

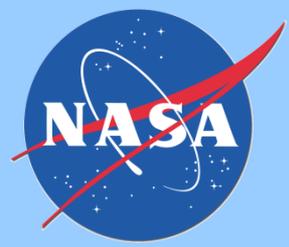


Integrated System Health Management: Pilot Operational Implementation in a Rocket Engine Test Stand

Fernando Figueroa
NASA Stennis Space Center, MS

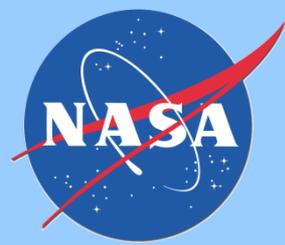
April 27th – 28th, 2010
Denver, Colorado
Building 100/SSB 6th Floor C/R





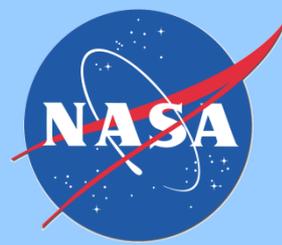
Contributors

- **John Schmalzel, Rowan University, NJ**
- **Jon Morris and Mark Turowski, Jacobs Technology, NASA Stennis Space Center, MS**
- **Richard Franzl, Smith Research Company, NASA Stennis Space Center, MS**



Outline

- Motivation
- Technology and Capabilities
 - Generic Architecture
 - ISHM Model
 - Embedded DIaK
 - Proximate Cause
 - VISE
 - Advanced Anomaly Detection
 - HADS
- ISHM Implementations
 - CSG Pilot Implementation
- ISHM Benefits
 - A3 Test Stand
 - Other facilities
- Conclusions



Support the rocket engine test mission with sustainable facilities that produce unquestionable measurements, affordably

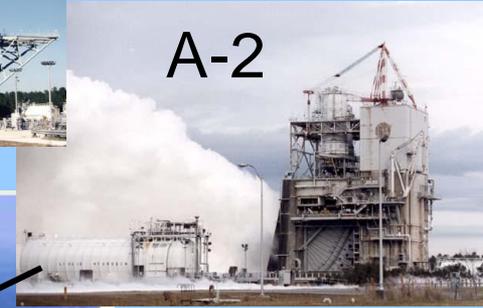


B-1/B-2

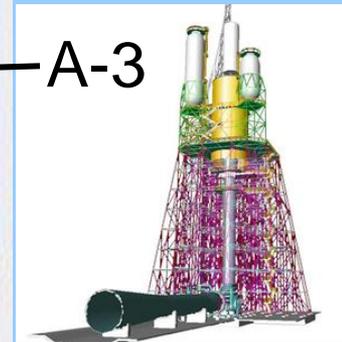
A-1



A-2



A-3



Others:
• High-pressure Gas
• Industrial Water

E-2

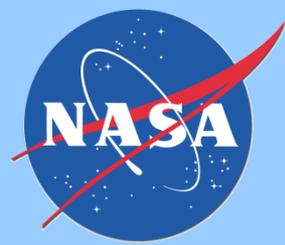


E-3



E-1

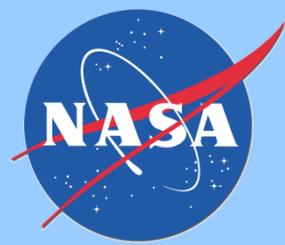




Requirements Driving ISHM

Through comprehensive, Integrated, and continuous vigilance and Analysis

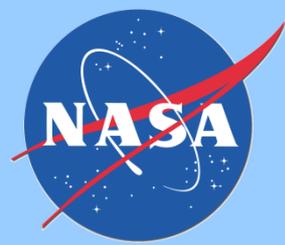
- **Improve quality and safety.**
 - By more accurately understanding the state of a system.
- **Minimize**
 - Time to operational readiness.
 - Uncertainty.
 - Risk.
- **Minimize costs.**
 - Of configuration.
 - Of maintenance, repair, and calibration.
 - Of operations.
 - Of analysis.
- **Minimize downtime.**
 - By predicting impending failures.
 - By timely intervention.
 - By faster diagnosis and recovery.
 - By improving availability and reliability.



ISHM Objectives

- Use available SYSTEM-WIDE data, information, and knowledge (DlaK) to
 - Identify system state.
 - Detect anomaly indicators.
 - Determine and confirm anomalies.
 - Diagnose causes and determine effects.
 - Predict future anomalies.
 - Recommend timely mitigation steps.
 - Evolve to incorporate new knowledge.
 - Enable integrated system awareness by the user (make available relevant information when needed and allow to dig deeper for details).
 - Manage health information (e.g. anomalies, redlines).
 - Capture and manage usage information (e.g. thermal cycles).
 - Enable automated configuration.
 - Implement automated and comprehensive data analysis.
 - Provide verification of consistency among system states and procedures.

ISHM implementation is a problem of “management” of data, information, and knowledge (DlaK) focused on achieving the above objectives.

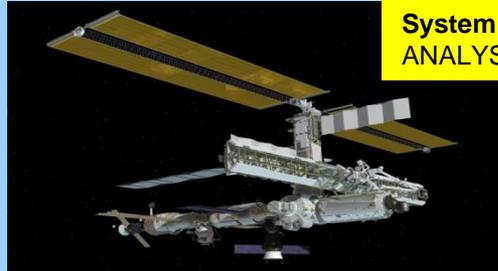


People-Based ISHM is Being Done Today

International Space Station

Rocket Engine Test Stand

Layer 1
Vehicle/
Test Stand



System: ON BOARD AUTOMATED ANALYSIS CAPABILITY



Signal threshold violation detection

Layer 2
Astronaut/
Test Conductor



Operator: FASTER, MORE ACCURATE ANALYSIS



Added DIaK from on-board users.

Layer 3
Control Room



Support: FASTER, MORE ACCURATE ANALYSIS
Decreased Need



Added DIaK from broad group of experts.

Layer 4
Back Control Room



Support: FASTER, MORE ACCURATE ANALYSIS
Decreased Need



Added DIaK resources from larger community

MOVE CAPABILITY TOWARD LEVELS 2 AND 1
DECREASE NEED FOR SUPPORT FROM LOWER LAYERS



John C. Stennis Space Center ISHM Partnerships for Rocket Propulsion testing A community of Expertise and Technologies

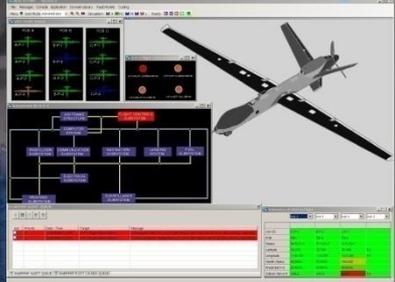
Rocket Engine Test Stand



Open Systems Architectures



Prognostics & Anomaly Detection



Proximal Cause Analysis



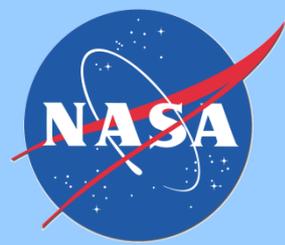
IEEE 1451 Smart & Intelligent Sensors



Integrated Awareness

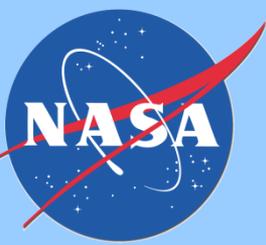
ISS Testbed





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ISHM Capabilities

Integrated System Awareness



ISHM Development Environment



Health Assessment Database



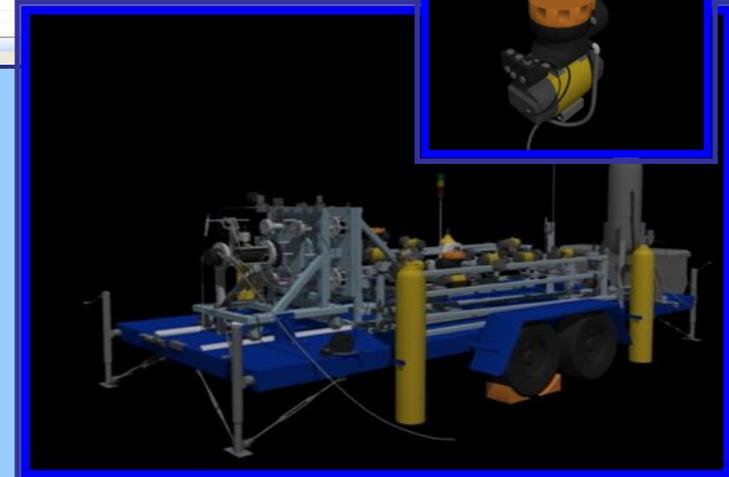
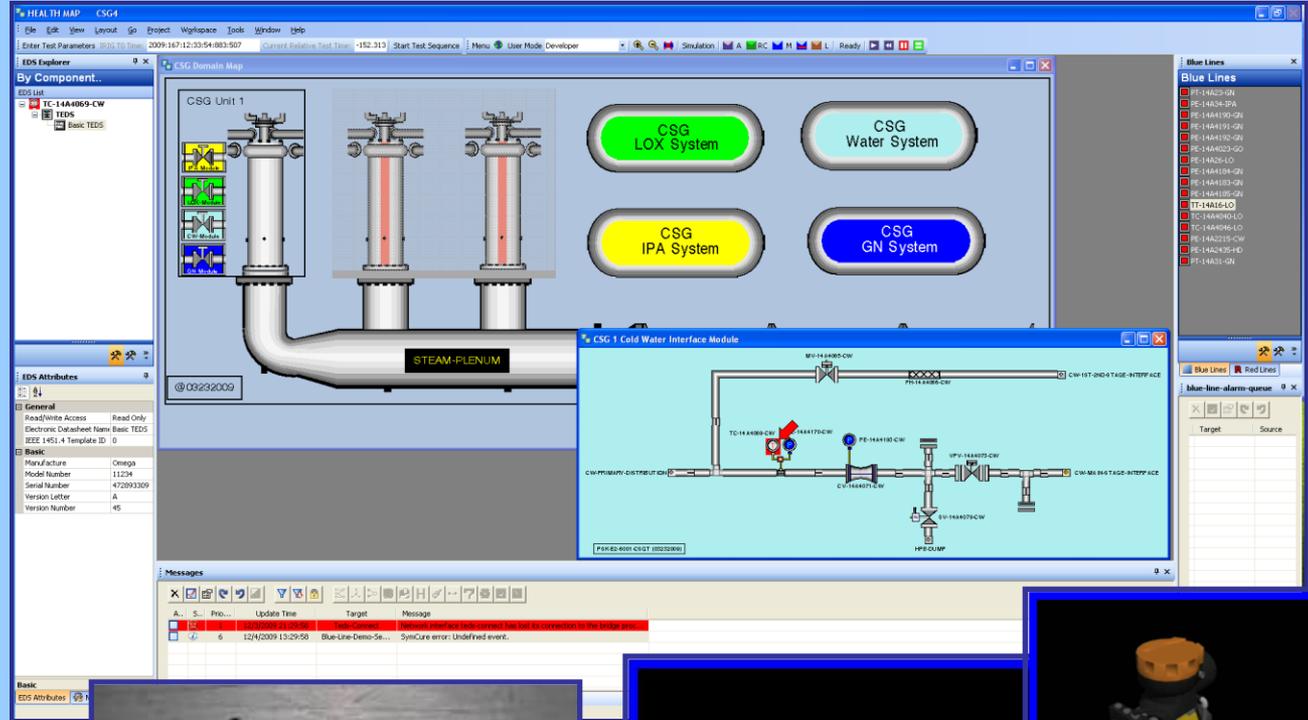
Anomaly Detection & Isolation



Integrated Predictive & Diagnostic Models

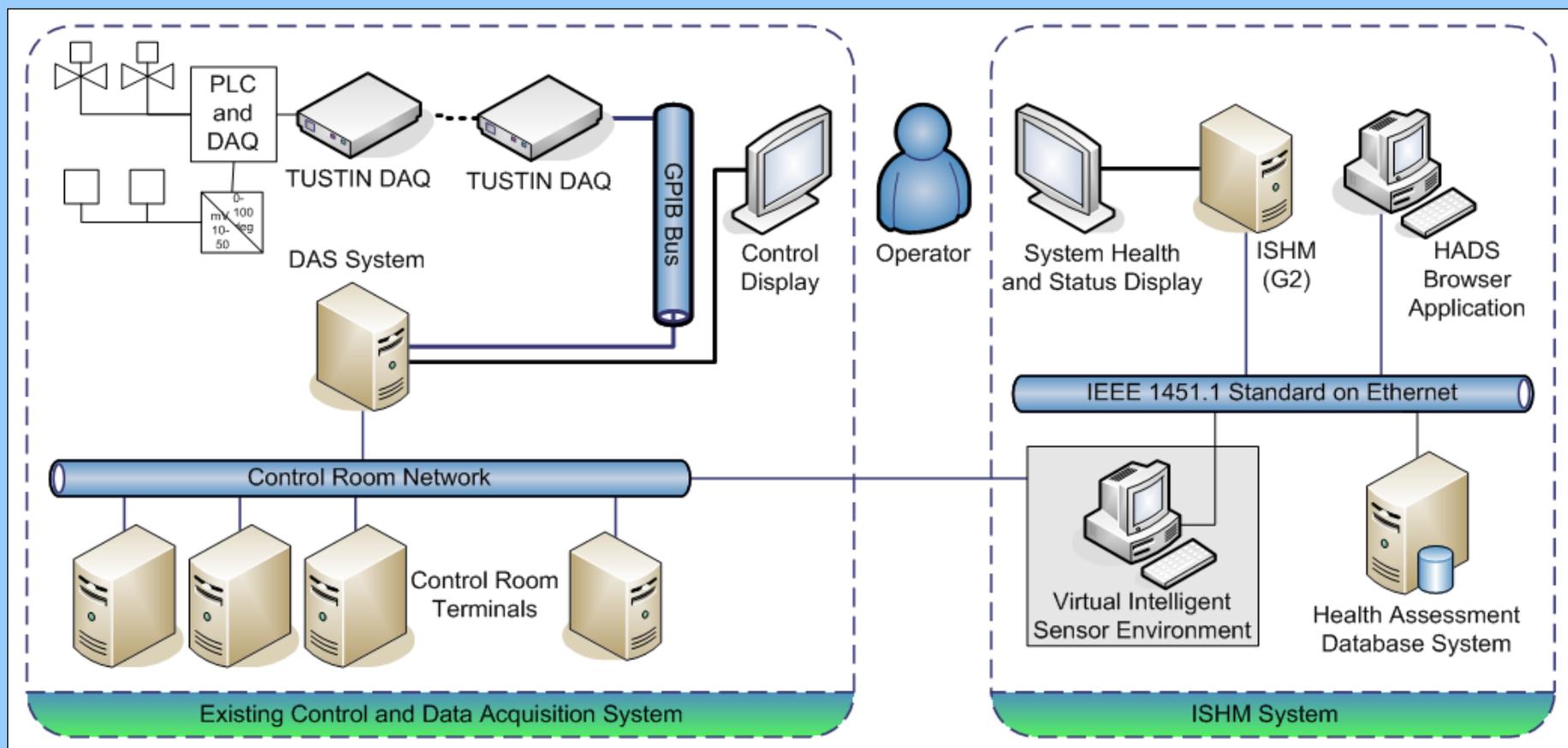


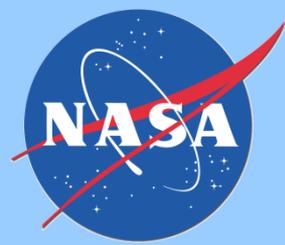
Intelligent Sensors





Generic ISHM System Configuration

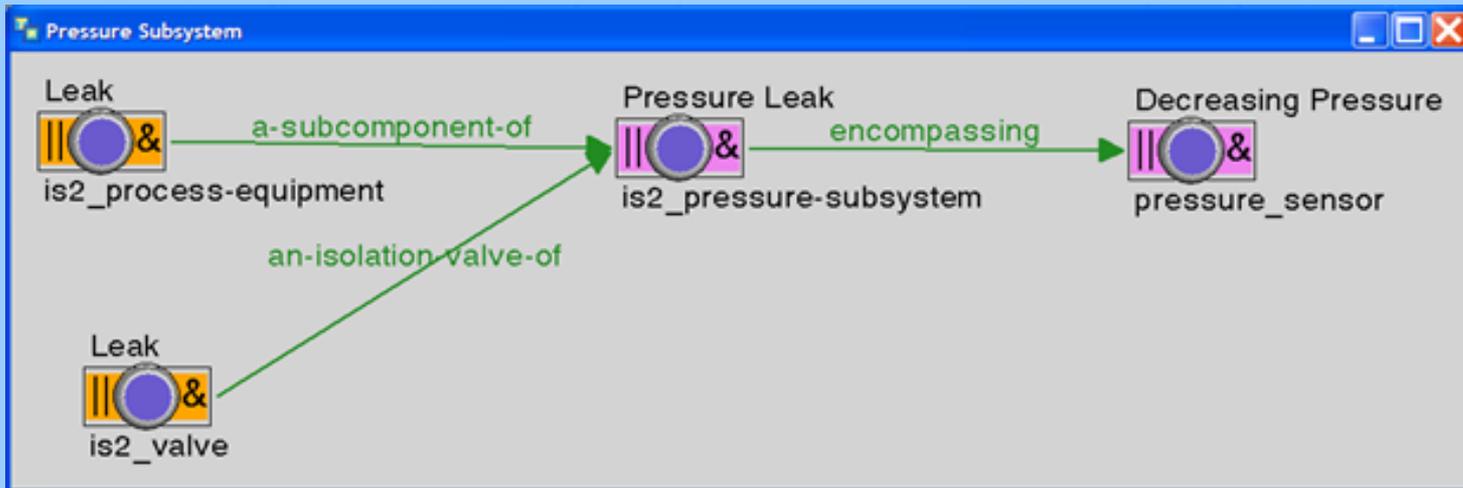


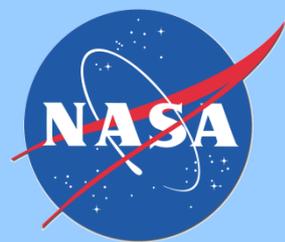


Failures Modes and Effects Analysis (FMEA)

MIL-STD-1629A(2) NOT 3

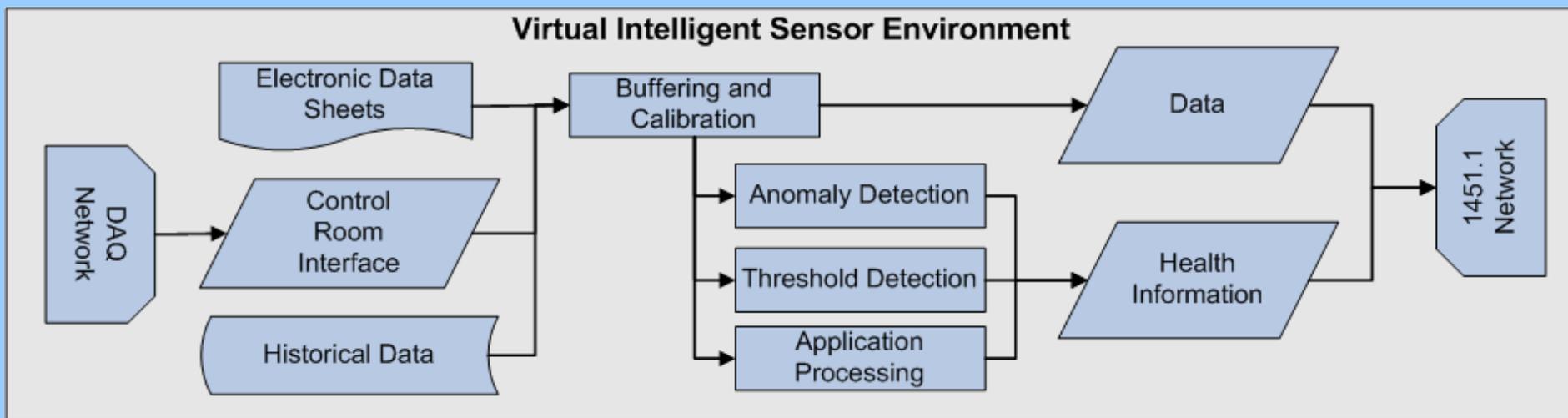
ID #	Item-Functional Identification	Function	Failure Modes and Causes	Mission Phase-Operational Mode	Failure Effects		Failure Detection Method
					Local End Effects	Next Higher Level	
	Process Equipment	Fluid feed subsystem	Leak	Sealed subsystem maintaining pressure	Pressure leak	Decreasing pressure measurement	Identify sealed subsystem, and check pressure sensors for decreasing pressure.

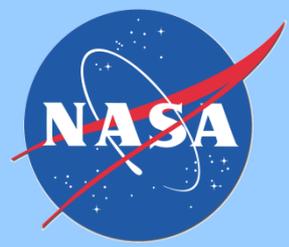




Virtual Intelligent Sensor Environment

- Provides benefits of ISHM capabilities to existing data acquisition systems by adding Virtual Intelligent Sensor capability

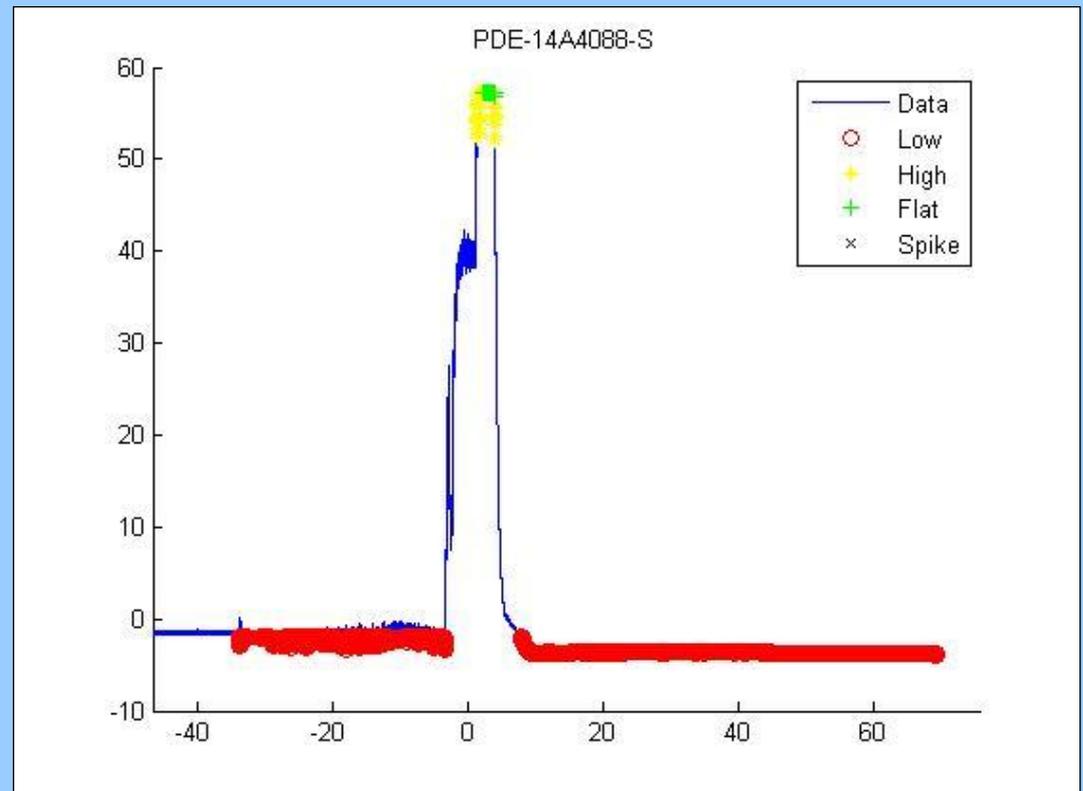


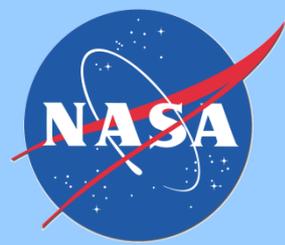


Advanced Anomaly Detection

Anomaly algorithms used by VISE

- Low physical limit exceedance detection
- High physical limit exceedance detection
- Flat line detection
- Impulse noise event/spike detection





HADS Browser Application

HADS Browser Capabilities

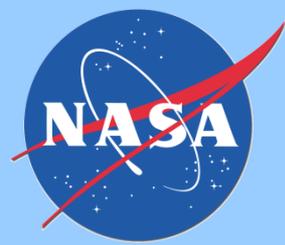
- Allows longitudinal analyses and comparisons with previous test results
- Viewing usage statistics on monitored elements
 - cycle times on valves
 - mean time to failure
- Viewing anomalous events/data trends
- Viewing TEDS

Test Names	Start Time	End Time
0911_019A_9160_CSST	-305.658	100.541
0911_019B_9160_CSST	-262.674	99.5208
0911_019C_9160_CSST	-222.078	100.717
4911_019A_Norm_Run_One	-20.5521	114.141
4911_019B_ADV2SD	-18.9601	45.2323
4911_019C_Norm_Run_Two	-21.1961	84.7965
4911_019D_Norm_Run_Three	-20.4282	84.7646
0911_020A_9162_CSST	-302.99	107.405
0911_020B_9162_CSST	-238.294	134.701
0911_020C_9162_CSST	-311.05	122.145
0911_020D_9162_CSST	-246.462	119.533
0911_021A_9167_CSST	-304.866	69.3285
0911_021B_9167_CSST	-223.75	52.6444
0911_021C_9167_CSST	-226.074	56.9204
0911_021D_9167_CSST	-278.066	46.1284
0911_021E_9167_CSST	-393.239	77.1566
4911_021D_9167_NormRun3	-43.5923	40.4002
0911_022A_9170_CSST	-345.07	134.725
0911_022B_9170_CSST	-135.709	151.485
0911_022C_9170_CSST	-135.445	141.949
4911_022A_9170_NormRun1_0	-136.6602	122.533
4911_022B_9170_ADV2SD	-38.0522	60.1404
4911_022C_9170_NormRun2	-37.4482	117.745

Channel	TEDS Field	TEDS Value
FE-14A4109-IPA		
FE-14A4117-IPA		
FE-14A4132-GN		
FE-14A4131-GN		
FE-14A4190-GN		
FE-14A4189-GN		
FE-14A4189-GN		
FE-14A4023-GO		
FE-14A4201D-LO		
PDE-14A4273-IPA		
FE-14A4047-LO		
FE-14A4026-GO		
FE-14A4026-GO		
FE-14A4026-GO		
FE-14A4044-LO		
FE-14A4052-LO		
FE-14A4034-GO		
FE-14A4185-GN		
FE-14A4184-GN		
FE-14A4183-GN		
FE-14A4131-S		
FE-14A4133-S		
FE-14A4135-S		
FE-14A4137-S		
FE-14A4172-S		
FE-14A4141-S		
FE-14A4140-S		
PDE-14A4086-S		
FE-14A4262-LO		
FE-14A4119-IPA		
FE-14A4075-CW		
FE-14A4090-IPA		
FE-14A4201-IPA		
PDE-14A2030-IPA		
ISVI-CURR		

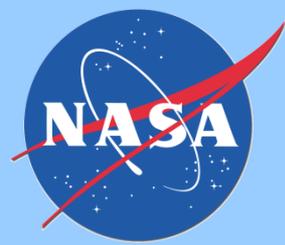
TEDS Field	TEDS Value
BASIC TEDS	
Manufacturer Name	Stellar Technology
Model Number	2000
Version Letter	G
Version Number	121
Serial Number	996546
BRIDGE TEDS	
Transducer Electrical Signal Type	Bridge Sensor
Physical Measurand	psi
Minimum Physical Value	0
Maximum Physical Value	2000
Full Scale Electrical Value Precision	mv/V
Minimum Electrical Output	0.007
Maximum Electrical Output	3.022
Mapping Method	Linear
Bridge Type	Full
Bridge Element Impedence	351.1
Response Time	0.1
Excitation Level, Nominal	10
Excitation Level, Minimum	10
Excitation Level, Maximum	15
Calibration Date	2/4/2009
Calibration Initials	CA
Calibration Period	180
Measurement Location ID	4032

Digit Data - Data to multiple channels



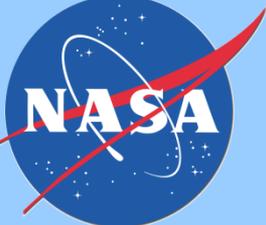
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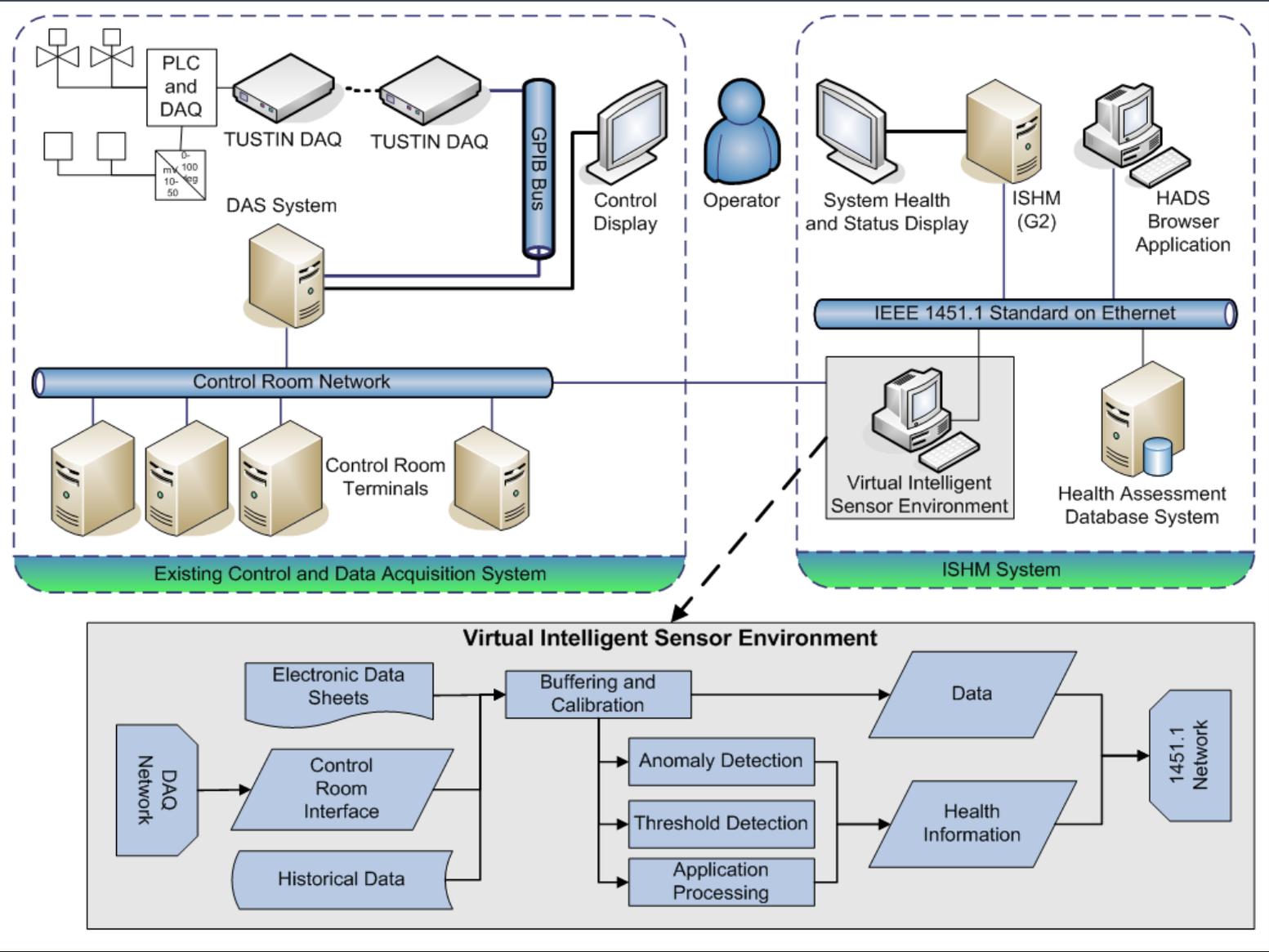


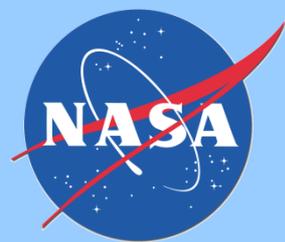
ISHM Pilot Implementation for Chemical Steam Generator (CSG)

- Complete an end-to-end ISHM Domain Model for the CSG program focused on sensor verification & validation for the facilities and test article
- Demonstrate near real time streaming of test data
- Operate on data streams in near real-time using anomaly detection algorithms implemented with two assets:
 - VISE
 - G2-based ISHM model
- Validate the CSG ISHM Domain-Model before, during, and after testing (3 test days).

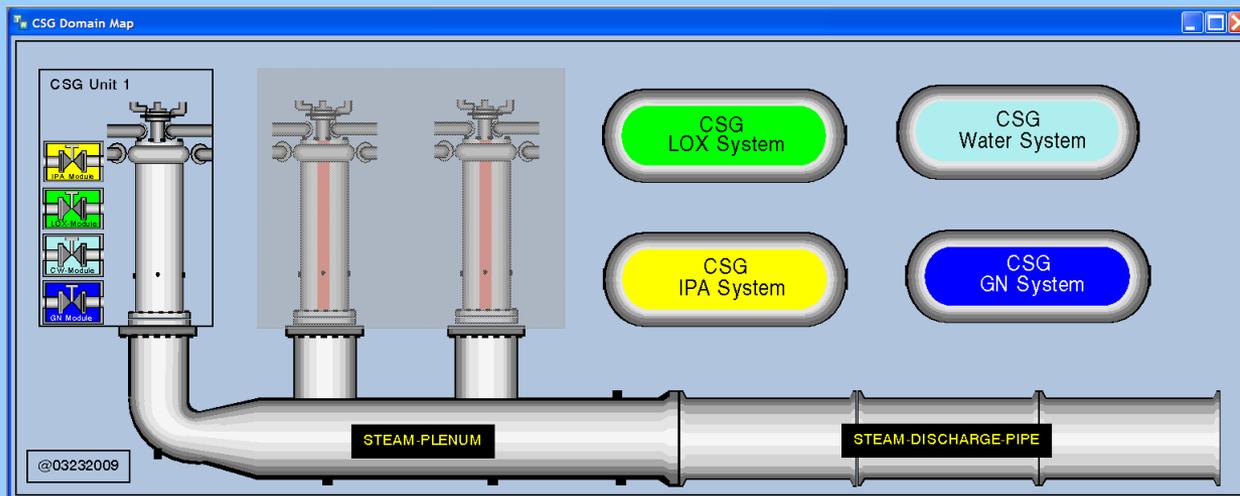


CSG Architecture

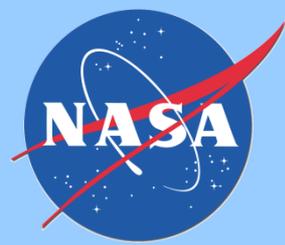




CSG ISHM Domain Model: Top Layer View

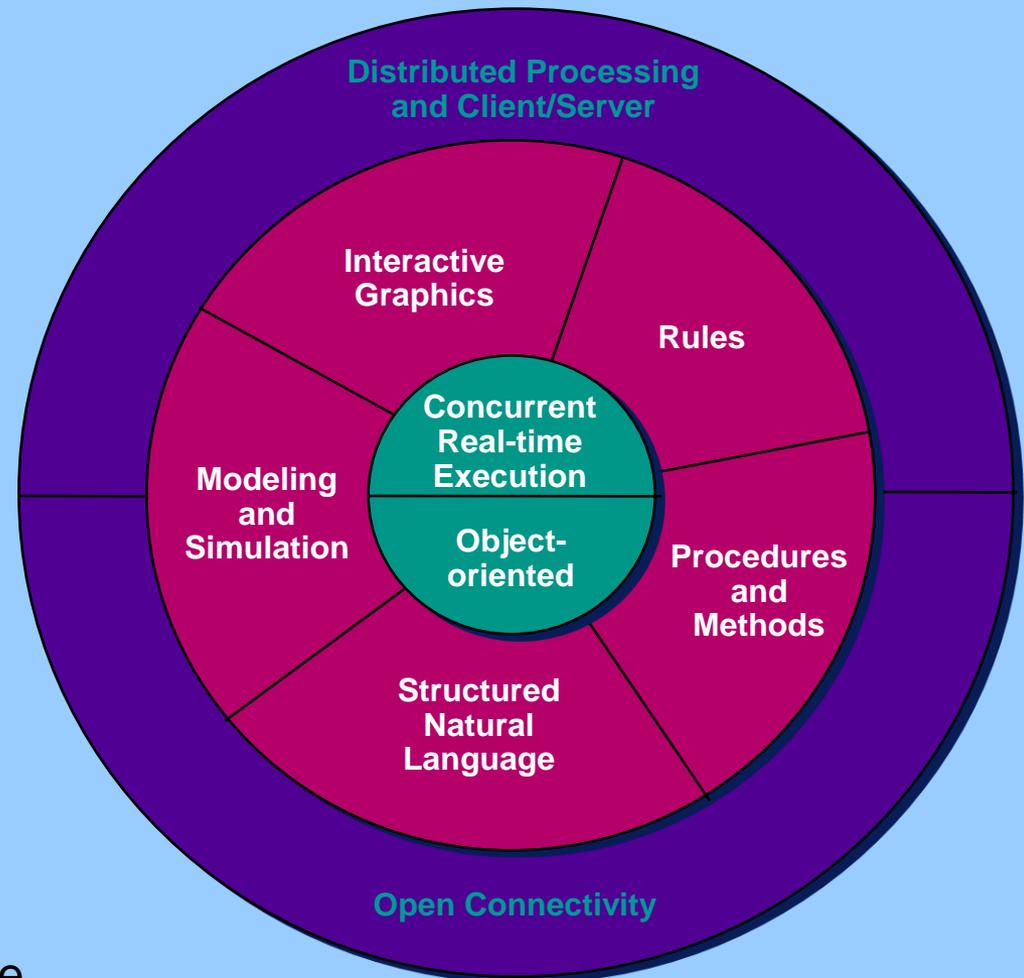


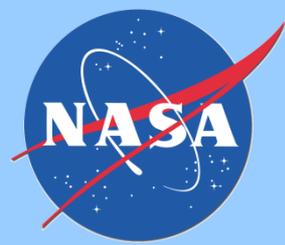
ISHM Domain
Model
Top Layer



G2/Optegrity Software Environment

- Object Oriented Graphical Programming Platform
- Rules Based Reasoning
- Model Based Reasoning
- Graphical Modeling
- Decision Trees
- Procedural Reasoning
- State Transition Diagrams
- Workflow Engine
- Real Time Process Modeling/Automation
- Causal Event Propagation Modeling
- Cause/Effect Modeling
- Fuzzy Logic
- Neural Networks
- Flexible, Structured Natural Language Interface





HM Domain Modeling - Palettes

HealthMAP

File Messages Console Application Domain Library Fault Models

Menu User Mode Developer Simulation

Domain Tree

- ISM-FLUID-EQUIPMENT
- ISM-GENERIC-FLOW-EQUIPMENT
 - ISM-FLOW-SOURCE
 - ISM-POTENTIAL-SOURCE
 - ISM-GENERIC-FLOW-SWITCH
 - ISM-FLOW-CIRCUIT-ELEMENT
 - ISM-GENERIC-GROUND
- HM-COMPUTING-EQUIPMENT
 - HM-COMPUTING-HARDWARE
- HM-MECHANICAL-EQUIPMENT
 - HM-PULLEY
 - HM-MECHANICAL-CABLE
 - HM-ROTATING-SHAFT
 - HM-BEARING
 - HM-FAN
- HM-ELECTRICAL-MACHINERY
 - HM-ELECTRICAL-EQUIPMENT
 - HM-ELECTRICAL-MACHINERY**
 - HM-UPS
 - HM-ELECTRICAL-SOURCE
 - HM-CURRENT-SOURCE

HM-ELECTRICAL-MACHINERY

HM-SERVO... HM-ROTOR HM-STATOR

HealthMAP

File Messages Console Application Domain Library Fault Models

Menu User Mode Developer Simulation

Domain Tree

- Domain Objects
 - HM-SUBSYSTEM
 - HM-EQUIPMENT
 - ISM-PHYSICAL-SENSOR
 - ISM-PHYSICAL-ANALOG-SENSOR**
 - ISM-ANGULAR-POSITION-SENSOR
 - ISM-SHAFT-ENCODER-SENSOR
 - ISM-VIBRATION-SENSOR
 - ISM-FLOW-SENSOR
 - ISM-VOLTAGE-SENSOR
 - ISM-TEMPERATURE-SENSOR
 - ISM-CURRENT-SENSOR
 - ISM-PRESSURE-SENSOR
 - ISM-CONDUCTIVITY-SENSOR
 - ISM-ABSOLUTE-POSITION-SENSOR
 - ISM-AIR-FLOW-SENSOR
 - ISM-LEVEL-SENSOR
 - ISM-PHYSICAL-DISCRETE-SENSOR
 - ISM-FLUID-EQUIPMENT
 - ISM-GENERIC-FLOW-EQUIPMENT
 - ISM-FLOW-SOURCE

ISM-PHYSICAL-ANALOG-SENSOR

ISM-ANGU... ISM-SHAF... ISM-VIBR... ISM-FLO...

ISM-VOLT... ISM-TEMP... ISM-CURR... ISM-PRES...

ISM-CON... ISM-ABSO... ISM-AIR-F... ISM-LEVE...

HEALTH MAP hm uav oct 21

File Messages Console Application Domain Library Fault Models Coding

Menu User Mode Developer Simulation A RC

Domain Tree

- HM-HYDRAULIC-EQUIPMENT
- IS2_PROCESS-EQUIPMENT
 - REDUCER
 - IS2_SENSOR
 - IS2_PIPE-SEGMENT
 - REGULATOR
 - FLOW_SOURCE
 - FLOW_SINK
 - IS2_MECHANICAL-EQUIPMENT
 - TANK
 - CATCH-TANK
 - SEPARATOR
 - KSC-BURSTDISC
 - A1-SC
 - DOME-REGULATOR
 - DISCONNECT
 - IS2_VALVE**
 - ORIFICE
 - TRYCOCK
 - ORIFICE-KSC

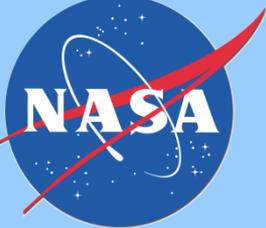
IS2_VALVE

2W-MANIF... DELTA-P-V... A1-FLOWM... MANUAL-V...

MOTOR-VALVE RELIEF-VALVE SERVO-VALVE VPV-VALVE

PRESSURE... CHECK-VALVE PRESS-REG... DOME-LOA...

REMOTE-O... SSC-PRESS... SOLENOID... SSC-TEMPE...



CSG ISHM Domain Model: User Interfaces

The screenshot displays the Telewindows Client interface for the CSG ISHM Domain Model. The main window shows a 3D model of the CSG Unit 1, including three vertical tanks and a horizontal pipe labeled 'STEAM-DISCHARGE-PIPE'. The interface is annotated with several callouts:

- Blueline Active Monitors:** A blue callout box pointing to the left sidebar, which lists various monitoring points such as PT-14A31-GN, PE-14A2435-HD, and TC-14A4046-LO.
- Redline Active Monitors:** A red callout box pointing to the left sidebar, which lists monitoring points such as PDE-14A4086-S, PE-14A26-LO, and TT-14A16-LO.
- Blueline Alarm Queues:** A blue callout box pointing to the 'BLUELINE-ALARM-QUEUE' window at the bottom left.
- Redline Alarm Queues:** A red callout box pointing to the 'REDLINE-ALARM-QUEUE' window at the bottom right.
- CSG LOX System:** A green callout box pointing to the top-left tank.
- CSG IPA System:** A yellow callout box pointing to the middle tank.
- CSG Water System:** A light blue callout box pointing to the top-right tank.
- Transducer Electronic Data Sheet Viewing Windows:** A grey callout box pointing to a window on the right side of the main model.

On the right side, the 'EDS Explorer' window is open, showing a tree view for 'PE-14A4052-LO' with sub-items 'TEDS' and 'Bridge Sensor'. Below it, the 'EDS Attributes' window displays a table of technical specifications:

Attribute	Value
Bridge Element Impedance (Ω)	351
Bridge Type	Full
Calibration Date	2009-04-21
Calibration Period	365
Calibrator's Initials	CA
Electronic Datasheet Name	Bridge Sensor
Full Scale Electrical Value Precision	mV/V
IEEE 1451.4 Template ID	33
Mapping Method	Linear
Maximum Electrical Output (V/V)	3.034
Maximum Excitation Level (V)	15
Maximum Physical Value	1000
Measurement Location ID	4052
Minimum Electrical Output (V/V)	0.015
Minimum Excitation Level (V)	10
Minimum Physical Value	0
Nominal Excitation Level (V)	10
Physical Measurand	psi
Read/Write Access	Read/Write
Response Time (S)	0.1
Transducer Electrical Signal Type	Bridge Sensor

At the bottom, two alarm queue windows are visible:

Target	Message	Priority	Repetitions	Detail
Pe-14a2435-Hd	ACHIEVED - 2009/06/16 12:31:37.406 p.m.	1	1	HYDRAULIC PRESSURE
Tt-14a16-Lo	ACHIEVED - 2009/06/16 12:31:37.406 p.m.	1	1	LOX RUN TANK TEMPERATURE
Pt-14a23-Gn	ACHIEVED - 2009/06/16 12:31:37.406 p.m.	1	1	UHP GN BOTTLE TANK PRESSURE (LOX PRESS)
Pe-14a4183-Gn	ACHIEVED - 2009/06/16 12:31:37.406 p.m.	1	1	1st STAGE GOX PURGE PRESSURE
Pe-14a4184-Gn	ACHIEVED - 2009/06/16 12:31:37.406 p.m.	1	1	2nd STAGE LOX S/D PURGE PRESSURE
Pe-14a4185-Gn	ACHIEVED - 2009/06/16 12:31:37.406 p.m.	1	1	MAIN STAGE LOX S/D PURGE PRESSURE
Pe-14a4023-Go	ACHIEVED - 2009/06/16 12:31:37.406 p.m.	1	1	GOX SUPPLY PRESSURE

Target	Message	Priority	Repetitions	Detail
Pe-14a4117-IPA	EXCEEDED - 2009/06/16 12:33:56.967 p.m.	1	1	Loss of IPA Main Stage Interface Pressure



CSG ISHM Domain Model: Blueline/Redline User Interfaces

Televindows Client

File Edit View Layout Go Project Workspace Tools Window Help

Enter Test Parameters IRRIG TO Time: 2009:167:12:33:54:883:5 Current Relative Test Time: 2.044 Start Test Sequence Menu User Mode Developer Simulation A RC M L Ready

Bluelines

- PT-14A31-GN
- PE-14A2435-HD
- PE-14A2215-CW
- TC-14A4046-LO
- TC-14A4040-LO
- TT-14A16-LO
- PE-14A4185-GN
- PE-14A4183-GN
- PE-14A4184-GN
- PE-14A26-LO
- PE-14A4023-GO
- PE-14A4192-GN
- PE-14A4191-GN
- PE-14A4190-GN
- PE-14A34-IPA
- PT-14A23-GN

Blueline Details

PE-14A4192-GN

Last Reading Gathered: 591.431
MAIN STAGE IPA S/D PURGE PRESSURE

psi

Time

Event Name: ACHIEVED
Event Time: 2009/06/16 11:29:24.814978

Blueline Configuration

PE-14A4183-GN

Last Reading Gathered: 586.691
1st STAGE GOX PURGE PRESSURE

psi

Time

High Blueline Parameters

Enabled	Settings	Description
<input type="checkbox"/>	psi	1st STAGE GOX PURGE PRESSURE

Low Blueline Parameters

Enabled	Settings
<input checked="" type="checkbox"/>	525.000 psi

Save Delete

Redlines

- PDE-14A4086-S
- PE-14A26-LO
- TT-14A16-LO
- PE-14A34-IPA
- PE-14A4131-S
- PE-14A2435-HD
- PE-14A2215-CW
- TC-14A4128-S
- TC-14A4126-S
- PE-14A4117-IPA
- PE-14A4084-CW
- PE-14A4023-GO

Redline Details Dialog

PE-14A4117-IPA

Current Reading: 16.548

psi

Time

Maximum Settings

Arm Time: 0.0
Disarm Time: 0.0

Condition: Enter High Red Line Condition Here.

Minimum Settings

Arm Time: 2.0
Disarm Time: 14.0

Condition: Loss of IPA Main Stage Interface Pressure

Event Name: EXCEEDED
Event Time: 2009/06/16 12:33:56.967 p.m.

Redline Configuration

PE-14A4084-CW

Last Reading Gathered: 1.036

psi

Time

Maximum Redline Parameters

Enabled	Settings	Arm Time	Disarm Time	Condition
<input type="checkbox"/>	psi	T ₀	T ₀	Enter High Red Line Condition Here.

Minimum Redline Parameters

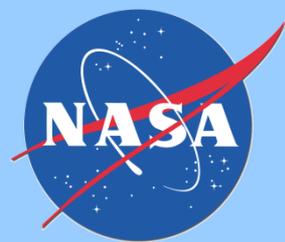
Enabled	Settings	Arm Time	Disarm Time	Condition
<input checked="" type="checkbox"/>	40.000 psi	T ₀ : -35.000	T ₀ : 14.000	Loss of Igniter Stage CW

Save Delete

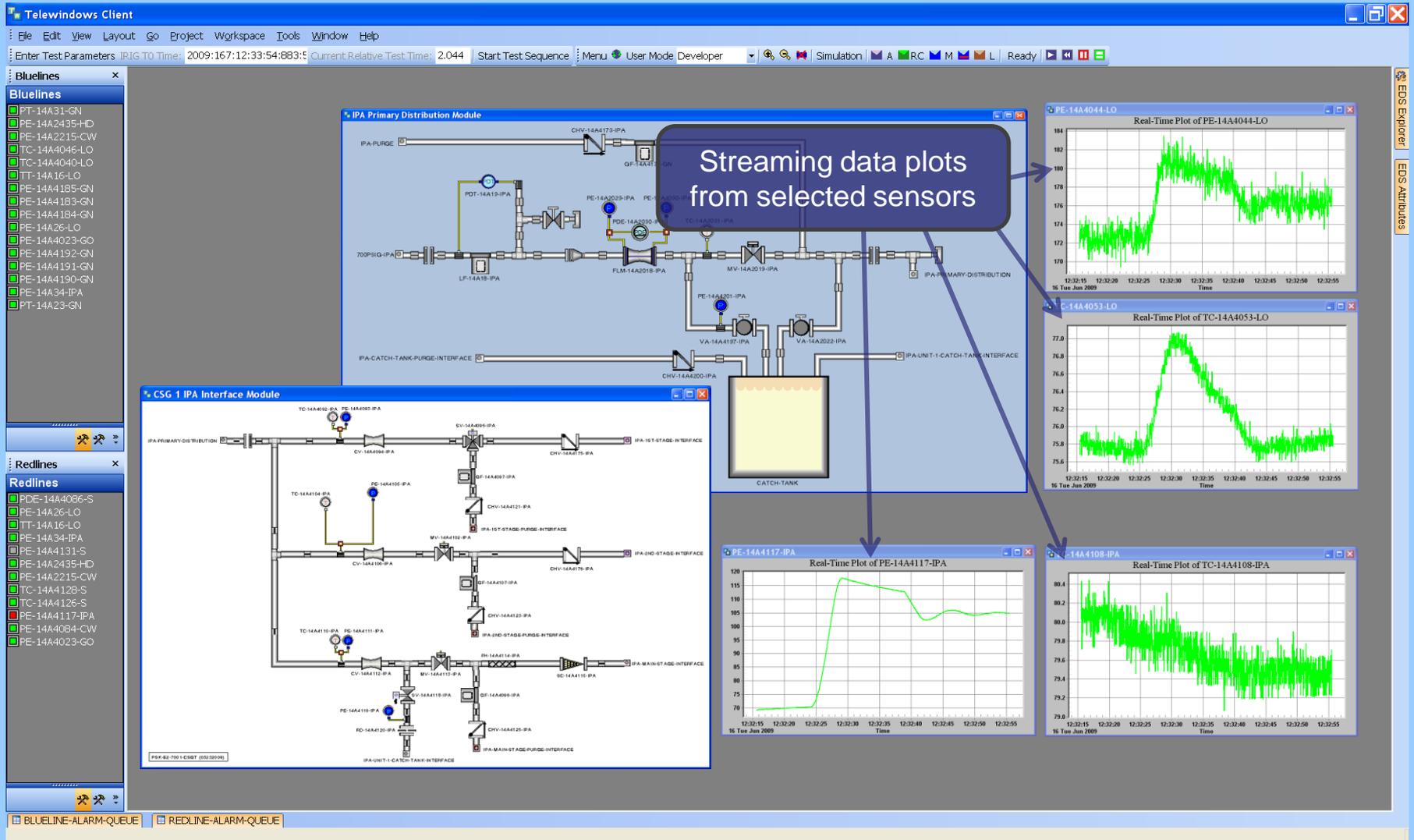
Blueline Details and Configuration User Interfaces

Redline Details and Configuration User Interfaces

BLUELINE-ALARM-QUEUE REDLINE-ALARM-QUEUE



CSG ISHM Domain Model: Transducer Data Plots





CSG ISHM Domain Model: Redline Event Handling

The screenshot displays a software interface for handling redline events. It includes a menu bar, a toolbar, and several panels:

- Bluelines Panel:** Lists various sensors and transducers, such as PT-14A31-GN, PE-14A2435-HD, and TC-14A4046-LO.
- Redlines Panel:** Lists active redlines, including PDE-14A4086-S, PE-14A26-LO, and PE-14A4117-IPA.
- G2 Redlines Anomaly Report:** A detailed report for the PE-14A4117-IPA event. It includes a table of Redline Anomaly Details and a graph showing the pressure over time.
- CSG Unit #1 Diagram:** A schematic diagram of the system showing the 2nd Stage and Main Stage, with various transducers and interfaces labeled.
- BLUELINE-ALARM-QUEUE:** A table listing all active alarms.
- REDLINE-ALARM-QUEUE:** A table listing the specific redline event.

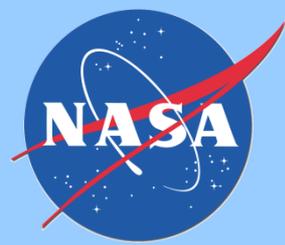
Auto-generated Redline Report

Redline Anomaly Details	
Sensor Name	PE-14A4117-IPA
Event Type	EXCEEDED
Event Threshold Limit	210.0 psi
Event Time	2009/06/16 12:33:56.967 p.m.
Event Time to T0	2.084
Ann. Time	2.0
Discm. Time	14.0
Condition	Loss of IPA Main Stage Interface Pressure
Test Name	0911_021A_9167_CSGT
Test T0 Time	2009/06/16 12:33:54.883 p.m.
Auto-sequence Start Time	-37.0
Auto-sequence End Time	14.0

Navigation to Transducer Where Redline Event Occurred

Target	Message	Priority	Repetitions	Detail
Pe-14a2435-Hd	ACHIEVED - 2009/06/16 12:31:37.406 p.m.	1	1	HYDRAULIC PRESSURE
Tt-14a16-Lo	ACHIEVED - 2009/06/16 12:31:37.406 p.m.	1	1	LOX RUN TANK TEMPERATURE
Pt-14a23-Gn	ACHIEVED - 2009/06/16 12:31:37.406 p.m.	1	1	UHP GN BOTTLE TANK PRESSURE (LOX PRESS)
Pe-14a4183-Gn	ACHIEVED - 2009/06/16 12:31:37.406 p.m.	1	1	1st STAGE GOX PURGE PRESSURE
Pe-14a4184-Gn	ACHIEVED - 2009/06/16 12:31:37.406 p.m.	1	1	2nd STAGE LOX S/D PURGE PRESSURE
Pe-14a4185-Gn	ACHIEVED - 2009/06/16 12:31:37.406 p.m.	1	1	MAIN STAGE LOX S/D PURGE PRESSURE

Target	Message	Priority	Repetitions	Detail
Pe-14a4117-ipa	EXCEEDED - 2009/06/16 12:33:56.967 p.m.	1	1	Loss of IPA Main Stage Interface Pressure



Example Redline Handling

PLC2 Redline Low Limit Enable Bits

Word 0 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 ■

Word 1 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16

Word 2 47 46 45 44 43 42 41 40 39 38 37 36 35 34 33 32

Word 3 63 62 61 60 59 58 57 56 55 54 53 52 51 50 49 48

Word 4 79 78 77 76 75 74 73 72 71 70 69 68 67 66 65 64

Word 5 95 94 93 92 91 90 89 88 87 86 85 84 83 82 81 80

Word 6 111 110 109 108 107 106 105 104 103 102 101 100 99 98 97 96

PLC2 Redline High Limit Enable Bits

Word 10 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0

Word 11 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16

Word 12 47 46 45 44 43 42 41 40 39 38 37 36 35 34 33 32

Word 13 63 62 61 60 59 58 57 56 55 54 53 52 51 50 49 48

Word 14 79 78 77 76 75 74 73 72 71 70 69 68 67 66 65 64

Word 16 111 110 109 108 107 106 105 104 103 102 101 100 99 98 97 96

PLC2 Voting Booths 0 1 2 3 4 5 6 7 8 9

Reset Current PLC Reset ALL PLCs Reset Advance DONE

E2C1PLC1 EN ALM State Mode

E2C1PLC2 ● ●

Seq. Acc. Seconds
0.000

DETECT ALARM

Seq. Clock @ Advance
0.000

Seq. Step @ Advance
0

First Out @ Advance
0

VS.

G2 Redlines Anomaly Report

G2 REDLINES ANOMALY REPORT Print Report

Redline Anomaly Details	
Sensor Name	PE-14A4117-IPA
Event Type	EXCEEDED
Min Threshold Limit	210.0 psi
Event Time	2009/06/16 12:33:56.991 p.m.
Event Time to T0	2.108
Arm Time	2.0
Disarm Time	14.0
Condition	Loss of IPA Main Stage Interface Pressure
Test Name	0911_021A_9167_CSGT
Test T0 Time	2009/06/16 12:33:54.883 p.m.
Auto-sequence Start Time	-37.0
Auto-sequence End Time	14.0

PE-14A4117-IPA
Redline EXCEEDED at: 2009/06/16 12:33:56.991 p.m.

Auto-Seq Start = -37.0 Redline EXCEEDED at: 2009/06/16 12:33:56.991 p.m. Auto-Seq End = 14.0

Event = 2.108 Arm Time = 2.0 Disarm Time = 14.0

Low 210.0

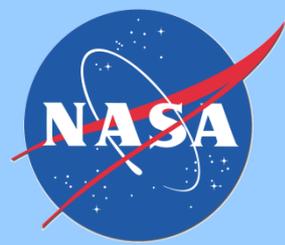
16 Tue Jun 2009 12:33:15 12:33:30 12:33:45 12:34:00 12:34:15

E2 Control Room Redlines UI

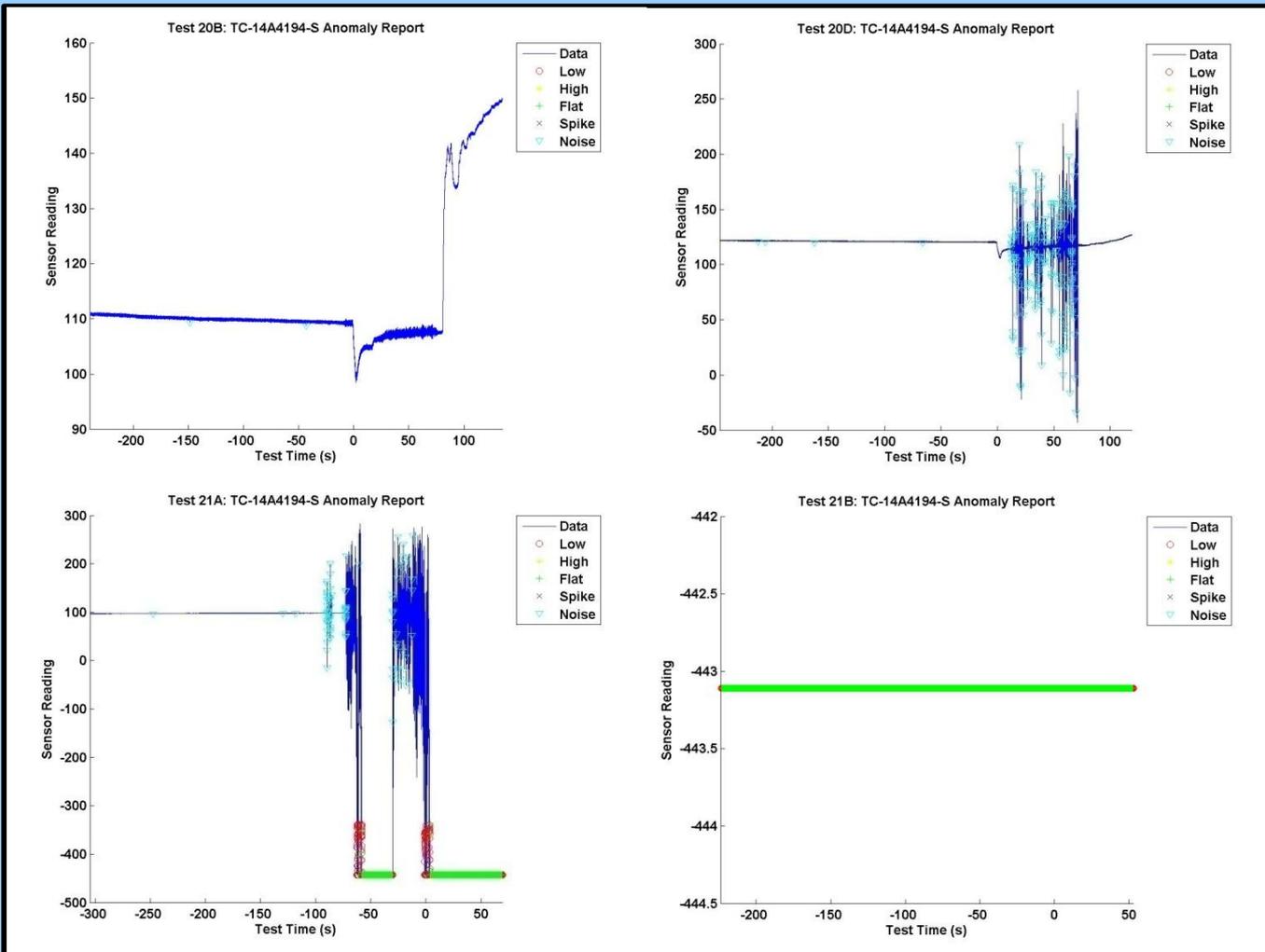
- Requires extensive expertise in interpreting events
- Analysis of events takes considerable time and effort
- Only viewed by selected personnel at control room facility

ISHM CSG Model Redlines UI

- Provides easily recognizable details of events
- Immediately accessible to all personnel at control room facility, hardcopy printouts allow for ease of distribution and record keeping
- Additional event and test parameters and associated data are depicted



CSG Anomalies Detected



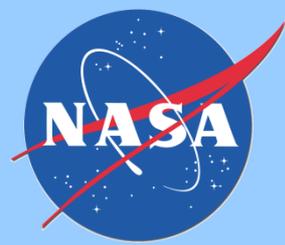
- Evidence of TC degradation detected by VISE anomaly detection
- Advanced notification to determine the health of the whole system before beginning a test

Transducer Anomaly Report Graphs for one sensor in four consecutive tests.



Key Implementation Objectives/Results

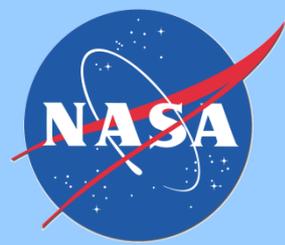
- **Support for test readiness**
 - Bluelines (time savings and improved reliability)
 - Fast and accurate setting of bluelines.
 - Fast and accurate identification of violations and relevant hardware.
 - TEDS (time savings and improved reliability)
 - Immediate identification of sensors.
 - Immediate availability of specifications and calibration information.
 - Immediate identification of sensor locations in the diagram.
- **Support during test**
 - Redlines
 - Fast and accurate setting of redlines (time savings and improved reliability).
 - Fast and accurate identification of violations and relevant hardware (time savings, improved reliability, quicker response to safety critical issues, and faster analysis).
 - Immediate viewing of trends for any sensor or signal (improved reliability).
- **Support for rapid return to test**
 - On-line analysis.
 - Re-stream data to simulate tests at any time (faster and better analysis).
 - Advanced post-test analysis and data review
 - View data windows for multiple sensors, involving multiple tests (improved understanding of system).



Improvements for the Next CSG Test Program

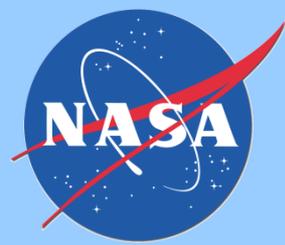
The following improvements, requested by the test director and test conductors, will be in place for testing in September, 2010.

- Continuous checking of all sensor values for violations of thresholds defined by any desired criteria (e.g. sensor specifications, operational requirements from the Test Request Document).
- Valve state verification.
- System state verification at test stages as specified by the Test Request Document.
- System interlocks verification as specified by the Test Request Document.
- Usage capture.
 - Valve cycling.
 - Tank thermal cycling.
- Post test quick-look analysis (immediate and accurate understanding of test results and any issues):
 - Select sensor sets and time windows for viewing trends from the current test or from across multiple tests.
 - Select redline occurrences and view details, including identification of relevant elements in the diagram.
 - View all anomalies and descriptions, and identify relevant elements in the diagram.
 - Proximal Cause Analysis



Outline

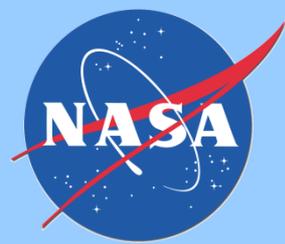
- Motivation
- Technology and Capabilities
 - Generic Architecture
 - ISHM Model
 - Embedded DIaK
 - Proximate Cause
 - VISE
 - Advanced Anomaly Detection
 - HADS
- ISHM Implementations
 - CSG Pilot Implementation
- **ISHM Benefits**
 - A3 Test Stand
 - Other facilities
- Conclusions



Benefits to A3

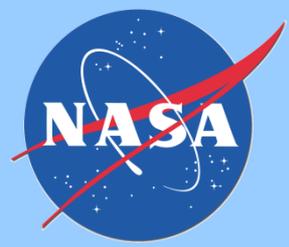
(and to other facilities)

- Improve assessment of test readiness—availability, reliability, configuration.
- Assist in verifying conformity of system states throughout the test, as per the Test Request Document.
- Improve information flow to operator during test.
- Improve post-test data review and analysis: accurate, fast, and comprehensive understanding of test results and test stand issues (including analysis across multiple tests).
- Improve safety: awareness of system condition, faster and accurate identification of safety issues.
- Automatic generation of reports.
- Capture safety critical events.
- Capture usage information.
- Capture anomaly information.
- Improve efficiency and effectiveness of PSM and RCM activities.
- Create and maintain a comprehensive database incorporating health information.



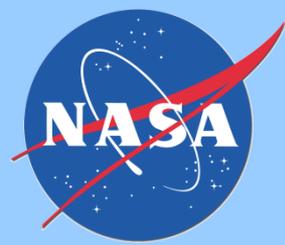
Extending ISHM to A-3 (and other facilities)

- Steps needed to extend CSG model to full-up A-3 configuration
 - Implement three-unit skid to prepare for 9-skid A-3 design
 - Incorporate leak detection, advanced valve anomaly management and other improvements in anomaly detection
 - Integrate with SSC configuration management
 - Develop ConOps
 - Use ISHM system for long-term benefits
 - Increase understanding of CSG reliability
 - Condition-Based Maintenance (CBM)
 - Reliability-Centered Maintenance (RCM)
 - Process safety management (PSM)



Outline

- Motivation
- Technology and Capabilities
 - Generic Architecture
 - ISHM Model
 - Embedded DIaK
 - Proximate Cause
 - VISE
 - Advanced Anomaly Detection
 - HADS
- ISHM Implementations
 - CSG Pilot Implementation
- ISHM Benefits
 - A3 Test Stand
 - Other facilities
- Conclusions



A-3: ISHM Will Reduce Risks and Enable Sustainable/Affordable Operations

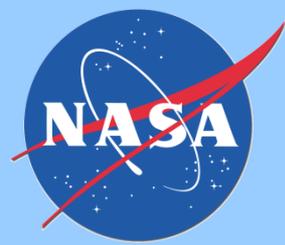
- A-3 has a high degree of complexity and its operation will present a substantially more difficult challenge than any system before. The number of data and signal streams to be monitored and reasoned about will be overwhelming. Testing might be seriously limited without the support from an ISHM capability.

**48+ VESSELS AS OPPOSED TO 3-4 IN EXISTING STANDS.
321+ MORE SENSORS THAN IN EXISTING STANDS.**



A-3: ISHM Will Reduce Risks and Enable Sustainable/Affordable Operations

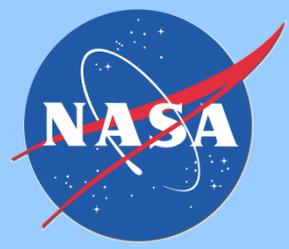
- A3 Will involve safe, accurate, and reliable synchronized-operation of multiple systems (27 CSG's, Steam Water System, IPA System, LOX System, LH2 System, Purge Systems, Industrial Water, Hydraulic System, Diffuser System, Test Chamber System).
 - Will require automated monitoring and analysis capability to achieve the appropriate degree of confidence for test readiness in a timely and affordable manner.
 - Will require improved approach to manage bluelines and redlines.
 - During tests, it will require awareness about a system one order of magnitude larger than typical test stands.
 - Will require improved analysis tools for accurate and fast assessment of test results, anomalies, and safety issues.



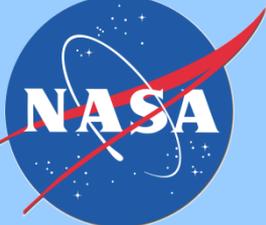
Summary

- ISHM Capability can be implemented without disturbing normal operations of a system. The only things needed are: (1) the data stream, and (2) information describing all elements in the system (P&ID's, specifications records, calibration records).
- A sound methodology for ISHM implementation has been validated in an operational setting.
- The implementation provides for systematic augmentation of the capability to meet user needs.
- Feedback from test conductors and test director has been very positive, and all became engaged in defining needed updates.
- Expertise and tools reside at the center, but capable industry partners are also available to support fast deployments and long term operations.
- The ISHM capability will make possible a more effective use of predictive models from the Analysis and Simulation Group. Quick access to relevant data and anomalies will make analysis with predictive models more effective and accurate. Also, predicted measurements will be used to detect anomalies, diagnose causes, determine effects, and predict future anomalies.

The difference between having ISHM capability and not having it is analogous to using a Windows computer connected to a network (WWW) as opposed to a DOS computer without network capability ... SIGNIFICANT DIFFERENCE IN DATA, INFORMATION, AND KNOWLEDGE AVAILABILITY; AND IN AWARENESS THROUGH USER INTERFACES



Backup Slides



Snapshot of SSC ISHM Capabilities

ISHM Models (Embedded Data, Information, and Knowledge):

Object-oriented model

Anomaly Detection:

Sensor faults, leaks, etc.

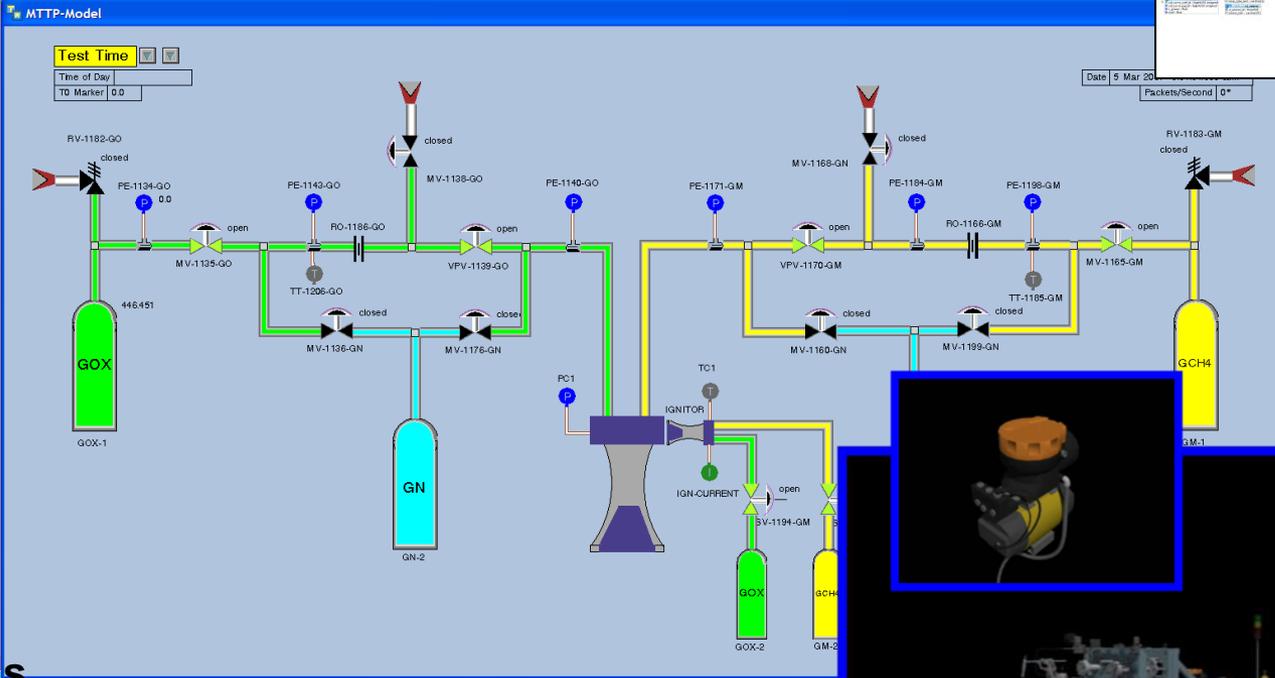
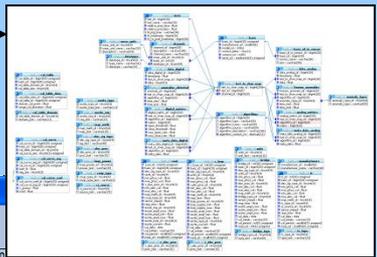
Intelligent Sensors:

IEEE Standard+Health



Health Assessment Database:

Health Electronic Data Sheets (HEDS)
Repository of anomalies, algorithms,
Transducer Electronic Data Sheets (TEDS),
Historical Test Data



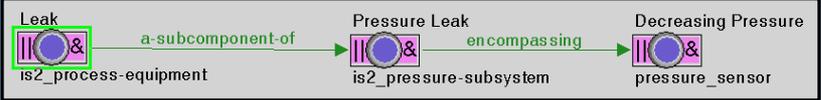
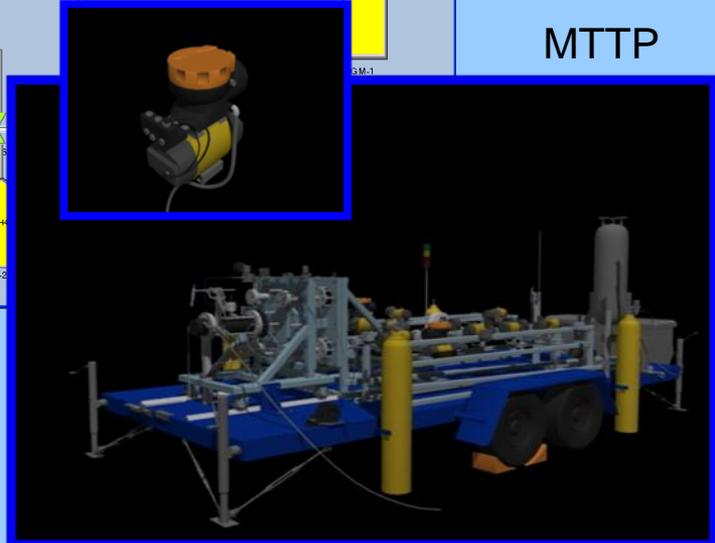
MTTP

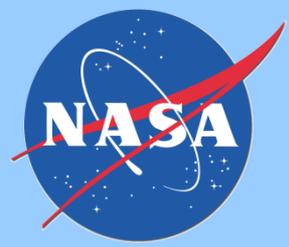
Embedding of Predictive Models

Proximate Cause and Effects Determination

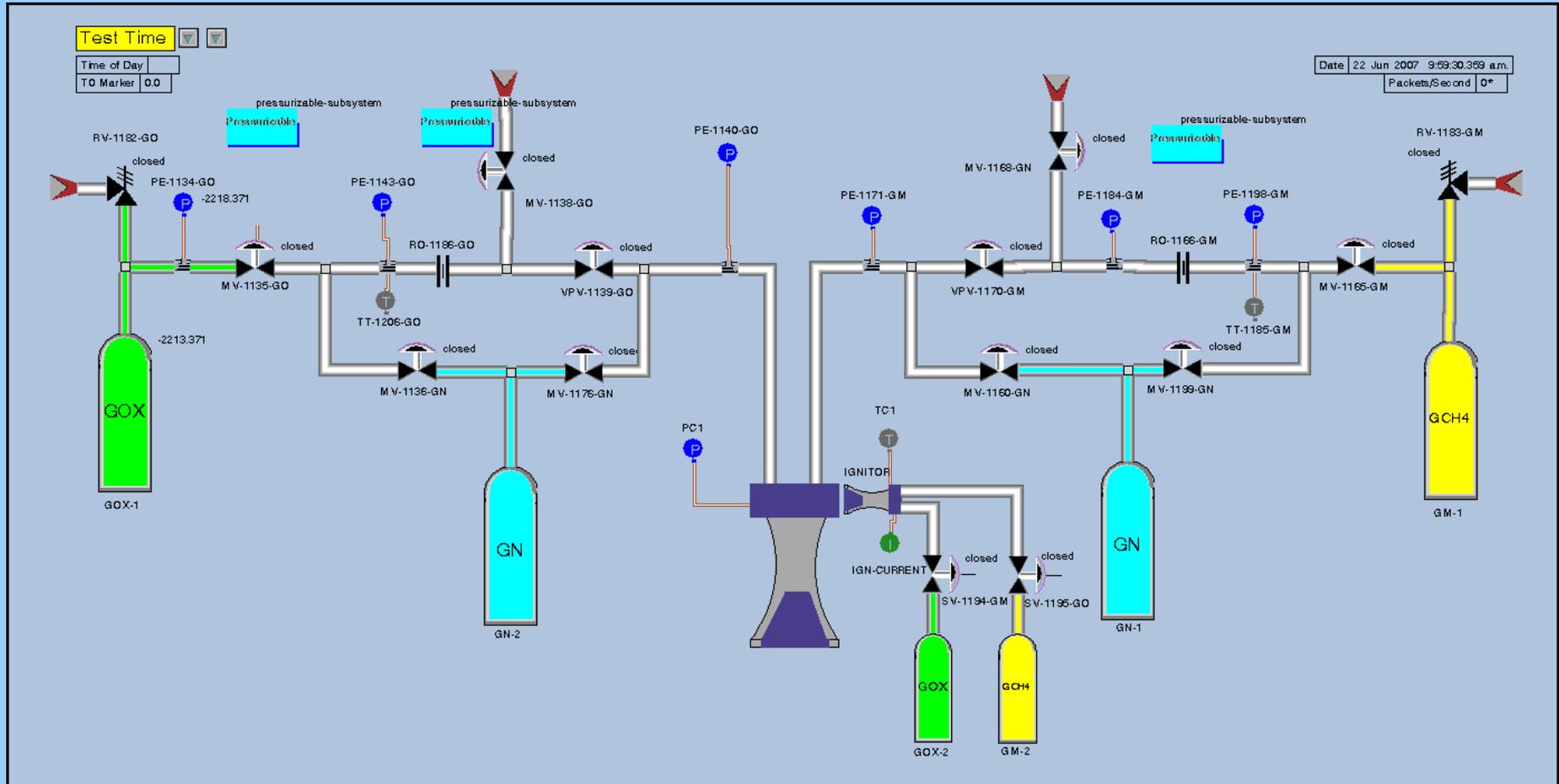
Integrated Awareness:

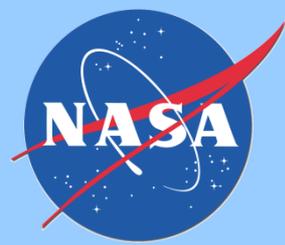
3-D Health Visualization



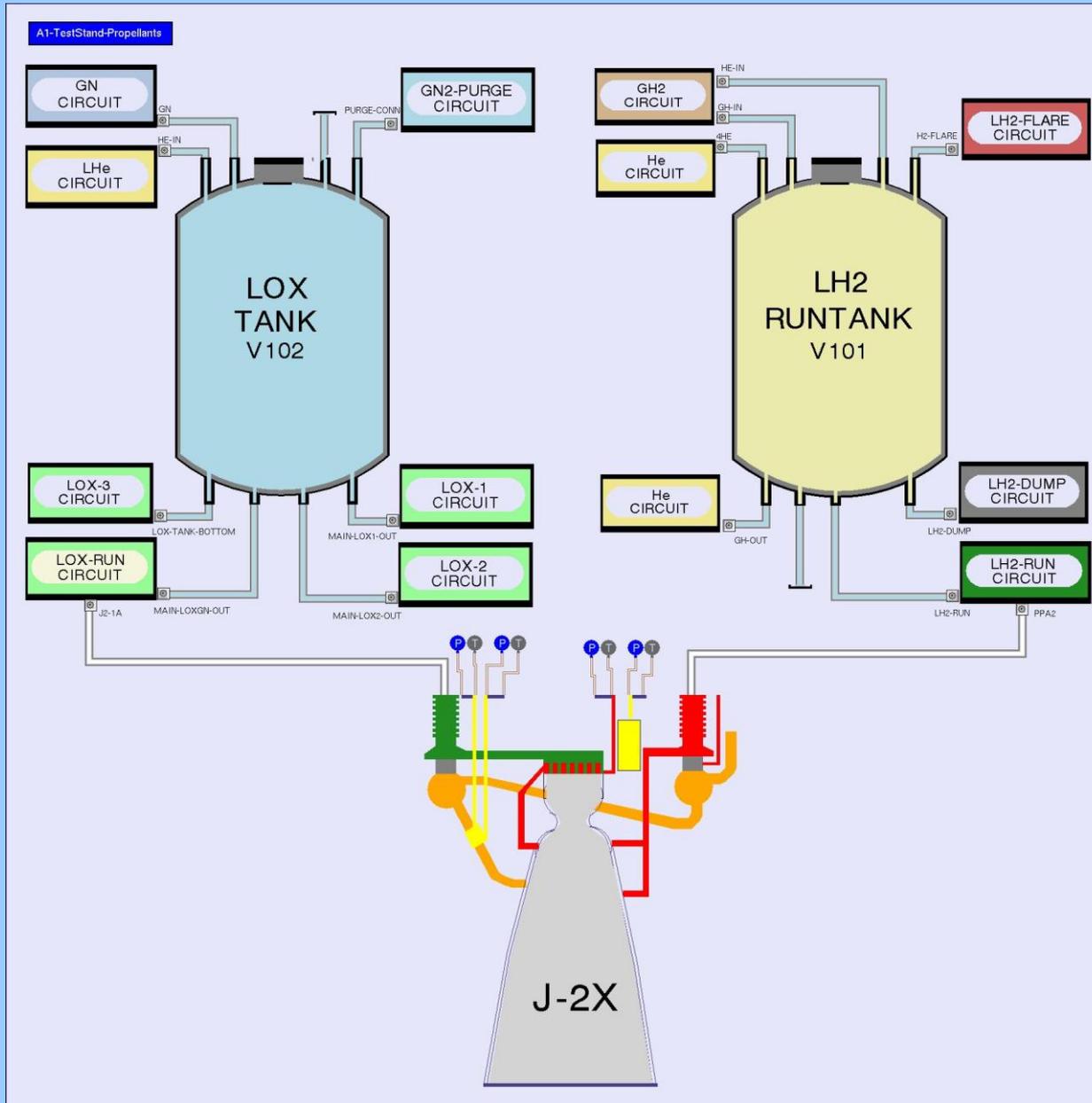


Elements of an ISHM System: ISHM Model - Proximate Cause Analysis



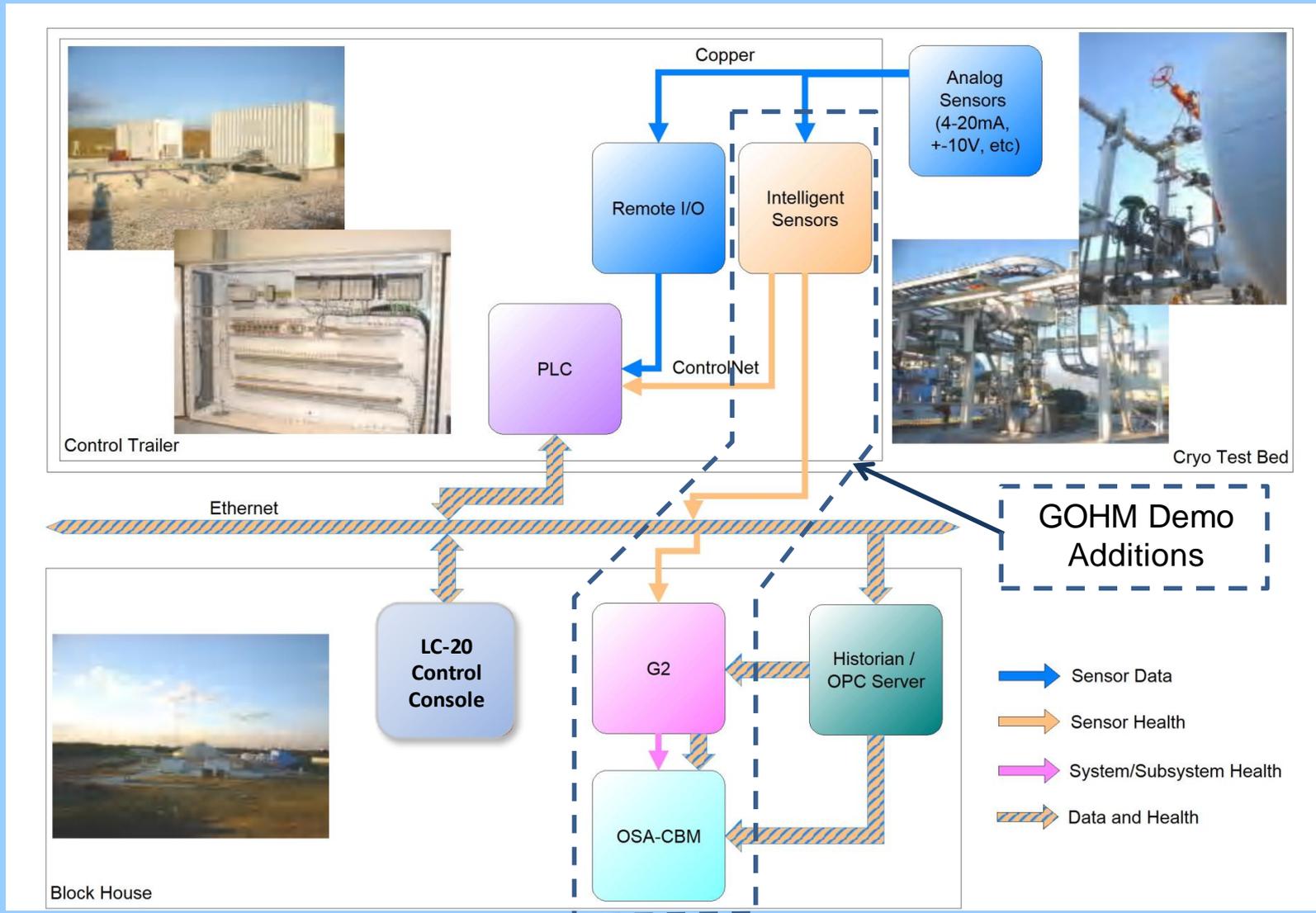


A1 and J2-X ISHM MODEL



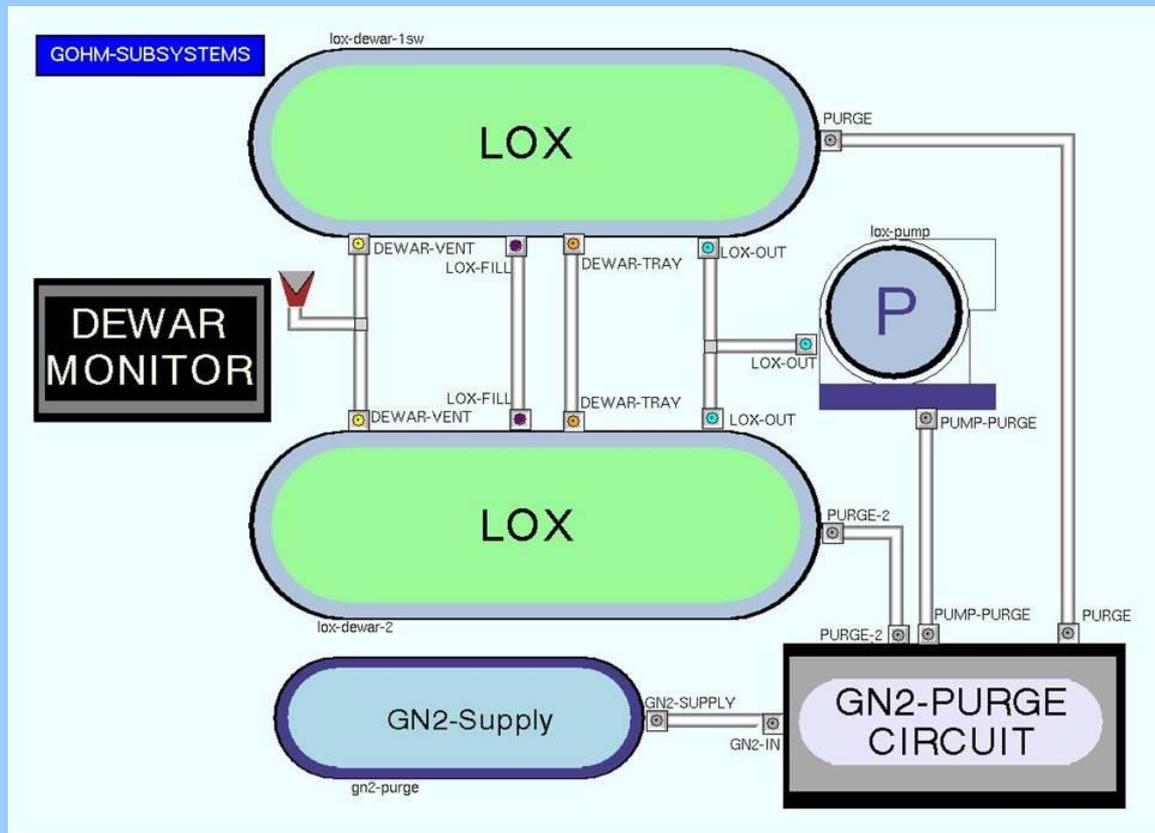


Launch Center 20 at KSC ISHM Pilot Implementation Validation During a LOX Pump Test



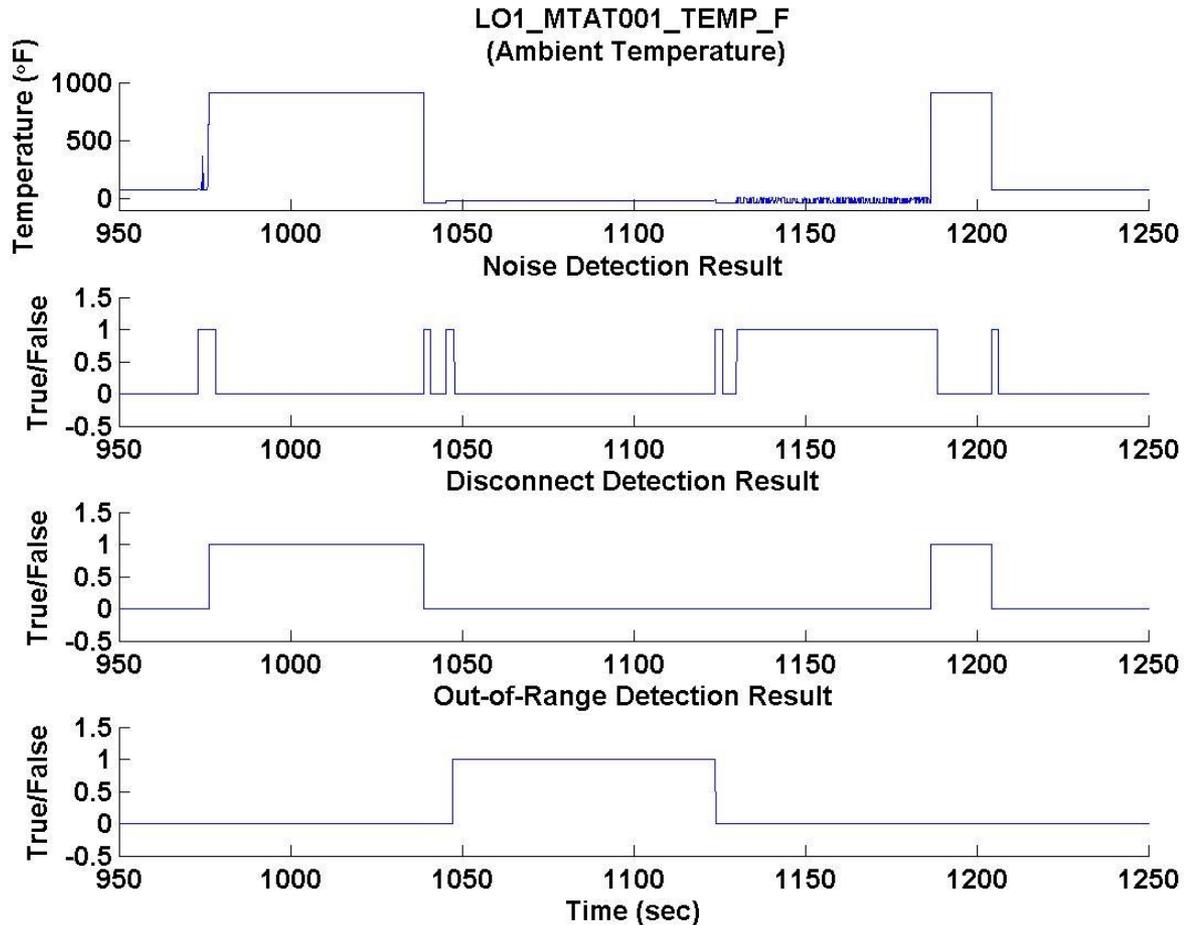


Top level view of the ISHM model of the Launch Complex 20 Facility at NASA Kennedy Space Center





Sensor anomaly indicators detected by an intelligent sensor during a pump test using the LC-20 facility at NASA Kennedy Space Center





Screenshot of the ISHM model of the LC-20 facility at KSC showing detection of a valve leak created by opening the valve manually

Telewindows Client

File Edit View Layout Go Project Workspace Tools Window Help

100% User Mode Developer Go To

EDS Explorer

By Component..

EDS List

- GNPT104
 - Processes
 - CEDS
 - HEDS
 - TEDS
 - Pressure Calibration Maintenance Re...
 - Pressure Transducer-EDS
 - Basic TEDS

EDS Attributes

Basic TEDS

Template ID	0
Template Control	READ-ONLY
Manufacturer ID	SOR
Model Number	1SGT1KAA
Version Letter	
Version Number	
Serial Number	

GNPT104

Real-Time Plot of GNPT104

8 Tue Apr 2008 Current Time HH:MM:SS

KB Workspace

Package Browser

Loaded Packages

- VISE Interface Classes
- EDS Classes
- Class Browser Classes

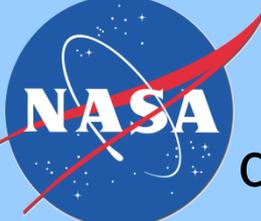
Alarms

Target	Event Name	Value
T-Junction-047-Pressure-Su...	Abnormally changing pressure	true
T-Junction-047-Pressure-Su...	Leak	suspect
T-Junction-047-Pressure-Su...	Higher Than Expected Pressure	false
T-Junction-047-Pressure-Su...	Lower Than Expected Pressure	true
Gnpt104	Abnormally changing pressure	true
Gnpt104	Higher Than Expected Pressure	false
Gnpt104	Lower Than Expected Pressure	true
X-Junction-005-Pressure-Su...	Leak	suspect

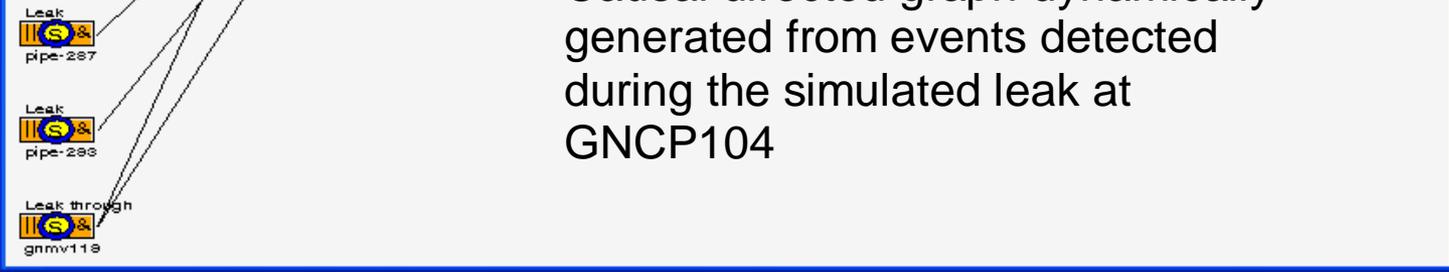
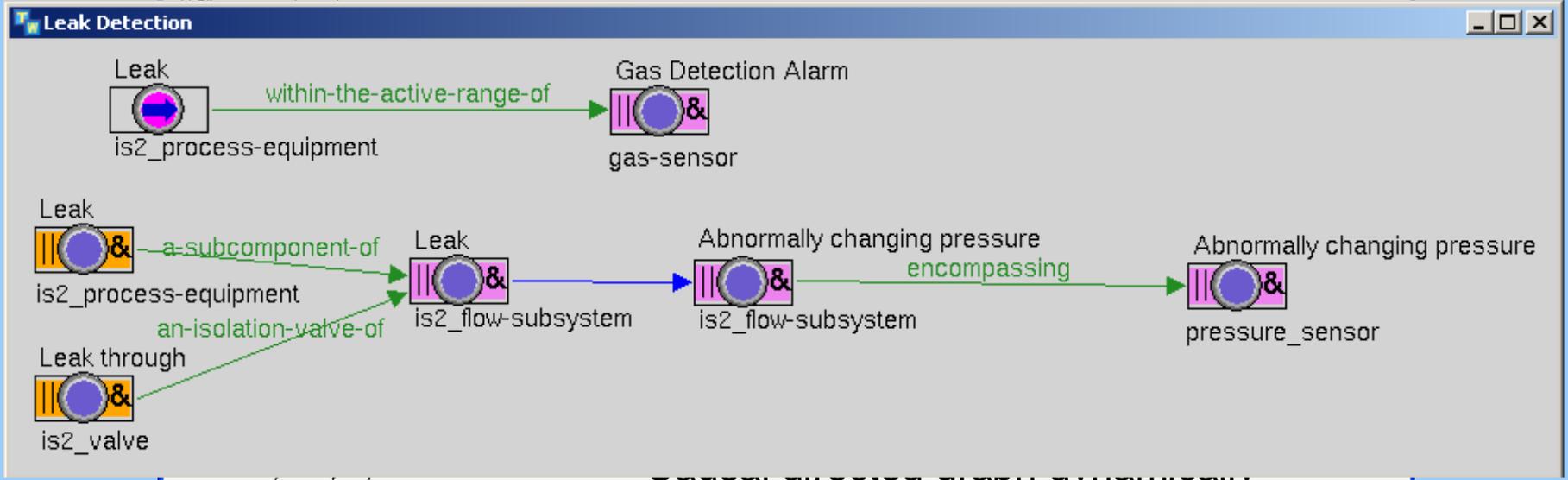
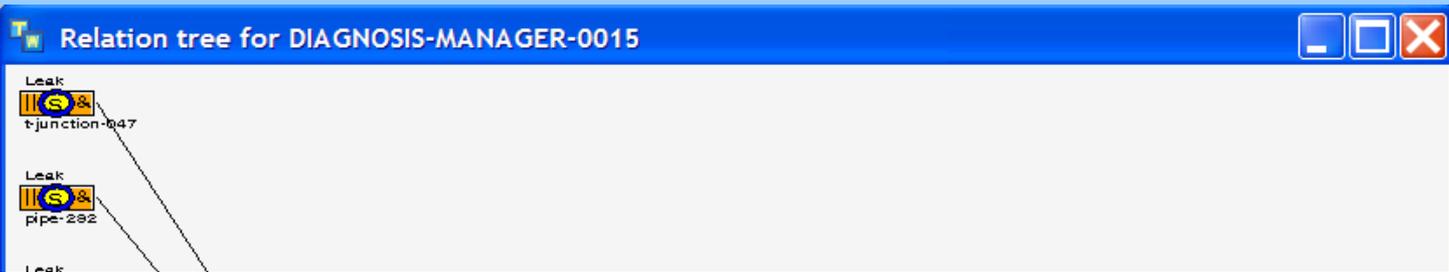
Root Causes

Target	Event Name	Va...	Status
Gncp104	Leak	suspect	upstream inferred
Gnpg104	Leak	suspect	upstream inferred
Gnpt104	Leak	suspect	upstream inferred
Pipe-285	Leak	suspect	upstream inferred
Pipe-287	Leak	suspect	upstream inferred
Pipe-292	Leak	suspect	upstream inferred
Pipe-293	Leak	suspect	upstream inferred
T-Junction-047	Leak	suspect	upstream inferred
Gnmv119	Leak through	suspect	upstream inferred

ISOS-DELL-M70:1111 4/8/2008 15:17:34: Alarm: Lower Than Expected Pres



Expanded causal-directed graph generated by the detection of a leak in the subsystem where a valve was opened manually (injected leak)

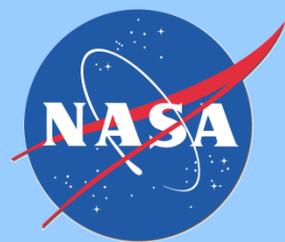


causal directed graph dynamically generated from events detected during the simulated leak at GNCP104

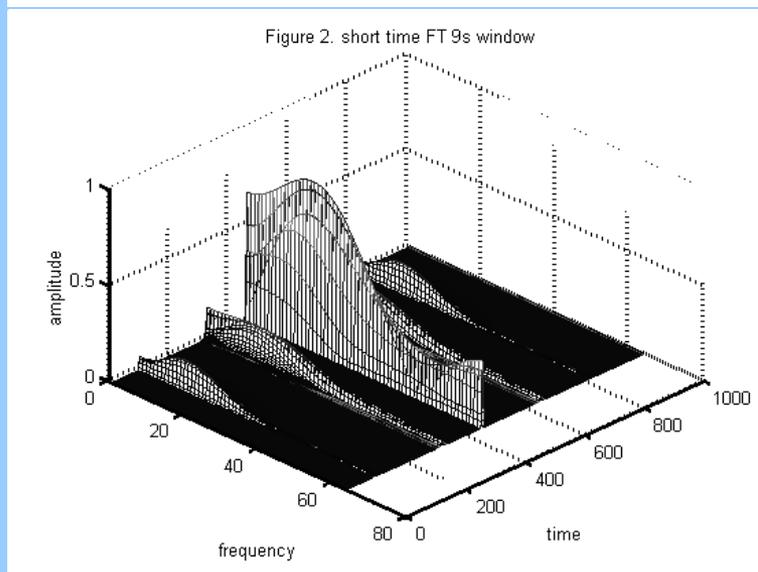
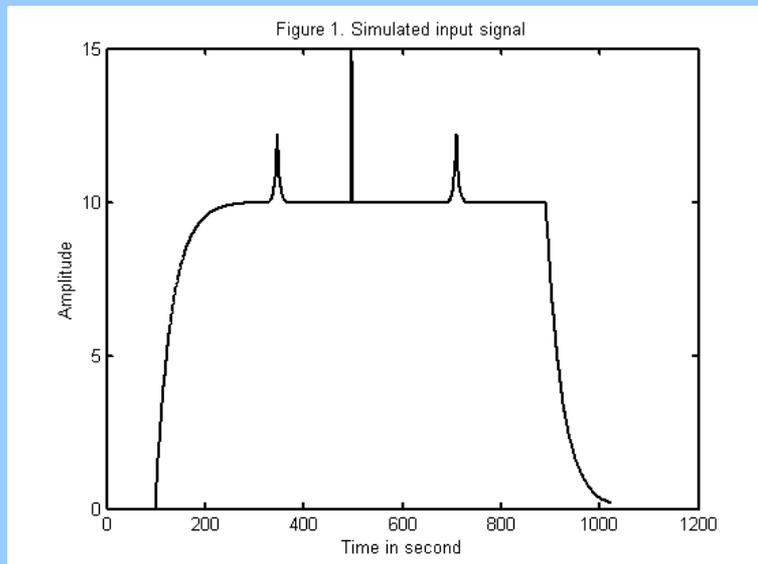


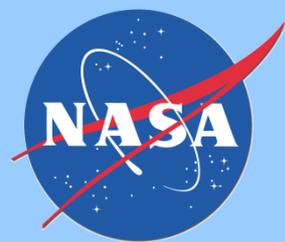
List of Anomaly Detection Capabilities

Anomaly/Behavior	Demonstrated Cause	Detection Approach
Leaks (pipes, valves, etc.)	Various	Checking for pressure leaks using the concept of Pressure Subsystems.
Valve state undetermined	Defective feedback sensor Controller failure	Determines valve state by checking consistency of command, feedback, open/close switches, and pressure conditions upstream and downstream.
Valve oscillation	Fluid contamination in hydraulic supply	Compare running standard deviation of command versus feedback.
Valve stuck	Fluid contamination in hydraulic supply Seat seizure	Feedback remains horizontal while command changes.
Excessive noise, spikes, etc.	Interference	Running standard deviation exceeds set limits. Thresholds violations during short time spans (compared to sensor time-constant).
Degradation	Wear, aging	Trend detection using curve fitting and determination of time-constants.
Prediction-Measurement mismatch	Various	Use predictive model (e.g. from Modeling & Analysis Group) to predict sensor values and compare with measurements.



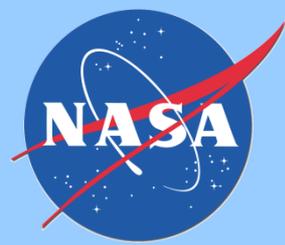
Short-Time Fourier Transform Segmentation



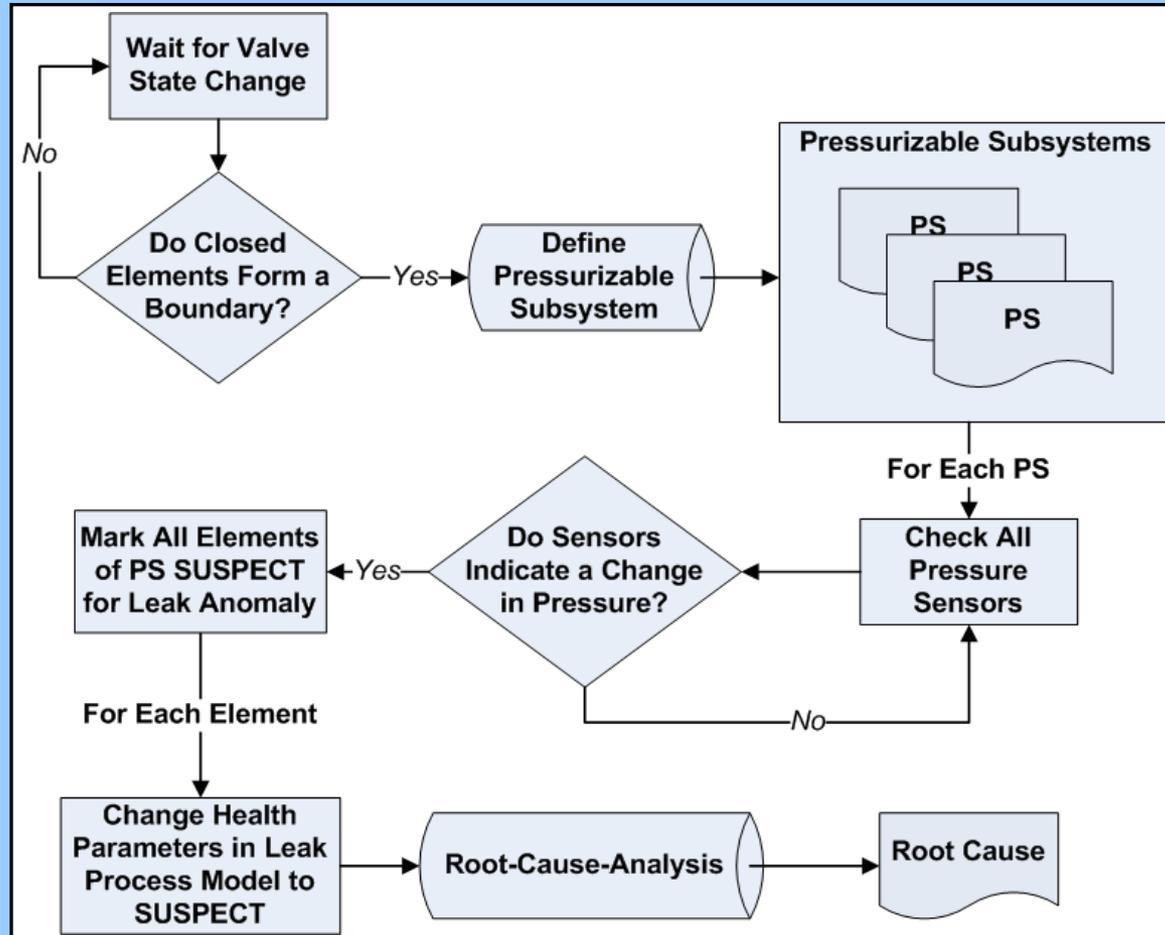


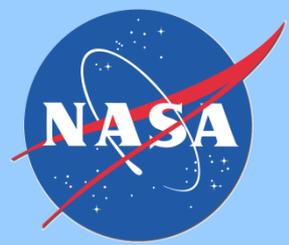
Determining Valve-State

Valve State	Command	Feedback	Open limit	Closed Limit	Associated Sensors
Open	Open	Open	True	False	Agree with model
	Healthy				
Closed	Closed	Closed	False	True	Agree with Model
	Healthy				

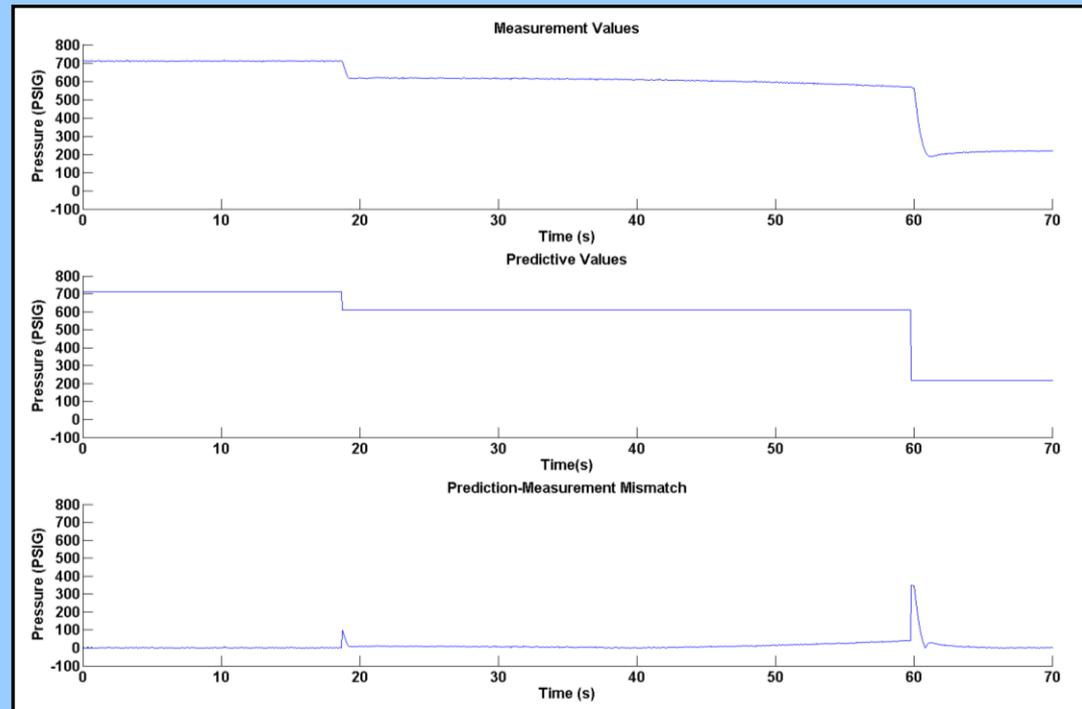
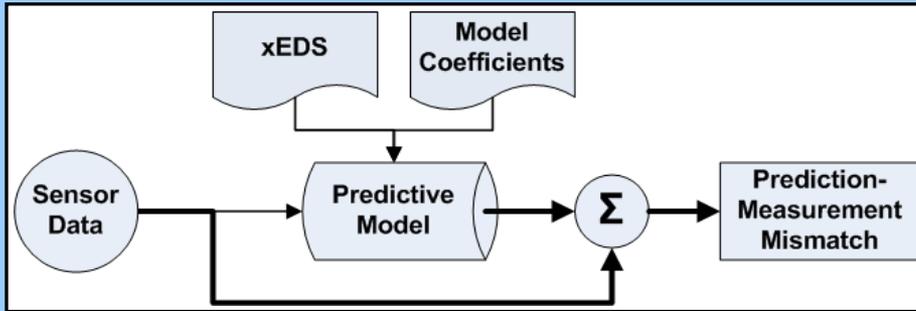


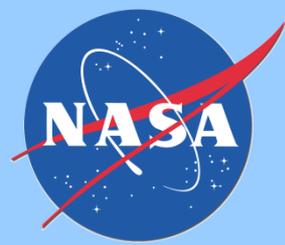
Checking for Pressure Leaks





Runtime Predictive Modeling





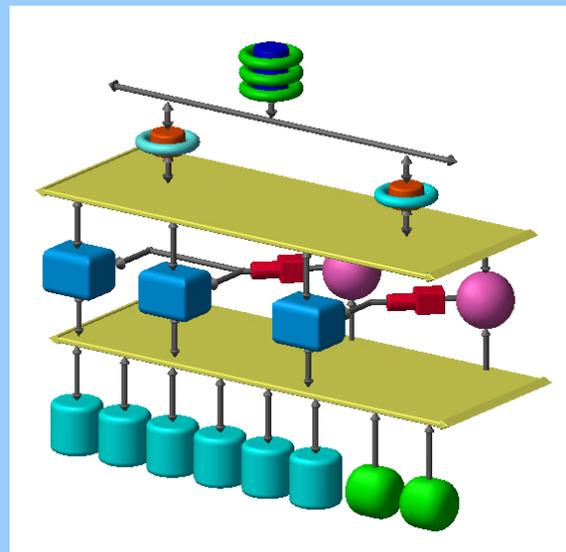
Electronic Datasheets

- Electronic Data Sheets (EDS)
 - Transducer Electronic Data Sheets (TEDS)
 - Calibration
 - Health Electronic Data Sheet (HEDS)
 - Quality of data
 - Codified fault conditions and system phases
 - Key detection algorithms w/ parameters
 - Component EDS (CEDS)
 - Manufacturing details
 - Engineering data
 - Traceability
 - Other EDS

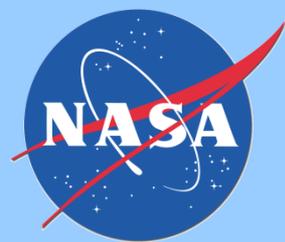


Intelligent Sensors

- Smart sensor
 - NCAP (Go Active, Announce)
 - Publish data
 - Set/Get TEDS
- Intelligent sensor
 - Set/Get HEDS
 - Publish health
- Detect classes of anomalies using:
 - Using statistical measures
 - Mean
 - Standard deviation
 - RMS
 - Polynomial fits
 - Derivatives (1st, 2nd)
 - Filtering—e.g., Butterworth HP
 - FFT—e.g., 64-point
 - Wavelet Transforms (segmentation)
 - Algorithms for
 - Flat
 - Impulsive (“spike”) noise
 - White noise
 - Other (ANN, etc.)

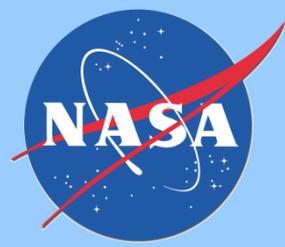


Intelligent Sensors have embedded ISHM functionality and support **Smart Sensor** standards

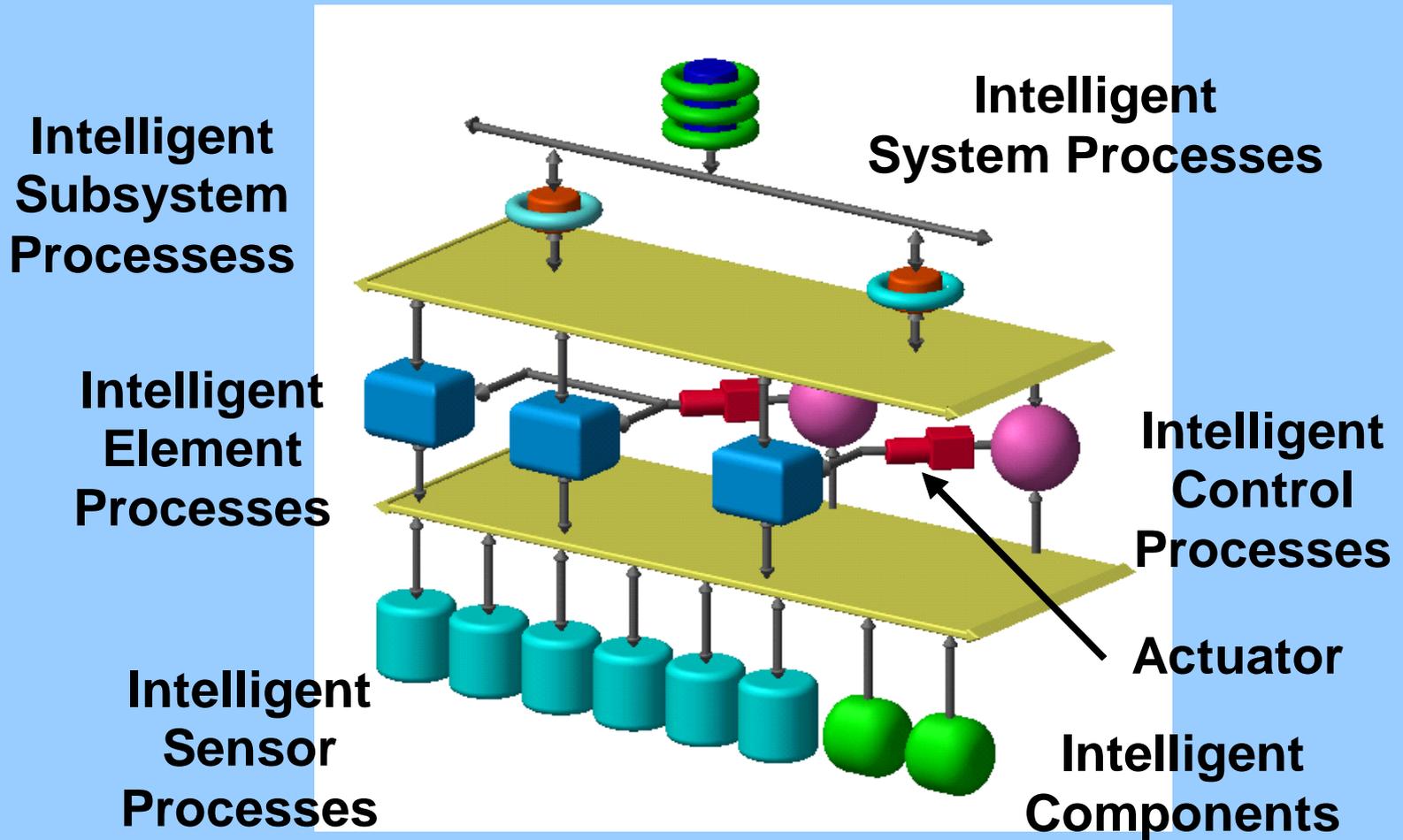


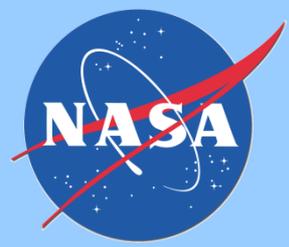
Concepts - Paradigm

- System of connected (networked) intelligent elements.
 - Standards for Plug&Play and Interoperability.
- Compartmentalized DIaK.
- ISHM Subsystem definitions are dynamic, based on current process analysis needs?
- ISHM Subsystems use resources from their intelligent elements, and improve the elements' own health assessment.

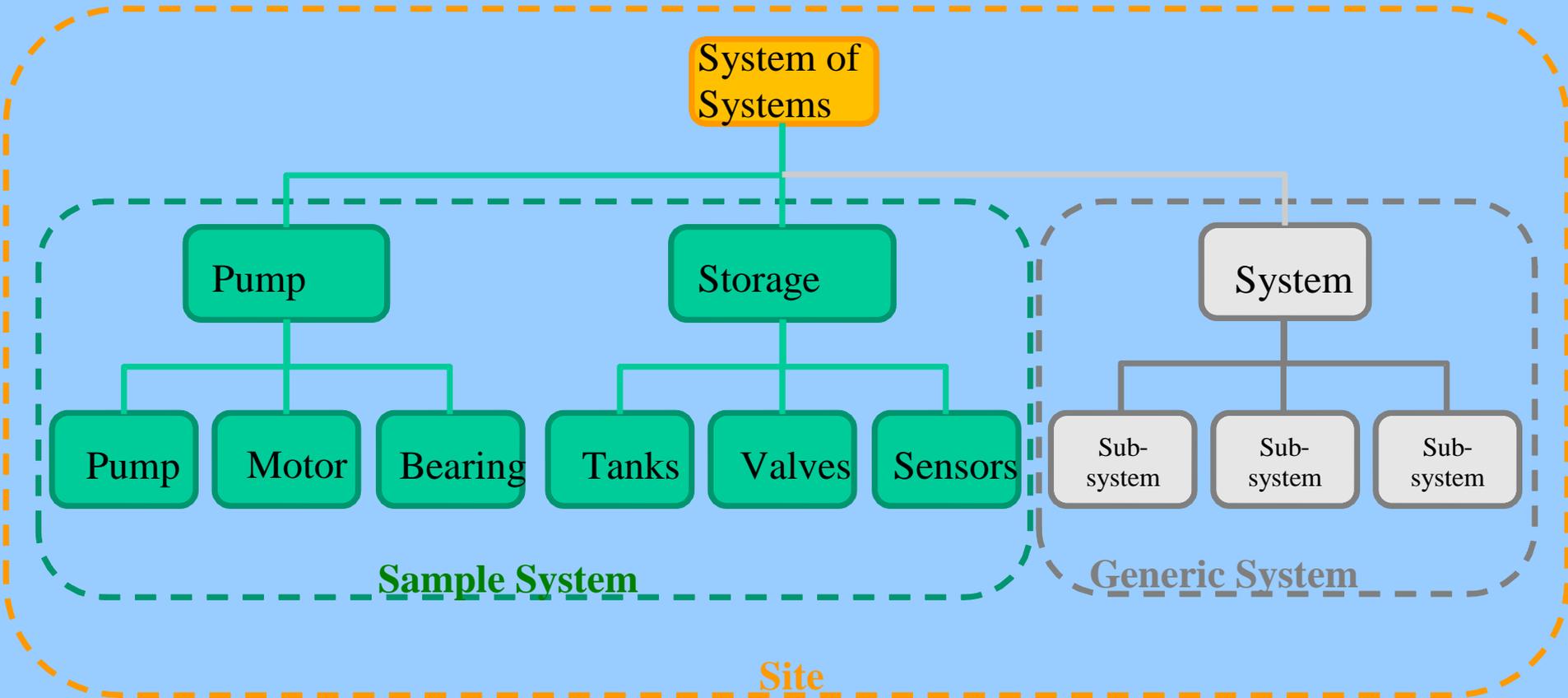


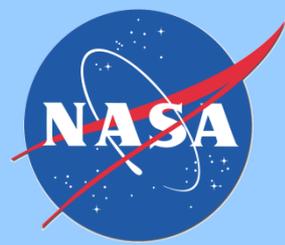
Data, Information, and Knowledge Management Architecture for ISHM (Information Architecture)





Classic architecture describing how systems are built





Detection and Confirmation of Anomalies Consistency Checking Cycle

