Human Spaceflight ISHM Technology Development

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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

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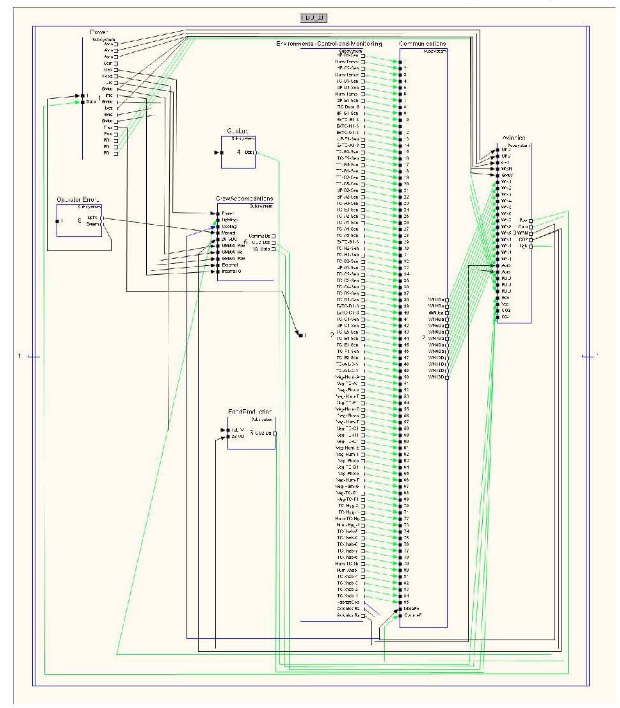
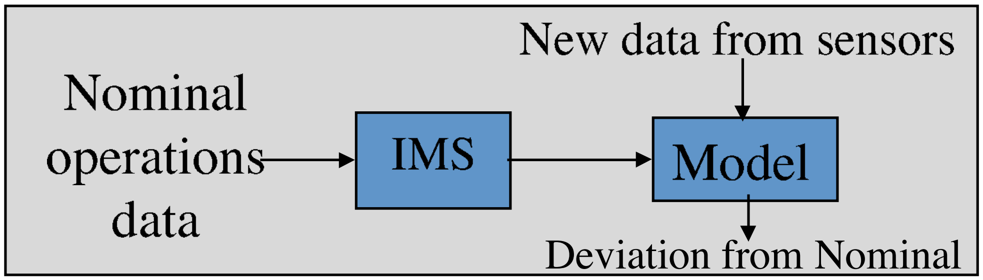
Habitat Demonstration Unit (HDU)

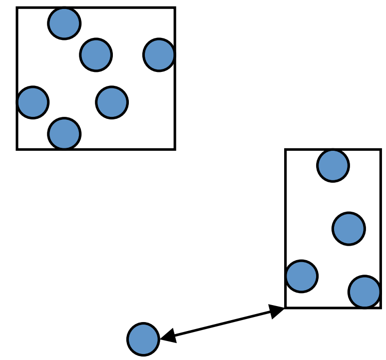


Functional Model in TEAMS

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

- Ares I-X: the first uninhabited test flight of the Ares I on 10/28/2009
- 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

Programs Projects 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)

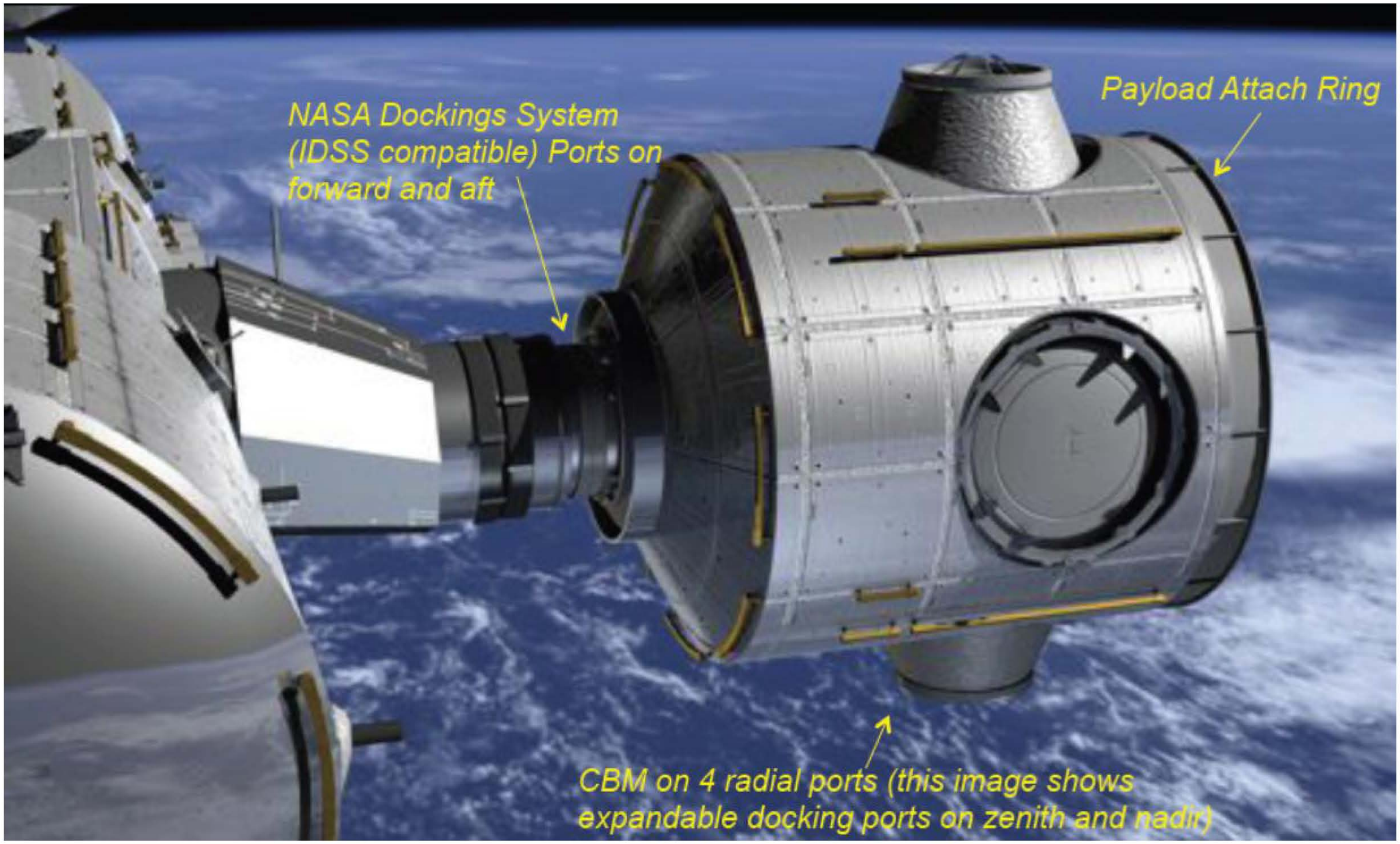
- Tested in Arizona desert in 2011
- Added “X-Hab” inflatable loft and Hygiene Module

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)

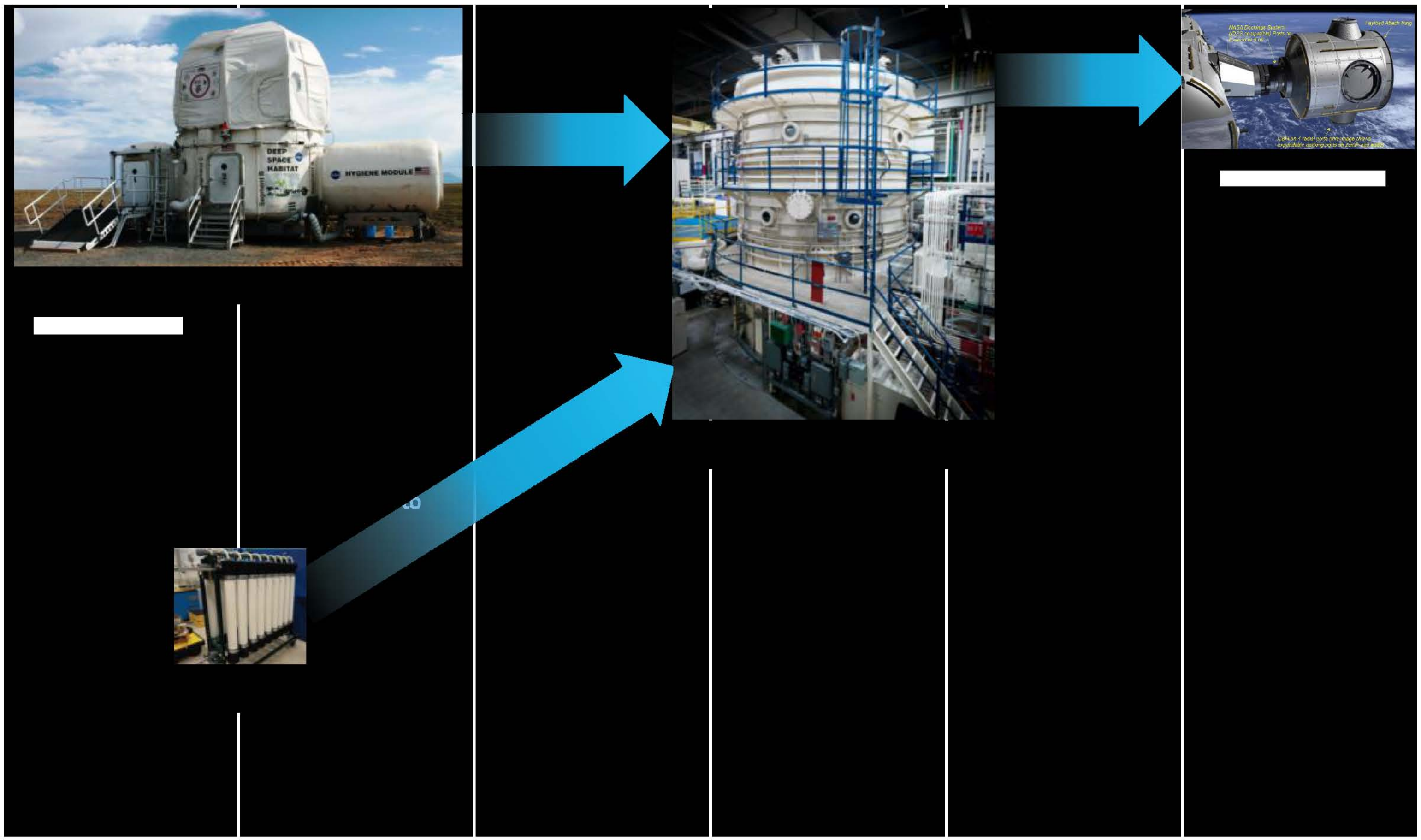
- When a real or induced failure occurs in the DSH, the failure will be detected and diagnosed using a TEAMS
  - The diagnosis will determine which components have failed.
- FCAS will determine which components have stopped functioning as a result of the components that have failed.
- FCAS will determine 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

Task



FY	12	13	14	15	16-17	18-21
TRL	4	5	6	6	7	8

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.).