



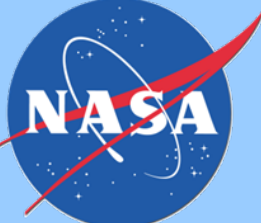
Intelligent Integrated System Health Management

Fernando Figueroa
NASA Stennis Space Center, MS

Presentation at Louisiana Tech

February 3, 2012





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

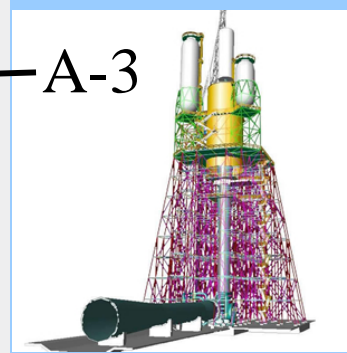
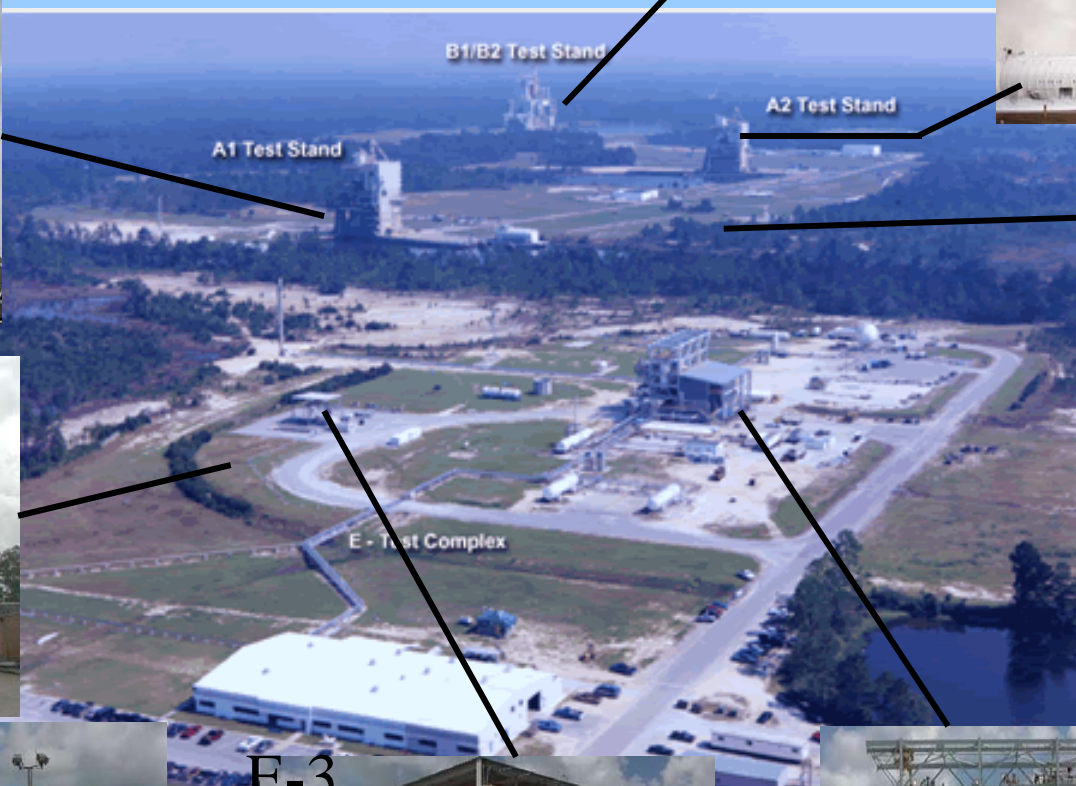


B-1/B-2

A-1



A-2



A-3



E-2

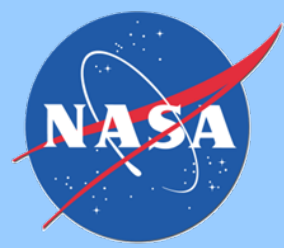
Others:
•High-pressure Gas
•Industrial Water



E-3

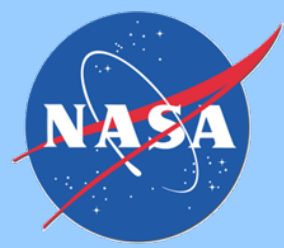


E-1



Outline

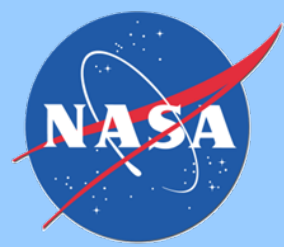
- ISHM Definition.
- ISHM Capability Development.
 - ISHM Knowledge Model.
 - Standards for ISHM Implementation.
 - ISHM Domain Models (ISHM-DM's).
 - Intelligent Sensors and Components.
- ISHM in Systems Design, Engineering, and Integration.
- Intelligent Control for ISHM-Enabled Systems.



Requirements Driving ISHM

Through comprehensive and continuous vigilance

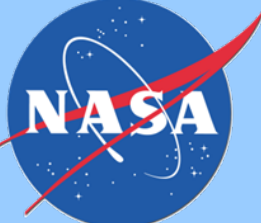
- Improve quality
 - By more accurately understanding the state of a system.
- Minimize costs
 - Of configuration
 - Of repair and calibration
 - Of operations
- Avoid downtime
 - By predicting impending failures
 - By timely intervention
 - By faster diagnosis and recovery
- Increase safety (protect people and assets)



ISHM Objectives

- Use available data, information, and knowledge to
 - Identify system state
 - Detect anomalies
 - Determine anomaly causes
 - Predict system impacts
 - Predict future anomalies
 - Recommend timely mitigation steps
 - Evolve to incorporate new knowledge

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

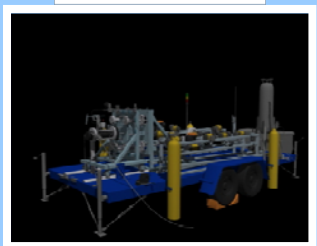
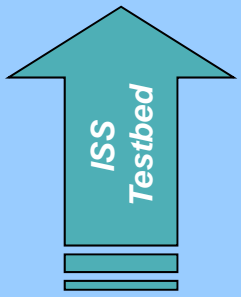
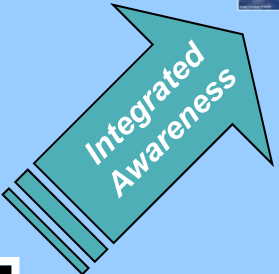
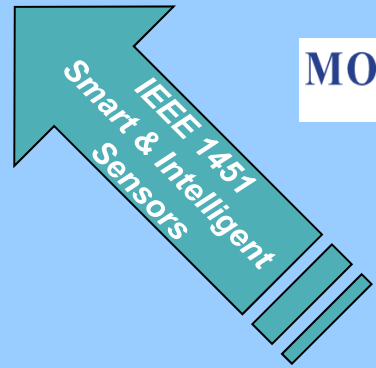
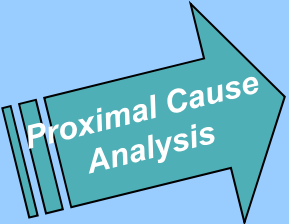
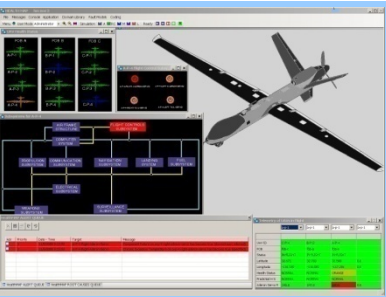
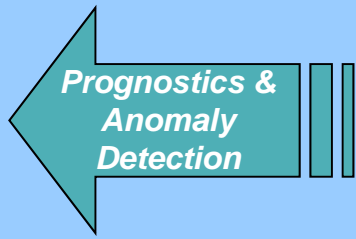
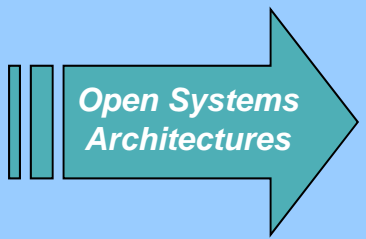
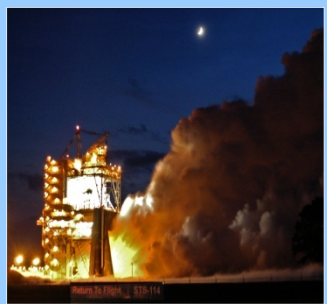


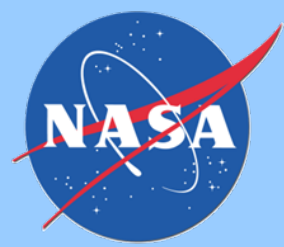
John C. Stennis Space Center

ISHM Partnerships for Rocket Propulsion testing

A community of Expertise and Technologies

Rocket Engine Test Stand

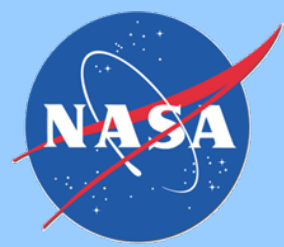




Concepts for iISHM

THE CAPABILITY MUST BE CREDIBLE AND AFFORDABLE

- **Intelligent System:** Manages data, information, and knowledge (DIaK) to achieve its mission (Manage: storage, distribution, sharing, maintenance, processing, reasoning, and presentation)
- **iISHM:**
 - 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, Engineering, and 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 its health.



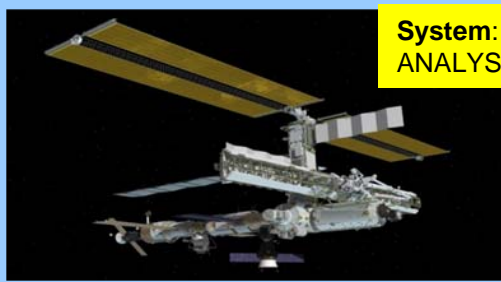
People-Based ISHM is Being Done Today

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.

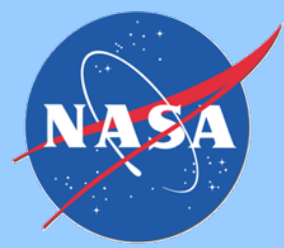
Layer 4
Back Control Room



Support: FASTER, MORE ACCURATE ANALYSIS
Decreased Need

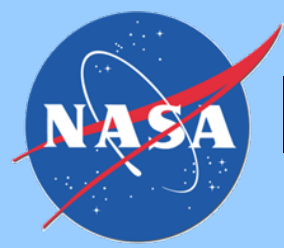


Added DIaK resources from larger community



Determination of Health

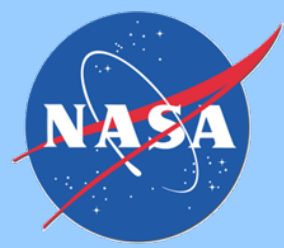
- Use available SYSTEM-WIDE data, information, and knowledge (DIAK) to
 - Identify system state.
 - Detect anomaly indicators.
 - Determine and confirm anomalies.
 - Diagnose causes and determine effects.
 - Predict future anomalies.
 - Recommend timely mitigation steps.
 - Evolve to incorporate new 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.



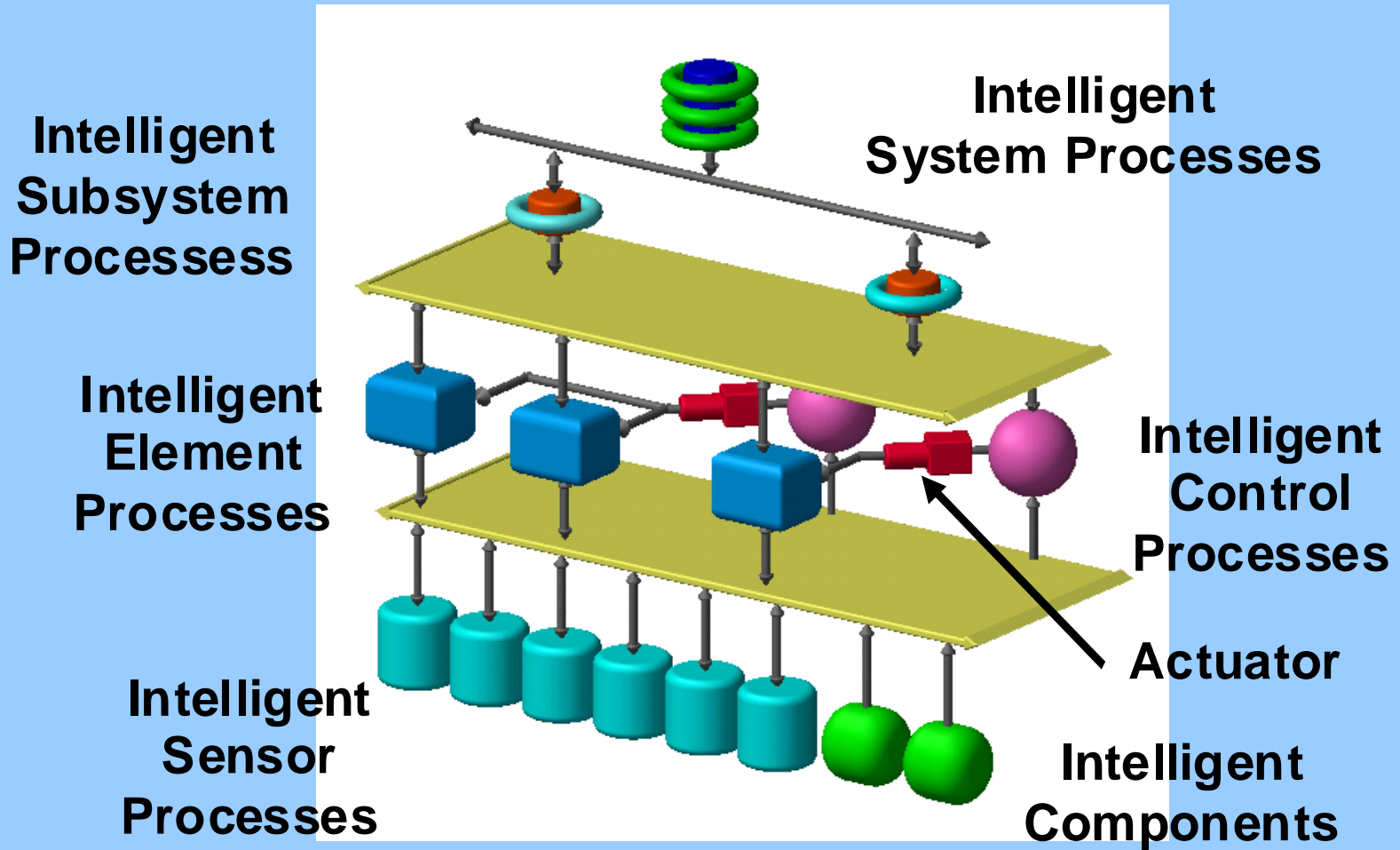
ISHM Capability Development

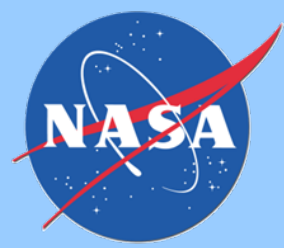
ISHM Knowledge Model

- 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.

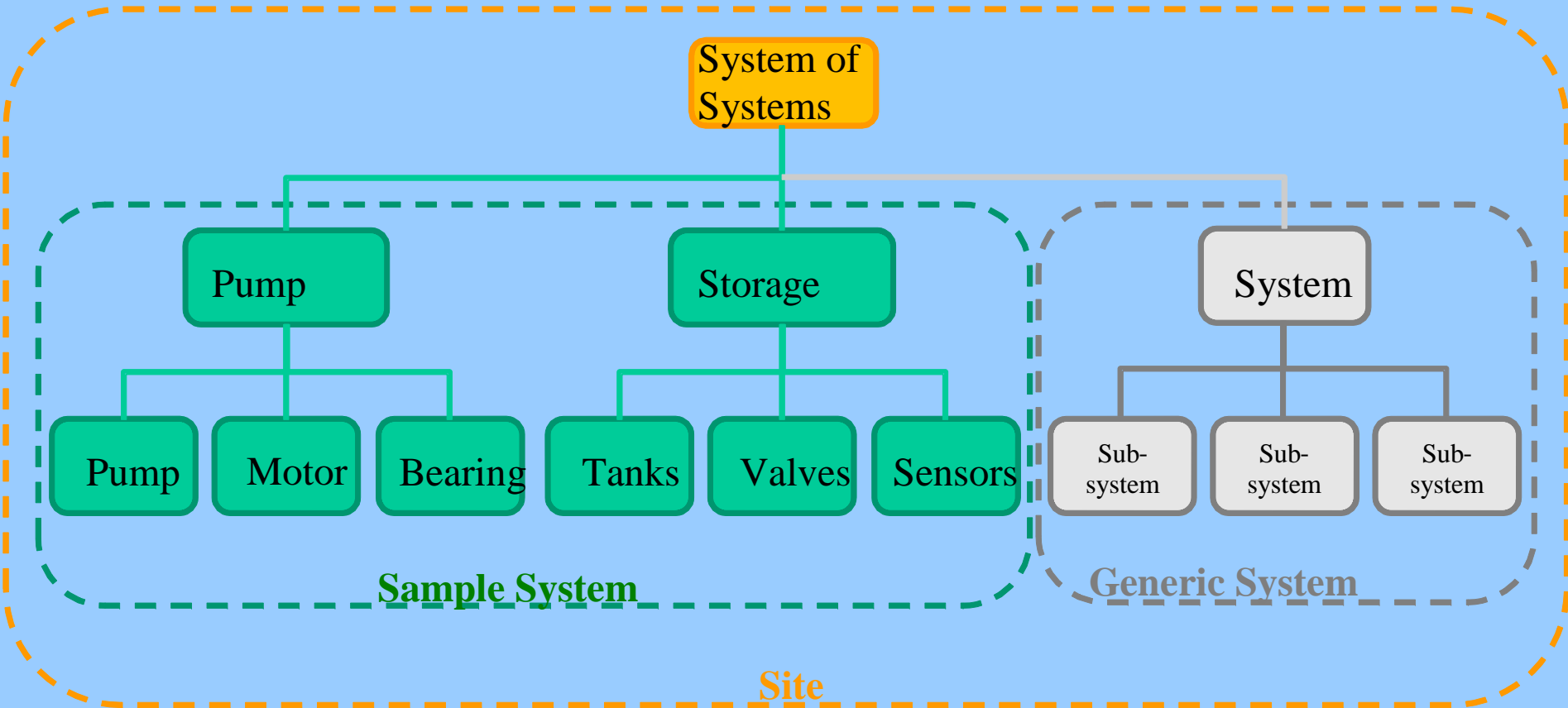


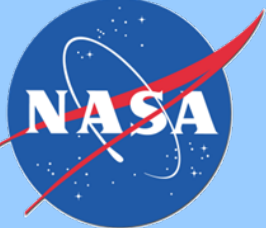
Data, Information, and Knowledge Management Architecture for ISHM (Information Architecture)



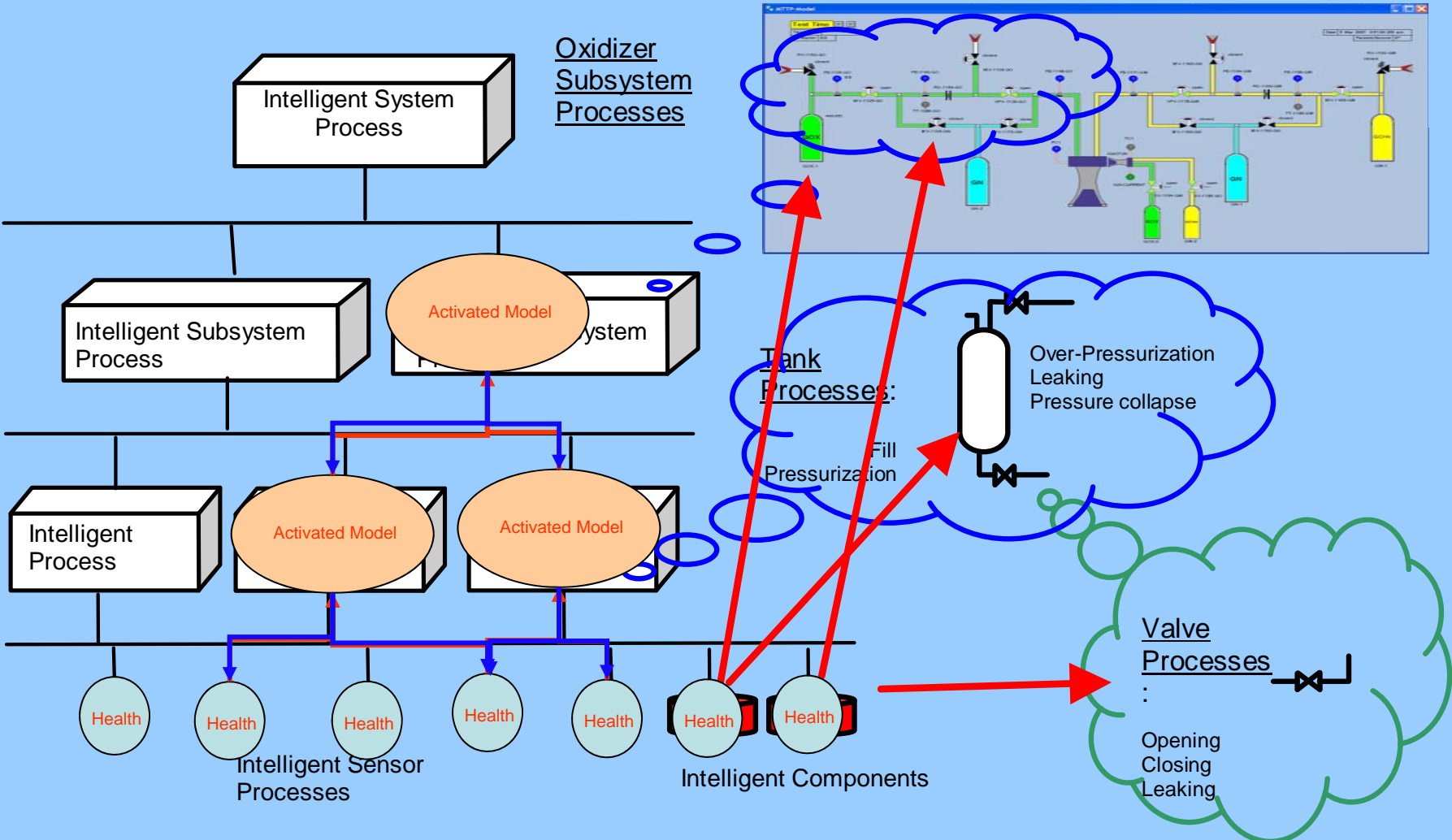


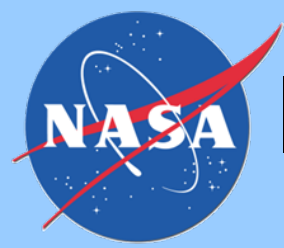
Classic architecture describing how systems are built





Detection and Confirmation of Anomalies Consistency Checking Cycle





ISHM Capability Development

Standards for ISHM

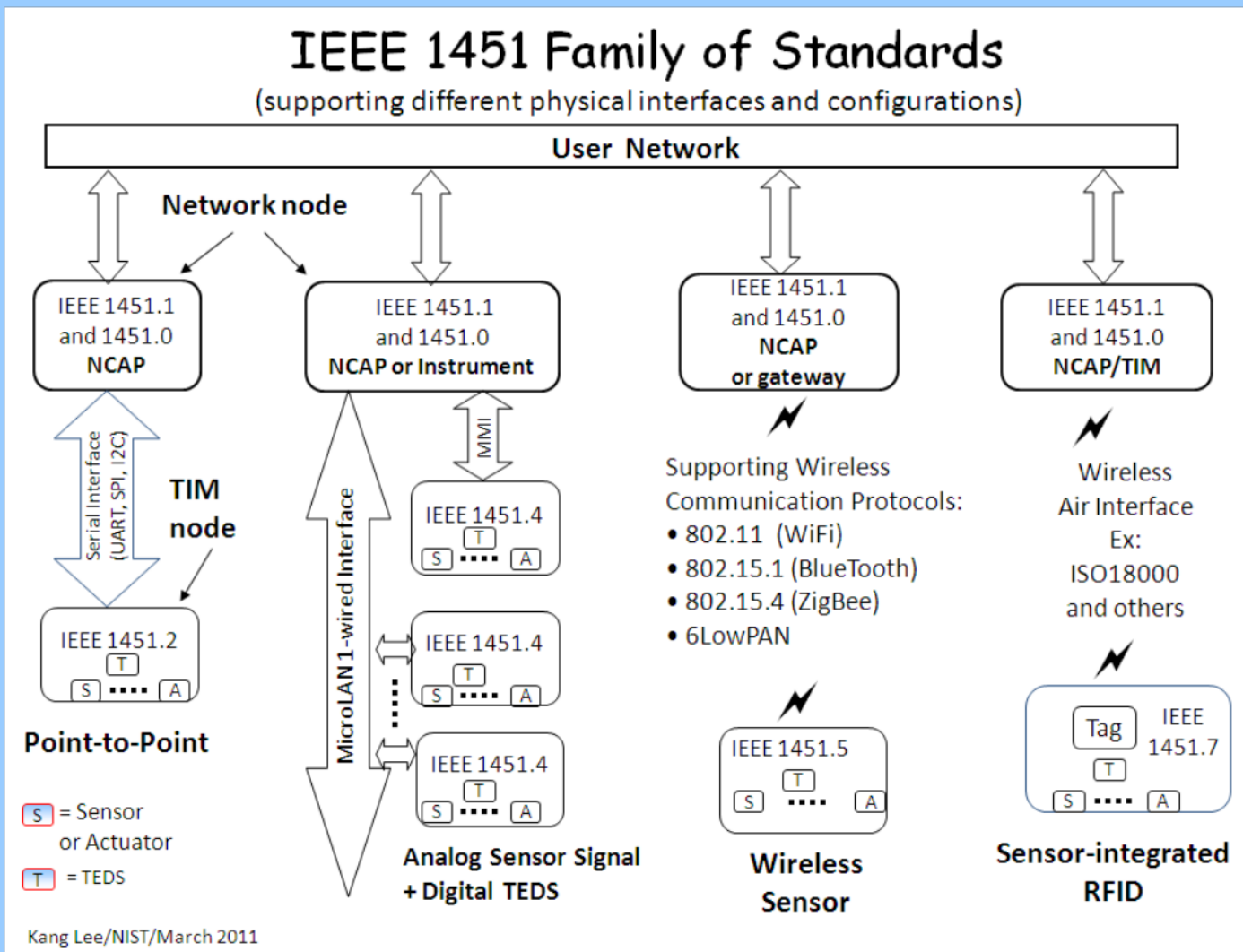
- IEEE 1451 Family of Standards for Smart Sensors and Actuators. Lead by NIST (Dr. Kang Lee).
- OSA-CBM (Open Systems Architecture for Condition Based Maintenance). Developed by industry and government, and transferred to the MIMOSA (Machine Information Management Open Standards Alliance) organization.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

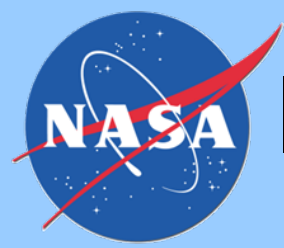
ISHM capability must integrate DLaK across physical, virtual, and discipline boundaries. This is not possible in an affordable manner unless standards are used to achieve plug&play and interoperability.



ISHM Capability Development

Standards for ISHM



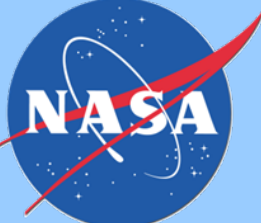


ISHM Capability Development

Standards for ISHM

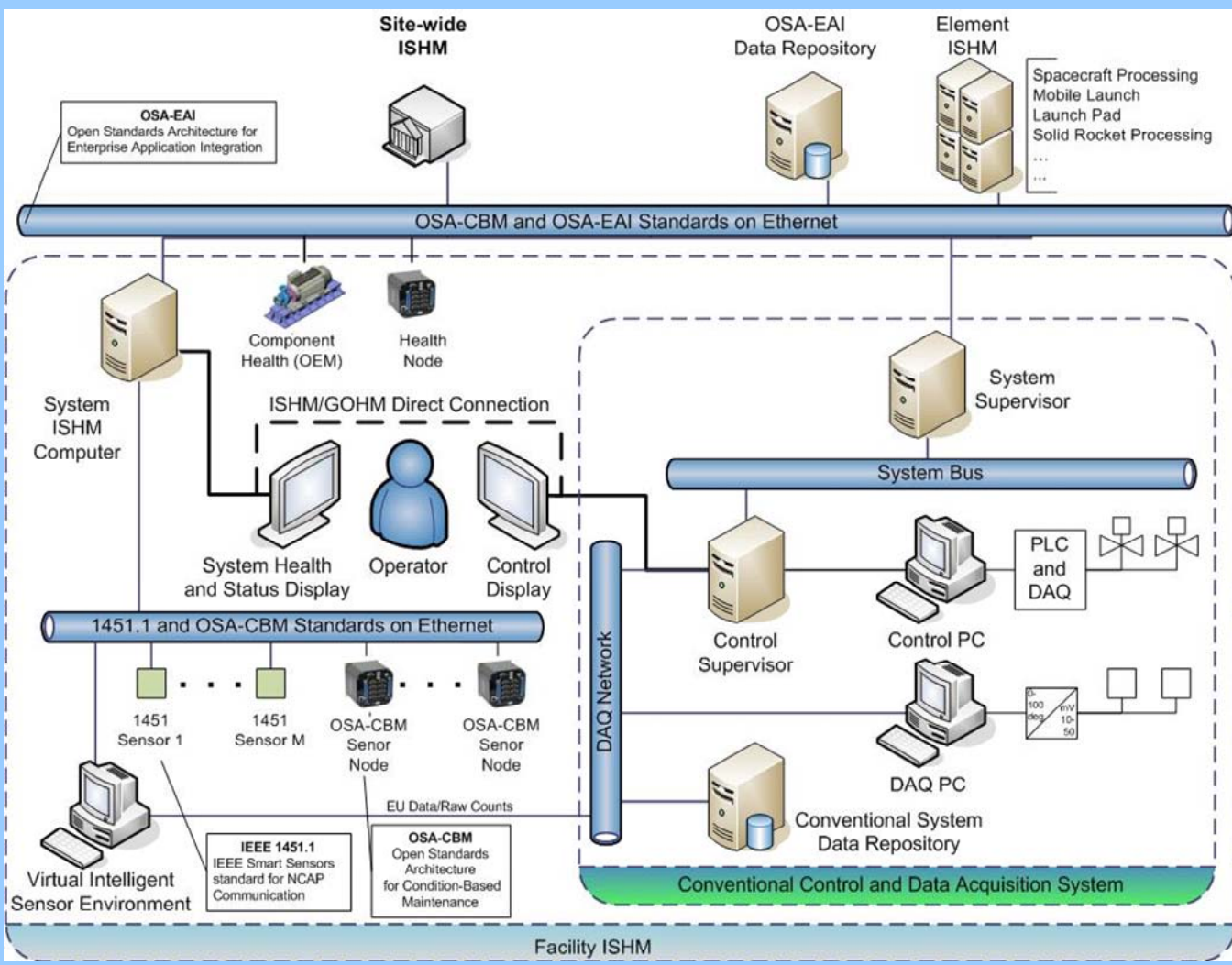
OSA-CBM (MIMOSA)



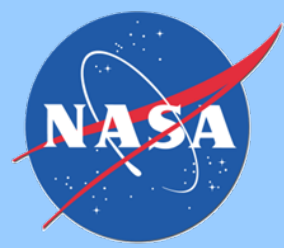


ISHM Capability Development

Standards for ISHM



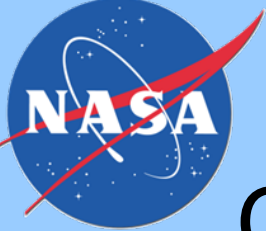
Architecture for pilot ISHM system implemented at NASA Kennedy Space Center, Launch Complex 20 (LC-20) showing the use of IEEE 1451.1, OSA-CBM, and OSA-EAI standards



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

A software system for ISHM capability should support all core capabilities by integrating systematically 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.



Pilot ISHM Implementation Chemical Steam Generator (CSG)

The screenshot displays the Telewindows Client interface for a Chemical Steam Generator (CSG) system. The main window, titled "CSG Domain Map", shows a schematic of the system with three main components: the CSA IPA System (IPA-RUNTANK), the CSA LOX System (LOX-RUNTANK), and the CSA Water System (WATER-RUNTANK). These are connected to a central unit labeled "CSG-1" which feeds into a "STEAM-PLENUM".

An inset window titled "CSG Unit #1" provides a detailed view of the internal piping and instrumentation. It shows various sensors (e.g., TC-14A4100-IP-A, TC-14A4035-G-O), control valves (e.g., 26 STAGE-LOX), and flow indicators. The diagram is color-coded to match the domain map, with red lines for IPA, green for LOX, and blue for water.

On the left side, the "EDS Explorer" pane shows the component hierarchy, including "PE-14A4101-IPA" and its associated "TEDS" data. Below this, the "EDS Attributes" pane lists technical specifications for the bridge element, such as impedance, calibration date, and electrical output.

At the bottom, there are three panes: "Alarms", "Root Causes", and "Repair Actions", each with a table for monitoring system events. The "Real-Time Plot of PE-14A4101-IPA" shows a stable signal around 1000 mV/V.

On the right side, there are two "Blue Lines" and "Red Lines" panels, which likely represent specific sensor or valve status indicators.



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. The interface is annotated with several callouts:

- Blueline Active Monitors:** A blue callout pointing to the left sidebar, which lists various sensors and modules.
- Redline Active Monitors:** A red callout pointing to the left sidebar, which lists various sensors and modules.
- Blueline Alarm Queues:** A blue callout pointing to the bottom-left window, which displays a list of alarm messages.
- Redline Alarm Queues:** A red callout pointing to the bottom-right window, which displays a list of alarm messages.
- Transducer Electronic Data Sheet Viewing Windows:** A grey callout pointing to the right sidebar, which displays the EDS Explorer and EDS Attributes for a specific component.

The interface also includes a menu bar (File, Edit, View, Layout, Go, Project, Workspace, Tools, Window, Help) and a status bar (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).

Blueline Active Monitors List:

- 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 List:

- 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

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

EDS Explorer:

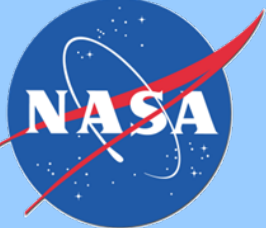
By Component..

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

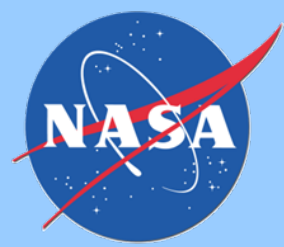


CSG ISHM Domain Model: Blueline/Redline User Interfaces

The screenshot displays the Telewindows Client interface with several windows open:

- Bluelines:** A list of various process elements (PEs) such as PT-14A31-GN, PE-14A2435-HD, etc.
- Blueline Details:** A window for PE-14A4192-GN showing a graph of MAIN STAGE IPA S/D PURGE PRESSURE (psi) over time. The current reading is 525.0. An event named 'ACHIEVED' occurred on 2009/06/16 at 11:29:24.814978.
- Blueline Configuration:** A window for PE-14A4183-GN showing 1st STAGE GOX PURGE PRESSURE (psi) over time. The current reading is 525.0. It includes parameters for High and Low Bluelines.
- Redlines:** A list of redline elements such as PDE-14A4086-S, PE-14A26-LO, etc.
- Redline Details Dialog:** A window for PE-14A4117-IPA showing current reading 18.544. It includes settings for Arm Time, Disarm Time, and Condition. An event named 'EXCEEDED' occurred on 2009/06/16 at 12:33:56.967 p.m.
- Redline Configuration:** A window for PE-14A4084-CW showing 1st STAGE GOX PURGE PRESSURE (psi) over time. The current reading is 1.816. It includes settings for Maximum and Minimum Redlines.

At the bottom of the interface, there are status bars for 'BLUETIME-ALARM-QUEUE' and 'REDLINE-ALARM-QUEUE'. On the right side, there are vertical buttons for 'EDS Explorer' and 'EDS Attributes'.



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	0
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

Seq. Acc. Seconds 0.000

DETECT ALARM

Seq. Clock @ Advance 0.000

Seq. Step @ Advance 0

First Out @ Advance 0

State Mode: E2C1PLC1 (EN, ALM, State Mode) E2C1PLC2 (EN, ALM, State Mode)

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 Auto-Seq End = 14.0
Arm Time = 2.0 Disarm Time = 14.0
Event = 2.108

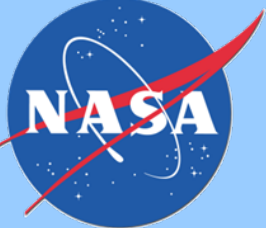
16 Tue Jun 2009 12:33:15 12:33:30 12:33:45 12:34:00 12:34:15

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



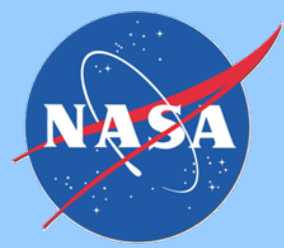
CSG ISHM Domain Model: Redline Event Handling

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

- Bluelines Panel:** Lists various system components such as PT-14A31-GN, PE-14A2435-HD, and TC-14A4046-LO.
- Redlines Panel:** Lists redline events including PDE-14A4086-S, TT-14A16-LO, and PE-14A4117-IPA.
- G2 Redlines Anomaly Report:** A detailed report for sensor PE-14A4117-IPA, showing an event type of EXCEEDED at 2009/06/16 12:33:56.967 p.m. with a main threshold limit of 210.0 psi. A red arrow points from the text "Auto-generated Redline Report" to this report.
- Pressure Graph:** A line graph titled "PE-14A4117-IPA" showing pressure (psi) over time. The pressure rises from approximately 100 psi to a peak of about 200 psi before dropping sharply. A red arrow points from the text "Auto-generated Redline Report" to the graph.
- CSG Unit #1 Piping Diagram:** A schematic diagram of the system showing the 2nd Stage and Main Stage. A red arrow points from the text "Navigation to Transducer Where Redline Event Occurred" to the location of transducer PE-14A4117-IPA on the Main Stage.
- BLUELINE-ALARM-QUEUE:** A table listing various alarm messages and their status.
- REDLINE-ALARM-QUEUE:** A table listing redline events, including the event for PE-14A4117-IPA.

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

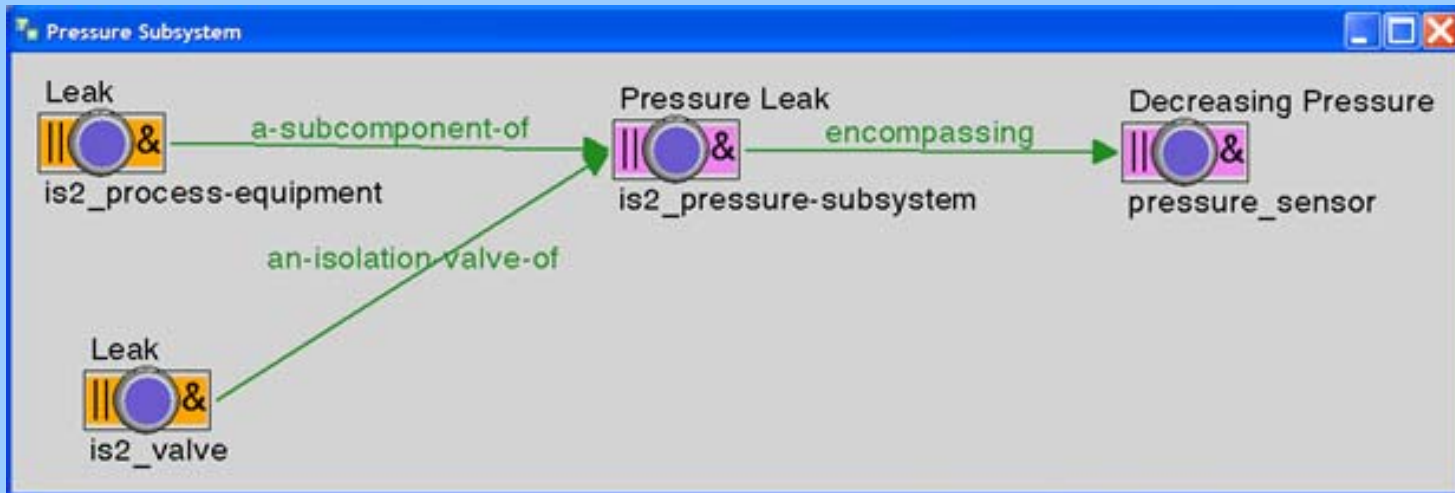
Target	Message	Priority	Repetitions	Detail
Pe-14a4117-IPA	EXCEEDED - 2009/06/16 12:33:56.967 p.m.	1	1	Loss of IPA Main Stage Interface Pressure

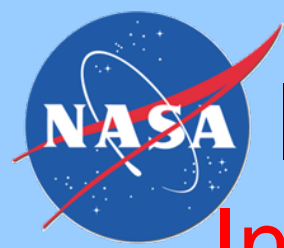


Failures Modes and Effects Analysis (FMEA)

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 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.





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

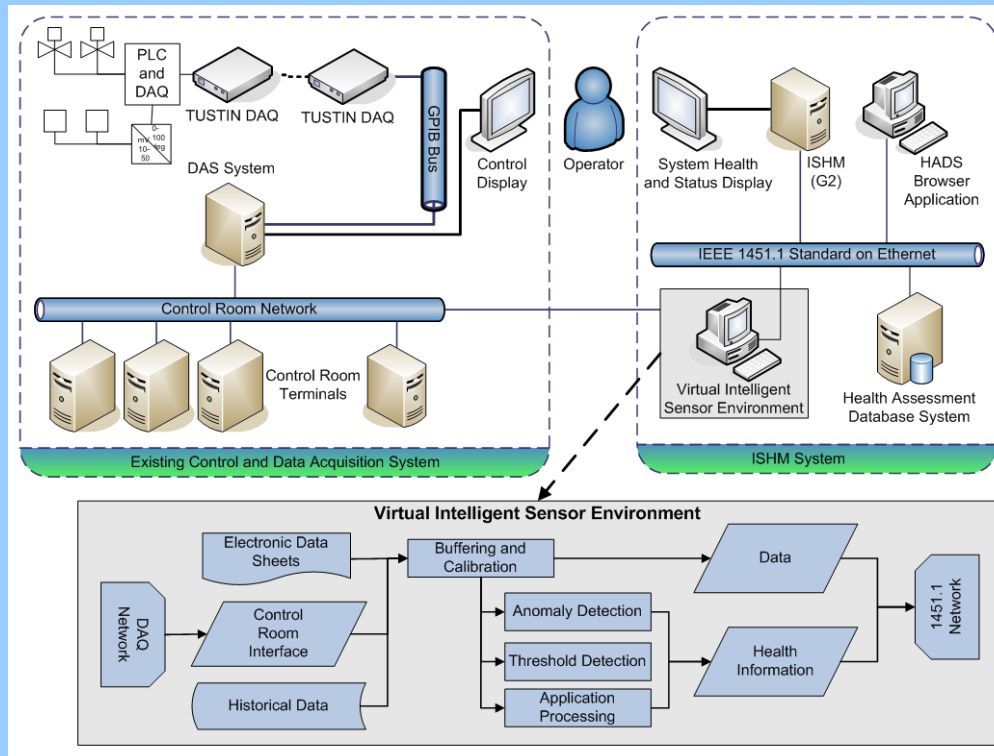
“Intelligent Sensor” is a “Smart Sensor” with the ability to provide the following functionality: (1) measurement, (2) measure of the quality of the measurement, and (3) measure of the “health” of the sensor. The better the sensor provides functionalities 2 and 3, the more intelligent it is.



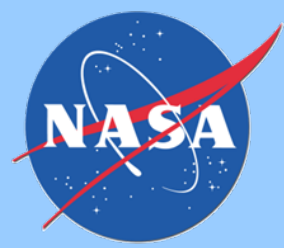
ISHM Capability Development

Intelligent Sensors and Components

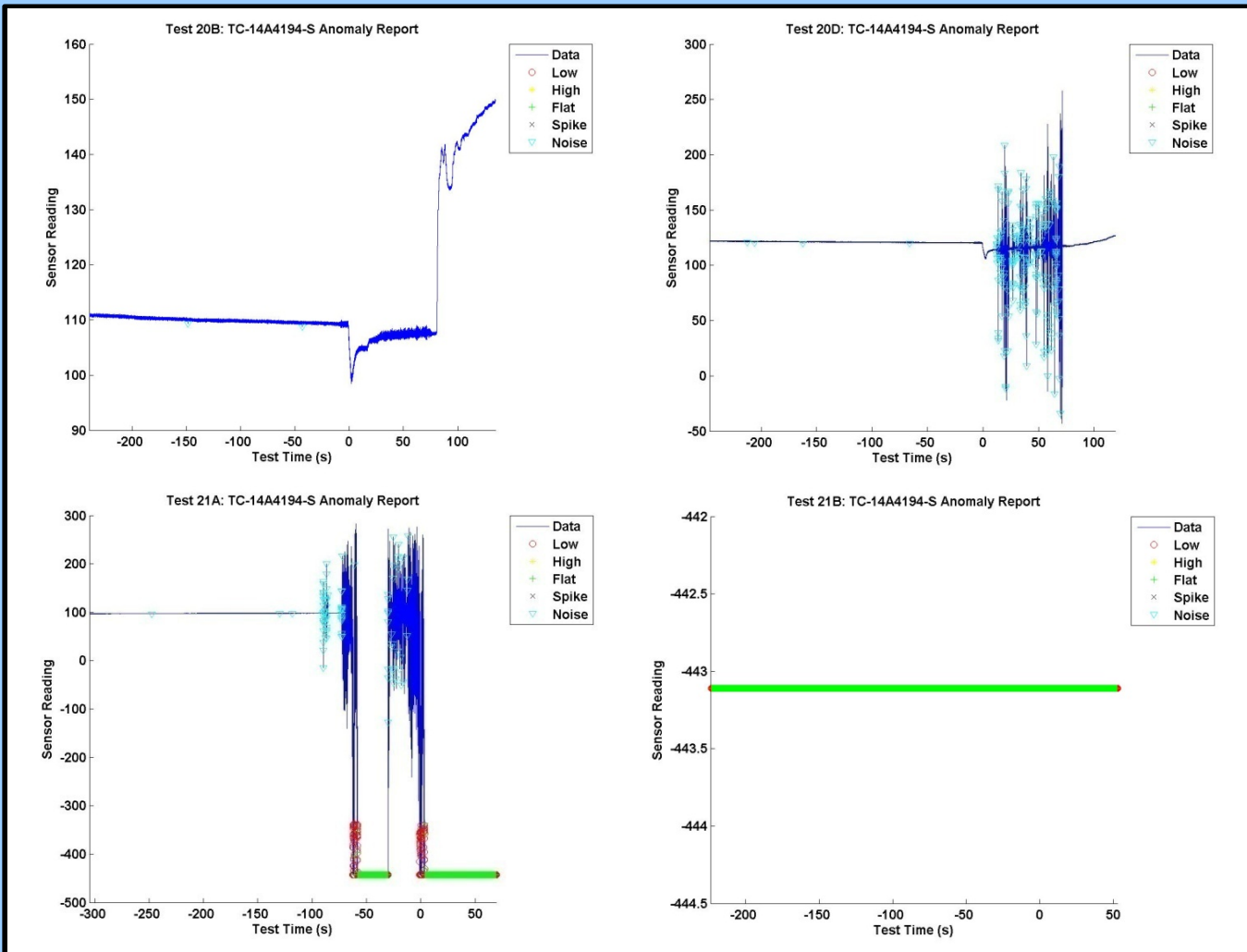
Example Intelligent Sensor Implementations



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

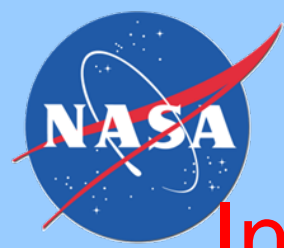


CSG Anomalies Detected



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

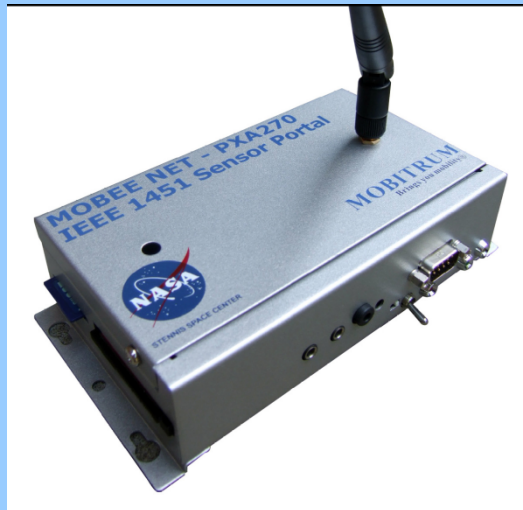
Transducer Anomaly Report Graphs for one sensor in four consecutive tests.



ISHM Capability Development

Intelligent Sensors and Components

Example Intelligent Sensor Implementations



Mobitrum

www.mobitrum.com



Smart Sensor Systems

www.smartsensorsystems.com



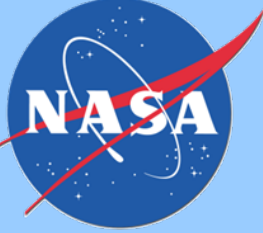
NIST

www.mel.nist.com



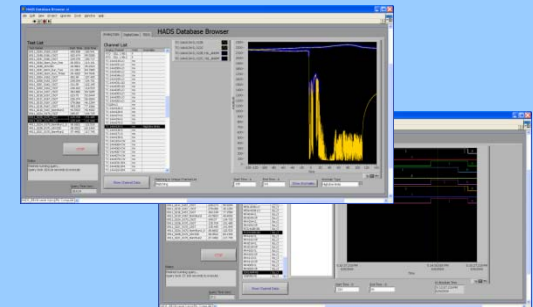
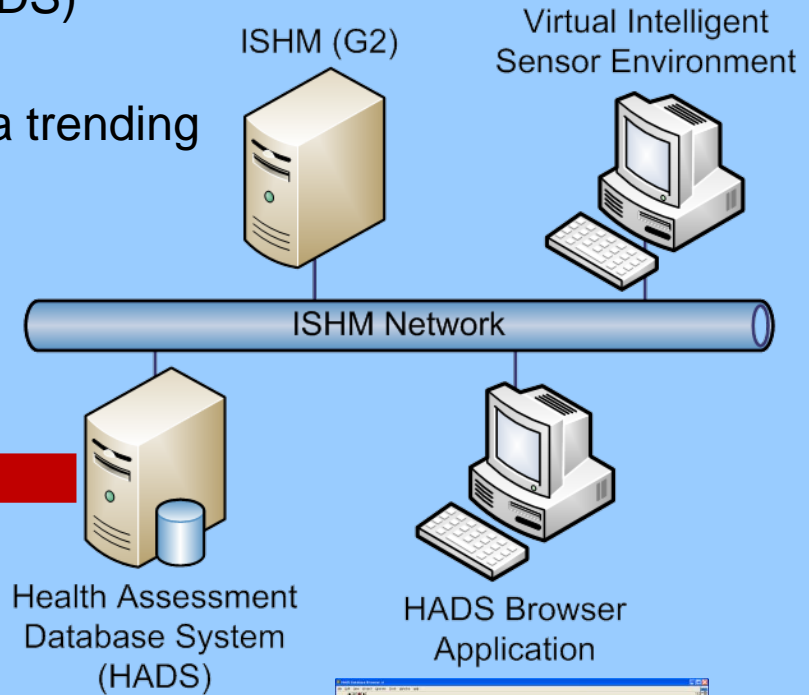
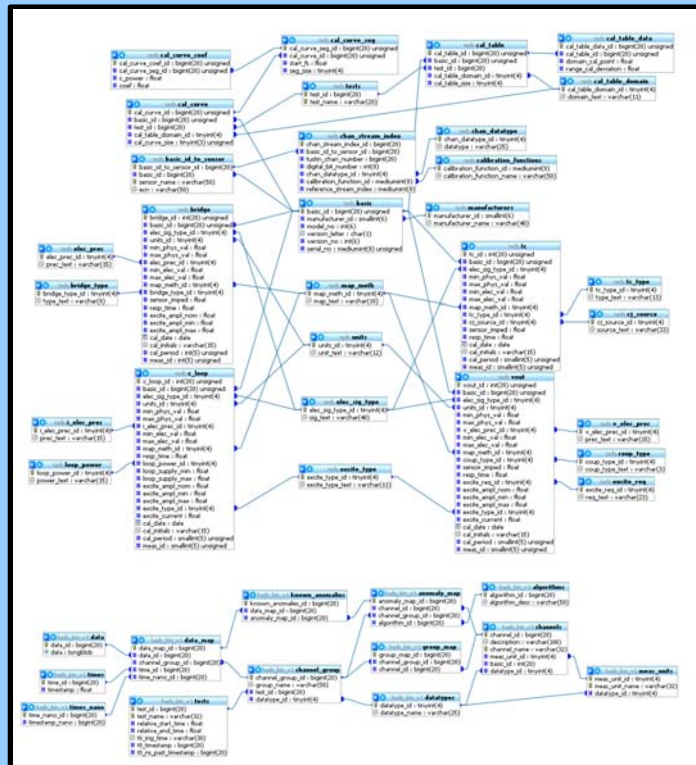
Esensors

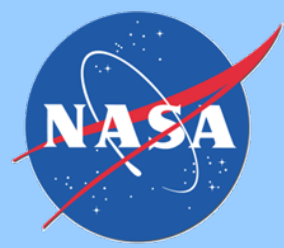
www.eesensors.com



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_CSQT	-305.650	100.541
0911_0196_9160_CSQT	-362.674	99.5208
0911_0198_9160_CSQT	-225.070	100.717
4911_0194_Norm_Run_One	+20.0521	114.141
4911_0196_ADV250	+18.9601	+8.2323
4911_0198_Norm_Run_Two	+21.1961	84.7965
4911_0190_Norm_Run_Three	+29.4202	84.7646
0911_020A_9162_CSQT	+302.99	107.405
0911_020B_9162_CSQT	+239.294	134.701
0911_020C_9162_CSQT	+311.05	122.145
0911_020D_9162_CSQT	+246.462	119.533
0911_021A_9167_CSQT	-304.866	69.3285
0911_021B_9167_CSQT	-223.75	52.6444
0911_021C_9167_CSQT	-226.074	56.9204
0911_021D_9167_CSQT	-278.066	46.1294
0911_021E_9167_CSQT	-393.239	77.1566
4911_021D_9167_NormRun3	-43.5923	40.4002
0911_022A_9170_CSQT	-845.07	134.725
0911_022B_9170_CSQT	-136.709	151.485
0911_022C_9170_CSQT	-129.445	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-14A4109-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-GO
- 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

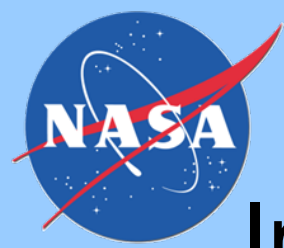
TEDS Field	TEDS Value
BASIC TEDS	
Manufacturer Name	Stellar Technology
Model Number	2000
Version Letter	G
Version Number	121
Serial Number	966546
BRIDGE TEDS	
Transducer Electrical Signal Type	Bridge Sensor
Physical Measurement	psi
Minimum Physical Value	0
Maximum Physical Value	2000
Full Scale Electrical 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.

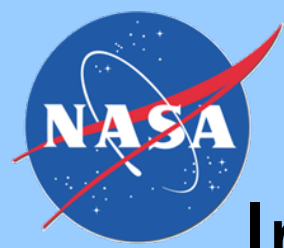
Query Time (sec)
37.1

Digit Data - Tests on multiple channels

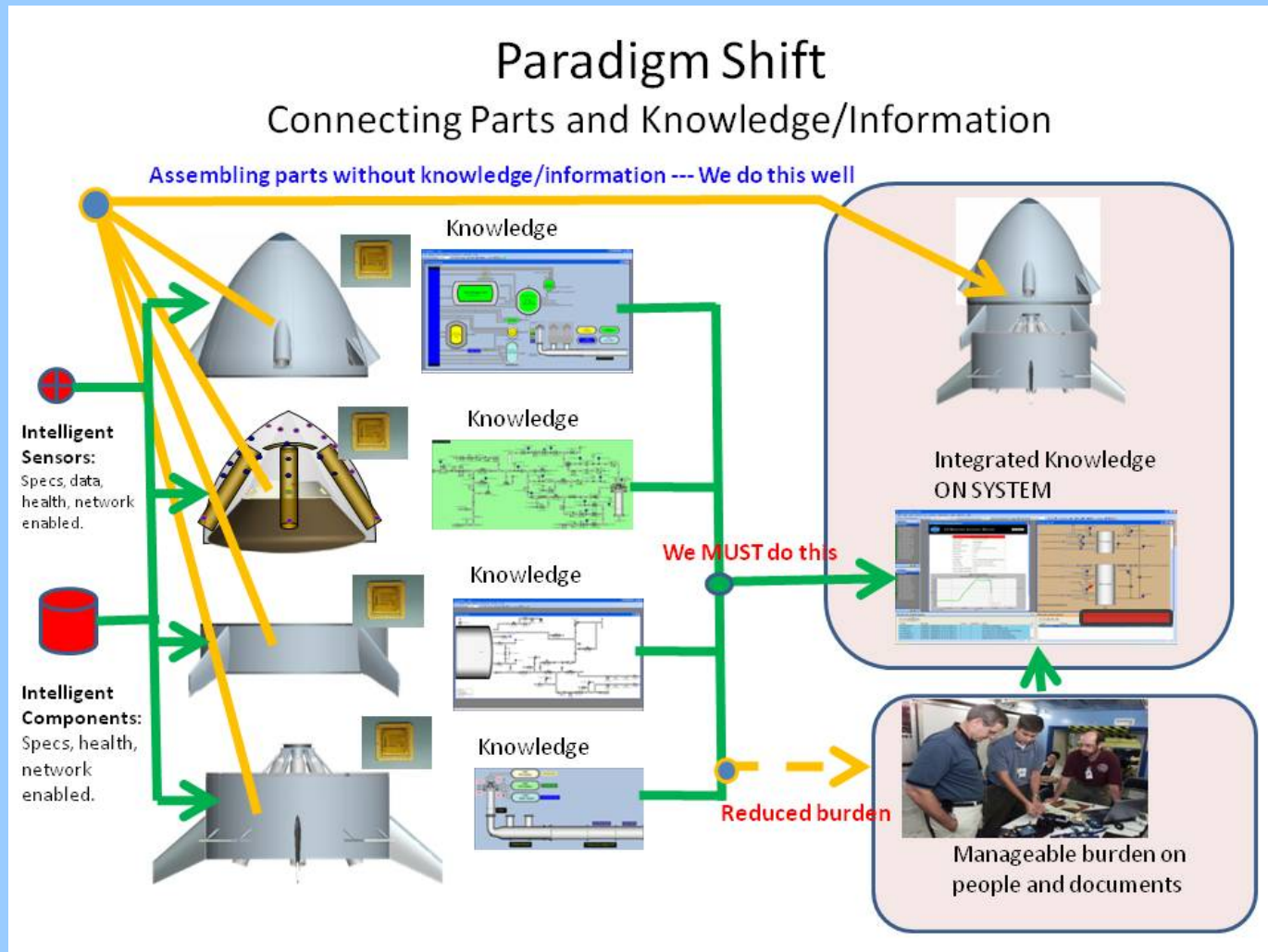


ISHM in Systems Design, Integration, and Engineering (SDI&E)

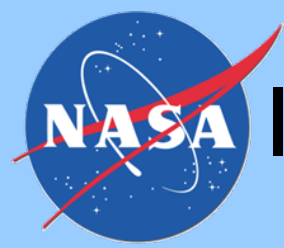
- SDI&E practices are employed to build complex systems.
- SDI&E for aerospace systems has developed into its own discipline, although theories and concepts have not been adequately formalized in an academic sense.
- The role of ISHM in SDI&E is linked to the concept of ISHM-DM's, whereby every element 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)



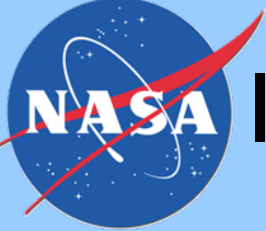
ISHM concept for systems integration of ISHM-DM's



Intelligent Control for ISHM-Enabled Systems

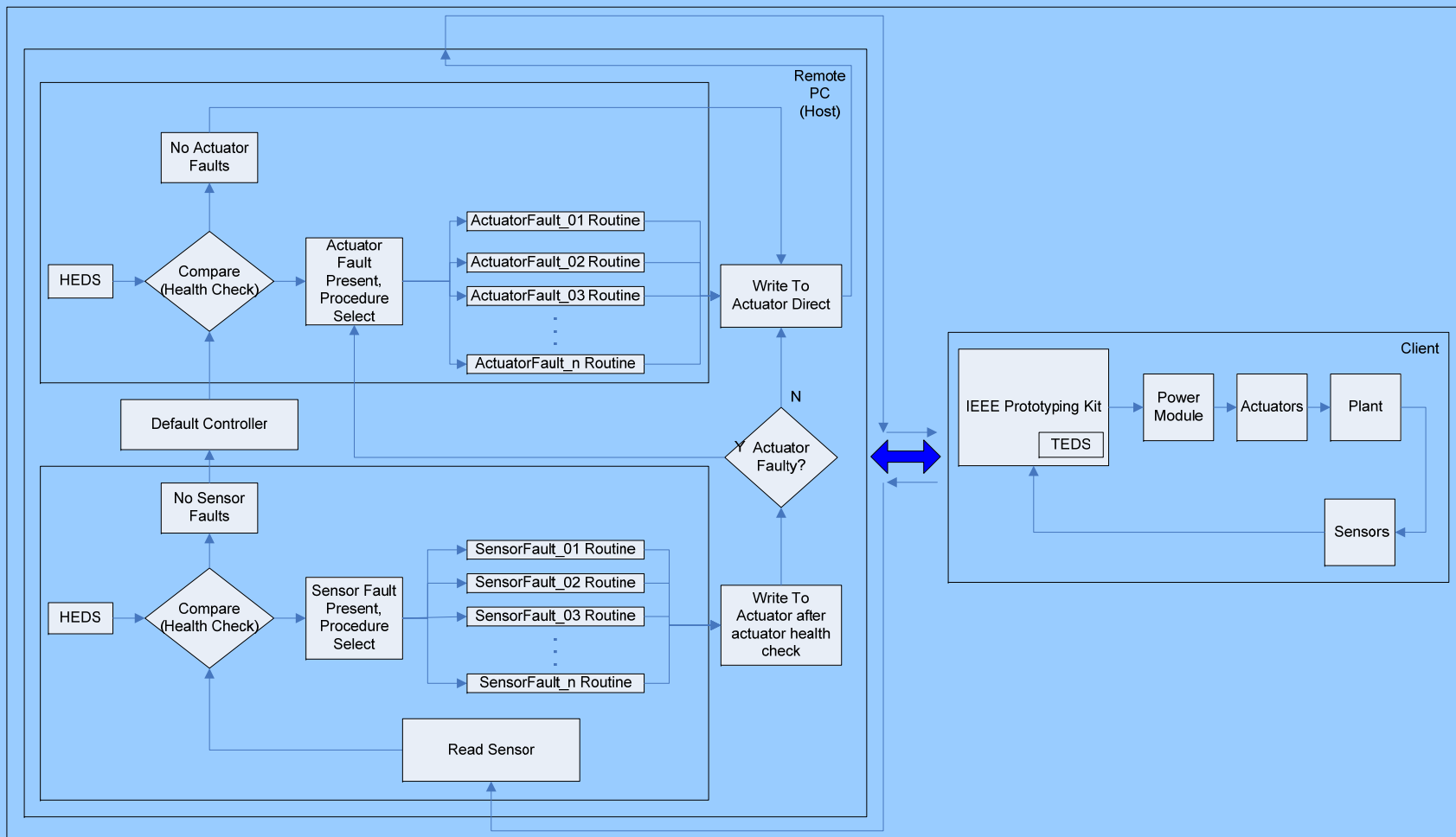
- Control of complex systems that are ISHM-enabled is a nascent area, simply because ISHM itself is also relatively new.
- The objective is for the control function to make use of system health information in order to achieve its objectives.

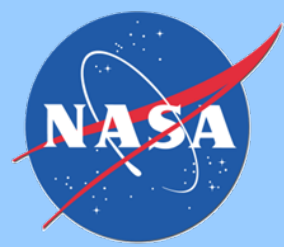
The paradigm implies that control systems become users of health information, while at the same time making use of actuators to help further improve determination of the system health



Intelligent Control for ISHM-Enabled Systems

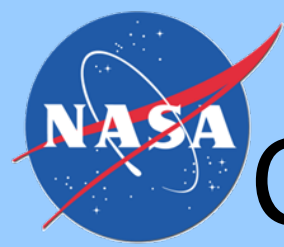
Example Application (Reference 18 of the paper)





Conclusions

- A sound basis to guide the community in the conception and implementation of ISHM capability in operational systems was provided.
- The concept of “ISHM Model of a System” and a related Data, Information, and Knowledge (DlaK) architecture were described. The ISHM architecture is independent of the typical system architecture, which is based on grouping physical elements that are assembled to make up a subsystem, and subsystems combine to form systems, etc.
- It was emphasized that ISHM capability needs to be implemented first at a low functional capability level (FCL), or limited ability to detect anomalies, diagnose, determine consequences, etc. As algorithms and tools to augment or improve the FCL are identified, they should be incorporated into the system. This means that the architecture, DlaK management, and software, must be modular and standards-based, in order to enable systematic augmentation of FCL (no ad-hoc modifications).
- A set of technologies (and tools) needed to implement ISHM were described. One essential tool is a software environment to create the ISHM Model. The software environment encapsulates DlaK, and an infrastructure to focus DlaK on determining health (detect anomalies, determine causes, determine effects, and provide integrated awareness of the system to the operator). The environment includes gateways to communicate in accordance to standards, specially the IEEE 1451.1 Standard for Smart Sensors and Actuators



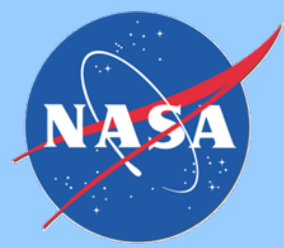
Challenges and Opportunities

- EDUCATION

- Inclusion of ISHM in the design process (Design for ISHM).
- ISHM concept as a knowledge-based capability.
- Software environments to build ISHM models.
- Physics of failure.
- Anomaly detection (algorithms, approaches, strategies).
- Failure modes and effects analysis (FMEA) and root-cause tree analysis concepts and automation.
- Software environments supporting processing within networked intelligent elements and standards-based interaction.
- User interfaces: “integrated awareness of system elements.”

- RESEARCH

- ISHM incorporates multiple disciplines: physics modeling or modeling of any phenomena occurring in a system, algorithm development, knowledge systems, user interfaces, software environments, intelligent systems, standards, network capabilities, etc.
- Laboratory/pilot implementations (e.g. university power plant) for validation of the research. Very few “low functional capability” ISHM systems have been implemented (Space Shuttle Main Engine, Boeing 777 are the more visible cases). Experimental validation will bring high visibility to potential users/investors (NASA, DoD, DoE, Chemical and Oil industries, power plants, ships, etc.).
- ISHM is in its infancy, but can develop very fast. Three notable annual conferences specific to ISHM are on- going:
 - ISHM Conference (usually in Covington Ky. Or Cincinnati, OH), started by AFRL (In its fifth year or so).
 - Prognostics and Health Management Annual Conference (its second event to take place at the end of September, in San Diego).
 - AIAA Infotech@jAerospace Conference has added ISHM as a technical area.
- ISHM capability can be implemented and validated without disturbing on-going normal operations.



MOON

WEEEEEE!!!

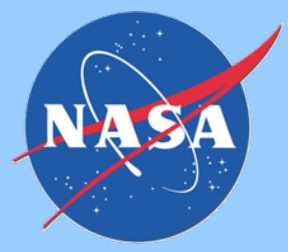
EARTH

It looks like someone needs a hug!

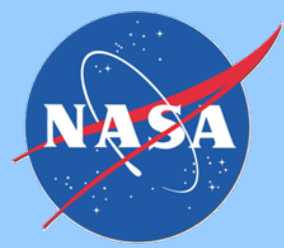
HEY! A little help over here!

Where did I leave the keys?

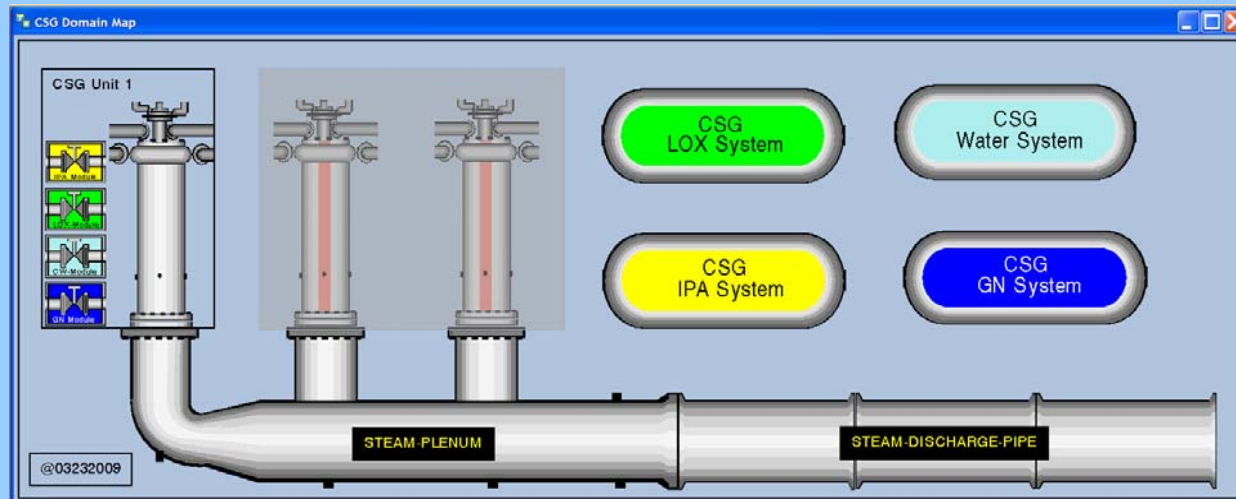
Mars Colony



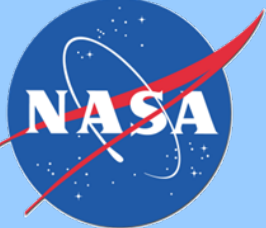
Backup Slides



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

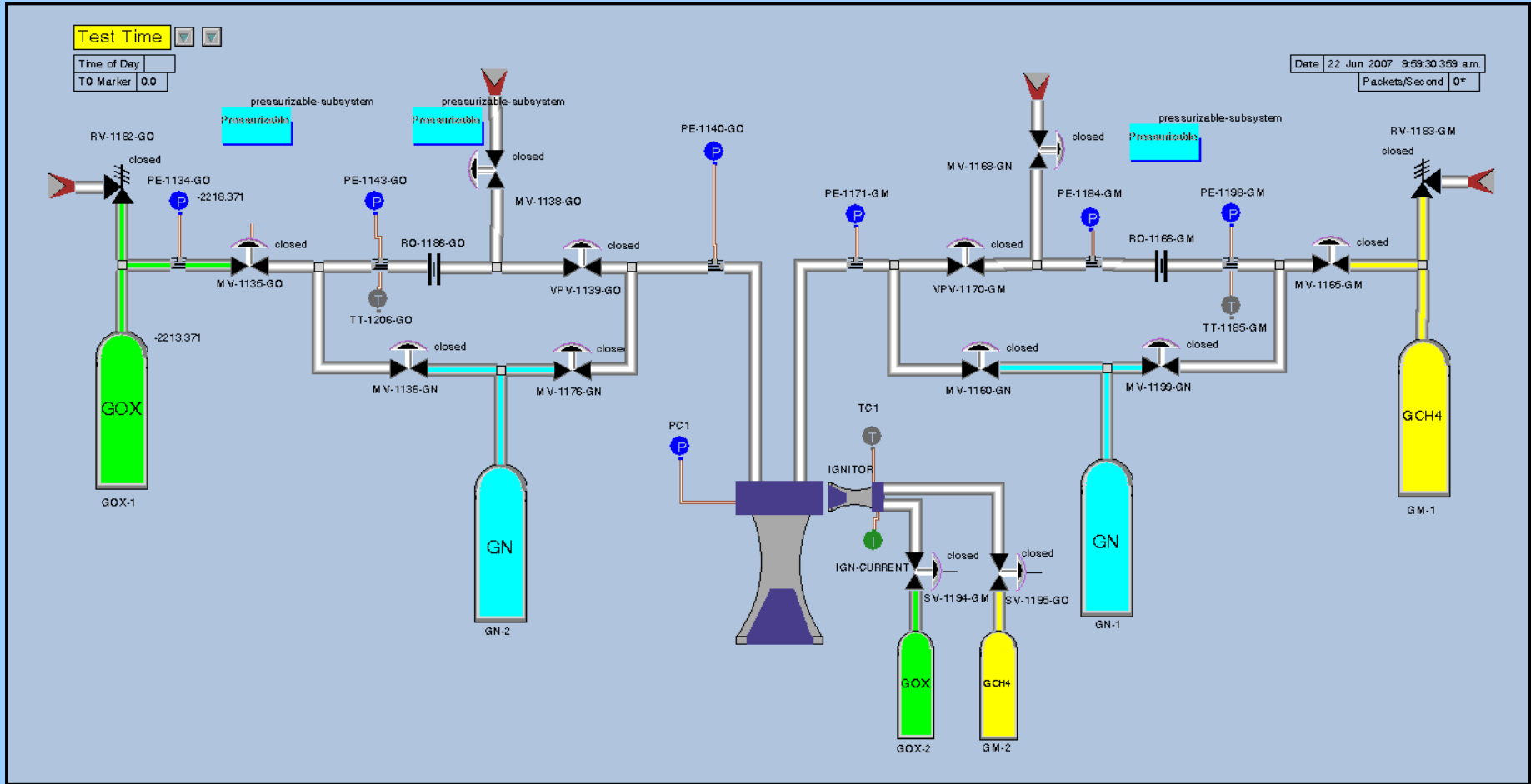
TC-14A4108-IPA Real-Time Plot of TC-14A4108-IPA

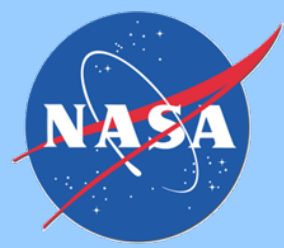
BLUELINE-ALARM-QUEUE REDLINE-ALARM-QUEUE

EDS Explorer EDS Attributes



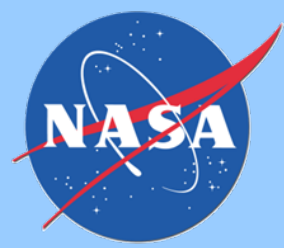
Elements of an ISHM System: ISHM Model - Proximate Cause Analysis



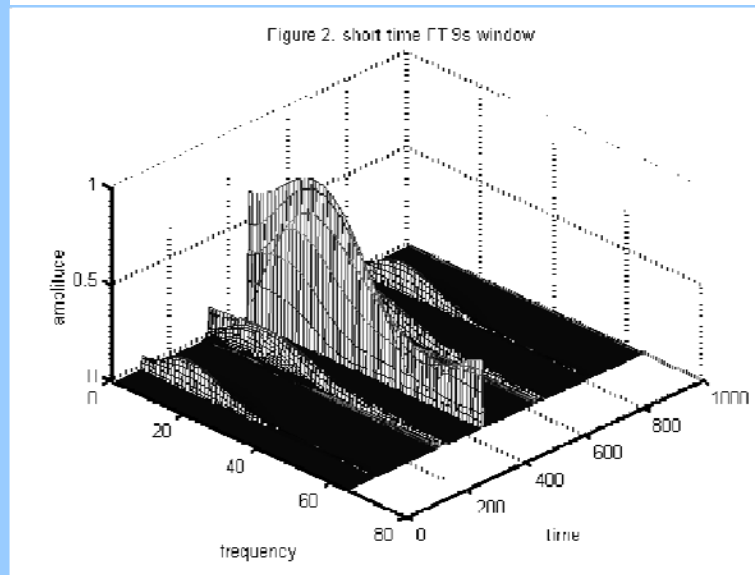
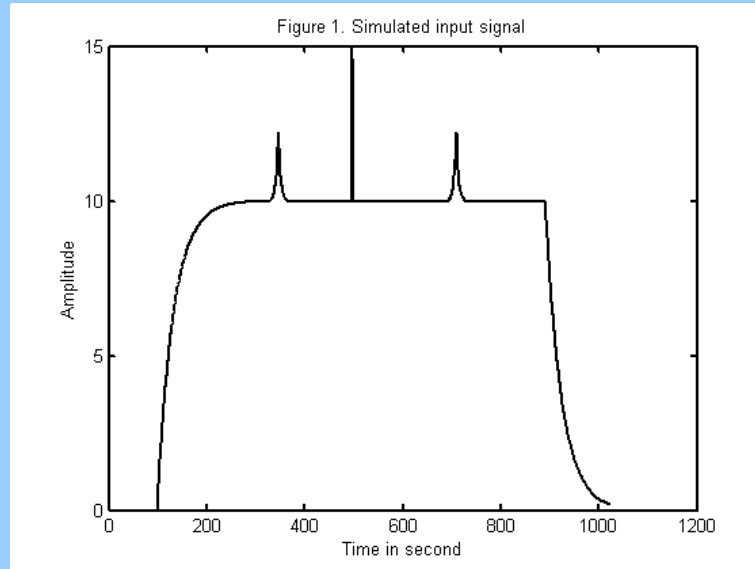


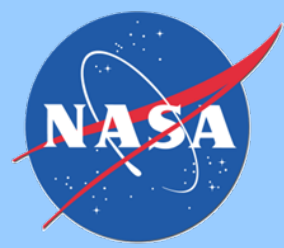
List of Anomaly Detection Capabilities

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.



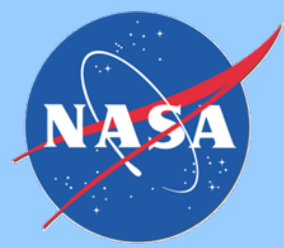
Short-Time Fourier Transform Segmentation



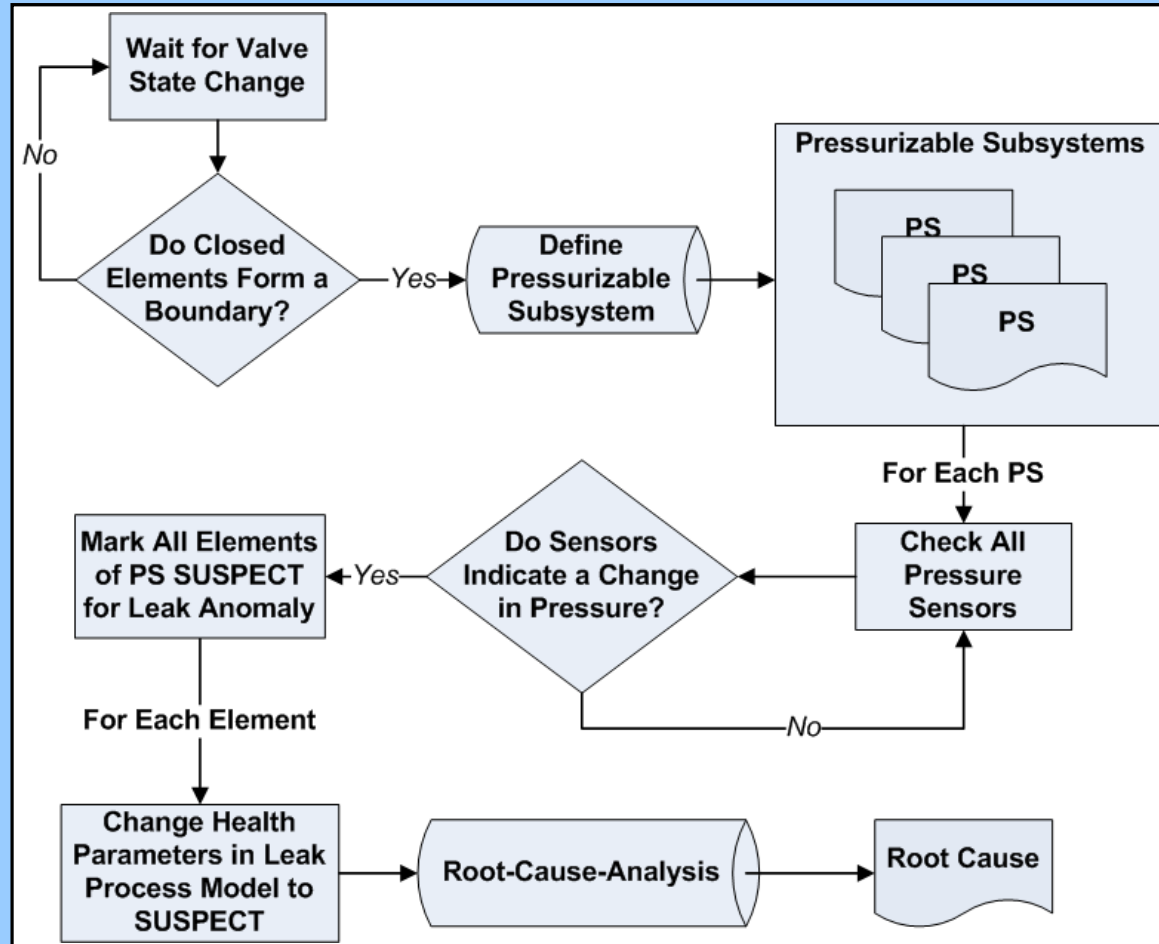


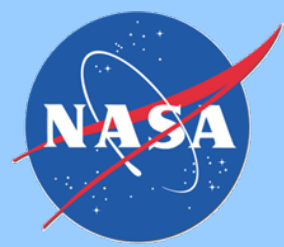
Determining Valve-State

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				

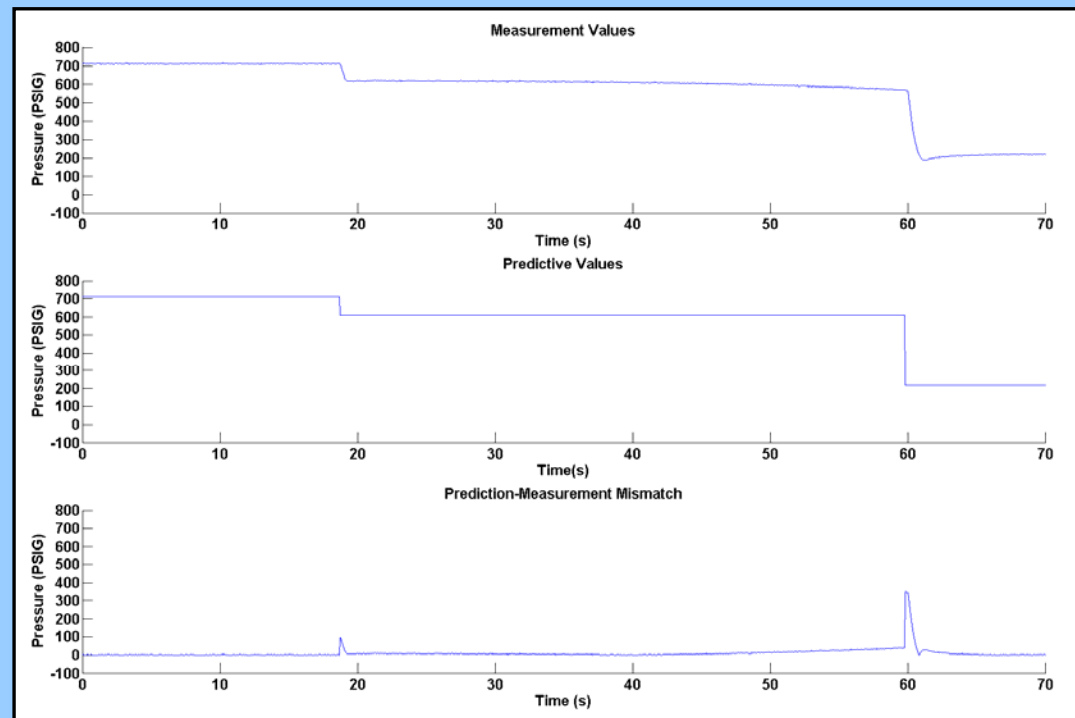
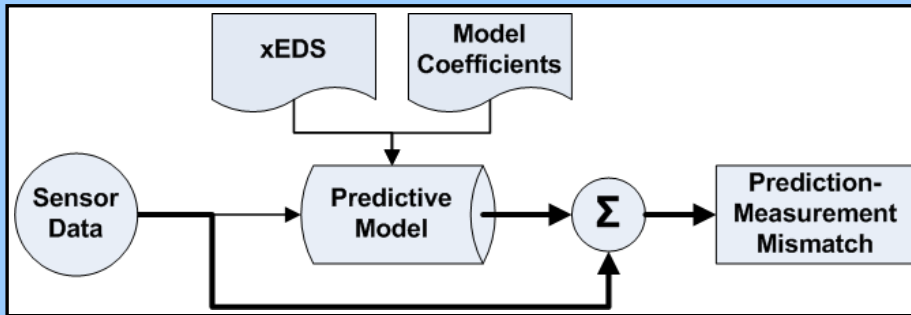


Checking for Pressure Leaks





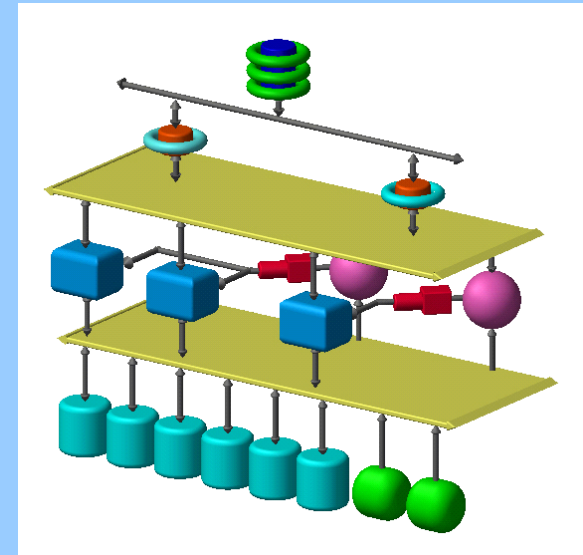
Runtime Predictive Modeling





Intelligent Sensors

- 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.)



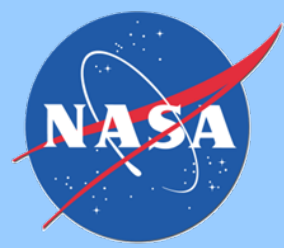
Intelligent Sensors have embedded ISHM functionality and support **Smart Sensor** standards



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

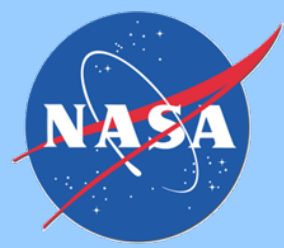
- ***Object orientation***: object representation of system physical elements and associated process models is the best way to embed DiaK in a systematic and in an organized manner.
- ***Distribution of ISHM-DM's within and across networks***: ISHM-DM's might be distributed among processors connected 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



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.