



Tutorial

Integrated Systems Health Management (ISHM)

Enabling Intelligent Systems

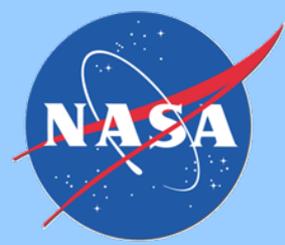
Fernando Figueroa, NASA Stennis Space Center, USA

NASA/ESA Conference on Adaptive Hardware and Systems (AHS-2011)

June 6-9, 2011

**San Diego Convention Center
San Diego, California, USA**

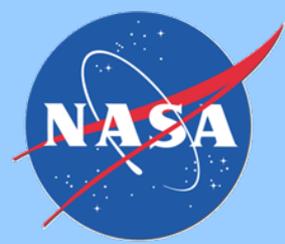




Acknowledgements

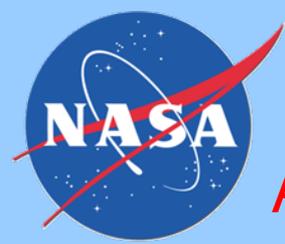
The author would like to thank NASA for providing the opportunity to work on advancing the area of ISHM.

The author also expresses his profound appreciation to the many individuals that, through insightful discussions and interactions, have enriched his understanding of ISHM.



Outline

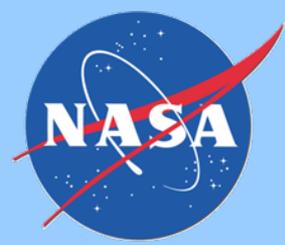
- Context of the Tutorial.
- ISHM Definition.
- ISHM Capability Development.
 - ISHM Knowledge Model.
 - Standards for ISHM Implementation.
 - Software to develop ISHM Domain Models (ISHM-DM's).
 - Intelligent Sensors and Components.
- Sensor Optimization and Placement for ISHM.
- ISHM in Systems Design, Engineering, and Integration.
- Intelligent/Adaptive Control for ISHM-Enabled Systems.
- Verification and Validation Considerations.



Context of the Tutorial

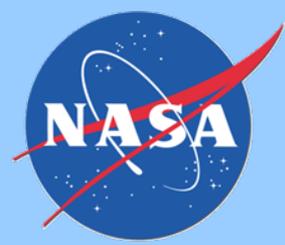
Adaptability from an Integrated System Perspective

- Intelligent/Adaptive System: Manages **data, information, and knowledge (DIaK)** to achieve its mission (Manage: storage, distribution, sharing, maintenance, processing, reasoning, and presentation)
- An attribute or quality of intelligent/Adaptive systems should be to possess a health management capability that:
 - Employs knowledge about the system embodying “systems thinking” (captures interactions among elements of the system).
 - Is continuously vigilant.
 - Is comprehensive in assessing health of each element of a system.
 - Is systematically evolutionary to achieve higher and higher functional capability levels (increasing effectiveness).
- In order to make this capability possible, the health management system needs to incorporate “intelligence.”

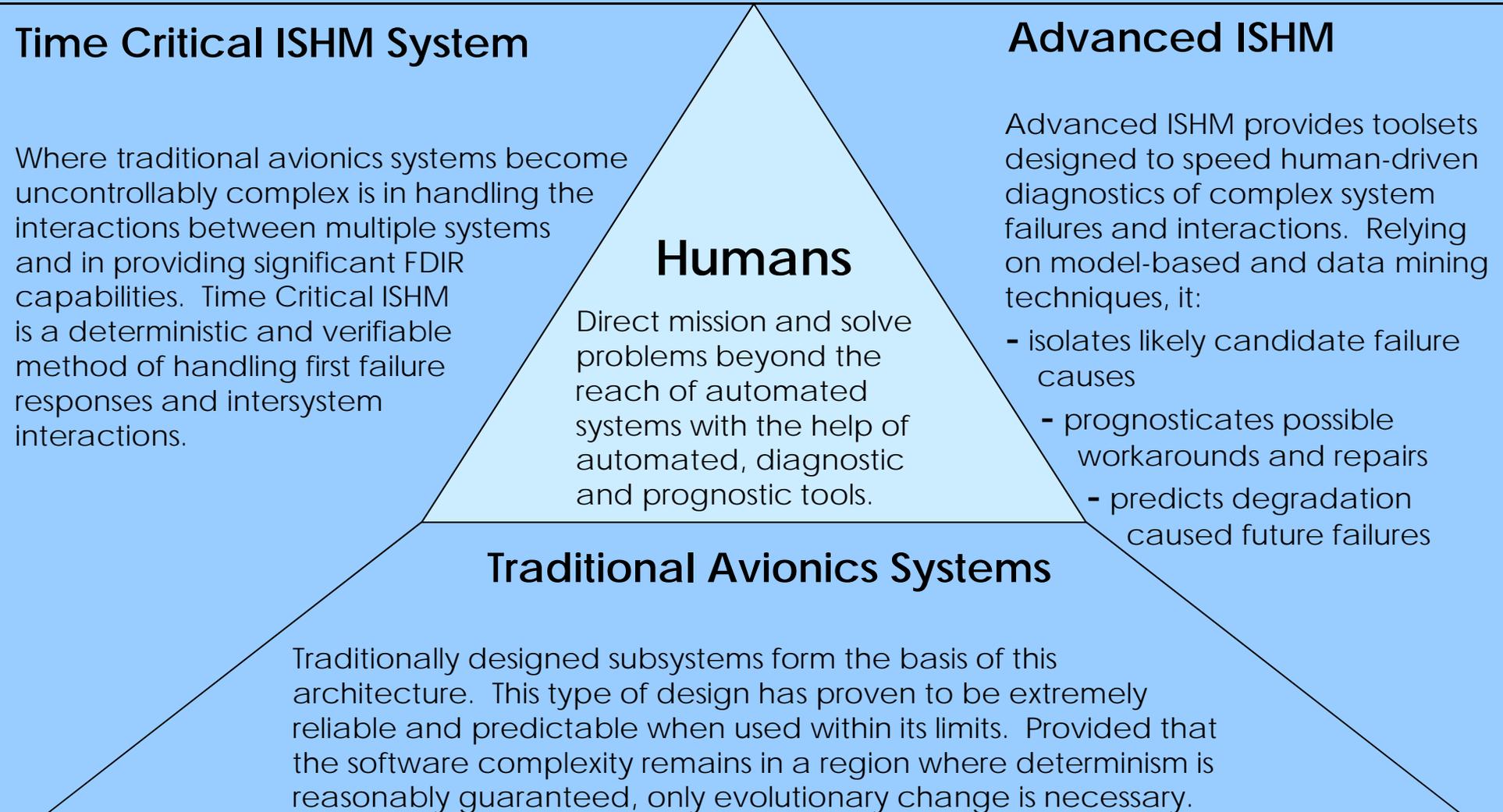


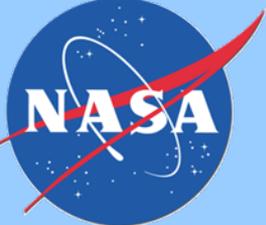
ISHM Definition

- **Its own discipline**, or sub-discipline under Aerospace Systems Design, Systems Engineering, and Systems Integration.
- Management of data, information, and knowledge (DIAK) with the purposeful objective of determining the health of a system (Management: storage, distribution, sharing, maintenance, processing, reasoning, and presentation).
- ISHM is akin to having a broad-base team of experts who are all individually and collectively observing and analyzing a complex system, and communicating effectively with each other in order to arrive at an accurate and reliable assessment of the health of each element of the system.



Interrelationship Between Traditional Avionics Systems, Time Critical ISHM and Advanced ISHM





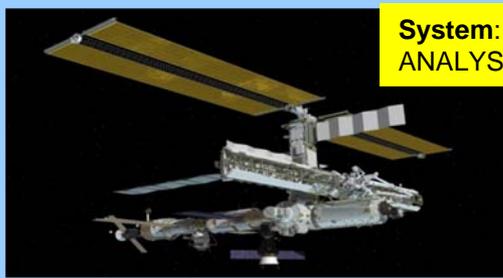
People-Based ISHM is Being Done Today

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

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.

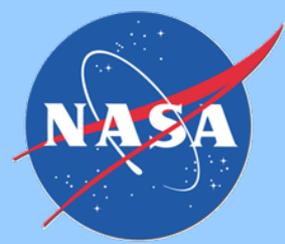
Layer 4
Back Control Room



Support: FASTER, MORE ACCURATE ANALYSIS
Decreased Need

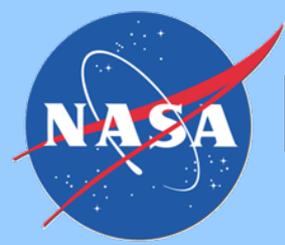


Added DIaK resources from larger community



Determination of Health

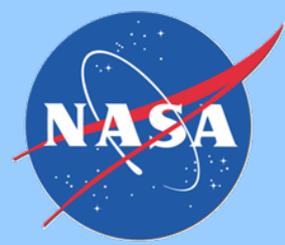
- Use available SYSTEM-WIDE data, information, and knowledge (DIAK) to
 - Identify system state.
 - Detect anomaly indicators.
 - Determine and confirm anomalies.
 - Diagnose causes and determine effects.
 - Predict future anomalies.
 - Recommend timely mitigation steps.
 - Evolve to incorporate new 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).
 - Capture and manage design life and maintenance schedule.
 - Enable automated configuration.
 - Implement automated and comprehensive data analysis.
 - Provide verification of consistency among system states and procedures.



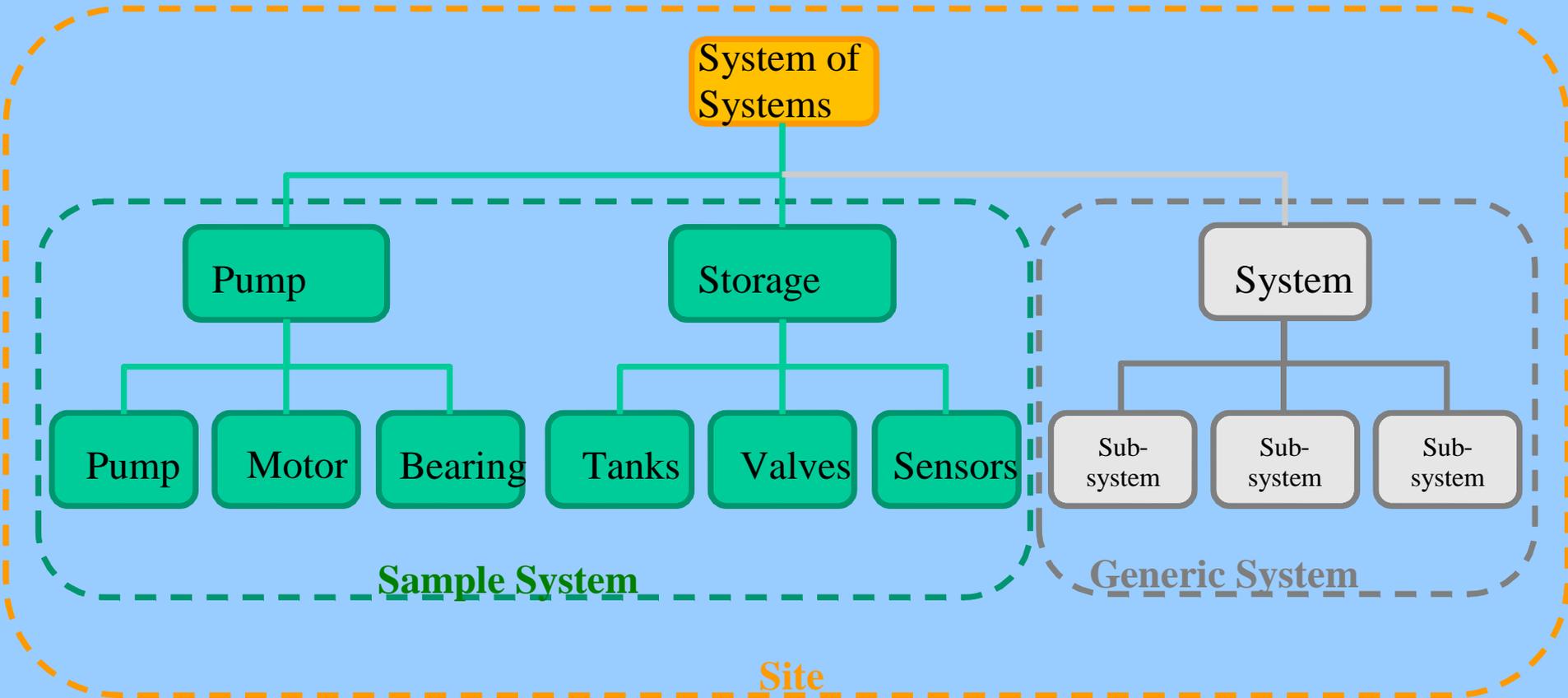
ISHM Capability Development

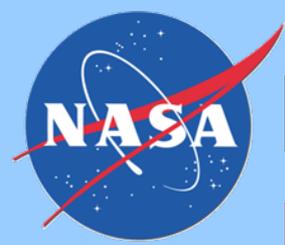
ISHM Knowledge Model

- A plethora of Data, Information, and Knowledge (DlaK) must be applied to achieve high functional capability level (FCL) health management.
- The ISHM Domain Model (ISHM-DM) encompasses DlaK and the tools to implement ISHM capability.



Classic architecture describing how systems are built

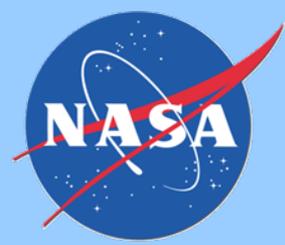




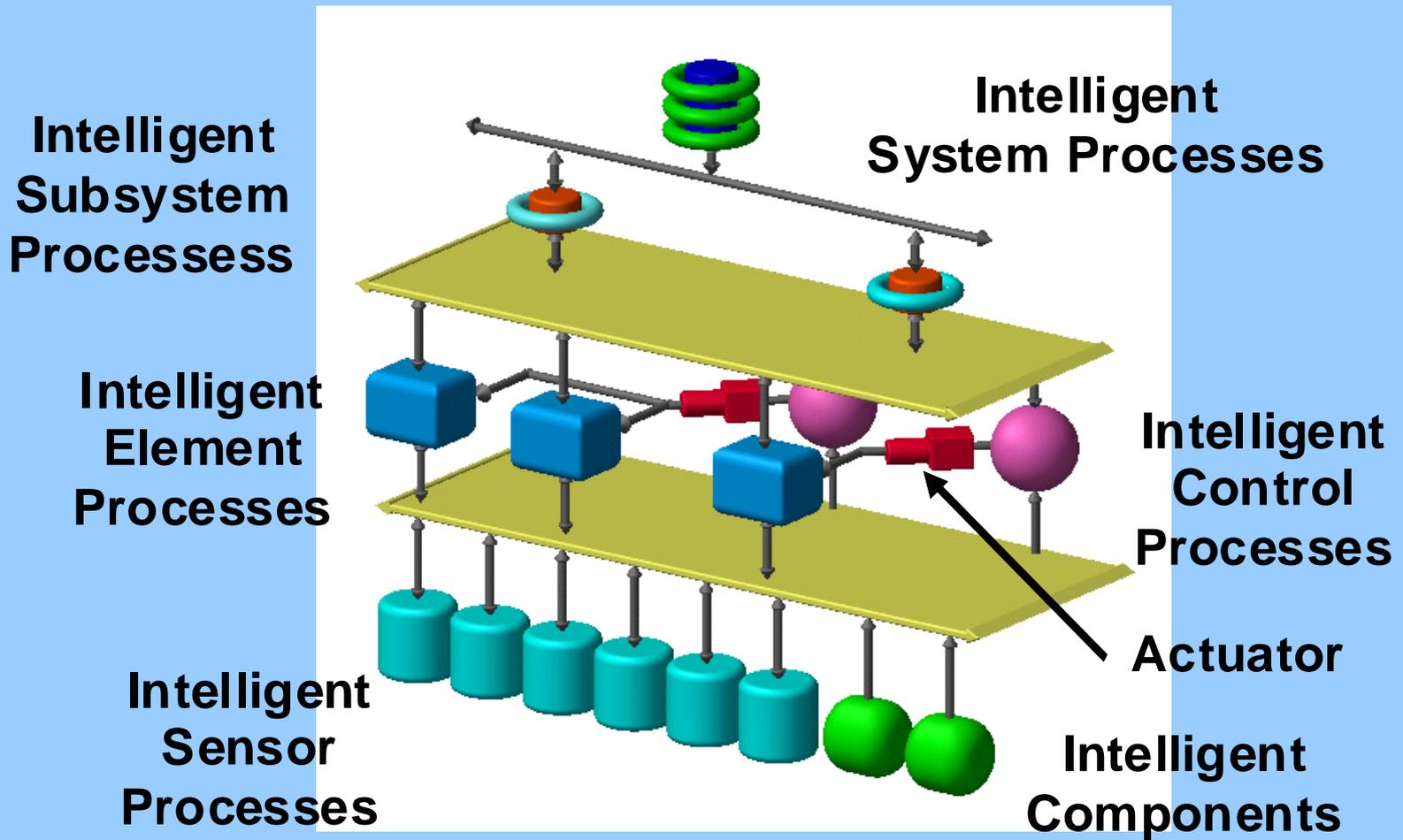
ISHM Capability Development

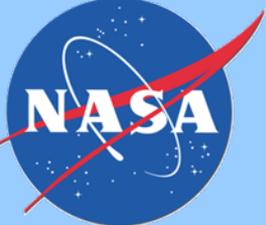
ISHM Knowledge Architecture

- DIaK in the ISHM-DM are associated with software objects that represent **process models** that take place in objects and/or collections of objects that encompass a system of interest.
- Process models are organized as objects in a hierarchical network (ISHM DIaK Architecture), to reflect levels of complexity as processes take place involving single elements, subsystems, or the entire system.
 - Local processes using local DIaK are at the bottom of the hierarchy.
 - Processes using increasing DIaK occupy higher levels in the network.

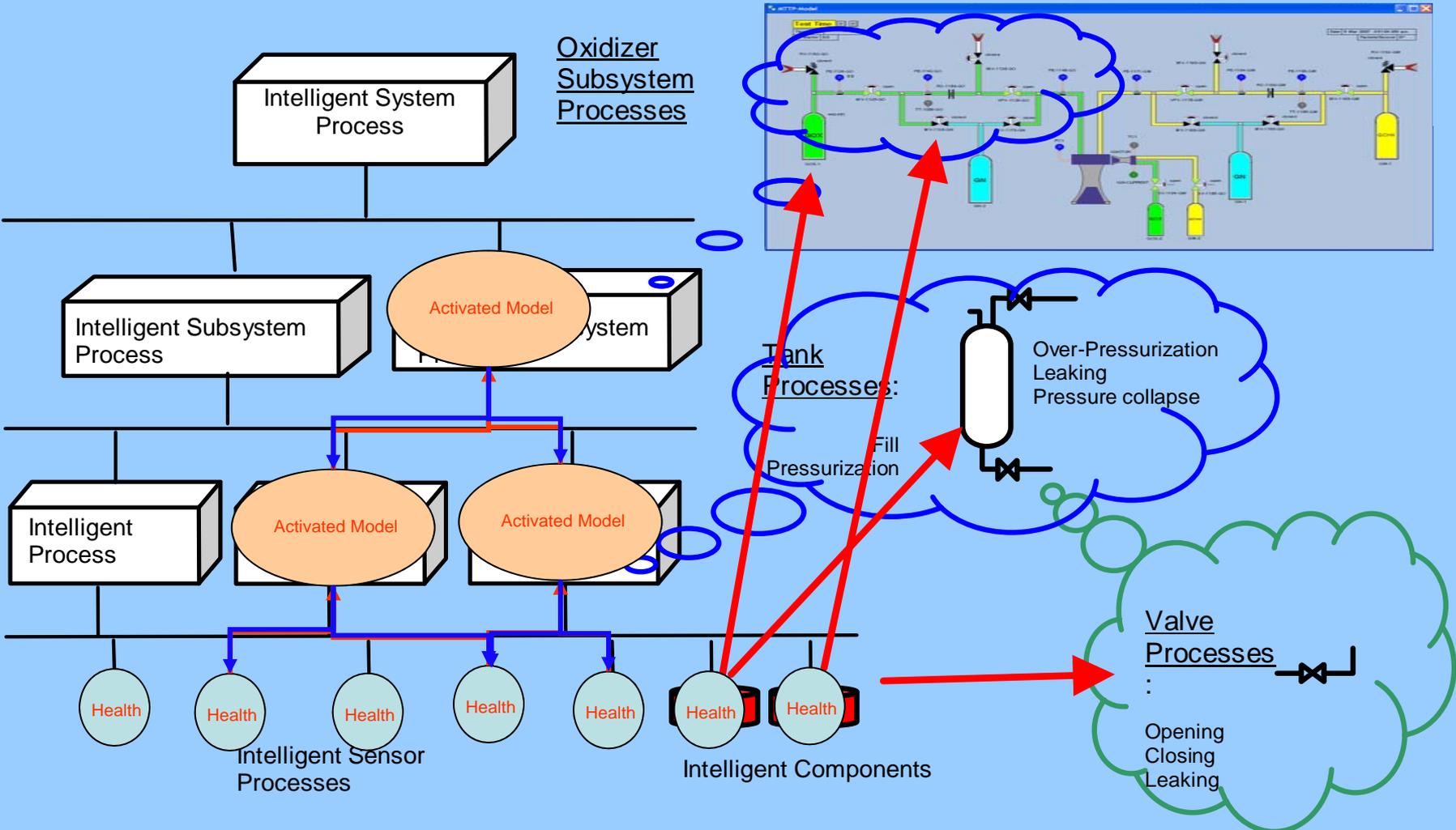


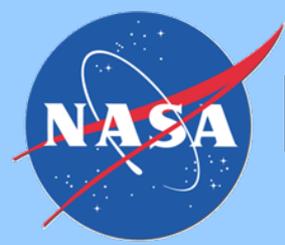
ISHM DiaK Architecture (DiaKA)





Detection and Confirmation of Anomalies Consistency Checking Cycle





ISHM Capability Development

Standards for ISHM

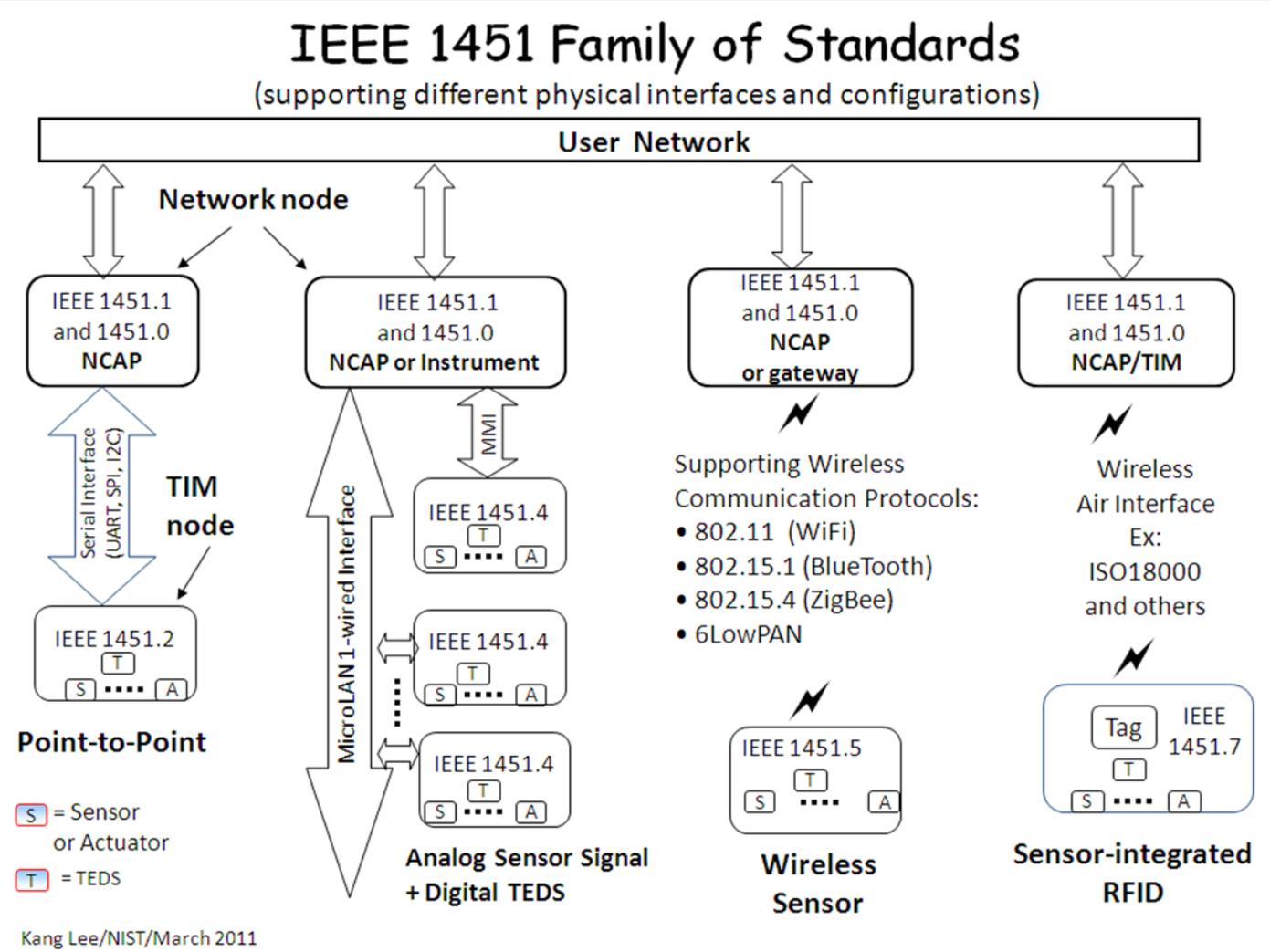
- IEEE 1451 Family of Standards for Smart Sensors and Actuators. Lead by NIST (Dr. Kang Lee).
- OSA-CBM (Open Systems Architecture for Condition Based Maintenance). Developed by industry and government, and transferred to the MIMOSA (Machine Information Management Open Standards Alliance) organization.
- OSA-EIA (Open Systems Architecture for Enterprise Application Integration). MIMOSA organization.

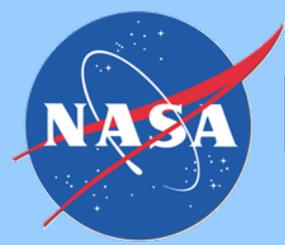
ISHM capability must integrate DiA across physical, virtual, and discipline boundaries. This is not possible in an affordable manner unless standards are used to achieve plug&play and interoperability.



ISHM Capability Development

Standards for ISHM



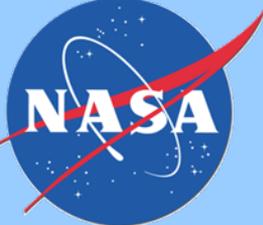


ISHM Capability Development

Standards for ISHM

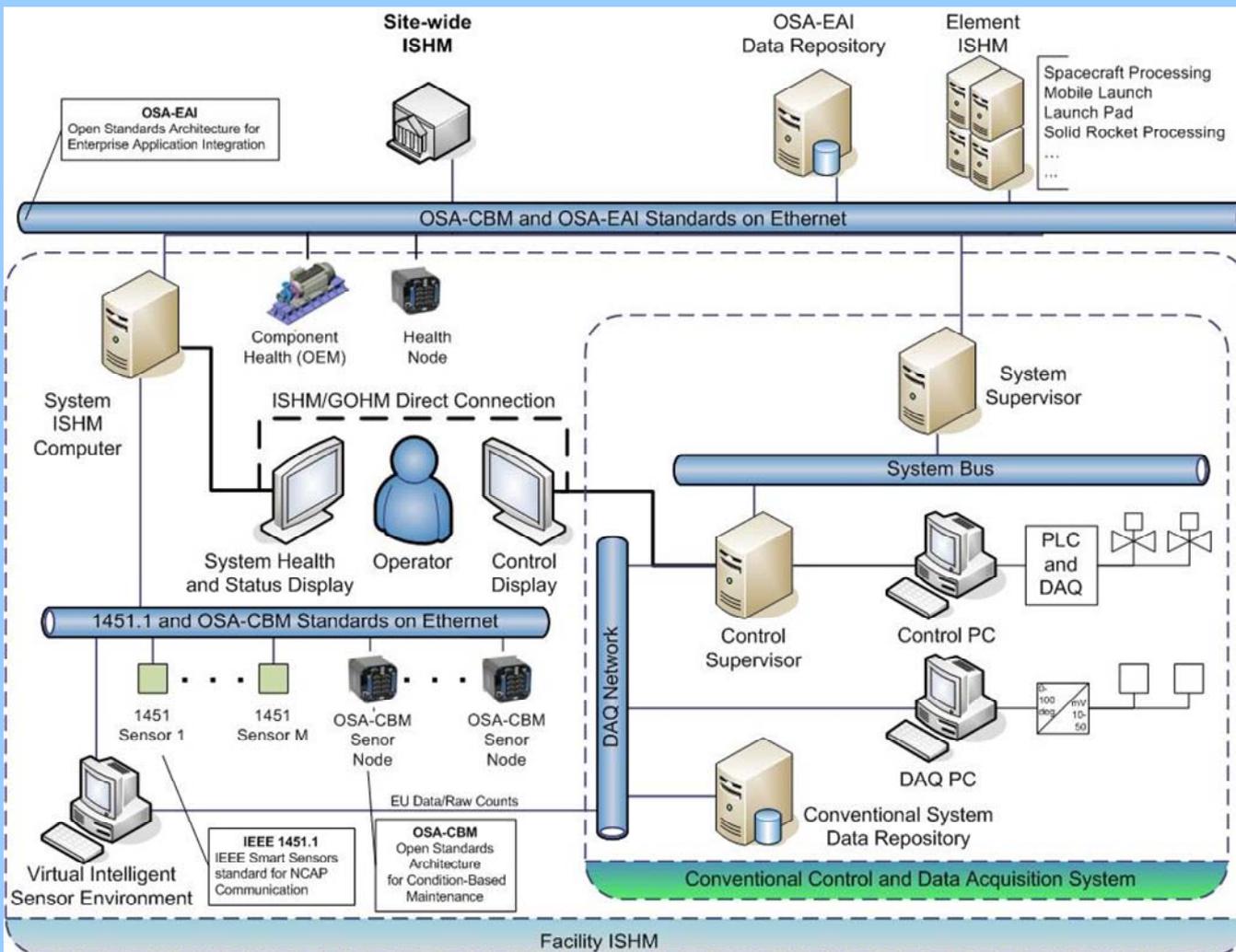
OSA-CBM (MIMOSA)



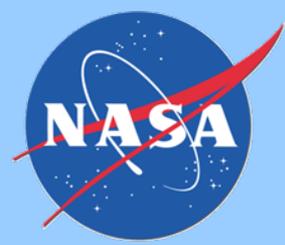


ISHM Capability Development

Standards for ISHM



Architecture for pilot ISHM system implemented at NASA Kennedy Space Center, Launch Complex 20 (LC-20) showing the use of IEEE 1451.1, OSA-CBM, and OSA-EAI standards



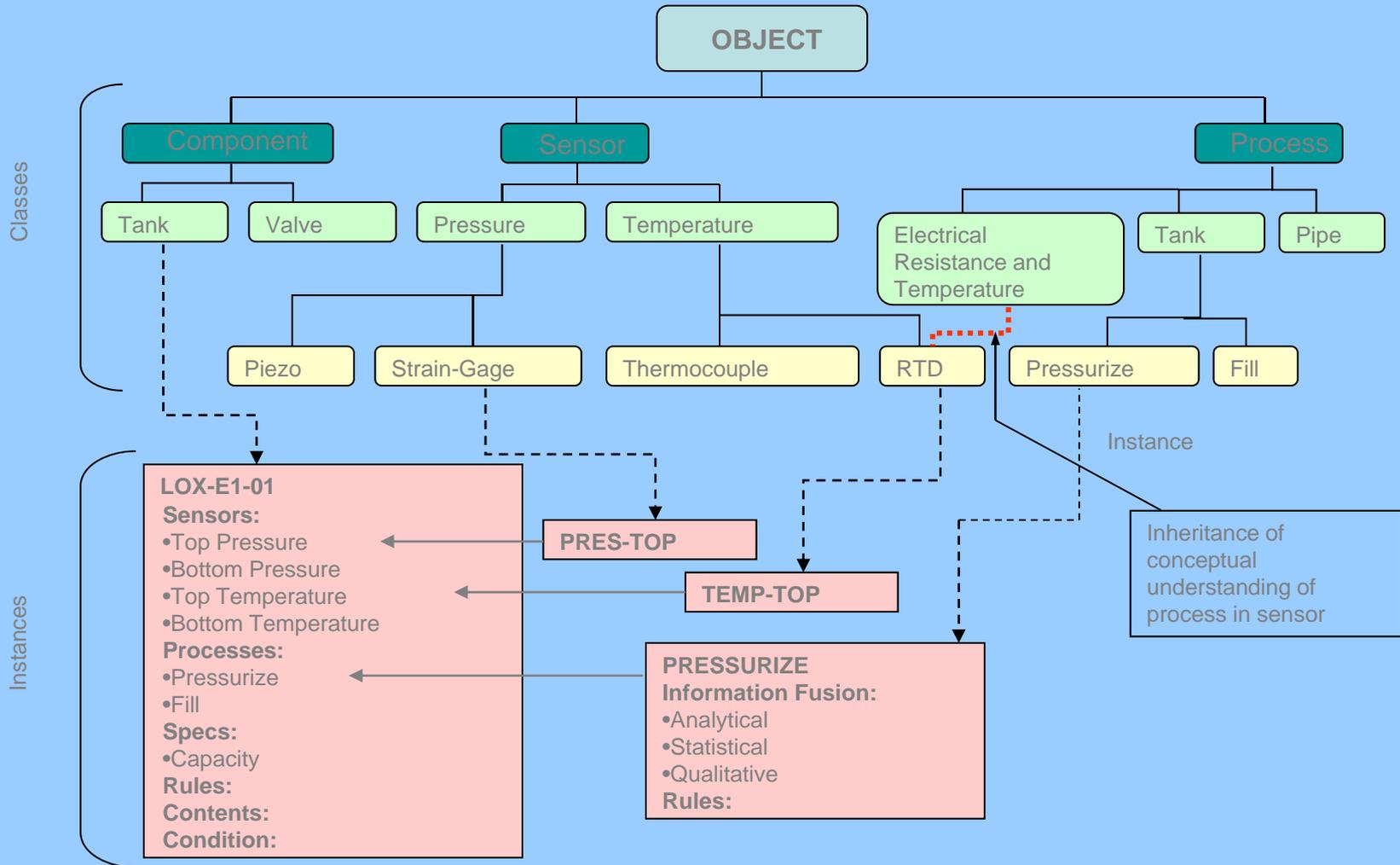
Software to develop ISHM Domain Models (ISHM-DM's)

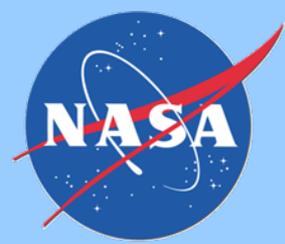
A software system for ISHM capability should support all core capabilities by integrating systematically DiaK through the ISHM-DM

- ***Object orientation***: object representation of system physical elements and associated process models is the best way to embed DiaK in a systematic and in an organized manner.
- ***Distribution of ISHM-DM's within and across networks***: ISHM-DM's might be distributed among processors connected to a network, simply because it is necessary to use parallel processing, and/or ISHM-DM's might be created by different people in various geographic locations



TAXONOMY/ONTOLOGY OF OBJECT ORIENTED IMPLEMENTATION

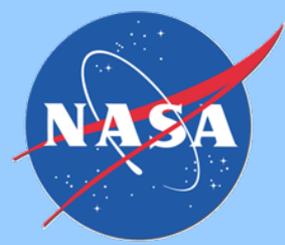




Software to develop ISHM Domain Models (ISHM-DM's)

A software system for ISHM capability should support all core capabilities by integrating systematically DIaK through the ISHM-DM

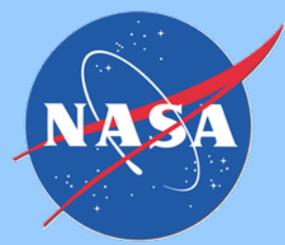
- ***Distribution across processing units:*** Since multiple process models are expected to be running at any given time, the software environments should support parallel processing.
- ***Inference engine:*** Many tasks require an inference engine. Reasoning and decision making leading to anomaly detection, diagnostics, effects, and prognostics; require contextual integrity and cause-effect analysis using heterogeneous data and information.



Software to develop ISHM Domain Models (ISHM-DM's)

A software system for ISHM capability should support all core capabilities by integrating systematically DLaK through the ISHM-DM

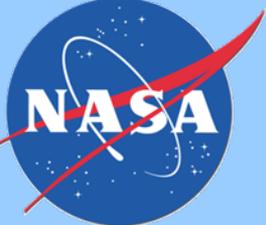
- ***Integrated management of distributed DLaK:*** DLaK must be managed in a way to allow embodiment of systems thinking across elements and subsystems. Often this is enabled by definitions of relationships among elements of systems that can be physically visible (i.e. attached to, belong to a system); or more abstracted relationships, as it relates to involvement by groups of objects in process models.
- ***Definition of dynamic relationships among objects for use in reasoning:*** Often, the framework for reasoning and application of process models changes dynamically with configuration changes, stages of operation, etc.



Software to develop ISHM Domain Models (ISHM-DM's)

A software system for ISHM capability should support all core capabilities by integrating systematically DLaK through the ISHM-DM

- ***Iconic representation of systems objects with visible and virtual links (relationships) used to provide intuitive representation of reasoning and context.*** The mix of object orientation and iconic representation of DLaK provides the ability to intuitively visualize interrelationships and dig deep into details of the ISHM system. As complexity increases, graphical programming and visualization become essential.



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 the STEAM-PLENUM and STEAM-DISCHARGE-PIPE. Various systems are highlighted: CSG LOX System (green), CSG Water System (light blue), CSG IPA System (yellow), and CSG GN System (dark blue). A central callout box labeled "Transducer Electronic Data Sheet Viewing Windows" points to these systems. On the left, a "Bluelines Active Monitors" callout points to the Bluelines list, and a "Redline Active Monitors" callout points to the Redlines list. At the bottom, two alarm queue windows are shown: "Blueline Alarm Queues" and "Redline Alarm Queues".

Bluelines Active Monitors

Redline Active Monitors

Blueline Alarm Queues

Redline Alarm Queues

Transducer Electronic Data Sheet Viewing Windows

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

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

EDS Explorer

By Component..

EDS List

- PE-14A4052-LO
 - TEDS
 - Basic TEDS
 - Bridge Sensor

EDS Attributes

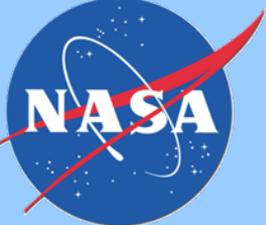
Attribute	Value
Bridge Element Impedance (Ω)	351
Bridge Type	Full
Calibration Date	2009-04-21
Calibration Period	365
Calibrator's Initials	CA
Electronic Datasheet Name	Bridge Sensor
Full Scale Electrical Value Precision	mV/V
IEEE 1451.4 Template ID	33
Mapping Method	Linear
Maximum Electrical Output (V/V)	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

BLUELINE-ALARM-QUEUE

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

REDLINE-ALARM-QUEUE

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

Telewindows Client

File Edit View Layout Go Project Workspace Tools Window Help

Enter Test Parameters (RIG 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

Low: 525.0

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

Blueline Configuration

PE-14A4183-GN
Last Reading Gathered: 585.691
1st STAGE GOX PURGE PRESSURE

Low: 525.0

High Blueline Parameters

Enabled	Settings	Description
<input type="checkbox"/>	0 psi	1st STAGE GOX PURGE PRESSURE

Low Blueline Parameters

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

Blueline Details and Configuration User Interfaces

Redlines

- FDE-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

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: 1.816

Low: 40.0

Maximum Redline Parameters

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

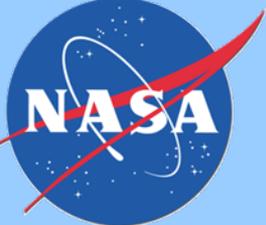
Minimum Redline Parameters

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

Redline Details and Configuration User Interfaces

EDS Explorer
EDS Attributes

BLUELINE-ALARM-QUEUE
REDLINE-ALARM-QUEUE



CSG ISHM Domain Model: Redline Event Handling

The screenshot displays the Telewindows Client interface with several key components:

- Bluelines Panel:** Lists various system parameters such as PT-14A31-GN, PE-14A2435-HD, and TC-14A4046-LO.
- Redlines Panel:** Lists active redlines including PDE-14A4086-S, TT-14A16-LO, and PE-14A4117-IPA.
- G2 Redlines Anomaly Report:** A detailed report for sensor PE-14A4117-IPA. It includes:
 - Redline Anomaly Details:**

Sensor Name	PE-14A4117-IPA
Event Type	EXCEEDED
Main Threshold Limit	210.0 psi
Event Time	2009/06/16 12:33:56.967 p.m.
Event Time to TO	2.084
Alarm Time	2.0
Drain Time	14.0
Condition	Loss of IPA Main Stage Interface Pressure
Test Name	0911_021A_9167_CSGT
Test TO Time	2009/06/16 12:33:54.883 p.m.
Auto-sequence Start Time	-37.0
Auto-sequence End Time	14.0
 - Graph:** A pressure (psi) vs. Time (p.m.) plot showing the pressure rising to a peak of approximately 200 psi before dropping sharply. A red vertical line marks the event at 12:33:56.967 p.m. with a duration of 2.084 seconds.
- CSG Unit #1 Diagram:** A schematic of the system showing the 2nd Stage and Main Stage. A red arrow points from the 'EXCEEDED' event in the report to the corresponding transducer (PE-14A4117-IPA) in the diagram.
- Alarm Queues:** Two panels at the bottom show the BLUELINE-ALARM-QUEUE and REDLINE-ALARM-QUEUE. The REDLINE-ALARM-QUEUE entry for PE-14A4117-IPA is highlighted, with a red arrow pointing to it from a callout box.

Auto-generated
Redline Report

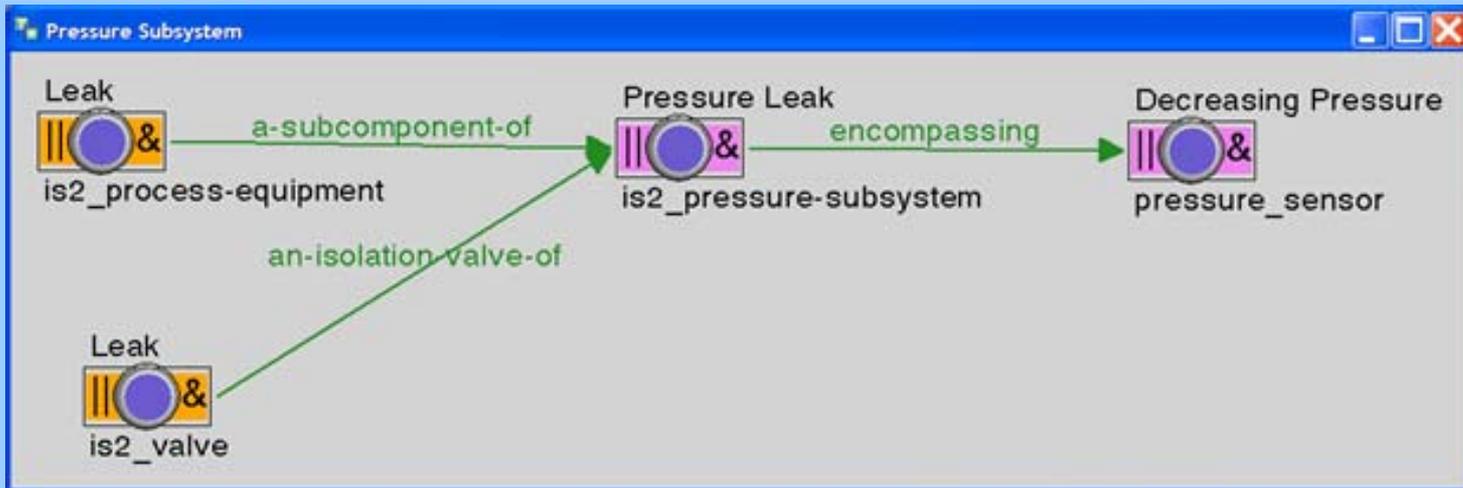
Navigation to Transducer
Where Redline Event Occurred

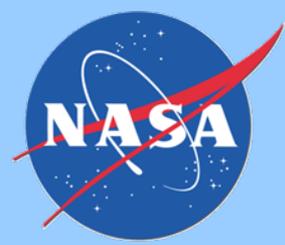


Failures Modes and Effects Analysis (FMEA)

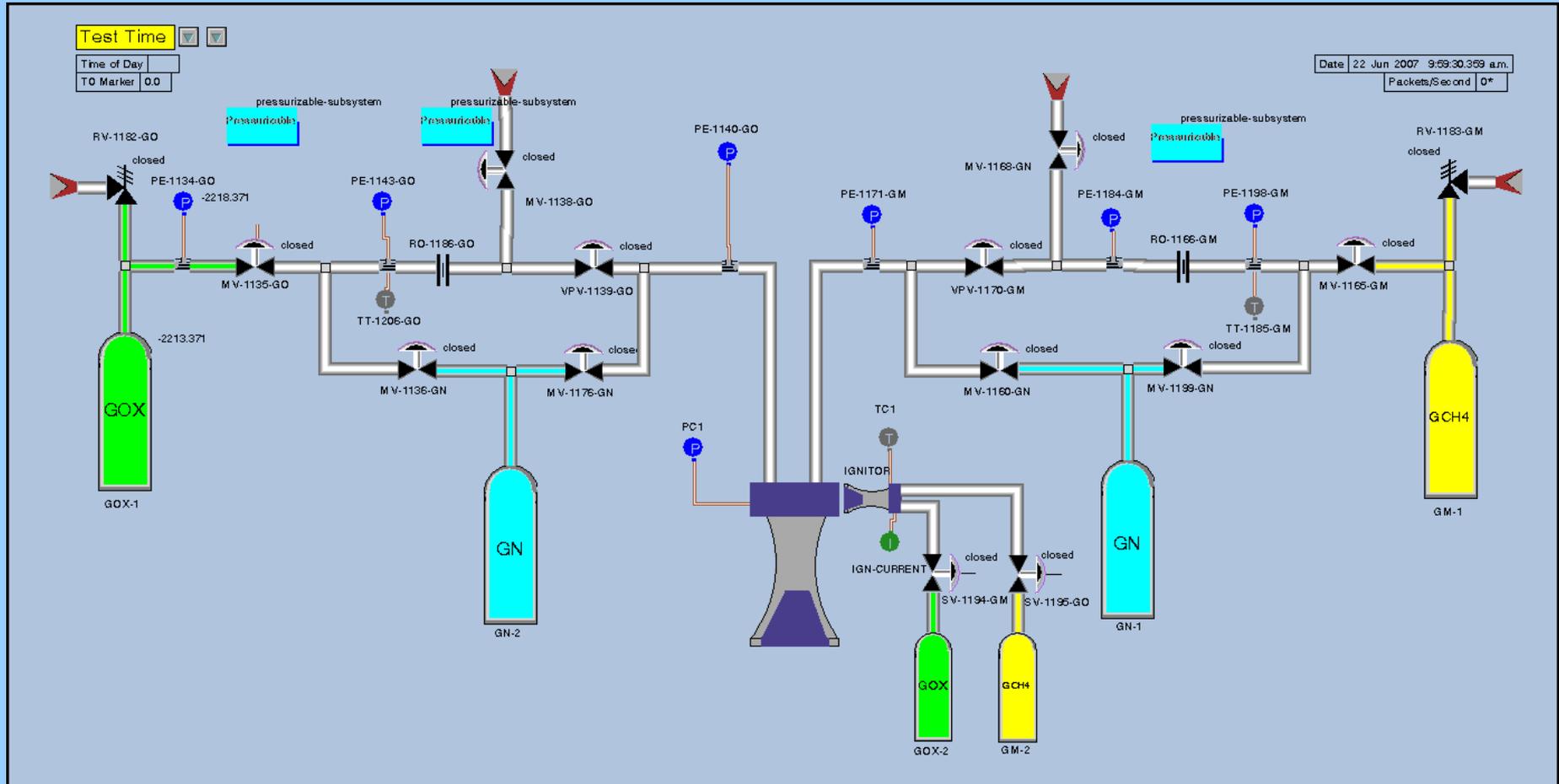
MIL-STD-1629A(2) NOT 3

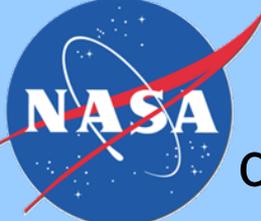
ID #	Item-Functional Identification	Function	Failure Modes and Causes	Mission Phase-Operational Mode	Failure Effects		Failure Detection Method
					Local End Effects	Next Higher Level	
	Process Equipment	Fluid feed subsystem	Leak	Sealed subsystem maintaining pressure	Pressure leak	Decreasing pressure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



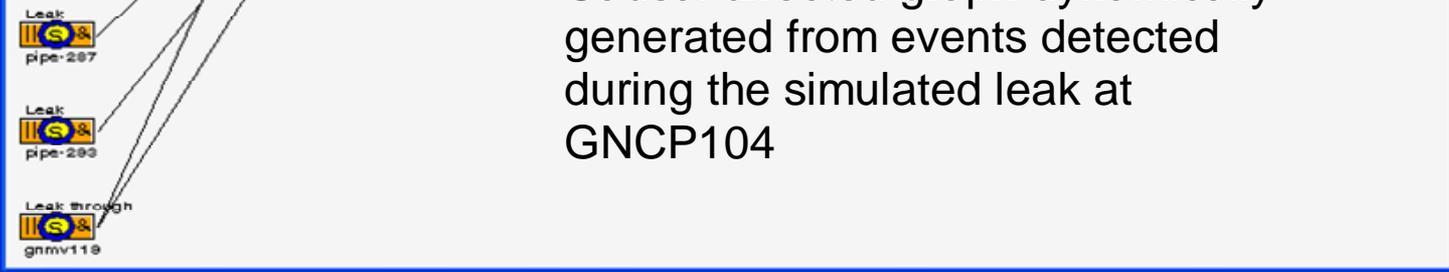
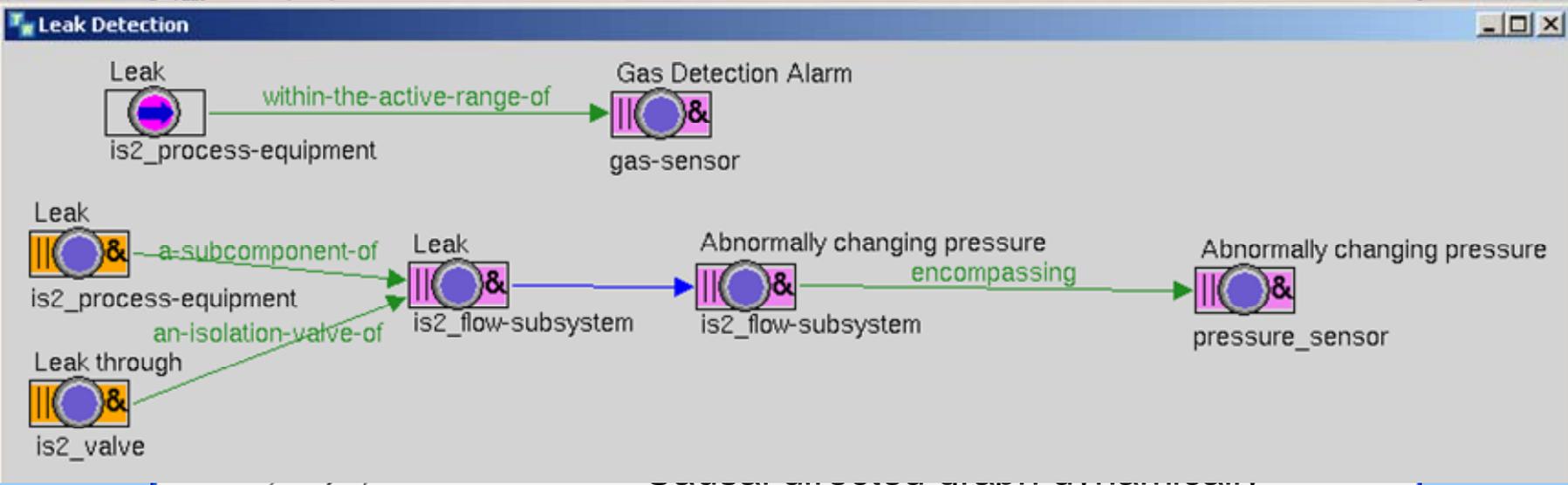
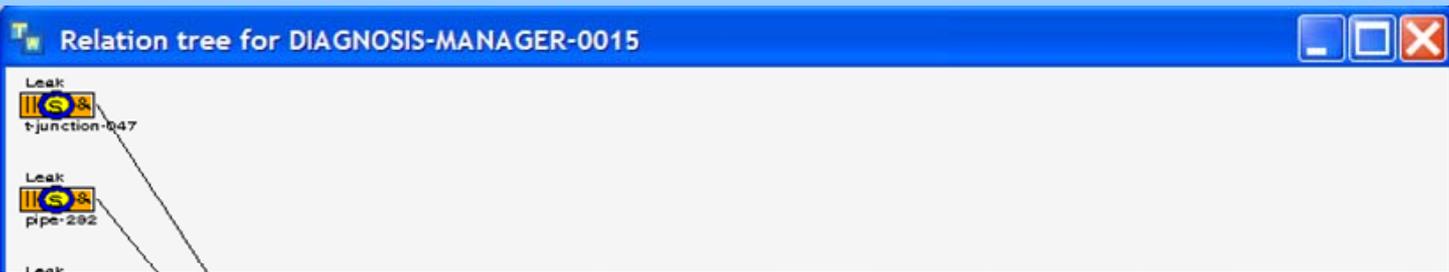


Elements of an ISHM System: ISHM Model - Proximate Cause Analysis

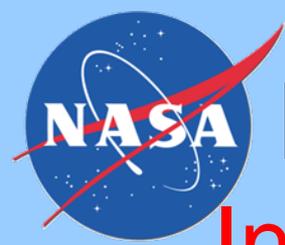




Expanded causal-directed graph generated by the detection of a leak in the subsystem where a valve was opened manually (injected leak)



generated from events detected during the simulated leak at GNCP104



ISHM Capability Development

Intelligent Sensors and Components

Smart Sensor/Actuator (NIST)

*“The IEEE (Institute of Electrical and Electronics Engineers) 1451 smart transducer interface standards provide the common interface and **enabling technology for the connectivity of transducers to microprocessors, control and field networks, and data acquisition and instrumentation systems**. The standardized TEDS specified by IEEE 1451.2 allows the **self-description** of sensors and the interfaces provide a **standardized mechanism to facilitate the plug and play of sensors to networks**. The network-independent smart transducer object model defined by IEEE 1451.1 allows sensor manufacturers to support multiple networks and protocols. Thus, **transducer-to-network interoperability** is on the horizon. The inclusion of P1451.3 and P1451.4 to the family of 1451 standards will meet the needs of the analog transducer users for high-speed applications. In the long run, transducer vendors and users, system integrators and network providers can all benefit from the IEEE 1451 interface standards [1].”*

“Intelligent Sensor” is a “Smart Sensor” with the ability to provide the following functionality: (1) measurement, (2) measure of the quality of the measurement, and (3) measure of the “health” of the sensor. The better the sensor provides functionalities 2 and 3, the more intelligent it is.



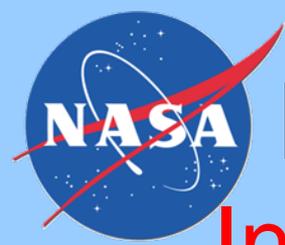
ISHM Capability Development

Intelligent Sensors and Components

Typical Process Models for Sensors

- Noise Level Assessment and History
- Spike Detection and History
- Flat Signal Detection and History
- Response Time Characterization
- Intermittency Characterization and History
- Physical Detachment Characterization and History
- Regime Characterization and History
- Curve Fit on Identified Regimes

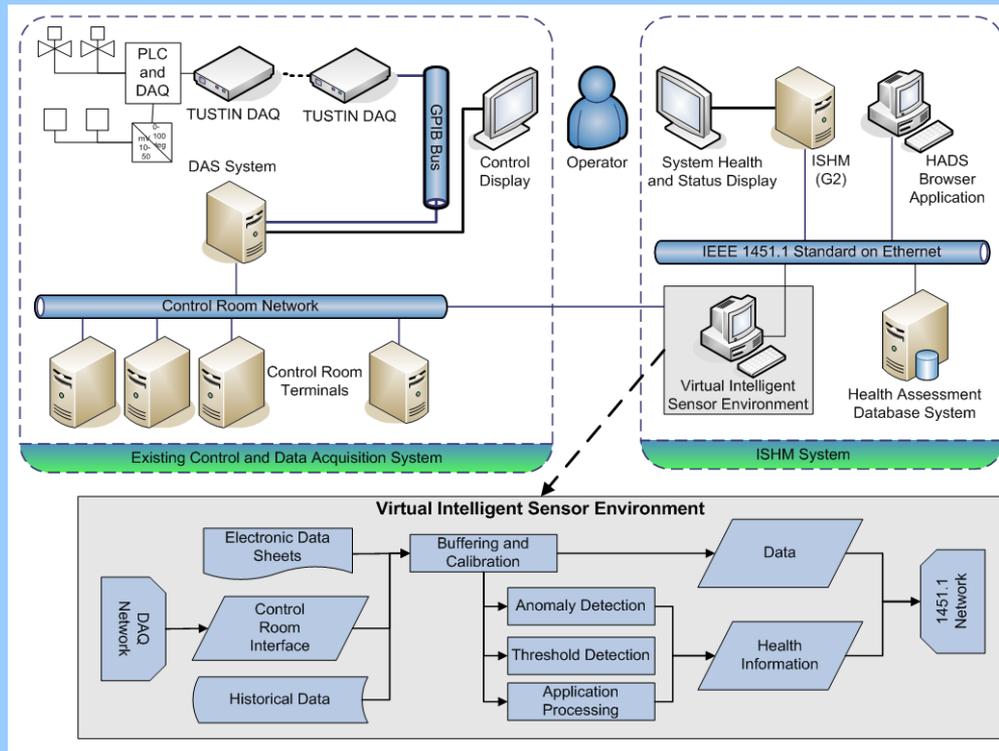
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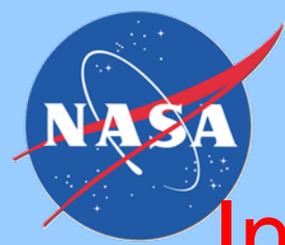
ISHM Capability Development

Intelligent Sensors and Components

Example Intelligent Sensor Implementations



The Virtual Intelligent Sensor Environment (VISE) converts all classic sensors installed in a rocket engine test stand into “intelligent sensors.”



ISHM Capability Development

Intelligent Sensors and Components

Example Intelligent Sensor Implementations



Mobitrum

www.mobitrum.com



Smart Sensor Systems

www.smartsensorsystems.com



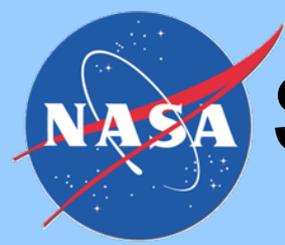
NIST

www.mel.nist.com



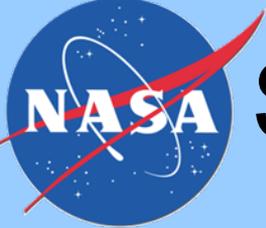
Esensors

www.eesensors.com



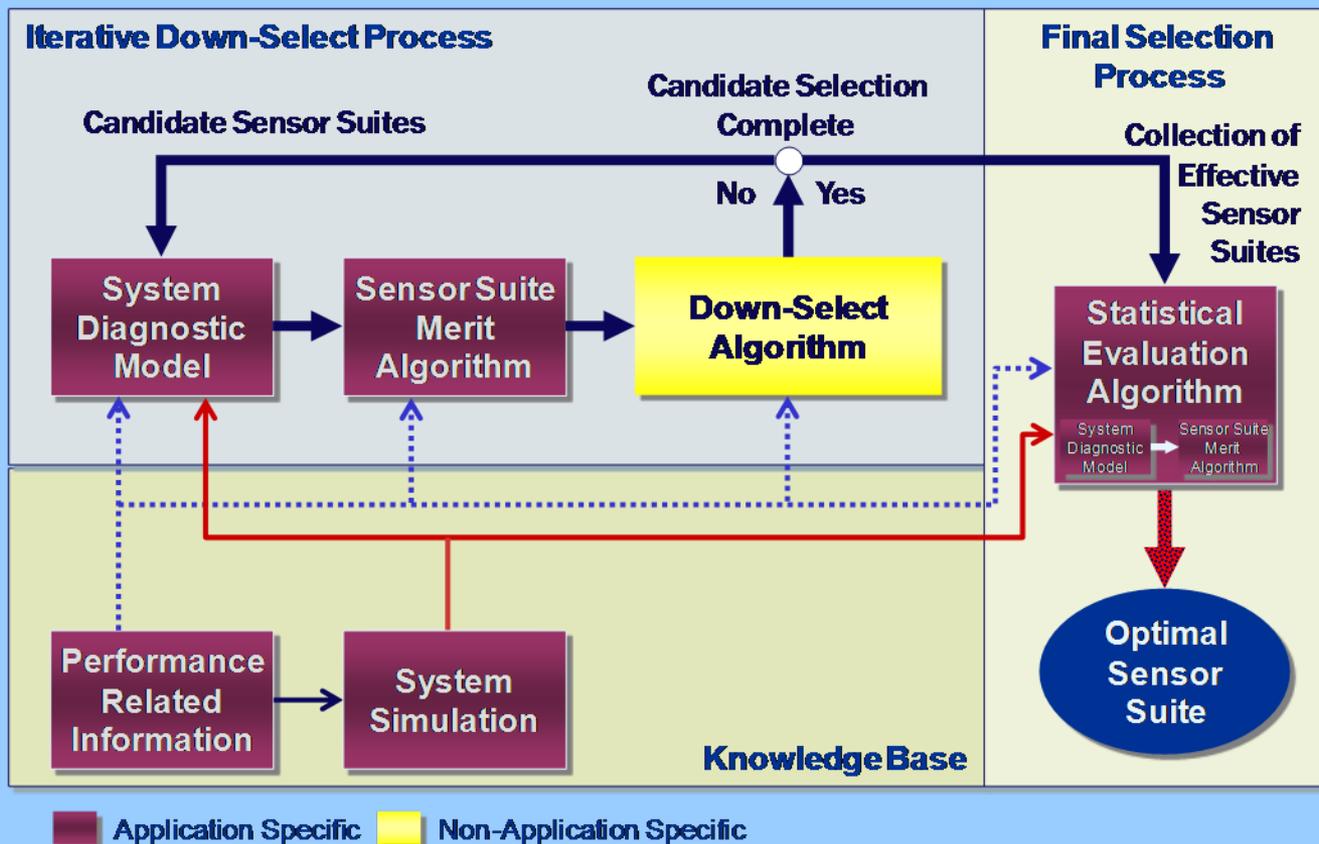
Sensor selection and Placement for ISHM

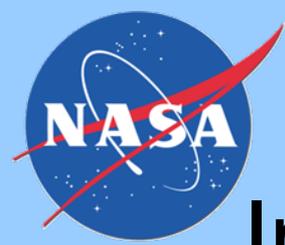
- When developing an ISHM capability from the ground up, one must optimize sensor suites to achieve maximum functional capability (anomaly detection, diagnosis, effects, prognostics).



Sensor selection and Placement for ISHM

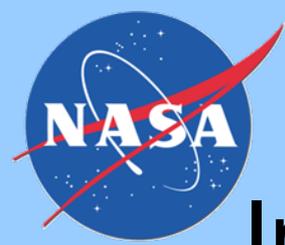
Systematic Sensor Selection Strategy (S4) is a model-based procedure for systematically and quantitatively identifying the sensor compliment that optimally achieves the health assessment goals of a system (Reference 14 of the paper).



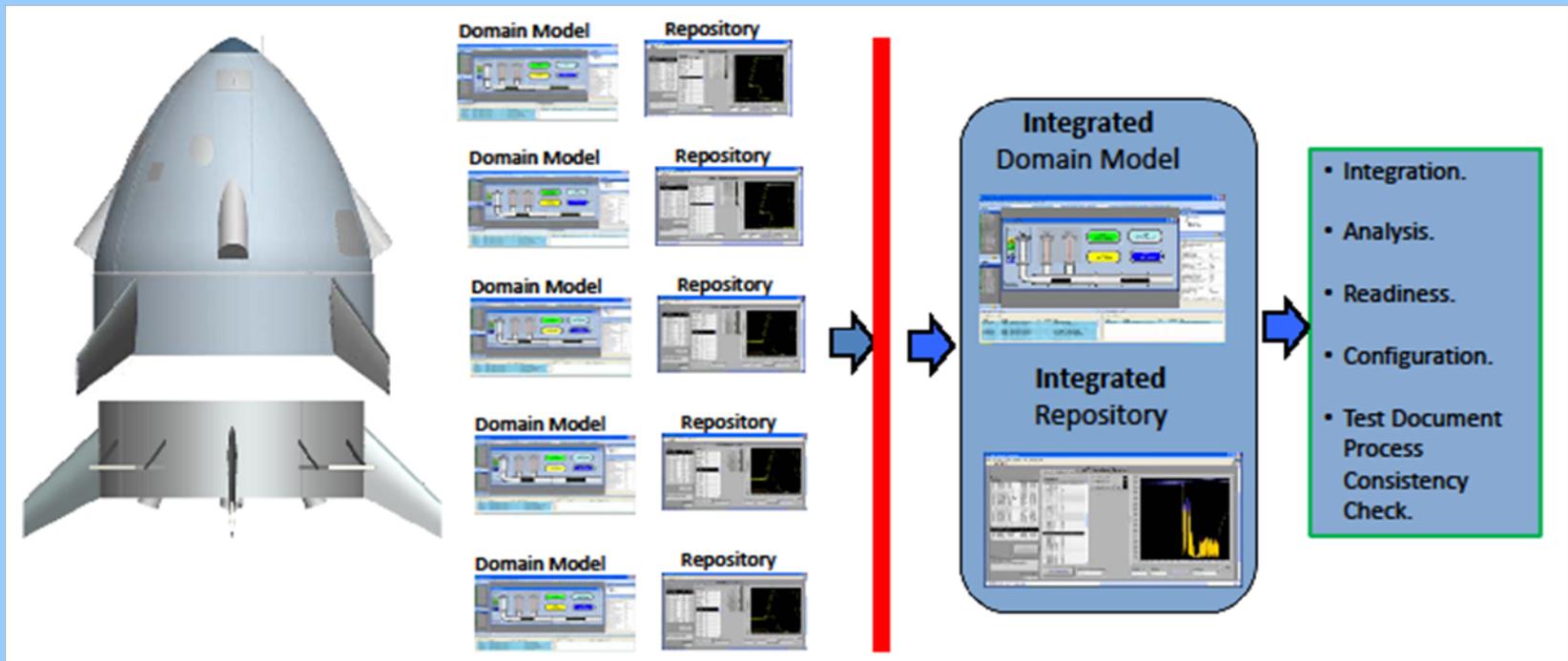


ISHM in Systems Design, Integration, and Engineering (SDI&E)

- SDI&E practices are employed to build complex systems.
- SDI&E for aerospace systems has developed into its own discipline, although theories and concepts have not been adequately formalized in an academic sense.
- The role of ISHM in SDI&E is linked to the concept of ISHM-DM's, whereby every element that is part of a system comes with its own ISHM-DM that can be rolled-up into an overall system ISHM-DM in a plug&play approach.
- When two elements are assembled, the ISHM-DM of each element is incorporated into the ISHM-DM of the assembly. In this manner, DIaK compartmentalized in each element becomes immediately available and useful to the ISHM-DM of the assembly.



ISHM in Systems Design, Integration, and Engineering (SDI&E)



ISHM concept for systems integration of ISHM-DM's



Intelligent Control for ISHM-Enabled Systems

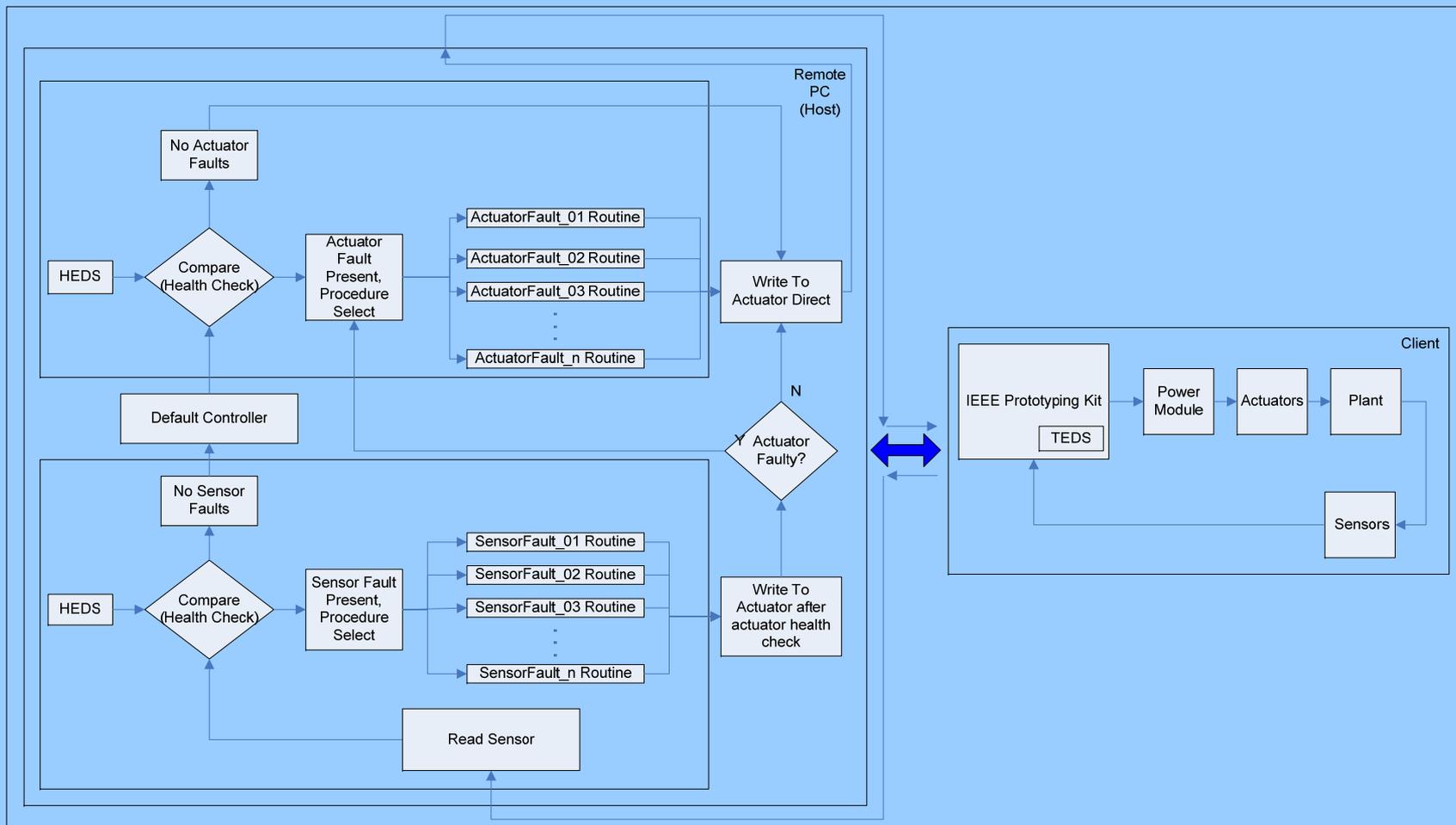
- Control of complex systems that are ISHM-enabled is a nascent area, simply because ISHM itself is also relatively new.
- The objective is for the control function to make use of system health information in order to achieve its objectives.

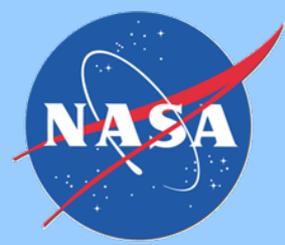
The paradigm implies that control systems become users of health information, while at the same time making use of actuators to help further improve determination of the system health



Intelligent Control for ISHM-Enabled Systems

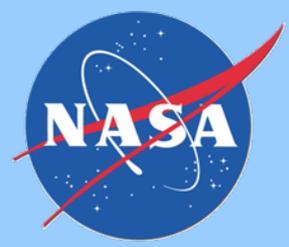
Example Application (Reference 18 of the paper)





Verification and Validation Considerations for ISHM

The need to use knowledge, and hence inference engines; and the complexities of parallel processing and reconciliation of potentially inconsistent outcomes that lead to anomaly determination; requires advances in verification and validation of the ISHM capability itself

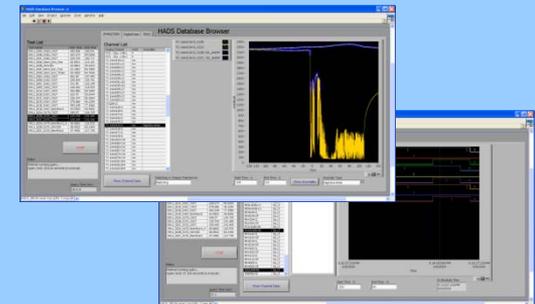
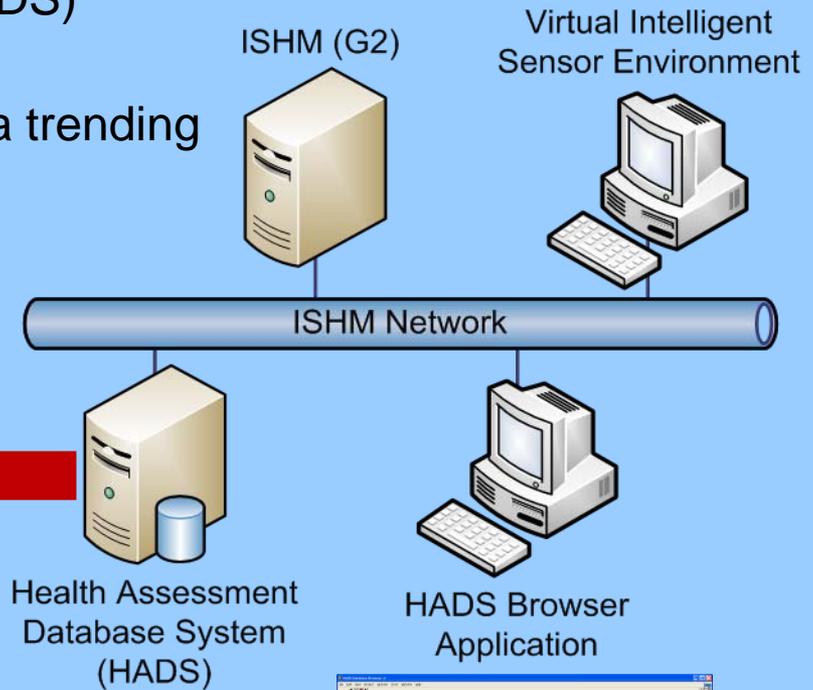
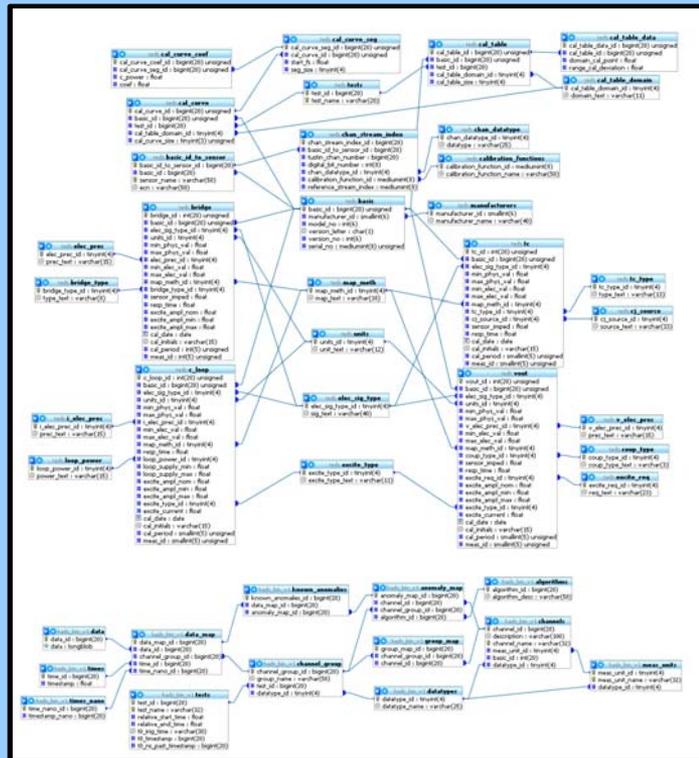


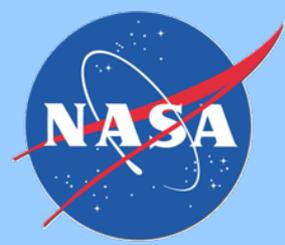
Backup Slides



Health Assessment Database System HADS

- Health Electronic Data Sheets (HEDS)
- Repository of anomalies and algorithms
- Transducer Electronic Data Sheets (TEDS)
- Historical test data and analysis results
- Provides ease of data analysis and data trending





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 List

Test Name	Start Time	End Time
0911_0194_9160_CSGT	-305.650	100.541
0911_0196_9160_CSGT	-362.674	99.5208
0911_0197_9160_CSGT	-225.070	100.717
4911_0194_Norm_Run_One	+20.0521	114.141
4911_0196_ADV250	+18.9601	+8.2323
4911_0197_Norm_Run_Two	+21.1961	84.7965
4911_0190_Norm_Run_Three	+29.4202	84.7646
0911_020A_9162_CSGT	+302.99	107.405
0911_020B_9162_CSGT	+239.294	134.701
0911_020C_9162_CSGT	+311.05	122.145
0911_020D_9162_CSGT	+246.462	119.533
0911_021A_9167_CSGT	+304.866	69.3285
0911_021B_9167_CSGT	+223.75	52.6444
0911_021C_9167_CSGT	+226.074	56.9204
0911_021D_9167_CSGT	+278.066	46.1294
0911_021E_9167_CSGT	+393.239	77.1566
4911_021D_9167_NormRun3	+43.5923	40.4002
0911_022A_9170_CSGT	+345.07	134.725
0911_022B_9170_CSGT	+135.709	151.485
0911_022C_9170_CSGT	+329.445	141.949
4911_022A_9170_NormRun1_0	+36.6602	122.533
4911_022B_9170_ADV250	+38.0522	60.1404
4911_022C_9170_NormRun2	+37.4482	117.745

Channel

- PE-14A4109-IPA
- PE-14A4117-IPA
- PE-14A4102-ON
- PE-14A4101-ON
- PE-14A4190-ON
- PE-14A4189-ON
- PE-14A4025-OO
- PE-14A4010-L
- PCE-14A4273-IPA
- PE-14A4047-L
- PE-14A4026-OO
- PE-14A4032-OO**
- PE-14A4044-L
- PE-14A4052-L
- PE-14A4034-OO
- PE-14A4185-ON
- PE-14A4184-ON
- PE-14A4183-ON
- PE-14A4131-S
- PE-14A4133-S
- PE-14A4135-S
- PE-14A4127-S
- PE-14A4172-S
- PE-14A4141-S
- PE-14A4140-S
- PDE-14A4086-S
- PE-14A4262-L
- PE-14A4119-IPA
- PE-14A4075-CW
- PE-14A4090-IPA
- PE-14A4201-IPA
- PDE-14A2030-IPA
- ISVI-CURA

TEDS Field

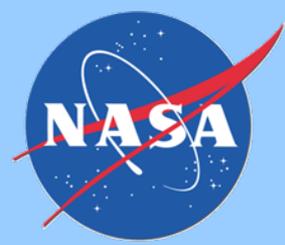
TEDS Field	TEDS Value
BASIC TEDS	
Manufacturer Name	Stellar Technology
Model Number	2000
Version Letter	G
Version Number	121
Serial Number	966546
BRIDGE TEDS	
Transducer Electrical Signal Type	Bridge Sensor
Physical Measurement	psi
Minimum Physical Value	0
Maximum Physical Value	2000
Full Scale Electrical Value Precision	mV/V
Minimum Electrical Output	0.007
Maximum Electrical Output	3.022
Mapping Method	Linear
Bridge Type	Full
Bridge Element Impedance	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

Status

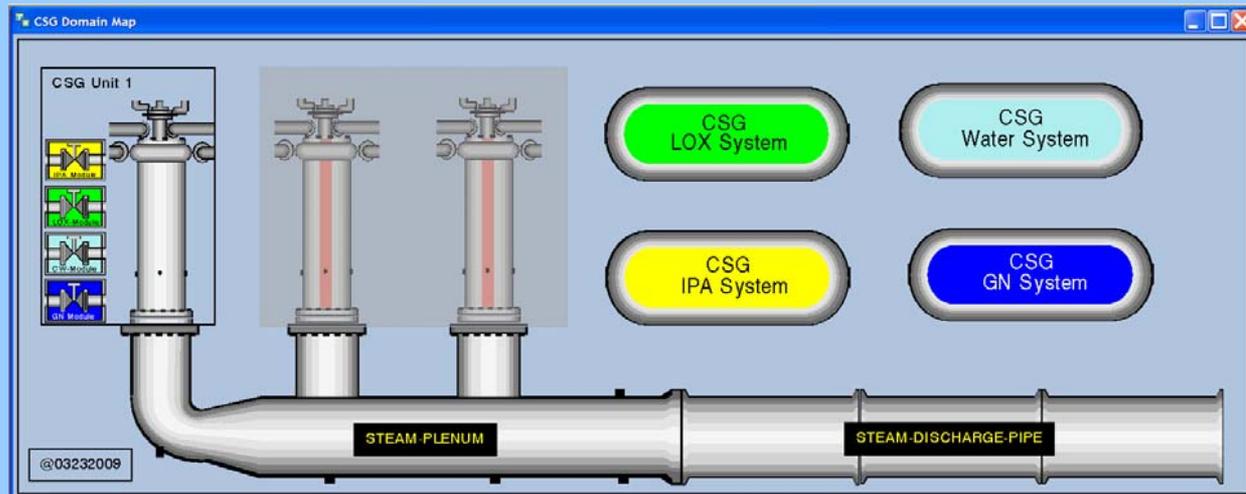
Finished running query...
Query took 37.100 seconds to execute.

Query Time (sec)
37.1

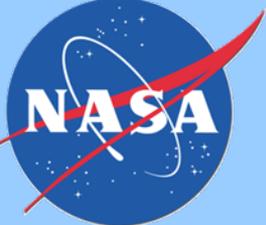
Digit Data - Tests on multiple channels



CSG ISHM Domain Model: Top Layer View



ISHM Domain
Model
Top Layer



CSG ISHM Domain Model: Transducer Data Plots

Telewindows Client

File Edit View Layout Go Project Workspace Tools Window Help

Enter Test Parameters (IRIG 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

Redlines

- FDE-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

CSG 1 IPA Interface Module

IPA Primary Distribution Module

Streaming data plots from selected sensors

PE-14A4044-LO Real-Time Plot of PE-14A4044-LO

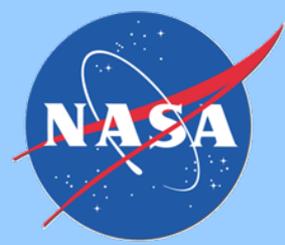
TC-14A4053-LO Real-Time Plot of TC-14A4053-LO

PE-14A4117-IPA Real-Time Plot of PE-14A4117-IPA

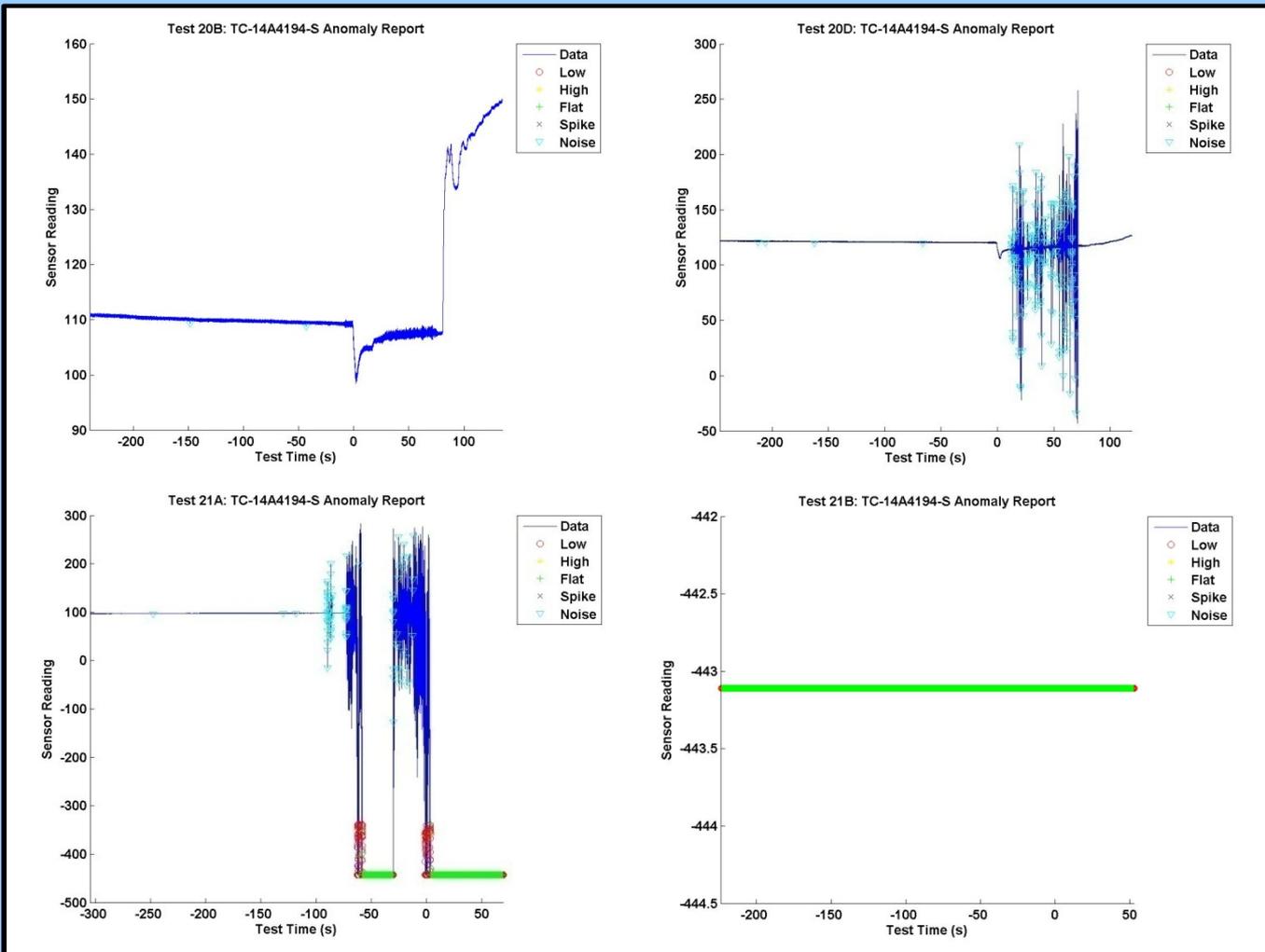
TC-14A4108-IPA Real-Time Plot of TC-14A4108-IPA

BLUELINE-ALARM-QUEUE REDLINE-ALARM-QUEUE

EDS Explorer EDS Attributes

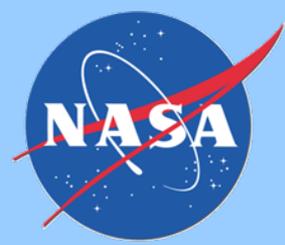


CSG Anomalies Detected



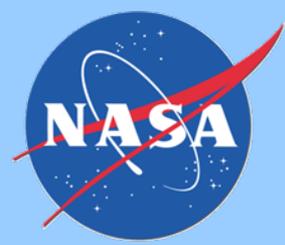
- Evidence of TC degradation detected by VISE anomaly detection
- Advanced notification to determine the health of the whole system before beginning a test

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

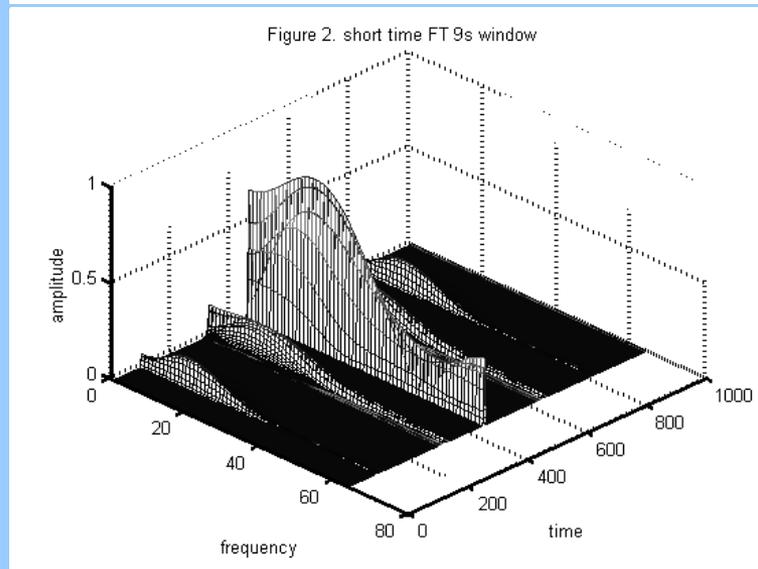
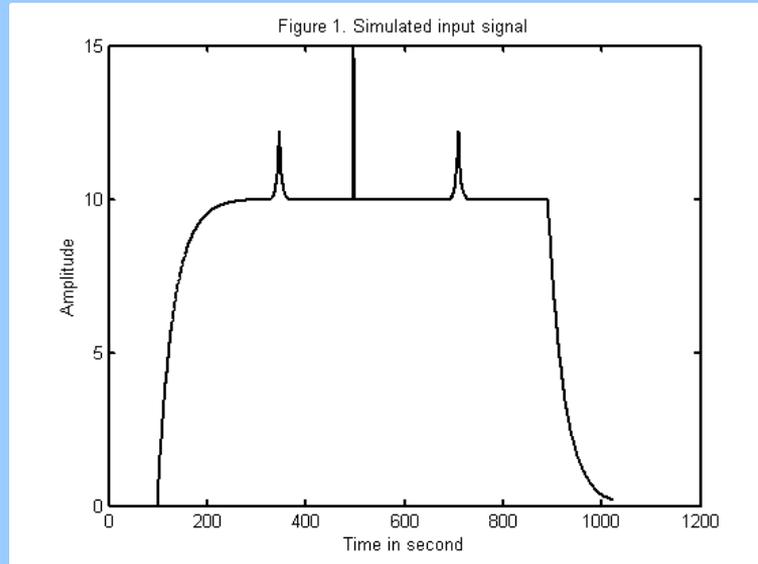


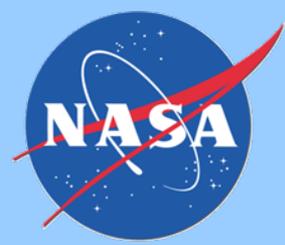
List of Anomaly Detection Capabilities

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.



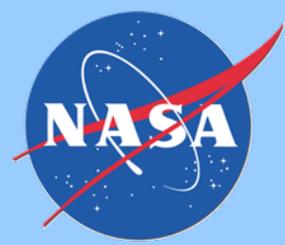
Short-Time Fourier Transform Segmentation



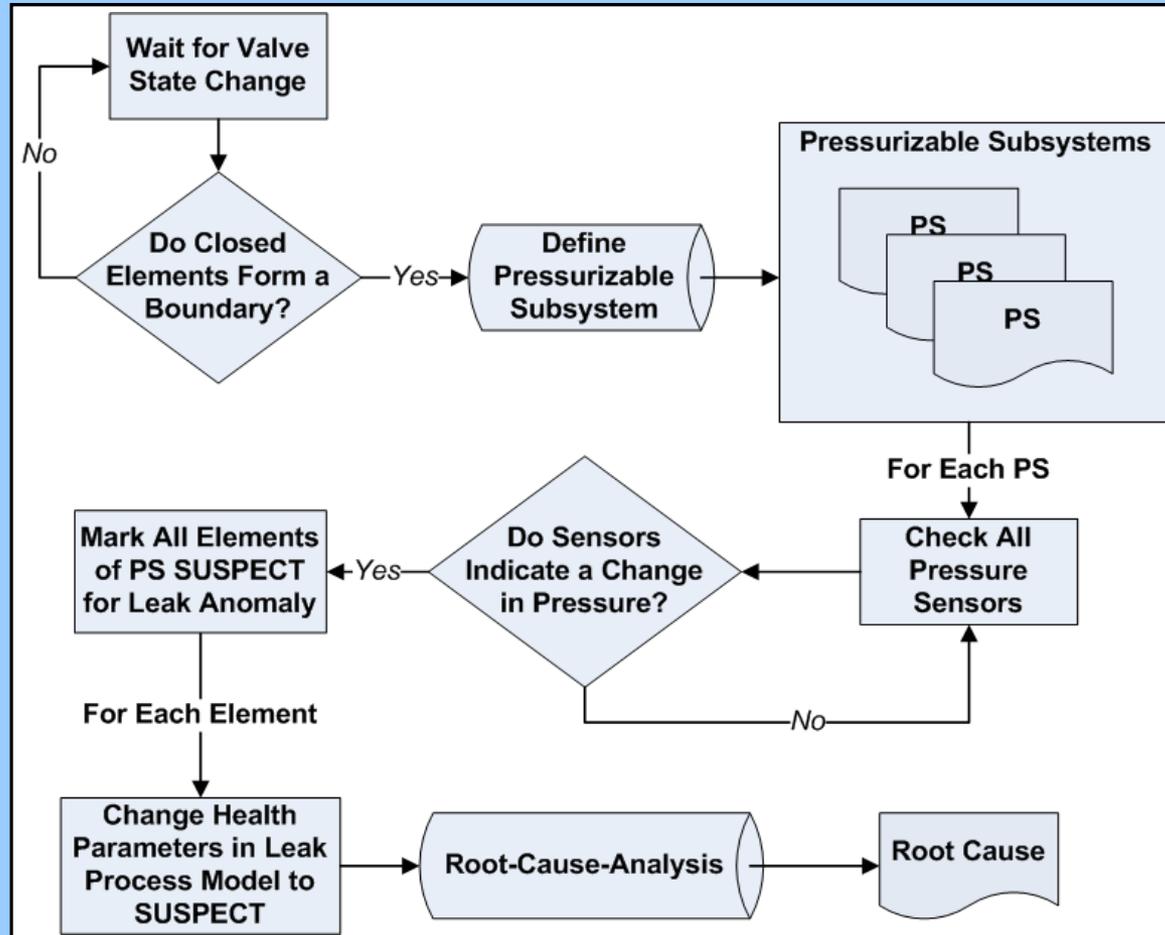


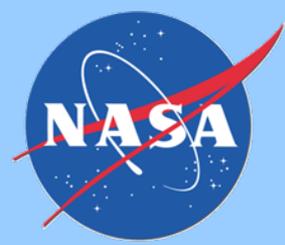
Determining Valve-State

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				

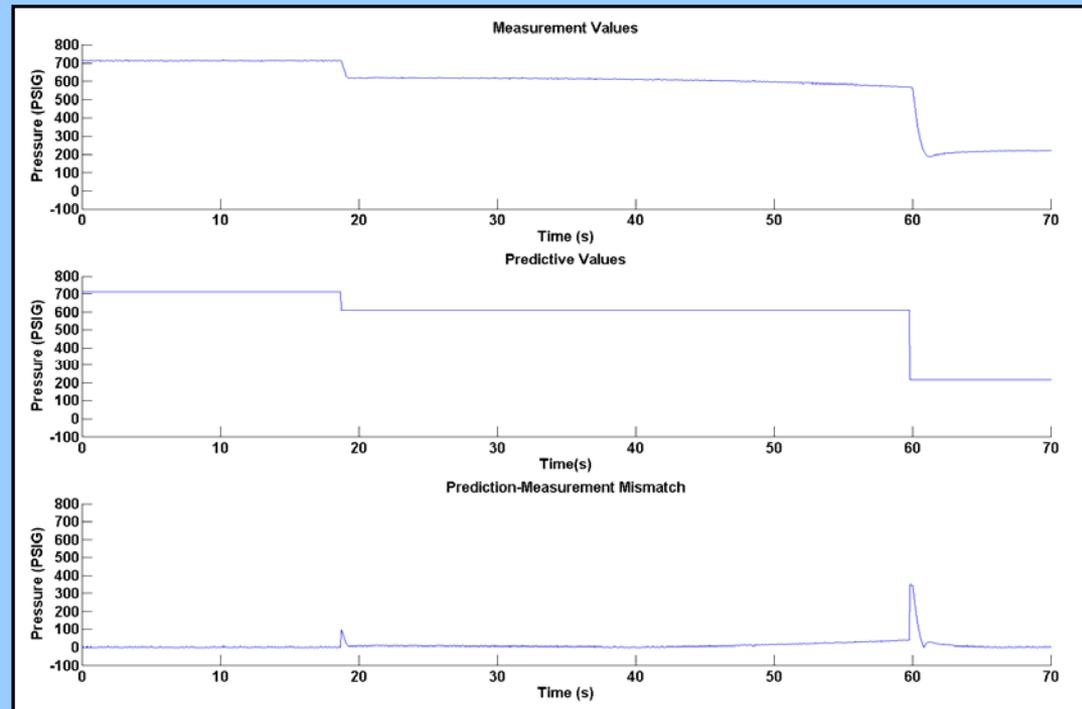
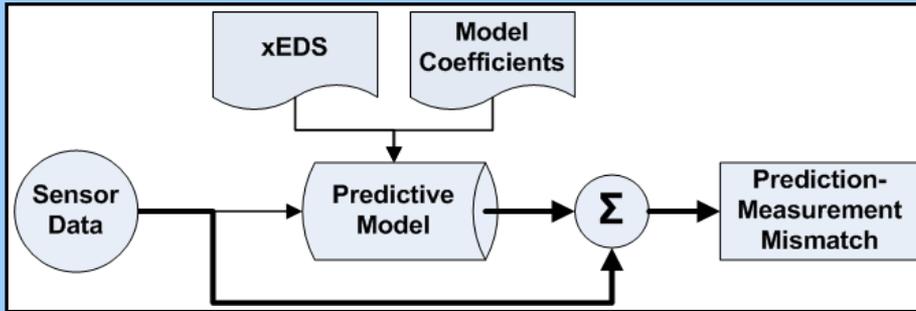


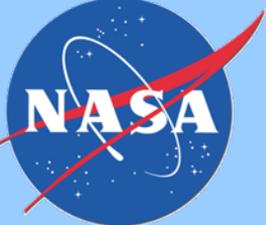
Checking for Pressure Leaks



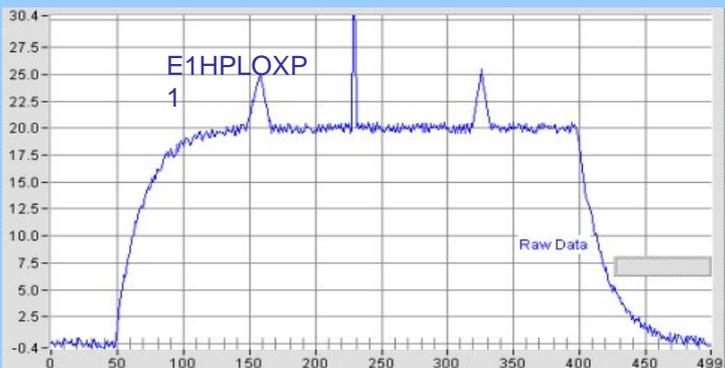


Runtime Predictive Modeling





Intelligent Sensors

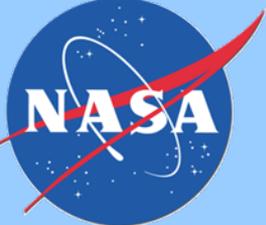


Example Signal

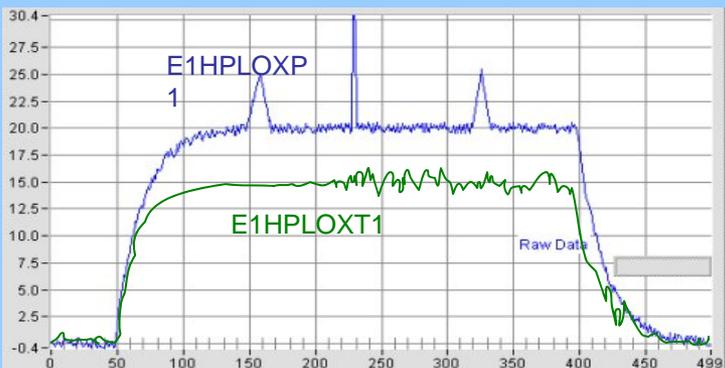
Process: HP LOX - Start: 2/5/01, 13:08 End: 2/6/01, 8:45 Sensors: E1HPLOXP1: Pressure, Strain-Gauge. Loc: Top E1HPLOXP2: Pressure, Piezoelectric. Location: Bottom E1HPLOXT1: Temperature, Thermocouple K, Loc: Top E1HPLOXT2: Temperature, Thermocouple K, Loc: Bott E1HPLOXV1: Valve position, Loc: Bottom	
PROCESS RELATED CONDITION MONITORING	
Behavior discrepancies	E1HPLOXP1: spike E1HPLOXP1: disturbance E1HPLOXP1: disturbance E1HPLOXT1: high noise

Sensor E1HPLOXP1: Pressure, Strain-Gauge - Process: HP LOX Start: 2/5/01, 13:08 End: 2/6/01, 8:45	
Condition Monitoring	
flat-with-noise	normal, occurrences: 5
step-up	normal, occurrences: 2 Exp. time-constant:0.50s Spec. time-constant: 0.52s
sensor-disturbance	occurrences: 5 Exp. time-constant:0.50s Spec. time-constant: 0.52s Limit-violation-count since 1/3/01, 3:45: 7
flat-with-noise	normal, occurrences: 6
spike	Spike-count since 1/3/01, 3:45: 35
sensor-disturbance	Occurrences: 6 Exp. time-constant:0.55s Spec. time-constant: 0.52s Limit-violation-count since 1/3/01, 3:45: 8
drift-with-noise	normal, occurrences: 3 drift-slope: -0.05 PSI/s expected drift with temp: -0.001 PSI/s expected-warm-up-drift: -0.005 PSI warm-up period: 2 hr. time-since-turn-on: 5 hr. 45 min expected-wear-drift: -0.005 PSI op-time-since-last-cal: 54 hr
step-down	normal, occurrences: 2 Exp. time-constant:0.51s Spec. time-constant: 0.52s





Intelligent Sensors

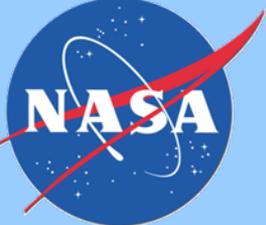


Example Signal

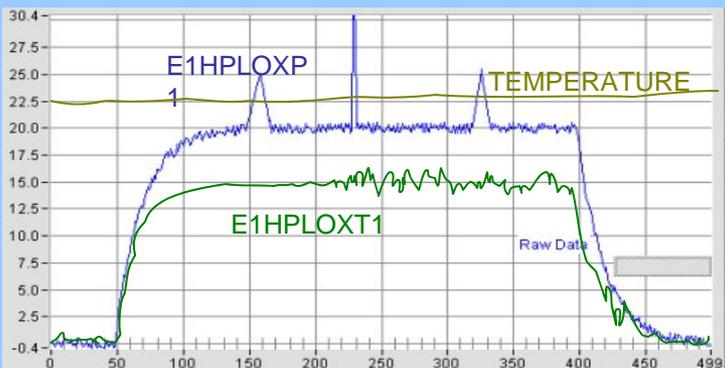
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PROCESS RELATED CONDITION MONITORING	
Behavior discrepancies	E1HPLOXP1: spike E1HPLOXP1: disturbance E1HPLOXP1: disturbance E1HPLOXT1: high noise

Sensor E1HPLOXP1: Pressure, Strain-Gauge - Process: HP LOX Start: 2/5/01, 13:08 End: 2/6/01, 8:45	
Condition Monitoring	
flat-with-noise	normal, occurrences: 5
step-up	normal, occurrences: 2 Exp. time-constant: 0.50s Spec. time-constant: 0.52s
sensor-disturbance	occurrences: 5 Exp. time-constant: 0.50s Spec. time-constant: 0.52s Limit-violation-count since 1/3/01, 3:45: 7
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step-down	normal, occurrences: 2 Exp. time-constant: 0.51s Spec. time-constant: 0.52s

CLOSE



Intelligent Sensors

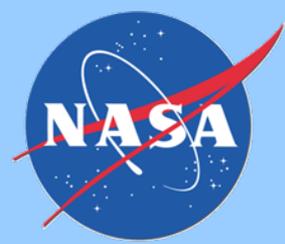


Example Signal

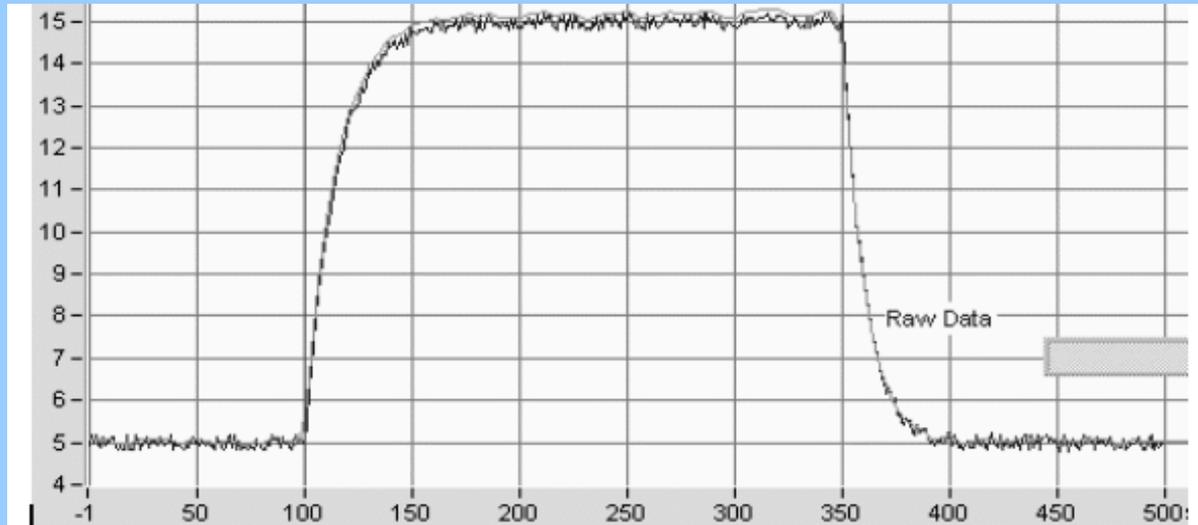
Process: HP LOX - Start: 2/5/01, 13:08 End: 2/6/01, 8:45	
Sensors: E1HPLOXP1: Pressure, Strain-Gauge. Loc: Top	
E1HPLOXP2: Pressure, Piezoelectric. Location: Bottom	
E1HPLOXT1: Temperature, Thermocouple K, Loc: Top	
E1HPLOXT2: Temperature, Thermocouple K, Loc: Bott	
E1HPLOXV1: Valve position, Loc: Bottom	
PROCESS RELATED CONDITION MONITORING	
Behavior discrepancies	E1HPLOXP1: spike E1HPLOXP1: disturbance E1HPLOXP1: disturbance E1HPLOXT1: high noise

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sensor-disturbance	Occurrences: 6 Exp. time-constant:0.55s Spec. time-constant: 0.52s Limit-violation-count since 1/3/01, 3:45: 8
drift-with-noise	normal, occurrences: 3 drift-slope: -0.05 PSI/s expected drift with temp: -0.001 PSI/s expected-warm-up-drift: -0.005 PSI warm-up period: 2 hr. time-since-turn-on: 5 hr. 45 min expected-wear-drift: -0.005 PSI op-time-since-last-cal: 54 hr
step-down	normal, occurrences: 2 Exp. time-constant:0.51s Spec. time-constant: 0.52s

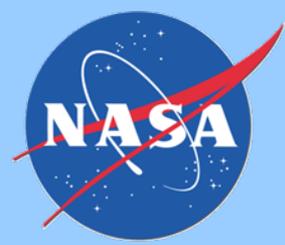
CLOSE



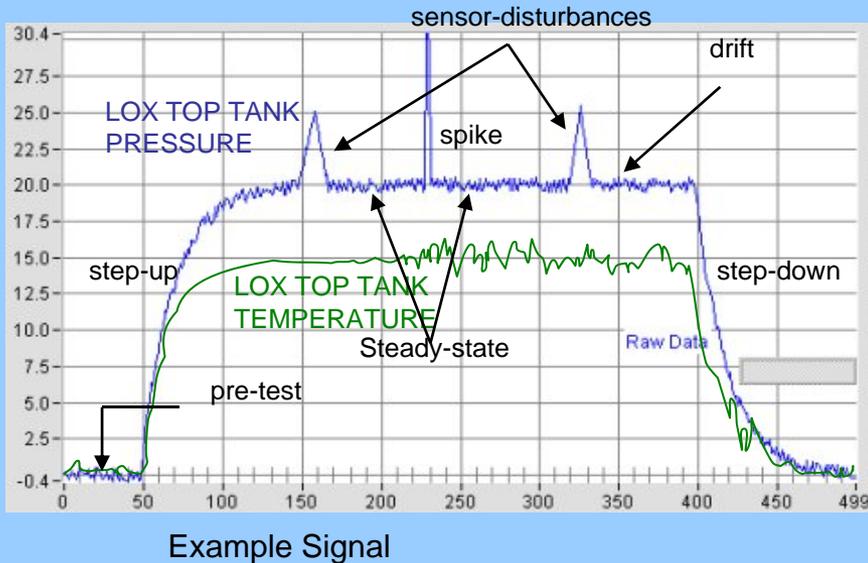
Intelligent Sensors



Point #	32	101	109	112	119	158	180	...	352	359	367	372	373	390	404	413
Deviation_check	N	N	N	H	H	N	N	...	N	H	H	H	H	H	N	N
Amplitude_check	N	N	N	N	N	N	N	...	N	N	N	N	N	N	N	N
Limit_check	N	N	N	N	N	N	N	...	N	N	N	N	N	N	N	N
Estimate_check	G	G	G	G	G	G	G	...	G	G	B	G	G	G	G	G
Sign_check	S	P	P	P	P	S	S	...	M	M	M	M	M	M	M	S
STC_check	V	V	V	V	V	V	V	...	V	V	V	V	V	V	V	V
MTC_check	V	V	V	V	V	V	V	...	V	V	V	V	V	V	V	V
Samples_concept	1	↓	1	1	1	1	1	...	1	1	1	1	1	1	1	1
ModelTrend	+	+	+	+	+	+	+	...	-	-	-	-	+	-	-	+
ModelType	1	2	3	3	2	2	1	...	2	2	3	2	1	2	2	1
ModelCoeff1	w	x	x	x	y	o	m	...	m	l	z	m	w	u	w	w
ModelCoeff2	-						-	...))	-)))	-
Concept: c(x)	0	1	2	3	4	1	0	...	5	6	7	6	8	6	5	0
Behavior	b(1)		b(2)		b(3)		b(4)		b(5)		b(6)		b(6)		b(7)	
Behavior Name	ConstWith Noise		Step Change Up		ChangeUp Settle		HighConstantWithNoise		Step ChangeD		Step Change Down		Step Change Settle		ConstWith Noise	



INTELLIGENT ISHM

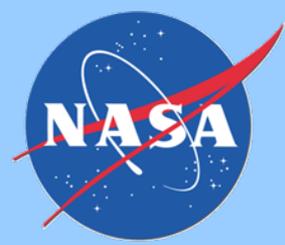


Record: pre-test, step-up, sensor disturbance, steady state, spike, steady-state, sensor-disturbance, drift, step-down

Abnormal Conditions: sensor-disturbance, spike, sensor-disturbance

Potential Abnormal Conditions: drift.

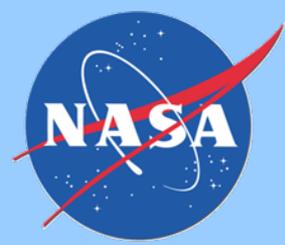
- Extract **continuously intuitive descriptions** of all signals **before, during, and after** tests (create a complete and meaningful record).
- Identify, diagnose, and propose remedies to abnormal or potentially abnormal conditions occurring in all test-stand components (sensors, actuators, processes).



ISHM RELATED NEWS ARTICLES

Leonard Nicholson, the Northrop Grumman-Boeing team's deputy program manager.

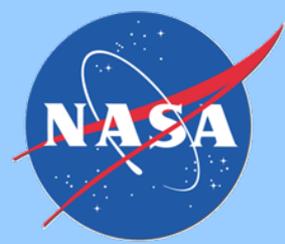
- "The CEV we plan to build will benefit not so much from a single, technical breakthrough but rather from evolutionary improvements in structural technologies, electronics, avionics, thermal-management systems, software and **integrated system health management** systems over the past 40 years."
- CEV will use two fault-tolerant subsystems and **integrated system health management systems** to allow it to detect, isolate and recover from subsystem failures. By comparison, Apollo generally had only single fault tolerance.



ISHM RELATED NEWS ARTICLES

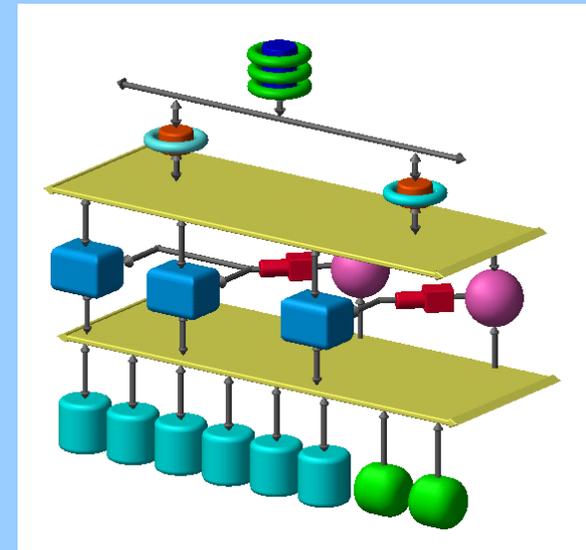
- The last Delta 4 to fly was the heavy-lift version, which blasted off from Cape Canaveral Air Force Station in December of last year. However, during what looked like a flaw-free ride to space, its first stage failed and its payload -- a mock weight simulating a satellite -- ended up 10,000 miles short of its target.
- The problem: fuel sloshing inside the booster caused some sensors to believe the rocket's tanks had run dry, shutting down the first-stage engines earlier than expected.

This is a case when a decision to shut down engines is done with limited information that does not take advantage of integrated awareness brought about by ISHM capability. Other relevant conditions such as the pressure in the tanks, signs of leakage in the tank and valves/pipes attached to it, other indicators that the engines and surrounding elements may (or may not) be entering a regime associated with fuel starvation, etc. could have been considered.



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



Interrelationship Between Traditional Avionics Systems, Time Critical ISHM and Advanced ISHM

Time Critical ISHM System

Where traditional avionics systems become uncontrollably complex is in handling the interactions between multiple systems and in providing significant FDIR capabilities. Time Critical ISHM is a deterministic and verifiable method of handling first failure responses and intersystem interactions.

Advanced ISHM

Advanced ISHM provides toolsets designed to speed human-driven diagnostics of complex system failures and interactions. Relying on model-based and data mining techniques, it:

- isolates likely candidate failure causes
- prognosticates possible workarounds and repairs
- predicts degradation caused future failures

Humans

Direct mission and solve problems beyond the reach of automated systems with the help of automated, diagnostic and prognostic tools.

Traditional Avionics Systems

Traditionally designed subsystems form the basis of this architecture. This type of design has proven to be extremely reliable and predictable when used within its limits. Provided that the software complexity remains in a region where determinism is reasonably guaranteed, only evolutionary change is necessary.



Current Division of Capabilities

Frequency of Function

Traditional Avionics System

- Constant activity
- Nominal operations
- Deterministic
- Autonomous, but monitored

Current FDIR

- Covers first failure
- Deterministic
- Advises humans on all actions

The wedge of work currently performed by humans necessitates a very large and complex operations infrastructure. Long term recurrent ops cost savings can only be realized through dramatically more capable tools.

Nominal system functions

Subsystem first failure response.

Imminent failures and complex or new failures.

Operations Personnel and Crew

- Handle all nontrivial anomalies
- Minimal computational assistance
- Expensive

Complexity of Function





Initial ISHM Capabilities Breakout

Frequency of Function

Traditional Avionics System

- Constant activity
- Nominal operations
- Deterministic
- Autonomous, but monitored

Time Critical ISHM

- Accounts for low-level FDIR response
- Covers first failure
- Deterministic
- Advises humans on all actions

Advanced ISHM Assisted Humans

- Takes no actions except human alerts
- Advises and assists humans
- Speculative

Nominal system functions

Intersystem coordination & first failure response.

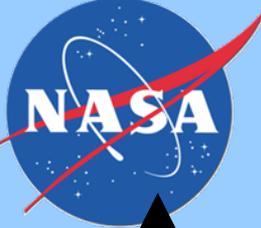
Imminent failures and complex or new failures.

Complexity of Function

Initially, the Time-Critical ISHM system will integrate the functions of FDIR and add only a small wedge of capability. Advanced ISHM will speed the human-directed troubleshooting efforts.

As Advanced ISHM technologies mature to a certifiable state, more are added to the Time-Critical portion, further relieving the human workload and therefore cost.





Evolved ISHM Capabilities

Frequency of Function

Traditional Avionics System

- Constant activity
- Nominal operations
- Deterministic
- Autonomous, but monitored

As Advanced ISHM technologies mature to a certifiable state, more are added to the Time-Critical portion, further relieving the human workload and therefore cost.

Time Critical ISHM

- Covers first failure
- Deterministic
- Advises humans on all actions

Nominal system functions

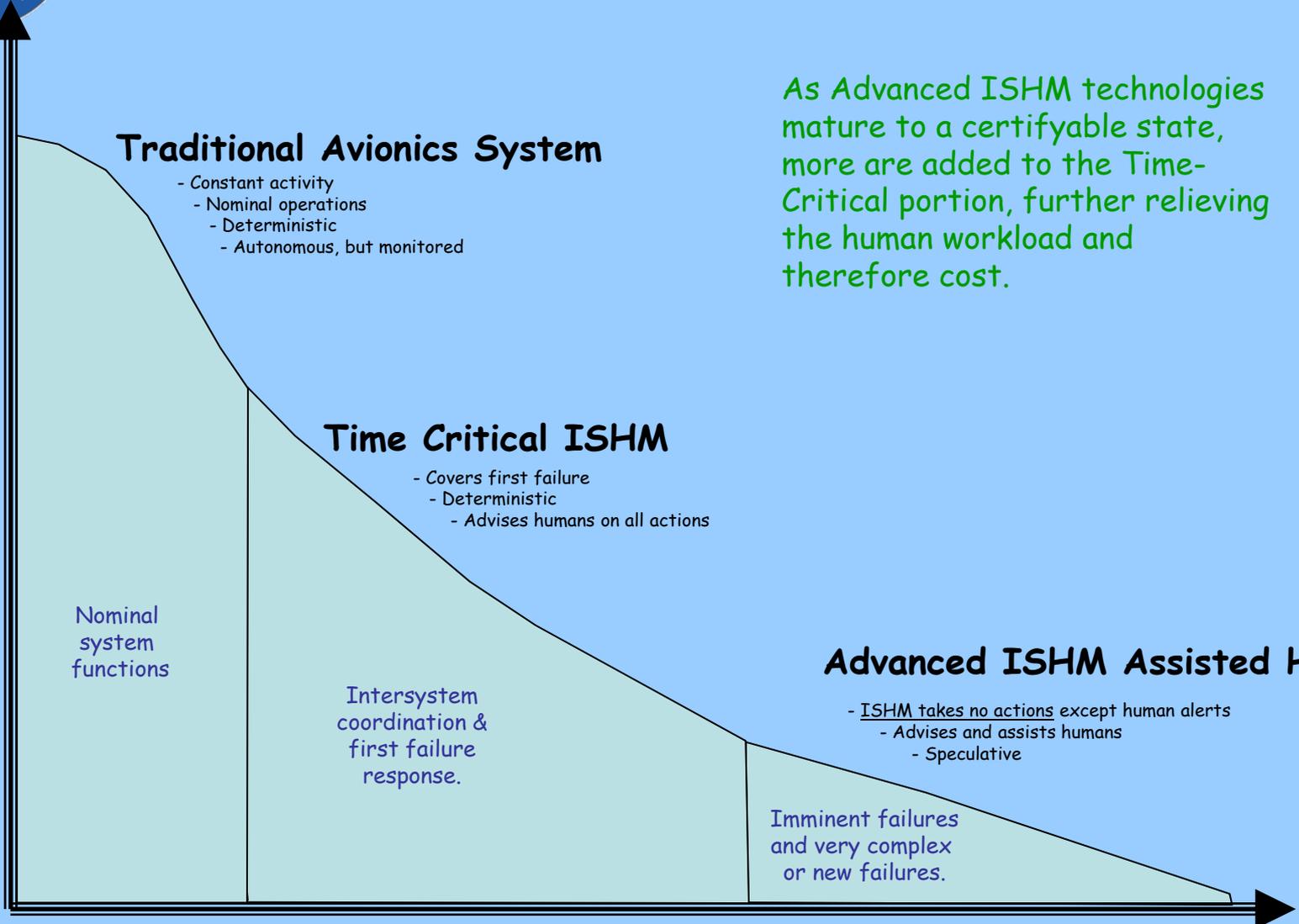
Intersystem coordination & first failure response.

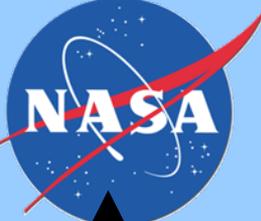
Advanced ISHM Assisted Humans

- ISHM takes no actions except human alerts
- Advises and assists humans
- Speculative

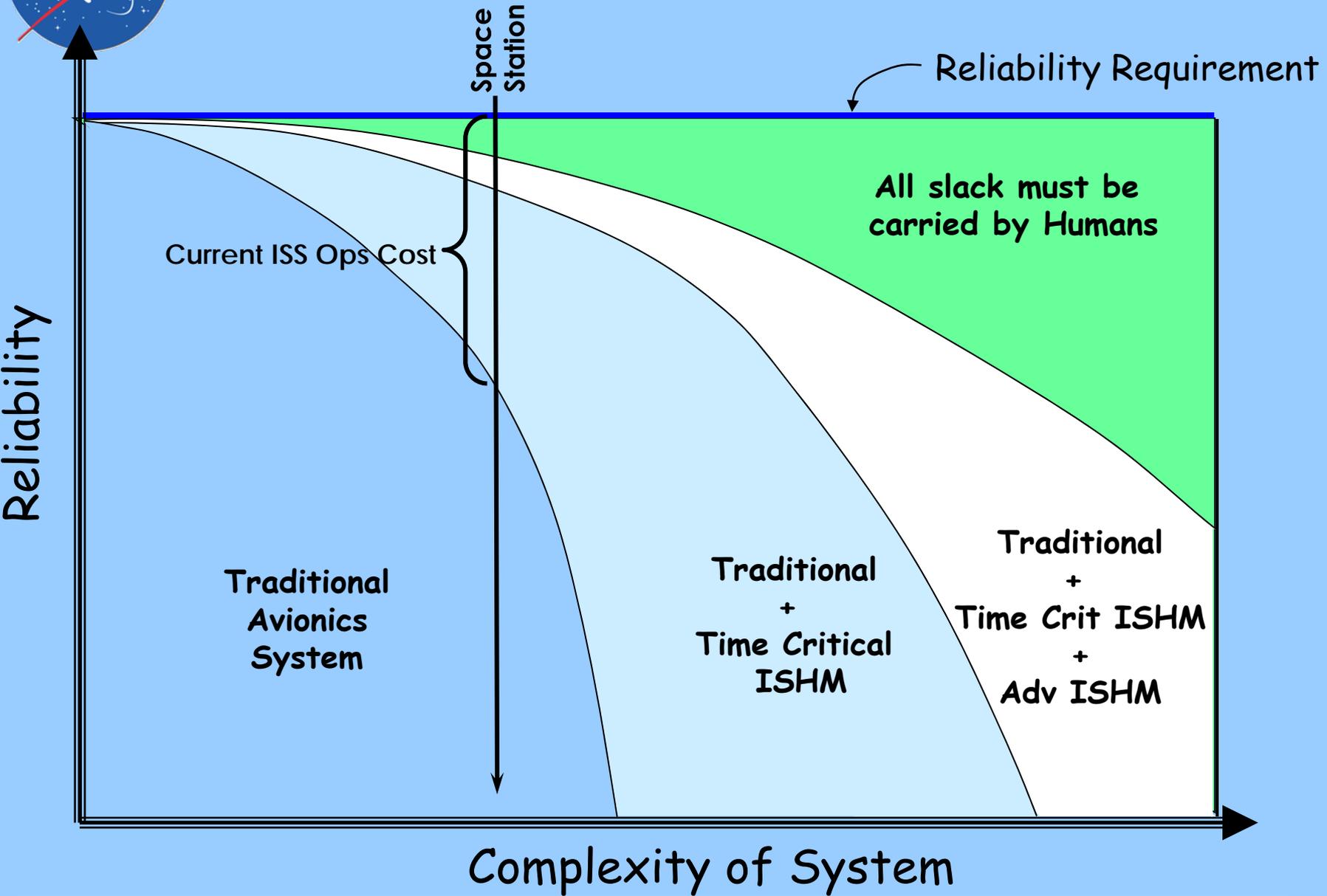
Imminent failures and very complex or new failures.

Complexity of Function





Cost Savings from Advanced Systems



Reliability

Complexity of System

Reliability Requirement

Space Station

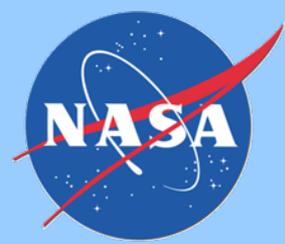
Current ISS Ops Cost

All slack must be carried by Humans

Traditional Avionics System

Traditional + Time Critical ISHM

Traditional + Time Crit ISHM + Adv ISHM



Safety Impacts

Source: 2002 Aerospace Safety Advisory Panel (ASAP) Report on ISS

"The C&DH system is vulnerable to instability under heavy load conditions. The ISS has developed operational guidelines that control this problem. This is an acceptable mode of operation during the construction phase of the ISS. But is not adequate for conducting scientific research in a production environment in which many activities execute concurrently. Recommendation 01-20a indicated that NASA should "Gain an improved understanding of the range of commanding problems that lead to constraints on the system." Although the Panel believes that NASA is making progress on this recommendation, the Panel plans to reexamine the issue in the coming year. Recommendation 01-20a is continuing."

ISHM technologies being matured include real time and design-time tools which assist in uncovering the state space of software and hardware-software interactions

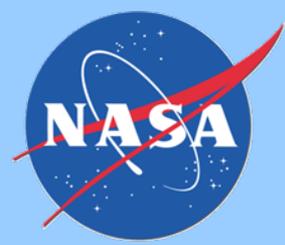
"Recommendation 01-20c renews the earlier concern about the adequacy of the current C&DH architecture and component performance. The recommendation is "Evaluate potential architectures that would improve the systems stability and robustness and ensure safe operations. Implement architecture improvements as soon as it is prudent to do so." Therefore Recommendation 01-20c is continuing."

One purpose of advanced components of ISHM is to address those faults and errors which are too complex to be programmed into a deterministic system. ISHM increases the robustness by accelerating and improving the ability of operators to handle complex faults.

"Finding 01-17 Instances of anomalies in crew performance may be increasing. Recommendation 02-17: Review all data on crew performance and all root causes of crew incidents to determine if a trend is apparent. Take appropriate action."

ISHM provides the crew with two capabilities:

- (a) increased insight into the system and correlations between events and*
- (b) moving training and operations away from fixed procedures and towards problem solving and adaptable mission management.*



Safety Impacts

Source: 2002 Aerospace Safety Analysis Panel (ASAP) Report on ISS

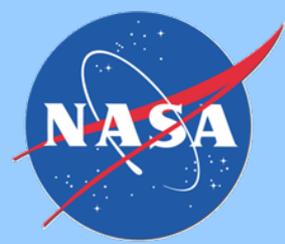
Recommendation 02-18: Ascertain the availability of functional redundancy through dissimilar computer hardware and software for all safety-critical functions. Predicated on a prioritization of criticality, develop a program to provide requisite functional redundancy.

ISHM components can be implemented as in-band and out-of-band systems, operating on different hardware, software and design processes than the core system. The ISHM embedded system can therefore provide critical system diversity without the added cost of providing redundant disparate control systems.

"Finding 02-22: It is necessary for software assurance, of which IV&V is a part, to evolve in response to advances in information technology. Nondeterministic systems, such as those constructed from neural nets and other artificial-intelligence approaches, offer particular challenges for validation and verification. The attempt to take advantage of COTS software requires that such software be verified and validated not only in accord with its original intent, but also in case it is modified or customized for a specific application and within its new environment. Recommendation 02-22: Maintain a robust research and development effort within the NASA IV&V program. Establish reasonable and supportive funding levels for this effort. Create a research agenda in cooperation with NASA's operational and research enterprises. Provide oversight by program and project managers to ensure that the research meets their needs."

ISHM addresses this recommendation in two ways:

- 1) ISHM brings the world's leaders in artificial intelligence, information technology, and COTS together. An endogenous expertise in these areas will facilitate the development of V&V technology designed for these types of computational systems.*
- 2) ISHM is, at its core, a runtime V&V system. The state space of any large software product is vast enough to invalidate the concept of complete testing. However, the state space of any software at a point in the runtime is calculable. Therefore, ISHM extends the viability of the formal V&V methods to the runtime environment, increasing their utility.*



Sustaining Engineering Cost Savings

Source: 2003 Cost Assessment Requirements Document (CARD) for ISS

Hardware Software Integration: CARD Table 3.7.4.D-1 identifies "Resources provided to support PR analysis" as a 1st order I&O cost driver. The same table identifies: "Resources required to support testing and other verification activities" as a 1st order cost driver for both I&O and DDT&E.

Software Development and Integration Lab: CARD Table 3.7.5.B-1 identifies "...test rig troubleshooting and anomaly resolution support..." as a Key Product and Service.

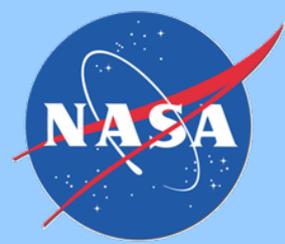
Prime Command & Data Handling Sustaining:

CARD Table 3.4.3.2.D-1 identifies "Number and complexity of anomalies; real time anomaly resolution; unknown variable increases as more HW added on-orbit; number of PRACAS requiring C&DH expertise; amount of on-going monitoring and trending" as the #1 cost driver for this \$22M/year cost element. The third driver includes: "Number and complexity of C&DH system on-orbit."

Prime Communication & Tracking, Guidance Navigation & Control and other Sustaining:

The CARD contains language for these areas that is similar to C&DH sustaining.

The #1 target of ISHM is rapid anomaly resolution. While current ISHM tools are targeted at acceleration of on-orbit anomaly resolution, the basic ISHM structure and technology is extensible to the more complex problems often faced in ground testing.



Training & Operations Cost Savings

Source: 2003 Cost Assessment Requirements Document (CARD) for ISS

SSTF: CARD Section 4.3.3.2.1C: "Space Station Training Facility costs are heavily dependant on the number of training hours required for both the crew and flight controller training" and "secondary cost drivers include troubleshooting..."

ISHM increases the ability to move training away from the large, costly integrated simulators used for troubleshooting of systems anomalies. Operating the still-required high fidelity simulators is facilitated by ISHM because many of the same ISHM components and algorithms used on the flight system are identical in the simulator.

Training Hours:

The current budget for ISS Prime Crew Training is 4552 hours. Of that, 970 hours (21%) are allocated to ISS systems which are related to the ISHM target. The #1 cost driver (CARD Table 4.3.4.D-1) for Flight Operations, Training and Mission Preparation is the "Number of hours of training instruction required." This includes crew, instructor and flight controller training.

Movement towards skills-based training has been hindered by the need for detailed system understanding. This need is driven by the lack of high level troubleshooting tools such as ISHM.

MCC Console: CARD Table 4.3.4.D-1 identifies "Number of hours of on-console support," "Continuous mission support," and the number of "people who must be in MCC at a given time" as major cost drivers. It also points to this being "diminished by how many Gemini shifts are applied." Simply achieving the current POP guidelines requires the replacement of 40% of the current full shifts by Gemini in FY05.

ISHM is absolutely required to move our operations concept away from a massive Mission Control Center towards a leaner Mission Support Center.