NASA's Independent Verification and Validation (IV&V) Program and Gateway IV&V Project

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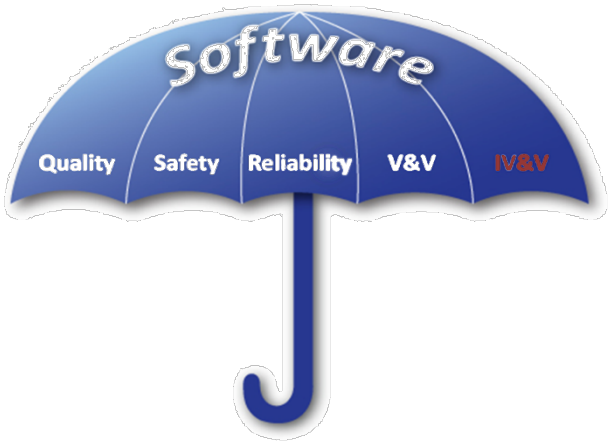
www.nasa.gov/centers/ivv

What is IV&V?

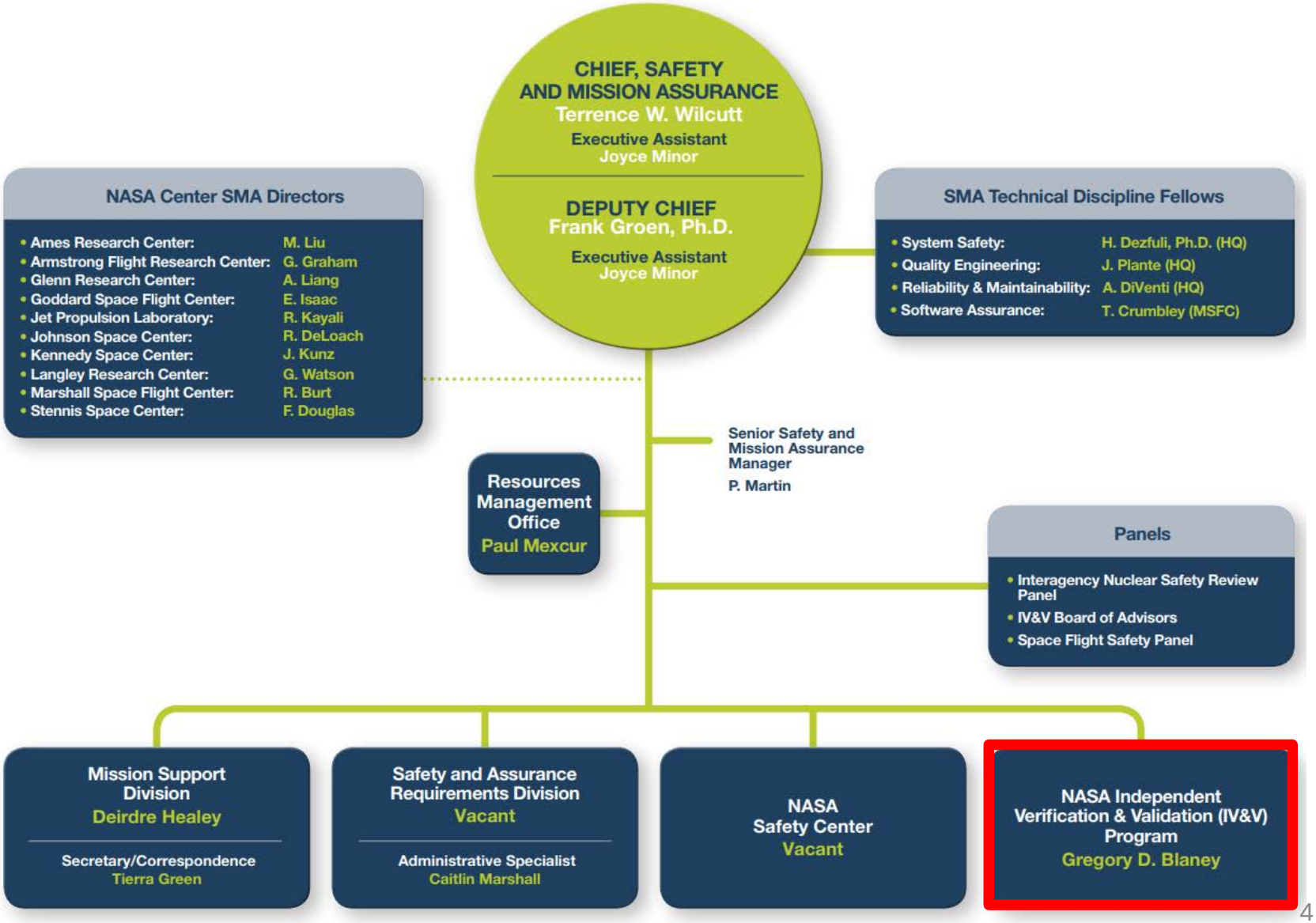
- **V**erification
  - Are we building the system right?
- **V**alidation
  - Are we building the right system?
- **I**ndependent
  - *IEEE Standard for System and Software Verification*, IEEE 1012, defines three important criteria for IV&V independence
    - Technical Independence - Different personnel; not the same people who build it
    - Managerial Independence - Planning and scoping control. Independent reporting path
    - Financial Independence - Funding from a source separate from project development



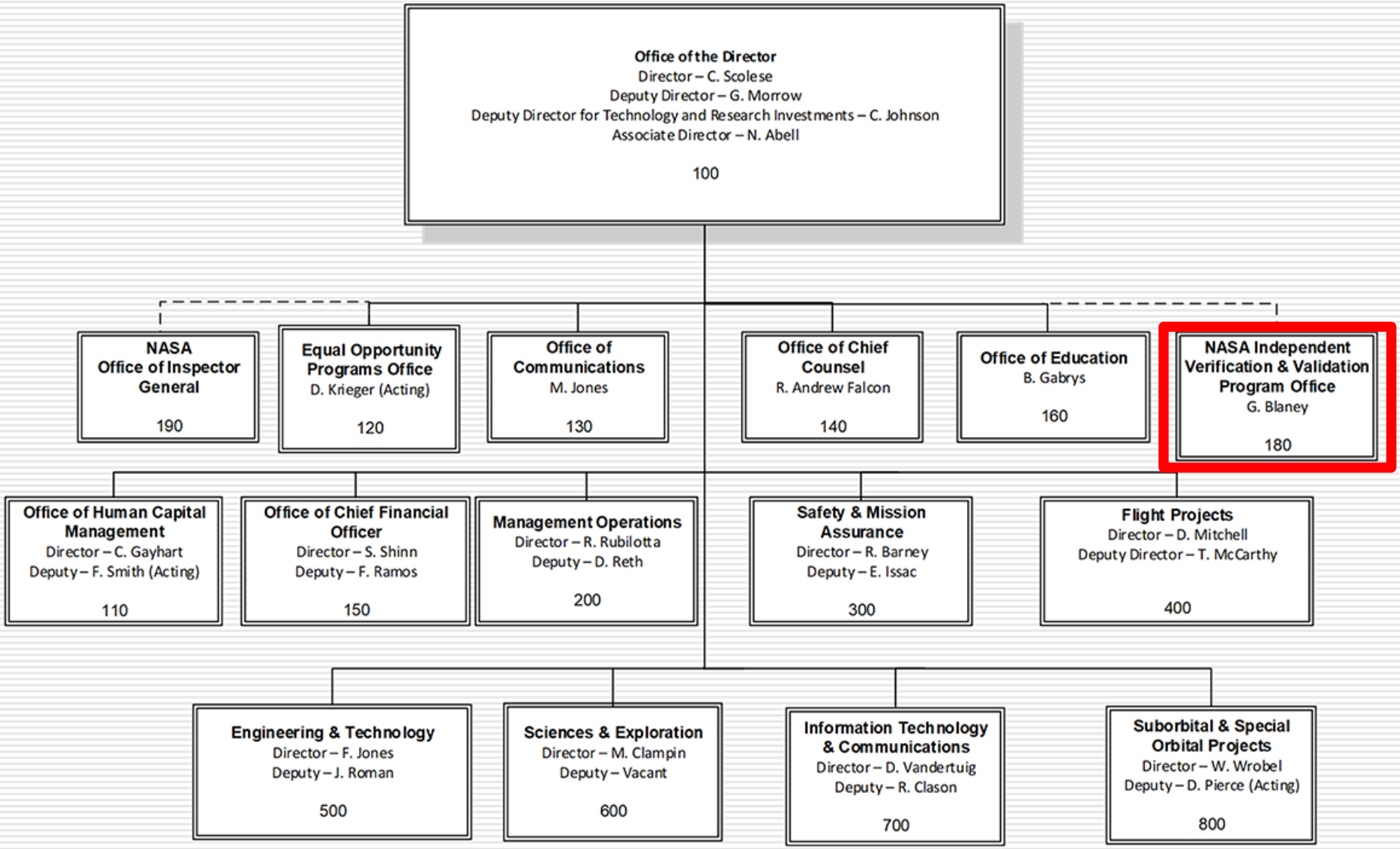
Origins of IV&V within NASA

- 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.

Office of Safety and Mission Assurance

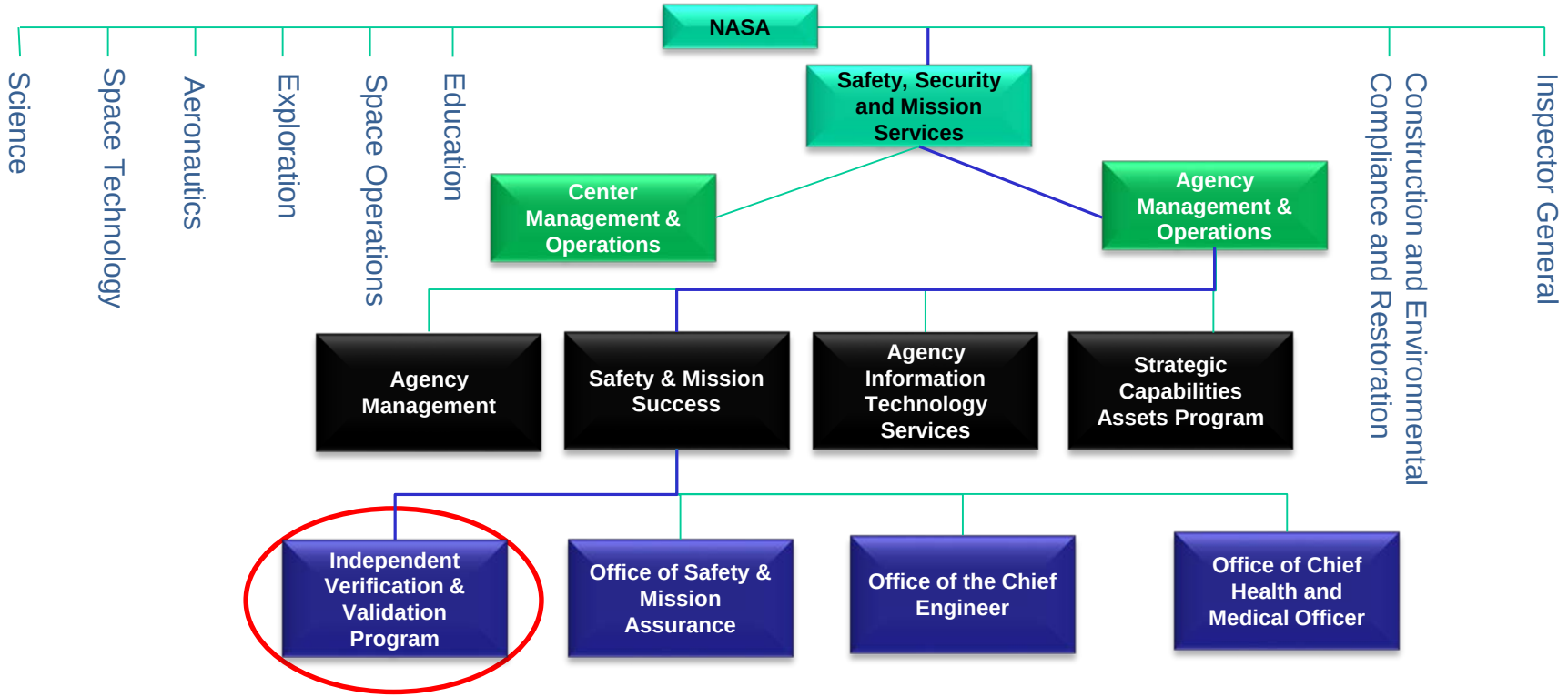


Goddard Space Flight Center - Center Org Chart



Updated: March 2019

Agency Budget Structure



IV&V Program budget covers all IV&V Program needs, including technical work, physical and IT infrastructure, security, etc.

Benefits of IV&V

- **Increased Safety and Dependability** - Greater confidence-delivered products are error free and meet user needs. Many IV&V-identified defects threaten loss of mission or loss of crew if not resolved
- **Reduced Risk** - Increased likelihood high-risk errors are detected early, allowing time for the development team to evolve a comprehensive solution rather than a forced makeshift fix to accommodate deadlines
- **Greater Management Insight** - Increased insight into project status and performance through independent perspective and objective evidence
- **Reduced Cost** - Reduced development rework, reducing total program and project costs for a positive return on investment
- **More Knowledge Transfer** – Increased communication across project teams and cross-project transfer of system and software engineering best practices

IV&V is an industry-proven approach to increase quality, reduce risk, gain development insight, reduce cost, and transfer knowledge

NASA's IV&V Approach

- **Full Lifecycle -** Not just testing at the end. For NASA, IV&V starts near Mission SRR, continues up to, and sometimes beyond, launch
- **Product Focused** – Not document or compliance focused. Examines concept, architecture, requirements, design, code, and test products
- **Capability Based Assurance (CBA) –** Keeping the "big picture" in view when assessing the software details
- **Follow the Risk –** Dynamically adapting plans to focus assurance activities where evidence indicates there is risk
- **Use Multiple Perspectives for Analyses**

Add assurance the software will do what it is supposed to do

Add assurance the software will not do what it is not supposed to do

Add assurance the software will respond appropriately under adverse conditions

NASA IV&V is a systems engineering process employing rigorous methodologies for evaluating the correctness and quality of software products throughout the SDLC for NASA's highest profile missions.

IV&V Assurance Strategy: Concept

- The IV&V Assurance Strategy is the identification/selection of
  - Which mission capability and system software risk to target
  - Which IV&V techniques to use to help reduce the targeted risk
- IV&V techniques include assessments, analyses, evaluations, reviews, inspections, and testing of software artifacts during the entire development lifecycle that create evidence
  - Aligned with IEEE 1012
  - Documented in a Catalog of Methods
- How much evidence? → it is a trade-off between criticality of the system(s) 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 and type of evidence needed determines the rigor of the analysis
  - Analytical Rigor is the type and amount of IV&V techniques to use

How IV&V Uses Evidence

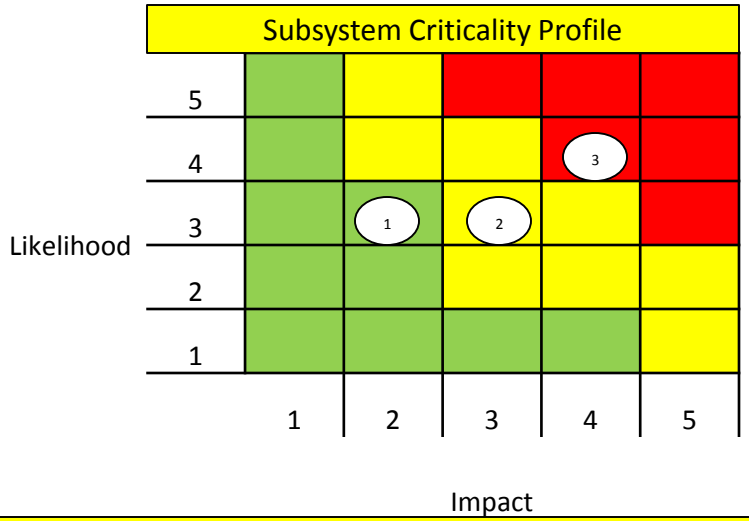
- Support recommendations for the developers that improve the quality (or reliability) of the system software
- Support assurance conclusions about the quality (or reliability) of the system software
- Adjust the IV&V Assurance Strategy to focus on the most critical software
- Gain insight into the progress of development
- Evaluate thoroughness of analysis

Establishing an IV&V Assurance Strategy

- The IV&V Program assesses a mission 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
- The IV&V Program's process for this assessment 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 an IV&V Assurance Strategy (continued)

Desired Capabilities	Cruise - GNC	1 Cruise - Thermal	2 Cruise - Telecom	Cruise Power	3 EDL GNC	Rover: Startup & Initialization	Rover: C&DH
	Responsible Subsystems						
Conduct habitability investigations							
Launch to Mars							
Cruise to Mars	x	x	x	x		x	x
Trajectory control	x		x				
Attitude Control	x		x				
Approach Mars					x		
Trajectory control	x				x		
Attitude Control	x						
Maintain flight systems							
Establish and maintain power				x			x
Establish and maintain thermal control		x					x
Perform fault detection							x
Establish and maintain communications			x				x
Gather engineering and housekeeping data	x	x	x	x	x	x	x
EDL							
Pre-EDL					x		
Entry					x		
Descent					x		
Landing					x		
Perform surface operations							
Traverse the Martian surface						x	x
Acquire and handle samples						x	x
Evaluate current position via TRS data							
Perform reconnaissance activity						x	x
Collect science data						x	x



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 …

less ← Amount of Rigor & Evidence Needed → more

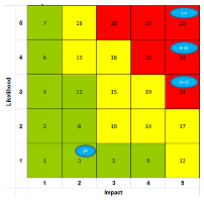
Manual Analysis	Static Analysis	Dynamic Analysis	Formal Analysis
SMEs conduct formal or informal inspections & evidence is recorded simply as issues	SMEs evaluate structure & content using various perspectives supported by CASE tools. Evidence is recorded as issues & supplemented with coverage	SMEs execute system & evaluate results. Evidence is recorded more thoroughly as to make the case for what works and what are limitations	SMEs apply formalisms & mathematical rigor to prove existence or absence of critical properties

Implementing an IV&V Assurance Strategy

- An IV&V Assurance Strategy is implemented by a set of Analysis Activities
  - Each Analysis Activity achieves one or more IV&V Project's Assurance Objective
  - The IV&V Assurance Strategy informs the Technical Reference and which IV&V technique to use
  - An Analysis Activity generates the evidence for a specific Assurance Objective
- Possible outcomes of implementing the IV&V Assurance Strategy
  - Assurance Conclusions at varying levels of confidence and that that are based on evidence from analyses performed
  - Findings or defects: "Issues", a.k.a "TIM"s (Technical Issue Memorandum)
  - Candidate technical risks for adoption by the Program or Project
  - Refinement of the technical reference
  - Refinement of IV&V Assurance Strategy

IV&V Assurance Strategy Implementation Process and *Example*

1. Risk-Prioritize System Capabilities and Software for Assurance using PBRA/RBA and IVV S3106, and Develop High-Level Assurance Objectives (AOs)



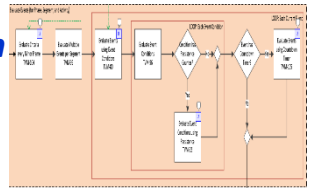
Capability: *Entry, Descent, and Landing (EDL)*
Entity: *Orion Timeline Vehicle Manager (TVM)*
Objective: ***Assure TVM correctly evaluates and detects critical events, to mitigate risk of inappropriate or missed event detection***

2. Formulate Risk-Driven Assurance Design in Technical Scope and Rigor (TS&R), and Select and Tailor Analysis Methods using COMPASS and IVV 09-1

Plan: ***M-38, Verify Software Design by Inspecting Traces to Requirements (Nominal, Off-Nominal, and Hazard Scenarios)***

3. Develop IV&V Technical Reference, Studying Artifacts and Collaborating with Developers and IV&V Team to Identify IV&V Questions/Concerns to "Follow the Risk"

Learn and Understand: ***IV&V created a flow diagram to model condition evaluation and event detection behavior, start to finish, capturing timing, data paths, and interfaces.***



IV&V Technical Reference

Condition	Equivalent
|x| < y	(x < y) AND NOT (x <= -y)

4. **Execute Planned Analysis:** ***IV&V traced expectations to TVM software and searched for answers to IV&V Questions/Concerns. IV&V noted differences in comparison logic between code methods intended to provide the same behavior, in critical event condition detection code.***

Incorrect Code in Critical Software Method

```
584: case TVM_Mission::LESS_THAN:
585:   if ( x <= -y ) {LclRet = false;}
586->: if ( x < y ) {LclRet = true;}
587:  break;
```

5. **Confirm Potential Issues:** ***IV&V analyzed the logic and proved the code incorrect in 8 separate instances.***

6. **Evaluate Issue Significance and Document Issues:** ***The incorrect code would have resulted in incorrect evaluation and detection of critical events, plausibly leading to Loss of Mission (LOM) during EDL, which relies significantly on event-driven behavior (Severity 1).***

7. **Communicate Issue and Track to Resolution:** ***Orion accepted and resolved this significant issue.***

IV&V Communication Methods

- Interact with Program and Project staff in working group meetings to establish system understanding and communicate IV&V focus and status
- Communicate findings as soon as possible directly to the developer (e.g. during peer reviews of artifacts or software hosted by the Program, Projects or providers)
- Deliver reports at the completion of major work activities that summarize analysis approaches and results
- Communicate status of assurance objectives and summaries of assurance conclusions in presentations at Program and Project milestone reviews
- Communicate value of IV&V accomplishments in the IV&V Program's weekly reports and monthly status reviews to the Agency

Status of Gateway IV&V

- First round of prioritizing the expected Gateway system capabilities and software and developing high-level Assurance Objectives (AOs) is complete and under internal review within the Program
  - Plan is to review results of the assessment with the Gateway Program and Module Projects
- Finalizing a risk-driven strategy to accomplish the assurance objectives that leverages the IV&V Program's technical framework and applies appropriate analytical rigor
- Developing the IV&V team
- Supporting the Gateway Program's efforts to certify Core Flight Software (CFS) for Gateway

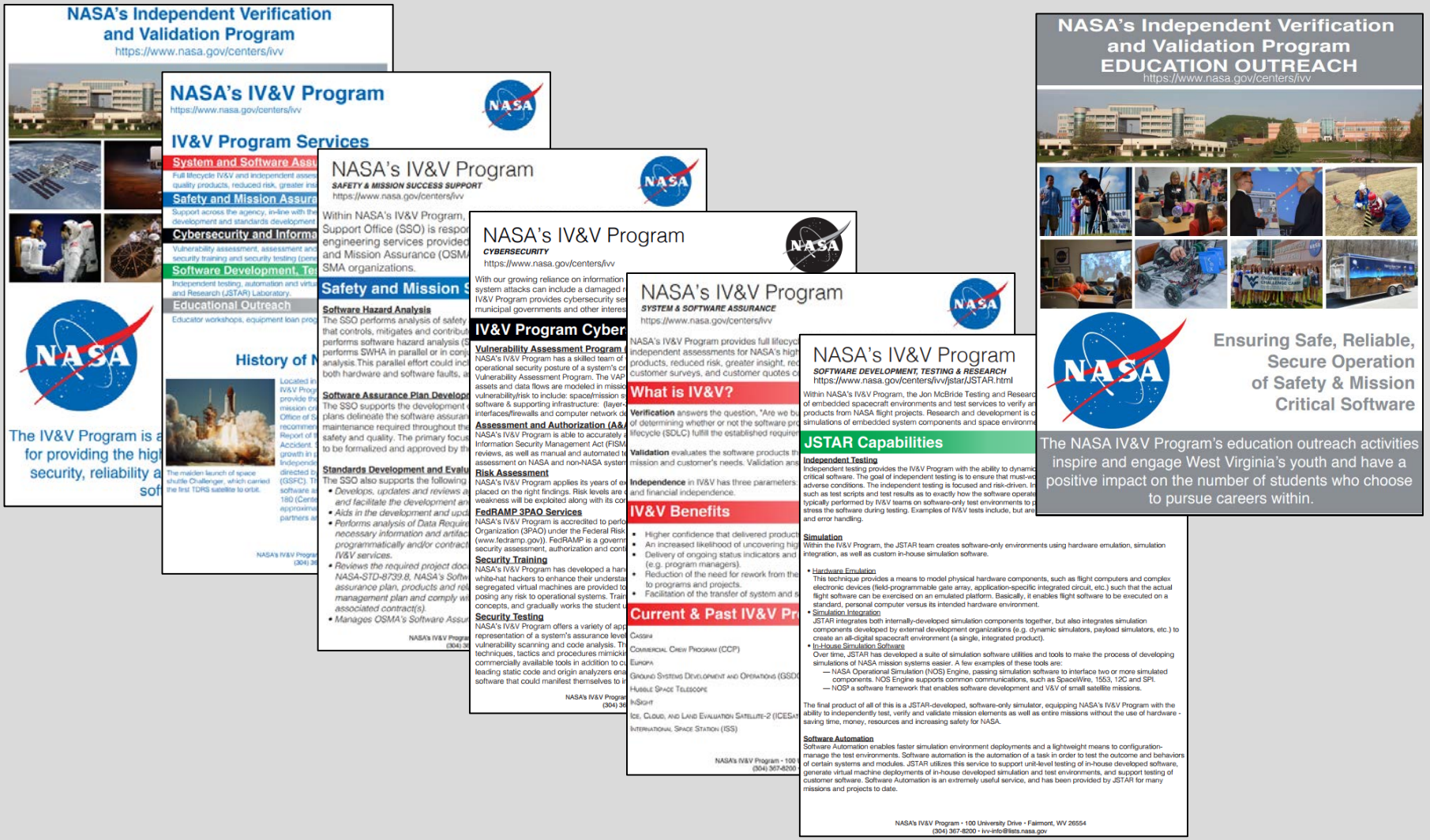
Gateway IV&V Next Steps

- Continue to support CFS certification effort
- Finalize the initial Gateway IV&V Project Execution Plan (IPEP)
  - Identify which Assurance Objectives (AOs) to target and what techniques to use (e.g. exploring option to use formal methods for some AOs like those for assuring autonomous behavior)
  - Review the IPEP with the Gateway Program
- Begin executing according to the IPEP
  - Plan analysis activities that targets integrated Gateway system and software artifacts and Gateway module system and software artifacts as they mature and become available
  - Develop technical references in SysML for analysis activities by studying Gateway artifacts and collaborating with Program and Project staff to identify questions/concerns to target analysis (i.e. “Follow the Risk”)
  - Develop plan for establishing an independent Gateway VSM and software test capability for the Gateway IV&V Project


IV&V's Goal is Mission Success

For More Information

https://www.nasa.gov/centers/ivv/program_flyers.html



QUESTIONS?


INDEPENDENT VERIFICATION AND VALIDATION PROGRAM
NASA
20 YEARS OF EXCELLENCE

IV&V Program Services

The IV&V Program's mission is to provide our customers assurance that their safety and mission-critical software will operate reliably and safely.

- System and Software Assurance
  - Full Lifecycle IV&V
  - Independent Assessments
- Safety and Mission Assurance (SMA) Support
  - Common support infrastructure for assuring core Software Assurance functions across the Agency
  - Software Assurance Research Program (SARP)
- Mission Protection Services (MPS)
  - Cybersecurity Threat/Risk Assessment, Vulnerability Assessment, Information Assurance (IA) Support, CyberLab, FedRAMP
- Jon McBride Software Testing And Research (JSTAR) Laboratory
  - Independent Test Capability (ITC), Robotics
    - Simulation, Testing, Automation, and Virtualization
- Partnerships, Collaboration, and Leadership
  - MDA, International IV&V WG, WVANG, DOE, OSMA, FBI, NOAA, DOD/Army, CCSDS, OCIO, OCE, STF-1, GSFC Code 300, 400, 500, 700, 800
- STEM Engagement

NASA IV&V Project Metrics

How do IV&V Projects provide the most value to the Agency?

… by getting involved early in the SW development lifecycle

13 of 13 active IV&V projects started before mission SRR.

… by detecting defects in-phase with SW development

Overall phase containment by active projects: **92%** over the past year.

… by detecting and submitting quality defects to the development teams

Overall issue acceptance for active projects was **95%** over the past year.

… by ensuring our customers are satisfied with our products and services

ACTUAL: 2018 Annual Survey: **99.7%** of all responses indicated a favorable ("Agree" or "Strongly Agree") perception of the support being provided by the IV&V Program.