INTEGRATED VEHICLE
HEALTH MANAGEMENT

Vehicle Level Reasoning for Integrated Vehicle Health Management

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Aviation Safety Program Technical Conference
November 17-19, 2009
Washington D.C.

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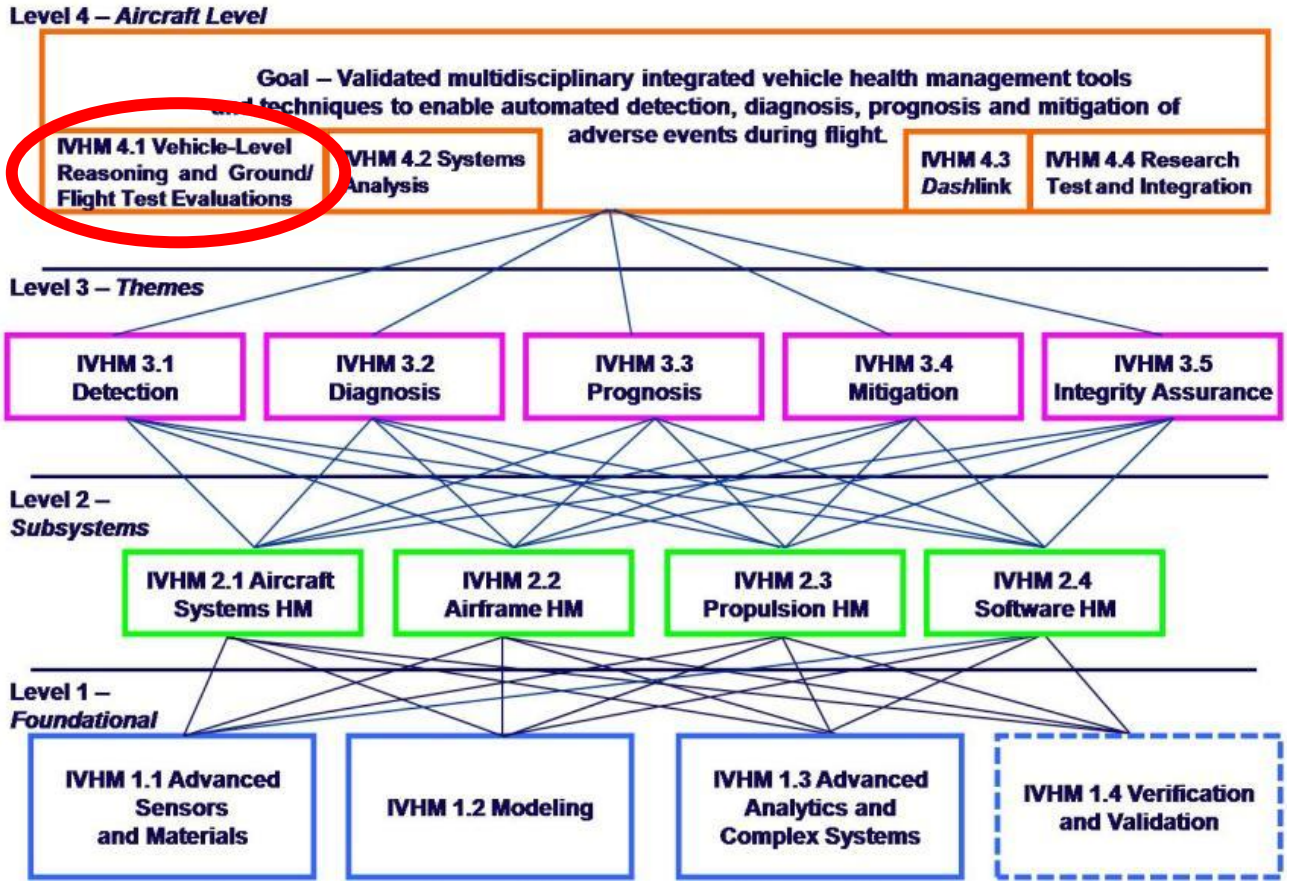


Problem Statement

IVHM subsystem research is focused on methods and tools that are required for the development of integrated health management systems within each of the four major elements of the aircraft: *Airframe*, *Propulsion*, *Aircraft Systems*, and *Software Systems*.

Integrating the large, heterogeneous, synchronous and asynchronous data streams generated by these subsystems is a complex undertaking, yet necessary for comprehensively detecting a potential adverse event, diagnosing its cause, predicting the effect of that event on the remaining useful life of the vehicle, and taking appropriate steps to mitigate the event.

The problem:

- How to assemble a *Vehicle Level Reasoning System* that
  - Provides for vehicle-level health management regardless of the subsystem (or subsystems) from which an adverse event arises
  - Supports *condition based maintenance* by capturing, reducing, and archiving vehicle health parameters
  - Is validated with sufficiently complex and complete data

Background

Vehicle Level Reasoning: Comprehensive vehicle health assessment through the collection of data and knowledge across subsystems. The reasoning strategy includes the generation and testing of internal hypothesis regarding the root-cause of a particular adverse event (or events), and relies upon a framework that enables the issuing of queries for purposes of verifying the hypothesis.

- Related Literature:
  - G. Karsai, G. Biswas, S. Abdelwahed, N. Mahadevan, and E. Manders, “Model-based Software Tools for Integrated Vehicle Health Management”, 2nd IEEE International Conference on Space Mission Challenges for Information Technology (SMC-IT'06)
  - J. W. Sheppard, and T. J. Wilmering, “Recent Advances in IEEE Standards for Diagnosis and Diagnostic Maturation”, IEEE Aerospace Conference, 2006
  - D. Gorinevsky, G. A. Gordon, S. Beard, A. Kumar, and F. Chang, “Design of Integrated SHM System for Commercial Aircraft Applications”, 5th International Workshop on Structural Health Monitoring, Stanford, CA, September 2005
  - A. Bartolini, T. M. Firestone, and R. M. Kent, “Aircraft Condition Analysis and Management System for Transports”, AIAA Guidance, Navigation, and Control Conference and Exhibit 15 - 18 August 2005, San Francisco, California
  - L. Atlas, G. Bloor, et. al, “An Evolvable Tri-Reasoner IVHM System”, Aerospace Conference, 2001, IEEE Proceedings
  - G. Hadden, et. al., “Application Challenges: System Health Management for Complex Systems”, 5th International Workshop on Embedded HPC Systems and Applications (EHPC’2000) (2000)
  - R. M. Kent, and D. A. Murphy, “Health Monitoring System Technology Assessments – Cost Benefits Analysis”, NASA/ CR-2000-209848

Background

Air France Flight 447 accident on 1st June, 2009
(Bureau d'Enquêtes et d'Analyses Interim Report *f-cp090601ae*)

- Analysis of the series of 24 broadcast maintenance messages concluded that various monitoring processes were triggered, with at least one corresponding to an inconsistency in speed measurement.

In-flight upset 154 km west of Learmonth, WA, 7 October 2008 Airbus A330-303 (ATSB Transport Safety Report AO-2008-070 Interim Factual)

- While cruising at 37,000ft the aircraft autopilot disconnected, various aircraft system failures were indicated, the aircraft abruptly pitched nose-down and descended 650 ft. The crew returned the aircraft to 37,000 ft and began actions to deal failure messages when a second un-commanded pitch-down event occurred and the aircraft descended about 400 ft.

Loss of Pitch Control During Takeoff, Air Midwest Flight 5481, Raytheon (Beechcraft) 1900D, N233YV, Charlotte, North Carolina, January 8, 2003 (NTSB/AAR-04/01)

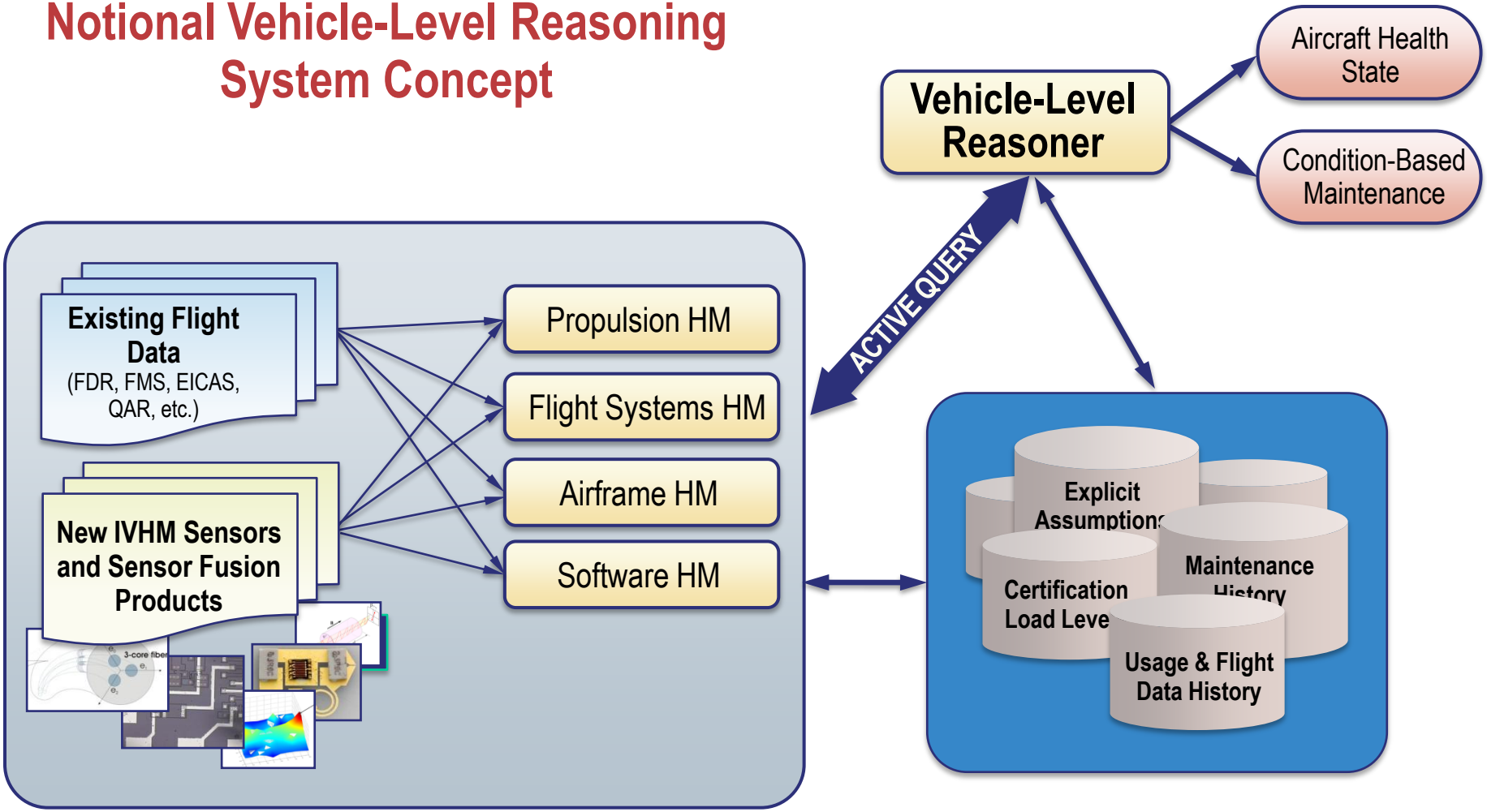
- Loss of pitch control during takeoff due to incorrect rigging of the elevator control system compounded by the airplane's aft center of gravity. An FDR study to examine the relationship between the 10 flights before the D6 maintenance check (which includes elevator cable tension check) on January 6, 2003, and the 9 flights after the D6 maintenance check (the accident flight was the 10th flight after D6 maintenance) showed differences in pitch control position values.

Background

New technologies, such as ‘vehicle level reasoning’, are needed to provide more accurate and better resolution to these types of problems by

- Incorporating comprehensive historical vehicle health information
- Identifying conflicts in subsystem health state
- Providing a means to query subsystem to disambiguate conflicts
- Resolving complex fault modes that involve both hardware and computer-software related faults before they lead to a crisis

Notional Vehicle-Level Reasoning System Concept



IVHM milestone being worked

Vehicle-Level Reasoning Systems: Research, develop, and test tools and technologies necessary for a Vehicle-Level Reasoning System (VLRS).

- The work is related to the topic “IVHM 4.1 Multidisciplinary IVHM Technologies, Tools, and Techniques under IVHM Technology Plan V2.01.
- Related IVHM milestone:

4.1.1	Ground-based test of detection, diagnosis, and prognosis for selected adverse event types (as specified in the Research Test and Integration Plan - RTIP) listed in Table 2.

Approach

- VLRS NRA Solicitation
  - NASA Research Announcement (NRA) NNH09ZEA001N entitled “Research Opportunities in Aeronautics” – 2009, Amendment B.4, Project Integrated Vehicle Health Management (IVHM), Topic IVHM-1.1 *Vehicle-Level Reasoning System / Evaluation of Multidisciplinary IVHM Technologies, Tools, and Techniques*.
  - NASA anticipates investing approximately $2700K in this topic over the next three years, at $1200K for Year 1 divided into two awards, $1000K for Year 2 for one award, and potentially $500K for Year 3 for a single award.

ROA 2009 http://nspires.nasaprs.com/external/viewrepositorydocument/cmdocumentid=192077/ROA-2009_amend_1_02June09.pdf

Approach

- VLRS NRA - Seeks proposals that will research, develop, and test tools and technologies for a Vehicle-Level Reasoning System (VLRS) that must take advantage of component, subsystem, and vehicle level models which would represent connectivity and potential causal chains of failure.
  - Provides for the active interrogation of specific systems and subsystems to determine their health status; the VLRS will generate and test internal hypotheses about the root-cause of a particular adverse event by selecting subsystems and issuing queries designed to verify the generated hypothesis
  - Supports Condition Based Maintenance whereby maintenance is performed when needed (as opposed to scheduled) using data and information derived from in-situ sensors and external test and measurement equipment and maintenance logs
  - Manages uncertainty through mathematically motivated and justifiable tools and techniques that ascribe a probabilistic confidence to each root-cause hypothesis
  - Incorporates component, subsystem, and vehicle level models which would represent connectivity and potential causal chains of failure as well as damage propagation for certain subsystems (such as aircraft systems, airframe, propulsion, or software)
  - Includes data-driven methods to characterize interactions between components, subsystems, and systems

VLRS NRA Key Activities

Year 1	Year 2	Year 3
VLRS Architecture Recommendations	Data mining algorithms to establish probability distributions	Demonstrate reasoning under uncertainty in a HWIL environment
Health Management Information protocol	Integrate and demonstrate on virtual testbed	Interrogate HWIL subsystems to disambiguate root-causes
VLRS Concept of operations; trade-space between complexity, accuracy, cost, and impact on aviation safety	Interrogate subsystems to disambiguate root-causes	Assess communications costs for VLRS architecture defined years 1 & 2
Requirements for CBM and appropriate metrics for VLRS	Asses communications costs for VLRS architecture defined year 1	Architecture requirements to enable adaptive control and flight deck automation
VLRS CBM Concept of Operations	Evaluate potential cost savings of VLRS-enabled CBM	Identify data and analysis needed for validation
Demo in software simulation		
Data set acquisition*		

VLRS NRA Award Key Activities

- Data set acquisition
  - Acquire data sets from a fleet of at least 10 aircraft with at least 10 flights per aircraft of similar make and model to establish probability distributions to characterize noise, uncertainty, and other statistical processes of the data streams from the at least two subsystems of the aircraft. Data from fixed-wing aircraft would be preferred but rotorcraft data would be acceptable.

Summary

- Vehicle-Level Reasoning Systems is a new IVHM research focus area added in FY 2009
- VLRS will provide aircraft with at least two significant capabilities:
  - improvement of aircraft safety due to enhanced monitoring and reasoning about the aircraft's health state, and
  - potential cost savings by enabling Condition Based Maintenance (CBM)
- The approach is to develop a VLRS that
  - provides for the active interrogation of specific systems and subsystems
  - supports Condition Based Maintenance
  - ascribes a probabilistic confidence to each root-cause hypothesis
  - incorporates component, subsystem, and vehicle level models
  - includes data-driven methods to characterize interactions between components, subsystems, and systems
- 2009 NASA Research Announcement (NRA) NNH09ZEA001N Topic IVHM-1.1 *Vehicle-Level Reasoning System*