2008 & 2009

NASA Independent Verification & Validation Program Value Report

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NASA IV&V VALUE REPORT 2008 & 2009

TABLE OF CONTENTS

Letter from Director	.....	Page i
Vision, Mission, Values	.....	Page ii
Overview of Program	.....	Page 1
Benefits of IV&V		
Benefit 1	**.....**	**Page 6**
Benefit 2	**.....**	**Page 12**
Benefit 3	**.....**	**Page 15**
Benefit 4	**.....**	**Page 16**
Benefit 5	**.....**	**Page 21**
2008 Project Summaries	.....	Page 24
2009 Project Summaries	.....	Page 42
Recent Program Highlights	.....	Page 58
Objectives for Continuous Improvement	.....	Page 64
Future Plans	.....	Page 69

Dear Reader,

Since 1993, the IV&V Program has provided our customers and stakeholders with assurance that safety- and mission-critical software will operate correctly, safely, and dependably. At the close of each year we take a moment to reflect on the culmination of our successes. In doing so, we often create a list of what we have completed. Although these lists are important, they do not tell the full story; they lack an explanation of meaning. What does our work mean for our customers and stakeholders? In other words, what is the value of our work?

Value is measured by the benefits received from a product or service. Sometimes these benefits are quantifiable and other times they are not. In this First Annual NASA IV&V Program Value Report, we provide an overview of the benefits of IV&V by which we measure the IV&V Program's performance and express our value. In addition, an overview of the IV&V Program, our accomplishments, and our strategies for continued growth and success are presented.

The trends found from the IV&V Program's evaluation are exciting! We confirmed our strengths and are conscious of our opportunities for improvement and growth. **Based on several performance measures, the IV&V Program's performance is improving significantly.** For example, our teams are beginning work with our customers earlier than ever, which enables the IV&V Program to detect a higher number of defects early in the development lifecycle. This earlier detection of defects improves the overall quality of the software products, reduces rework, and reduces total project costs. Additionally, our communications with customers and stakeholders continue to strengthen.

We celebrate our successes, but we also appreciate the awareness of areas in which we can improve. Through the process of defining our value, we discovered many lessons learned. For example, in order to apply the benefit metrics to the IV&V Program, we must collect additional information. Future reports will include a measure called 'turnaround time', which will measure our responsiveness and timeliness with regard to communication with our customers and stakeholders. Please note our plans to achieve improvements in the final section of the report.

For those parts of the IV&V Program that are going well, we will build upon our successes. However, for our opportunities for improvement and growth, we have devised specific goals to address these areas. Through regular evaluation comes progress; therefore, the IV&V Program will continue to progress and to provide additional value to our Projects and the Agency.

Sincerely,

Dr. Butch Caffall,
Director, NASA IV&V Program

VISION OF THE NASA IV&V PROGRAM

The National Aeronautics and Space Administration (NASA) Independent Validation & Verification (IV&V) Program is valued for its superior performance in independent validation and verification, its ability to provide high confidence safety and mission assurance of NASA software, its positive impact on the development of high quality software, and its expertise in software engineering.

MISSION OF THE NASA IV&V PROGRAM

The NASA IV&V Program provides assurance to our stakeholders and customers that NASA's mission-critical software will operate dependably and safely.

The NASA IV&V Program performs leading-edge research that improves IV&V and software assurance methods, practices, and tools.

The NASA IV&V Program participates in the vitality of the community, as well as engages the public in the experience and benefits of exploration and discovery.

VALUES OF THE NASA IV&V PROGRAM

The NASA IV&V organization embraces these values in words and deeds, as they collectively shape behaviors, pilot actions, deliver services to customers, and establish the NASA IV&V organization's culture.

SAFETY

Being safe and ensuring personal safety for employees and the public; providing security for everyone and protection of our resources and assets; being good stewards.

EXCELLENCE

Producing quality goods and services; doing the right thing; performing second to none; practicing continuous improvement; being distinctive, creative, and committed; leading in best practices; being efficient.

INTEGRITY

Doing what was said would be done; having trust; being honest, fair, and accountable, both personally and organizationally; having steadfast ethical conduct; living by high standards of individual behavior.

TEAMWORK

Working together; supporting each other; collaborating effectively; sharing accomplishments and successes; providing collective wisdom; being responsible; helping others; leveraging synergy; exhibiting open communication.

RESPECT

Noticing individual worth; being open-minded; accepting diversity; seeking first to understand and then to be understood; having credibility; empowering oneself and others; welcoming every idea; listening; being civil.

BALANCE

Being well rounded with work, family, and self; balancing professional and personal time; giving to the community; practicing wellness of living; having a balanced involvement that enhances all; being there; coaching others.

INNOVATION

Seeking better ways or new methods to do things; being imaginative to enhance processes; staying on the leading edge; being original, agile, adaptive, and responsive to change.

OVERVIEW OF PROGRAM

OVERVIEW OF NASA IV&V PROGRAM

WHAT IS INDEPENDENT VERIFICATION AND VALIDATION?

Since its establishment in 1993, as a result of the Rogers Commission Report, the NASA IV&V Program has provided NASA with additional assurance on mission and safety critical software. **Verification and validation (V&V) objectively assess the correctness and quality of software and should occur in phase with the development lifecycle of the project.** Validation assesses that the correct system is being built. Verification assures that the correct system is built correctly. Both processes are guided by the following three questions, which are the foundation of the IV&V Program's assessments throughout the development lifecycle:

1. Will the system software do what it is supposed to do?
2. Will the system software do what it is not supposed to do?
3. Will the system software respond as expected under adverse conditions?

The development lifecycle consists of several phases in which the outcomes of one phase are used as the initial inputs for the following phase. Below are the notional development lifecycle phases that are referred to for the purposes of this report:

CONCEPT:	REQUIREMENTS:	DESIGN:	IMPLEMENTATION:	TEST:
System **goals** are determined.	…the **functions** necessary to meet goals are documented.	…the **architecture** is designed to carry out the functions.	**…code** is written to satisfy the functions and the architecture of the system.	…operates the system, which is **introduced into the intended environment** to be sure it operates as intended.
Based on the goals…	Based on the functions…	Based on the architecture…	The code…	

WHAT DOES IT MEAN TO BE INDEPENDENT?

"Verification and validation activities produce their best results when performed by a V&V agent who operates independently of the development project or specification agent," according to Barry Boehm, a frequently cited software engineering expert (Boehm, 1984, p. 76). To be considered independent, the Institute of Electrical and Electronics Engineers (IEEE) states that a program must be technically, managerially, and financially independent from the projects they serve (IEEE, 2004). Technical independence is achieved by IV&V Program personnel using their expertise to assess software development processes and products independent of the project (2004). Managerial independence requires responsibility for the IV&V Program's effort to be vested in an organization separate from those responsible for performing the system implementation (2004). Finally, the control of the IV&V Program's budget is independent of the development organization, explaining how the IV&V Program gains financial independence (2004). Independence from the project allows for objectivity (Arthur & Nance, 2000), which promotes the following advantages:

a) encourages one to "consider a wider range of solutions" (Arthur, Groener, Hayhurst, & Holoway, 1999),

(b) aids in the detection of subtle defects often overlooked by those too close to the solution (Wallace & Fujii 1989), and

(c) supports an unbiased critique of how well the software performs (Wallace & Fujii, 1989).

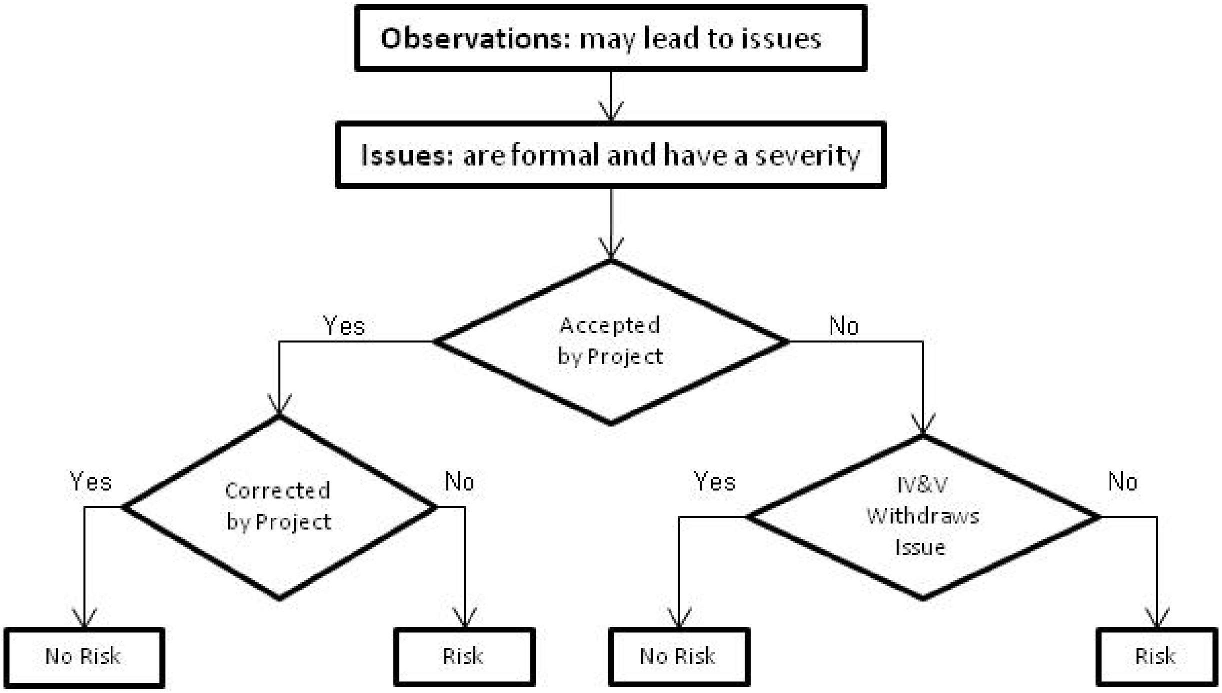
HOW DOES THE IV&V PROGRAM APPROACH IV&V AT THE PROJECT LEVEL?

Understanding a system's goals is what drives the IV&V Program's approach to verification and validation; modeling is the tool used to depict that understanding. Modeling is the act of diagramming a system's goals as understood from the Concept of Operations document written by the project. Multiple iterations of the model are produced, with each iteration illustrating an additional level of detail, or level of capabilities. Capabilities are the abilities needed to perform an action or set of actions that result in accomplishing a goal. The initial model captures the overall goals of the system, and then the goals are delineated into capabilities. The first delineation of the goal into capabilities is referred to as the level one capabilities. The second level of capabilities refers to a delineation of the level on capabilities. The goals of the system and levels one and two capabilities compose the System Reference Model (SRM).

Once the SRM is developed, the IV&V Program and the project resolve differences between the project's intended system and the IV&V Program's SRM. This vital step allows projects and IV&V practitioners to gain concurrence on the system's purpose and requirements. Once concurrence is gained, the SRM becomes the central communication device between the IV&V Program and customers; the SRM is referenced in subsequent validation and verification activities that occur throughout the development lifecycle. Through these activities, the SRM is continuously enhanced and elaborated as the project progresses through the development lifecycle and the IV&V Program gains understanding of the capabilities and supporting behaviors.

When the IV&V Program detects a suspected defect in project documents or other artifacts, these defects are communicated to the project. The approach to these communications is presented in the diagram below. Upon detection of what is suspected to be a defect, IV&V practitioners either communicate the defect as an observation or a formal issue, both of which are tracked in a database. Observations are communicated to projects, and either result in becoming an issue or are resolved quickly. Issues are defects that are formally documented in a database for tracking purposes. Upon documentation and communication of a defect to projects, the defect evolves into one of three states: accepted, withdrawn, or it becomes a risk.

Accepted defects are those which the IV&V Program and the project agree is a defect. If the project resolves the defect, no risk is created; however, if a project decides to move forward with development without resolving the defect, the defect becomes a risk. When the IV&V Program communicates a defect to the project and the project does not agree that the defect exists, it is either withdrawn or it becomes a risk. Formally documented defects may be withdrawn if the detection is a result of a misunderstanding of the system. But if the IV&V Program is certain that the defect exists, and the project does not accept it, the defect results in a risk. Risks indicate that a problem exists, but the project is willing to move forward with development without resolving the problem.



WHY IS THERE A NEED FOR THE IV&V PROGRAM?

Statement of the Problem

Software failure stories are documented across the software development industry. Examples of common problems include using software in applications and environments not considered during development, as well as software behaving in unpredictable ways when exposed to adverse conditions (Hakuta, M. & Ohminami, M., 1997). Another common cause of software problems is reliance on testing to make sure that the software system will achieve its intended goals. This reliance on testing is faulty because testing cannot determine the absence of defects; it can only determine the presence of defects (Sommerville, I. 1992). Additionally, exhaustive testing is impossible because the number of conditions that would need tested is astronomical.

The 3 Questions:

1. Will the system software do what it is supposed to do?
2. Will the system software do what it is not supposed to do?
3. Will the system software respond as expected under adverse conditions?

Because software failures have meant loss of dollars, loss of missions, and in some instances loss of life, developing strategies to mitigate these problems are vital to the software development community. The IV&V Program's response to eliminating software defects is comprehensive assessment of system software that focuses on answering the three questions. The goal of the assessments is to detect high risk defects as early as possible. All defects are assigned a severity level when formally documented. These levels range from low (5) to high (1). A low severity defect is a defect that could result in an inconvenience to the user or operator, but does not affect essential mission capabilities. The highest severity level refers to a defect that may prevent essential capabilities or may jeopardize safety, security, or other critical requirements. For the purposes of this report, defects designated as a level 1, 2, or 3 severity level are included because these are the most critical defects.

By considering the three questions, the IV&V Program provides increased assurance to projects that the software will operate as intended, not operate as it is not intended, and will operate as it is supposed to under adverse conditions. This assurance is a result of the combined benefits of IV&V. These benefits, listed below, are the foundation of the IV&V Program's Value Report, which expresses the value that the IV&V Program adds to NASA.

Benefit 1: The IV&V Program increases **the likelihood of uncovering high-risk defects early in the development lifecycle – allowing the design team to evolve a comprehensive solution rather than forcing them into a makeshift fix to accommodate software deadlines.**

Benefit 2: The IV&V Program **provides ongoing status indicators and performance reporting to NASA program level managers. The customer is provided an incremental preview of system performance with the chance to make early adjustments.**

Benefit 3: The IV&V Program **provides stakeholders with the visibility into progress and quality Provides stakeholders with visibility into the progress and quality of the system-software development effort.**

Benefit 4: The IV&V Program reduces **the need for rework by the developing contractor, and thereby reduces the total costs to programs and development projects.**

Benefit 5: The IV&V Program r**educes defects in delivered products.**

WHAT ARE THE CAPABILITIES AND LIMITATIONS OF THE DATA?

An important note is that the IV&V Program implemented a new approach to validation and verification in early 2007. This approach is goal-based and utilizes modeling practices. Charts for each performance measure are shown based on data collected before 2007 and after 2007, before and after the new approach was implemented. A more detailed explanation of this transition can be located in the "Recent Program Highlights" section.

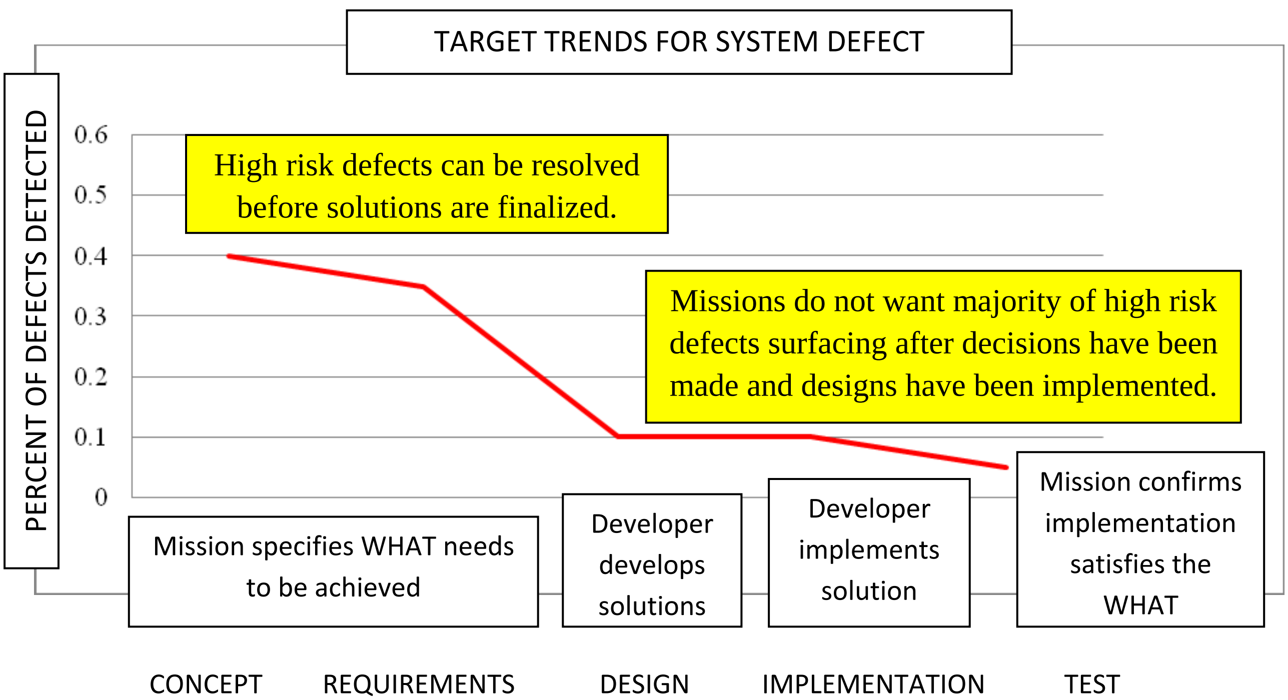
Charts titled "Before 2007" include defects found on 16 projects, dates back to 2002, and includes data through December 31, 2006. Charts titled "After 2007" include defects found on 19 projects and dates from January 1, 2007 through July 24, 2009.

The strengths of the IV&V Program data are that it can be used to provide good indicators and predict trends; however, readers must consider that the data is project-focused, has limited standardization and is not always precise. Charts included in this report represent all projects that were served by the IV&V Program in the years listed above, with the exception of the Space Shuttle Program (SSP) and the International Space Station (ISS), which comprise the Space Operations Mission Directorate (SOMD). Because these projects are currently operational, versus being developed, the SOMD data is separated from the larger data set. Throughout the report, charts reflecting the performance of SOMD will be included following the charts representing all other projects combined. These charts indicate data from projects in the Science Mission Directorate (SMD) and Space Exploration Mission Directorate (SEMD).

BENEFITS OF THE IV&V PROGRAM

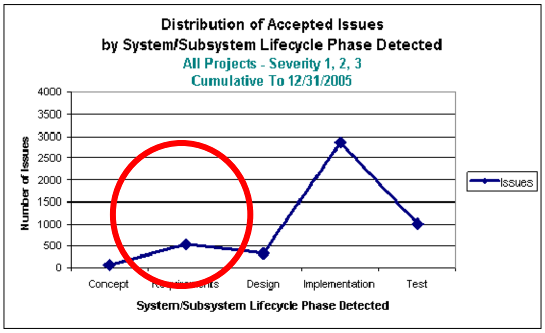
Benefit 1:
The IV&V Program provides an increased likelihood of uncovering high risk defects early in the development lifecycle – allowing the design team to evolve a comprehensive solution rather than forcing them into a makeshift fix to accommodate software deadlines.

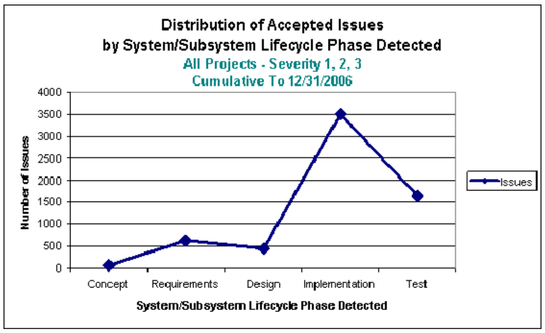
The IV&V Program adds value to the selected Agency projects by discovering high risk defects at a time that enables the project to generate a comprehensive solution - rather than discovering high risk defects after the project has begun to implement a solution, which may force the project into a less-than-optimal fix to accommodate software deadlines. Therefore in order to detect defects early, the IV&V Program must begin its work as early as possible in the project's development lifecycle. Work by the developer completed in the concept, requirements, and design phases is the foundation for what the system should do, what the system should not do, and how the system should react under adverse conditions. Beginning with the implementation phase, the focus is on writing the code needed to execute the design. Before coding begins in the implementation phase, it is critical that the requirements of the system are correct, complete, consistent, unambiguous and testable. The image below demonstrates the IV&V Program's target for finding the majority of defects early, prior to the implementation of the design.

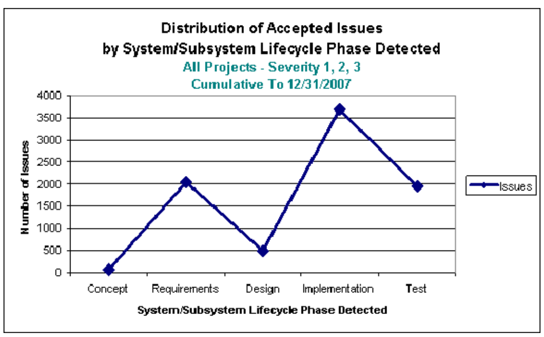


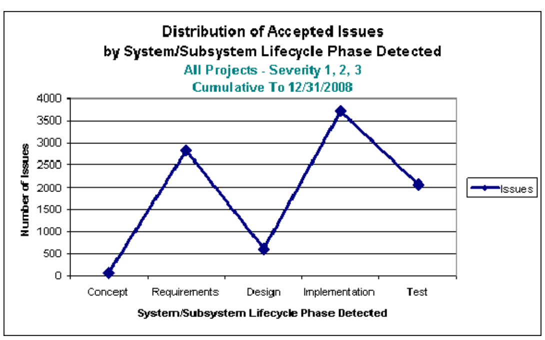
The goal is to uncover high-risk defects in time for the mission to integrate the defect resolution strategy into the design solution rather than after the design decisions have been implemented, which has been shown to be more costly.

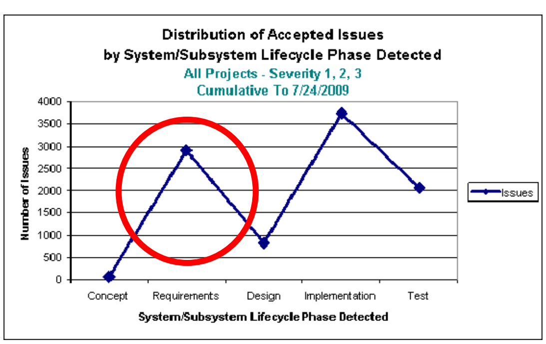
SMD and ESMD Cumulative By Year











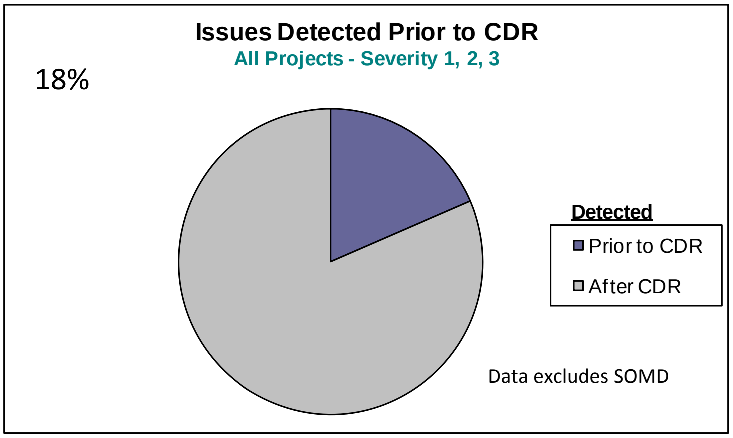
Above Charts Exclude SOMD

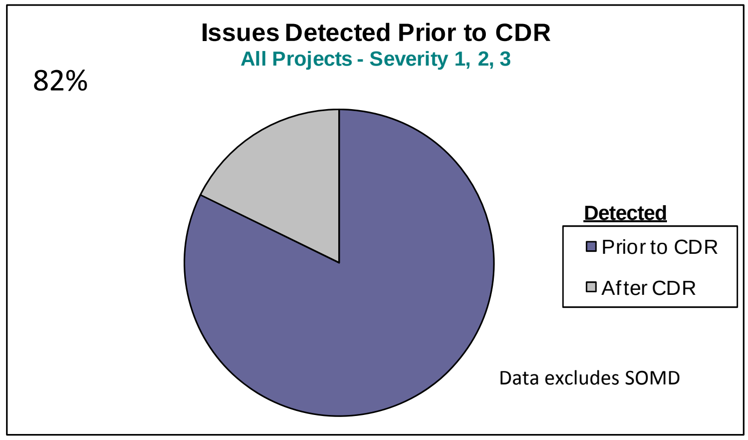
The charts to the left demonstrate the IV&V Program's improving performance related to detecting defects early in the development project's lifecycle. Until recent years, the majority of defects detected were discovered during implementation. Finding defects during late phases of the development lifecycle is beneficial, but may not provide the project with sufficient time to devise optimal solutions for the detected defects. For example, if the code is already written before the IV&V Program detects a defect, then the developers may be forced into a sub-optimal solution to accommodate software deadlines.

In recent years, the IV&V Program has made considerable effort to begin working with projects earlier in their development lifecycle. This effort has resulted in an increase in value to the projects because **the IV&V Program is detecting a greater number of high severity defects early in the development lifecycle**. In future years, the IV&V Program expects that the incline in the number of defects detected during implementation will decline given the increased number of defects detected for projects that are either in the requirements phase or design phase, but recognizes that cumulative change occurs slowly as the projects move to the implementation phase.

The charts below provide a view of the IV&V Program's improving ability to detect a majority of high severity defects prior to the implementation of the design of the overall system, allowing comprehensive solutions to be included in the design. "CDR" refers to a key decision point for projects that occurs prior to implementation of the design of the software.

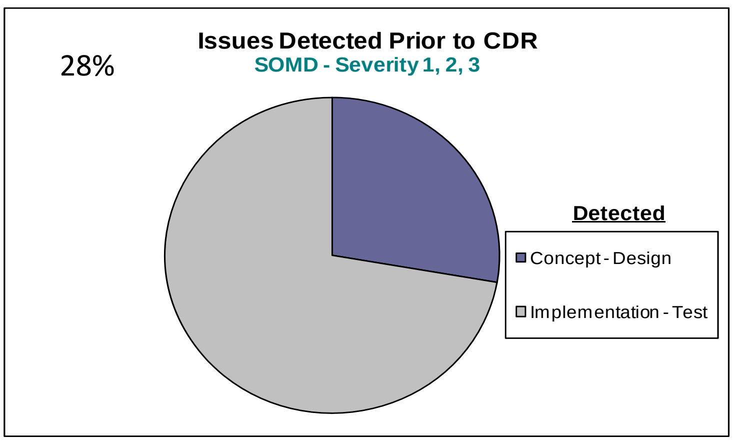
SMD and ESMD Projects Before 2007	SMD and ESMD After 2007





In recent years, the IV&V Program has increased the number of high severity issues detected prior to the implementation of the design by 64 %.

SOMD Projects After 2007



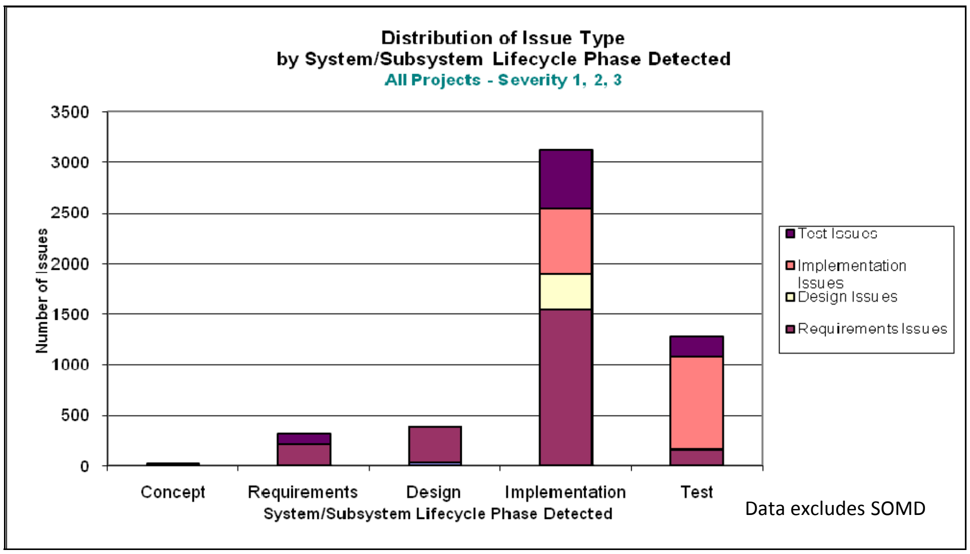
In addition to early detection of defects, software projects are provided with the opportunity for optimal defect solutions when a defect is detected and resolved in the same phase in which it was introduced. This is called *phase containment* and is imperative because the project is given an opportunity to fix a defect before it reappears in a subsequent phase where, if undetected, it would further impair the quality of the software.

VOICE OF THE CUSTOMER:

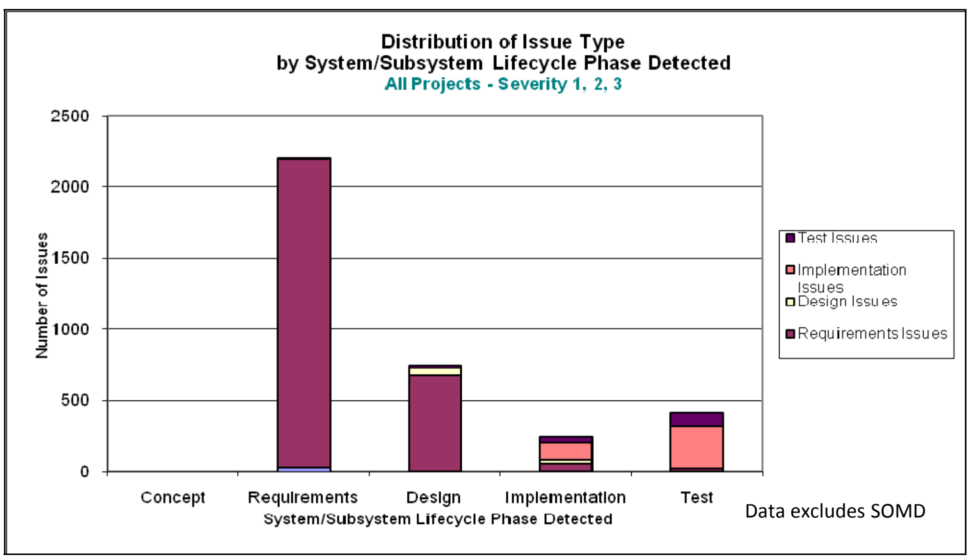
"In-depth analysis of proposed design changes helps to ensure the final product met the intents with the highest level of quality and safety."

When the IV&V Program finds defects early and is in phase with the project, the IV&V Program has the ability to impact the quality of the design by providing the project with an opportunity to create comprehensive solutions for detected defects. The charts below demonstrate both early detection of defects and phase containment. The number of defects detected during each phase is represented, as well as the type of defects detected in that phase. A number of factors have contributed to the IV&V Program's ability to achieve better phase containment. In recent years, the IV&V Program's performance has improved significantly.

SMD and ESMD Before 2007

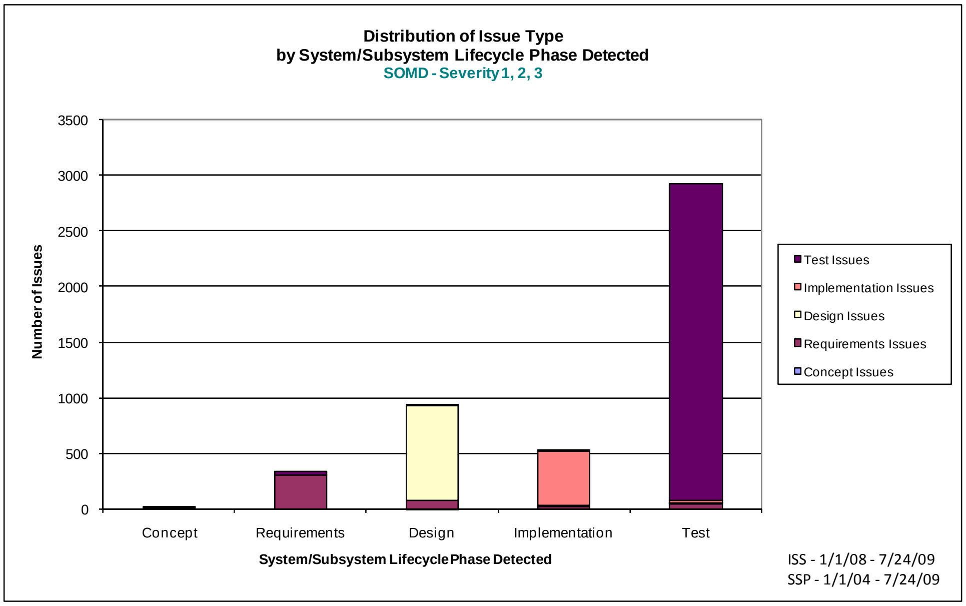


SMD and ESMD After 2007



The charts above show two things: 1) The IV&V Program is beginning to detect defects earlier in the development lifecycle. Notice the "Before 2007" chart peaks in the Implementation Phase, while the "After 2007" chart peaks much earlier in the Requirements Phase. 2) The IV&V Program is improving Phase Containment. Notice the "Before 2007" chart shows that Requirement type defects (plum color) slip into the Design Phase and peak in the Implementation Phase, while the "After 2007" chart shows that Requirements type defects (plum color) peak in the Requirements Phase and there is minimal slippage.

SOMD

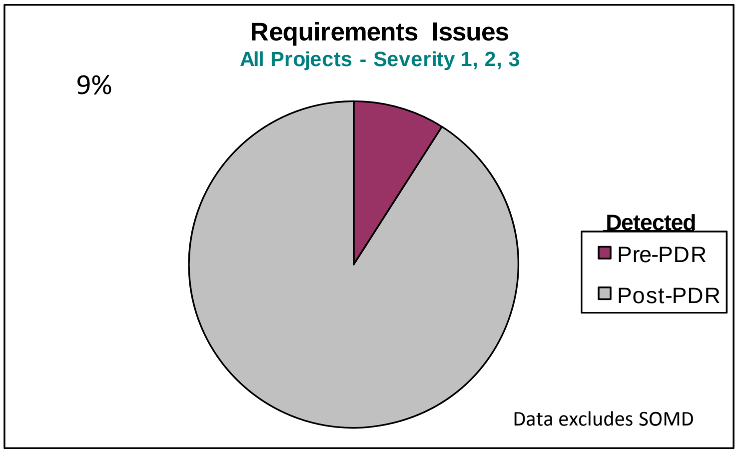


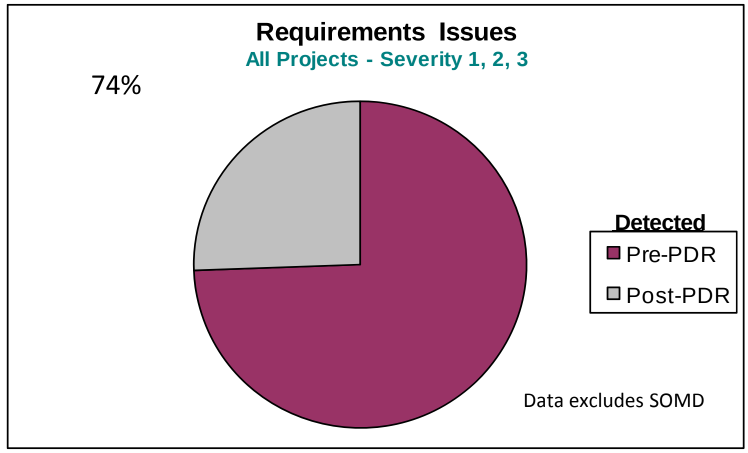
As noted earlier in this report, the projects that comprise the Space Operations Mission Directorate (SOMD) are different than most other projects served by the IV&V Program. The difference is that the SOMD projects (Space Shuttle and International Space Station) have been operational for several years. Each operational increment to these projects is designed to function in the same environment, which has allowed the SOMD projects to establish mature design processes. Therefore, the IV&V Program is not finding many defects within the requirements or design of the SOMD software. Instead, the IV&V analysts are finding defects within the test scripts. Even though the software is designed to operate on the same environment for each operational increment, the code that is written is different. Test scripts play an important role in verifying that the code will implement the desired functionality, and the IV&V analysts validate that the test scripts are correct, complete, consistent, and unambiguous.

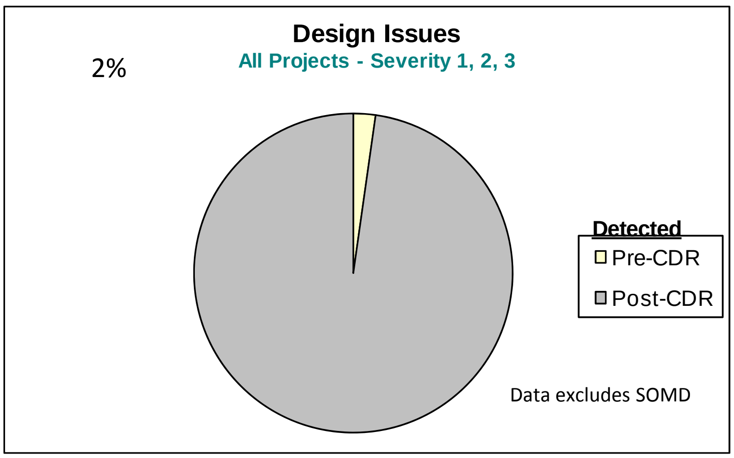
Below is an alternate view of phase containment with regard to the detection of requirements and design issues prior to key decision points, occurring at the end of each phase. Preliminary Design Reviews (PDR) occur at the end of the requirements phase and prior to the start of the design phase. The target of the IV&V Program is to detect the majority of the requirement defects prior to this review, or pre-PDR. Likewise, it is preferred that design defects are detected prior to the end of the design phase when the Critical Design Review (CDR) occurs. The improvement in phase containment performance is apparent.

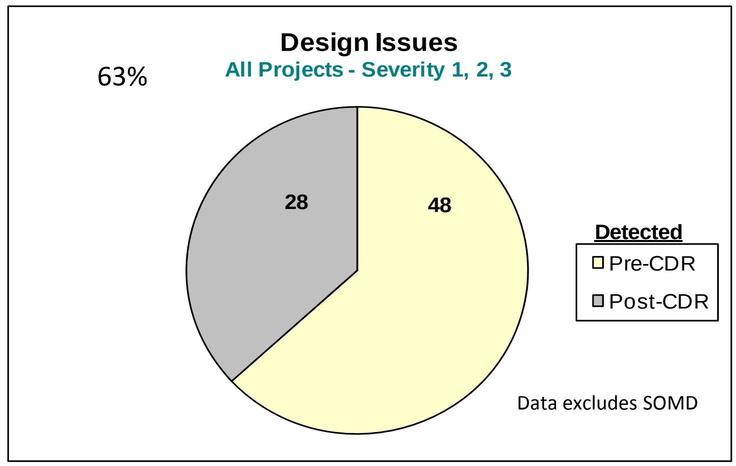
SMD and ESMD Before 2007

SMD and ESMD After 2007



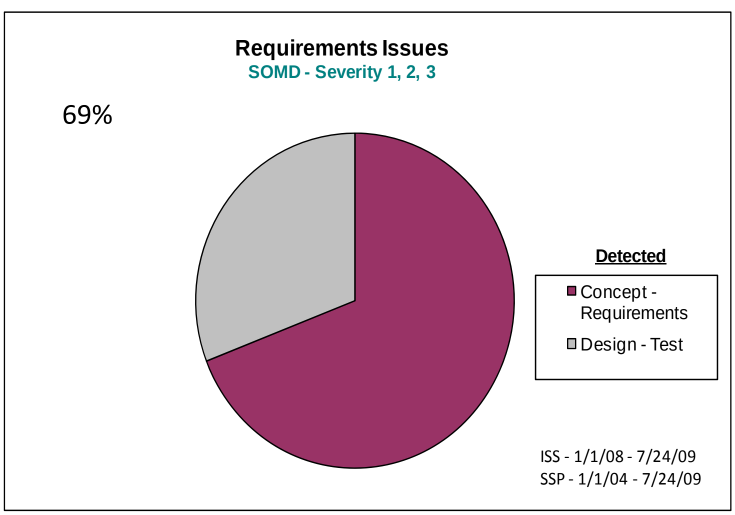


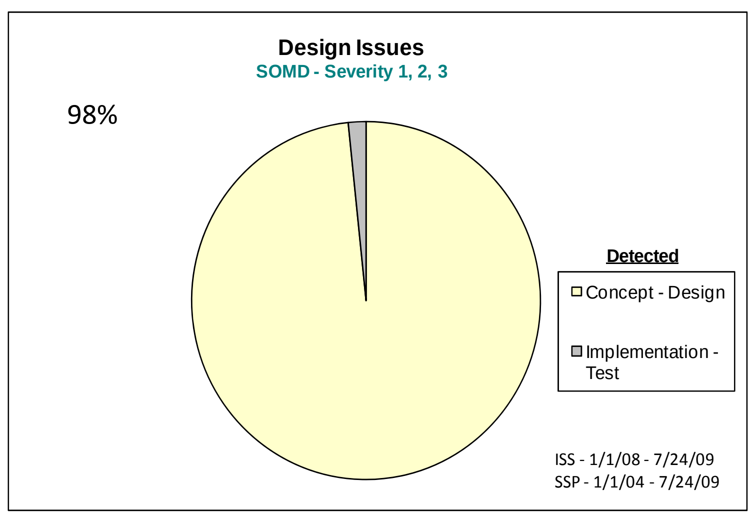




The IV&V Program's phase containment performance has improved significantly.

SOMD





Benefit 2:
The IV&V Program provides ongoing status indicators and performance reporting to NASA program/project level managers. The customer is provided an incremental preview of system performance with the chance to make early adjustments.

One of the most important factors that affect project success is communication between customers and software developers (Standish Group, 2001). Because the IV&V Program is an independent, third party analyst, it generally does not communicate directly with the software developers. However, **the status indicators and performance reports produced by the IV&V Program lay the foundation for communication between the IV&V customers and the software developers.** For the purpose of this section of the report, the term customer refers to the Agency Projects served by the IV&V Program. Regular updates regarding the quality of the software, summaries of the validation and verification work completed, goodness and limitations of the system software, and risks are provided to the IV&V Program customers.

Ongoing communication with the IV&V Program customers is necessary to provide opportunities for early design adjustments. Communications occur both informally and formally. Informal communications, such as scheduled and ad hoc meetings, often focus on discussing defects detected by the IV&V Program. These discussions usually result in either an increased understanding of the project by the IV&V Program or communication to the project of a detected defect and its location. These communications lead to a new, better, or more complete model of the system software.

VOICE OF THE CUSTOMER:

"The thoroughness and accuracy of assessments, and particularly the reporting has improved tremendously, and therefore become a value added effort. As a result, the relationship with the Projects is much improved. I think that we have come a long way in improving S/W development in NASA, and you have become an integral part of it."

These informal communications provide periodic updates, leading to development lifecycle reviews, which are formal communications. Formal development lifecycle reviews are key decision points in the development process that provide a baseline for moving on to subsequent development activities. Providing feedback about the quality of the overall system to customers prior to these reviews is crucial in order to provide customers with the opportunity to make necessary adjustments at an optimal time.

Other examples of communication exchanged between the IV&V Program and its customers are analysis reports, observations, issues, and risks. Analysis reports are provided to the project personnel after a major analysis activity is completed, such as the completion of code analysis; observations, issues, and risks are provided to customers as they are generated.

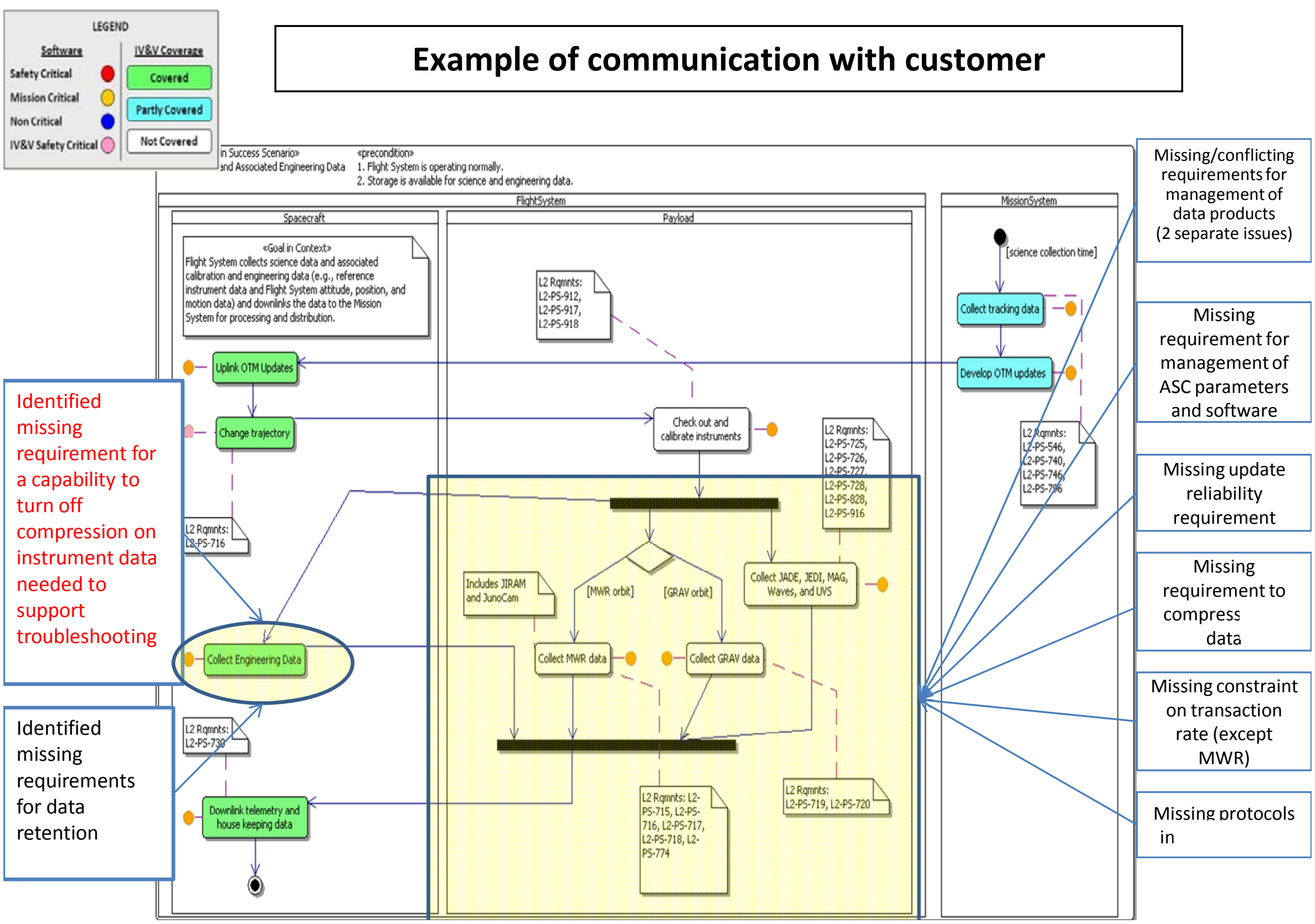
The IV&V Program's communication with customers is both timely and effective according to customer feedback.

Communication between the IV&V Program and the customer must be timely and effective. **According to results of a customer survey conducted in 2009, customers are satisfied with the timeliness and the accuracy and quality of the IV&V Program's communication.** Timely communication is demonstrated by the IV&V Program when feedback about defects and the goodness of projects is provided to customers prior to key development lifecycle reviews, enabling the projects to make early adjustments when necessary. The effectiveness of the IV&V Program's communication is indicated by the project's use of the provided feedback. If the project accepts and resolves a detected defect, the IV&V Program knows that the communication provided is effective.

VOICE OF THE CUSTOMER:

"Excellent work, timely in nature and well developed in content. IVV is providing value-added analysis of the project software."

Below is one example of how the IV&V Program communicates a defect detected in a project. This example is referred to as an activity diagram and depicts the interactions between a spacecraft and its instruments; the project's mission is to collect, store, and transmit science data. Included in this diagram are the locations and details regarding defects with requirements that were discovered on mission critical software, which is indicated by orange circles. Mission critical software is software that must perform properly in order for the mission to be completed. One example of mission critical software from the diagram below is "collect engineering data", located in the bottom left corner of the diagram. The IV&V Program provided the project with this diagram, this led to a discussion about the potential detected defect, the rationale justifying why the IV&V Program considers it a defect, and the location of the potential defect. The discussion resulted in the project agreeing that the IV&V Program detected a defect and it should be resolved. The project communicated to the IV&V Program that the missing requirement was written, and the IV&V Program verified that it was in fact resolved.



(Project identifiers have been removed from above activity diagram.)

Benefit 3:
The IV&V Program provides stakeholders with visibility into progress and quality of the system – software development effort.

Stakeholders expect projects to be completed within cost, meet established deadlines, and produce desired results; however, in a 2001 study, the Standish Group found that only "28% of the attempted software development projects were successful", meaning the project was "completed on time and on budget, with all features and functions originally specified" (2001). **Because the IV&V Program provides stakeholders with visibility into the progress and quality of the system-software development effort, it helps to ensure that "goals are met for cost, dates, and results"**, according to research stating that projects which receive IV&V services are more likely to be successful (Gates, 2006).

> **VOICE OF THE CUSTOMER:**
> "Incredibly supportive team...easy to work with, fully engaged in the project, **primary goal is ensuring the project is successful** by providing real, substantial analysis and observations."

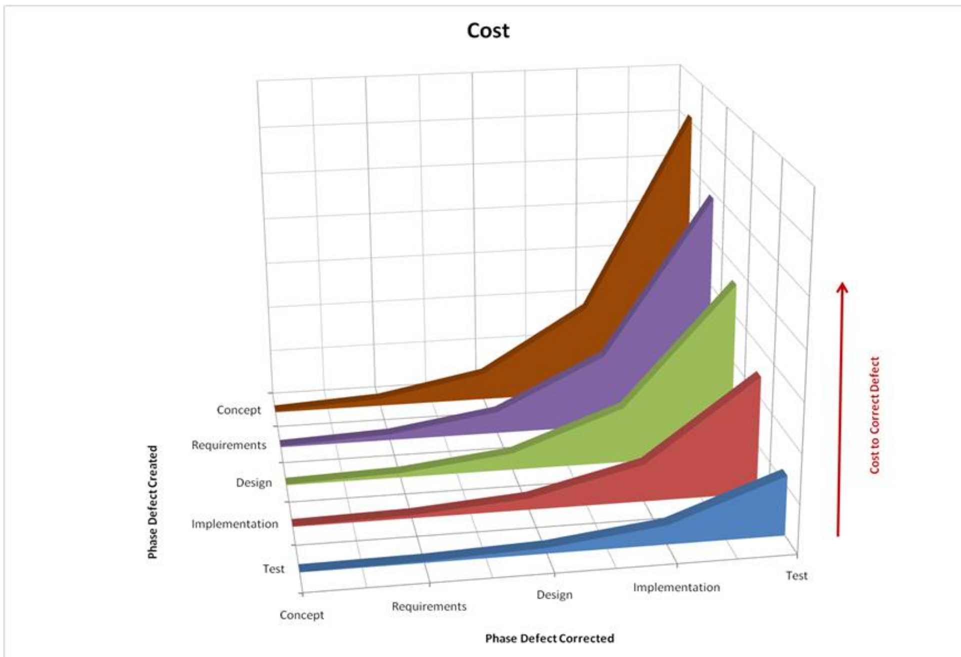
In order for stakeholders to have visibility into the system software development effort, the IV&V Program provides information regarding the selections of projects to be assessed, as well as observations about trends in the NASA software development process. The IV&V Program determines which projects to assess using a portfolio-based risk assessment (PBRA) approach. This approach focuses on the likelihood of a mishap occurring and the severity level of the consequences due to the mishap. Combined, the consequence and likelihood determine what capabilities within a project should be assessed. The outcomes of the PBRA are presented once per year to the IV&V Board of Advisors (IBA). Trends related to the Agency's software development process are communicated based on analysis of the metrics being collected by the IV&V Program at the project, mission directorate, and program levels. The implementation of the Product Oriented Metrics Program has enhanced the information available for the production of this report and enables the IV&V Program to identify data-based trends.

> **VOICE OF THE CUSTOMER:**
> "NASA IV&V advocacy and involvement has prompted software improvements to mitigate project risks. Preliminary static assessment of prototype software has **heightened attention to good software development practices.** NASA IV&V is an asset to the [Project A] program."

Primarily, the IV&V Program communicates with two audiences at NASA Headquarters: the Office of Safety and Mission Assurance (OSMA) and members of the IBA. Informal communication occurs throughout the year; however, formal presentations are planned at a minimum of two times per year with each audience. Meetings are held at NASA Headquarters. Leading up to the meetings with the IBA, the IV&V Program coordinates with each designated Mission Directorate Representative on the IBA to review the upcoming presentation, allowing the Mission Directorate Representative to become aware of the IV&V Program's official selection recommendations and trends related to their projects.

Benefit 4:
Reduces the need for rework by the developing contractor, and thereby reduces the total costs to programs and projects.

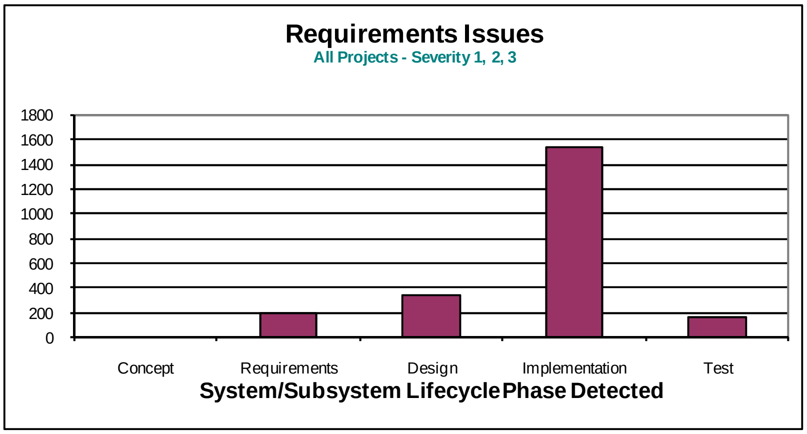
The greatest contributing factor to the increase of total project cost is the occurrence of defects (Narayana, 2003). The work that is required by the project to resolve a defect is referred to as rework. When a defect is detected in phases subsequent to the one in which it was introduced, it is said that the defect slipped. For each phase a defect slips, the effort and cost required to resolve the defect increases exponentially. Results from one study estimates that for each phase a defect slips, the amount of effort required to fix it is 2.5 times more than what would be required if it had been resolved during the phase it was introduced (Hevner, 1996). The diagram below illustrates the increasing cost to correct a defect as it slips into later phases of the development lifecycle and shows why reducing rework is essential to projects.



Defects related to software requirements are the most common, according to industry research, (Leveson, 2004; Mogyorodi, 2003). These defects, if undetected, impact every subsequent phase of the software development life cycle. This occurrence is referred to as the "ripple forward effect" (Lewis, 1992), and explains why the **"greatest cost-benefit ratio in IV&V" comes from requirements analysis** (1992). Preventing the ripple forward effect reduces rework but requires that the IV&V Program work begin early and that defects be found in phase.

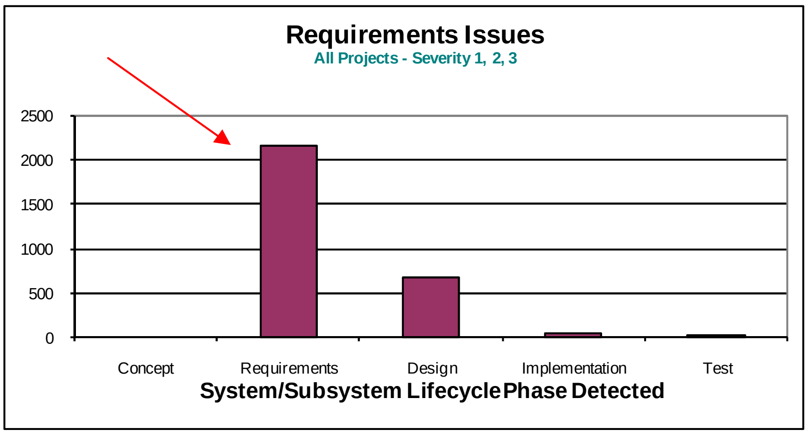
The charts below show the IV&V Program's detection of requirements defects and the phase detected. For requirements defects, the goal is to detect them in the requirements phase. Recent trends, as shown below, indicate that the IV&V Program is improving significantly with regard to detecting requirements defects in phase. In recent years, approximately 74% of requirements defects are found in the requirements phase.

SMD and ESMD Before 2007



Data excludes SOMD

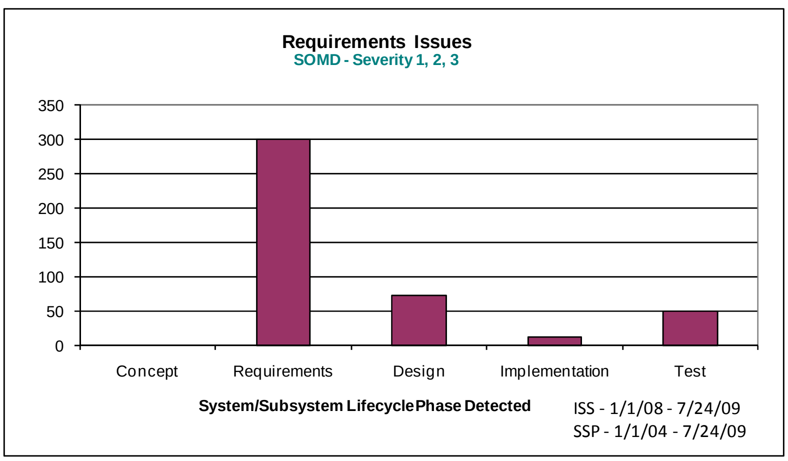
SMD and ESMD After 2007



Data excludes SOMD

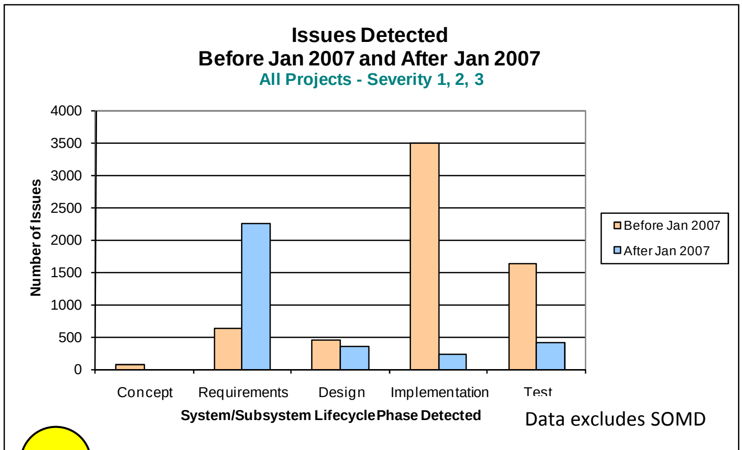
In recent years, approximately 74% of requirements issues are phase contained.

SOMD



When defects are detected in-phase, as well as early in the lifecycle, rework is reduced. The goal of the IV&V Program is to increase its early defect detection rate and thereby reduce rework for the developers. The figure below describes how rework savings is calculated based on the earlier detection of defects by the IV&V Program.

SMD and ESMD



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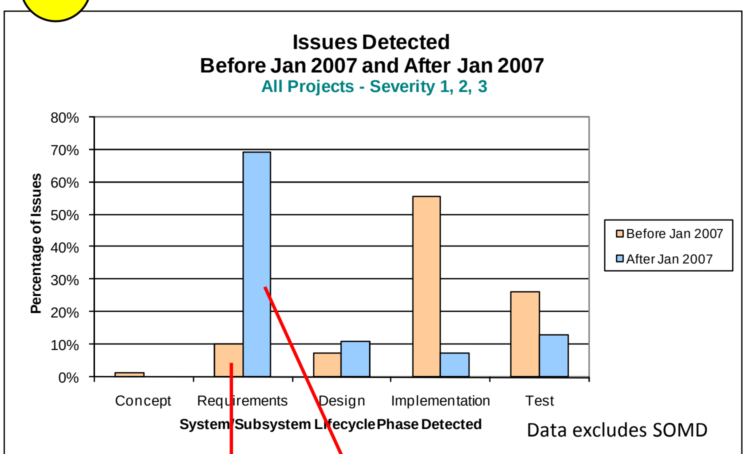


High Severity Issues Submitted….

Phase		**Before** Jan 1, 2007	**After** Jan 1, 2007	**Rework Savings**
Concept	2	1%	3 0%	4 (2.81)
Requirements		10%	69%	147.48
Design		7%	11%	8.77
		19%	**80%**	**153.43**

Step 1: Excluding SOMD, the IV&V Program detected 7026 defects during the 13 years represented by the "Before 2007" data. In contrast the IV&V Program detected 3912 defects during the 3 years represented by the "After 2007" data. In order to properly account for the differences in the number of defects over the years represented in these data sets, they were normalized into percentages. To normalize the number of defects found before 2007 and after 2007, determine the percentage of defects detected.

Step 2: Determine the Percentage of Issues Detected Before 2007.

Step 3: Determine the Percentage of Issues Detected After 2007.

Assumption 1: The difference in issues (before and after) is how many more issues IV&V found during the requirements phase (relative to the total number of issues found).

Assumption 2: That difference slipped to a later phase. Assume that the defect slipped by one phase. According to Hevner's research, issues that slip by one phase require 2.5 times more effort to fix.

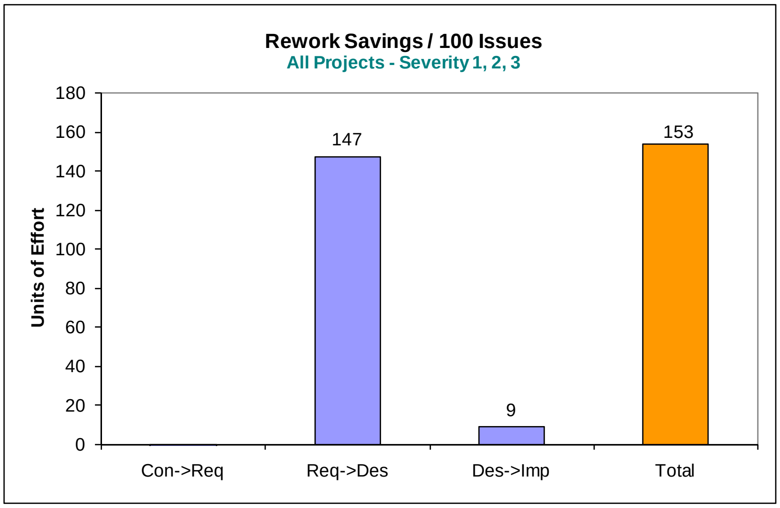
Step 4: Using Hevner's data, multiply the difference by 2.5 units of effort.

1 Unit of Effort =
Effort required to fix a defect in-phase

The IV&V Program has increased its early defect detection rate of <u>requirements</u> defects by 59%. This translates to a rework savings of 147 units of effort for every 100 defects – <u>requirements</u> defects alone.
This savings *does not* include defects of all types.

The chart below captures the data for rework savings when defects of *all types* are considered. Overall, the IV&V Program saves developers 153 units of effort for every 100 defects detected including defects related to *all phases*. This reduction in rework effort translates into dollars saved by projects. **One unit of effort is equal to the effort required to fix a defect in-phase.**

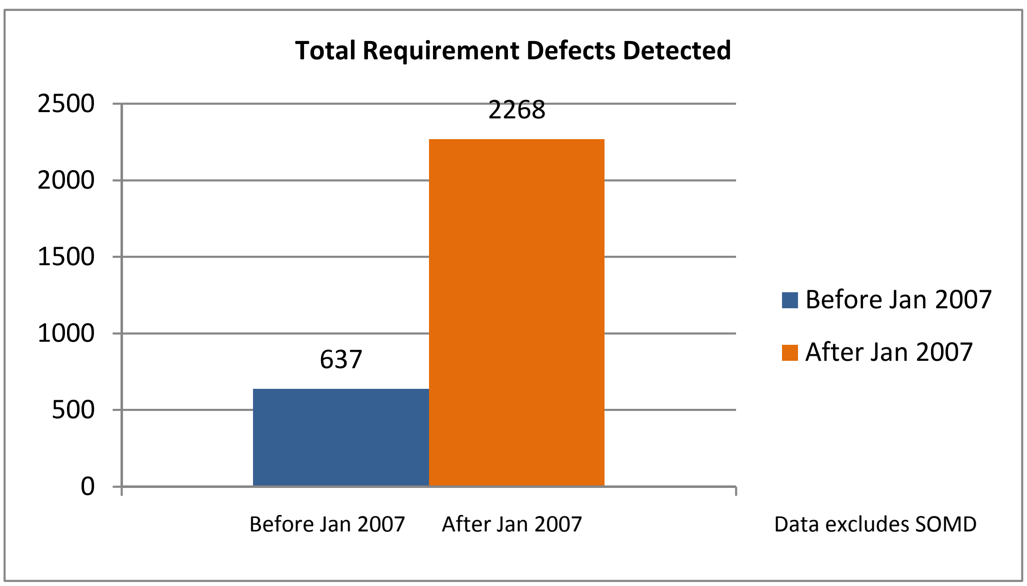
SMD and ESMD Total Effort Saved



Because rework requires additional time and effort on the part of the developer, it increases the total cost of a development project. Studies indicate that rework costs developers between 30 and 50% of a project's total cost (Leffingwell & Widrig, 2000). Of this cost, approximately 70% of the rework cost will be due to defects related to requirements (2000).

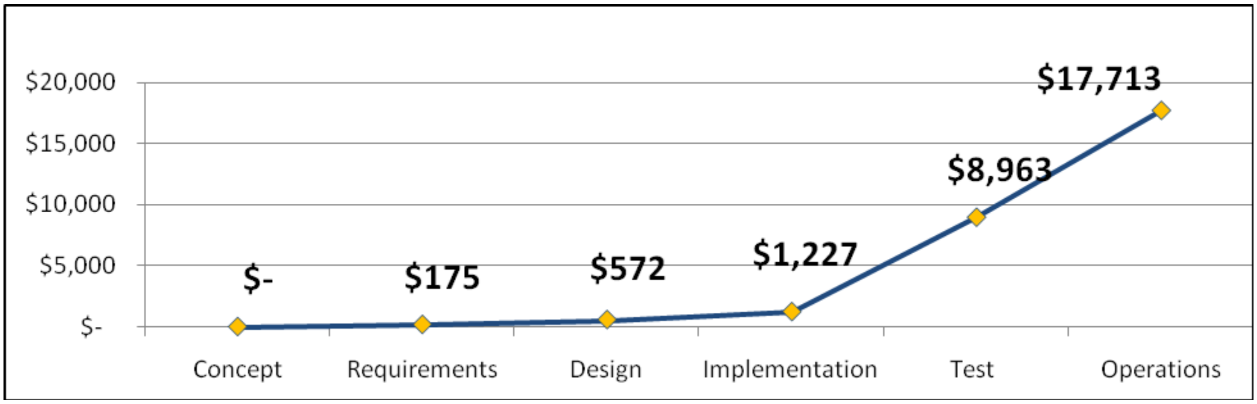
Below is a chart which demonstrates the difference between requirements defects detected before and after 2007. **This is a difference of 1,631 requirements issues.**

SMD and ESMD Total Requirement Defects Detected



If a requirements defect manifests itself in an operational system, it would cost $17,713 dollars per defect to correct each defect based on the model shown below. **The total cost saved by projects due to the IV&V Program's earlier detection of requirements defects exceeds $28 million – and this is only considering requirements defects, not all defects that occur throughout the lifecycle.**

Cost of Correcting Software Defects



Capers Jones, *Software Assessments, Benchmarks, and Best Practices*, Addison-Wesley, 2000
NOTE: Dollars in 2009 dollars.

**Since January 2007, the IV&V Program has potentially detected over $28 million dollars in requirements related defects *alone*.
This does not include defects related to all phases.**

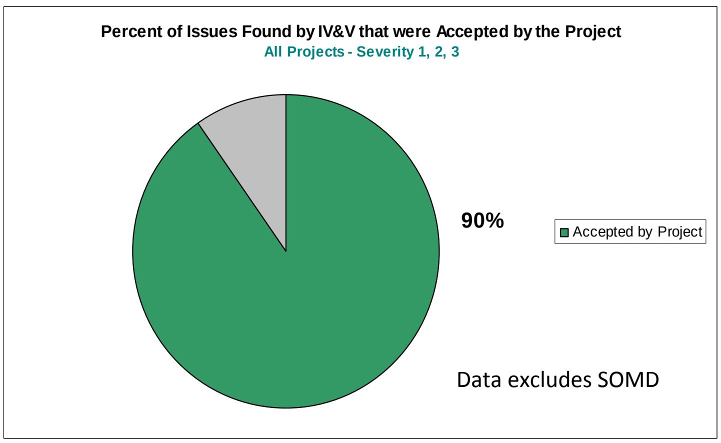
Benefit 5: Reduces defects in delivered products.

The goal of every project is to produce software that performs as intended by the customer. In order for a system to operate as intended, the software must be as defect-free as possible. **The IV&V Program provides projects with opportunities to reduce defects by detecting a majority of defects early in the development lifecycle, achieving phase containment, and communicating defects that are accepted by the projects.**

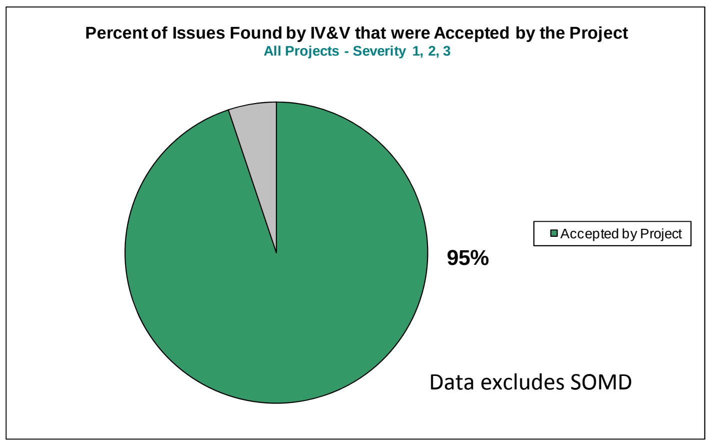
> **VOICE OF THE CUSTOMER**:
>
> "IV&V is a valuable tool for ensuring NASA is developing quality products".

It is important to note that the value of the IV&V Program's services is in defects being found and resolved. According to data captured by the IV&V Program, 92% of detected defects were accepted by the projects prior to 2007 and has increased slightly to 95% after 2007. This high percentage indicates the IV&V Program provides opportunities for the project to reduce defects and those projects that undergo IV&V can expect a higher quality (Radatz, 1981).

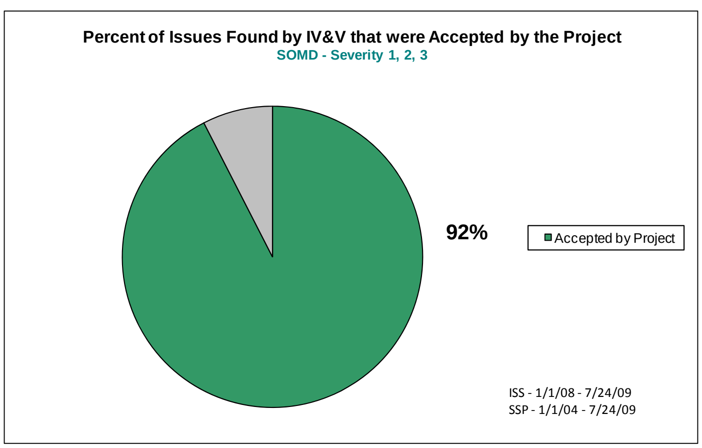
SMD and ESMD Before 2007



SMD and ESMD After 2007



SOMD



Over 90% of defects detected are accepted by projects; therefore, the IV&V Program is contributing to reducing defects in delivered products.

2008 PROJECT SUMMARIES

2008 PROJECT SUMMARIES

Ares

Contractor: L-3 Communications
Project Lead: Lisa Nicklow
Lead Engineer: Heath Haga

The Ares I Crew Launch Vehicle (CLV) is a key component of the Cx Program. Ares I is a two-stage launch vehicle intended to carry the Orion Crew Exploration Vehicle (CEV) to an ascent target from which Orion can reach low Earth Orbit (LEO).(http://www.nasa.gov/mission_pages/constellation/ares/index.html)

In 2008, the Ares IV&V team continued development of the Ares System Reference Model (SRM) and validation of subsystem and component requirements. The Ares project held several design reviews attended and supported by IV&V. The team spent the rest of the year preparing for the upcoming PDRs by validating and verifying requirements and reviewing associated artifacts as they became available. The Ares project commended IV&V for their valuable technical contributions. The RIDs submitted against the requirements and design during the reviews will enable the Ares project to evolve solutions for the software requirements and design prior to their later design reviews and subsequent software implementation.

Constellation CxP

Contractor: L-3 Communications and Northrop Grumman Corporation
Project Lead: G. Scott Kinney
Lead Engineers: Don Ohi (L-3 Communications), Anyika Johnson (Northrop Grumman Corporation), Shirley Savarino (Northrop Grumman Corporation), Steve Driskell (Northrop Grumman Corporation)

A new generation of spacecraft will carry humans to the moon, Mars and beyond. (http://www.nasa.gov/mission_pages/constellation/main/index.html)

Although not identified as an individual project within Cx, the Exploration Systems Mission Directorate Integration (ESMDI) IV&V team has been created by the IV&V Facility to ensure that the Cx systems are developed to satisfy the needs, goals and objectives of Cx, and that the integration of these systems is planned and conducted in a manner that supports the safety and success of the mission. The ESMDI IV&V team has interfaced primarily with the Cx Systems Engineering and Integration Office (SE&I) and has focused particularly on integration risks. The team has worked closely with the individual Cx IV&V Projects, such as Orion and Ares, to ensure system interfaces and integrated behaviors of these systems provide the desired end-to-end system performance and do not result in undesired emergent behaviors. The ESMDI IV&V team has and will continue to leverage the relationship with Cx SE&I to build working relationships with other organizations and teams within the CxP program. The ESMDI IV&V team will report at Program milestone reviews on the overall integrity of the software and systems.

The IV&V Team assigned to ESMDI efforts in 2008 developed and refined the SRM at a higher level than Orion and Ares in order to focus on system of system interactions. The analysis focused on the CxP system interfaces as used as references the Interface Requirements Documents (IRDs), specifically performing validation of interface requirements for three critical system interaction scenarios: 1) Orion-Ares I Upper Stage Separation, 2) Orion Rendezvous and Proximity Operations for Docking with ISS, and 3) Orion Operations while Docked with ISS. The IV&V team assessed the capabilities associated with these three scenarios, evaluating both the completeness of the architectural design for system interactions and the documented requirements for these capabilities. IV&V identified limitations in both aspects and documented 17 issues as a result of this analysis. These issues include eight missing or inconsistent interface requirements. The other nine issues address clarity problems with existing requirements in IRDs or the Constellation Architectural Requirements Document (CARD). IV&V concerns with the completeness of the architectural design were documented in 28 observations. The results of this effort was documented in the IVV-CxSI-SDR Report and shared with the Constellation Program prior to the Program Baseline Synch-up System Definition Review Checkpoint. Because IV&V uncovered issues and requirements defects early in the development lifecycle, this enabled the project to resolve defects early, and save cost and rework.

Fermi Gamma-ray Space Telescope

Contractor: Northrop Grumman Corporation
Project Lead: John Hinkle
Lead Engineer: Eric Sylvania

The Fermi Gamma-ray Space Telescope (formerly the Gamma-ray Large Area Space Telescope, or GLAST) began opening the high-energy world of black holes to exploration after a successful launch on 11 June 2008. Astronomers at long last have a superior tool to study how black holes, notorious for pulling matter in, can accelerate jets of gas outward at fantastic speeds. (http://glast.gsfc.nasa.gov/)

In 2008 the IV&V Team completed IV&V for the Spacecraft Flight Software that included analysis activities for the Command and Data Handling (CDH), Guidance Navigation and Control (GNC) and the Large Area Telescope (LAT) instrument. Activities included the completion of code and test analysis of the flight software in CDH and GNC, having completed LAT IV&V in 2007.

IV&V identified numerous discrepancies in the software through the means of manual inspection and through the use of automatic code analyzers. The IV&V Team ensured that Fermi requirements were adequately and completely tested, and assisted the project in correcting and adding tests to that end. The Fermi project office and development teams accepted the IV&V Team's findings and made the necessary corrections as appropriate.

Because IV&V, along with the developers, was able to resolve all issues raised against the Fermi software, IV&V was able to report at both the Mission Readiness Review and the Safety and Mission Success Review that the software was ready to fly. This provided greater assurance that there would be no problems with the flight software in orbit.

Geostationary Operational Environmental Satellite-R Series (GOES-R)

Contractor: Northrop Grumman Corporation
Project Lead: Jerry Sims
Lead Engineer: Anita Berns

The GOES-R series of satellites will be comprised of improved spacecraft and instrument technologies, which will result in more timely and accurate weather forecasts, and improve support for the detection and observations of *meteorological phenomena that directly affect public safety, protection of property, and ultimately, economic health and development. The first launch of the GOES-R series satellite is scheduled for FY2015. (http://www.goes-r.gov/)*

Efforts performed by the IV&V Team were representative of an Independent Assessment (IA), as the scope of the analysis efforts was limited to the Advanced Baseline Imager (ABI) instrument, the Energetic Heavy Ion Sensor (EHIS)

instrument and the Space Environment In-Situ Suite (SEISS) Data Processing Unit (DPU). The IV&V Team performed test analyses – specifically test plan, test procedure, and test results analyses – and attended/supported peer reviews associated with these artifacts.

The IV&V test analysis efforts on the ABI instrument provided stakeholders with visibility into the adequacy of the test program and approach. Specifically, the IV&V test analysis indicated that the scope and approach for testing the ABI instrument software was complete and thorough. No issues or risks were submitted in 2008. As a result of the IV&V analysis efforts, the GOES-R Project has increased confidence and assurance that the ABI instrument test program is sufficient and adequately tests the levied requirements, which ultimately reduces the overall risk profile of the ABI instrument software.

Glory

Contractor: Northrop Grumman Corporation
Project Lead: Tom Macaulay
Lead Engineer: Phil Loftis

Glory is a remote-sensing Earth-orbiting observatory designed to achieve two separate mission objectives. One is to collect data on the chemical, microphysical, and optical properties, and spatial and temporal distributions of aerosols. The other is to continue collection of total solar irradiance data for the long-term climate record. (http://glory.giss.nasa.gov)

The IV&V Team assigned to Glory is inspecting its safety- and mission-critical software and has reviewed the requirements, design, and code artifacts to assure that the Attitude Determination and Control System (ADACS) and that the Command and Data Handling (CDH) code will properly initiate solar array deployment, perform attitude maneuvers, and properly receive, validate, and execute ground commands.

Using state-of-the-art code analysis tools and unified modeling techniques, the IV&V Team has assured stakeholders that the Glory ADACS, CDH, and Payload Interface processors will work as intended. Glory's instruments – the Aerosol Polarimetry Sensor, Cloud Camera, and Total Irradiance Monitor – are nearly complete and ready for launch. The Glory mission will provide data to help scientists conclude whether climate changes are caused by humans or are by-products of naturally occurring events.

In 2008 the IV&V Team saved the Glory software development team from test delays and possible on-orbit troubleshooting time by providing valuable feedback on coding errors that the IV&V Team had discovered using state-of-the-art code analysis tools and Unified Modeling Language techniques. For example, the IV&V Team discovered an attempt by the Total Irradiance Monitor's software to dereference a null pointer. Dereferencing null pointers can cause a processor to crash. If this issue had not been discovered, the Science Team could have lost receipt of data from the Total Irradiance Monitor until the team could perform troubleshooting steps to isolate the problem and upload the software patch or updated software to resolve the issue.

Gravity Recovery and Interior Laboratory (GRAIL)

Contractor: L-3 Communications
Project Lead: Meagan Carrier
Lead Engineer: Van Casdorph

Gravity Recovery and Interior Laboratory (GRAIL) has two primary objectives: determine the structure of the lunar interior, from crust to core, and advance understanding of the thermal evolution of the Moon. GRAIL has one secondary objective which is to extend knowledge gained on the internal structure and thermal evolution of the Moon to other terrestrial planets.

The overall scientific goal of GRAIL is to understand the internal structure and thermal evolution of the Moon in order to provide key information on the origin and evolution of that body as well as all terrestrial planets in the early stages of the solar system history. The Moon's accessibility as an example of a preserved primary crust that formed shortly after accretion makes it a linchpin for our comprehension of the evolution of silicate worlds, and the early evolution of the Earth is strongly tied to lunar origin. Assessing models of thermal evolution requires knowledge of a planetary body's internal structure, and the biggest impediment to progress in studies of lunar internal structure has been the lack of reliable farside gravity data. GRAIL's gravity data will yield greatly improved models of the structure of the lunar interior, especially when combined with other data types from past and/or future lunar missions. The scientific goals are achieved via measuring the lunar gravitational field, for which GRAIL's dual spacecraft and instrumentation are designed.

The IV&V Program's team began work in November 2008. During November and December, the GRAIL modeling team was able to develop the GRAIL system goals. The SysGoals product was used to determine the scope of effort needed for IV&V. The SysGoals were used to facilitate the Portfolio Based Risk Assessment. From this assessment, the scope of IV&V effort was defined. As a result of the work, the SysGoals and the PBRA determined the scope of IV&V work. With this foundation established, validation and verification work was able to begin in calendar year 2009.

Hubble Space Telescope (HST) Servicing Mission 4 (SM4)

Project Lead: Ken Vorndran
Lead Engineer: Jerry Gilley

The Hubble Space Telescope was reborn with Servicing Mission 4 (SM4), the fifth and final servicing of the orbiting observatory. During SM4, two new scientific instruments were installed: the Cosmic Origins Spectrograph (COS) and Wide Field Camera 3 (WFC3). Two failed instruments, the Space Telescope Imaging Spectrograph (STIS) and the Advanced Camera for Surveys (ACS), were brought back to life by the first ever on-orbit repairs. With these efforts, Hubble has been brought to the apex of its scientific capabilities. (http://hubble.nasa.gov/missions/sm4.php)

Efforts performed by the IV&V Team were representative of an Independent Assessment (IA), as the scope of the analysis efforts was limited to the instruments only. The primary focus of the IV&V Team's efforts was the ACS-R flight software (FSW) and late lifecycle testing. Specifically, the IV&V Team performed code, test, and change impact analysis on the ACS-R FSW and test analysis associated with Servicing Mission Ground Test (SMGT) efforts. In addition, the IV&V Team completed their requirements traceability analyses efforts on the COS and WFC3 instruments. As a result of an on-orbit HST anomaly/failure, the IV&V Team performed code and test analysis associated with efforts to replace the Science Instrument Command & Data Handling unit (SI C&DH). Specific HST

SM4 lifecycle/milestone reviews that IV&V supported include the COS and WFC3 Pre-Ship Reviews (PSRs) and the ACS-R Pre-Environmental Review (PER).

As a result of the NASA IV&V Program's efforts on HST SM4, IV&V requirements traceability analysis on COS and WFC3 provided stakeholders with visibility into the quality of the system software development efforts. Specifically, the IV&V requirements traceability analysis on COS and WFC3 revealed several instances of missing requirement traces and incorrect requirement traces.

IV&V code analysis efforts on the ACS-R FSW contributed to the overall reduction of errors in delivered products. IV&V test analysis efforts on the ACS-R FSW provided stakeholders with visibility into the adequacy of the test program/approach. Specifically, the IV&V test analysis on ACS-R FSW revealed an instance in which ACS-R FSW requirements were not tested/tested completely.

Finally, the IV&V Team provided HST Project and Agency stakeholders with visibility into the progress and quality of the system software development efforts as it pertained to the COS, WFC3, and ASC instrument software. Specifically, the IV&V Team provided favorable recommendations on the instrument software at the COS and WFC3 Pre-Ship Reviews (PSRs) and the ACS-R Pre-Environmental Review (PER), indicating that the IV&V Team was confident that the instrument software would perform as intended.

No risks were submitted in 2008; however, examples of issues submitted in 2008, as related to the identified results above, include missing and/or incorrect requirement traces, incorrect use of a variable in the code, and FSW requirements not being tested/tested completely. If these issues had not been detected, the Project would have had an increased potential for software maintenance-related issues. Specifically the Project could have encountered rework, challenges in performing change impact analysis, and increased cost associated with software maintenance activities. Additionally, there would have been a potential for ACS-R FSW to do something that it is not supposed to do, leading to the ACS instrument not releasing the detector for a higher priority task. Also, the Project potentially could have had the ACS-R "Take Data Flag" capability not perform as expected operationally.

The NASA IV&V Program added value to HST SM4 because the Project took corrective action and updated the inaccuracies in the COS and WFC3 requirements traceability data, which ultimately improved the quality of this software development artifact. With these improvements in quality, the Project is able to perform a more complete and thorough change impact analysis related to their software maintenance efforts. In addition, these improvements in quality have the potential to reduce the amount of rework as a result of using incorrect or incomplete software development artifacts related to the software maintenance efforts.

The HST SM4 Project took corrective action and updated the code to utilize the correct variable, which led to an overall reduction in the overall amount of errors in the delivered product (ACS-R FSW). In addition, these corrective actions increased the likelihood of stakeholders getting the system software that is desired in the implemented system.

Finally, the HST SM4 Project took corrective action and tested the requirements in the System Functional Tests, which ultimately increased stakeholder confidence levels in terms of the likelihood for getting the system software that is desired in the implemented system as well as reduced the overall risk profile pertaining to this capability.

International Space Station (ISS)

Contractor: L-3 Communications
Project Lead: John Hinkle
Lead Engineer: Harry St. John

The International Space Station (ISS) is an Earth-orbiting platform providing a permanent human presence in space. Numerous scientific experiments supporting medicine and biology, the effects of space on materials and living beings, and commercial ventures are already being performed aboard ISS, even though the facilities and capabilities are still under construction. (http://www.nasa.gov/mission_pages/station/main/index.html)

The NASA IV&V Program has been and is involved with all NASA-developed ISS mission-critical software, assuring that software for ISS is of high quality. In 2008, the IV&V Team verified new releases of most of the on-orbit software that were transitioned to operation. Analyses on these systems included requirements review, design and implementation verification, and analysis of testing performed.

ISS IV&V utilized its fully capable IV&V test bed to exercise multiple software components in many configurations. This permitted the IV&V Team to independently test key areas prone to potential problems. The software baseline for ISS is largely complete but continues to be updated by new releases to provide new capabilities and ensure safe operations.

New major additions to the ISS in 2008 were the European Columbus Module and the Japanese Experiment Module (Kibo), both launched on-board the Space Shuttle. Also new in 2008 was the commencement of development efforts for the program's additions of a new computer platform for computers at the top tiers of the command and control hierarchy, and the redesign of the communications system internal components, including five new single board computers. Each component added to the on-orbit configuration through assembly complete in 2010 results in varying levels of software addition/change. In 2008, ISS IV&V personnel began 24/7/365 on-call support, should a problem requiring immediate attention be found with ISS on-orbit software.

The depth and breadth of knowledge and experience in systems and software applied by IV&V on ISS has made the IV&V Team a primary contributor of technical findings, which improves the quality and safety of ISS software systems.

The IV&V ISS Emergency Response Real Time Support Team was activated in September 2008 at the request of the NASA Avionics and Software Office. IV&V was asked to support anomaly resolution for an on orbit problem in which both Guidance Navigation and Control (GN&C) computers crashed shortly after transitioning to the new flight software release. IV&V supported the Flight Investigation Team meetings and reviewed the command log and GN&C

code. IV&V also reviewed the flight software patches that were created to address this compiler problem. IV&V independently confirmed that the problem appeared to be a random, very rare timing issue involving the compiler, and also reviewed the flight software patches that were created to address this compiler problem. This independent confirmation permitted the program to continue operations with increased confidence that future problems would be rare and not be disabling.

IV&V's extensive efforts helped ensure that the water and oxygen systems were functioning when the ISS went to a permanent, six-person crew in 2009.

Interstellar Boundary Explorer (IBEX)

Contractor: Northrop Grumman Corporation
Project Lead: Tom Macaulay
Lead Engineer: Darilyn Dunkerley

The Interstellar Boundary Explorer (IBEX) is the first satellite designed to detect the edge of the Solar System. (http://nasascience.nasa.gov/missions/ibex)

Since it was successfully launched on 19 October 2008 aboard a Pegasus rocket built by Orbital Sciences Corporation, the IBEX satellite has been successfully mapping the sky for energetic nuclear atoms. The first sky maps are complete, and a group of international Science Teams, scientists from Lockheed Martin Advanced Technology Center, Los Alamos National Laboratories, and Southwest Research Institute, are currently compiling the results. According to preliminary indications, the Science Teams are discovering surprising new things about the solar system. In fact, some of the discoveries do not fit current theories, causing scientists to formulate exciting new paradigms about the solar system. Indications to date are that the IBEX mission is well on its way to being a huge success.

The IV&V Team assigned to IBEX reviewed requirements, design, code, and test artifacts to assure that the launch and deployment code would enable the IBEX spacecraft to reach its intended orbit; that the attitude control software would spin the spacecraft at required rates and orient the spacecraft to allow sensors to capture particles away from the sun; that the battery charge-regulating software would keep the spacecraft battery properly powered; and that commands from the ground would be properly sent to the spacecraft and properly received, validated, and executed.

Using state-of-the-art code analysis tools and unified modeling techniques, the IBEX IV&V Team passed several findings to the project so that cost-saving software updates could be made prior to testing. For example, the IV&V Team discovered an issue with the bounds of an array that stored analog measurements on the electrical power subsystem processor being overwritten. Overwriting arrays can cause unpredictable results ranging from no apparent fault to crashing the processor. A processor crash would result in the processor not functioning until a commanded restart. The electrical power subsystem processor was the processor that controlled critical launch and deployment tasks, such as separating the spacecraft segments and igniting the solid rocket motor that placed the IBEX satellite in its desired orbit. If this issue were not fixed, it had the potential to cause a failure of the spacecraft being able to reach its required orbit, which would result in loss of meeting mission objectives.

James Webb Space Telescope (JWST)

Contractor: L-3 Communications
Project Lead: Wes Deadrick
Lead Engineer: Bob Jarrett

The James Webb Space Telescope (JWST) is a large, infrared-optimized space telescope, scheduled for launch in 2014. JWST is a successor to the aging Hubble Space Telescope; however, it will not be a complete successor because it will not be sensitive to all of the light wavelengths that Hubble can see. The main scientific goal is to observe the most distant objects in the universe, those beyond the reach of either ground based instruments or the Hubble. As the premier observatory of the next decade, JWST serves thousands of astronomers worldwide by finding the first galaxies that formed in the early Universe, connecting the Big Bang to our own Milky Way Galaxy. Additionally, JWST will peer through dusty clouds to see stars forming planetary systems, connecting the Milky Way to our own Solar System.

The NASA IV&V team is analyzing JWST's critical software behaviors that are implemented in both the flight software as well as some aspects of the ground software. During the course of 2008, the NASA IV&V team performed various validation and verification activities. Specific validation related analyses included requirements validation and validation of the test design. These efforts utilized/leveraged use cases and activity diagrams, which depict desired/undesired behaviors and adverse conditions as they relate to a particular operational thread for the mission. Items resulting from the IV&V analyses are currently under review by the project to determine an appropriate corrective action. Specific verification related analyses conducted included both design and implementation analysis. These analysis activities resulted in the early identification and removal of defects.

During 2008 the JWST IV&V Team generated a severity 2 issue regarding the Spacecraft Element Specification Requirements for health and safety inhibits not being completely or correctly captured In the Spacecraft FSW Requirements Document. The lack of the specification of critical health and safety related requirements increases the likelihood that the required functionality will not be implemented by the FSW. Health and safety data is a necessary component of both on-board fault management as well as ground based fault management. This data is used to identify and respond to anomalies experienced on-board the spacecraft and the failure to do so has the potential to interrupt the planned science observations as well as, in a worst case scenario, impact the ultimate health of the spacecraft.

Juno

Contractor: L-3 Communications
Project Lead: Wes Deadrick
Lead Engineer: Sam Brown

Juno is a mission of discovery and exploration that will conduct an in-depth study of Jupiter, the most massive planet in our solar system. Peering through the clouds deep into Jupiter's atmosphere, the mission will reveal fundamental processes of the formation and early evolution of our solar system. Juno's goal is to understand the origin and evolution of the gas giant planet, which will pave the way to a better understanding of our solar system and other planetary systems being discovered around other stars. Using a spinning, solar-powered spacecraft, Juno will make *maps of the gravity, magnetic fields, and atmospheric composition of Jupiter from a unique polar orbit. Carrying precise high-sensitivity radiometers, magnetometers, and gravity science systems, Juno's 32 orbits will sample Jupiter's full range of latitudes and longitudes.(* http://www.nasa.gov/mission_pages/juno/index.html)

The software deployed on the Juno spacecraft is responsible for controlling the highest criticality event of the mission's lifetime -- to insert the spacecraft into polar orbit around Jupiter. Additionally, software is responsible for various other maneuvers required to keep Juno on track to Jupiter and the collection of science data from the nine instruments on-board the spacecraft. The Juno IV&V team is providing full life-cycle support to the Juno mission that began with validation of the Juno mission requirements and is now proceeding with the validation and verification of critical software behaviors documented in the software design, implementation, and test products. During 2008 the Juno IV&V team focused on establishing confidence that the requirements driving the critical software behaviors of the Juno system adequately specify what the system should do, what the system should not do, and how the system should respond in the presence of adverse conditions. These analyses enabled the Juno IV&V team to report confidence in the Juno requirements at the Juno Critical Design Review in early 2009.

During 2008 the Juno IV&V Team identified a missing requirement for the Juno flight software (FSW) to assert the list of failed components on reboot. A FSW requirement was identified which requires the FSW to maintain a list of failed components but does not require FSW to actually assert the list. Additionally a higher level requirement identifies reboot recovery as an autonomous operation; therefore, the IV&V Team recommended that the developer consider specifying requirements that the FSW assert the list of failed cross-strapped components following a spacecraft reboot to prioritize selection/activation of cross-strapped components. The lack of the specification of the requirement for the FSW to assert the list of failed components increases the likelihood that the required functionality will not be implemented by the FSW. Should this be the case, it is possible that the FSW could command a failed cross-strapped component and thus result in a series of reboots until the FSW is manually commanded to assert the list of failed components upon reboot. Depending on the mission phase in which this condition could be present an impact to the science data collection could take place (in the case the condition occurs during the Science phase of the mission).

Kepler

Contractor: L-3 Communications
Project Lead: Wes Deadrick
Lead Engineer: Patrick Olguin

The Kepler Mission is designed to search for extrasolar planets by observing periodic transits of planets across the stellar disks. As observed by the Kepler spacecraft, stars with a transit will dim slightly during the several hours that it takes for the planet to cross. This dimming is measured by the Kepler photometer, which provides the data that ultimately leads to the determination of the size and orbital period of the planet. The Kepler Mission will perform a census of 100,000 dwarf stars to detect and characterize the hundreds of terrestrial and larger planets expected to be found in or near the Habitable Zones (HZ). The HZ encompasses the distance from the star where liquid water can exist on the surface of an orbiting terrestrial planet.(http://www.kepler.arc.nasa.gov)

Kepler was launched on March 6, 2009 aboard a Delta II rocket from Cape Canaveral Air Force Station, Florida. The launch was a complete success and the first light images were taken on the next day. On June 19, 2009, the spacecraft successfully sent its first science data to Earth. Kepler team members say these new data indicate the mission is indeed capable of finding Earth-like planets, if they exist. Kepler will spend the next three-and-a-half years searching for planets as small as Earth, including those that orbit stars in a warm zone where there could be water. It will do this by looking for periodic dips in the brightness of stars, which occur when orbiting planets transit, or cross in front of, the stars.

During 2008, the scope of the Kepler IV&V analysis efforts were focused on closing out open issues with the behaviors implemented by the Flight System as the Flight Software (FSW) development neared completion. Additionally, the Kepler IV&V team supported several project milestone reviews in CY2008, including:

- Kepler Risks Assessment Review (Provided IV&V status)
- Kepler Pre-Ship Review

The IV&V was able to provide evidence at these reviews to support that the Kepler system software will behave as intended, will not behave as unintended, and will respond predictably to adverse conditions. Additionally, the IV&V Team was in a position to assure the project that IV&V was not tracking any open significant issues or risks against the Kepler project or the FSW.

Lunar Reconnaissance Orbiter (LRO)

Contractor: Northrop Grumman Corporation
Project Lead: Jerry Sims
Lead Engineer: Eric Sylvania/Anita Berns

The Lunar Reconnaissance Orbiter (LRO) is the first mission in NASA's Vision for Space Exploration, a plan to return to the moon and then to travel to Mars and beyond. The LRO objectives are to find safe landing sites, locate potential resources, characterize the radiation environment, and demonstrate new technology. The spacecraft will be placed in low polar orbit (50 km) for a 1-year mission under NASA's Exploration Systems Mission Directorate. LRO will return global data, such as day-night temperature maps, a global geodetic grid, high resolution color imaging and the moon's UV albedo. However there is particular emphasis on the polar regions of the moon where continuous access to solar illumination may be possible and the prospect of water in the permanently shadowed regions at the poles may exist. Although the objectives of LRO are explorative in nature, the payload includes instruments with considerable heritage from previous planetary science missions, enabling transition, after one year, to a science phase under NASA's Science Mission Directorate. (http://lro.gsfc.nasa.gov/)

The NASA IV&V Program began work on the LRO software in 2006. The scope of NASA IV&V's work includes the spacecraft flight software (including Command and Data Handling [C&DH]; Guidance, Navigation, and Control [GN&C]; and the Core Flight Executive [cFE]), software for four instruments (LOLA, LAMP, LROC, and Diviner), and limited ground system software.

For the spacecraft flight software, the IV&V Team performed requirements and code analyses as well as test analyses at the build level. For the ground system, the IV&V Team performed analysis of the ground system requirements.

During 2008, the IV&V Team performed verification of the implementation of the equirements/behavior in the spacecraft FSW code as well as analyses of the spacecraft FSW tests at the build and system levels. As a result of this verification, the IV&V Team identified over 30 high severity issues with the spacecraft FSW code and/or test artifacts. Several of the issues identified with the test artifacts related to requirements that were not completely or adequately tested. Had these issues not been identified, the spacecraft FSW requirements may not have been properly verified, ultimately allowing for the potential that the associated FSW behaviors not perform as intended.

The LRO Project was able to ensure that the spacecraft FSW requirements were adequately and completely tested, thereby ensuring that the associated FSW behaviors were verified, potentially reducing the need for rework or reducing the risk of the FSW not behaving as intended.

Magnetospheric Multiscale (MMS)

Contractor: Northrop Grumman Corporation
Project Lead: Jerry Sims
Lead Engineer: Anita Berns

The Magnetospheric Multiscale (MMS) mission is a Solar-Terrestrial Probe (STP) mission comprising four identically instrumented spacecraft that will use Earth's magnetosphere as a laboratory to study the microphysics of three fundamental plasma processes: magnetic reconnection, energetic particle acceleration, and turbulence. These processes occur in all astrophysical plasma systems but can be studied in situ only in our solar system and most efficiently only in Earth's magnetosphere, where they control the dynamics of the geospace environment and play an important role in the processes known as "space weather." (http://stp.gsfc.nasa.gov/missions/mms/mms.htm)

The NASA IV&V Program began analysis of the MMS spacecraft and instrument flight software in early 2008. The scope of NASA IV&V's work includes the MMS Flight Software (FSW) system for the Spacecraft, selected instruments, and portions of the Ground System.

In 2008, the IV&V Team initiated the IV&V effort by completing the initial risk-based assessment of MMS to support the IV&V Portfolio-Based Risk Assessment (PBRA) and began development of the System Reference Model (SRM) to facilitate future IV&V activities in 2009.

Mars Science Laboratory (MSL)

Contractor: Northrop Grumman Corporation
Project Lead: Wes Deadrick
Lead Engineer: Shirley Savarino

The Mars Science Laboratory (MSL), known as Curiosity, will continue the exploration of Mars that has so successfully been performed by the two Mars Exploration Rovers (MER) Spirit and Opportunity. MSL is a rover that is scheduled to be launched between October and December 2011 and perform the first-ever precision landing on Mars. The MSL rover will be over five times as heavy and carry over ten times the weight in scientific instruments as one of the Mars Exploration Rovers. It will carry more advanced scientific instruments than any other mission to Mars to date;

including instruments for the analysis of samples scooped up from the soil and drilled powders from Martian rocks. It will also investigate the past or present ability of Mars to support microbial life.(http://mars.jpl.nasa.gov/msl/)

IV&V of the MSL system software is presently being performed on selected software behaviors. IV&V analysis will target the behaviors necessary to perform Entry, Descent, and Landing to assure that the rover safely lands in the desired location on Mars, the behaviors necessary to navigate the rover as it traverses the Martin terrain, and the behaviors necessary to acquire and handle the samples. IV&V is currently providing feedback to the project on issues and risks that have been identified by the analysis being performed.

During 2009 the IV&V team communicated several risks related to the MSL project's development activities. These activities enabled the IV&V team to provide the customer with insights into areas of suggested improvement related to both development products and processes. Examples of risks included concerns regarding the lack of formal unit test procedures/documentation as well as the lack of rigor in regards to the specification of module level requirements.

National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP)

Project Lead: Jerry Sims
Lead Engineer: Jerry Gilley

The National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) is a joint mission involving the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the Department of Defense (DOD). Goddard Space Flight Center (GSFC) is the center responsible for the NASA effort. The NPP mission will collect and distribute remotely-sensed land, ocean, and atmospheric data to the meteorological and global climate change communities as the responsibility for these measurements transitions from existing Earth-observing missions to the NPOESS. The specific mission goal of the NPP is to maintain environmental data sets initiated with NASA's TERRA and AQUA satellites until the launch of the NPOESS satellite. It will provide atmospheric and sea surface temperatures, atmospheric moisture profiles, land and ocean surface biophysical and climatic parameters, cloud and aerosol properties, ozone column abundance and ozone vertical profiles.(http://jointmission.gsfc.nasa.gov/)

Work completed by the IV&V Program during 2008 includes efforts representative of an Independent Assessment (IA) as the scope of the analysis efforts was limited to the Spacecraft Control Computer (SCC), Command Data Processor (CDP) and interfaces to the instruments. The primary focus of the IV&V Team's efforts were to perform requirements, design, traceability and test related analysis on the CDP as a result of the addition of the Clouds and the Earth's Radiant Energy System (CERES) instrument to NPP. In addition, the IV&V Team supported NPP related lifecycle/milestones reviews, specifically the CDP FSW Test Readiness Review (TRR) and Post Test Review (PTR).

Analysis on IV&V requirements and interface requirements completed by the IV&V Team resulted in providing the NPP customer with assurance that the updates to the CDP FSW requirements and CERES Unique Instrument ID/ Interface Control Document (ICD) were correct and complete. Additional efforts on IV&V test analysis provided stakeholders with visibility into the adequacy of the Formal Qualification Test (FQT) program/approach. Finally, the IV&V Team provided NPP Project and Agency stakeholders with visibility into the progress and quality of the system software development efforts as it pertained to the addition of the CERES instrument to the NPP payload as well as the NPP spacecraft FSW (SCC & CDP). The IV&V Team provided stakeholders with visibility into the progress and quality of the system-software development efforts.

Orbiting Carbon Observatory (OCO)

Contractor: L-3 Communications
Project Lead: Dan Solomon
Lead Engineer: Van Casdorph and David Wirkkala

The OCO mission was to collect precise global measurements of carbon dioxide (CO2) in the Earth's atmosphere. Scientists would have analyzed OCO data to improve understanding of the natural processes and human activities that regulate the abundance and distribution of this important greenhouse gas. This improved understanding would have enabled more reliable forecasts of future changes in the abundance and distribution of CO2 in the atmosphere and the effect that these changes may have on the Earth's climate. Unfortunately, due to a launch failure, the OCO spacecraft was lost in February 2009. (http://oco.jpl.nasa.gov/)

Efforts performed by the IV&V Team were concentrated on the OCO spacecraft flight software (FSW) and included code and test analysis. In addition, the IV&V Team supported OCO lifecycle/milestone reviews, specifically the OCO Risk Assessment Review (RAR) and OCO Pre-Ship Review (PSR).

IV&V code analysis efforts on the OCO spacecraft FSW contributed to the overall reduction of errors in delivered products. Specifically, the IV&V code analysis on OCO revealed several instances of uninitialized variables in the OCO Attitude Control Subsystem (ACS) and Command & Data Handling (C&DH) Subsystem FSW. Additionally, IV&V test analysis efforts provided stakeholders with visibility into the adequacy of the OCO test program/approach.

The IV&V Team provided OCO Project and Agency stakeholders with visibility into the progress and quality of the system software development efforts as it pertained to the OCO spacecraft FSW. Specifically, the IV&V Team provided favorable recommendations on the OCO spacecraft FSW at the OCO RAR and PSR, indicating that the IV&V Team was confident that the spacecraft FSW would perform as intended and the measures were in place to prevent off-nominal behaviors and address adverse conditions.

No risks were submitted in 2008. One issue detected in 2008 was that there were several instances of uninitialized variables in the ACS and C&DH code, which created the potential for OCO spacecraft FSW to do something unintentional or behave in unexpected fashion. Because this issue was detected by NASA IV&V, the OCO Project was able to take corrective action and update the code so that the variables were initialized, which led to an overall reduction in the amount of errors in the delivered product (OCO spacecraft FSW). These corrective actions increased the likelihood of stakeholders getting the system software desired in the implemented system.

Orion Crew Exploration Vehicle (CEV

Contractor: Northrop Grumman Corporation
Project Lead: Lisa Nicklow
Lead Engineer: Dan Sivertson and Todd Gauer

Making its first flights early in the next decade, Orion is part of the Constellation Program to send human explorers back to the moon, and then onward to Mars and other destinations in the solar system. (http://www.nasa.gov/mission_pages/constellation/orion/index.html)

The IV&V Team assigned to Orion in 2008 continued to develop and refine the SRM in order to validate Orion subsystem and component requirements. Work is ongoing to continue to the avionics level and to perform traceability to the remaining ERDs (Launch Abort System and Service Module). To date there have been several findings, including parent requirements without children and child requirements without parents, among others. These findings have been presented at the applicable subsystem and component reviews. The IV&V team also supported the Software Readiness Review (SwRR) and provided issues detailing several of the software artifacts that were presented during this review. Because IV&V has uncovered requirements defects early in the development lifecycle, this will enable the project to resolve the defects now and save cost and rework later.

Solar Dynamics Observatory (SDO)

Contractor: Northrop Grumman Corporation
Project Leas: Judith Connelly
Lead Engineer: Eric Sylvania

The Solar Dynamics Observatory (SDO) is the first mission to be launched for NASA's Living With a Star (LWS) Program, a program designed to understand the causes of solar variability and its impacts on Earth. SDO is designed to help us understand the Sun's influence on Earth and Near-Earth space by studying the solar atmosphere on small scales of space and time and in many wavelengths simultaneously.

SDO's goal is to understand, driving towards a predictive capability, the solar variations that influence life on Earth and humanity's technological systems by determining

- *how the Sun's magnetic field is generated and structured*
- *how this stored magnetic energy is converted and released into the heliosphere and geospace in the form of solar wind, energetic particles, and variations in the solar irradiance. (http://sdo.gsfc.nasa.gov/)*

The NASA IV&V Program began analysis of the SDO spacecraft and instrument flight software in March 2004. The scope of NASA IV&V's work includes all of the SDO flight software (FSW) system for the spacecraft, the observatory instruments (the Atmospheric Imaging Assembly [AIA], Helioseismic and Magnetic Imager [HMI], and EUV Variability Experiment [EVE]), and the Ground System. The spacecraft systems and associated FSW are being developed at Goddard Space Flight Center (GSFC). The AIA and HMI instruments and FSW are being developed by the Solar and Astrophysics Laboratory (LMSAL) at Lockheed Martin's Advanced Technology Center (ATC) in Palo Alto, California. The EVE instrument and FSW are being developed by the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado. The Ground System software is being developed at GSFC.

During 2008, the SDO IV&V Team performed verification of the spacecraft FSW tests at the build and system levels. As a result of this verification, the IV&V Team identified over 30 high severity issues with the FSW test artifacts. Several of the issues identified with the test artifacts related to requirements that were not completely or adequately tested. Had these issues not been identified, the FSW requirements may not have been properly verified, ultimately allowing for the potential that the associated FSW behaviors not perform as intended.

The SDO Project was able to ensure that the FSW requirements were adequately and completely tested, thereby ensuring that the associated FSW behaviors were verified, potentially reducing the need for rework or reducing the risk of the FSW not behaving as intended.

Space Shuttle (SSP)

Contractor: L-3 Communications
Project Lead: John Hinkle
Lead Engineer: Harry St. John

The Space Shuttle is the world's first reusable spacecraft and the first spacecraft in history that can carry large satellites and equipment to and from orbit. It provides U.S. and International Partner access to the International Space Station (ISS) for crew, cargo, and ISS components. The Shuttle is the only vehicle capable of bringing the final pieces of the ISS into space to achieve the goal of "assembly complete." (http://www.nasa.gov/mission_pages/shuttle/main/index.html)

In 2008, NASA IV&V supported four Shuttle missions, all to the ISS. Before each Shuttle mission, NASA IV&V performed an independent analysis of software discrepancy reports and change requests having flight safety or mission success implications for the main computer system, the backup computer system, and the crew displays; engine controllers; and the Global Positioning System (GPS) receivers.

NASA IV&V provided additional assurance that changes being made to the mission- and safety-critical software did not adversely affect flight safety or mission success.

NASA IV&V code walkthrough of Abort-related flight code raised issues. While initially viewed by the software developer as a less critical issue, NASA IV&V operational analysis showed that the issues, if left uncorrected, could result in the potential loss of crew or vehicle due to an insufficient propellant dump under some abort conditions.

SpaceX

Contractor: Northrop Grumman Corporation / L-3 Communications
Project Leads: Christina Moats and Ken Vorndran

The Commercial Orbital Transportation Services (COTS) program was initiated to facilitate U.S. private industry demonstration of cargo and crew space transportation capabilities with the goal of achieving reliable, cost effective access to low-Earth orbit. SpaceX was selected to build and demonstrate commercial cargo transportation capabilities, initially for cargo transport to the International Space Station (ISS). SpaceX intends to leverage the cargo transport capability and extend it for human transport.

The NASA IV&V Program focused its efforts on the COTS Ultra High Frequency (UHF) Communications Unit (CUCU) Familiarization and Analysis of Concept. NASA IV&V reviewed development artifacts – such as the Software (SW) development plan; CUCU development plan; SW architecture; CUCU architecture; Fault Detection, Isolation, and Recovery (FDIR) Requirements; Concept of Operations; and design briefings – for familiarity and content appropriateness, as well as completeness and technical consistency.
NASA IV&V participated in the Dragon 1 Preliminary Design Review (PDR) on 9 June 2008 via WebEx. All issues, concerns, and comments from the development artifact review and the PDR participation were documented in a

memorandum and provided to the SpaceX technical POC by 13 June 2008. NASA IV&V utilized the results of Phase 1 to refine the Phase 2 work specification and provide updates to SpaceX for review as part of the 13 June 2008 memorandum.

Overall, based upon the participation in PDR3 and the limited analysis that was performed, NASA IV&V feels that, for the most part, the SpaceX development artifacts were appropriate, complete, and technically consistent. There were thirteen issues that identified the artifacts as not complete or technically consistent in some areas.

In terms of general observations relevant to SpaceX objectives to implement a human-rated system in the future, the NASA IV&V Team concluded that the amount of formality in the development processes should be considered in terms of extensibility to the future. For example, currently addressing any shortcomings with regard to development activities, associated processes, and documentation (e.g., CM) would minimize rework for future development phases/activities.

2009 PROJECT SUMMARIES

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Ares

Contractor: L-3 Communications
Project Lead: Lisa Nicklow
Lead Engineer: Heath Haga

The Ares I Crew Launch Vehicle (CLV) is a key component of the Cx Program. Ares I is a two-stage launch vehicle intended to carry the Orion Crew Exploration Vehicle (CEV) to an ascent target from which Orion can reach low Earth Orbit (LEO).(http://www.nasa.gov/mission_pages/constellation/ares/index.html)

The Ares I Project, as part of the CxP, is to design an effective Crew Launch Vehicle to carry the Orion Crew Exploration Vehicle into Low Earth Orbit (LEO). The Ares rockets will return human explorers to the moon and beyond. The first stage, Ares I, is powered by a single five segment solid rocket booster and can lift more than 55,000 pounds to low earth orbit. Ares I may also be used to deliver resources and supplies to the International Space Station. The Ares I upper stage is propelled by a J-2X main engine fueled with liquid oxygen and liquid hydrogen. NASA's Marshall Space Flight Center leads the Ares Projects, but collaboration between team projects working at NASA centers and contract organizations around the nation are elemental in designing, building, testing, and ensuring that the Ares Crew Launch Vehicle is safe, cost effective and reliable. The NASA IV&V's primary focus for validating the safety and reliability of the Ares Launch Vehicle software is consistent with the Orion Exploration Vehicle: answering the three questions to best understand the system's expected performance. The Ares IV&V team continued its review support at 2009 at both the Upper Stage PDR1 and J-2X Engine Control Unit CDR. The Ares project indicated that IV&V provided a unique technical insight and issues that would greatly improve their development effort. 110 IV&V issues were submitted during PDR 1, with 97% being accepted, which will allow the design team to evolve solutions prior to the CDR, reducing rework and costs later in the project.

Constellation CxP

Contractor: L-3 Communications and Northrop Grumman Corporation
Project Lead: G. Scott Kinney
Lead Engineers: Don Ohi (L-3 Communications), Robert Donegan (Northrop Grumman Corporation), Anyika Johnson (Northrop Grumman Corporation), Joelle Spagnuolo-Loretta (Northrop Grumman Corporation), Shirley Savarino (Northrop Grumman Corporation)

A new generation of spacecraft will carry humans to the moon, Mars and beyond. (http://www.nasa.gov/mission_pages/constellation/main/index.html)

Although not identified as an individual project within Cx, the Exploration Systems Mission Directorate Integration (ESMDI) IV&V team has been created by the IV&V Facility to ensure that the Cx systems are developed to satisfy the needs, goals and objectives of Cx, and that the integration of these systems is planned and conducted in a manner that supports the safety and success of the mission. The ESMDI IV&V team has interfaced primarily with the Cx Systems Engineering and Integration Office (SE&I) and has focused particularly on integration risks. The team has worked closely with the individual Cx IV&V Projects, such as Orion and Ares, to ensure system interfaces and integrated behaviors of these systems provide the desired end-to-end system performance and do not result in undesired emergent behaviors. The ESMDI IV&V team has and will continue to leverage the relationship with Cx SE&I to build working relationships with other organizations and teams within the CxP program. The ESMDI IV&V team will report at Program milestone reviews on the overall integrity of the software and systems.

In 2009 the ESMDI efforts continued but took on a different approach as directed by the IV&V Director, who expressed a problem statement for the team identifying that an approach is needed for integration analysis of systems of systems (SoS) for CxP. The Director amplified the importance of this effort by identifying integration as a major risk. Thus the team, labeled as the Constellation Domain Analysis (CxDA) Team, made up of the IV&V Exploration Systems Mission Directorate (ESMD), the Architecture Product Line Lead, and members of the System Reference Modeling and Validation (SRMV) product line was charged with developing a reference architecture modeling and integration analysis techniques, with the potential for application of these techniques to other domains. Model products developed by CxDA were created during the experimental piloting and development process. Details of this effort and lessons learned were documented in the CxDA Transition Team Report. This Domain Reference Model was used to perform a Performance Based Risk Assessment (PBRA) assess CxP mission capabilities in order to prioritize IV&V analysis tasks. To date the focus has been in these critical areas and the identification of critical system interactions.

Glory

Contractor: Northrop Grumman Corporation
Lead Engineer: Phil Loftis
Project Lead: Tom Macaulay

Glory is a remote-sensing Earth-orbiting observatory designed to achieve two separate mission objectives. One is to collect data on the chemical, microphysical, and optical properties, and spatial and temporal distributions of aerosols. The other is to continue collection of total solar irradiance data for the long-term climate record. (http://glory.giss.nasa.gov)

The IV&V Team assigned to Glory is inspecting the project's mission- and safety-critical software and has reviewed the requirements, design, code, and test artifacts to assure that the Attitude Determination and Control Subsystem (ADACS) and the Command and Data Handling (CDH) code will properly initiate solar array deployment, perform attitude maneuvers, and properly receive, validate, and execute ground commands.

In FY009, the IV&V Team saved the Glory software development team test delays and possibly on-orbit troubleshooting time by providing valuable feedback on coding errors that the IV&V Team discovered using state-of-the-art code analysis tools and Unified Modeling Language (UML) techniques. For example, in issues GLORY-TIM-1366 and GLORY-TIM-1367 the IV&V Team documented attempts by the Attitude Determination and Control Subsystem (ADACS) software to dereference empty pointers. Dereferencing empty pointers can cause unpredictable behavior ranging from no apparent harm to processor crash. If these issues had not been discovered, the spacecraft could have lost the ability to control its attitude until the operations team could have performed troubleshooting steps to isolate the problem and upload updates to repair the software. Without proper attitude control, the spacecraft's solar arrays may not be pointed directly at the sun to maximize battery power recharge, which would result in instruments being powered down, with associated loss of acquisition of science data, as needed to conserve power.

Glory's instruments – the Aerosol Polarimetry Sensor, Cloud Camera, and Total Irradiance Monitor – are nearly complete and ready for launch. The Glory mission will provide data to help scientists conclude whether climate changes are caused by humans or are byproducts of naturally occurring events.

Global Precipitation Measurement (GPM)

Contractor: Northrop Grumman Corporation
Lead Engineer: Ken Haught
Project Lead: Tom Macaulay

GPM is a remote-sensing, Earth-orbiting observatory with four mission objectives: 1) to produce an accurate representation of Earth's water cycle; 2) to establish a numerical relationship between global water variability and temperature changes; 3) to improve short- to medium-range weather forecasting and climate simulations; and 4) to improve predictions of floods, droughts, crop conditions, and other weather-related applications. (http://gpm.gsfc.nasa.gov)

The IV&V Team assigned to GPM has developed a system reference model that has been used to validate requirements and verify the GPM software architecture. The model will also be used to verify the implementation of the software used to control the orbit and orientation of the GPM spacecraft, check out the spacecraft instruments, maintain the health and safety of the spacecraft, and obtain global precipitation measurements. Using a risk-based assessment approach, the IV&V Team has identified the mission-critical operational threads and the areas critical to software safety on which to focus independent verification and validation of associated software, thereby helping to assure mission success.

In 2009, the IV&V Team provided valuable feedback on navigation and instrument software to the GPM development team that immeasurably saved the developer time in troubleshooting and tracking down the causes of unexplained anomalies and potential processor resets.

Early IV&V efforts also resulted in the discovery of a potential loophole in one NASA Center's software configuration management process that will result in more robust code across multiple missions that use the Center's common code.

Gravity Recovery and Interior Laboratory (GRAIL)

Contractor: L-3 Communications
Project Lead: Meagan Carrier
Lead Engineer: Van Casdorph

Gravity Recovery and Interior Laboratory (GRAIL) has two primary objectives: determine the structure of the lunar interior, from crust to core, and advance understanding of the thermal evolution of the Moon. GRAIL has one secondary objective which is to extend knowledge gained on the internal structure and thermal evolution of the Moon to other terrestrial planets.

The overall scientific goal of GRAIL is to understand the internal structure and thermal evolution of the Moon in order to provide key information on the origin and evolution of that body as well as all terrestrial planets in the early stages of the solar system history. The Moon's accessibility as an example of a preserved primary crust that formed shortly after accretion makes it a linchpin for our comprehension of the evolution of silicate worlds, and the early evolution of the Earth is strongly tied to lunar origin. Assessing models of thermal evolution requires knowledge of a planetary body's internal structure, and the biggest impediment to progress in studies of lunar internal structure has been the lack of reliable farside gravity data. GRAIL's gravity data will yield greatly improved models of the structure of the lunar interior, especially when combined with other data types from past and/or future lunar missions. The scientific goals are achieved via measuring the lunar gravitational field, for which GRAIL's dual spacecraft and instrumentation are designed.

During 2009, IV&V continued developing a System Reference Model. This model was used as a tool to perform System Level and Segment Level Validation. Also, the modeling team developed a system level architecture model. This model was used to assist with the Segment Level validation of integration requirements between the Flight System and the Mission System. The architecture model was also used to analyze architecture at the System Level.

To date, the GRAIL IV&V effort has established the pedigree of the Level 2 and Level 3 requirements. IV&V determined that the Flight System and Mission System interfaces as documented in the Flight-to-Ground ICD are adequately defined. Also, IV&V System Architecture analysis efforts revealed that the proposed system architecture satisfies the behaviors in the System Reference Model and it is a feasible solution.

Hubble Space Telescope (HST) Servicing Mission 4 (SM4)

Lead Engineer: Jerry Gilley
Project Lead: Ken Vorndran

The Hubble Space Telescope was reborn with Servicing Mission 4 (SM4), the fifth and final servicing of the orbiting observatory. During SM4, two new scientific instruments were installed: the Cosmic Origins Spectrograph (COS) and Wide Field Camera 3 (WFC3). Two failed instruments, the Space Telescope Imaging Spectrograph (STIS) and the Advanced Camera for Surveys (ACS), were brought back to life by the first ever on-orbit repairs. With these efforts, Hubble has been brought to the apex of its scientific capabilities. (http://hubble.nasa.gov/missions/sm4.php)

Efforts performed by the IV&V Team were representative of an Independent Assessment (IA), as the scope of the analysis efforts was limited to the instruments only. The IV&V Team performed code and test analysis on the ACS-R Control Section (CS) FSW build 5.13 (final flight build), test procedure and results analysis on the ACS-R Servicing Mission Ground Test (SMGT), and ACS-R HST SM4 Observatory Verification (SMOV) Dry Run test efforts, code and test analysis associated with efforts to replace the Science Instrument Command & Data Handling unit (SI C&DH) and supported HST SM4 lifecycle/milestone reviews, specifically the delta Safety and Mission Success Review (SMSR).

The IV&V Team provided HST Project and Agency stakeholders with visibility into the progress and quality of the system software development efforts as it pertained to the COS, WFC3 and ASC instrument software. Specifically, the IV&V Team provided favorable recommendations on the instrument software at the delta HST SM4 SMSR, indicating that the IV&V Team was confident that the instrument software will perform as intended. No issues or risks were submitted in 2009.

International Space Station (ISS)

Contractor: L-3 Communications
Project Lead: John Hinkle
Lead Engineer: Harry St. John

The International Space Station (ISS) is an Earth-orbiting platform providing a permanent human presence in space. Numerous scientific experiments supporting medicine and biology, the effects of space on materials and living beings, and commercial ventures are already being performed aboard ISS, even though the facilities and capabilities are still under construction. (http://www.nasa.gov/mission_pages/station/main/index.html)

The NASA IV&V Program has been and is involved with all NASA-developed ISS mission-critical software, assuring that software for ISS is of high quality. In 2009, the IV&V Team verified new releases of most of the on-orbit software that was transitioned to operation. Analyses on these systems included requirements review, design and implementation verification, and analysis of testing performed.

ISS IV&V utilized its fully capable IV&V test bed to exercise multiple software components in many configurations. This permitted the IV&V Team to independently test key areas prone to potential problems. The software baseline for ISS is largely complete but continues to be updated by new releases to provide new capabilities and ensure safe operations.

New major additions to the ISS in 2009 included the final major U.S. truss segment, Starboard 6, and its final pair of power-generating solar array wings; the Kibo Japanese Experiment Module Exposed Facility and Experiment Logistics Module Exposed Section; upgrades to the Environmental Control and Life Support System to support the permanent crew increase from three to six astronauts; and the Lightweight Multi-Purpose Experiment Support Structure Carrier. Each component added to the on-orbit configuration through assembly complete in 2010 results in varying levels of software addition/change.

The depth and breadth of knowledge and experience in systems and software applied by IV&V on ISS has made the IV&V Team a primary contributor of technical findings, which improves the quality and safety of ISS software systems.

The IV&V Team has supported and continues to support the development of the software that manages the water recycling on-board the ISS. This system is critical toward maintaining the full six-person crew, as it provides water and oxygen for crew consumption and atmosphere maintenance.

The IV&V Team, along with the contractor developer and NASA Marshall Space Flight Center (MSFC) personnel, worked through many challenges to meet the software development time and cost constraints. Initial IV&V work followed traditional lines; however, to meet the challenging schedule, IV&V was asked to expand its scope of analysis to include support of verification efforts such as test development, and support of risk mitigation, including hazard control analysis.

James Webb Space Telescope (JWST)

Contractor: L-3 Communications
Project Lead: Wes Deadrick
Lead Engineer: Bob Jarrett

The James Webb Space Telescope (JWST) is a large, infrared-optimized space telescope, scheduled for launch in 2014. JWST is a successor to the aging Hubble Space Telescope; however, it will not be a complete successor because it will

not be sensitive to all of the light wavelengths that Hubble can see. The main scientific goal is to observe the most distant objects in the universe, those beyond the reach of either ground based instruments or the Hubble. As the premier observatory of the next decade, JWST serves thousands of astronomers worldwide by finding the first galaxies that formed in the early Universe, connecting the Big Bang to our own Milky Way Galaxy. Additionally, JWST will peer through dusty clouds to see stars forming planetary systems, connecting the Milky Way to our own Solar System. (http://www.jwst.nasa.gov)

The NASA IV&V Team is analyzing JWST's critical software behaviors that are implemented in both the Flight Software (FSW) as well as some aspects of the ground software.

During 2009, the JWST IV&V Team provided assurance to the JWST Project that the desired, preventive, and responsive Integrated Science Instrument Module (ISIM) and instrument FSW behaviors were implemented in the design and code to satisfy the levied software requirements. The IV&V Team also provided Deployment Electronics Unit (DEU) FSW requirements validation results in-phase with DEU FSW requirements review, allowing the JWST Project to address limitations early in the life-cycle, at the most optimal time. Additionally, the IV&V Team provided CryoCooler Electronics (CCE) FSW requirements validation results as input at the CCE FSW Preliminary Design Review (PDR)/Critical Design Review (CDR), allowing the JWST Project to address limitations early in the life-cycle, at the most optimal time

The IV&V Team identified defects in early builds of the NIRSpec software, which allowed the NIRSpec Team to address these defects prior to or in the flight build, ultimately reducing errors in the delivered product. The IV&V Team identified and documented JWST Project-related risks associated with lack of insight/accessibility to interim development artifacts for the CCE, Optical Telescope Element Application Development Unit (OTE ADU) and DEU software, as well as the lack of Operational Scripts Subsystem (OSS) L4 – L5 requirements traceability, and provided assurance to the JWST Project concerning the completeness, correctness, and consistency of the Science and Operations Center (S&OC) requirements more than one year prior to the S&OC PDR.

During the latter part of 2009, the IV&V Team attended and participated in the ADU FSW Critical Design Audit (CDA) at Ball Aerospace Technologies Corporation. During the CDA, the IV&V Team submitted one Request for Action (RFA) concerning a statement that the same test procedures used for Computer Software Component (CSC) Testing were to also serve as the basis for testing at the Baseline Build Testing level and Formal Qualification Testing (FQT) level. The concern with this approach is based on the fact that the objectives of each test phase are different and require different test approaches and procedures to meet the test objectives. The RFA requested an explanation as to how the CSC level tests will be used to accomplish the objectives for Build Test and FQT. The lack of the appropriate specification of the test procedures at each level could result in adequate verification, given that the objectives for each of these levels of test differ, and may ultimately result in critical functionality that has not been fully verified against the levied requirements.

Juno

Contractor: L-3 Communications
Project Lead: Wes Deadrick
Lead Engineer: Sam Brown

Juno is a mission of discovery and exploration that will conduct an in-depth study of Jupiter, the most massive planet in our solar system. Peering through the clouds deep into Jupiter's atmosphere, the mission will reveal fundamental processes of the formation and early evolution of our solar system. Juno's goal is to understand the origin and evolution of the gas giant planet, which will pave the way to a better understanding of our solar system and other planetary systems being discovered around other stars. Using a spinning, solar-powered spacecraft, Juno will make maps of the gravity, magnetic fields, and atmospheric composition of Jupiter from a unique polar orbit. Carrying precise high-sensitivity radiometers, magnetometers, and gravity science systems, Juno's 32 orbits will sample Jupiter's full range of latitudes and longitudes. (http://www.nasa.gov/juno/)

The software deployed on the Juno spacecraft is responsible for controlling the highest criticality event of the mission's lifetime: to insert the spacecraft into polar orbit around Jupiter. Additionally, software is responsible for various other maneuvers required to keep Juno on track to Jupiter and the collection of science data from the nine instruments on-board the spacecraft. The Juno IV&V Team is providing full life-cycle support to the Juno mission that began with validation of the Juno mission requirements and is now proceeding with the validation and verification of critical software behaviors documented in the software design, implementation, and test products.

During 2009, the Juno IV&V Team continued assessment of the critical software behaviors of the Juno system adequately specify what the system should do, what the system should not do, and how the system should respond in the presence of adverse conditions. Focus in 2009 was directed toward completing validation of the flight software domain level requirements, validation of the requirements specifying the integration between the flight system and the science instruments, validation of the requirements specifying the integration between the flight software and the spacecraft hardware, validation of the test scope, and verification of the initial software design.

Performance of these analyses further supported the assessment provided at the Juno Critical Design Review (CDR) that the Juno flight software requirements are generally of high quality and implement the desired behaviors of the system, have guards in place to inhibit undesired events, and responds appropriate in the presence of adverse conditions. Since the Juno CDR, the IV&V Team has continued to provide regular indicators as to the progress and quality of the Juno system-software development through regular discussions and the submission of IV&V findings. Through the course of the IV&V efforts, the Juno IV&V Team has remained largely in-step with the development team ensuring the results are provided in a timely manner when they are most cost effective to respond to.

During the validation of the Juno integration requirements the Juno IV&V Team generated several findings regarding the relegation of the specification of a number of Level 4 Juno Flight Software (FSW) Input/Output requirements to the Juno Hardware/Software Interface Control Document (HW/SW ICD). The Level 4 requirements indicated that certain FSW requirements would be specified in the HW/SW ICD. Upon examination of the HW/SW ICD it was noted that no FSW requirements were specified in the ICD. This lack of specification was an indication of a potential disconnect between the Level 4 FSW specification and the ICD. This disconnect was communicated to the developer and later addressed via several updates to the Level 4 requirements specification. Had this concern not been addressed it could have potentially resulted in increased development costs as a result of rework stemming from an inadequate specification of the Level 4 Input/Output FSW requirements.

Kepler

Contractor: L-3 Communications
Project Lead: Wes Deadrick
Lead Engineer: Patrick Olguin

The Kepler Mission is designed to search for extrasolar planets by observing periodic transits of planets across the stellar disks. As observed by the Kepler spacecraft, stars with a transit will dim slightly during the several hours that it takes for the planet to cross. This dimming is measured by the Kepler photometer, which provides the data that ultimately leads to the determination of the size and orbital period of the planet. The Kepler Mission will perform a census of 100,000 dwarf stars to detect and characterize the hundreds of terrestrial and larger planets expected to be found in or near the Habitable Zones (HZ). The HZ encompasses the distance from the star where liquid water can exist on the surface of an orbiting terrestrial planet. .(http://www.kepler.arc.nasa.gov)

Kepler was launched on March 6, 2009 aboard a Delta II rocket from Cape Canaveral Air Force Station, Florida. The launch was a complete success and the first light images were taken on the next day. On June 19, 2009, the spacecraft successfully sent its first science data to Earth. Kepler team members say these new data indicate the mission is indeed capable of finding Earth-like planets, if they exist. Kepler will spend the next three-and-a-half years searching for planets as small as Earth, including those that orbit stars in a warm zone where there could be water. It will do this by looking for periodic dips in the brightness of stars, which occur when orbiting planets transit, or cross in front of, the stars.

The scope of the Kepler IV&V analysis efforts were focused on the behaviors implemented by the Spacecraft Flight System. 2009 activities on Kepler included verifying that the results of the Mission Scenario Tests (MSTs) adequately tested the behaviors of the Kepler system as identified in the Kepler System Reference Model (SRM). IV&V of Kepler was completed prior to launch and the IV&V team was able to provide evidence to support that the Kepler system software will behave as intended, will not behave as unintended, and will respond predictably to adverse conditions.

During 2009 the Kepler IV&V team supported the following Kepler project milestone reviews, leading up to the successful launch of Kepler:

- Flight Readiness Review (FRR) – IV&V Provided Assessment
- Safety and Mission Assurance Review (SMSR) – IV&V Provided Assessment

As of the Kepler Safety and Mission Success Review (SMSR) IV&V was not tracking any risks or issues relevant to the Kepler system software. Leading up to the SMSR and launch, IV&V provided status indicators to the project regarding the progress and quality of the Kepler flight software at the Kepler Risk Assessment Review (RAR) as well as the Kepler Flight Readiness Review (FRR).

Lunar Reconnaissance Orbiter (LRO)

Contractor: Northrop Grumman Corporation
Project Lead: Jerry Sims
Lead Engineer: Eric Sylvania

The Lunar Reconnaissance Orbiter (LRO) is the first mission in NASA's Vision for Space Exploration, a plan to return to the moon and then to travel to Mars and beyond. The LRO objectives are to find safe landing sites, locate potential resources, characterize the radiation environment, and demonstrate new technology. The spacecraft will be placed in low polar orbit (50 km) for a 1-year mission under NASA's Exploration Systems Mission Directorate. LRO will return global data, such as day-night temperature maps, a global geodetic grid, high resolution color imaging and the moon's UV albedo. However there is particular emphasis on the polar regions of the moon where continuous access to solar illumination may be possible and the prospect of water in the permanently shadowed regions at the poles may exist. Although the objectives of LRO are explorative in nature, the payload includes instruments with considerable heritage from previous planetary science missions, enabling transition, after one year, to a science phase under NASA's Science Mission Directorate. (http://lro.gsfc.nasa.gov/)

The NASA IV&V Program began work on the LRO software in 2006. The scope of NASA IV&V's work includes the spacecraft flight software (including Command and Data Handling [C&DH]; Guidance, Navigation, and Control [GN&C]; and the Core Flight Executive [cFE]), software for four instruments (LOLA, LAMP, LROC, and Diviner), and limited ground system software.

For the spacecraft flight software, the IV&V Team performed requirements and code analyses as well as test analyses at the build level. For the ground system, the IV&V Team performed analysis of the ground system requirements.

During 2009 the LRO IV&V Team supported the following LRO project milestone reviews, leading up to the successful launch of LRO on 18 June 2009:

- Pre-Ship Review (PSR) – January 2009
- Flight Software Acceptance Test Readiness Review (ATRR) – January 2009
- Flight Operations Readiness Review (FORR) – March 2009
- Safety and Mission Assurance Review (SMSR) – April 2009
- Mission Readiness Review (MRR) – April 2009

Mars Science Laboratory (MSL)

Contractor: Northrop Grumman Corporation
Project Lead: Wes Deadrick
Lead Engineer: Shirley Savarino

The Mars Science Laboratory (MSL), known as Curiosity, will continue the exploration of Mars that has so successfully been performed by the two Mars Exploration Rovers (MER) Spirit and Opportunity. MSL is a rover that is scheduled to be launched between October and December 2011 and perform the first-ever precision landing on Mars. The MSL rover will be over five times as heavy and carry over ten times the weight in scientific instruments as one of the Mars Exploration Rovers. It will carry more advanced scientific instruments than any other mission to Mars to date; including instruments for the analysis of samples scooped up from the soil and drilled powders from martian rocks. It will also investigate the past or present ability of Mars to support microbial life. (http://mars.jpl.nasa.gov/msl/)

IV&V of the MSL system software is presently being performed on selected software behaviors. IV&V analysis will target the behaviors necessary to perform Entry, Descent, and Landing to assure that the rover safely lands in the desired location on Mars, the behaviors necessary to navigate the rover as it traverses the Martin terrain, and the behaviors necessary to acquire and handle the samples. IV&V is currently providing feedback to the project on issues and risks that have been identified by the analysis being performed.

During 2009 the analyses performed by the MSL IV&V team were largely scaled back as a result of an early FY09 decision to postpone the launch of MSL from 2009 to 2011. The change in launch date required the IV&V team to delay a number of planned assessments due to limited development on the part of the customer. Several assessments were performed to enable the IV&V team to further assess confidence that the requirements driving the critical software behaviors for performing Entry, Descent, and Landing (EDL) adequately specify what the system should do, what the system should not do, and how the system should respond in the presence of adverse conditions.

As a result of the analysis a potential severity 2 issues was generated regarding the incomplete specification of flight software (FSW) requirements regarding the reading and logging of safety critical data. A parent requirement was identified specifying that the flight system shall provide the ability to monitor all safety critical states, enables, interfaces, voltages, and conditions; however the single child requirement decomposing the parent limits the FSW role to only the available data and does not specify what data is considered to be safety critical data. Without further specification of which safety data needs to be read and logged, and the limitation of only collecting available data instead of the needed data, implementation of this requirement could result in limitations to rover safety. The collection of safety critical data feeds into the MSL Fault Protection system and ground telemetry. Lack of correct (based on incomplete specification) or complete (based on "available") data could lead to MSL's inability to perform a safety critical response.

National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP)

Project Lead: Meagan Carrier
Lead Engineer: Jerry Gilley

The objective of the National Polar Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) is a joint mission involving the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the Department of Defense (DOD). Goddard Space Flight Center (GSFC) is the center responsible for the NASA effort. The NPP mission will collect and distribute remotely-sensed land, ocean, and atmospheric data to the meteorological and global climate change communities as the responsibility for these measurements transitions from existing Earth-observing missions to the NPOESS. The specific mission goal of the NPP is to maintain environmental data sets initiated with NASA's TERRA and AQUA satellites until the launch of the

NPOESS satellite. It will provide atmospheric and sea surface temperatures, atmospheric moisture profiles, land and ocean surface biophysical and climatic parameters, cloud and aerosol properties, ozone column abundance and ozone vertical profiles(http://jointmission.gsfc.nasa.gov/)

Efforts by the IV&V Team during 2009 were representative of an Independent Assessment (IA) as the scope of the analysis efforts was limited to the Spacecraft Control Computer (SCC), Command Data Processor (CDP) and interfaces to the instruments. The primary focus of the IV&V Team's efforts were to perform requirements, design, traceability and test related analysis on the CDP as a result of the addition of the Clouds and the Earth's Radiant Energy System (CERES) instrument to NPP.

Work completed by the Team resulted in stakeholders being provided with visibility into the quality of the SCC/CDP software based on design and code analysis. Additional efforts on test analysis provided stakeholders into the visibility into the adequacy of the Formal Qualification Test (FQT) program/approach. The IV&V Team also provided NPP Project and Agency stakeholders with visibility into the progress and quality of the system software development efforts as it pertained to the addition of the CERES instrument to the NPP payload as well as the NPP spacecraft FSW (SCC & CDP). No issues or risks were submitted in 2009. The IV&V Team also increased assurance to stakeholders that the SCC/CDP code was free of errors and correctly/completely implemented the levied requirements, as well as necessary updates to the test program and associated test related artifacts were made and were complete/correct.

Orbiting Carbon Observatory (OCO)

Contractor: L-3 Communications
Project Lead: Dan Solomon
Lead Engineer: Van Casdorph and David Wirkkala

The OCO mission was to collect precise global measurements of carbon dioxide (CO2) in the Earth's atmosphere. Scientists would have analyzed OCO data to improve understanding of the natural processes and human activities that regulate the abundance and distribution of this important greenhouse gas. This improved understanding would have enabled more reliable forecasts of future changes in the abundance and distribution of CO2 in the atmosphere and the effect that these changes may have on the Earth's climate. Unfortunately, due to a launch failure, the OCO spacecraft was lost in February 2009. (http://oco.jpl.nasa.gov/)

In 2009, the NASA IV&V Program was limited in scope to Spacecraft Bus Software Systems. The IV&V Team created a basic reference model (BRM) describing the goals, what the system must do to achieve these goals, and the operational environment. The IV&V Team used the BRM to validate the testing approach and its associated artifacts. The IV&V Team performed static analysis of the source code to verify correct implementation of the behaviors in the SRM.

Nine Severity 3 issues were submitted against the source code and corrected in subsequent builds. One test coverage issue was submitted and corrected. NASA IV&V expressed confidence that the spacecraft software would behave as expected and that measures were in place to prevent off-nominal behaviors and address adverse conditions

Orion

Contractor: Northrop Grumman Corporation
Project Lead: Lisa Nicklow
Lead Engineer: Dan Sivertson and Todd Gauer

Making its first flights early in the next decade, Orion is part of the Constellation Program to send human explorers back to the moon, and then onward to Mars and other destinations in the solar system. (http://www.nasa.gov/mission_pages/constellation/orion/index.html)

The Orion Crew Exploration Vehicle is one of the Constellation Program's (CxP)fleet of vehicles that will send human explorers to the International Space Station (ISS) and to the moon. Orion is the key to space exploration beyond low Earth orbit, and future capabilities could take crew members to other destinations in our solar system such as Mars. Orion is being designed to be safe, affordable, reliable, versatile and reusable. The NASA Orion Crew Exploration team at NASA IV& V is focused primarily on the safety and reliability of its computer software, mainly that the system performs the functions it is supposed to perform, does not perform the functions it is not supposed to perform, and that the system performance is satisfactory under adverse conditions. A calculated understanding of how the system will perform under adverse conditions is a special priority at NASA IV&V, as an error of this magnitude could result in the loss of mission/loss of life for the Orion Crew Exploration team. The Orion project held a number of subsystem design reviews in 2009 where IV&V had the opportunity to present its findings. The IV&V presence in both Houston at JSC, and Denver at the developer's site, has been acknowledged by the Orion project as providing superior technical input and expertise. IV&V provided the Orion project with several software architecture risks which will enable to project to improve the functionality and quality of the software design and architecture prior to implementation of the requirements.

Solar Dynamics Observatory (SDO)

Contractor: Northrop Grumman Corporation
Project Lead: Eric Sylvania

The Solar Dynamics Observatory (SDO) is the first mission to be launched for NASA's Living With a Star (LWS) Program, a program designed to understand the causes of solar variability and its impacts on Earth. SDO is designed to help us understand the Sun's influence on Earth and Near-Earth space by studying the solar atmosphere on small scales of space and time and in many wavelengths simultaneously.

SDO's goal is to understand, driving towards a predictive capability, the solar variations that influence life on Earth and humanity's technological systems by determining

- *how the Sun's magnetic field is generated and structured*
- *how this stored magnetic energy is converted and released into the heliosphere and geospace in the form of solar wind, energetic particles, and variations in the solar irradiance. (http://sdo.gsfc.nasa.gov/)*

The NASA IV&V Program began analysis of the SDO spacecraft and instrument flight software in March 2004. The scope of NASA IV&V's work includes all of the SDO flight software (FSW) system for the spacecraft, the observatory instruments (the Atmospheric Imaging Assembly [AIA], Helioseismic and Magnetic Imager [HMI], and EUV Variability

Experiment [EVE]), and the Ground System. The spacecraft systems and associated FSW are being developed at Goddard Space Flight Center (GSFC). The AIA and HMI instruments and FSW are being developed by the Solar and Astrophysics Laboratory (LMSAL) at Lockheed Martin's Advanced Technology Center (ATC) in Palo Alto, California. The EVE instrument and FSW are being developed by the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado. The Ground System software is being developed at GSFC.

For the spacecraft flight software, the IV&V Team performed verification of the implementation of the requirements/behavior in the spacecraft and instrument FSW code as well as analyses of the spacecraft FSW test at the build and system levels.

During 2009, the SDO IV&V Team supported the following SDO project milestone reviews, leading up to the anticipated launch of SDO in December 2009:

- Pre-Ship Reviews (PSRs) – January 2009, June 2009
- Safety and Mission Assurance Review (SMSR) – December 2009
- Mission Readiness Review (MRR) – December 2009

Space Shuttle (SSP)

Contractor: L-3 Communications
Project Lead: John Hinkle
Lead Engineer: Harry St. John

The Space Shuttle is the world's first reusable spacecraft and the first spacecraft in history that can carry large satellites and equipment to and from orbit. It provides U.S. and International Partner access to the International Space Station (ISS) for crew, cargo, and ISS components. The Shuttle is the only vehicle capable of bringing the final pieces of the ISS into space to achieve the goal of "assembly complete." (http://www.nasa.gov/mission_pages/shuttle/main/index.html)

By the end of 2009, NASA IV&V will have supported five Shuttle missions: four to the ISS and one final servicing mission to the Hubble Space Telescope.

Before each Shuttle mission, NASA IV&V performs an independent analysis of software discrepancy reports and change requests having flight safety or mission success implications for the main computer system, the backup computer system, and the crew displays; engine controllers; and the Global Positioning System (GPS).

NASA IV&V provided additional assurance that changes being made to the mission- and safety-critical software did not adversely affect flight safety or mission success.

NASA IV&V was called upon during the Shuttle's STS-127 mission after an Orbital Maneuvering System (OMS) gaseous nitrogen tank pressure leak was discovered. Gaseous nitrogen provides pressurization for the OMS fuel tanks. The leak was not mission-threatening; however, flight controllers determined that the leak would result in very annoying alarms during the latter part of the mission, including during sleep times for the crew.

Two software patches were created for the onboard computer systems to modify limits that set off the alarms: one patch for the primary flight software and the other for the backup flight software. NASA IV&V performed full lifecycle verification of the two patches, providing assurance to the Shuttle Avionics Software Control Board that the patches would function properly. The patch created for the primary Shuttle software was uploaded to the Shuttle, alleviating the situation before the pressure leak reached the limit at which alarms would have been triggered.

RECENT PROGRAM HIGHLIGHTS

RECENT PROGRAM HIGHLIGHTS

Portfolio Based Risk Assessment – Training and Implementation

Risk assessment has been used for years by the NASA IV&V Program to make decisions about where to focus IV&V analysis and how much effort to apply. The focus in 2008 was to find a way to ensure that the most critical software within NASA gets IV&V support. As a result, the Portfolio Based Risk Assessment (PBRA) was created.

Challenges related to this task included ensuring that the process met Program needs, ensuring a consistent understanding of the intent of the PBRA and how to use it, setting standards for consistent usage and expectations, getting buy-in on roles and responsibilities, and the Program need for an agile, flexible process versus individual preferences for a very detailed process that accounts for all possibilities. The PBRA focuses on assessing system capabilities instead of whole projects.

Upon the release of the first draft of the process, feedback was solicited and refinements were made accordingly. Refinements focused on the requirement for a fairly simple, straightforward process focused on criteria that would highlight differentiation between capabilities. In order to accomplish this, the process is intentionally general, providing a structure and guidance without hard rules and checklist; this allows for every project to provide unique rationale for scoring changes that might be limited by a more rigid process. Initial feedback made it clear that more structure/rules/guidance was desired by users. To address the feedback, the subsequent training focused on intent and usage, specifically how the current process provides more flexibility and how it can be used to a Project's advantage.

Part of the implementation of the PBRA was briefing the IBA on the process. During the initial discussion with the IBA, scoring rationale changes were made to rely on agency processes already in place (vs. defining new IV&V criteria/rational/processes). This strengthened the PBRA and was key in minimizing stakeholder challenges on the process and criteria; allowing them to focus on the intent and results. The PBRA was also lauded by the IBA members, because they felt it was a fairer way to provide IV&V coverage to critical software across the Agency.

Program Metrics

Since the inception of the NASA IV&V Program, the Program has struggled with the successful launch of a solid metrics program. The need to prove the value of any organization is essential to survival; this is also true for the NASA IV&V Program. During 2009, the top five benefits received by the Agency from the NASA IV&V Program were established, and methods for measuring these benefits were determined.

Although significant progress has been made to date, the metrics program remains in its infancy. Lessons learned are ample, but data necessary to measure some benefits has not been recorded, and the way data has been recorded has not been consistent across all project entities.

Despite the challenges, the implementation of the current metrics program has allowed the quantitative statements related to expressing the value of the NASA IV&V Program to begin. This first report is considered a benchmark for successive years. The NASA IV&V Program continues to refine its metrics program, which will enable the Program to measure its effectiveness and aid in determining opportunities for improvement.

Risk Management Approach

The NASA IV&V Program's Risk Management approach was generated through Facility Advisory Board recommendations in 2007 and implemented in 2008 to create a working process for reviewing and approving risks. The approach was to retire the past work instruction and create a system level procedure that established a consistent and documented method of performing risk management within the NASA IV&V Program.

An educational guide was established to incorporate learning aspects for functional organizations to anticipate, mitigate, and control risks that are internal to the Program and external to the projects. A consistent method for documenting risks for approval at risk board reviews is utilized and standardized to assure proper communication across NASA IV&V functional organizations. This communication extends to Senior Leadership through organizational reviews in the form of a top risk profile of the NASA IV&V Program.

An effective risk management process was created to impact Program/Project objectives in the focus of performance, safety, schedule, and cost. This effort will reduce the likelihood of problems and provide stakeholders with performance concerns that may hinder project success.

Transition to Product-Lines

Prior to January 2007, the NASA IV&V Program performed verification and validation activities primarily using a Subject Matter Expert (SME) method. The work was project-focused, meaning that a team of experts was assigned to a project to perform both verification and validation activities for that specific project. Beginning 1 October 2008 the Program transitioned from this project-focused approach to a product-focused approach. This transition required that contracts be modified and task orders be focused on product lines, and it required a complete reorganization of the entire NASA IV&V Program. The transition required that every member of the staff play a part.

Today, rather than having teams become experts solely on their projects, the teams are experts in their products – modeling, verification, or validation – and the project knowledge (domain knowledge) is shared across the product lines. This transition allows NASA IV&V teams to focus on the Program's core reason for doing business: making sure that developers are building the correct product, and building the product correctly, while using the domain knowledge efficiently across all projects.

Although the Program is still adjusting to the learning curve of this change in approach, we anticipate significant improvements in efficiency in the coming years.

The NASA IV&V Engineering Apprenticeship Program

The NASA IV&V Engineering Apprenticeship Program, or NEAP program, is a spinoff of the high school internship program known as the Science and Engineering Apprenticeship Program (SEAP) started by the Department of Defense around 25 years ago. The target for the NEAP program is students who are interested in careers related to science, technology, engineering, and math (STEM). This annual, 8 week summer program hosts 20 high school students who are paired with computer engineers, business managers, and IT professionals. Each student is assigned a project to be completed within the 8 weeks and is guided by their professional counterpart. The students gain valuable hands on experience working in a professional STEM career setting that will better prepare them for future programs of study and professional career choices. The program ends with a three day trip to Washington D.C. where students present their projects to staffers at NASA Headquarters. The students and their families also get to tour popular attractions of our Nation's Capitol. This program provides an experience that lays the foundation for them to pursue careers in STEM and approximately 80% of these students go on to fill jobs within this area of expertise.

Day in the Park

The NASA IV&V Program, in collaboration with the West Virginia High Technology Consortium Foundation, holds an annual event called Day in the Park. This unique educational event reaches approximately 900 seventh graders from schools throughout North Central West Virginia.

Students attend Day in the Park to be introduced to science, technology, engineering, and math (STEM) related careers. They are engaged in live shows, such as "Fractured Physics" and "The Great Color Caper Show" from the Carnegie Science Center, and a special guest, Astronaut Jon McBride, a West Virginia native, presents to the students "A Day in the Life of an Astronaut," allowing the students a glimpse into what it takes to become an astronaut and what it is like to make the journey to space.

The Day in the Park event is important because research shows that many students begin losing interest in science and mathematics at around the seventh grade. Therefore, the intent of the event is to provide students with opportunities to interact with STEM subjects in fun and practical ways, and it is the NASA IV&V Program's goal to inspire today's seventh graders to pursue careers in these fields.

Activity Based Costing

In 2009 the Resource Management Office (RMO) deployed ABC, a costing model that serves as an alternative to traditional accounting and that identifies activity centers in an organization. As a result of ABC use, NASA IV&V Program funding allocations can be maximized and performance can be improved. The effectiveness of budgeting by identifying the cost/performance relationship of different activity centers can also be improved.

Training

All NASA IV&V staff – civil servants as well as contractors – were invited to participate in a number of training sessions coordinated by the NASA IV&V Knowledge Management Office (KMO) in order to achieve a shared understanding of core IV&V concepts and practices across the Program.

First, KMO surveyed all employees, asking respondents to determine their level of understanding and comfort in using terms and concepts related to IV&V. From those responses, training topics and session objectives were determined. Throughout the summer of 2009, NASA IV&V staff were given the option to attend the following training sessions:

- Work Breakdown Structure (WBS) and the 3 Questions (Does the system do what it is supposed to do? Does it not do what it is not supposed to do? How will the system react under adverse conditions?)
- Program-wide definitions of Limitations and Capabilities
- Expectations of a Project Manager according to IV&V standards

- System Reference Modeling
- Software Architecture
- Software Validation
- Software Verification

Currently, NASA IV&V staff members are being asked to complete the knowledge survey again in order to gauge training effectiveness and provide insight into the next iteration of needed sessions.

Voluntary Protection Program Star Certification

The NASA IV&V Program achieved Voluntary Protection Program (VPP) Star certification from the Occupational Health and Safety Administration (OSHA) in June of 2008. The NASA IV&V Program received official recognition and presentation of a Star certification plaque in August 2008 in NASA IV&V's first Star certification ceremony.

VPP Star certification is the highest health and safety certification recognized by OSHA to honor the outstanding efforts of employers and employees who have achieved exemplary occupational safety and health. OSHA VPP Star-certified sites have low injury and illness rates, which equate to greater occupational efficiency and fewer worker compensation claims.

All VPP-certified sites have recognized that in order for their companies and all of American industry to compete in the global economy, they must accomplish the goal of achieving better cost savings, enhanced productivity, and high quality production. VPP-certified sites are considered superior in pursuing technical and managerial advances in worker safety and health protection. The NASA IV&V Program implements worker safety and health programs following VPP guidelines in order to ensure that it can meet these goals of quality.

Additionally, Star-level certification allows the NASA IV&V Program to mentor other sites – like the Goddard Space Flight Center – in their accomplishments toward safety goals and reduction in lost-time accidents. Star certification also allows the NASA IV&V Program to leverage Government resources with both OSHA and industry to achieve its safety and health goals.

Offsetting Facility Operating and Capital Improvement Costs

The IV&V Program continues to offset facility operating and capital improvement costs by leasing unused floor space to NOAA National Center for Environmental Prediction, NOAA Master Ground Station and the department of the ARMY Automated Biometrics Information System Program. Continued to achieve significant capital investment cost savings to NASA because the lease tenants continue to fund upgrades, enhances, or maintenance activities to the facility's infrastructure. This also augments G&A funding needs.

OBJECTIVES FOR CONTINUOUS IMPROVEMENT

OBJECTIVES FOR CONTINUOUS IMPROVEMENT

To achieve excellence, one of the NASA IV&V Program's values, it is understood that improvement is a must. An important step in this endeavor is to determine the IV&V Program's objectives, strategies to achieve the goals, and performance measures to know when the goals are achieved. During the last several years, the IV&V Program has focused on understanding our customers and stakeholders, developing metrics to measure our performance on many levels, and maximizing efficiencies through the use of our resources. Below are the objectives on which the IV&V Program has focused efforts, as well as a description of the progress accomplished:

OBJECTIVE 1: MEET CUSTOMER REQUIREMENTS

To ensure that the IV&V Program meets customer requirements, first the customers and their requirements were identified. Following requirements identification, the IV&V Program will develop measures to gauge growth in meeting and or exceeding the requirements.

OBJECTIVE 2: MEET STAKEHOLDER REQUIREMENTS

Stakeholders and their requirements were identified for all functional organizations of the IV&V Program. With the stakeholders' expectations understood, the IV&V Program will develop measures to track its progress towards meeting and or exceeding the expectations.

OBJECTIVE 3A: MEASURE GOODNESS OF IV&V PRODUCTS

"Goodness" with regard to IV&V products was defined. A team that includes representatives and advisors from a number of key areas was assembled to assure breadth and depth to the understanding of goodness. The team is currently working on a strategy for incorporating the many details of the goodness of IV&V products into one view that communicates a project's overall goodness in a meaningful way.

OBJECTIVE 3B: MEASURE GOODNESS OF IV&V SERVICES

The IV&V Program's assessment of the goodness of its services resulted in a group of measures related to quality and effectiveness. A team comprised of Services leaders developed metrics.

OBJECTIVE 4: MEASURE GOODNESS OF RESEARCH

The research performed by the Software Assurance Research Program (SARP) supports the improvement of software assurance methods, practices and tools. Centers identify areas of need for research; and upon proposal selection, work with SARP Researchers to develop/improve tools, methods, and applications that can ultimately serve all of NASA.

OBJECTIVE 5: MEASURE GOODNESS OF OUTREACH

The Outreach Program provides educational opportunities and NASA curriculum support products to educators and students with the goal of increasing awareness of science, mathematics, geography, engineering and technology areas of study. Measures of goodness related to the products of the IV&V Program's outreach have been developed and are refined continuously.

OBJECTIVE 6: OPTIMIZE GOVERNMENT STAFF FOR OUR PROJECTS

Optimizing government staff for projects requires that all staff understand clearly their roles in the IV&V work and possess the identified required skills and knowledge. This information is documented in the document, SLP 9-4, which has been recently updated with regard to the guidelines for project management, incorporated new WBS, CAR/PARs. Additionally, metrics have been determined to measure the goodness of technical management's performance.

OBJECTIVE 7/8: OPTIMIZE RESOURCES/IMPLEMENTATION OF PROJECTS

The Chief of IV&V Integration, supported by technical managers at the IV&V Program, is responsible for optimizing resources and implementing projects. The IV&V Program defined task plans in relation to projects' summaries of goals, tailored work based structure (WBS), handling procedures for risks, PERT, and cost estimates. This information is recorded in IPEP templates by each project's IV&V Program's point of contact. IPEPs are used as a guide that documents the planning and execution of projects.

OBJECTIVE 9: INCREASE STAFF TECHNICAL PROFICIENCY

In order to increase the staff's technical proficiency, the IV&V Program identified the required skills to both lead and work as a team member on projects; government only work; government staff assignments; and formal training requirements. Once these tasks were complete, training initiatives were developed to provide the knowledge and understanding of needed proficiencies. Training sessions on topics met the purpose of clarifying terms commonly used, processes executed, and theories that support the processes, as well as provided an opportunity for staff to achieve common understanding. Weekly "IV&V Workshops" are scheduled to assure that all government employees and contractors are aware of latest software development research, theories, and best practices.

In addition to the training initiative, collection of "lessons learned" was implemented. This repository collects lessons that staff learn from their daily tasks with the purpose of information sharing in the hopes of improving efficiencies.

FUTURE PLANS

WHAT ARE FUTURE PLANS FOR THE IV&V PROGRAM?

The IV&V Program enjoys continued success. A few key areas of interest have shown significant improvement in recent years. The numbers of high severity defects detected early in the development lifecycle have increased. Performance related to phase containment is advancing, especially with regard to requirements defects. Relations with customers and stakeholders are both timely and effective. Opportunities provided to projects to reduce rework and total project costs are abundant, and with each defect detected resolved by the project, the IV&V Program reduces defects in delivered products. The IV&V Program eagerly anticipates continued improvement in the performance measures included in this report. With these improvements, the projects served by the IV&V Program will continue to experience greater benefits.

Future plans for improvement encompass all areas of performance within the IV&V Program. Continued development of the metrics program will foster additional analysis of the processes used to perform IV&V. By enhancing the data collection, the IV&V Program will be better prepared to inform its customers and stakeholders about project capabilities, severity of defects found and any patterns in software defects. This effort may grow to include trends across mission directorates and agency in years to come. By enhancing the metrics program, incorporating success stories and lessons learned, and identifying areas where additional training is needed within the IV&V Program, the overall quality of service and value brought by the program will increase.

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