Assuring NASA’s Safety and Mission Critical Software

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Origins of IV&V within NASA

• NASA's IV&V Program: established in 1993
• Founded under the NASA Office of Safety and Mission Assurance (OSMA) as a direct result of recommendations made by the National Research Council (NRC) and the Report of the Presidential Commission on the Space Shuttle Challenger Accident.
The Need for IV&V

Developing complex, safety and mission-critical software systems is inherently challenging, and that creates risk.
What is IV&V?

Independent Verification and Validation (IV&V) is an objective examination of safety and mission critical software processes and products.

**Independence:** 3 key parameters:
- Technical Independence
- Managerial Independence
- Financial Independence

**NASA IV&V perspectives:**
- Will the system’s software...
  - Do what it is supposed to do?
  - Not do what it is not supposed to do?
  - Respond as expected under adverse conditions?

**Systems Engineering:** Determines if the **right system** has been built and that it has been **built correctly**.

**IV&V Technical Approaches:**
- Aligned with IEEE 1012
- Captured in a Catalog of Methods
- Spans the full project lifecycle

**IV&V Assurance Strategy**
The IV&V Project’s strategy for providing mission assurance Assurance Strategy is driven by the specific needs of an individual project Implemented via an Assurance Design Communicated via Assurance Statements
What is IV&V? (continued)

• The IV&V Assurance Strategy is the selection and implementation of IV&V validation and verification processes
  − Implementation of the IV&V processes are driven by the IV&V Project’s risk assessment and unique characteristics
  − The Assurance Strategy is tailored to the needs of the individual projects

• The validation process provides empirical evidence that engineering products:
  − Satisfy system requirements allocated to software
  − Solve the right problems
  − Satisfy the intended use and user needs in expected operational environments

• The verification process provides empirical evidence that engineering products:
  − Conform to requirements (for example: for correctness, completeness, consistency, accuracy) during all life cycle phases (requirements, design, code, test)
  − Satisfy standards and best practices
  − Establish a basis for assessing the completion of each life cycle phase, and initiating other life cycle phases
What is IV&V? (continued)

- IV&V processes include assessments, analyses, evaluations, reviews, inspections, and testing of software artifacts during the entire development lifecycle that create evidence
  - Evidence is used to formulate recommendations that improve the quality (or reliability) of the system software
  - Evidence is used to make conclusions about the quality (or reliability) of the system software
  - Evidence is used to gain insight into the technical progress
  - Evidence is used to judge how thorough you’ve critiqued the system
- How much evidence → it is a trade-off between criticality of the system being acquired/deployed
  - Life-sustaining subsystems would warrant an evidence package that clearly & objectively shows the software will operate safely (or clearly shows that it won’t)
  - Data management subsystems may warrant less of an evidence package
- The amount of evidence needed determines the rigor of the analysis
  - Analytical Rigor is the type and amount of IV&V processes to use for analysis
Establishing the IV&V Assurance Strategy

• The IV&V Program assesses the system to determine:
  – The inherent risk associated with the system capabilities
  – The role of software in those capabilities
  – Which software elements of the system warrant IV&V analysis
    – Software elements are generally the focal point of IV&V analyses; however, other lifecycle artifacts (for example: concept documentation, system design, etc…) are utilized to inform lower-level analyses

• Our process is called “Portfolio Based Risk Assessment” (PBRA)
  – Results in scores for impact (a measure of the effect of a problem) and likelihood (the potential for the existence of errors) for each system capability and software element
  – Enables informed decision making regarding:
    • What parts of the system should IV&V work on
    • What analytical rigor should IV&V apply (for example: dynamic analysis should be conducted to thoroughly test the implementation of the protocol used for communications)
Establishing the IV&V Assurance Strategy (continued)

<table>
<thead>
<tr>
<th>Desired Capabilities</th>
<th>Responsible Subsystems</th>
<th>Cruise - On-Orbit</th>
<th>Cruise - Off-Orbit</th>
<th>Cruise Power</th>
<th>EELV</th>
<th>Orbiter Startup &amp; Integration</th>
<th>Orbiter OML</th>
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</thead>
<tbody>
<tr>
<td>Conduct habitability investigations</td>
<td>Launch of Mars</td>
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<td>Trajectory control</td>
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<td>Attitude Control</td>
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<td>Trajectory control</td>
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<td>Maintain flight systems</td>
<td>Establish and maintain power</td>
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<tr>
<td>Perform fault detection</td>
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<tr>
<td>Establish and maintain communications</td>
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<tr>
<td>Gather engineering and housekeeping data</td>
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<td>Landing</td>
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<td>x</td>
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<td>x</td>
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<td>Perform surface operations</td>
<td>Traverse the Martian surface</td>
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<td>x</td>
<td>x</td>
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<td>Acquire and handle samples</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Evaluate current situation via TPS data</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>Perform reconnaissance activity</td>
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<td>Collect science data</td>
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### Subsystem Criticality Profile

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Impact</th>
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<td>1</td>
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<td>2</td>
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<td>4</td>
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<td>5</td>
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- **Subsystem 1** – do not recommend IV&V
- **Subsystem 2** – recommend IV&V utilizing Static Analysis
- **Subsystem 3** – recommend IV&V utilizing Dynamic Analysis
- **Subsystem n** ...

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### Amount of Rigor & Evidence Needed

**Manual Analysis**
- SMEs conduct formal or informal inspections & evidence is recorded simply as issues

**Static Analysis**
- SMEs evaluate structure & content using various perspectives supported by CASE tools. Evidence is recorded as issues & supplemented with coverage

**Dynamic Analysis**
- SMEs execute system & evaluate results. Evidence is recorded more thoroughly as to make the case for what works and what are limitations

**Formal Analysis**
- SMEs apply formalisms & mathematical rigor to prove existence or absence of critical properties
Implementing the IV&V Assurance Strategy

- IV&V Assurance Strategy is implemented through the Assurance Design
  - The Assurance Design specifics the Technical Reference, inputs, analysis techniques, and objective evidence necessary to achieve the IV&V Project’s Objectives
  - Like the Assurance Strategy, the Assurance Design is specific to the needs of an individual project
    - Constructed to allow the IV&V Project to generate evidence to assure the critical capabilities and mitigate system risk
    - Areas of risk identified in the PBRA are key inputs into the development of the Assurance Design

- Assurance Statements are utilized to communicate the results of the implementation of the IV&V Assurance Strategy
  - A statement of the assurance that is being provided (or intended to be provided) by IV&V to a stakeholder or stakeholders on a system or subsystem
    - Assurance statements are typically formulated at the beginning of a IV&V Project and refined as necessary throughout execution
Tools for Implementing the IV&V Assurance Strategy

• NASA’s IV&V Program strives to continually develop new capabilities to support the execution of the IV&V Assurance Strategy
  – IV&V Techniques are documented in a Catalog of Methods (CoM)
  – Techniques are continually refined and tailored to the needs of the projects

• To maintain relevance, the IV&V Program selectively invests in new technologies necessary to assure NASA’s safety and mission critical software
  – NASA’s IV&V Program is advancing the state of the practice in Cybersecurity / Information Assurance and Independent Testing
    • Advanced techniques and capabilities are being developed to enable the program to keep pace with current development trends and emerging risk factors
    • Information Assurance and Independent Testing are becoming an increasingly prominent component of IV&V Project’s Assurance Strategies
<table>
<thead>
<tr>
<th><strong>Threat and Risk Assessment</strong></th>
<th><strong>Vulnerability Assessment / Penetration Testing</strong></th>
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<tbody>
<tr>
<td>• FISMA Compliance</td>
<td>• Implementation of Security Controls</td>
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<tr>
<td>• Life-cycle</td>
<td>• Monitoring of Security Controls</td>
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<tr>
<td>• Provide mission security assurance throughout design, development, implementation, operation, maintenance, and disposition</td>
<td>• Static Code Analysis (SCA)</td>
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<tr>
<td>• Assessment and Authorization (A&amp;A)</td>
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<tr>
<td>• Authority to Operate (ATO)</td>
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<thead>
<tr>
<th><strong>IV&amp;V In-Phase IA Support</strong></th>
<th><strong>CyberLab</strong></th>
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<tbody>
<tr>
<td>• Build security in “from the ground up.”</td>
<td>• Component of ITC JSTAR Lab</td>
</tr>
<tr>
<td>• Security Architecture Verification</td>
<td>• Virtualized servers</td>
</tr>
<tr>
<td>• IV&amp;V Methods</td>
<td>• Penetration Test tools</td>
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<tr>
<td></td>
<td>• Cybersecurity Knowledge Base</td>
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<td>• Cybersecurity Training Program</td>
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<td></td>
<td>• Mission System Virtualization and Testing</td>
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</table>
Independent Testing

Develop, maintain, and operate adaptable test environments for NASA’s IV&V Program that enable the dynamic analysis of software behaviors for multiple NASA missions

**Simulation**

- Functional Software-only Simulators
- NASA Operational Middleware (NOS)
  - Common emulation software
  - Middleware
- Spacecraft Simulators
  - Ground systems, instruments, spacecraft dynamics
- Small Sat
- Integrate many technologies to create solutions

**Automation**

- Simulation Verification
- Increase Testing
  - Unit Testing
  - System Testing
- Automated Installations and Simulator Deployments

**Testing**

- Provide evidence-based assurance to customer
- Risk-focused independent testing
- Focused on testing adverse conditions
  - Fault injection, back-to-back scenarios, etc.

**Virtualization**

- Heavy reliance on virtualization technologies
  - Development
  - Simulator Releases
  - Rapid Deployment
  - Evaluation Environments
Summary
Benefits of IV&V

• Yields higher confidence that delivered products are error free and meet the user needs.
• Increases likelihood of uncovering high-risk errors early in the development lifecycle.
  – Allows time for the design team to evolve a comprehensive solution rather than forcing them into a makeshift fix to accommodate deadlines
• Delivers ongoing status indicators and performance reporting to decision makers (e.g. program managers).
  – The customer is provided an incremental preview of system performance with the chance to make early adjustments.
• Reduces the need for rework from the developing contractor thereby reducing total costs to programs and projects.
• Facilitates the transfer of system and software engineering best practices.

IV&V leads to higher quality products, reduced risk, greater insight, reduced cost, and knowledge transfer.
QUESTIONS?
IV&V plays a key role in a number of high-profile NASA and non-NASA missions.
Generic Look at IV&V

- **Needs Analysis & Concept Phase**
- **Requirements Specification**
- **Design**
- **Implementation**
- **Integration & Test**
- **Ops & Maintenance**

**Concept Analysis**
{validate selected solution, validate s/w reuse strategy, verify sys. architecture is complete, ensure security threats & risks are known}

**Requirements Analysis**
{ensure the requirements are high quality (correct, consistent, complete, accurate, unambiguous, and verifiable) and adequately meet the needs of the system and user}

**Design Analysis**
{ensure the design is a correct, accurate, and complete transformation of the requirements that will meet the operational need under nominal and off-nominal conditions and that no unintended features are introduced}

**Code Analysis**
{ensure the implementation is correct, accurate, and complete, relative to requirements, operational need under nominal and off-nominal conditions, and introduces no unintended features}

**Test Analysis**
{ensure testing will serve as a sufficient means to verify and validate that the implementation meets the requirements and operational need under nominal and off-nominal conditions}

**Operational & Maintenance Analysis**
{ensure operating procedures are correct and usable, new constraints & changes are understood and appropriately addressed, and ensure anomalies are understood and appropriately addressed