Integrated Health with Networked Intelligent Elements (IHNIE) Prototype

NASA John C. Stennis Space Center Program Development Directorate Technology Development and Transfer Office

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NASA H&RT Related Projects

Integrated Health with Networked Intelligent Elements (IHNIE) Prototype

Project Title: ISHM Testbed and Prototypes (ITP)
Project Number: ASPS-002/040
Project Manager: Dan Duncavage (JSC).
Principal Investigator: Fernando Figueroa (SSC).

This Project is the result of the merging of two Intramural proposals:

ASPS-040: Integrated Health with Networked Intelligent Elements (SSC)
ASPS-002: ISS as a Testbed for Vehicle Health Management Technologies (JSC)

This Project supports the first Exploration Systems cycle of innovation (FY05-08), within the Advanced Space Platforms Systems (ASPS) Element Program, the Technology Maturation Program (TMP) major program, and the Exploration Systems Research and Technology investment portfolio.
Reporting Organizational Chart

Integrated Health with Networked Intelligent Elements (IHNIE) Prototype

SSC Exploration Systems
Mission Directorate

ESR&T Element Mgr
Robert Wegeng

Project Manager
Daniel Duncavage, JSC
Principle Investigator
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ISS Avionics and Software Office

ARC Center Lead

GRC Center Lead

KSC Center Lead

MSFC Center Lead

JPL Center Lead

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To increase the safety, affordability and sustainability of Exploration missions through Integrated Health Management of complex, mission-critical vehicles and systems.
### ISHM LAYERS IN EXISTING OPERATIONS

<table>
<thead>
<tr>
<th>Layer 1</th>
<th>International Space Station</th>
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<tbody>
<tr>
<td>Vehicle/ Test Stand</td>
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<table>
<thead>
<tr>
<th>Layer 2</th>
<th>Rocket Engine Test Stand</th>
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<tbody>
<tr>
<td>Astronaut/ Test Conductor</td>
<td></td>
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</table>

| Layer 3 | |
|---------| |
| Control Room |

| Layer 4 | |
|---------| |
| Back Control Room |
Objectives of ISHM Capabilities

Complete knowledge of the condition of every element in a system (sensors, components, and processes).

- Determination of the quality, accuracy, and reliability of the data (in the case of sensors).
- Detection of anomalous behavior of the system elements.
- Determination of the cause of anomalous behaviors (diagnostics).
- Prediction of future anomaly occurrences (prognosis).
- Guidance on following operating procedures to avoid human mistakes.
- Recommend a reasonable course of action to fix a problem.
- Store relevant information pertaining to system performance and health for use by management and investigation teams.
- Provide an integrated view of the system.

Technology measured by TRL and Functional Capability Level (FCL) in %
• Test stand itself to develop and validate ISHM Technologies.
  – Extensive historical data to define a solid baseline prior to ISHM implementation.
    • Discrepancy reports (key knowledge of failure modes for HM Systems).
    • Test data (means of validation).
  – Expert Test Engineers (key component to build knowledge bases and to experience and acknowledge ISHM benefits – should become advocates of the technology).
  – Data from prior test programs (more validation and knowledge management).
  – Data and information available in real time as tests are executed.
  – Suitable for staged implementation, e.g. the GN subsystem, followed by the RP subsystem, and so on.

• The test stand can also be established as a permanent site to test new HM elements such as “intelligent sensors,” “intelligent components,” HM system integration frameworks, etc. Adding new sensors or making modifications is much less complicated than in the case of flight hardware.

• Relevant facility in that ground and flight are integrated systems, since flight systems will be tested in these facilities (facilities replicate vehicle propulsion subsystems).
ISHM Challenges

• ISHM Architectures and Frameworks: must support “intelligent” data, information, and knowledge management (storage, availability, interpretation, integration, maintenance, modification, flexibility, evolution).
• Sensor health assessment.
• Models for failures; methods for detection.
• Complete data base of sensor/process/system failures.
• Advanced/Intelligent Integrated Control Functionality (PSU).
• Credibility: Quantify benefits of ISHM technologies.
• Visualization for awareness and quick reaction by operator (Visual ISHM).
ISHM Credibility

• Measure benefits of ISHM-enabled systems.
• Prove effective integration of distributed intelligent elements (real or virtual).
  – Deliver timely information.
  – Deliver context-proper information
• Prove expandability on relevant continuous operation systems.
• Prove self evolution of ISHM (again needs relevant continuous operation system).

All can be done to reach a high percent of Functional Capability Level (X%), with existing ISHM technologies.
ISHM Development Tools

• Hardware Testbeds
  – Test Stands
  – International Space Station

• Software Testbeds/Environments – appropriate tools that allow reasoning and decision making involving time and behaviors, in a setting that includes knowledge, information, and data, from a wide range of ISHM related technologies.
Test Stand: Ready System to Develop and Validate ISHM Technologies

Integrated Health with Networked Intelligent Elements (IHNIE) Prototype

- Integration architectures for health management and operations.
- Networked intelligent elements (sensors, components, processes).
- Measurement/Information Fusion Algorithms.
- Anomaly Detection, diagnostics, and prognostics methods.
- Model Based approaches to accomplish health management functions.
- In general, development and validation of software technologies that address the capabilities of an ISHM.

Intelligent Integration Framework developed using the G2 software environment.

- Commercial software developed specifically for creation of intelligent applications.
- True object oriented environment (multiple inheritance, AI tools, ANN tools, reasoning and decision making using time, events, etc., encapsulation of data, information, knowledge, functions, and relationships, bridges to communication protocols (ethernet, devicenet, etc.), databases, spreadsheets).
Summary ISHM Testbed Environments

Integrated Health with Networked Intelligent Elements (IHNIE) Prototype

SSC ISHM Testbed Environments

- Test Stand as System of Systems
  - Test Stand with ISHM to properly test the Test Article
  - DACS Laboratory/Cryo Component TF
    - Verification of components, sensors, data acquisition and processing systems, controls, software.

ISHM Technologies
- Integration Architecture/Framework for networked intelligent elements
- Data/Information/Knowledge Management (storage, transmission, maintenance, evolution, suitability (context), availability (timely))

We Provide
- A base/flexible architecture.
- A catalog of methods/algorithms.
- A catalog of anomalies.
- Intelligent networked elements and/or hook-ups (HW/SW)
Real or Virtual Framework Architecture

Integrated Health with Networked Intelligent Elements (IHNIE) Prototype

I-System

Health and Process/System Information

I-Process

Health and Sensor/Process Information

I-Sensor

TEDS

HEDS

I-Sensor
G2 ISHM Framework

Integrated Health with Networked Intelligent Elements (IHNIE) Prototype

**OBJECT**

- Component
- Sensor
- Process

**Classes**

- Tank
- Valve
- Pressure
- Temperature

**Sensor**

- Thermocouple
- Strain-Gage
- Piezo
- RTD

**Instances**

- LOX-E1-01
- PRES-TOP
- TEMP-TOP
- PRESSURIZE

**Rules**

- Electrical Resistance and Temperature

**Info Fusion**

- Analytical
- Statistical
- Qualitative

**Properties**

- Sensors:
  - Top Pressure
  - Bottom Pressure
  - Top Temperature
  - Bottom Temperature

- Processes:
  - Pressurize
  - Fill

- Specs:
  - Capacity

- Contents:
  - Condition

**Inheritance**

- Inheritance of conceptual understanding of process in sensor
SSC ISHM Development: Centralized G2-Based ISHM Incorporating Smart Sensors

Emphasis on Architecture And Framework for ISHM Functionality
JSC/SSC ISHM Testbed Architecture

Integrated Health with Networked Intelligent Elements (IHNE) Prototype

Data Sources
- Telemetry from Vehicle and Simulations
- Distributed Health Metrics (TEDS/HEDS) Databases
- Conventional and Smart Sensors
- Design Databases (EDMS, PVCS, etc)
- Sensor, Process & System Knowledge Bases

Information Distribution Architecture
- High Speed Comm Protocols
- Interoperability Standards
- Diagnostic Data Server
- Knowledge Mining Application

Analysis Components
- Information Extraction and Fusion
- Inference and Decision Making
- Quality of Service
- Information Displays
- External Client Applications (e.g. BAA and ICP)
- Smart Sensor Algorithms
Test Stand with its ISHM: Effective Testing of test articles with ISHM capabilities

when the standard deviation of the reading of any pressure-sensor P during the last 5 seconds > (the standard deviation of the reading of P during the last 2 minutes + MinDELTA) then change the control icon-color of P to red and inform the operator that "Noise Level Unacceptable - [(the pressure-sensor)]"
ISHM DACS LAB SIMULATION, TEST SYSTEMS INTEGRATION, & VERIFICATION
DACS Development Testbed

Integrated Health with Networked Intelligent Elements (IHNE) Prototype

CONTROLS DEVELOPMENT

DAS DEVELOPMENT
Valve Testing: DACS Laboratory

Integrated Health with Networked Intelligent Elements (IHNIE) Prototype
Needed from PTD Operations

We will develop ISHM capability for RETS without interfering with scheduled activity.

Needs:

• Access to real time data from E1 (facility sensors – our current model is of the hydraulic system).
• Advice from expert test engineers and technicians.
ISHM Projects Contribution to PTD

- Opening up a new line of business (Penn State is first customer).
- Creating technological advantage so that SSC will continue to be the facility of choice for rocket propulsion testing throughout the World (we are defining what will be the test-stand of the future).
  - ISHM-enabled test stands will be very attractive to customers, because Exploration Systems has indicated that products built for the new mission will have to have ISHM capability. These products (in particular rocket engines and all its components) will need to be tested using ISHM-enabled RETS.
- An ISHM Screen in the control room to help determine the condition of all elements in the test facility, and provide timely and focused information to diagnose anomalies.
Verification Process

Integrated Health with Networked Intelligent Elements (IHNIE) Prototype

Test Article ISHM

DAS Graphical Interface

Analytical System Model

Signal Conditioning

HS DAS & Data Processing

LS DAS & Data Processing

Field Simulator

Field Devices

Programmable Logic Controllers

Data Simulator

User Interface Scripting

Controls Graphical Interface
DACS Development Laboratory

The Development Laboratory Provides an “Off-Stand” Data Acquisition & Control System (DACS) with capability to provide support to propulsion ground testing projects.

- DACS Development & Verification – Development and verification of control screens, controls PLC software, data acquisition software
- Controlled Trouble Shooting – Can isolate systems and inject known parameters to target specific areas of interest.
- Field Simulation Capability – Ability to simulate the field environment by utilizing a one to one match of hardware and software as in the E-Complex Test Facilities.
- Hardware Qualification – Qualification of signal conditioners, data acquisition, controls processors and I/O, and testing of field devices prior to installation.
- Risk Reduction – Provides an environment to verify that systems are fully operable prior to integration within the test stands, which aids in providing safety, significant cost savings, and risk reduction.
DACS Development Laboratory

- Various System/Sub-System Simulation Capability – Can simulate end-to-end test and validate input and output parameters.
- Low/ High Speed Data Acquisition – All system simulations can be recorded via HS or LS DAS for retention of data.
- Evaluation of System Upgrades
- Evaluation and Integration of New Technologies – Can evaluate new technologies and verify configurations prior to implementing integration into existing systems.
- Verified Spare Equipment – Ability to qualify spare equipment and maintain calibration cycles for utilization within the test cells.
• Control Capabilities
  – Multitude of Various Types of Controls Capabilities
  – Five SLC-500 Processors for E1 Simulation – Can handle a multi-processor simulated environment
  – Flexible Integration of Field Devices
    • I/O Checkout Cabinet
    • Mobile I/O Checkout Cart
  – Controls Display & Ladder Logic Software

• Data Acquisition Capabilities
  – Pacific Instruments Signal Conditioners
  – Techkor RMS & Speed Conditioners
  – Tustin MUX/ADC (analog, discrete, & collector)
  – Racal High Speed DAS Channels (100 Ksp)
  – Voltage & Frequency Standards
  – Termination Cabinet & Patch Panel
  – DAS LabView & G2 Software
Stennis Modeling Capabilities

Industry Standard & Custom Methods

- Rocket Propulsion Test Analysis (RPTA)
- Pro/Engineer (CAD) & Pro/Mechanica (Analysis)
- ROCETS Code (Rocket Engine Transients Simulation)
- Fanno Flow Code
- NIST properties for real Fluids
- ALGOR Pipeplus
COMPONENT, ENGINE, & FULL SCALE INTEGRATION TESTING
SSC Provides a Range of Facilities

B-1/B-2 Test Stand

A-2 Test Stand

A-1 Test Stand

E-2 Test Stands

E-3 Test Stands

E-1 Test Stands
E-1 Test Stand Provides Large Thrust Component Test Capability

THRUST CAPABILITIES:
- Cell 1 – 750,000 lbf horizontal thrust
- Cell 2 – 60,000 lbf at angles up to 10° above horizontal
- Cell 3 – 60,000 lbf at angles up to 10° above horizontal

HIGH PRESSURE GAS AND CRYOGENIC LIQUID VESSELS:
- LOX Storage: Total of 48,240 gal @ 165 - 9,000 psig
- LOX Catch Tank 28,000 gal
- LH$_2$ Storage: Total of 75,653 gal @ 33 - 8,500 psig
- LN$_2$ Storage Tank 28,000 gal @ 165 psig
- UHP GH$_2$: Total of 1,875 ft$^3$ @ 15,000 psig
- UHP GN$_2$ Storage: Total of 2,750 ft$^3$ @ 4,500 - 15,000 psig
- HP He 1,515 ft$^3$ @ 4,500 psig

TEST CONTROL CENTER (TCC):
- 128 High Speed Data Channels
- 512 Low Speed Analog Channels
- Facility control consoles
- Environmentally controlled
- Closed-circuit television
- Graphics display instrumentation system
E-1 Test Stand
## SSC ISHM Testbeds: Technology Development Chart

### Potential Testbeds

<table>
<thead>
<tr>
<th>Thrust (K Pounds)</th>
<th>Potential Testbeds</th>
<th>TRL</th>
<th>SW Off-line</th>
<th>SW On-Line</th>
<th>SW + HW On-Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.5</td>
<td>Portable Test Stand</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>1-30</td>
<td>E3</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>30-100</td>
<td>E2</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>100-750</td>
<td>E1</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>1000</td>
<td>A-1/A-2</td>
<td></td>
<td>X (SSME)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>B-1/B-2</td>
<td></td>
<td>X (RS68)</td>
<td></td>
<td>Holy Grail</td>
</tr>
</tbody>
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- **Increasing TRL of Propulsion Test Article**
- **Increasing Scale/Size/Complexity**
Summary

• ISHM is a critical technology for future space missions.
• The development effort leverages
  – Technology
  – Available test bed resources
  – Broad team expertise
• Brings technology developers, research scientists, and operations people together to design, test, and validate.