INTEGRATED VEHICLE HEALTH MANAGEMENT

Integrated Vehicle Health Management Overview

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Overview / Project Goals

National Aeronautics R&D Policy and JPDO NextGen R&D Plan

"Develop technologies to reduce accidents and incidents through enhanced vehicle design, structures, and subsystems."

"Aircraft-level health-management systems, including sensors and analytical tools, will be developed that will identify problems before accidents occur. Research in health management requires not only monitoring and detecting, but also confident prognostics of latent potential failures before they occur … with extensive verification and validation of automation systems."

R-1280	Complete applied research on system health management to support alternative NextGen equipage decisions.

JPDO NextGen Research and Development Plan

IVHM Strategic Objectives Derive from Aviation Safety Program Objectives

1. **New operations**
   1.a. Robust, collaborative work environments
   1.b. Effective, robust human-automation systems
   1.c. Information management and portrayal for effective decision making

2. **Flight in or around hazardous conditions**
   2.a. Sensing and portraying environmental hazards
   2.b. Modeling and sensing airframe and engine icing and icing conditions

3. **Loss-of-control**
   3.a. Avoidance of conditions conducive to loss-of-control (sensing and planning)
   3.b. Detection of onset of loss-of-control (sensors, alerting, pilot awareness)
   3.c. Recovery from loss-of-control (piloted recovery, automatic recovery)

4. **Durable aircraft structures and systems**
   4.a. Full fundamental knowledge about legacy aircraft
   4.b. Start on knowledge about likely emerging materials and structures

5. **On-board system failures and faults**
   5.a. Detection of system anomalies and adverse events
   5.b. Diagnosis of causal factors, assess severity of and distinguish adverse events
   5.c. Prognosis of remaining useful life
   5.d. Mitigation of impact of adverse effects to continue safe flight and landing

Integrated Vehicle Health Management

6. **Analyzing complex systems for safety**
   6.a. On-going monitoring [and prediction] of potential safety issues from operational data
   6.b. Validation of system requirements relative to safety objectives
   6.c. Verification that designs meet system safety requirements

IVHM Research Objectives*

Detection of system anomalies and adverse events

- Microwave Blade Tip Clearance Sensor
- High Temperature Wireless Sensors
- Multifunctional Sensing with Fiber Bragg Gratings
- Integrated Large Area Sensor Actuator Network

Prognosis of Remaining Useful Life

- Damage Propagation Modeling in a Particle Filtering Framework
- Probabilistic Fatigue Damage Prognosis and Uncertainty Management
- Early-Indicators of Failure Prognosis of Electronics under Shock, Vibration, and Thermo-mechanical Loads

Diagnosis of causal factors, assess severity of and distinguish adverse events

- Onboard Model-based Engine Performance Estimation
- Lightning Damage Diagnosis for Composite Aircraft
- Probabilistic Methods for Diagnosis of Aircraft Systems
- Diagnostics of Avionics Systems Using Causal Models

Mitigation of impact of adverse effects to continue safe flight and landing

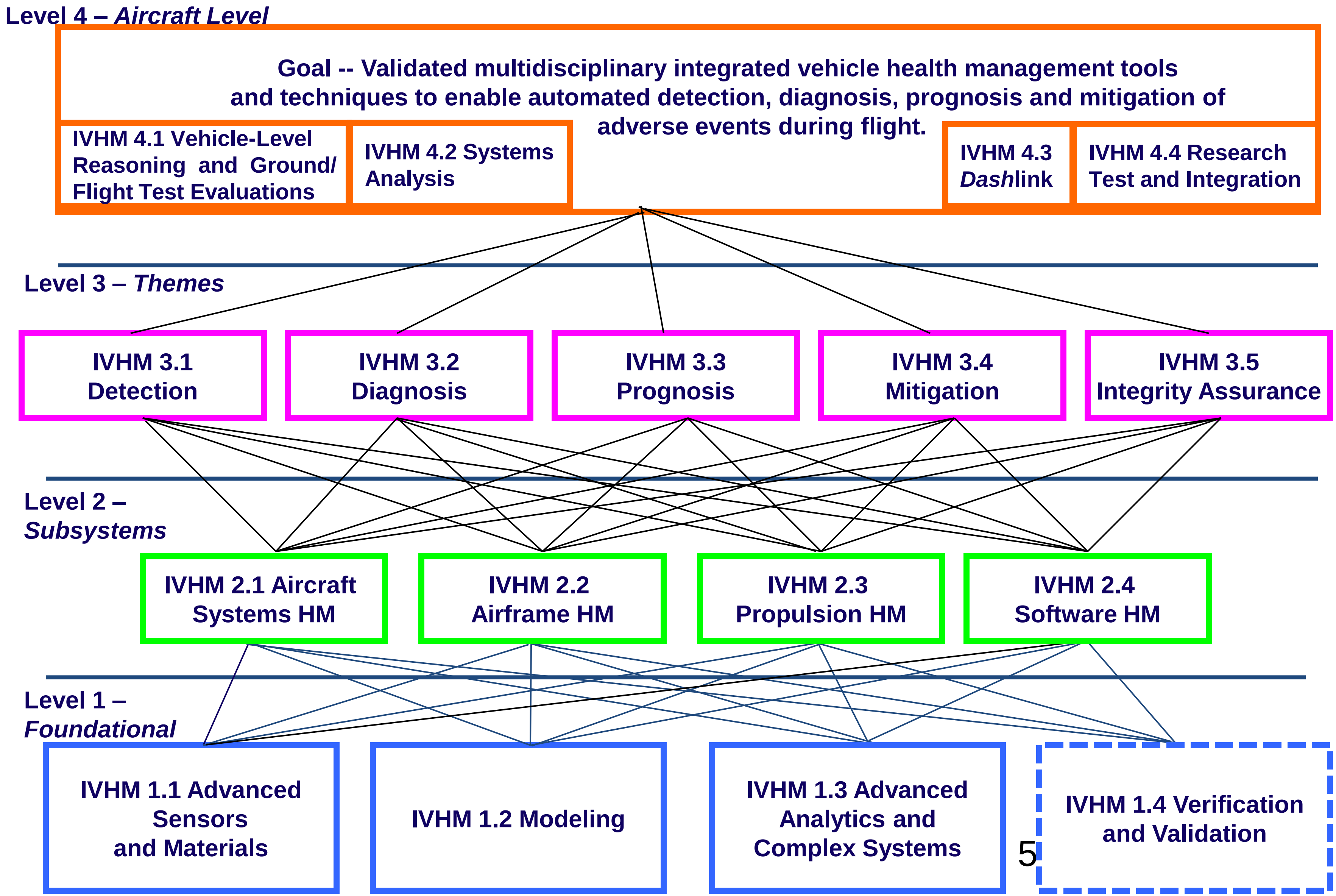
- Mitigation of Crack Damage in Metallic Materials

On-going monitoring [and prediction] of potential safety issues from operational data

- Data Mining for Fleet-Wide Health Monitoring
- Event Cube: An Organized Approach for Mining and Understanding Anomalous Aviation Events

* Items in bullets are selected to illustrate talks at the AvSafe conference that supports the Research Objective

IVHM Research Framework



A Comprehensive Approach to Assessments, Testing, and Integration

Adverse Events Table

- Evaluated and updated by the SA and RTI tasks to remain current with the trends in aviation
- Particular adverse events targeted in IVHM technology evaluations will be selected and documented as part of RTIP

Adverse Event Type	Definition	Example Damage Condition
1. Incipient Faults	Hard to detect and differentiate due to extremely slow degradation in performance	1. Icing conditions in propulsion system 2. Fault of power electronics.
2. Slow Progression Fault	Very hard to detect, gradual degradation in performance	3. Fatigue cracks on metallic airframe structure 4. De-lamination in composites 5. Ball-jam in EMA
3. Intermittent Faults	Fault does not degrade but instead is a recurring hard fault that comes and goes, for example a signal conducted via a loose connector.	6. Wire chafing resulting in an electrical short due to an unexpected ground path
4. Cascading Fault	Faults that may have a single root cause yet progress to create faults in other systems, subsystems, or components.	7. Power syste[illegible] wide-spr[illegible]
5. Fast Progression Fault	Limited precursor signature but rapi[illegible] degradation	[illegible] elated

* Depending on the nature of the s[illegible] to fast progression, as in the case of a stack overflow, or a slo[illegible] case of a memory leak. Either way, a key challenge for IVHM is to [illegible] manage these sorts of faults.

Integration Architecture and Assessment Working Group

- NASA IVHM Researchers
- NASA ARMD Researchers
- Academia
- Industry Partners

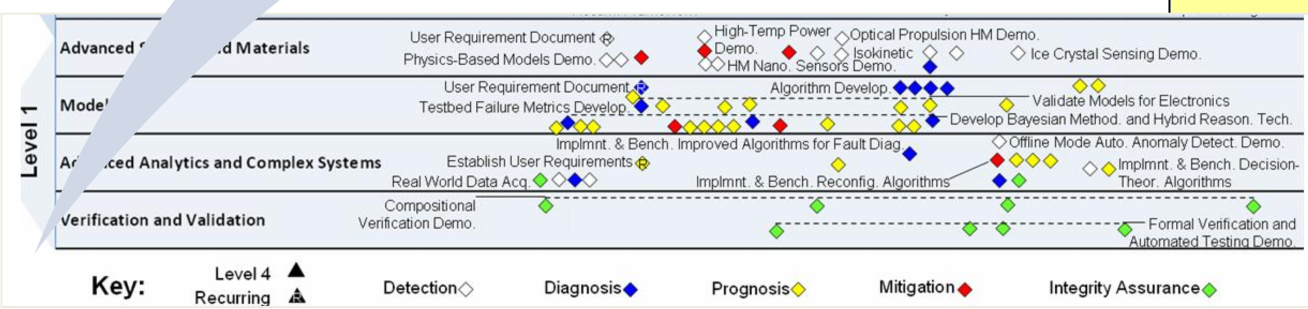
Testing Opportunities at NASA and Other Agencies

Systems Analysis

Research Test and Integration Plan

System Integration and Testing

Sample Research Center						
	Name	**Primary Number**	**Alternate Phone**	**Email**	**Position**	**Discipline**
Center POC	Bob Protaginist			here@nasa.gov	F-22 Project Manager	Management/Systems Integration
Technical POC	Jill Hero			there@nasa.gov	Senior Propulsion Engineer	Propulsion
Technical POC	Doug Leader			somewhere@nasa.gov	Flow Physics Branch Chief	Computational Aerodyanmics
Technical POC	Dick Whitcomb			lost@nasa.gov	Wind Tunnel Director	Experimental Aerodyanmics
Technical POC						
Research Assets						
Lab	**Fixture**	**Aircraft**	**Other**	**Capabilities**	**Projected Availability**	**Estimated Cost/Unit**
			Wright Computer Cluster		25% average utilization on 32 CPU cluster	None, if no upgrades or software purchases are required
		Big Aircraft			Periodic Dedicated Flights, Frequent Ride Along flights. Must schedule and prioritize with owning OGA.	$100K fixed, $22K/hr dedicated flight, $5K/flight ride along
	Thrust Stand				Schedule downtime for maintenance in Q3-Q4 FY 09 otherwise available.	5K/day
Big Aircraft Simulator					Highly available	Labor, .25 FTE
		Subscale RPV			Highly available and quick turn around	$50K fixed, $1k/hr



IVHM Management Team

NRA
Manager: Lilly Spirkovska

Principal Investigator: Ashok Srivastava
Project Scientist: Robert Mah
Project Manager: Claudia Meyer

ARC, DFRC, GRC, LaRC
Center POCs

ARC APM: Steve Jacklin
DFRC POC: Mark Dickerson
GRC APM: Bob Kerczewski
LaRC APM: Sharon Graves

Level 4

VLRS* & Ground/ Flight Test Evals
Leads: VLRS lead and PI, PS, PM

Systems Analysis for Health Management
Lead: Mary Reveley

Research Test and Integration
Lead: Robert Mah

DASHlink
Lead: Elizabeth Foughty

*VLRS = Vehicle Level Reasoning System; VLRS Lead: Eric Cooper

Level 3 Associate Principal Investigators

Detection
API: John Lekki

Diagnosis
API: Rick Ross

Prognosis
API: Kai Goebel

Mitigation
API: Rick Ross

Integrity Assurance
API: Eric Cooper

Level 2

Aircraft Systems

Airframe

Propulsion Systems

***Traditional** Aircraft Subsystems – well represented in Levels 1,3 and 4*

Software
Lead: Paul Miner

***Newly Recognized** Aircraft Subsystem*

Level 1 Lead Researchers

Advanced Sensors and Materials
Lead: Tim Bencic

Modeling
Lead: Kevin Wheeler

Data Mining and Complex Systems
Lead: Nikunj Oza

Verification and Validation
Lead: Steve Jacklin

IVHM Theme: Detection

Detection of system anomalies and adverse events

If a potential threat to aircraft safety develops, the first step is to DETECT it quickly, accurately, and reliably.

A Microwave Blade Tip Clearance Sensor for Propulsion Health Monitoring,

Mark Woike, NASA Glenn Research Center

Novel capability to measure blade tip clearance, which provides information indicative of the engine health.

High Temperature Wireless Sensor Systems,

Gary Hunter, NASA Glenn Research Center

Record-breaking capability to monitor high temperature sections in engine which would revolutionize engine health management

Multifunctional Sensing Using Fiber Bragg Gratings,

Cy Wilson, NASA Langley Research Center

Enhanced capability to monitor aircraft 'hotspot' locations

IVHM Theme: Detection Continued

Integrated Large Area Sensor Actuator Network Technology for Structural Health Monitoring,

Fu-Kuo Chang, Stanford University,

Revolutionary capability to detect structural damage at critical spots (bird /object strike at engine inlet locations and leading surfaces at takeoff and landing; cargo bay door sections; landing gear high stress areas)

Data Mining for Fleet-Wide Health Monitoring,

Nikunj Oza, NASA Ames Research Center,

Automated capability to search for precursor fault indications in archived databases, as well as online monitoring

Event Cube: An Organized Approach for Mining and Understanding Anomalous Aviation Events,

Jiawei Han, University of Illinois, Urbana-Champaign

Revolutionary text mining capability to identify root cause of threats

IVHM Theme: Diagnosis

Diagnosis of causal factors, assess severity of and distinguish adverse events

Once one or more potential threats are detected, the next step is to determine the root cause and disambiguate between a set of potential root causes.

Onboard Model-Based Aircraft Engine Performance Estimation for IVHM Applications,

Don Simon, NASA Glenn Research Center

Enhanced real-time onboard engine diagnostic capability

Lightning Damage Diagnosis Research for Composite Aircraft,

George Szatkowski, NASA Langley Research Center

Lightning damage diagnostics for composite aircraft

Probabilistic Methods for Diagnosis of Aircraft Systems,

Ole Mengshoel, NASA Ames Research Center

Bayesian methods for diagnostics, providing a structured framework for uncertainty management

IVHM Theme: Diagnosis Continued

Diagnostics of Avionics Systems Using Causal Models,

Raj Bharadwaj, Honeywell

Advanced analytics to improve the performance of diagnostic tools

New Algorithms for Diagnosis of Multiple Faults,

Stephen Boyd, Stanford University

Novel algorithms based on convex optimization to rapidly disambiguate faults

Vehicle Level Reasoning for Integrated Vehicle Health Management,

Eric Cooper, NASA Langley Research Center

Vehicle level reasoning system to diagnose vehicle level performance, disambiguate any conflicting subsystem health information, and determine best course of action

IVHM Theme: Prognosis

Estimation of remaining useful life

Once the cause of the threat is diagnosed, the next step is to determine the urgency, remaining useful life of the component/subsystem, and effect on aircraft safety.

Damage Propagation Modeling in a Particle Filtering Framework,

Kai Goebel, NASA Ames Research Center

Advanced analytics to improve the performance of prognostics methods

Probabilistic Fatigue Damage Prognosis and Uncertainty Management,

Yongming Liu, Clarkson University

A combination of physics-based and data-driven techniques to model fatigue in composite materials.

Early-Indicators for Failure-Prognosis of Electronics under Shock, Vibration and Thermo-mechanical Loads,

Pradeep Lall, Auburn University

Revolutionary techniques to identify precursors to failures in electronics.

IVHM Theme: Mitigation

Mitigation of impact of adverse effects to continue safe flight and landing

Following prognosis of a potential threat, the next step is to determine what mitigation actions should be taken. The IVHM R&D effort is focused on mitigating hardware faults as well as software faults.

Mitigation of Crack Damage in Metallic Materials,

Andy Newman, NASA Langley Research Center

Mitigation of crack damage in metallic materials using self-healing materials.

IVHM Theme: Software Health Management

A new area of research to detect, diagnose, predict, and mitigate adverse events due to software that has already passed verification and validation.

Software health management is a new area in the IVHM R&D portfolio.

Development of a Baseline Taxonomy of Flight-Critical Software Failures,
Walter Storm, Lockheed Martin
Developing a baseline taxonomy for flight-critical software failures

Towards Model-based Software Health Management,
Gabor Karsai, Vanderbilt University
A model-based approach to software health management