Human Spaceflight ISHM Technology Development

Mark Schwabacher
OCT GCD Autonomous Systems Project Manager
AES Habitation Systems ISHM Lead

NASA Spacecraft Fault Management Workshop
April 10, 2012
Overview

• Two ISHM tools that are widely used in human spaceflight
  – TEAMS
  – IMS (aka AMISS)
• Two past and current applications of ISHM in human spaceflight
  – AMISS for ISS
  – Ares I-X Ground Diagnostic Prototype
• Current technology development in OCT and AES for 2 testbed domains
  – Habitats
  – Cryogenic fuel loading
Functional Fault Modeling in TEAMS

• Goals
  – Uncover design issues across subsystem boundaries
  – Assess effectiveness of sensor suite to isolate faults to LRU
  – Provide Diagnostics Model for operations
  – Document failure effect propagation times

• Approach
  – Model basic system connectivity, interfaces, interactions, and failure modes
  – Use information from schematics, FMEA, IP&CL, ICD, etc.
  – Implement using COTS tool called TEAMS (Testability Engineering and Maintenance System) that was originally developed under ARC SBIR funding
  – Represent propagation of failure effects along physical paths (fluid, thermal, electrical, mechanical)
  – Transform failure effects as they propagate to a sensor
  – Sensor data evaluation represented as nodes (‘test points’)

• Results
  – Applied to SLS, Ares I, LADEE, HDU, KSC GO

POC: Eric Barszcz; eric.barszcz@nasa.gov
Inductive Monitoring System (IMS)
(aka Anomaly Monitoring Inductive Software System (AMISS))

- Data-driven one-class anomaly detection system
- Automatically derives system models from archived or simulated nominal operations data
  - Does not require off-nominal data
  - Does not require knowledge engineers or modelers to capture details of system operations
- Analyzes multiple parameter interactions
  - Automatically extracts system parameter relationships and interactions
  - Detects variations not readily apparent with common individual parameter monitoring practices
- Able to detect subtle anomalies and faults that are not listed in the FMEA
- Monitoring module can detect anomalies whose signatures are not known ahead of time
- On-line monitoring takes as input observations about the physical system (parameter values) & produces “distance from nominal” anomaly score
- Algorithm:
  - clusters the training data
  - uses distance to nearest cluster as anomaly measure
- Developed by Dave Iverson of ARC
IMS for ISS

• Has been running 24/7 at JSC MCC since 2008, monitoring live telemetered sensor data from the ISS
• Has been certified (Level C) for that application
• Monitors:
  – Control Moment Gyroscopes (CMGs)
  – Rate-Gyro Assemblies
  – External Thermal Control System (ETCS)
Ares I-X Ground Diagnostic Prototype

- NASA ARC, KSC, MSFC, and JPL worked together to build a prototype ground diagnostic system
- Was deployed to Hangar AE at KSC, where it monitored live data from the vehicle and the ground support equipment while Ares I-X was in the VAB and while it was on the launch pad
- Combined three data-driven and model-based ISHM algorithms: TEAMS-RT, IMS (aka AMISS), and SHINE
- Focused on diagnosing the first-stage thrust vector control and the ground hydraulics
- Ensured a path to certification
- Kept up with live data from 280 MSIDs using only a PC
- Led by Mark Schwabacher at ARC
- Funded by Ares I, by ETDP, and by KSC Ground Ops
2 Testbed Domains

Habitats

Cryogenic fuel loading
3 Programs

- OCT Game Changing Development (GCD)
  - TRL 4-6
- HEOMD Advanced Exploration Systems (AES)
  - TRL 5-7
- HEOMD Ground Systems Development and Operations (GSDO) Program
  - TRL 7-10
5 Projects

- OCT GCD Autonomous Systems (AS)
- AES Autonomous Mission Operations (AMO)
- AES Habitation Systems (HS)
- AES Integrated Ground Operations Demonstration Units (IGODU)
- GSDO Advanced Ground Systems Maintenance (AGSM) element
2 testbed domains, each supported by 3 projects

- **Deep Space Habitats**
  - GCD AS
  - AES HS
  - AES AMO

- **Cryogenic Fuel Loading**
  - GCD AS
  - AES IGODU
  - GSDO AGSM
Summary of Programs, Projects, and Testbeds
Gen-1 Habitat Demonstration Unit (HDU)

- Tested in Arizona desert in 2010
- Not sealed
- Astronauts lived in it for multiple days
Gen-2 HDU: Deep Space Habitat (DSH)

- Tested in Arizona desert in 2011
- Added “X-Hab” inflatable loft and Hygiene Module
Gen-3 DSH

- Will be built inside 20’ Chamber at JSC in FY13-16
- Will be sealed
- Astronauts will live in it for 2 weeks
Gen-4 DSH

- Proposed to be attached to ISS in 2018
Major ISHM technologies being developed for habitats by OCT GCD AS

- Failure Consequence Assessment System (FCAS)
- Interface to planner
- Prognostics for forward-osmosis water recovery system
Failure Consequence Assessment System (FCAS)

- When a real or induced failure occurs in the DSH, the failure will be detected and diagnosed using a TEAMS
  - The diagnosis will determine which components have failed.
- FCAS will determine which components have stopped functioning as a result of the components that have failed.
- FCAS will determine the loss of capability resulting from the non-functioning components based on the current environment.
- A procedure to respond to the loss of capability will be automatically selected and displayed.
Integration of ISHM with automated planner

• Will be used in cases where no predetermined procedure exists to recover from the loss of capability (determined by FCAS).

• The loss of capability will be communicated to an automated planning system, which will either automatically or semi-automatically replan the rest of the mission to:
  – repair the components that are broken, and/or
  – accomplish as many mission objectives as possible given the loss of capability (if some broken components can’t be fixed).
ISHM for Habitats 10-year Roadmap

<table>
<thead>
<tr>
<th>FY</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16-17</th>
<th>18-21</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRL</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>
Cryogenic Propellant Loading
Goals of ISHM (and Automation) for Cryo

• Reduce cost, increase safety and reliability of cryogenic loading operations at KSC
• Prepare for future in-space cryo loading
IMS for cryo

• STS-119 launch attempt #1 (3/11/09) was scrubbed due to LH2 leakage exceeding specification at the Ground Umbilical Carrier Plate (GUCP)

• Real time monitoring subsequently deployed in KSC LCC for STS-134 (Endeavour) fueling operations in Spring 2011
Current work in ISHM for cryo

- IMS
- TEAMS modeling
- Knowledge-based Autonomous Test Engineer (KATE)
- Prognostics
- Physics-based models
Objectives of ISHM for Cryo

- Demonstrate autonomous cryogenic (LN2) loading operations at the Cryogenic Test bed Facility with recovery from selected failure modes
- Develop prognostics capability for selected complex failure modes
- Demonstrate tank health/diagnostics using physics models and simulation
Conclusions

• OCT and AES are developing ISHM technology in the following areas
  – Anomaly detection
  – Diagnostics
  – Prognostics
  – Failure Consequence Assessment
  – Interface to automated planning
  – Physics-based modeling

• These technologies are being tested using two testbed domains (habs and cryo), but are also applicable to many other systems (launch vehicles, robotic spacecraft, aircraft, etc.).