Integrated Vehicle Health Management for the 2nd Generation RLV Program

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Integrated Vehicle Health Management
2\textsuperscript{nd} Generation RLV Program
3\textsuperscript{rd} Generation RLV Program
The NASA X-37 IVHM Flight Experiment
Propulsion and Power IVHM
Integrated Vehicle Health Management (IVHM) Activity at Kennedy Space Center
IVHM Technology at JPL
Structures IVHM for 3\textsuperscript{rd} Generation RLVs
IVHM Systems Engineering and Integration

Integrated Vehicle Health Management Session Overview
Space Launch Initiative Goals

- Commercial Convergence – Flying on Privately Owned and Operated Launch Vehicles
- Competition - bringing innovation and new ideas to bear
- Assured Access – ensuring alternate means of getting to space despite launch mishaps
- The Ability to Evolve – adding new capabilities affordably as new mission needs emerge

2nd Generation RLV Program Goals

- Safety – Fewer than 1 loss of crew incident every 10,000 flights
- Reliability – Fewer than 1 loss of vehicle every 1,000 flights
- Cost – Less than $1000/lb payload cost to low earth orbit

Integrated Vehicle Health Management

2nd Gen Program Goals
Collect, process, and integrate information about the health of a launch system including the vehicle, subsystems, components, sensors, and ground support systems to make informed decisions and take appropriate actions to ensure the success of a mission.

- Anomaly detection and isolation
- Recovery/Reconfiguration
- Component degradation detection

The Union of Advanced Hardware and Software - Providing higher reliability, with greater robustness, at lower costs

Integrated Vehicle Health Management

IVHM
Propulsion/Engine/OMS
- Automated Data Analysis
- Condition based maintenance
- Advanced Real-time Anomaly Detection
- Advanced Instrumentation -MEMS, Hi temp, plum spec, high freq
- On-Board Automated Leak detection

Thermal Protection
- MEMs Temp/Pressure Sensors for Overgap Filling
- Real-Time Smart TPS Diagnostic SW

Airframe Structure
- Flight Fiber Optic (FO) Tunable Lasers
- Real-time Dynamic FO Measurements
- Acoustic Emission/Acoustic Ultrasound
- Advanced low/high temp sensitivity

Crew System
- Crew Monitoring/Diagnostic Systems
- Human-centered computing (HCC) Crew Smart Sensor Algorithms

Avionics
- Non-intrusive high response measurements of Pressure, Temp, Strain, Acceleration
- Fiber Optic Network Management SW
- Wireless High Speed Data Mgmt
- Multi-tasked/cause-effect data mining
- Multi-use Smart Sensor Algorithms
- Distributed decision-making software
- Vehicle and Subsystem MBR Tech
- Automated feature recognition
- Real-time fault prediction software
- Reprogrammable/Reconfigurable FDIR
- Automated software V&V technologies.
- Auto mission planners/schedulers

Ground System
- Advanced Launch/Mission Diagnostics/Prog
- Automated ground-based maintenance planners/schedulers/work order generator
- Facility Automated Leak detection Hand-Held Portable Maintenance Aid HW
- Automated TPS/Airframe NDE/NDI

Integrated Vehicle Health Management

Some IVHM Technologies
Integrated Vehicle Health Management Roadmap
Contribute to the increased reliability goals
(loss of vehicle <1 in 1000)

Vehicle and Ground Goals

- **Improve PROPULSION LOV**
  - W/O IVHM = 1 in 500
  - WITH IVHM = 1 in 3100

- **Improve AIRFRAME LOV**
  - W/O IVHM = 1 in 1400
  - WITH IVHM = 1 in 5400

- **Improve VEHICLE SYS LOV**
  - W/O IVHM = 1 in 700
  - WITH IVHM = 1 in 3500

- **Improve CREW SYS LOV**
  - W/O IVHM = 1 in TBD
  - WITH IVHM = 1 in TBD

- **Improve GROUND LOV**
  - W/O IVHM = 1 in TBD
  - WITH IVHM = 1 in TBD

Subsystem Objectives

- **Develop Engine IVHM Systems**
  - Improve catastrophic reliability
    - From 1 in 600 to 1 in 4100

- **Develop Tank/Feed IVHM**
  - Improve catastrophic reliability
    - From 1 in 5000 to 1 in 15000

- **Develop OMS/RCS IVHM**
  - Improve catastrophic reliability
    - From 1 in TBD to 1 in TBD

Tech Challenges

- **Improve Automated Fault Detection**
  - On-Board to 95%
  - Ground to 99.5%

- **Improve Automated Fault Isolation**
  - On-Board to 90%
  - OB+Ground to 95%

- **Provide less than 2% False Alarm Rate**
  - of all Detected Faults

- **Enable Mean Time To Repair MTTR**
  - of 300 Hrs

Approaches (Tasks)

- Adv Real-Time Anomaly Detection
- Advanced Sensor Validation
- Fault Tolerant Reconfigurable Controls
- On-Board Information Fusion
- Integrated Subsystem Testing
- Hi Temp, High Freq MEMs Sensors
- On-Board Automated Leak Detection

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**Requirements Flowdown (TA-5.1)**
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Interface Definitions TA-5.2
The introduction of IVHM will dramatically increase the amount of software required. Overall viability of IVHM may hinge on developing the ability to write and flight certify this software more cheaply than present practice, but with no compromise on safety. How can we do this?

- Formal Methods - Provable adherence to standards and requirements
- Agency Best Practices – Example: Shuttle software team
- Automated verification strategies. Use of Cardinality.
- Fault Tolerant software.
- Automated software generation environments
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Requirements Definition (TA-5.4)
Requirement: Five Flights between Overhauls
99.9 reliability/mission
Mission = 600 sec. @ 100% Power

3000 * 600 seconds
101% Power
Overhaul Every 3000 sec
Brute Force

300 * 600 seconds
115% Power
Overhaul Every 4500 sec
Accelerated Life

30 * 600 seconds
105% Power
Overhaul Every 4500 sec
Design for 125% Power
Design & Test

Red Team-Independent Requirements Review

Requirement: Completion by 2005
Limited total budget
Facility Availability

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Requirements Verification & Testing (TA-5.4)
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Roadmap
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<th>Technical Area</th>
<th>Name</th>
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**IVHM Interfaces**