New Developments in ISHM for NASA Ground, Launch, and Flight Systems

Fernando Figueroa
NASA Stennis Space Center

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**Paradigm for Autonomy and ISHM**

- Autonomy is a capability that is not absolute. There are degrees of autonomy, ranging from low levels to high levels, but there is no maximum level (how many autonomy strategies are implemented?).
- It is an evolutionary capability that can handle increasing degrees of complexity for reasoning and decision making.
- It must know the condition of the system elements and their ability to carry out specific tasks. Integrated System Health Management (ISHM) then becomes an enabler for autonomy.

NASA has developed the software platform **Autonomous Operations Flexible Software Suite (AO-FlexSS)** that is used to make systems operate with any desirable degree of autonomy and provides comprehensive system awareness to developers and users.
• Development of a software platform to implement autonomous systems enabled by ISHM and encompasses creation and execution of mission plans.
  – Validated initially at the KSC Cryogenic Testbed Laboratory, continues development using a portable launch system (autonomous propellant loading – APL), and infused at the High Pressure Gas Facility (HPGF) at NASA SSC, and the ORION Power System integrated health management.
  – NASA SSC plans to use AO-FlexSS to implement autonomous operations at the HPGF and potentially test stands.
  – Pilot space habitat implementations are being formulated.
Autonomy Software Functional Architecture with Knowledge Domain Models

Operational Plans use Application Domain Model

Autonomy Domain Model (ADM)

Autonomy Strategies

Mission Planning Domain Model (MPDM)

Mission

System Domain Model (SDM) (The Application)

Use

Sensor and Component Health

Enables Autonomy

Update SDM

Autonomous plan modifications

Autonomous Plan Sequence
Implementation of Autonomy:
NASA’s AO-FlexSS

1. Comprehensive Knowledge Modeling System
   a) Object libraries to create domain-knowledge from schematics (i.e. electrical, fluid, mechanical) including specification/behavior (i.e. sensors, pumps, RPCs)
   b) Supports modeling paradigms including physics, empirical, statistical, FMEA, system engineering processes

2. Integrated System Health Management (ISHM)
   a) Provides integrated and comprehensive system awareness
   b) Detects anomalies, diagnosis causes; predicts future anomalies

3. Autonomy Strategies
   a) Strategies based on using redundancy, alternate paths to an objective, alternate and intermediate goals, temporary solutions, and the like; can adjust operations- when unexpected anomalies occur

4. Autonomous Operations
   a) Incorporates autonomy strategies as part of operational plans
   b) Dynamically executes multiple plans simultaneously incorporating ISHM, autonomy strategies, concepts of operations and system state
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SSC High Pressure Gas Facility Implementation
NASA SSC High Pressure Gas Facility
Nitrogen System Control Screen
Not Schematic
ORION EFT-1 Capsule
ORION EFT-1 Power System Integrated Health Management
Overall Software Architecture

ORION Prototype

G2 System Modules
Layered Product Modules

G2 Engine

NASA AO-FlexSS
KSC Autonomous Propellant Loading Implementation

Not Schematics
Steps Toward Advancing ISHM

- Move beyond brute-force approaches. Enable the system to work the solutions based on concepts and models instead working out all the solutions off-line and creating a lookup table for use by the system.
- Paradigm: capability must leverage a knowledge domain and generic models. This is consistent with model-based systems engineering processes.
- Develop capable software platforms that enable creation of application knowledge models, and be able to leverage of these models for mission planning, reasoning, and decision making based on a broad range of process models that describe nominal and anomalous behaviors.