Aviation Safety Program

John White
Director (Acting), Aviation Safety
Aeronautics Research Mission Directorate
Aviation Safety Program

Research Thrusts

- Integrated Vehicle Health Management
- Integrated Intelligent Flight Deck
- Integrated Resilient Aircraft Control
- Aircraft Aging & Durability

Develop technologies, tools, and methods to:
- Improve inherent safety attributes of new and legacy vehicles
- Overcome safety technology barriers that would otherwise constrain full realization of the Next Generation Air Transportation System
Safety Challenges

Expanding Capacity

Hull loss accidents per year

Hull loss accident rate [Accidents per million departures]

Departures, Millions

Safety Challenges

Expanding Capabilities

Next Generation Air Transportation System

- Equivalent Visual Operations
- Super Density Operations
- 4D Trajectory Management
- Weather Assimilated into Decisions
- ...
Safety Projects

Project Areas

Integrated Intelligent Flight Deck
• Optimum Workload Allocation
• External/Internal Situation Awareness
• Off Nominal Behavior Detection
• …

Integrated Resilient Aircraft Control
• Prevent Loss-of-Control Accidents
• Autonomous Vehicle Mission Management
• V&V of Complex Flight Critical Systems
• …

Integrated Vehicle Health Management
• Prevent System and Component Failures
• Self Recovery from Malfunctions
• Improve Maintenance
• …

Aircraft Aging & Durability
• Damage Science for Materials & Structures
• Detection and Integrity Assessment
• Design for Reliability and Durability
• …

Challenges

Data Driven Requirements

Graphic and textual content about safety projects focusing on integrated intelligent flight deck, integrated resilient aircraft control, integrated vehicle health management, and aircraft aging & durability. Challenges include data driven requirements and graphical representations.
## Approach

- **Space Act Agreements to collaborate with industry; Establish partnerships with other Government Agencies (FAA, DOD, etc.)**

- **NASA development of multidisciplinary technology solutions and validation methods**

- **NASA development of discipline-related solutions and validation tools**

- **In-house research, supplemented with Universities and companies performing foundational research to address technology gaps**

| Level 1 | Conduct foundational research to further our fundamental understanding of complex safety-related problems facing aeronautics community |
| Level 2 | Leverage the foundational research to develop technologies and analytical tools focused on discipline-based solutions and efficient validation processes |
| Level 3 | Integrate methods and technologies to develop multi-disciplinary solutions |
| Level 4 | Solve aeronautics safety challenges for a broad range of vehicles with system-level optimization, assessment, and technology integration |
Four-Step Planning Process

Step 1: Assess the long-term research needs and goals in the Aviation Safety program and establish technical roadmaps to accomplish those goals.

Step 2: Solicit information on key areas of interest from the external community and determine opportunities for collaboration through an RFI

Step 3: Develop research proposals at the field centers

Step 4: Issue a NASA Research Announcement to solicit proposals for foundational research in safety related problems
## Aviation Safety Top Level Roadmap

<table>
<thead>
<tr>
<th>FY07</th>
<th>FY08</th>
<th>FY09</th>
<th>FY10</th>
<th>FY11</th>
<th>FY12</th>
<th>FY13</th>
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### Integrated Vehicle Health Management
- **Baseline assessment of IVHM state of the art**
- **Requirements definition for Next Generation IVHM framework & implementation**
- **Define Next Generation IVHM capability**
- **Develop and demonstrate IVHM validation capability**
- **Develop and validate IVHM technologies for prevention, detection and mitigation**

### Integrated Intelligent Flight Decks
- **Initial conceptual framework for AFDS**
- **Specification of Application Domains**
- **Criteria for assessing AFDS safety risk**
- **Validation experiments**
- **Inferencing transfer functions**
- **Validation assessment of tools, AFDS concepts and technologies**

### Integrated Resilient Aircraft Control
- **Requirements definition for IRAC System & implementation**
- **V&V and Predictive Capability Assessment Process Demonstration and Evaluation**
- **Evaluate predictive capability and extended life (Generation 1)**

### Aircraft Aging & Durability
- **Interagency Test bed**
- **Integration Framework**
- **Insert advanced technology methods, assess**
- **Baseline SOA against advanced concept test**
- **Baseline SOA against existing database**
- **Inter/intra-agency portfolio assessment**
- **Validate predictive capability and extended life (Generation 2)**
# Integrated Vehicle Health Management

## Multidisciplinary Vehicle-Wide Health Management System, Tools, and Technologies for:
- Graceful Recovery from In-Flight Failures (SAFETY)
- Preventive and Adaptive Systems for In-Flight Operability (SAFETY, PERFORMANCE)
- Informed Logistics & Maintenance (COST, PERFORMANCE)

## LEVEL 3
- Integration & Assessment of Adaptive IVHM Systems into Vehicles
- Validation & Predictive Capability Assessment
- Airframe
- Propulsion
- Aircraft Systems
- Environmental
- System Architectural Framework

## LEVEL 2
- Integration, Understanding, & Assessment of Self Aware and Adaptive Subsystems
- Characterization, Validation & Predictive Capability
- Intelligent Sensing, Monitoring, & Diagnosis
- Prognosis
- Failure & Hazard Mitigation
- Architecture & Information Management

## LEVEL 1
- Integration & Assessment of Models, Materials, and Smart Subsystems/Components
- Analytical, Simulation, and Experimental Methods and Techniques
- Physics Based and Data Driven Modeling
- Sensor and Actuator Technology
- State Awareness
- Advanced Materials for IVHM
- IVHM Architectures
- Advanced Data Analysis & Data Mining
- Detection Theory & Reasoning Methods
- Design Methods
## Integrated Vehicle Health Management: Research Topics

<table>
<thead>
<tr>
<th>Airframe Health Management</th>
<th>Self-awareness and prognosis; anomaly detection and identification; in-flight damage, degradation and failure mitigation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsion Health Management</td>
<td>Self-awareness and prognosis of gas path, combustion, and overall engine state; fault-tolerant system architecture.</td>
</tr>
<tr>
<td>Aircraft Systems Health Management</td>
<td>State-awareness and prognosis of landing gear, hydraulic and pneumatic systems, electrical and power systems, fuel and lubrication systems, and avionics/communication-navigation-surveillance/flight critical/flight management systems; robust distributed fault-tolerant self-recoverable architectures.</td>
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<tr>
<td>Environment Health Management</td>
<td>Prevent, detect, and mitigate the effects of hazards such as onboard fire and fuel detonation; interior air quality degradation; ice; lightning strikes; EMI/EMC; and ionizing radiation.</td>
</tr>
<tr>
<td>System Architectural Framework</td>
<td>System design, analysis and optimization; information management, data flow and communication; control and reconfiguration; architecture development and validation.</td>
</tr>
<tr>
<td>Validation and Predictive Capability Assessment</td>
<td>Analysis, simulation, ground-testing, flight testing, environmental testing, and software assurance.</td>
</tr>
</tbody>
</table>
Develop and validate IVHM technologies for prevention, detection and mitigation of malfunctions, failures, & damage

Vehicle-Wide IVHM

Airframe HM

Failure & Hazard Mitigation

Intelligent Sensors, Monitoring & Diagnosis

Prognosis

Modeling & State Awareness

Sensors, Actuators & Materials

Architecture & Design Methods

Technology Flow

Level 4

FY07 FY08 FY09 FY10 FY11 FY12 FY13 FY14 FY15 FY16

Level 3

Level 2

Level 1

Technology Flow / Requirements Flow

Annual portfolio assessment reviews at Level 4 not shown
Develop and validate IVHM technologies for prevention, detection and mitigation of malfunctions, failures, & damage.

Demonstrate highly accurate and reliable health management methods for engine gas path systems.

Demonstrate model-based engine gas path performance tracking and intrinsic diagnostics/prognostics.

Develop prognosis methodologies, accounting for degradation effects, on remaining engine operability margins.

Demonstrate model predictive control fault avoidance and mitigation techniques, and optimal reconfigurable control techniques developed.

Demonstrate lightweight, robust, active clearance control system for an intelligent engine.

Demonstrate adaptive turbine cooling for durability.

Demonstrate stall prevention & recovery for turbomachinery.

Develop control limit logic reconfiguration techniques for restoration of engine operability.

Model aircraft engine performance faults.

Develop hybrid (analytical + empirical) engine model and nonlinear tracking filter techniques.

Advanced diagnostic and prognostic reasoners for engine gas path system developed.

Model predictive control fault avoidance and mitigation techniques, and optimal reconfigurable control techniques developed.
INTEGRATED INTELLIGENT FLIGHT DECK

Tools, Methods, Concepts, Principles, Guidelines, And Technologies For Revolutionary Adaptive Flight Decks That Improve Safety

LEVEL 4

TAILORED FLEXIBLE OPERATOR-AUTOMATION MANAGEMENT

LEVEL 3

ADAPTIVE DISPLAYS AND INTERACTION

DECISION ASSOCIATE TECHNOLOGY

LEVEL 2

ADAPTIVE INTELLIGENT INFORMATION MANAGEMENT

LEVEL 1

MULTI-MODAL INTERFACE TECHNOLOGIES

SENSOR TECHNOLOGY DEVELOPMENT

CHARACTERIZATION OF EXTERNAL HAZARDS

FORMAL DESIGN, MODELING, & VERIFICATION METHODS

SIGNAL, SPEECH, AND IMAGE PROCESSING METHODS

DETECTION THEORY

OPERATOR CHARACTERIZATION & INTERACTION MODELING

INFORMATION SYSTEMS AND INFRASTRUCTURE

EXPERIMENTAL CAPABILITIES
## Integrated Intelligent Flight Deck: Research Topics

<table>
<thead>
<tr>
<th>Tailored Flexible Operator-Automation Management</th>
<th>Dynamic operator/automation function allocation strategies with formally verified fail-safe reversionary modes for automation assigned functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptive Displays and Interaction</td>
<td>Equivalent visual environments; spatially-integrated displays that enable optimal presentation and management of flight deck information; optimized controls and displays that support extra- and intra-flight deck information coordination</td>
</tr>
<tr>
<td>Decision Associate Technology</td>
<td>Tools and functional capabilities that support hazard remediation; situational awareness and analysis; integrated crew advisory and warnings; collaborative decision making; and tactical guidance and re-planning</td>
</tr>
<tr>
<td>Intelligent Information Management</td>
<td>Information systems that support the needs of technologies above while enabling integrated flight deck and external environment state assessment and safety analysis, tracking of real-time navigation, communication and surveillance performance, supporting collaborative information management (with ATC/AOC), and providing predictive information.</td>
</tr>
</tbody>
</table>
Integrated Resilient Aircraft Control

Integrated Modeling, Control, and V&V Technologies for Hazard-Resilient Aircraft Control & Flight Management:
- Graceful Recovery from In-Flight Failures/Damage, External Disturbances, Upsets, & System / Control Input Errors (SAFETY)
- Effective Mission Management under Adverse/Upset/Hazard Conditions (SAFETY, PERFORMANCE, COST)

Integrated Design, Implementation, and V&V of IRAC Subsystems

Resilient Flight Control
Resilient Propulsion Control
Resilient Airframe Control
Resilient Vehicle Mission Management
Safety-Critical System V&V

Integration & Assessment of Flight Safety Prediction and Control Remediation Subsystem Components

Intelligent Sensing, Monitoring, & Diagnostics for Vehicle Control
Flight Safety Prognostics
Coupled Hazard Effects & Vehicle Response Characterization
Control Mitigation & Recovery
Control Autonomy
V&V of Complex Systems

Characterization and Assessment of Safety-Critical Adverse / Upset / Hazard Conditions and their Effects on Vehicle System Safety and Control

Advanced Control Structures
Resilient Materials
Robust Design and Risk Analysis / Mitigation
Instrumentation for Resilience
Vehicle Dynamics & Hazards Effects Modeling
Simulation of Complex Systems
Detection, Identification, & Prediction Methods
Control and Guidance for Hazards Conditions
Validation of Complex Models & Systems
Software Safety Assurance & Formal Verification Methods for IRAC
## Integrated Resilient Aircraft Control: Research Topics

<table>
<thead>
<tr>
<th>Resilient Flight Control</th>
<th>Fault tolerance and hazard effects protection; onboard hazard effects assessment, mitigation and recovery</th>
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<tbody>
<tr>
<td>Resilient Propulsion Control</td>
<td>Damage tolerance and design for extended envelope operation; onboard hazard effects assessment, mitigation and recovery</td>
</tr>
<tr>
<td>Resilient Airframe Control</td>
<td>Damage tolerance and structural damage avoidance; onboard damage effects assessment, mitigation and recovery</td>
</tr>
<tr>
<td>Resilient Vehicle Mission Management</td>
<td>Control and performance management; vehicle-based mission management and autonomous collision avoidance; interface and communication management</td>
</tr>
<tr>
<td>Safety-Critical System V&amp;V</td>
<td>Safety assurance methods for complex avionics systems; integrated V&amp;V methods, tools and test techniques for adaptive control systems; predictive capability assessment methods and tools</td>
</tr>
</tbody>
</table>
Re-curring milestones (yearly, every 2 yrs, etc)

Level 1

Integrated Resilient Control Technologies

Integration & Assessment
- Define current engine capabilities
- Assess critical technologies
- Advanced Structural Control Concepts
- Advanced Structural Control Concepts
- Mission management concepts
- Stochastic life models
- Optimization techniques
- Reduced-order methodologies
- Safety case approach
- Quality probabilistic uncertainty models
- Code level verification tools
- Reduced-order methodologies
- Safety case assurance

Materials & Structures
- Component life analyses
- Component failure analysis
- Probabilistic analyses
- Structural design methods
- Mission management concepts
- Stochastic life models
- Optimization techniques
- Reduced-order methodologies
- Safety case approach
- Quality probabilistic uncertainty models
- Code level verification tools
- Reduced-order methodologies
- Safety case assurance

Robust Design & Instrumentation
- Define current engine capabilities
- Assessment critical technologies
- Advanced Structural Control Concepts
- Advanced Structural Control Concepts
- Mission management concepts
- Stochastic life models
- Optimization techniques
- Reduced-order methodologies
- Safety case approach
- Quality probabilistic uncertainty models
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Modeling & Simulation
- Define current engine capabilities
- Assessment critical technologies
- Advanced Structural Control Concepts
- Advanced Structural Control Concepts
- Mission management concepts
- Stochastic life models
- Optimization techniques
- Reduced-order methodologies
- Safety case approach
- Quality probabilistic uncertainty models
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Systems, Control & Guidance
- Define current engine capabilities
- Assessment critical technologies
- Advanced Structural Control Concepts
- Advanced Structural Control Concepts
- Mission management concepts
- Stochastic life models
- Optimization techniques
- Reduced-order methodologies
- Safety case approach
- Quality probabilistic uncertainty models
- Code level verification tools
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Validation & Verification
- Define current engine capabilities
- Assessment critical technologies
- Advanced Structural Control Concepts
- Advanced Structural Control Concepts
- Mission management concepts
- Stochastic life models
- Optimization techniques
- Reduced-order methodologies
- Safety case approach
- Quality probabilistic uncertainty models
- Code level verification tools
- Reduced-order methodologies
- Safety case assurance

Level 2

Level 3

Level 4
Aircraft Aging & Durability

Develop Integrated Methods to Enable the Detection, Prediction, Mitigation/Management of Aging-Related Hazards

LEVEL 4

Experimental Validation of Airframe, Propulsion and Flight Systems Durability

LEVEL 3

Detect and Characterize

Predict (life, strength, durability)

Mitigate

LEVEL 2

IVHM / IRAC Interface
* models, onboard state

LEVEL 1

Sensing and Diagnostic Technologies

Physics-based Modeling

Computational Methods

Material Science (metals, ceramics, composites)

Characterization / Validation Test Technologies

NDE / Structural Health Monitoring Systems

Structural Integrity

Lifting Methods/ Material Durability

Mitigation Technologies
## Aging Aircraft & Durability: Research Topics

<table>
<thead>
<tr>
<th>Detection and Characterization of Aging Related Hazards</th>
<th>Establish linkage between structural analysis and NDE techniques; Damage and environmental state quantification; repair assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prediction of Life, Strength, and Durability of Aircraft Systems with Degradation</td>
<td>Variable fidelity analysis methods and predictive tools; methods incorporating usage and NDE information; reliability/margins of safety with uncertainty</td>
</tr>
<tr>
<td>Mitigation of Aging Related Hazards</td>
<td>Advanced material systems (surface treatment/coatings, multifunctional); degradation management; design for aging prevention, maintainability/repair, and damage containment</td>
</tr>
</tbody>
</table>
### Experimental Validation for Airframe, Propulsion and Flight Systems Durability

- **Integration Framework**
  - Interagency Testbed
  - Integration Framework
  - Baseline SOA against existing database
  - Baseline SOA against advanced concept test

- **SOA assessment**
  - Needs: Load and damage detection (updated annually)

- **Validation**
  - Integrated analysis tools for strength prediction
  - Life prediction linking NDE and analysis tools
  - Validate GEN 1 concepts for durability
  - Validate GEN 2 concepts for durability
  - Validate design for aging and damage containment
  - Validate design for maintainability

### Detect and Characterize

- **SOA assessment**
  - Baseline SOA capability
  - Multi-sensor data management tools
  - Characterization by linking NDE and analysis tools

- **Validation**
  - Prototype repair assessment tech.
  - Certified NDE and sensor methods
  - Integrated certified NDE/sensor methods
  - Validate predictive capability and extended life

### Predict (life, strength)

- **SOA assessment**
  - Detection and Characterize
  - Multi-sensor data assessment tech.

- **Validation**
  - Validate predictive capability and extended life
  - Life prediction methods
  - Validate life prediction methods
  - Validate life prediction methods

### Mitigate

- **SOA assessment**
  - Definition validation strategies for mitigation concepts

- **Validation**
  - Validate GEN 1 concepts for durability
  - Validate methods to integrate maintenance, NDE, and analysis
  - Validate methods to integrate maintenance, NDE, and analysis
  - Validate design for aging and damage containment
  - Validate design for maintainability

### NDE/SHM Systems

- **Assessment**
  - NDE/SHM systems
  - Structural Integrity

### Lifting Methods/Material Durability

- **Assessment**
  - Lifting Methods/Material Durability

### Mitigation Technologies

### Sensing and Diagnostic Tech

### Physics-based Modeling

### Computational Methods

### Materials Science (metals, ceramics, composites)

### Characterization/Validation Test Tech

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### Technology Flow / Requirements Flow

1. **Level 1**
   - Experimental Validation
   - Detect and Characterize
   - Predict (life, strength)
   - Mitigate

2. **Level 2**
   - NDE/SHM Systems
   - Structural Integrity
   - Lifting Methods/Material Durability
   - Mitigation Technologies

3. **Level 3**
   - Sensing and Diagnostic Tech
   - Physics-based Modeling
   - Computational Methods
   - Materials Science
   - Characterization/Validation Test Tech

4. **Level 4**
   - Integrated Advanced Technology Methodologies
Aviation Safety Program
Project Area Interdependencies - Examples

Integrated Intelligent Flight Deck
Tools, Methods, Concepts, Principles, Guidelines and Technologies for Revolutionary Adaptive Flight Decks That Improve Safety

Integrated Vehicle Health Management
Multidisciplinary Vehicle-Wide Health Management System, Tools, and Technologies

Integrated Resilient Aircraft Control
Integrated Multidisciplinary Modeling, Control, and V&V Technologies for Hazard-Resilient Aircraft Control & Flight Management

Aircraft Aging & Durability
Integrated Methods to Enable the Detection, Prediction, Mitigation/Management of Aging Related Hazards

Situational Awareness Data
Airframe & Control Damage Info
Control System State Changes
Mission Management & Execution

Damage effects characterization and mitigation information for inclusion in aging and residual strength models

Life & Strength Prediction Technologies

Database tools for large-area inspection over extended time

Control State
Safety Program/Project Leads

Aviation Safety Program
Director (Acting) – John White

Integrated Vehicle Health Management
PI - Dr. Celeste Belcastro
PM – Cheryl Allen

Integrated Resilient Aircraft Control
PI – Dr. Christine Belcastro
PM – Joseph Totah

Integrated Intelligent Flight Deck
PI – Dr. Steve Young
PM – Leighton Quon

Aircraft Aging & Durability
PI – Dr. Rick Young
PM – Doug Rohn

Principle Investigator (PI)
Project Manager (PM)