National Aeronautics and Space Administration

Independent Verification and Validation Facility
100 University Drive, Fairmont WV 26554

NASA IV&V Program

2007 Annual Report

<u>Management Challenge:</u>

If you cannot measure, then you cannot manage.
If you cannot manage, then you cannot improve.
If you cannot improve, then you cannot change.
If you cannot change, then you cannot remain relevant.
If you cannot remain relevant, then you cannot be useful.
If you cannot be useful, then you cannot retain your customer base.
If you cannot retain your customer base, then you cannot obtain resources.
If you cannot obtain resources, then you cannot exist as an organization.

Front Cover Image: The image on the front cover shows NGC 2207, a galaxy positioned at the western region of Canis Major as captured by the Hubble Space Telescope (HST). *(NASA and The Hubble Heritage Team (STScl) - Hubble Space Telescope Wide Field Planetary Camera 2.)*

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EXECUTIVE SUMMARY

The NASA Independent Verification and Validation (IV&V) Program strives to improve the safety, reliability, and quality of software developed for NASA's most critical projects through the effective application of software IV&V methods, practices, and techniques. The IV&V Program is responsible for delivering the highest quality, state-of-the-art IV&V services to its customers. The application of IV&V is a proven systems engineering technique for increasing the rate of defect prevention/removal within a development project.[1] The application of IV&V is most beneficial on projects where the desired rates of defect prevention/removal are 95% or greater.[2] For each IV&V project, our goal is to objectively answer the following three questions:

Does the software exhibit behaviors as intended?

Does the software not exhibit behaviors that were not intended?

Does the software behave as expected under adverse conditions?

In 2007, the Agency directed the IV&V Program to conduct IV&V on 22 of the most critical Agency missions under development. The overarching goal is to independently ensure that the most critical software capabilities are fit for their intended use and defect free. During this reporting period, IV&V executed ~270,000 person hours supporting these projects.

In 2007, IV&V provided analysis for 6 human-rated missions, 15 major earth and space science missions[3], and one Agency supported financial system. The Agency's 2007 development portfolio value on these missions exceeded $10,000,000,000 and the overall Life Cycle Cost portfolio exceeded $50,000,000,000[4], representing a significant investment for the Agency and the American public. As NASA's independent agent for software verification and validation, the IV&V Program targets each development activity's most critical and highest risk elements for analysis.

The IV&V Program's focus is driven, not only by the criticality, but also by the available resources. A combination of software criticality and resource constraints are used to determine the final scope of IV&V on any given project. Ultimately, it is the IV&V Program's goal to provide the highest confidence in software fit and function for the most critical portions of the systems being developed. IV&V's mission is to provide the Agency with an independent assessment of the software development effort and to make an associated statement at each major project milestone review and at the Safety and Mission Success Review.

The data in this report represents the work accomplished by the IV&V Program in 2007. Based upon the IV&V Program metrics and the observations of the IV&V Project Mangers, this report provides information that should be of critical interest to NASA's Software Engineering and Assurance communities.

KEY FINDINGS

The IV&V Program documented 10,677 software artifact defects on 22 NASA projects in 2007 and of those, 6,788 were high severity (IV&V Severity 1 – 3 issues[5]). The IV&V Program analyzed the defects

[1] Software Productivity Research, Software Quality in 2002: A Survey of the State of the Art, Capers Jones, (Survey based on client data from 1984 through 2002 with 600 companies, 30 government / military groups and 12,000 total projects).

[2] Ibid.

[3] Note that throughout this report the missions are organized by type of mission and not by the NASA Directorate responsible for the mission.

[4] Total NASA effort in FY07 (Hardware; Software; and, Integration) per NASA FY08 Budget Request (http://www.nasa.gov/about/budget/FY_2007/index.html)

[5] For the purposes of this report, the IV&V Program categorizes severity 1 – 3 issues as mission impact issues. Issues of this type result in an impact to the mission's ability to perform its mission. This definition

sorting them by severity and type of defect. This analysis characterizes defect type and trends across the current set of IV&V projects.

It is important to note that the International Space Station dominated the 2007 IV&V issue data set (64,000 hours of support and 5,766 Issues), therefore for the purpose of this report, we separate ISS from the larger data set to illustrate trends across the Agency. Of the remaining 207,000 hours performed by IV&V, 48% was allocated to the Requirements Phase; finding 73% of the 2007 high severity issues (Severity 1 – 3). The remaining phases (Design, Code, and Test) accounted for 12%, 30%, and 10% (respectively) of the overall IV&V support effort. The distribution for the remainder of the 2007 high severity issues were: Design - 9%; Code - 13%; and, Test - 5%. Obviously, the distribution of issues found by IV&V will naturally shift with development lifecycles and the combination of those lifecycles for the missions during any given year. Our analysis further shows that NASA's results are similar to the overall software industry where errors are introduced in every phase of the development lifecycle. Finally, the fact that 1484 of 2044 (73%) high severity issues were requirements-related, further demonstrates the importance of IV&V's contribution to the individual missions and Agency from both the early detection and risk-reduction perspectives.

FUTURE DIRECTION OF IV&V METRICS

Along with IV&Vs commitment to the safety and success of the missions, the IV&V Program is also dedicated to continuously enhancing the practice of IV&V by developing a relevant metrics program that is a part of day-to-day operations. The IV&V Program captures its findings in a database called the Project and Issue Tracking System (PITS), from which the projects' metrics information are drawn. However, in the past there has been limited consistency in how each of the projects collected issue data. The IV&V Program began efforts to improve the consistency of the PITS database three years ago, focusing on the standardization of the issue state machine and the definition of the IV&V severity levels. This increased consistency in data collection has allowed for a more accurate analysis of the issues from a programmatic standpoint by providing a consistent foundation upon which the issues can be compared.

The IV&V Program operates under the premise that "*the absence of bad does not equal good.*" The fact that there are no findings does not, by itself, assure mission success. It is IV&V's belief that it is important to characterize/measure the quality of the development artifacts within the context of work performed. With this in mind, a Product-Oriented Metrics initiative was started in 2007 to define, develop, and implement additional metrics to characterize "*goodness*" of software development artifacts. This effort will help refine the current IV&V measurement process with regard to product quality (desired and produced) on mission-related software elements and Agency software risk. In addition, IV&V has revised and refined the PITS issue type categories to enable more detailed and relevant trend analyses in the future. This effort will further enhance the consistency of the issue data being collected. It will also focus on root cause and software engineering enhancement opportunities through the use of specific IV&V measures and metrics from a Goal, Question, and Metric (GQM) perspective[6].

The IV&V Program will continue to work with development projects, the Office of the Chief Engineer (OCE), and the Office of Safety and Mission Assurance (OSMA) to gain access to development data to enhance the usefulness of the IV&V effectiveness metrics. Therefore, 2008 will be the formal starting point for the majority of these enhanced measurements to show how software engineering and IV&V effectiveness is improving within NASA. These new measurements should also provide, from the IV&V

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reinforces the IV&V severity definitions, where a severity 3 issue prevents the accomplishment of a mission goal. The IV&V Program definition of severity can be found in Section .

[6] V. Basili, G. Caldiera, and H.D. Rombach, The Goal Question Metric Approach, Encyclopedia of Software Engineering, pp. 528-532, John Wiley & Sons, Inc., 1994

perspective, even greater insight into the state of software engineering across NASA for both OCE and OSMA.

SECTION I: METRICS OVERVIEW

INTRODUCTION

The ultimate goal of the IV&V Program is to increase overall mission success and reduce Agency risk by identifying critical software defects (those with the potential for catastrophic or severe impact) as early in the software development lifecycle as possible. A primary focus of this effort is on phase containment, which seeks to detect and report defects in the phase in which they were introduced in order to prevent them from leaking into later development phases and increasing the cost to repair. According to Boehm, a defect generated in the Requirements Phase could cost as much as 100 times what it would if not discovered, fixed, and prevented from leaking into the Operations Phase. [7]

In addition to trying to detect defects in the phase introduced, the IV&V Program strives to ensure adequate IV&V coverage[8] of those missions assigned by the IV&V Board of Directors (IBD), while efficiently managing available resources. The IV&V Program scopes assigned projects according to software-element risk (likelihood and consequence of specific failures). The IV&V Program works diligently to understand its effectiveness and impact on development projects by measuring (metrics collection) and assessing (analysis and reporting) the findings and performance of the IV&V Program on a continuing basis.

The IV&V Program has the unique opportunity of having complete insight into a broad range of NASA projects that are responsible for the development of mission critical software. A key aspect of this opportunity is the ability to perform detailed technical analyses of the artifacts being developed by NASA's most important projects and the ability to provide the results directly to project management and development teams. This insight allows the creation of a collective set of software related data that the IV&V Program is able to generate, concerning the state of NASA software engineering as a whole. Consistently correlating information from a diverse set of projects into useful/relevant data and capturing the overall state of the Agency's software engineering practices can present significant challenges. This report is the most recent effort to manage those challenges and present an unbiased perspective to our stakeholders.

The following section presents an overview of the 2007 findings, examines associated trends, and sets the stage for the IV&V Program's future metrics collection and analysis plans. The introduction of enhanced data collection is also included in this section. For example, IV&V has revised and refined issue type categories for more relevant trend analysis. Further analysis will focus on root cause and software engineering enhancement opportunities through the use of specific IV&V measures and metrics from a Goal, Question, and Metric (GQM) perspective[9]. Therefore, 2008 will be the formal starting point for the majority of these enhanced measurements designed to show how software engineering and IV&V effectiveness is improving within NASA.

IV&V METRICS ANALYSIS

In 2007 the IV&V Program worked with fifteen robotics, one Agency-support, and six human-rated missions. Four of these missions were not included in the 2007 issue data set -- HST SM4, GOES R, Juno, and IEMP (Agency-support financial system). Juno started in the third quarter of 2007 with no formal

[7] B. Boehm. Software Engineering Economics, pp. 39-41, Prentice Hall, 1981
[8] IV&V coverage is defined as providing IV&V analysis based upon a prioritized list of software behaviors taking into account any resource constraints imposed by NASA. This may result in a minimal application of IV&V to some of the missions identified by the IBD.
[9] V. Basili, G. Caldiera, and H.D. Rombach, The Goal Question Metric Approach, Encyclopedia of Software Engineering, pp. 528-532, John Wiley & Sons, Inc., 1994

findings during this reporting period and the other three were Independent Assessments. The remaining twelve robotic missions and six human-rated missions were analyzed and the associated data is included in this report.

The IV&V Program focuses on the highest criticality and safety-related software for a given mission providing an additional layer of assurance. The criticality/safety-related determination is made through the application of a risk assessment process that prioritizes the required behaviors for a given development project. This prioritization drives not only the software analyzed by the IV&V analysis teams but also the type of analysis performed.

Any defects found as a result of the analysis are documented as IV&V issues (also known as TIMs – Technical Issue Memoranda) and then categorized according to severity. The severity is a measure of the potential impact the issue, if realized, will have upon the mission in terms of mission success. For the purposes of the IV&V metrics discussion in this report, mission impact issues are those that fall into the Severity 1 through Severity 3 categories. These severity levels indicate product-oriented issues and identify significant mission/system limitations (See Appendix C for Severity Definitions).

Two-thirds of all IV&V issues fall into the mission impact classifications (Severity 1-3) with the remainder having essentially minimal or no-mission impact (Severity 4 and 5). The IV&V metrics effort and this Section focus on mission impact issues. In 2008, the IV&V Program plans to establish an effort to study Severity 4 and 5 issues from a root cause and IV&V Program efficiency perspective as time and resources permit. The IV&V Program intends to follow this study with a root cause analysis for the OCE and OSMA.

Overall Issue Distribution (Agency-Wide)

In 2007, the IV&V Program generated 10,677 total IV&V issues. The Severity 1 – 3 grouping accounted for 6,788 issues (64%).

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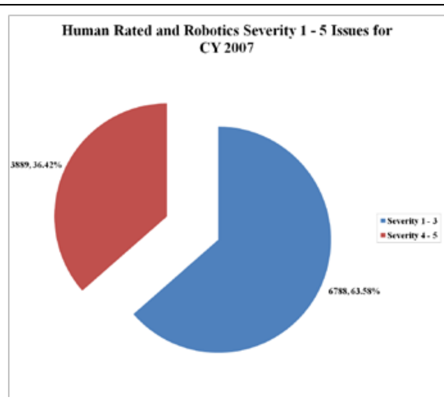
<tr>
<td>

Figure 1 – Human Rated/Robotics Severity 1 – 5 Issues</td>
<td>Robotic Missions

AIM Kepler
Dawn LRO
GLAST MSL
Glory OCO
IBEX Phoenix
JWST SDO</td>
<td>Human Rated Missions

Constellation:
• ARES
• ORION
• Integration
International Space Station
Space Shuttle
PC Goal II</td>
</tr>
</table>

Table 1 - Overall Issue Distribution

The next series of charts decompose the overall distribution into four additional perspectives: Robotics; Shuttle-ISS-PC Goal (Human-rated); ISS (Human-rated); and, Constellation (Human-rated). The ISS project was included separately as it was the single highest contributor and skewed the programmatic outcome; accounting for more than 50% of the overall issue count. Within this context, it was important to examine how the distribution of issues on the ISS project impacts the overall distribution.

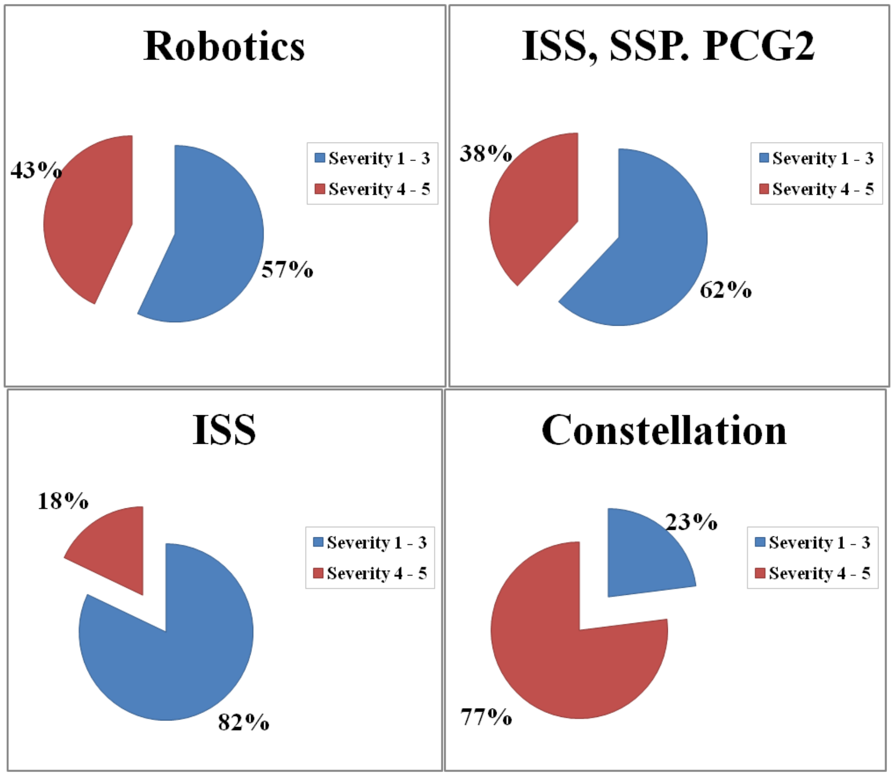


Figure 2 - MissionType Distribution

As Figure 2 illustrates, the ISS project has the largest percentage of mission impact issues among the four views. The ISS distribution is nearly the exact opposite of the Constellation data. The IV&V Program attributes this difference to the maturity of the two projects. Maturity in this case is based upon the length of project development time and state of software artifact development. The ISS project has been developing software for over ten years. The project continues to update existing software behaviors as problems are discovered. The project also produces new software to support the addition of new ISS hardware. Constellation projects are early in their development life cycle and just beginning to create software artifacts.

A new project often spends a significant portion of the initial development effort defining the context of the system – the capabilities of the system and the boundaries in which the system must function. This often results in a limited understanding of what is required for the system. This limited understanding is reflected in the larger number of lower severity issues. A more mature project, typically already has its capabilities and boundaries well defined. Issues found with software artifacts are easier to categorize in regards to their severity and leads to the discovery of higher severity mission impact issues.

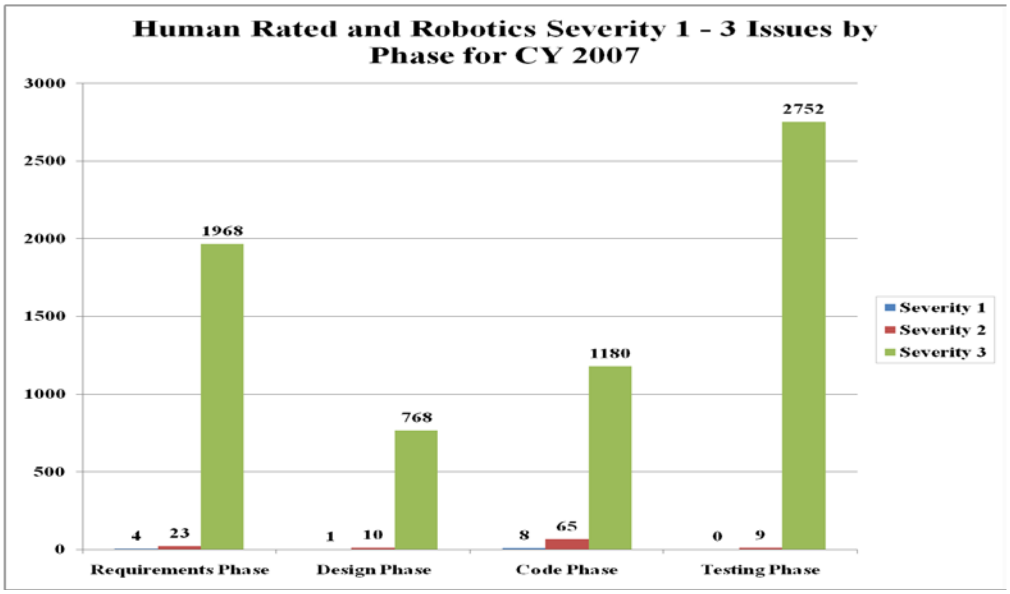
Mission Impact Issue Distribution

While the metrics data is collected on a per project basis, the information presented in this report is a summary of those metrics. The IV&V Program generally treats specific project metric information with confidentiality.

Overall, the distribution of defects identified is usually fairly consistent from project to project. Generally, the high severity issues are distributed such that the majority are Severity 3, followed by Severity 2, and the smallest portion categorized as Severity 1.

IV&V Identified Defects Distributed by Phase (Agency-Wide)

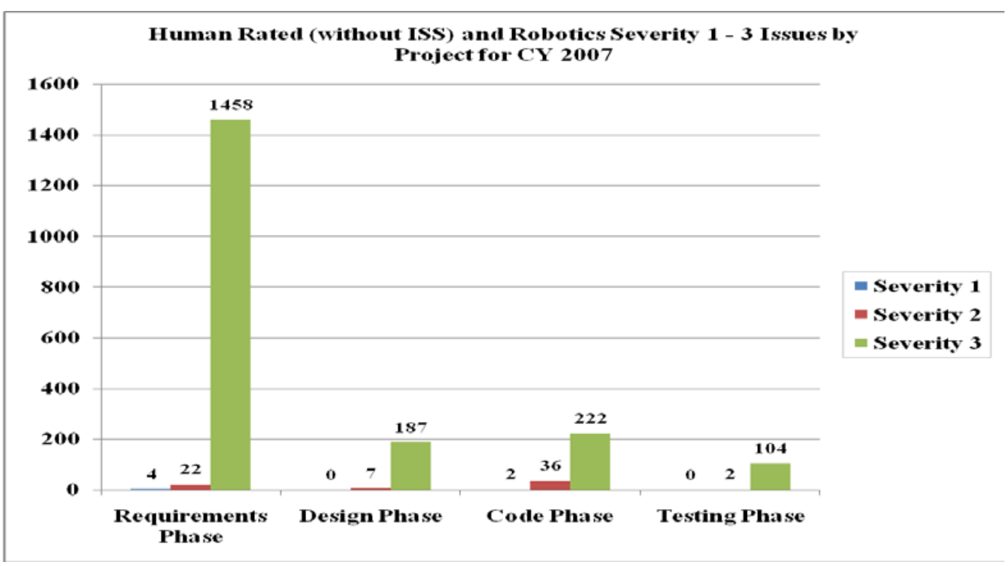
In 2007, the IV&V Program expected that the majority of defects found, would occur as a result of requirements issues. This expectation was based upon the conscience decision to focus most of the Program's resources on requirements artifact analysis. However, the initial defect distribution table indicated that rather than a majority of defects being found in requirements artifacts, the majority were actually identified in the testing artifacts warranting further assessment and understanding of the outcome.



Based on further analysis, ISS accounted for 4700+ of the High Severity Issues (5700+ of the overall issues) thus dominating the outcomes and trends when included

Figure 3 - Issue Distribution By Phase

Examination of this data showed that one project in particular, the International Space Station (ISS), contributed 2655 testing defects or about 96% of the overall testing defects identified. ISS accounted for 57% of the overall issues (and 70% of the high severity issues). To better visualize the impact of this number, Figure 4, was created with the ISS data removed since ISS was dominating the overall IV&V Programmatic results.



48% of the IV&V Effort was allocated to the Requirements Phase finding 73% of the 2007 high severity issues (Severity 1 – 3).

Figure 4 - Issue Distribution by Phase without ISS

The ISS data is shown in Figure 5, but will be removed from the remaining charts to allow IV&V and the reader to focus on more accurate Agency trends. Based on our analysis, the International Space Station IV&V executed 64,000 hours of IV&V support in 2007. 64% of the ISS IV&V effort was executed in the test phase and is consistent with the distribution of issues by phase and type.

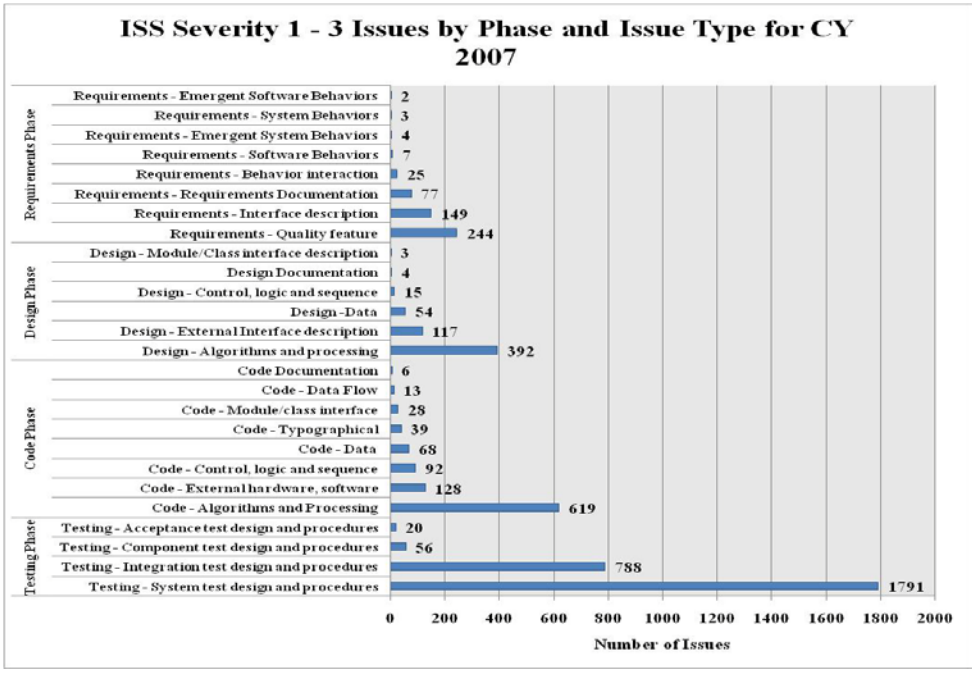


Figure 5 – ISS Issue Distribution by Type

- *Consistent with the mission development phase activity (Operations and System Enhancements) and IV&V Effort expended by Phase*
- *Demonstrates a significant number of defects are still being introduced; 82% of Overall Issues were High Severity*
- *Important question -- How does the Agency train (and eliminate) defect introduction out the development teams and activities?*

Mission Impact Issue Distribution by Phase (Robotics and Human-Rated without ISS)

It is important to note that Figures 3 and 4 only captured the issues found in 2007. In order to better understand the source of the issues, the data was decomposed and is presented by project type for Robotics and Human-rated systems. These charts show the distribution of IV&V issues across the different development artifacts. The Robotics issues (Figure 6) were focused mostly on design and code analysis, while the human-rated systems (Figure 7) focused on requirements analysis (Constellation). It is important to note that, in 2007, the majority (70%) of the robotics-related, IV&V work was focused on design and code analysis based on where the projects were in their development lifecycle.

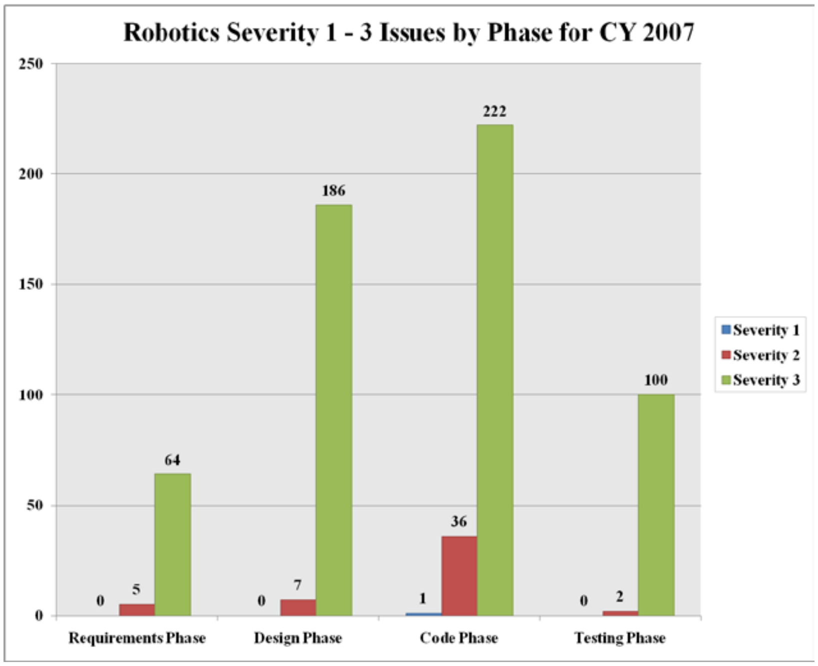


Figure 6 - Robotic Issue Distribution

- *IV&V Issues found on Robotics Projects in 2007 parallels IV&V Effort expended by Phase (13% - Requirements, 30% - Design, 40% - Code, 16% - Test)*
- *Key areas for Agency Engineering and V&V Improvements are in the Design and Code Phases with respect to Software Development Fundamentals and Discipline (e.g. coding standards, using automated V&V tools, etc.)*

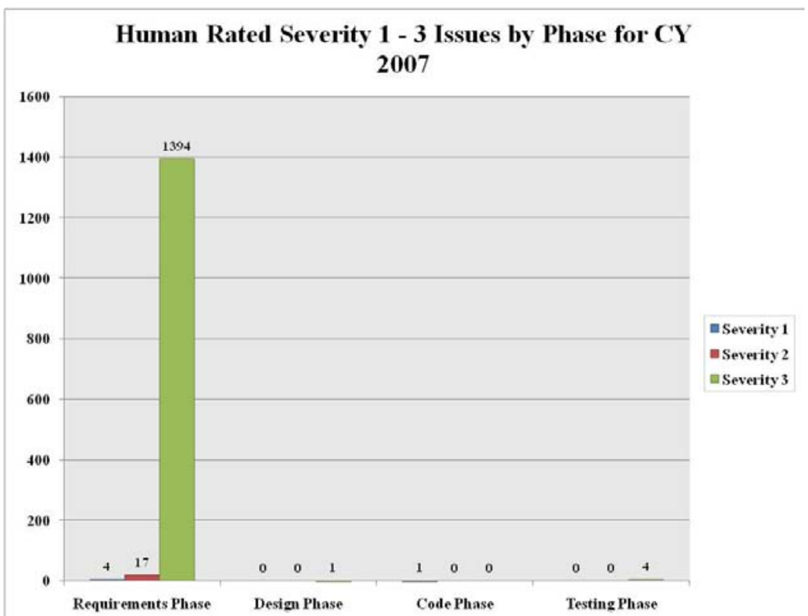
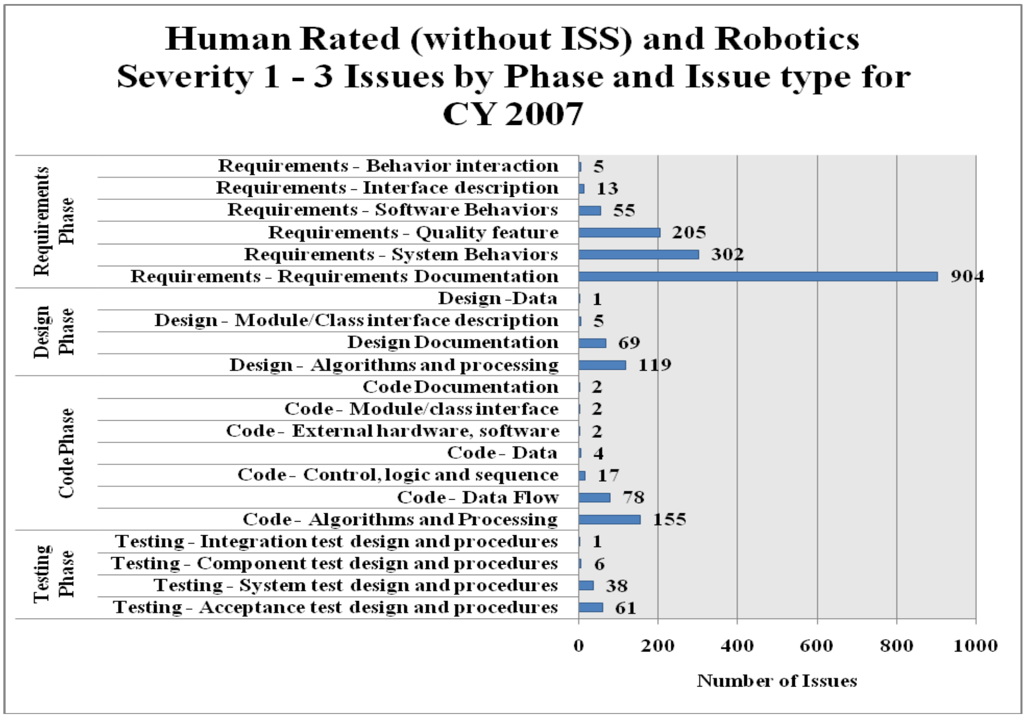


Figure 7 - Human-Rated Issue Distribution (without ISS)

Demonstrates the need for additional Agency emphasis on the Requirements fundamentals and general practices.

Mission Impact Issue Distribution by Type/Frequency (Agency-Wide)[10]

While the previous charts show overall distribution, Figure 8 shows the types of issues being found by the IV&V Program based upon the IV&V issue categories. In addition to severities by project, the IV&V Program also examines the distribution of severities by issue type. The issue categories are broken down into four phases: Requirements, Design, Implementation and Test. This chart shows where the IV&V Program has the greatest impact in terms of the number of issues found for a given issue type.



The focus in on System Behaviors that drive Software Behaviors.

Figure 7 – Issue Distribution by Type

The largest number of issues found in analyzing requirements artifacts is associated with defects in requirements documentation. This category captures issues that occur when the documentation of the requirements is incomplete or ambiguous. Examples of errors are such things as incorrect references to other documents or information that is not applicable to the current project. These errors are generally not errors in the requirements themselves, but errors in the information that surrounds the requirements, such as rationale.

The majority of design artifact issues deal with defects in algorithms and processing. This category captures issues that occur when the description of an algorithm defined in a design artifact is incorrect or if the algorithm chosen is not the correct algorithm for the design. These types of defects arise from the lack of error checks for incorrect and/or invalid inputs, lack of a path for users to correct erroneous inputs, or, lack of a path to recover from erroneous inputs. As such, this category also contains other data processing defects, such as error condition checks, for example; divide by zero.

[10] The IV&V Program uses a set of issue categories derived from the IEEE 1044 Standard for Classification of Software Anomalies and the Orthogonal Classification concept. The categories are associated with specific artifact types so that defects in requirements artifacts are captured in the requirements phase section, defects in test artifacts are captured in the test phase, etc.

The code artifact issues deal, in largest measure, with defects in algorithms and processing. This category is similar to the design category but adds a level of detail to the information being analyzed. The defects would include not only those documented above with the design issues, but would now include unchecked overflow and underflow conditions, the comparison of inappropriate data types, converting one data type to another, incorrect ordering of arithmetic operators, misuse or omissions of parentheses, precision loss, and incorrect use of signs.

The greatest number of test defects found occurred in acceptance test design and procedures. This category is not as detailed as the other categories, as it does not denote specific types of issues, but rather issues associated with a particular type of testing--in this case, system-level testing. Generally the issues found are related to incorrect, incomplete, missing, or inappropriate test cases and procedures. Issues are most often found during test plan reviews or sometimes during the testing process itself, through an analysis of test conditions and test results.

Effectiveness Metrics

Effectiveness metrics could provide insight into how effective both the developers and IV&V are in finding and fixing defects in the phase introduced. An IV&V program is most effective in helping development projects succeed when it can report issues found to the development projects concurrent with the artifact being developed. Additionally, if the issue can be resolved in the phase in which it was introduced, then the overall impact (including rework and associated cost) to the project is minimized. The IV&V Program had been capturing IV&V Phase Containment Effectiveness (PCE) metrics for about three years on five prototype projects. Unfortunately, it has been found to be extremely difficult to attain detailed software defect metrics from NASA Development Teams. Therefore, we are not able to analyze or present PCE-based metrics or make relative assessments of IV&V effectiveness.

SUMMARY

The findings and observations in this report show that the IV&V Program provides a positive impact to the missions that the Program supports. This positive impact is seen in both the robotic and the human-rated systems through the early identification of defects to the development projects as shown in the effectiveness metrics. However, the application of IV&V alone does not ensure mission success. Software quality cannot be tested into a system, but must be built into a system. The IV&V Program documented several challenges to NASA software development, including concerns with software development effort and reuse estimation. The IV&V Program recommends further examination of these challenges to further increase the quality of the software being developed by and for NASA.

In the future, the IV&V Program will continue to update its metrics program to further enhance the consistency of the data being collected as well as integrating the tasking of the new Work Breakdown Structure into the metrics process. This will include modifications to the effectiveness metrics tools and processes[11].

Additionally, the effectiveness metrics program will continue to grow as more project information (including Constellation projects) is added to the database. Finally, the IV&V Program will continue to work with development projects, the Office of the Chief Engineer and the OSMA to gain access to development data to enhance the usefulness of the IV&V effectiveness metrics.

[11] The latest version of the IV&V WBS is on the internet at http://www.nasa.gov/centers/ivv/pdf/170825main_IVV_09-1.pdf

SECTION III: PROJECT HIGHLIGHTS

Under the leadership and direction of the Agency, the IV&V Program dedicated over 270,000 person hours of effort towards the IV&V of NASA's most critical development projects. While each NASA project supports the overall Agency mission, each one has unique characteristics that drive the IV&V approach executed. Additionally, each project occupied its own unique position within the software development life cycles with some projects focusing almost solely on requirements engineering while other projects developed artifacts across the entire development life cycle.

The following section provides a high-level overview of the mission of each project and the IV&V work performed for the projects listed below. The results of the IV&V Program's annual customer survey are also included. The customer survey results continue to show that the development projects respect and value the services provided by the IV&V Program.

IV&V PROJECTS

Robotic Missions

- Agronomy of Ice in the Mesosphere (AIM)
- Dawn
- Gamma Ray Large Area Space Telescope (GLAST)
- Glory
- Interstellar Boundary Explorer (IBEX)
- James Webb Space Telescope (JWST)
- Juno
- Kepler
- Lunar Reconnaissance Orbiter (LRO)
- Mars Science Laboratory (MSL)
- Mars Scout Phoenix Lander (Phoenix)
- Orbiting Carbon Observatory (OCO)
- Solar Dynamics Observatory (SDO)

Human -rated Systems

- Constellation
  - Ares I and Constellation Ground System
  - Constellation Program System Integration (CxSI)
  - Orion Crew Exploration Vehicle (CEV)
- International Space Station (ISS)
- Personal Computer Ground Operations Aerospace Language 2 (PCG2)
- Space Shuttle (SSP)

Robotic Missions

Agronomy of Ice in the Mesosphere (AIM)

AIM's mission is to study why noctilucent clouds form and why they vary. The AIM mission will provide unprecedented advances in the understanding of Polar Mesospheric Clouds (PMCs), also called noctilucent or "night shining" clouds. http://www.nasa.gov/mission_pages/aim/

The IV&V Team has performed IV&V on the AIM spacecraft and three on-board instruments, including the Solar Occultation for Ice Experiment (SOFIE), Cloud Imaging and Particle Size (CIPS), and Cosmic Dust Experiment (CDE). IV&V contributed to the mission through meticulous analysis of each of the components. Additionally, IV&V participated in peer reviews and technical review boards for the mission software. The AIM project addressed technical issues associated with software requirements and flight software that IV&V identified and documented as part of its analysis efforts.

Dawn

Dawn's goal is to characterize the conditions and processes of the Solar System's earliest epoch by investigating in

detail very different asteroids, Ceres, and Vesta, which reside in the asteroid belt between Mars and Jupiter.
http://dawn.jpl.nasa.gov/

The IV&V Team continued to inspect the Dawn mission-critical software to ensure that the software will perform as intended. This year the team performed code and test case analysis activities to ensure that the Dawn mission will be successful. The key areas of analysis were focused on the Ion Propulsion System, On Board Computer software, and the Fault Protection software. Additionally, the IV&V Team supported a number of major milestone reviews leading up to the Dawn launch on September 27, 2007. Throughout IV&V's involvement, the Dawn project has been very supportive of IV&V activities and has agreed with the majority of findings.

Gamma Ray Large Area Space Telescope (GLAST)
GLAST will open the high-energy world of black holes to exploration. Astronomers will 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/

The IV&V Team is performing IV&V for the Spacecraft Flight Software that includes analysis activities for the Command and Data Handling (CDH), Guidance Navigation and Control (GNC) and the Large Area Telescope (LAT). Activities in 2007 included code and test analysis of all the flight software in these three areas. IV&V identified numerous discrepancies in the software through the means of manual inspection and through automatic code analyzers. The IV&V Team found significant value in the results of the code analyzers. The GLAST project was positively impressed with the value to the project resulting from this effort. Similar important contributions were made by the IV&V Team through its analysis of testing artifacts, test plans, procedures, scripts, and results. The IV&V Team ensured that GLAST requirements were adequately and completely tested, and assisted the project in correcting/adding tests to that end. The GLAST project office and development teams have accepted IV&V's findings and have made the necessary corrections as appropriate.

Glory
Glory is a remote-sensing Earth-orbiting observatory designed to achieve two separate mission objectives: 1) to collect data on the chemical, microphysical, and optical properties and on the spatial and temporal distributions of aerosols; and 2) 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 mission-critical software and has reviewed the requirements, design, and code artifacts to ensure that the Attitude Determination and Control System (ADACS) and the CDH code will properly initiate solar array deployment, perform attitude maneuvers, and will 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, and CDH subsystems will work as intended. The Aerosol Polarimetry Sensor, Total Irradiance Monitor, and Payload Interface Processor software elements are in the final stages of development.

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

The IV&V Team assigned to IBEX is inspecting the mission-critical software to ensure that the software will perform as intended. The team is reviewing the requirements, design, code, and test artifacts to ensure that the launch and deployment code will enable the IBEX spacecraft to reach its intended orbit, the attitude control software will be able to spin the spacecraft at required rates and orient the spacecraft so that the instruments capture particles away from the sun, the battery charge regulating software will keep the spacecraft battery properly powered, and commands from the ground will be properly sent to the spacecraft and be received, validated, and executed. Using state-of-the-art code analysis tools and unified modeling techniques, the IBEX IV&V Team found several code defects early in the implementation phase and passed the findings to the development project so that cost-saving software updates could be made prior to testing.

James Webb Space Telescope (JWST)

The James Webb Space Telescope (JWST) will be the premier observatory of the next decade, serving thousands of astronomers worldwide. A large, infrared-optimized space telescope, scheduled for launch in 2013, JWST will find the first galaxies that formed in the early Universe, connecting the Big Bang to our own Milky Way Galaxy.
http://www.jwst.nasa.gov/

The IV&V Team is analyzing flight software as well as some aspects of the ground software. During the course of 2007, the IV&V Team performed various validation and verification activities. Specific validation related analyses included requirements validation. 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. To date, the team's requirements validation efforts have uncovered some instances where behaviors associated with mission critical events were missing from the requirements documentation. These items are currently under review by the development Project to determine an appropriate corrective action. Specific verification related analyses conducted include requirements evaluation; design and code analysis; test plan; test case and test results analysis; and, traceability analysis. These analysis activities resulted in the early identification of and removal of defects.

Juno

Juno is an extraordinary 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.
http://juno.wisc.edu/

The Juno IV&V Team initiated its efforts on the Juno project in the summer of 2007. The team started providing full life-cycle support to the Juno mission, beginning with validation of the Juno mission requirements and proceeding through the software development, including design, implementation, test, and finally deployment. The IV&V Team is taking a model-based approach to requirements and test validation by leveraging the strengths of the Unified Modeling Language (UML), as well as applying some of the traditional approaches in the IV&V toolbox.

Kepler

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.
http://www.kepler.arc.nasa.gov/

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. The scope of IV&V is the Flight Segment Bus and the Photometer instrument. The results of IV&V work will verify system level behavior by testing artifacts and by validating the software system behavior within the observatory system as a whole.

Lunar Reconnaissance Orbiter (LRO)

LRO is the first robotic mission of the Robotic Lunar Exploration Program (RLEP). The primary objective of the LRO mission is to conduct investigations that support future human exploration of the Moon.
http://lro.gsfc.nasa.gov/

The IV&V Team assigned to LRO is inspecting the mission-critical software to ensure that the software will perform as intended. The team is reviewing the requirements, design, code, and test by using state-of-the-art code analysis tools, manual artifact analysis, and Unified Markup Language (UML) models of the LRO system. All software that supports the LRO mission could potentially be evaluated by IV&V, including but not limited to, flight software, ground software, mission systems software, and instrument software. In order to optimize the allocation of IV&V resources, a risk assessment is performed on the mission's systems and mission critical threads are identified from a system reference model. These results identify which areas of the system IV&V plans to analyze and evaluate. Currently, and projected through the scheduled October 2008 launch, the scope includes the LRO flight software (FSW) system for the Spacecraft, the DLRE, LAMP, LOLA, and LROC instruments, and the Ground System.

Mars Science Laboratory (MSL)

Mars Science Laboratory (MSL) will continue the exploration of Mars that has so successfully been performed by the two Mars Exploration Rovers Spirit and Opportunity. The Rover, approximately the size of a small automobile, will utilize an extensive payload of instruments, (numbering 10), to provide detailed analysis of soil and rock samples in support of MSL's main mission goals.
http://mars.jpl.nasa.gov/msl/

All major software subsystems of the project will be analyzed, including Rover Compute Element Flight Software, Instrumentation and Ground Data Systems. The IV&V Team is already providing feedback to the project on issues that have been identified by the analysis now being performed, as well as on issues raised during appropriate project reviews and walkthroughs. The team has also provided feedback to the project on potential software risk and associated impact.

Mars Scout Phoenix Lander (Phoenix)

The Phoenix mission is the first chosen for NASA's Scout program, an initiative for smaller, lower-cost, competed spacecraft. Phoenix mission-critical software controls all phases of the mission, including maneuvers during cruise, descent and landing on Mars, digging up samples, chemical analyses, and relay of data back to Earth.
http://www.nasa.gov/mission_pages/phoenix/main/index.html

The IV&V Team performed IV&V for the Flight Software that includes analysis activities for the Spacecraft and Payload subsystems. The team has supported all major milestone reviews since the PDR in March 2005, and completed analysis of the requirements (software and interface), design, code, and test artifacts. Although the IV&V Team found no issues that could prevent accomplishment of any essential capability, they discovered several issues which could have adversely affected the accomplishment of essential capabilities. Corrections have been implemented for all of these issues.

Orbiting Carbon Observatory (OCO)

The OCO mission will collect precise global measurements of carbon dioxide in the Earth's atmosphere. Scientists will analyze OCO data to improve understanding of the natural processes and human activities that regulate the abundance and distribution of this important greenhouse gas.
http://oco.jpl.nasa.gov/

The IV&V Team began performing analysis on selected elements of the Orbiting Carbon Observatory (OCO) spacecraft flight software in 2006. IV&V supported the Spacecraft Critical Design Review held in February 2007, the Mission Critical Design Review in August, 2007, and four ACS reviews held at the developer's site. IV&V performed a criticality assessment and system requirements review. IV&V performed requirements and traceability analysis and has started analyzing tests and source code.

Solar Dynamics Observatory (SDO)

The Solar Dynamics Observatory (SDO) is a 3-axis stabilized spacecraft carrying a payload of three instruments (the Atmospheric Imaging Assembly (AIA), the Extreme Ultraviolet Variability Experiment (EVE), and the Helioseismic Magnetic Imager (HMI)). SDO is designed to provide understanding of the Sun's influence on Earth and Near-Earth space, and will study the solar atmosphere on small scales of space and time and in many wavelengths simultaneously. SDO will be launched aboard an Evolved Expendable Launch Vehicle (EELV) to deliver SDO into a Geosynchronous Transfer Orbit (GTO), and will be required to perform several maneuvers to circularize the orbit and ultimately place SDO into its final inclined geosynchronous orbit (GEO).
http://www.nasa.gov/topics/solarsystem/features/sdo_overview.html

The scope of NASA IV&V's work includes all of the SDO Flight Software (FSW) system for the Spacecraft, the Observatory instruments (AIA, HMI, and EVE), and the Ground System. The Spacecraft systems and associated FSW are being developed at 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, CA. 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. The results of NASA IV&V work will verify system level behavior through testing artifacts and validate the software system behavior within the observatory system as a whole.

Human-Rated Systems

Ares I and Constellation Ground Systems

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

This NASA IV&V effort kicked off in June 2007. The IV&V Team reviewed the system level Operational Concepts document and the Design Reference Missions (DRMs) and has developed a System Reference Model (SRM) describing the desired system behavior. The SRM also explores potential off nominal behaviors. Through the development of this SRM, the team has identified a number ambiguities in the systems level documentation and "touch points" where the Ares I documentation doesn't completely agree with the Orion documentation. The IV&V Team has developed a process to identify lower level areas needing further investigation. This process will be used again each time the team examines artifacts at a lower level of detail. The IV&V Team has traced the Cx Program level requirements to the Ares I System Requirements Document (SRD). The IV&V Team is scheduled to present its initial finding to the project the Project the third week of January 2008.

Constellation Program System Integration (CxSI)

The Constellation Program is the future of human space exploration for NASA. The CxP is comprised of the following major projects which manage the development of the primary systems comprising the Constellation architecture: the Orion Crew Exploration Vehicle (hereafter referred to as Orion) Project, the Ares I Crew Launch Vehicle (hereafter referred to as Ares I) Project, Ground Operations (GO) Project, Mission Operations (MO) Project and Advanced Projects (AP). As the program matures, additional projects will be established to manage the development of additional systems such as the Cargo Launch Vehicle (hereafter referred to as Ares V) and Lunar Surface Access Module (LSAM) projects.

http://www.nasa.gov/mission_pages/constellation/main/index.html

The CxSI IV&V Team will create a system behavior model describing the goals, what the system must do to achieve these goals, and the environment in which the system operates. This model will serve as a reference for validating the system behavior from requirements specifications through test artifacts. Validation on CxSI will confirm that the right system is being built; that is, the desired system behaviors are specified and the associated requirements are unambiguous, correct, consistent, feasible, and verifiable. Central to validation is answering the questions: (1) Does the system do what it is supposed to do? (2) Does it not do what it is not supposed to do? (3) What does the system do under adverse conditions? To verify each phase of the life cycle, the IV&V Team will review CxP artifacts for correctness, as well as compliance and coverage with the previous phase. All issues found will be provided to the responsible CxP organization, and their resolution tracked. The IV&V Team will report at Program and Project milestone reviews on the overall integrity of the software and systems. All software that supports the mission in any way, including but not limited to flight software, ground software, mission systems software, and instrument software, is in scope for IV&V. In order to optimize the allocation of IV&V resources, a risk assessment is performed on the mission's systems. Due to the integrated systems-of-systems nature of CxP, the CxSI risk assessment will also focus on shared responsibility for system behaviors. The risk assessment results identify which areas of the system IV&V plans to work on, as well as which areas of the system IV&V does not plan to work on, given the amount of risk is understood and acceptable.

Orion Crew Exploration Vehicle (CEV)

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 has used unified modeling techniques to develop a System Reference Model (SRM) against which the Orion spacecraft systems requirements are being validated. This methodology and approach for the SRM development and subsequent validation activities have been communicated to and accepted by the Orion project. The IV&V Team is also performing the requirements traceability verification analysis down to the software level. To date traceability analysis has been completed to verify tracing from the Constellation Architecture Requirements Document (CARD) to the Orion System Requirements Document (SRD), from the SRD to the Lockheed Martin Spacecraft Specification, and from that specification to the Command Module Element Requirements Document. 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 are currently in review for presentation to the Project, as well as a detailed review by IV&V of the Orion architecture. This work is partially completed and slated for completion in 2008.

International Space Station (ISS)

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 things, and commercial ventures are already being performed aboard ISS, even though many of the facilities and capabilities are still under construction.
http://www.nasa.gov/mission_pages/station/main/index.html

NASA IV&V has been and is involved with all NASA-developed ISS mission-critical software assuring that software for ISS is of high quality. 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. In 2007, the IV&V Team verified new releases of much 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. Additionally, the team created traceability between ISS hazard reports and Node 2 software requirements, which provides a way to understand how changes to requirements may cause hazardous conditions and helps assure that software mitigates hazardous conditions under its control. New to ISS IV&V in 2007 is the addition of an IV&V test bed that is fully capable of testing multiple software components in easily reconfigurable configurations to allow the IV&V Team to test, independently, a key area prone to potential problems--the interfaces among components. The software baseline for ISS is largely complete but continues to be updated by new releases to provide new capabilities and ensure safe operation. Each component added to the on-orbit configuration through assembly (complete in 2010) results in varying levels of software addition/change.

Personal Computer Ground Operations Aerospace Language 2 (PC Goal 2)

PCG2 is an advisory system consisting of a set of computer platforms, network hardware and software aimed at providing increased situational awareness. The system supports the Shuttle processing team in decision-making during the safety and time-critical processing and pre-launch periods of Shuttle missions.

In 2007, the IV&V Team's support of PCG2 continued to take the form of criticality and risk-based assessment of changes to PCG2. Specifically, the IV&V Team looked at portions of ESRs/PRACA pertaining to embedded mathematical calculations, data merge and fusion functionality, real-time plotting, and Shuttle Data Center (SDC) interfaces. The scope of the IV&V Team's activities included a general review of project plans, processes and schedules, analysis of requirements, design, code and test artifacts, and development of a partial System Reference Model (SRM) for the PCG2 system. In addition, the IV&V Team used FxCop, a tool specifically designed for code analysis of .NET (Managed) C++ Code, to perform static code analysis. During the past year, the team provided numerous recommendations to improve project artifacts, including criteria for bringing design into conformance with the National Space Transportation System 07700 requirements, methods for capturing system concept of operations, and improvements to the PCG2 software implementation standard.

Further, the IV&V Team participated in peer reviews and technical review panels for software in development and maintenance. In these forums, the team's input was aimed at improving software quality with minimal impact on cost and schedule. The IV&V Team also assisted the PCG2 Project in adopting an automated static code analyzer to help eliminate several classes of implementation errors prior to testing. In addition, the team identified discrepancies in project metrics reporting, as well as deficiencies in the Project's assessment of safety critical requirements, which resulted in the review and update of project guidelines in these areas. In late 2007, PCG2 proposed moving the project to a prototyping approach. Based on the resources that would be needed to support PCG2 in this new paradigm, PCG2's status as a sustaining engineering project, and the constrained funding environment, NASA IV&V support of PCG2 ended October 31, 2007, with concurrence of the Space Operations Mission Directorate.

Space Shuttle

The Space Shuttle is the world's first reusable spacecraft and the first spacecraft in history that can carry large satellites to and from orbit. It provides US 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 ISS into space to achieve our goal of "assembly complete". The Shuttle will visit the Hubble Space Telescope for one last servicing mission in 2008 in addition to supporting the ISS.
http://spaceflight.nasa.nasa.gov/shuttle/

The IV&V Team performed two Independent Assessments (IAs) in 2007. The first IA was performed on selected software in the new Solid Rocket Booster Command Receiver/Decoder, first flown on STS-118. The CRD receives signals from the Range Safety System and would be the mechanism by which the SRBs were destroyed in-flight if certain safety parameters were violated. Thus, it's important that the CRD work perfectly, both when it is needed for a destruct and when it isn't. The IA found no safety of flight issues, and provided that assessment, along with a more detailed report, to OSMA as well as to various Shuttle project offices.

The second IA was related to flying the Shuttle over the end of the calendar year, referred to as Year-End Roll-Over (YERO). YERO occurs when the Shuttle's Master Timing Units (MTUs), which are highly accurate time sources for the onboard computers (GPCs), experience rollover of Greenwich Mean Time (GMT) from 365 days to 0 days. The GPCs have a second time source, internal clocks, which are less accurate than the MTUs. The GPCs' internal clocks were not designed to roll over but continue to count up to 366 days and so on. Once the end of the calendar year occurs, the two time sources are no longer synchronized, with the MTUs showing day 0 and the GPC internal clocks showing day 366. As a protection, the GPCs are designed to use internal time instead of MTU time if the two are out of sync. In order to successfully deorbit and land the orbiter after YERO, use of MTU time by all five GPCs must be re-established on-orbit. Previously this required the crew and ground to follow a lengthy and complicated procedure that had limited testing on the ground and had never been performed in flight. The Shuttle Program implemented GPC flight software changes to simplify and shorten the procedure and provide greater flexibility to fly the Shuttle with fewer schedule constraints. The Shuttle IV&V Team used operational scenario analysis, supported by modeling techniques, of the modified software and the "system" of the modified YERO procedure to look for flaws and safety concerns. The IA found no safety of flight issues and provided that assessment, along with a more detailed report, to OSMA as well as to various Shuttle project offices.

In 2007, IV&V supported four Shuttle missions. Before each Shuttle mission, IV&V reported on the analysis at the Software Readiness Review conducted by the Shuttle Program's Flight Software Office. IV&V is also a voting participant in each mission's Safety and Mission Success Review, co-chaired by astronaut Bryan O'Connor, the Agency's Chief of Safety and Mission Assurance, and Michael Ryschkewitsch, the Agency's Chief Engineer. All the members of the Shuttle IV&V Team are proud of their continuing contribution to the safety of the Shuttle Program and look forward to the five scheduled Shuttle missions in 2008, which include STS-125, the final Hubble Space Telescope servicing mission.

ATTACHMENT A: ISSUE TYPE CATEGORIES

Requirements	
System Behaviors	This category captures defects associated with system-level functionality. A defect in functional description captures the ideas of missing, incorrect, incomplete, ambiguous, or unverifiable system requirements/behaviors.
Emergent System Behaviors	While performing IV&V analysis undocumented system behaviors may be discovered. These behaviors are documented in this category. Note that these are different from missing behaviors/requirements. A missing behavior/requirement is generally something that is desired but was not documented. An emergent behavior is generally one that was not planned for. It may ultimately become a desired behavior or it may become an undesired behavior.
Software Behaviors	A defect in software behavior is related to the functional aspects of the software rather than the complete system. Generally a behavior can be mapped to a functional requirement(s) or defined by a model element(s) as described by the developer/user. A defect in a behavior can be seen as missing, incorrect, incomplete, ambiguous, or unverifiable.
Emergent Software Behaviors	While performing IV&V analysis undocumented software behaviors may be discovered. These behaviors are documented in this category. Note that these are different from missing behaviors/requirements. A missing behavior/requirement is generally something that is desired but was not documented. An emergent behavior is generally one that was not planned for. It may ultimately become a desired behavior or it may become an undesired behavior.
Quality feature	A quality feature can be mapped to performance, reliability, or other non-functional requirements. Quality feature defects are due to missing, incorrect, incomplete, unverifiable, or unexpected quality features.
Behavior interaction	Defects in this category are due to incorrect descriptions of how the behaviors interact. These interactions are usually defined across interfaces and describe communication problems internal portions of the software. For example, communication between modules and functions within the system. Note that if the interaction produces an unintended consequence or emergent behavior, that fact should be captured under Emergent Software Behaviors. However, if the interaction itself is incorrect, then the defect is captured here whether or not it generates an emergent behavior.
Requirements Documentation	Requirements documentation defects occur when the documentation of the requirements is incomplete or ambiguous. Requirements documentation is generally concerned with the textual information that surrounds the actual requirements (functional, non-functional, etc.). Errors in documentation may point to incorrect references in other documents or may include information that is not applicable to the current project.
Interface description	These defects focus on the interaction of the software with external software, hardware, and users. Similar to behavior interaction, however, this category describes communications with entities external to the software. For example, communication with external software systems such as a database, external hardware systems, such as sensors, or end effectors and interface with the users.
Design	
Algorithms and processing	This defect occurs when the description of an algorithm defined in a design artifact is incorrect or if the algorithm chosen is not the correct algorithm overall. These types of defects arise from the lack of error checks for incorrect and/or invalid inputs, lack of a path for users to correct erroneous inputs or lack of a path to recover from erroneous inputs. As such, this category also contains other data processing checks such as error conditions checks like a divide by zero. Examples: Possible divide by zero Missing input validation

	Missing path for correcting erroneous input
Control, logic and sequence	This defect occurs when logic flow captured in design descriptions (pseudo code, models, etc.) are not correct. Logic defects are usually related to the use of logic operators such as < or > and their use in Boolean expressions. This category would also include sequencing constructs that define branching along with defects related to the chosen architectural style.
Architectural	This defect is related to the architectural choices made for the software. Defects of this type usually result from the performance of an architectural analysis and capture issues regarding the ability of the selected architecture to meet the quality attribute requirements for the system.
Design Data	Incorrect design of data structures. Incorrect records, incorrect types, array issues, incorrect storage allocation etc.
Module/Class interface description	Using incorrect and/or inconsistent parameter types, an incorrect number of parameters, incorrect order of parameters, or lack of pre- and/or post-conditions for calling the interface/service. This is defined at the architecture/design level. The focus of this category in on design interfaces internal to the software system being developed.
External Interface description	This is similar to the Module/Class interface description but captures defects associated with interfaces to external entities such as COTS components, external software systems, database, or hardware devices such as FPGAs, sensors, effectors, etc. User interface issues would also be captured here to include such things as missing or improper commands, improper sequences of commands, lack of proper message, and/or lack of feedback messages for users.
Design Documentation	Design documentation defects occur when the documentation of the design is incomplete or ambiguous. Design documentation is generally concerned with the textual information that surrounds the actual design. Errors in documentation may point to incorrect references in other documents or may include information that is not applicable to the current project.
Code	
Algorithms and Processing	This adds a level of detail to the design category of this name. The defects would now include unchecked overflow and underflow conditions, the comparison of inappropriate data types, converting one date type to another, incorrect ordering of arithmetic operators, misuse or omissions of parentheses, precision loss, and incorrect use of signs as documented in the code.
Control, logic and sequence	At the coding level errors of this type include incorrect expression of case statements, incorrect iteration of loops (loop boundary problems), and missing paths.
Typographical	These are generally syntax errors, such as the incorrect spelling of a variable name that are captured by a compiler, self-reviews, or peer reviews. Note that these are errors in the code itself or associated with typos in programming language constructs. Other code artifact typos, such as typos in comments are captured in the Code Documentation category below.
Data	These are defects that are indicated by incorrect implementation of data structures. Examples might be a missing field in a record, an incorrect type or access is assigned to a file, an array may not be allocated the proper number of elements. This defect type also includes such things as flags, indices, and constants set incorrectly.
Data Flow	A defect of this type is associated with the flow of information through the program. In general, there are certain sequences that should occur within code. An example of this is that a variable should be initialized before it is used. It should only be initialized only once. In some cases, these may not be actual defects; however, they represent good programming practices and may indicate the presence of other defects or hide potential defects.
Module/class interface	Code interface defects are similar to design interface defects, but at the code level. Examples include an incorrect number of parameters or improper ordering of the parameters. Other examples might be an incorrect sequence of calls or calls to

	nonexistent modules. This interface category is concerned with interfaces internal to the software being developed.
Code documentation	Code documentation defects occur when the documentation does not reflect what the program actually does or is incomplete or ambiguous. Poor code documentation can affect testing efforts. Code reviews are generally the best tool to find these types of defects.
External hardware, software	These defects are related to system calls, links to databases, input/output sequences, memory usage, resource usage, interrupts and exception handling, data exchanges with hardware, protocols, formats, interfaces with build files, and timing sequences. This category is focused on external interfaces.
Testing	
Test harness	In order to test software, especially at the unit and integration levels, auxiliary code must be developed. This is often called the test harness or sometimes instrumentation code. Often the test harness code must be designed, implemented, and tested as stringently as the product code. This is necessary since test harness code is a work product and much of this code can be reused when a new release of the software is developed. A test harness is subject to the same types of code and design defects that can be found in all other types of software. A question needs to be answered as to whether it is important capture issues related to the test harness in this separate category or to capture those issues in the other development categories.
System test design and procedures	This category captures issues related to incorrect, incomplete, missing, or inappropriate test cases and procedures associated with System-level testing. These types of issues can be found during test plan reviews or sometimes during the testing process itself through an analysis of test conditions and test results.
Acceptance test design and procedures	This category captures issues related to incorrect, incomplete, missing, or inappropriate test cases and procedures associated with Acceptance testing. These types of issues can be found during test plan reviews or sometimes during the testing process itself through an analysis of test conditions and test results.
Integration test design and procedures	This category captures issues related to incorrect, incomplete, missing, or inappropriate test cases and procedures associated with Integration testing. These types of issues can be found during test plan reviews or sometimes during the testing process itself through an analysis of test conditions and test results.
Component test design and procedures	This category captures issues related to incorrect, incomplete, missing, or inappropriate test cases and procedures associated with Component or Unit testing. These types of issues can be found during test plan reviews or sometimes during the testing process itself through an analysis of test conditions and test results.

ATTACHMENT B: ACRONYMS

The following acronyms and terms are used in this document:

Acronym	***Description***
ACS	Attitude Control Subsystem
ADACS	Attitude Determination and Control System
AHMS	Advanced Health Monitoring System
AIA	Atmospheric Imaging Assembly
AIM	Aeronomy of Ice in the Mesosphere
AP	Advanced Projects
ASIC	Application Specific Integrated Circuit
ATC	Advanced Technology Center
CLCS	Checkout and Launch Control System
CARD	Constellation Architecture Requirements Document
CAU	Cockpit Avionics Upgrade
CDE	Cosmic Dust Experiment
CDH	Command and Data Handling
CEV	Orion Crew Exploration Vehicle
CIPS	Cloud Imaging and Particle Size
CLV	Crew Launch Vehicle
CMM	Capability Maturity Model
CMMI	Capability Maturity Model Integration
CRD	Command Receiver/Decoder
CSCI	Computer Software Configuration Item
Cx	Constellation
CxP	Constellation Project
CxSI	Constellation Program System Integration
DLRE	Diviner Lunar Radiometer
DRM	Design Reference Missions
EELV	Evolved Expendable Launch Vehicle
ESR	Engineering Support Request
EVE	Extreme Ultraviolet Variability Experiment
FPGA	Field-Programmable Gate Array
FSW	Flight Software
GEO	Geosynchronous Orbit
GLAST	Gamma Ray Large Area Space Telescope
GMT	Greenwich Mean Time
GN&C	Guidance Navigation and Control
GO	Ground Operations
GOES-R	Geostationary Operational Environmental Satellite R Series
GPC	General Purpose Computer
GPS	Global Positioning System
GQM	Goal, Question, and Metric
GSFC	Goddard Space Flight Center
GTO	Geosynchronous Transfer Orbit
HMI	Helioseismic Magnetic Imager
HST	Hubble Space Telescope
IBD	IV&V Board of Directors
IBEX	Interstellar Boundary Explorer
IEEE	Institute of Electrical & Electronics Engineers, Inc.
IEMP	Integrated Enterprise Management Program
IMS	IV&V Management System
ISS	International Space Station

Acronym	***Description***
IV&V	Independent Verification and Validation
IVVP	IV&V Plan
JWST	James Webb Space Telescope
LAMP	Lyman Alpha Mapping Project
LASP	Laboratory for Atmospheric and Space Physics
LEO	Low Earth Orbit
LMSAL	Lockheed-Martin Solar and Astrophysics Laboratory
LOLA	Lunar Orbiter Laser Altimeter
LRO	Lunar Reconnaissance Orbiter
LROC	Lunar Reconnaissance Orbiter Camera
LSAM	Lunar Surface Access Module
MAC	Multiple Award Contract
MEDS	Multifunction Electronic Display System
MO	Mission Operations
MOA	Memorandum of Agreement
MSL	Mars Science Laboratory
MTU	Master Timing Unit
NASA	National Aeronautics and Space Administration
NPD	New Product Development
NPR	NASA Procedural Requirements
OCO	Orbiting Carbon Observatory
OO	Object Oriented
OSMA	Office of Safety and Mission Assurance
PCE	Phase Containment Effectiveness
PCG2	Personal Computer Ground Operations Aerospace Language 2
PDR	Preliminary Data Requirements
PITS	Project Issue Tracking System
PM	Project Manager
PRACA	Problem Reporting and Corrective Action
RLEP	Robotic Lunar Exploration Program
SDC	Shuttle Data Center
SDLC	Software Development Life Cycle
SDO	Solar Dynamics Observatory
SILAP	Software Integrity Level Assessment Process
SM4	Servicing Mission 4
SOFIE	Solar Occultation for Ice Experiment
SRD	Software Requirements Document
SRM	System Reference Model
SSP	Space Shuttle Program
SW	Software
THEMIS	Time History of Events and Macroscale Interactions during Substorms
TIM	Technical Issue Memorandum
UML	Unified Markup Language
WBS	Work Breakdown Structure
YERO	Year-End Roll-Over

ATTACHMENT C: ISSUE SEVERITY LEVELS AND DEFINITIONS

Severity	Definition
1	a) Prevent the accomplishment of an essential capability b) Jeopardize safety, security, or other requirement designated critical
2	a) Adversely affect the accomplishment of an essential capability and no work-around solution is known b) Adversely affect technical, cost or schedule risks to the project or life cycle support of the system, and no work-around solution is known
3	a) Adversely affect the accomplishment of an essential capability but a work-around solution is known b) Adversely affect technical, cost, or schedule risks to the project or life cycle support of the system, but a work-around solution is known
4	a) Result in user/operator inconvenience but does not affect a required operational or mission essential capability b) Result in inconvenience for development or maintenance personnel, but does not affect the accomplishment of these responsibilities
5	Any other effect