUNTABLES.dat	
Use Temporal Transient Wall Temp File	F	
Evaluate Wall Temp	T	
Mass of Diffuser	311.	lbm
Determine Energy Transfer from Splashing	F	
- RV Pressure Table (Bottom Right):** A table showing pressure values.

RV Pressure Table (psia)	
-1.0	50.0
4300.0	5300.0
5400.0	10000.0
- Commands Panel (Right):** A vertical stack of buttons for system control:
 - Select Model Configuration
 - Run
 - View Results
 - Save Changes
 - View Configuration Files
 - MCM Admin
 - Exit



Provides Access to All Configuration Data



MCE - View Configuration Files

Model Configuration Files

Model Test: test Date: 11/4/2008 1:10:41 PM

Config | Initial | PLC | PCV | RunTables | Tables | TankMDF | Trajectory | VPV_Cv

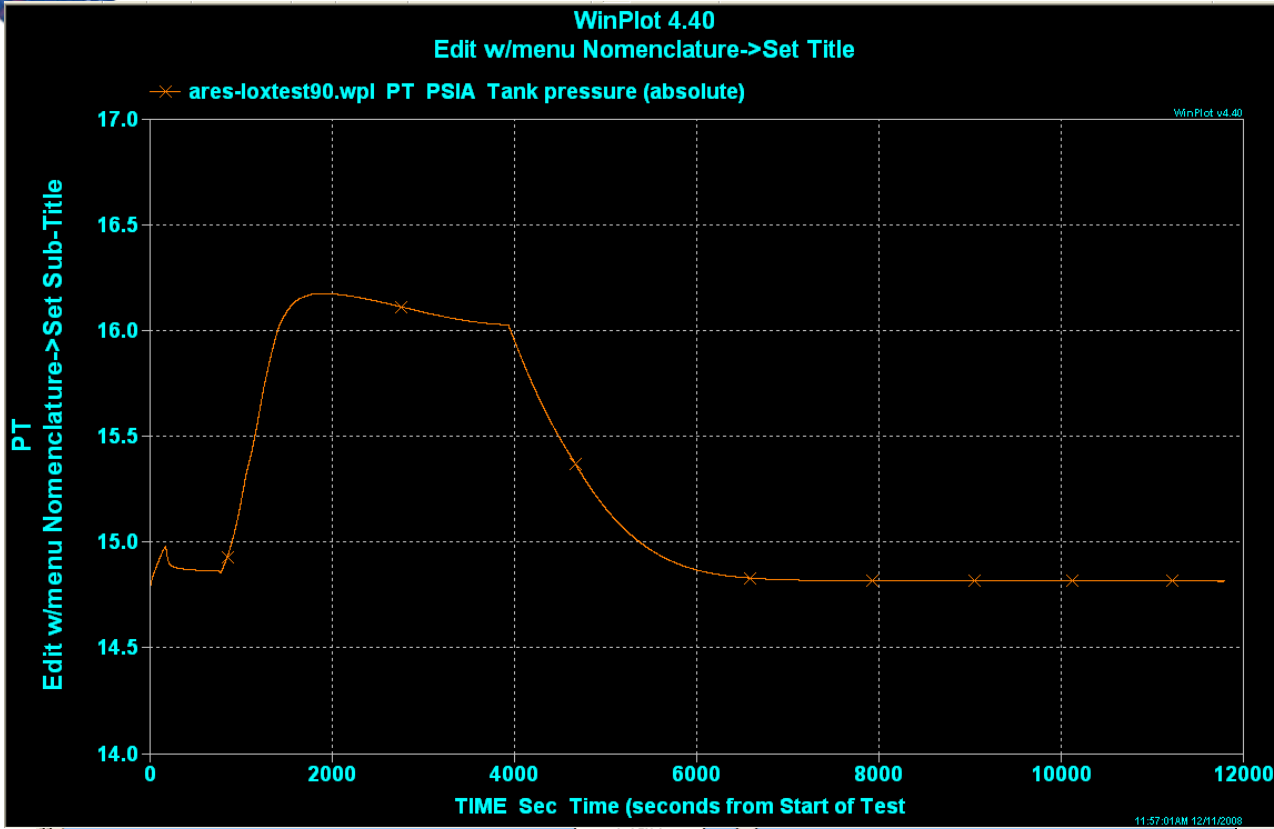
```
$DATA
IN_OUTPUT=TANKMDF.DAT
IN_TABLES=TABLES.DAT
LDV=F
LTGE=F
LVDL=F
POW=0.33,0.33,0.8,0.8,0.33,0.33,0.8,0.33,
WDHEI=0.
!ACDEF=0.09,0.12,0.23,10,0.13,0.13,3.70,0.06,
TA=530.
!VOLSPH=5611.97665450645
ACDEF=0.,0.0,0.0,0.,0.,0.,0.,0.,
ADIF=0.555
ALT=0.
ATOM=0.0023
BOTMAT=3
BUBV=0.
CRAD=0.0000000000000384
DGHEBTL=135.282990179341
VGHEBTL=1002.
DIAL=4.04,10.,
DTSOP=0.
DVDTT=0.
GAMMA=1.4
IGAS=5
PRTHICK=2.25
IN_TANK='RUNTABLES.dat'
IRTPLOT=0
LHEAT=F
LPA=F
LSPL=F
MONTNEB=0
```

View Configuration Files

OK Cancel



Model Execution & WinPlot Results



test
11/4/2008 1:10:41 PM
A3_CSG_IPA
Liquid

Commands
Select Model Configuration

Run

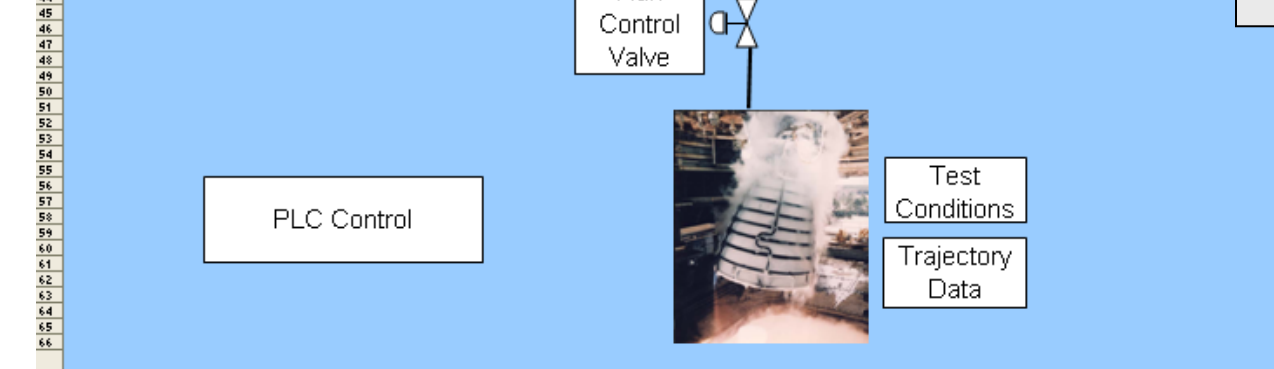
View Results

Save Changes

View Configuration Files

MCM Admin

Exit





Propellant Systems Modeling Environment Model Library & Configuration Editor

Interactive Schematic Integration Prototype



Created by SSC RPT
Engineer Expertise;
Predefined Liquid
Propellant Models
for Specific Test
Facilities are Base-
lined

Home

Pressurant Tanks

Number of bottles 6

Wall Thickness 2.25 in

Temp. 538. R Vol. 1002. ft³

Press. 2814.696 psia

Bottle Diameter 135.282990179341 in

Test Stand Photo

Tank Material

- 1. Titanium
- 2. Aluminum
- 3. Steel

Pressurant Fluid

- 1. H₂
- 2. O₂
- 3. N₂
- 4. He
- 5. CH₄

The Engineer's Model
Revisions are Managed in a
Familiar Tree Structure
Format



Propellant Systems Modeling Environment

Gas Model Support Scheduled in Early 2009



	A	B	C	D	E	F	G	H	I	J	K	L	
1	Home												
2													
3													
4													
5													
6	A	B	C	D	E	F	G	H	I	J	K	L	
7	TEST CONDITIONS (G)		Home										
8													
9													
10													
11													
12													
13													
14													
15	Winplot Closeout Time	10.0	sec										
16	Solver Time Step	0.0005	sec										
17	Winplot File Write Interval	0.01	sec										
18	Screen output time interval	10.	sec										
19													
20	Trajectory File Name	Trajectory.ovs'						n/d					
21	Bottle Wall Mat'l Properties	WALL_DATA.dat'						n/d					
22	Winplot File Name	Gas-Output.wpl'						n/d					
23													
24													
25	Model Start Time	-20.	sec										
26	Pressurant Speed	3	n/d										
27	Assess Heat Transfer Across Pressurant Bottle Wall?	T	n/d										
28	Heat Transfer Coefficient Multiplier	1.00	n/d										
29	Add'l External Heat Soak to Bottles	0.0	Btu/s										
30													
31													
32	Pressurant Bottle Charge Supply Pressure	1000.	psia										
33	Pressurant Bottle Charge Supply Temp	500.	R										
34													
35	Pressure D/S of Regulator / PCV	14.7	psia										
36	Regulator / PCV Temperature	554.45	R										
37													
38	Line Discharge Pressure	14.7	psia										
39													
40	Vent Relief Cracking Pressure	4950.	psia										
41	Enable Pressurant Tank Pressure Cycling?	T	n/d										
42													
43	Fluid Enveloping Pressurant Tank	3	n/d										
44	Pressurant Tank External Pressure	14.7	psia										
45	Pressurant Tank External Temperature	546.5	R										
46	Fluid State	0	n/d										
47													
48													
49	Regulated Outflow?	F	n/d										
50	Accel Force on Bottle	32.174	(lbm-ft)/(lbf-s ²)										
51													
52													
53													
54													
55													
56													
57													
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Propellant-Aware, PSME Detects Whether Model Selections are Liquid or Gas and Serves up the Correct Executable and Parameter Editing Screens to the Engineer

PSME Provides Automated Validation Checking of Parameter Fields with Defined Value Types and/or Min / Max Ranges for Both Liquid and Gas



Trajectory Data

Exit



SSC Engineering & Test Directorate (ETD)



ITAR Notice



John C. Stennis Space Center
Engineering and Science Directorate

**Propellant Systems
Modeling Environment**
(PSME)

Excel Model Configuration Editor
(EMICE)

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OK Cancel

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