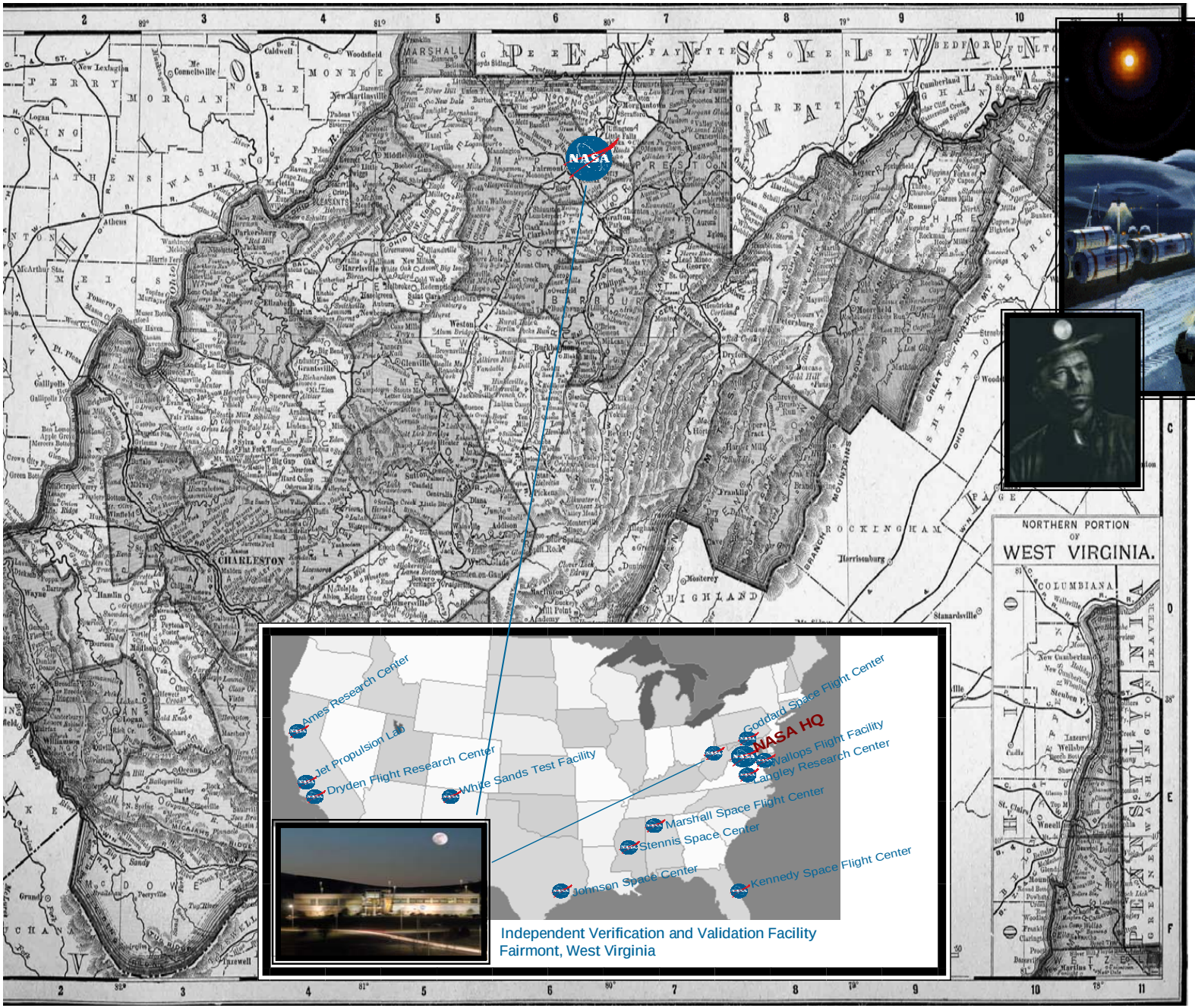
National Aeronautics and Space Administration

Independent Verification and Validation Facility

NASA IV&V 2006

www.nasa.gov/ivv

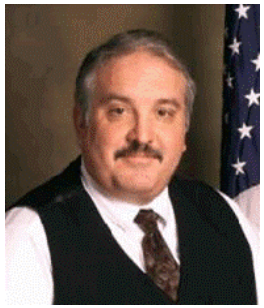


Lunar Base Mining
Robert McCall
NASA Art Gallery

Lunar Base Mining, one of Robert McCall's many imaginative illustrations found in the NASA Art Gallery, strikes an historic chord with those of us fortunate to work for NASA IV&V in West Virginia. Hidden ore deep within the Appalachian mountains has fueled great efforts for more than a century.

It is our vision that the software embedded in NASA's mission critical systems, when verified and validated for safety and reliability, will continue to fuel our nation's greatest efforts to understand, discover and explore for generations to come.

***Cover Art*:** *New exploration technologies are key to sustained robotic and human exploration of the Moon, Mars and beyond. Image Credit: European Space Agency*



Dear Reader:

I invite you to take a few moments to review the work of NASA's Independent Verification and Validation Facility. This catalogue has been compiled to identify the Services that IV&V provided to support NASA missions in 2006.

The *Service* of Independent Verification and Validation provides an objective assessment of the product during its creation; adds a new analytical perspective not present in the development environment; brings its own set of tools and techniques to bear on ensuring development accuracy and validity; introduces "intermediate" users of the system who serve as "beta testers" before the product goes to market; and, significantly enhances testing and the discovery of design flaws and coding errors.

IV&V *Research* initiatives deepen our expertise and develop innovative tools and practices to support current and future missions. IV&V's *Outreach* is designed to meet the needs of a variety of stakeholders and broaden their understanding of and appreciation for the value of our work on behalf of our Agency.

It was my great privilege to join IV&V's committed team of professionals in 2006, and I am pleased to present their work to you in the following pages. Many of you are well aware of the value that effective independent verification and validation adds to your projects. For those of you who are reading of our Services for the first time, I encourage you to take advantage of the expertise in software engineering and leading-edge research that can be found at IV&V.

Even as we describe the work of the past year, we dedicate ourselves to reaching greater heights of achievement in the year to come.

Dr. Butch Caffall
Director, NASA IV&V Facility

Vision

The NASA IV&V Facility is valued for its superior performance in independent software 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

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

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

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

Serving NASA in 2006...

The Independent Verification and Validation Facility exists to provide an additional level of assurance for NASA missions that involve human safety or other core Agency objectives. Mission objectives are assigned to Centers based on Center expertise. IV&V proudly served NASA throughout 2006 by working beside the Centers to provide software and systems assurance to the Agency's most critical missions. Forty-two civil service employees and one hundred forty-six Full Time Equivalent (FTE) contractors on-site and sixty-one FTE contractors off-site formed an impressive team of experts. L-3 Communications Titan Corporation and Northrup Grumman Information Technology, our principal suppliers of IV&V services, contributed value added/needed service to the projects upon which we worked ensuring a positive return on investment.

In 2006, our NASA/contractor Services team provided IV&V Services to twenty-three projects across six Centers in the Agency. The details of the technical analyses provided by the IV&V Services team vary from project to project, tailored to the specifics that make each NASA project unique. What doesn't change is our commitment to the safety and success of the projects we support. For each project, our goal is to objectively answer the following questions:

Will the software and the system do what it's supposed to do?

Will the software and the system not do what it's not supposed to do?

How will the software and the system behave under adverse conditions?

During our analysis efforts, we provide information to each project to help them know where they stand with respect to being able to achieve their goals and objectives. At various critical points during the project's development, IV&V provides our assessment of the software's readiness for use both to the project's management and to our management in the Agency's Office of Safety and Mission Assurance.

IV&V's unique situation provides a "cross-Agency" view of the software engineering challenges facing critical, complex projects. A cross-Agency view affords IV&V the opportunity to provide value by not only addressing specific, discrete issues to improve the quality of the software products on a given project but also by helping to improve software engineering across NASA. *This document catalogues the services IV&V provided to NASA Missions in 2006.*

IV&V executed research Agency-wide to improve the disciplines of software assurance. The Facility focused its research efforts on practical and applied initiatives to the current and future benefit of NASA projects and missions. On behalf of the Office of Safety and Mission Assurance, the IV&V Facility hosted its most successful Software Assurance Symposium (SAS 06) to date. More than 200 national and international project managers, administrators, and academicians came together to discuss the forward-leaning initiatives being conducted by 40-plus researchers under the auspices of the Agency's Software Assurance Research Program (SARP) as well as IV&V Facility sponsored initiatives. *You will find examples of these impressive Research efforts throughout this document and a complete index of SARP and IV&V Facility Research in the appendix.*

2006 Customer Survey

"IV&V made the project aware of several errors in the FSW. ..very helpful. It was important that all review these issues and come to an independent evaluation. IV&V PM's communication skills are excellent."

2006 Customer Survey

NASA IV&V analysis tools have been useful in identifying potential code issues...this has given me higher confidence in the product."

2006 Customer Survey

"IV&V PM support has been invaluable … contractors have in depth understanding of the project and perform well above expectations. ...errors found and subsequently fixed. This reduces risk considerably as finding these problems during I&T or flight would be expensive."

Our Agency is Our Customer

The Community and Student Outreach Programs inspired over 3,500 West Virginia students by way of classroom visits, community events, presentations, on-site programs, high school and college career fairs and IV&V's annual Day in the Park. The NASA IV&V Educator Resource Center (ERC) provided teacher workshops for nearly 1,200 West Virginia educators. IV&V's 2006 Science Engineering Apprenticeship (SEAP) program provided ten exceptional high school students the opportunity to work beside computer, software, mechanical and aerospace engineers, and IV&V program managers for eight weeks. The apprentices presented their project data to their professional mentors from the Department of Defense, NASA and other agencies, at an annual event in Washington D.C. NASA IV&V's SEAP is the only one of its kind in the Agency and has resulted in the selection of many of its participants for IV&V college internships and co-op positions. We are exceedingly proud that 80% of the apprentices pursue degrees in science, math, technology, engineering, and geography. *Descriptions of just a few of the many events and programs sponsored by IV&V Outreach this year appear in the following pages.*

IV&V, determined to be considered a center of excellence, has secured such a reputation by the efforts of a dedicated administrative and operations management team. IV&V enjoys a safe, comfortable, and well-equipped workplace that is conducive to high performance and supports individual and team productivity. The IV&V Facility underwent infrastructure upgrades in 2006 that included the heart of the Facility's electrical systems; the Main Switchgear. A new diesel generator, uninterruptible power supply and three additional power distribution units were also safely installed. The IV&V Facility is under constant fire from computers on the Internet. Some are botnet attacks, while others are more concerted efforts by hackers to gain access to our systems. Attackers have been unable to infiltrate our network or compromise any network services in 2006. The IV&V Facility applied for and received Enterprise Architecture (EA) certification of our Enterprise Content Management (ECM) solution. ECM will combine several aspects of our network to better enable us to perform our process workflow and document management. *The Facility is also proud to have merited designation as a Voluntary Protection Program (VPP) site by OSHA in 2006* *(see page 7).*

We look back on 2006, a year of leadership transition, as one of great accomplishment. Under the able direction of Deputy/Acting Director Bill Jackson, our focus on safety and excellence, remained constant. Upon his appointment in October, Director, Dr. Butch Caffall found a confident team of professionals, standing on a sure foundation of values and achievement ready to follow his leadership — leadership that has already begun to guide us to greater levels of competency and innovation in our efforts *"to be valued for our expertise in software engineering, superior performance in software verification and validation, and the ability to positively impact the development of quality software."*

2006 Customer Survey

"IV&V PM has demonstrated outstanding understanding of the nuances of IV&V and has demonstrated a keen intellect..a decisive response to issues...high degree of competency. IV&V issues are raised early in our process and thus are considered to be of a more significant nature … correction is easier to implement."

2006 Customer Survey

"The IV&V PM is extremely effective at helping us identify issues and at keeping the project on track. We appreciate this PM's insight and dedication. PM is exceptionally professional, thorough and organized. Excellent knowledge of the IV&V process; very flexible to our changing requirements and unique environment.

2006 Customer Survey

The IV&V team has helped us ensure that all our requirements can be traced back to higher level requirements. We have expanded the use of IV&V services…"

Thirty years of software industry experience, research and reports indicate that the cost of software rework can approach 50% for large software projects. Additionally, finding and fixing requirements errors can consume 70% - 85% of total project rework costs. In Figure 1, we present Barry Boehm's software *Relative Cost to Repair* model*. Boehm has proven that it is 200 times more cost efficient to find and fix a requirements error in the requirements phase than it is to find and fix the same error in the operations phase. Software defect phase containment is an extremely important aspect of software and systems engineering to help ensure that correct and reliable systems are delivered on-time and within the costs allocated to the software effort. To fully understand the model, containing errors in the other phases yield the following cost savings: Design – 40x; Code – 20x; Unit Test – 10x; System Test – 4x; and, Operations and Maintenance – 1x.

During the past year, software issues found by the IV&V Facility on the various NASA missions supported to date were analyzed These missions included Human Space Flight missions (e.g. Space Shuttle, the International Space Station, etc.). Additionally, full IV&V support for most Space and Earth Science missions began between 2000 and 2003. Our analysis yielded 18,700+ IV&V issues on both Human Space Flight and Science missions.

For our Return on Investment analysis, we restricted the data to our most significant issues found (Severity 1 & 2). We present this data in Figure 2 (by Phase and Mission Category) for our Return on Investment calculation along with our notes/assumptions. ***Based on this analysis, our current Return on Investment (ROI) yield is 83:1. For every dollar spent on IV&V, NASA gains a benefit of $83 of software rework risk reduction.***

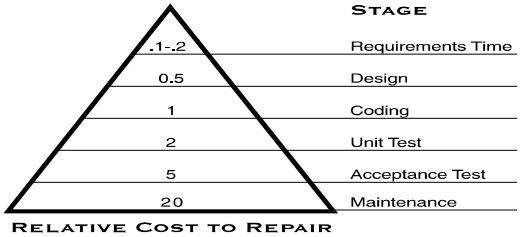
In 2006, NASA allocated $27 Million to the IV&V Facility Budget of which $19 Million went directly to IV&V Services. Based on our current Return on Investment analysis, ***NASA realized a software rework risk reduction benefit of $1.6 Billion in Fiscal Year 2006 alone.***

*Relative Cost to Repair -- B.W. Boehm, "Verifying and Validating Software Requirements and Design Specifications," IEEE Software, 1984

Figure 1

IV&V: Can you afford not to?

As much as a 200:1 cost savings results from finding errors in the requirements stage versus finding errors in the maintenance stage of the software life-cycle.



Barry Boehm- '76, 88

56% of all bugs can be traced to errors made during the requirements stage

Figure 2

IV&V Return on Investment Average

(Severity 1 & 2 Issues by Phase)

	RQMTS	DESIGN	CODING	UNIT TEST	SYSTEM TEST	O&M	Total
Savings Ratio	(200:1)	(40:1)	(20:1)	(10:1)	(4:1)	(1:1)	
Missions							
Space Shuttle & ISS (pre 2004 - 2007)	490	84	675	110	0	5	1364
Science (2004 - 2007)	304	69	205	287	0	10	875
Weighted Sub-Total	158,800	6,120	17,600	3,970	0	15	
Total Weighted Score	186,505						
ROI Average	83						

Software Rework Cost Reduction Ratio: 83:1

Notes
- IV&V ROI is based only on Severity 1 and 2 Issues found.
- Does not include the 16,500+ Severity 3, 4 & 5 Issues found on same IV&V projects.
- Does not factor any additional savings for preventing total loss of mission due to software.

IV&V Issues are classified into five Severity levels (with Severity I being the most significant): **Severity 1** Prevents the accomplishment of an essential capability. Jeopardizes safety, security, or other requirements designated critical. **Severity 2** Adversely affects the accomplishment of an essential capability and no work-around solution is known. Adversely affects technical, cost or schedule risks to the project or life cycle support of the system, and no work-around solution is known. **Severity 3** Adversely affects the accomplishment of an essential capability but a work-around solution is known. Adversely affects technical, cost, or schedule risks to the project or life cycle support of the system, but a work-around solution is known. **Severity 4** Results in user/operator inconvenience but does not affect a required operational or mission essential capability. Results in inconvenience for development or maintenance personnel, but does not affect the accomplishment of these responsibilities. **Severity 5** Any other affect.

IV&V SERVICE: Integrated Enterprise Management Program (IEMP)

IV&V Project Manager: Pat Callis
Contractor: L-3 Communication Titan Corporation
Project Manager: Garlan Bradshaw

Agency-wide management and improvement of financial, physical, and human resource processes are at the heart of the Integrated Enterprise Management Program (IEMP). IEMP will dramatically improve NASA's business processes and increase information collaboration among the Centers, enhancing the ability to support multiple programs by sharing accounting and financial data. The IEMP will help NASA meet key objectives of the President's Management Agenda, including expanded electronic government; strategic management of human capital; improved financial management; and budget and performance integration.

The IV&V Facility performed an Independent Assessment (IA) on specific requirements, design documents, test coverage, application security, and risk management aspects of the Integrated Enterprise Management Program (IEMP) system. Issues and project risks were provided in the following reports:

Requirements Traceability Report for Human Capital Information Environment (HCIE) based on IV&V analyzing traceability among Level I through Level IV requirements; Requirements Traceability Report for Contract Management Module (CMM) based on IV&V analyzing traceability among Level IV through Level V requirements; two Requirements Traceability Reports for eTravel, (the first based on IV&V analyzing traceability among Level I through Level IV requirements, and the second based on IV&V analyzing traceability among Level IV through Level V requirements); Requirements Traceability Reports for SAP Version Update (SVU) project based on IV&V analyzing traceability among Level I through Level V requirements. IV&V Produced Test Analysis Reports for the SVU and CMM projects. IV&V produced Business Assurance (BA) reports: Documentation Management Framework, Program Documentation Taxonomy, and the Program Library Plan.

The results of IA analysis identified requirements that were not measurable, testable, or defined at the appropriate level of detail. The IA Team provided a very concise view of the traceability between all levels of requirements allowing the Project to benefit from the additional review without an impact to cost or schedule. *"...exceptionally professional, thorough and organized."*

CENTER of EXCELLENCE: IV&V Facility OSHA VPP Work Site

In late 2006 the Facility underwent a comprehensive Health and Safety review, performed by OSHA to certify the IV&V Facility as a OSHA VPP work site. The Voluntary Protection Programs (VPP) promotes effective worksite-based safety and health. Approval into VPP is OSHA's official recognition of the outstanding efforts of employers and employees who have achieved exemplary occupational safety and health. OSHA noted that the Facility has several areas of excellence including:

- Safety Culture
- Plant Environment
- Maintenance Program
- Health and Safety Resources
- First Aid, CPR, AED Training Program
- Incident Reporting System
- Wellness Program
- Timely Response to Employee Concerns

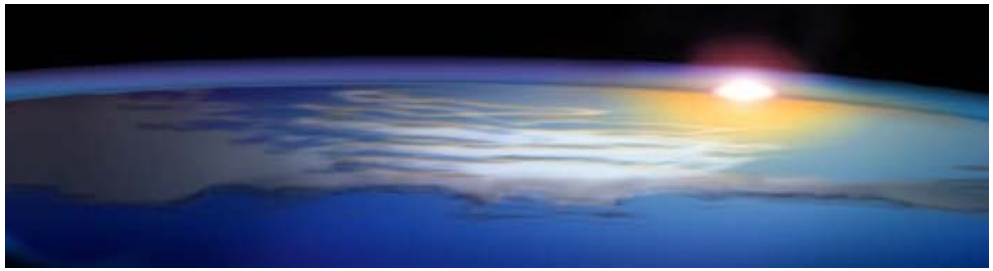
IV&V SERVICE: Aeronomy of Ice in the Mesosphere (AIM)

IV&V Project Manager: Raju Raymond
Contractor: Northrup Grumman Information Technology (10/2006 – Present) – Project Manager: Phil Loftis
Contractor: SAIC (10/2003 – 9/2006) – Project Manager: Paige Highsmith

IV&V SERVES EARTH SCIENCE

The Aeronomy of Ice in the Mesosphere (AIM) mission, part of NASA's Explorers program, is slated for launch in April 2007. The AIM mission will provide unprecedented advances in the understanding of Polar Mesospheric Clouds (PMCs), also called noctilucent or "night shining" clouds. Recorded sightings of these clouds began in the late 1800s and have increased in frequency. The overall goal of the AIM mission is to study why noctilucent clouds form and why they vary. By measuring noctilucent clouds and the environment in which they form, we will learn more about the connection between these clouds and the meteorology of the mesosphere.

The AIM mission will result in a rigorous validation of predictive models that can reliably use past changes and present trends of noctilucent clouds as indicators of global change. This goal can only be achieved by a complement of instruments on-board the AIM spacecraft, which will orbit Earth at an altitude of 550 km. These instruments will take wide-angle photos of noctilucent clouds, measure their temperatures and chemical abundances, monitor dusty aerosols and count meteoroids raining down on Earth, all critical factors associated with the formation of noctilucent clouds.



The IV&V Facility is performing 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 is contributing to the mission through meticulous analysis of each of the components.

To date, IV&V has completed requirements and design analysis efforts. Code and test analysis activities are ongoing. Additionally, IV&V participated in peer reviews and technical review boards for the mission software. The AIM project addressed the technical issues associated with software requirements and flight software that IV&V identified and documented as part of its analysis efforts.

For further information about AIM, visit http://aim.hamptonu.edu

IV&V SERVICE: Geostationary Operational Environmental Satellite-N Series (GOES-N)

IV&V Project Manager: Richard Grigg
Contractor: L3-Communications Titan Corporation
Project Manager: (none in 2006)

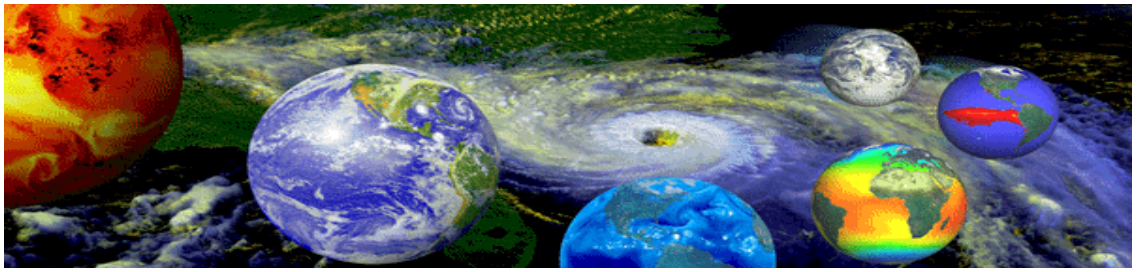
The National Oceanic and Atmospheric Administration (NOAA) funds and operates the GOES program. GOES, commonly called weather satellites, do more than just report on the weather. The new N-series satellites, as compared to the previous series of GOES satellites, will locate severe storms and other weather phenomena.

The spacecraft design and geostationary positions enable the primary sensors to stare at Earth and frequently take images of clouds, monitor Earth's surface temperature and sound Earth's atmosphere for its vertical temperature and water vapor distribution. Atmospheric phenomena can be tracked, ensuring real-time coverage of short-lived dynamic events such as severe local storms and tropical hurricanes and cyclones, types of meteorological events that directly affect public safety, property and ultimately economic health and development. The GOES satellites also have a search-and-rescue capability to detect distress signals from hikers, sailors and pilots.

IV&V SERVICE: Geostationary Operational Environmental Satellite-R Series (GOES-R)

IV&V Project Manager: Richard Grigg
Contractor: Northrop Grumman Information Technology
Project Manager: Jennilyn Ball

The GOES-R series of GOES will be comprised of improved spacecraft and instrument technologies. The new R-series satellites will more accurately locate severe storms and other weather phenomena, resulting in more precise warnings to the public. As its predecessor, GOES will have search and rescue capability and will also monitor the sun's x-rays for the early detection of solar flares and other space weather. This early warning is important because solar flares affect not only the safety of humans in high-altitude missions, such as the Space Shuttle, but also military and commercial satellite communications.



GOES-N The IV&V Facility activities culminated with our participation in the Safety and Mission Assurance Readiness Review (SMARR) in 2006. The GOES-N satellite was successfully launched on May 24, 2006. The instruments, undergoing calibration checks to be ready to re-place an older GOES satellite whenever it is needed, has been handed over to NOAA and is now known as GOES 13.

GOES-R The IV&V Facility began Test Analysis of one of the instruments, Advanced Baseline Imager in 2006. The project stated *"… these are just the kind of issues we were expecting."*

For further information about GOES-N, visit: http://www.nasa.gov/missionpages/goes-n/main/

For further information about GOES-N, visit: https://osd.goes.noaa.gov//

IV&V SERVICE: Glory

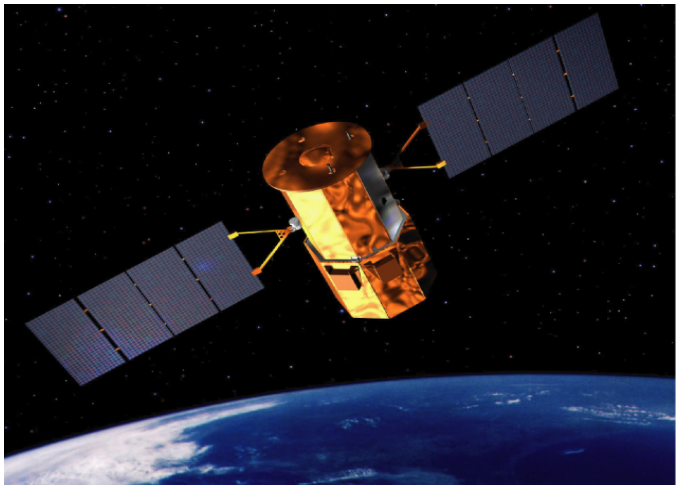
IV&V Project Manager: Steven Raque
IV&V Contractor: Northrop Grumman Information Technology
Project Manager: Lisa Nicklow

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. The Glory mission's scientific objectives are met by implementing two separate science instruments, one with the ability to collect polarimetric measurements along the satellite ground track within the solar reflective spectral region (0.4 to 2.4 micrometers) and one with the ability to monitor changes in sunlight incident on the Earth's atmosphere by collecting high accuracy, high precision measurements of total solar irradiance. The science objectives of the Glory mission include:

1.) the accurate determination of the global distribution, microphysical properties, and chemical composition of natural and anthropogenic aerosols and clouds with coverage sufficient for a reliable quantification of the aerosol direct and indirect effects on climate; and,

2.) the continued measurement of the total solar irradiance to determine the Sun's direct and indirect effect on the Earth's climate.

The Glory mission will respond to the U.S. Climate Change Science Program (CCSP) by continuing and improving upon NASA's research of the forces influencing climate change in the atmosphere. Measurements produced by this mission and the scientific knowledge such observations will provide are essential to predicting future climate change, and to making sound, scientifically based economic and policy decisions related to environmental change.



The IV&V Facility began performing analysis on the Glory Mission in 2006. Analysis of the spacecraft requirements and design documentation has been achieved, and analysis of the TIM instrument is underway. The IV&V team also supported the spacecraft and mission Critical Design Reviews. The Glory Project has been very positive and responsive to the findings of the IV&V team.
"...IV&V PM is easy to work with; good attention to deliverables and schedule."

For further information visit http://glory.gsfc.nasa.gov/

IV&V SERVICE: National Polar-Orbiting Operational Environmental Satellite System Preparatory Project (NPP)

IV&V Project Manager: Stephanie Ferguson
Contractor: L3-Communication Titan Corporation
Project Manager: Larry Ullom

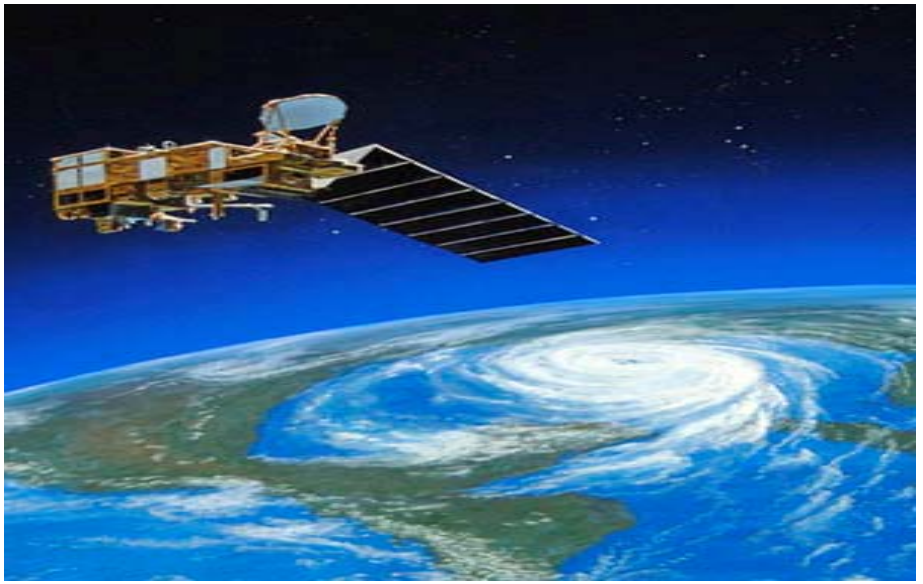
The National Polar-Orbiting Operational Environmental Satellite System (NPOESS) will provide long-term systematic measurements of key environmental variables beginning about 2010. In preparation for this system, NASA and the Integrated Program Office are conducting a joint mission, the NPOESS Preparatory Project (NPP).

NPP will provide risk reduction for this future operational system and will maintain continuity of certain environmental data sets initiated with NASA's Terra and Aqua satellites. These measurements will be taken by three different sensors:

- VIIRS: Visible Infrared Imaging spectro Radiometer Suite;
- CrIS: Crosstrack Infrared Sounder; and,
- ATMS: Advanced Technology Microwave Sounder.

The data collected by these sensors will be processed into sensor data records (SDRs). The SDRs are used to create environmental data records (EDRs), which are operational data products, and climate data records (CDRs) for long-term climate and global change studies. Launch is now scheduled for September, 2009.

For further information about NPOESS, visit http://jointmission.gsfc.nasa.gov/



IV&V participated in Test Readiness Reviews (TRR) and Flight Qualification Test (FQT) and Delta FQT reviews for the Spacecraft Control Computer (SCC) and the Command and Data Processor (CDP) spacecraft flight software. The developer has agreed to address all issues (project and IV&V) identified during the reviews. We have completed all the IV&V work currently planned for NPP. The Final Report , including all documents and the analysis activities that IV&V has performed will be delivered in January 2007.

IV&V SERVICE: Orbiting Carbon Observatory (OCO)

IV&V Project Manager: Stephanie Ferguson
Contractor: L-3 Communications Titan Corporation
Project Managers: Bob Jarrett and David Wirkkala

The OCO mission will collect precise global measurements of carbon dioxide (CO_2) in the Earth's atmosphere. Scientists will analyze OCO data to improve our understanding of the natural processes and human activities that regulate the abundance and distribution of this important greenhouse gas.

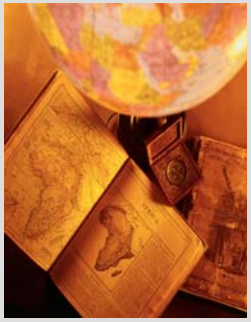
This improved understanding will enable more reliable forecasts of future changes in the abundance and distribution of CO_2 in the atmosphere and the effect that these changes may have on the Earth's climate.

For further information about OCO, visit http://oco.jpl.nasa.gov/

The IV&V Facility started performing analysis on selected OCO spacecraft flight software in 2006. IV&V supported the Spacecraft Critical Design Review held in February, the Mission Critical Design Review held in August and 4 ACS reviews held at the developer's site.

Conducted in an impressive "badgeless" manner, the ACS reviews engaged contributors from all levels and centers in open dialogue at the onset of the project and was receptive to IV&V's recommendation. IV&V expects to work effectively with the project and has already performed a criticality assessment and system requirements review, and has begun performing requirements and traceability analysis. *"...IV&V team evaluations and recommendations represent a detailed analysis of the products delivered…"*

OUTREACH: Educator Resource Center GLOBE Program



GLOBE (Global Learning and Observations to Benefit the Environment) is an exciting international initiative funded in partnership with NASA and the NSF and run through a cooperative agreement by University Corporation for Atmospheric Research and Colorado State University that allows students in 109 countries and at all grade levels to engage in authentic scientific research. Using strictly defined experimental protocols, participants collect environmental monitoring data sets that are uploaded through the GLOBE webiste (www.globe.gov) and then made freely available to students and other researchers worldwide. The ERC and the Math Science and Technology Consortium train teachers statewide in the use of GLOBE protocols with funding from the *No Child Left Behind Improving Teacher Quality* grant program. Todd Ensign, Program Manager for the NASA IV&V Educator Resource Center and Assistant Professor of Geoscience at Fairmont State, the GLOBE coordinator for the state of West Virginia, made his third overseas trip promoting GLOBE this year. The American contingent included Deb Hemler, Professor of Geoscience Education, Tom Berlin, Land Cover expert from Alderson-Broaddus College, and Tiffany Litton, Lewis County High School teacher. In August 2006, the team worked side by side with trainers from Nigeria, Cameroon, and South Africa to train over 80 teachers, professors, and local scientists in the first GLOBE workshop in the most populous country in Africa. Plans are underway for a May 2007 workshop in Ondo State and a federal government sponsored workshop in Abuja, the capitol of Nigeria.

IV&V SERVICE: Solar Dynamics Observatory (SDO)

IV&V Project Manager: Thomas Robinson; IV&V Deputy Project Manager: Judi Connelly
Contractor: Northrup Grumman Information Technology
Project Manager: Jennilyn Ball

The Solar Dynamics Observatory (SDO) mission. part of NASA's "Living with a Star" program, will help us develop a better scientific understanding of the solar variations that directly affect Earth's magnetic fields and atmosphere. SDO is scheduled to launch in August of 2008.

There are three primary scientific investigations being implemented on the spacecraft observatory:

1) The Helio-seismic Magnetic Imager (HMI) will image the Sun's helio-seismic and magnetic fields over the Sun's entire visible disk and help us understand the Sun's interior and magnetic activity.

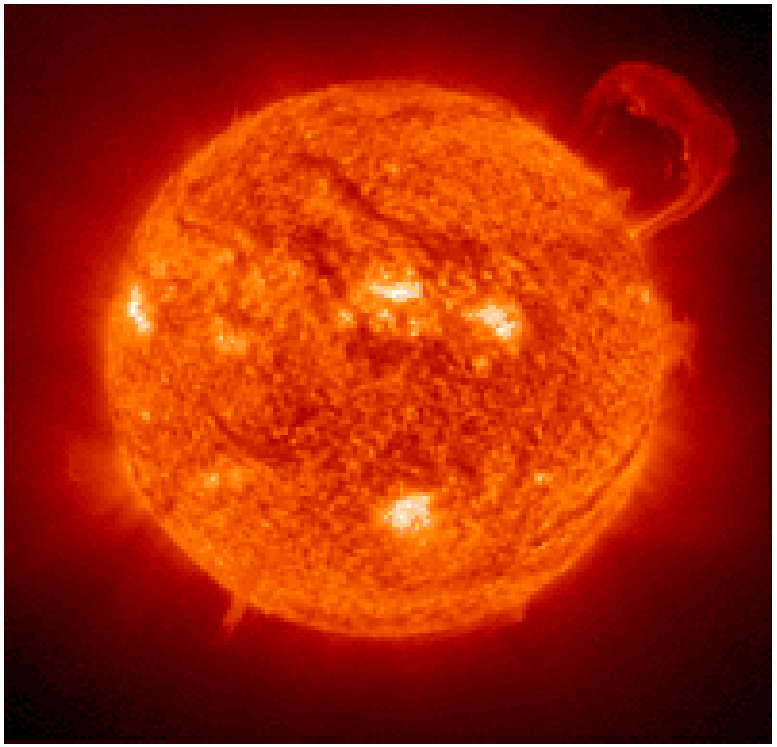
2) The Atmospheric Imaging Assembly (AIA) and Guide Telescopes (GT) will capture multiple, simultaneous, full-Sun-view high resolution images of the Sun's chromosphere and low corona over a wide range of temperatures.

3) The Extreme Ultraviolet Variability Experiment (EVE) will measure the solar extreme ultraviolet (EUV) spectral irradiance to help us understand solar variations.

NASA IV&V began analysis of the SDO spacecraft and instrument flight software in March 2004.

The latest IV&V initiatives include assessment of mission operational scenarios ("treads") and evaluation of the spacecraft software operating systems.

NASA IV&V and the SDO project's excellent working relationship has resulted in a number of spacecraft flight software technical issues being identified and successfully resolved.



IV&V SERVES EARTH SCIENCE

For further information on SDO, visit http://sdo.gsfc.nasa.gov/

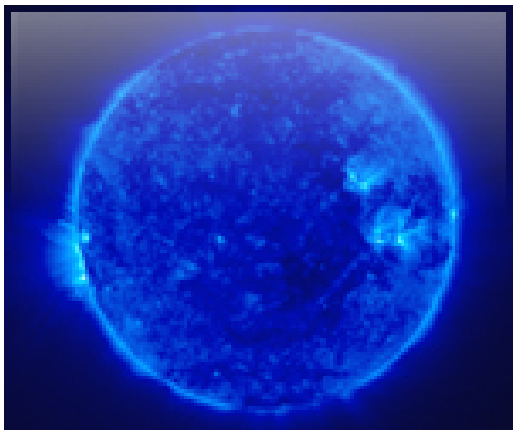
IV&V SERVICE: Solar Terrestrial Relations Observatory (STEREO)

IV&V Project Manager: Steve Pukansky
Contractor: SAIC and L-3 Communications Titan Corporation
Project Manager: Steve Husty

The STEREO mission will provide a new perspective on solar eruptions by imaging Coronal Mass Ejections (CMEs) and background events from two observatories simultaneously. To obtain unique views of the Sun, the twin observatories must be placed into a challenging orbit where they will be offset from one another. One observatory will be placed "ahead" of the Earth in its orbit and the other "behind" using a series of lunar swing-bys. Just as the slight offset between your eyes provides you with depth perception, this placement will allow the STEREO observatories to obtain 3-D images of the Sun.

The STEREO twin spacecraft were launched on October 25, 2006. Both spacecraft are functioning normally and will be in position to produce the first 3-D images of the sun by April of 2007.

For further information about STEREO, visit http://stp.gsfc.nasa.gov/missions/stereo/stereo.htm



The IV&V team performed change analysis on the STEREO flight software (FSW). IV&V's evaluation of the STEREO flight software (FSW) is that it has been thoroughly tested. All IV&V TIMs have been adequately addressed by the developers. Based on this analysis, the IV&V team concludes that the STEREO FSW does not pose a risk to the Mission and is ready to fly.

The analysis performed by the team provided additional assurance that the STEREO FSW would operate as advertised. In addition, the testing of the FSW by the developer (JHU/APL) in both the "nominal" and "off-nominal" modes of operation provided additional assurance that the FSW would operate as specified. *"I have received positive feedback that the IV&V support to the project has been beneficial as an independent check and balance."*

RESEARCH: Tandem Experiments in Finding Faults During Model-Based Development

Model-based development centers the software development effort on models of the intended software behavior and relies on code generation to produce the production software. Existing V&V analysis processes and tools do not readily accommodate models that contain numeric data variables involved in interrelated constraints including most control models expressed in languages such as Simulink® and SCADE. Such models are being used increasingly for NASA missions such as STEREO. New analysis methods and an expanded V&V toolset are required to effectively perform V&V on flight-critical software developed using such models. The effectiveness of existing V&V methods when data variables are present is currently very limited. This project aims at developing and empirically assessing alternatives to existing techniques.

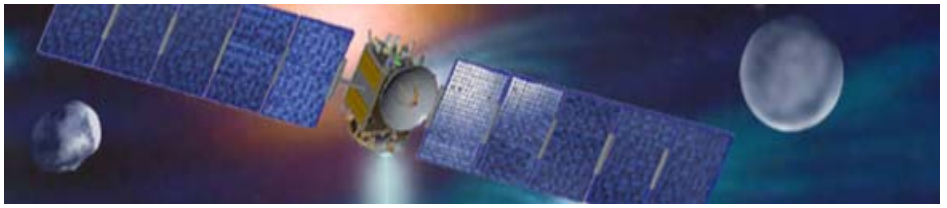
IV&V SERVICE: Dawn

IV&V Project Manager: Stephanie Ferguson
Contractor: L3-Com/munication Titan Corporation
Project Managers: Bob Jarrett and Van Casdorph

DAWN's goal is to characterize the conditions and processes of the Solar System's earliest epoch by investigating in detail Ceres and Vesta, which reside in the asteroid belt between Mars and Jupiter. Ceres and Vesta are two of the largest protoplanets remaining intact since their formation. DAWN will provide data on the role of size and water in planetary evolution and form a bridge between the exploration of the rocky inner Solar System and the icy outer Solar System.

DAWN will complete the first-order exploration of the inner Solar System, address NASA's goal of understanding the origin and evolution of the Solar System and complement ongoing investigations of Mercury, Earth and Mars.

For further information about DAWN, visit http://dawn.jpl.nasa.gov/



The IV&V Facility continued performing analysis on selected DAWN spacecraft and digital control interface flight software (FSW).

This year, IV&V completed analysis on portions of the On Board Computer (OBC FSW). IV&V began work on Requirements Test Matrix test case analysis. Throughout our involvement, the DAWN project has been very supportive of IV&V activities and has agreed with the majority of our findings. *"...meeting all of our project's expectations."*

OUTREACH: **Podcasting in West Virginia Classrooms** Podcasting allows teachers and students to listen to lectures or lessons, the latest news events, and much more, on demand. Podcasts are free and can deliver educational content for viewing on a computer or portable device, such as an iPod, freeing learning from constraints of the physical classroom. Once teachers subscribe to a podcast appropriate for classroom use or their own professional development, the audio files are downloaded and instantly ready for integration in the learning process. Through a K-12 Teacher grant provided by the West Virginia NASA Space Grant Consortium, 50 WV teachers from Clay, Marion, and Upshur counties traveled to the NASA IV&V Facility's Educator Resource Center (*ERC*) and received training in locating, downloading, managing, and integrating podcasts in their classrooms. They also received an iPod Nano and a set of portable speakers and equipment to develop and publish the WV Science Podcast for educators, located at www.wvglobe.org/podcast/. This podcast is an "ask the scientist" series, where students' questions are answered by experts from West Virginia University, Fairmont State University, A-B College, Glenville State College, and West Virginia State University. *"With the plethora of new technology flooding the educational environment, training like this is invaluable for those of us who are 'digital immigrants.' Please keep us up-to-date with these advances in technology and professional development opportunities."*

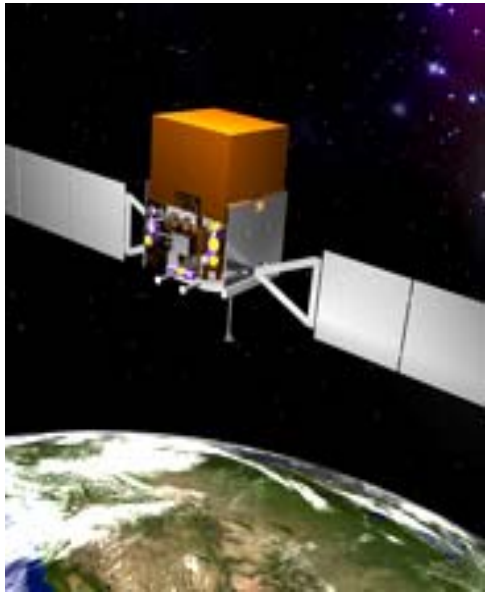
IV&V SERVICE: Gamma Ray Large Area Space Telescope (GLAST)

IV&V Project Manager: Steve Pukansky
Contractor: Northrop Grumman Information Technology
Project Manager: Shirley Savarino

The Universe is home to numerous exotic and beautiful phenomena, some of which can generate almost inconceivable amounts of energy. The Gamma-ray Large Area Space Telescope (GLAST) will open the high-energy world of black holes to exploration.

GLAST is part of the Structure and Evolution of the Universe (SEU) theme, one of four major science themes within the NASA Office of Space Science. Through the SEU program, scientists seek to explore the limits of gravity and energy in the Universe, explain the structure of the Universe, and forecast our cosmic destiny.

For this unique endeavor, one that brings together the astrophysics and particle physics communities, NASA is teaming up with the U.S. Department of Energy and institutions in France, Germany, Japan, Italy and Sweden. The launch is scheduled for May of 2007.



The Facility is performing IV&V for the GLAST Spacecraft Flight Software that includes analysis activities for the Command and Data Handling (C&DH), Guidance Navigation and Control (GN&C) and the Large Area Telescope (LAT).

Activities in 2006 included code and test analysis of the flight software and design analysis of the GN&C element. Code analysis activities resulted in identified bugs. IV&V also participated as a member of a tiger team exercise on LAT to troubleshoot an erroneous reset during which a bug was identified. Test analysis was peer reviewed with the project office, sustaining engineering and the development team.

GN&C design analysis is identifying discrepancies with the GN&C model and associated logic implementation errors, including unit discrepancies and model implementation. The GLAST project office and development teams have accepted IV&V findings and have made the necessary corrections as appropriate.

For further information about GLAST visit http://glast.gsfc.nasa.gov

IV&V SERVICE: Interstellar Boundary Explorer (IBEX)

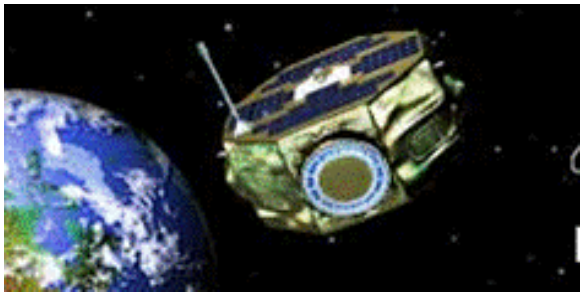
IV&V Project Manager: Tom Macaulay
Contractor: Northrop Grumman Information Technology
Project Manager: Kevin Morgan

The Interstellar Boundary Explorer (IBEX) is the first satellite designed to detect the edge of the Solar System. The area of the galaxy between stars is called the "interstellar medium". The area of the galaxy between other stars and our sun is called the "local interstellar medium." It is composed of particles from our sun's solar wind, from the solar winds of other stars, from novae and from supernovae. IBEX will make the first map of the boundary between our Solar System and interstellar space.

The IBEX spacecraft will orbit the earth in a highly elliptical orbit (approximately 50 earth radii by 1 earth radius), point the Energetic Neutral Atoms (ENA) imagers away from the Sun, and capture particles. The ENA imagers will capture the desired ENAs, and the electrons, ions, and ultraviolet light (UV). Collimators within each instrument filter out all but the ENAs and UV. Downstream of the collimators, the neutral particles are converted to ions, and electrostatic analyzers select the ionized ENAs for study.

Studying the captured ENAs will allow scientists to characterize the edge of our Solar System and help them discover the global interaction between the solar wind and the interstellar medium. Consider this: NASA's longest-lasting mission, Voyager 1, was launched nearly thirty years ago, on September 5, 1977, and Voyager 1 is *currently* passing through the edge of the Solar System. Within hours of its June 2008 launch, the IBEX instruments will start receiving data that will corroborate and expand on the information being gathered by Voyager 1.

For further information about IBEX, visit http://www.ibex.swri.edu/



The NASA IV&V team is focusing requirements, design, code, and test analyses on the IBEX spacecraft's Flight Computer, Battery Charge Regulator, Attitude Control Electronics, and the Combined Electronics Unit, components critical to the success of the IBEX mission. The IV&V team will also be reviewing ground software, to verify that data is properly received on the ground and that scientists' and ground controllers' commands are properly delivered, received, and executed on board the satellite.

IV&V findings are being reviewed by the IBEX software development team, which has been very responsive in making required changes, thereby reducing, if not eliminating, potential software defects and contributing to mission success.

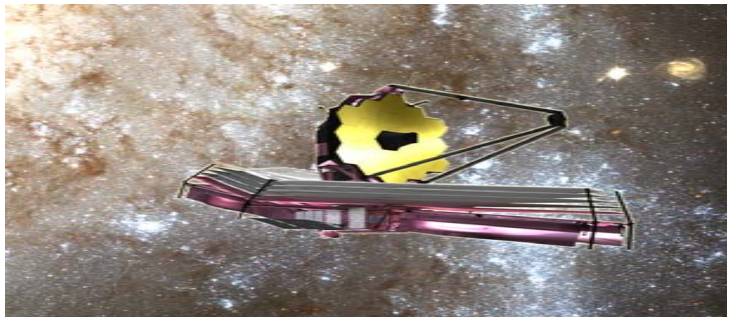
IV&V SERVICE: James Webb Space Telescope (JWST)

IV&V Project Manager: Ken Vorndran IV&V Deputy Project Manager: Jerry Sims
Contractor: L3-Communication Titan Corporation
Project Manager: Bob Jarret

The James Webb Space Telescope (JWST) is an orbiting infrared observatory, scheduled for launch in 2013, that will take the place of the Hubble Space Telescope. The JWST will study the Universe at the important but previously unobserved epoch of galaxy formation. It will peer through dust to witness the birth of stars and planetary systems similar to our own. Using JWST, scientists hope to get a better understanding of the intriguing dark matter problem. JWST is designed to study the earliest galaxies and some of the first stars formed after the Big Bang. These early objects have a high red-shift from our vantage point, meaning that the best observations for these objects are available in the infrared. JWST's instruments will be designed to work primarily in the infrared range of the electromagnetic spectrum, with some capability in the visible range. Some of the goals of the JWST mission include:

- determine the shape of the Universe;
- explain galaxy evolution;
- understand the birth and formation of stars;
- determine how the planetary systems form and interact;
- determine how the Universe came to have its present chemical/elemental composition; and,
- probe the nature of dark matter.

For further information about JWST, visit http://www.jwst.nasa.gov/



Throughout this year the IV&V Facility has performed IV&V on the spacecraft, Integrated Science Instrument Module (ISIM) and JWST instruments (Mid-Infrared Instrument (MIRI), Near-Infrared Spectrograph (NIRSpec), Near-Infrared Camera (NIRCam), Fine Guidance Sensor (FGS)). Specific analysis performed included requirements, traceability, design, code and test program analysis. These activities resulted in the early identification of and removal of defects.

IV&V SERVES SPACE SCIENCE

RESEARCH: 2006 Office of Safety and Mission Assurance Software Assurance Symposium (SAS 06) *"As an SMA Director, I have attended the annual SAS to keep current on NASA Software Assurance challenges. This year's event followed the established tradition of continual improvement, providing great technical variety and Q&A opportunity in the break cuts. You have definitely raised the bar and I look forward to the 2007 SAS." William Wessel, GRC*

"The NASA IV&V Facility in WV and the annual SAS opportunity for collaborative technical exchange is a precious resource to the entire NASA community. Coupling this superb annual effort with a companion session at selective NASA community sites will give our nation's space exploration efforts the assurance of having the software and hardware systems that will prevail in the most unusual circumstances with successful results." Dudley Killam, JPL

IV&V SERVICE: Kepler

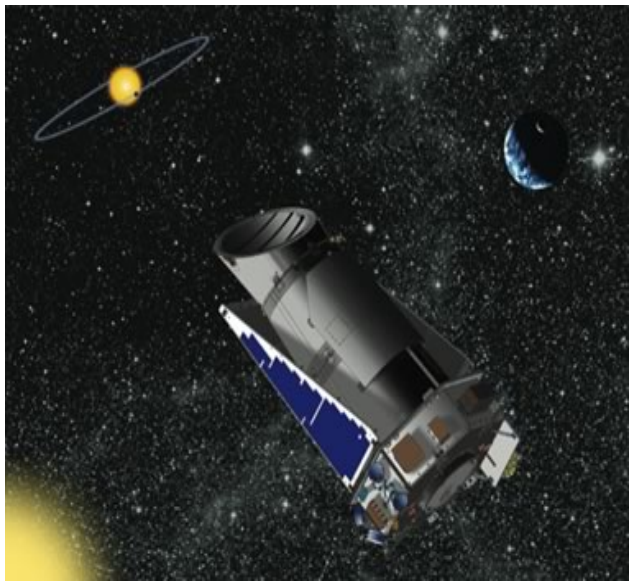
IV&V Project Manager: Richard Grigg
Contractor: L3 –Communication Titan Corporation
Project Manager: Travis Dawson

Kepler is a special-purpose space mission in the NASA Headquarters Discovery Program for detecting terrestrial planets around other stars—meaning rocky and Earth-size planets. When a planet passes in front of (or transits) its parent star, as seen by us, it blocks a small fraction of the light from that star. If the dimming is truly caused by a planet, then the transits must be repeatable.

Observing a minimum three transits, all with a consistent period, duration, and change in brightness provides a rigorous method for discovering and confirming planets—planets even smaller than the Earth. From the brightness change, the planet size can be calculated. From the period, the orbital size can be calculated and the planet's temperature estimated. Kepler will work with earth-bound telescopes to verify the planets it discovers.

The IV&V Facility began performing analysis on the Kepler Mission in 2004. Since Kepler has only one instrument the flight software and instrument software has been combined into one set of software called the Kepler Control Box (KCB). Analysis of the KCB spacecraft concept, requirements and design documentation has been achieved, and analysis of the software code is underway.

The IV&V team also supported the spacecraft and mission Critical Design Reviews. The Kepler Project has been very responsive to the findings of the IV&V team.



In addition to finding Earth-like planets, the Kepler mission will strive to learn about the structure and diversity of planetary systems. Some of the things we hope to learn are the size, mass, frequency, and semi-major axes of planets in or near the habitable zone of a wide variety of stars. Kepler will help us estimate the frequency and orbital distributions of planets in multiple-stellar systems. The Kepler mission also supports the objectives of the NASA Origins Space Interferometry Mission (SIM) and Terrestrial Planet Finder (TPF) Mission.

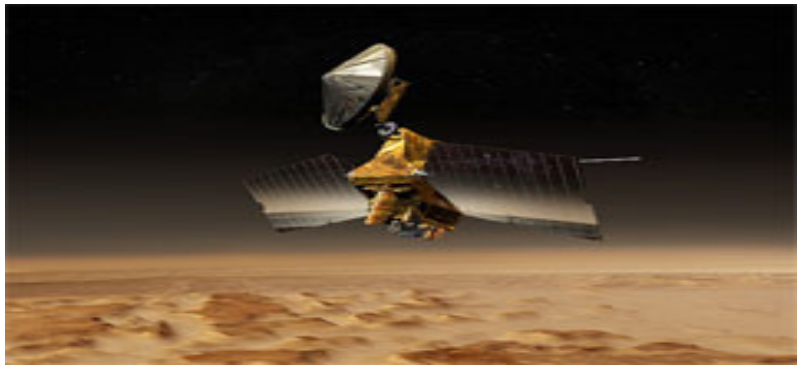
For further information about Kepler, visit http://www.kepler.arc.nasa.gov/

IV&V SERVICE: Mars Reconnaissance Orbiter (MRO)

IV&V Project Manager: Richard Grigg
Contractor: L3-Com/munication Titan Corporation
Project Manager: Travis Dawson

NASA's Mars Reconnaissance Orbiter (MRO), launched August 12, 2005. While other Mars missions have shown that water flowed across the surface in Mars' history, it remains a mystery whether water was ever around long enough to provide a habitat for life. After a seven-month cruise to Mars and six months of aerobraking to reach its science orbit, MRO started its science phase in November of 2006 to find out about the history of water on Mars with its science instruments.

In its survey of the red planet, MRO will increase tenfold the number of spots surveyed close-up. One of the MRO's cameras is the largest ever flown on a planetary mission. Its imaging spectrometer is also able to look at small-scale areas about five times smaller than a football field, at a scale perfect for identifying any hot springs or other small water features. The Orbiter's telecommunications systems will establish a crucial service for future space craft, becoming the first link in a communications bridge back to Earth, an "interplanetary internet" that can be used by numerous international spacecraft in coming years. Testing the use of a radio frequency called Ka-band, MRO has demonstrated the potential for greater performance in communications using significantly less power. The Orbiter also carries an experimental navigation camera.



The Facility performed IV&V on MRO's flight software. Specific analysis included requirements, traceability, interface, code and test analysis. The MRO project has responded positively and addressed issues identified by IV&V. *"The MRO project and the IV&V team worked well together towards a common goal: a successful MRO mission. A process was defined that enabled both organizations to complete their assigned tasks without conflicting with one another and together they reduced the risk posture of the mission."*

For further information about MRO, visit http:// mars.jpl.nasa.gov/mro/

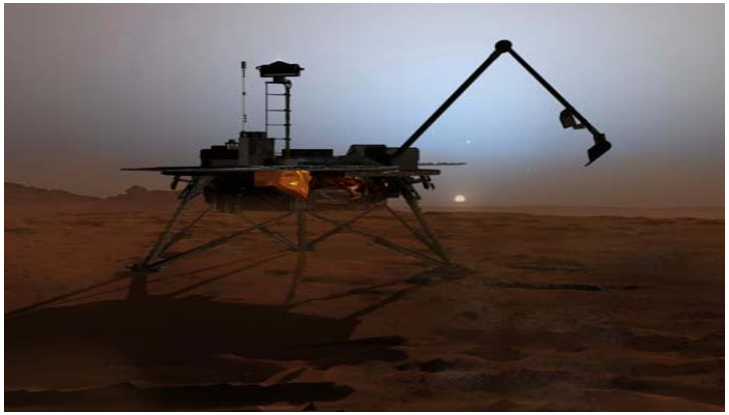
IV&V SERVICE: Mars Scout Phoenix Lander (PHOENIX)

IV&V Project Manager: Dan Solomon
Contractor: L3-Communication Titan Corporation (May 11, 2005 – August 3, 2005)
Project Manager: Travis Dawson Northrop Grumman (August 4, 2005 – Present) Project Manager: Lisa Nicklow

The Phoenix mission is the first chosen for NASA's Scout program, an initiative for smaller, lower-cost, competed spacecraft. Named for the resilient mythological bird, Phoenix uses a lander that was intended for use by 2001's Mars Surveyor mission prior to its cancellation. It also carries a complex suite of instruments that are improved variations of those that flew on the lost Mars Polar Lander.

In the continuing pursuit of water on Mars, the poles are a good place to probe, as water ice is found there. Phoenix will land near the icy northern pole of Mars between 65 and 75 degrees latitude. During the course of the 150 Martian day mission, Phoenix will deploy its robotic arm and dig trenches up to half a meter (1.6 feet) into the layers of water ice. These layers, thought to be affected by seasonal climate changes, could contain organic compounds that are necessary for life. To analyze soil samples collected by the robotic arm, Phoenix will carry an “oven" and a "portable laboratory." Selected samples will be heated to release volatiles that can be examined for their chemical composition and other characteristics. Imaging technology inherited from both the Pathfinder and Mars Exploration Rover missions will also be implemented in Phoenix's stereo camera, located on its 2-meter (6.6-foot) mast.

The camera's two "eyes" will reveal a high-resolution perspective of the landing site's geology, and will also provide range maps that will enable the team to choose ideal digging locations. Multi-spectral capability will enable the identification of local minerals. To update our understanding of Martian atmospheric processes, Phoenix will scan the Martian atmosphere up to 20 kilometers (12.4 miles) in altitude, obtaining data about the formation, duration and movement of clouds, fog, and dust plumes. It will also carry temperature and pressure sensors.



The IV&V Facility is performing 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. The IV&V team completed analysis of the software and interface requirements and design. Analysis continues on the code and test artifacts. Although IV&V did not find issues that could prevent accomplishment of any essential capability, they did discover several issues which could adversely affect the accomplishment of essential capabilities. Corrections have been found for all of these issues.

For further information about Phoenix, visit http://phoenix.lpl.arizona.edu

IV&V SERVICE: Mars Science Laboratory (MSL)

IV&V Project Manager: Peter Medley
Contractor: Northrop Grumman Information Technology
Project Manager: Shirley Savarino

In line with the new Vision of Space Exploration that NASA has embarked on, Mars Science Laboratory (MSL) will continue the exploration of Mars which has so successfully been performed by the two Mars Exploration Rovers Spirit and Opportunity.

MSL will continue to search for the existence of life or evidence of pre-existing life. In addition, the recent discoveries of evidence of flowing water near or above the surface of Mars lends itself to the additional goals of determining the survivability and habitability for human exploration.

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. High resolution imaging instruments will provide for both still and video recording of the Martian surface which will combine with the high resolution images currently being returned by Martian Reconnaissance Orbiter (MRO) to provide a detailed 3-D surface map of Mars.

For further information about MSL, visit http://mars.jpl.nasa.gov/msl/

IV&V will be performed on selected software components as described in the MSL Critical Functions List (CFL) Report created by IV&V. All major software subsystems of the project will be analyzed, including Rover Compute Element Flight Software, Instrumentation and Ground Data Systems. IV&V is already providing feedback to the project on issues that have been identified by the analysis being performed as well as on issues raised during appropriate project reviews and walkthroughs. IV&V has also provided feedback to the project on risk management processes and associated impact.

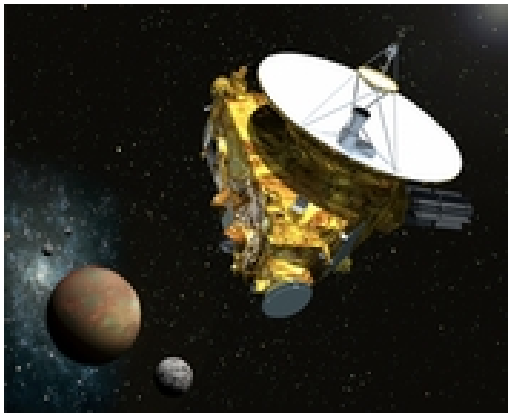
IV&V SERVES SPACE SCIENCE

RESEARCH: **Contingency Software in Autonomous Systems** The need for autonomous agents, such as the Mars Rovers, will increase as NASA fulfills new exploration objectives. These new autonomous vehicles, such as rotorcraft and spacecraft, operate in harsh environments with limited capacity to mitigate failures. Currently, when a failure occurs, vehicles may switch to a safe mode while ground crews devise a solution. Solutions are difficult because failures are hard to pinpoint and contingencies may be too complex, novel or high-risk for current autonomous software. This work will enhance diagnostic techniques to identify failures, provide software contingency planning to mitigate failures, perform tool-based verification of contingency software and investigate contingencies in safely relinquishing control to autonomous controllers. Results, applied to current NASA programs, will pave the way to more resilient, adaptive unmanned systems.

IV&V SERVICE: New Horizons Pluto-Kuiper Belt (PKB)

IV&V Project Manager: Peter Medley
Contractor: L-3 Communication Titan Corporation
Project Manager: Van Casdorph

Pluto, the smallest planet, is the only planet not yet visited by a spacecraft. Discovered in 1930, it is sometimes likened to a large asteroid or comet, or even a double planet system, since its moon Charon is about half the diameter and mass of Pluto. Today it is understood that both Pluto and Charon were former inhabitants of the mysterious Kuiper Belt which resides outside the orbit of Neptune. Most of what we know about Pluto we have learned since the late 1970s from ground-based observations, the Infrared Astronomical Satellite (IRAS), and the Hubble Space Telescope. Many of the key questions about Pluto and its satellite Charon await the close-up observation of a space flight mission.

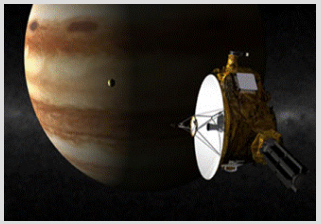


IV&V was performed on selected software components as described in the New Horizons Critical Functions List (CFL) Report created by IV&V. All major software subsystems of the project were analyzed, including Guidance & Control, Command & Data Handling, Autonomy, Instrumentation, and Ground Systems Requirements. IV&V has provided feedback to the project on issues that have been identified by the analysis being performed as well as on issues raised during appropriate project reviews and walkthroughs. IV&V has also provided feedback to the project on risk management processes and associated impact.

The spacecraft will use a remote sensing package that includes imaging instruments and a radio science investigation, as well as spectroscopic and other experiments, to characterize the global geology and morphology of Pluto and its moon Charon, map their surface composition, and characterize Pluto's neutral atmosphere and its escape rate. New Horizons spacecraft is on the doorstep of the solar system's largest planet. The spacecraft will study and swing past Jupiter, increasing speed on its voyage toward Pluto, the Kuiper Belt and beyond. The fastest spacecraft ever launched, New Horizons will make its closest pass to Jupiter on Feb. 28, 2007. Jupiter's gravity will accelerate New Horizons away from the sun by an additional 9,000 miles per hour, pushing it past 52,000 mph and hurling it toward a pass through the Pluto system in July 2015.

For further information about New Horizons, visit http://solarsystem.jpl.nasa.gov/missions/profile.cfm?Sort=Target&Target=Pluto&MCode=PKB

OUTREACH: **New Horizons Educator Workshops** The NASA IV&V Facility Educator Resource Center hosted a number of New Horizons mission workshops for West Virginia educators at the Facility, at schools across the state, and at the WV Science Teachers' Association Conference. The workshops were designed to train educators about the discovery of Pluto, the scientific expectations of the New Horizons mission, and how to relate the mission to younger learners. Through a partnership with the Maryland Science Center, the ERC also hosted a Teachers' Thursday video-conference and hands-on activity session at which Dr. Hal Weaver of JHU's Applied Physics Laboratory spoke about the scientific rationale for the mission.



IV&V SERVICE: Time History of Events and Macroscale Interactions During Substorms (THEMIS)

IV&V Project Manager: Judi Connelly
Contractor: Northrop Grumman Information Technology/Keylogic
Project Manager: Eric Sylvania

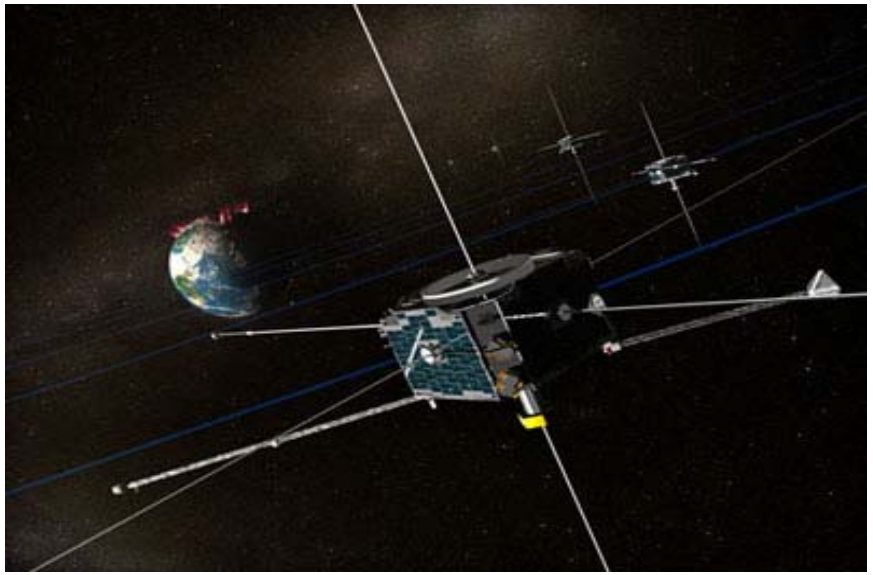
IV&V SERVES SPACE SCIENCE

THEMIS is a NASA Explorers Mission that will study the onset and evolution of Magnetospheric Substorms. Five identical probes will be deployed simultaneously minutes after launch. Over the following months these will be stationed throughout the Earth's Magnetic Field (magnetotail). The probes will coordinate measurements with 20 ground stations to measure the solar wind interactions with the magnetic field producing the onset of Northern Auroral storms. The result will answer 30-year-old questions in Magnetospheric Physics, such as:

1) How does the Earth's magnetosphere process solar wind energy?
2) What is the delineation between the cause and effect of main substorm processes?

The results of this mission will provide a better understanding of the dynamics of the Sun-Earth environment in which our communication and science satellites operate. What is the sequence of events that triggers these auroral eruptions? One theory proposes that the solar wind disrupts a sheet of moving charged particles about 10 Earth radii down the magnetotail, triggering the eruption, then causing the Earth's magnetic field to reconnect. A second theory proposes that magnetic reconnection happens first, at about 25 Earth radii, which then disrupts the sheet of current to trigger the substorm.

THEMIS is named after the Greek goddess of justice, often called "blind justice," because it will impartially decide which comes first, current disruption or magnetic reconnection. Spread out along the magnetotail, THEMIS will time the sequence of electrical discharges and magnetic field changes, and coordinate with ground-based cameras spread over Alaska and Canada, to discover the time history of these events.



For the past three years IV&V has focused on the flight software for instruments and flight avionics critical for the successful collection of science data as well as various orbit maneuvering required throughout the mission lifetime.

Specific analysis performed included requirements, traceability, design code and test. These analyses resulted in mitigation of programmatic and residual risks and identification of specific issues within software artifacts. *"..extremely pleased with IV&V PM performance."*

For further information about THEMIS, visit http://ds9.ssl.berkeley.edu/themis/flash.
http://www.nasa.gov/mission_pages/themis/main/index.html

IV&V SERVICE: Lunar Reconnaissance Orbiter (LRO)

NASA IV&V Project Lead: Deborah Kromis (through 11/06); Melissa S. Northey (11/06-present)
Contractor: Northrup Grumman Information Technology
Project Manager: Eric Sylvania

The Lunar Reconnaissance Orbiter (LRO) is the first of the Lunar Precursor and Robotic Program (LPRP) missions, planned for launch by late Fall 2008 and will orbit the Moon for at least one year. LPRP missions to the moon will prepare for and support future exploration activities to enable sustained human and robotic exploration of Mars and more distant destinations in the solar system. The LRO will carry an instrument complement that includes six instruments to achieve the LRO specific objectives to:

- characterize the lunar radiation environment, biological impacts, and potential mitigation;
- determine a high resolution global, geodetic grid of the Moon in 3 dimensions;
- assess in detail the resources and environments of the Moon's polar cap regions; and,
- perform high spatial resolution of the Moon's surface.

For more information on LRO, the Lunar Precursor and Robotic Program, visit http://lunar.gsfc.nasa.gov/.

The IV&V Program began work on the LRO software in 2006. The scope of the work includes the spacecraft flight software, software for four instruments, and limited ground system software. For the spacecraft flight software, which includes the Command and Data Handling (C&DH), Guidance, Navigation, and Control (GN&C), and the Core Flight Executive (cFE), the IV&V team performed requirements and code analyses as well as limited design and test analyses. For the four instruments in scope (LOLA, LAMP, LROC, and Diviner), the IV&V team performed requirements and design traceability analyses and will continue with test analysis in the upcoming year. The ground system work is scheduled to begin in January 2007 after the Ground Systems Single Design Review (SDR). In November 2006, the IV&V team presented at the LRO Mission Critical Design Review (CDR) where IV&V was lauded for *"the value-added contribution to the flight software development."*

RESEARCH: **Engineering Research/Developer Collaborations** The NASA Software Engineering Initiative Research Infusion is an innovative effort to ensure that theoretical research supports current practicalities. These initiatives pair cutting-edge research with a current development project. The goal is to make sure research that looks good in the lab translates seamlessly to practice. One of the challenges with our work is finding new ways to make our test conditions as much like the real thing as possible. The research infusion effort is our way to make sure that a theory works even under the less than ideal reality inherent in most human-led efforts. In 2006 there were three Research Infusion initiatives: Application of SCR to ISS Biological Research Project On-Orbit Crew Displays at ARC, Application of SpecTRM at JPL's Advanced Project Design Team (TeamX) and Infuse Code Surfer into NASA Code S IV&V Process.

IV&V SERVICE: International Space Station (ISS)

IV&V Project Manager: Deborah Kromis (through November 06) Markland Benson (December 06-present)
Contractor: L3-Communication Titan Corporation
Project Manager: Don Ohi

The International Space Station (ISS) is an Earth-orbiting platform providing a permanent human presence in space. The vision of the ISS Program is to produce international cooperation, advance scientific discovery, enable exploration of the universe, and stimulate commerce in space. The Russian Space Agency, European Space Agency, Japan Aerospace Exploration Agency, and other international partners cooperate with NASA in the construction, maintenance, and utilization of ISS. 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.

The software baseline for ISS is largely complete but continues to be updated by new releases to provide new capabilities and ensure safe operation. IV&V is an integral partner in assuring that software for ISS is of the highest quality. IV&V analysts cover areas of guidance, navigation and control, human-computer interface, internal and external systems (including power generation and existing life support), command and control, next generation life support, and integrated systems testing.

The depth and breadth of knowledge and experience in systems and software applied by IV&V on ISS made IV&V a primary contributor of technical findings, which improved the quality and safety of ISS software system, laboratory system and external control zone software that were transitioned to operation. Analyses on these systems included requirements review, design and implementation verification and analysis of testing performed. Additionally, IV&V created traceability between ISS hazard reports and Node 3 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.

IV&V also evaluated the firmware controllers for the Space Integrated Global Positioning System/Inertial Navigation System and the Regenerative Environmental Control and Life Support Racks. These regenerative racks include the Oxygen Generation Assembly, the Water Processing Assembly, and the Urine Processing Assembly, all of which are needed to support a larger crew for the ISS. *"The IV&V team has been of great value to ISS software and has done a great job...technical excellence, great constructive attitude, good judgment, excellent communication."*

IV&V SERVICE: Personal Computer Ground Operations Aerospace Language 2 (PCG2)

IV&V Project Manager: Raju Raymond
IV&V Contractor: L3-Communication Titan Corporation
Project Manager: Daniel Victor

The PCG2 system is an advisory system consisting of a set of computer platforms, network hardware and software aimed at providing increased situational awareness for Shuttle processing personnel. The PCG2 system collects, merges, and filters data from other Shuttle ground processing systems and provides it to the user for display. The PCG2 system leverages off of the existing PC GOAL Certified Data Advisory System, providing new system advisory capabilities and enhancing existing ones.

The ability to understand what is going where during Space Shuttle processing or launch operations is increased through additional and enhanced system capabilities, and through additional advisory applications and user displays that execute on the PCG2 system. The PCG2 system has no command and control capabilities, but the PCG2 software and hardware system will be certified for use on the Space Shuttle Program such that it can be used to perform advisory functions.

Possible advisory functions include using the PCG2 system to verify that Space Shuttle Operational and Maintenance requirements are being met, make Launch Commit Criteria violation calls, monitor trends, or perform data analysis, system troubleshooting, and problem resolution.

During the past year IV&V evaluated PCG2 software products and provided improvement recommendations. Recommendations included criteria for bringing design into conformance with the National Space Transportation System 07700 requirements, input into requirements and design templates, methods for capturing system concept of operations, and improvements to the PCG2 software implementation standard.

Further, IV&V participated in peer reviews and technical review panels for software in development and maintenance. In these forums, IV&V inputs were provided to improve software quality with minimal impact on cost and schedule. IV&V assisted PCG2 in adopting an automated static code analyzer to help eliminate several classes of implementation errors prior to testing. *"IV&V team is open with regard to comments and issues and we work well together."*

IV&V SERVICE: Space Shuttle

IV&V Project Manager: Melissa J. Bodeau
Contractor: L3-Communication Titan Corporation
Project Manager: John Bradbury

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. The Shuttle launches like a rocket, maneuvers in Earth orbit like a spacecraft and lands like an airplane. The Space Shuttle and its software are immensely complex systems. IV&V of Shuttle software is crucial to providing the high level of safety and mission assurance necessary when human life is at stake.

IV&V's work on the Shuttle primarily involves the software in the onboard General Purpose Computers (GPCs) and Multi-function Electronic Display Subsystem (MEDS), in the Space Shuttle Main Engine Controllers (SSMEC), and in the Miniaturized Airborne GPS Receivers (MAGRS-3S) flown on board. IV&V is performed on critical changes to the existing GPC, MEDS and SSMEC software, as well as several other critical software areas. Each change is analyzed with appropriate requirements, design, code, test and systems analysis tasks to ensure both the correctness of the final software and that there are no unintended consequences to the unchanged areas. In 2006, IV&V supported three Shuttle missions: STS-121, STS-115, and STS-116.

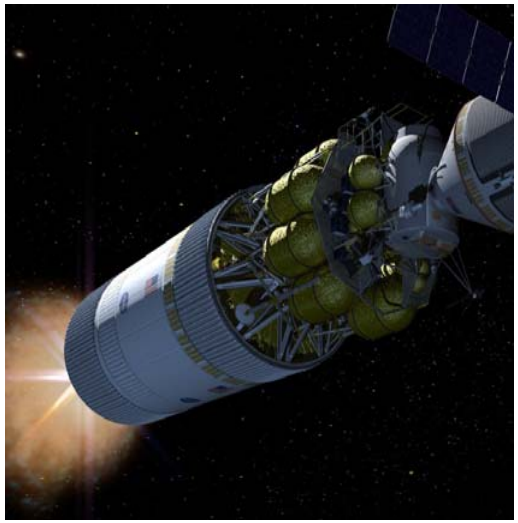
Before each Shuttle mission, we reported on our analysis at the Software Readiness Review conducted by the Shuttle Program's Flight Software Office. IV&V is also a voting participant in each mission's Safety and Mission Success Review, co-chaired by astronaut Bryan O'Connor, the Agency's Chief of Safety and Mission Assurance, and Chris Scolese, the Agency's Chief Engineer. All of the Shuttle IV&V team members are proud of our continuing contribution to the safety of the Shuttle Program and look forward to the five scheduled Shuttle missions in 2007. *"...IV&V PM is easy to work with...demonstrated a high degree of competence…"*

For further information about the Space Shuttle, visit http://spaceflight.nasa.gov/shuttle/ or http://www.nasa.gov/centers/johnson/missions/shuttle.html

OUTREACH: **Day in the Park 2006** Dr Charles Camarda, who served as Mission Specialist on STS 114 Return to Flight in 2005, held the attention of nearly 900 West Virginia seventh graders by describing the training and teamwork required for a journey to the International Space Station on board the Shuttle. His remarks were peppered with introductions by way of photographs of his teammates and descriptions of their contributions to the workings of that historic flight. He painted vivid pictures of the work that was conducted, the competence and courage of those who planned and manned the mission and the awe that they each felt at the opportunity to participate with one another in such an endeavor. It was especially inspiring to the young girls in the audience to hear this highly respected astronaut speak of his admiration for the mission's commander Eileen Collins. The young people were riveted by Dr. Camarda's description of the fifteen minutes of being surrounded by a fireball that marks the return through the earth's atmosphere.

IV&V SARP and Facility Research

The challenges we face as an Agency are those that require us to do that which has not been done before.



To support our need to find new and better ways to leverage our past successes to achieve future goals, there is always research going on. Just about everything we all do could be considered research; but there are two programmatic efforts underway specifically at IV&V.

NASA's Office of Safety and Mission Assurance sponsors the Software Assurance Research Program. Managed by IV&V, this program seeks to help us to do software better. It's hardly possible to overstate the importance of software in current and future endeavors.

The IV&V Facility also has its own research program focused more specifically on improving tools and techniques that assist us in providing independent oversight on safety and mission critical projects.

Lyapunov Stability Analysis and On-Line Monitoring (UI03)
PI: Bojan Cukic - WVU
Research Team: Bojan Cukic, Edgar Fuller, Sampath Yerramalla, Srikanth Gururajan,
Government POC: Lisa Montgomery - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/65.jsp

Model Checking Artificial Intelligence Based Planners (CI04)
PI: Margaret Smith - Jet Propulsion Laboratory (JPL)
Research Team: Klaus Havelund (JPL), Gerard Holzmann (JPL), Alex Groce (JPL), Rajeev Joshi (JPL), Anthony Barrett (JPL), Roshan Shah (JPL), Benjamin Smith (JPL)
Government POC: Allen Nikora - Jet Propulsion Laboratory (JPL)
http://sarpresults.ivv.nasa.gov/ViewResearch/57.jsp

Verification and Validation of Adaptive Systems (UI03)
PI: Bojan Cukic – WVU
Research Team: Bojan Cukic, Yan Liu, Srikanth Gururajan, Marcello Napolitano
Government POC: Lisa Montgomery - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/35.jsp

A Compositional Approach to Validation of Formal Models (UI04)
PI: Bojan Cukic – WVU
Research Team: Dejan Desovski (WVU), David Owen (WVU), Constance Heitmayer, Director of Software Engineering, Naval Research Laboratory
Government POC: Lisa Montgomery - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/64.jsp

A Software Safety Certification Plug-in for Automated Code Generators (FI06)
PI: Ewen Denney - USRA/RIACS
Research Team: Johann Schumann, Doug Greaves, Srinivas Nedunuri.
Government POC: Peter Medley - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/105.jsp

Application of SAE Architecture Analysis & Design Language (AADL) to IV&V of NASA Flight Projects (FI06)
PI: Kurt Woodham – L-3 Titan Communications Corporation
Research Team: Dave Gluch, Nick Brixius, Matt LinkEmbry Riddle Aeronautical University/Carnegie Mellon Software Engineering Institute
Government POC: Stephen Pukansky - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/99.jsp

FPGA Finite State Machine (FSM) Modeling and Analysis (FI06)
PI: Jack Smith - MATRIC
Research Team: Jack Smith, Heath Haga
Government POC: Lisa Montgomery - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/113.jsp

Research and Development of Deployable IV&V Methods for FPGA Applications (FI06)
PI: Scott Schield - Northrop Grumman Corporation (KeyLogic Systems)
Research Team: Scott W. Schield, Tim Reyes, Shan Elahi, Amy Robinson, Kevin Morgan, Shirley Savarino
Government POC: Kenneth Costello - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/118.jsp

Software Process Assurance for Complex Electronics (SPACE) (CI05)
PI: Richard Plastow – SAIC
Research Team: Richard Plastow, Kalynnda Berens
Government POC: Cynthia Calhoun - Glenn Research Center (GRC)
http://sarpresults.ivv.nasa.gov/ViewResearch/90.jsp

Bounds Computation for Adaptive Systems V&V (UI06)
PI: Giampiero Campa – WVU
Research Team: Giampiero Campa, Eddie Fuller, James Oldendick, , Marcello Napolitano, Bojan Cukic, John Burken, Sr. Engineer, NASA Dryden Flight Research Center
Government POC: Lisa Montgomery - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/115.jsp

Contingency Software in Autonomous Systems (CI04)
PI: Robyn Lutz - Jet Propulsion Laboratory (JPL)
Research Team: Robyn Lutz (JPL), Ann Patterson-Hine (Ames), Scott Poll (Ames), Anupa Bajwa (UARC/Ames), Stacy Nelson (NelsonConsult/QSS), Rob Harris (Ames), Chad Frost (Ames), Doron Tal (USRA/RIACS at NASA Ames)
and from Qualtech Systems, Inc: Sudipto Ghosal, Charles Domagala, Somnath Deb
Government POC: Allen Nikora - Jet Propulsion Laboratory (JPL)
http://sarpresults.ivv.nasa.gov/ViewResearch/55.jsp

Formal Approaches to Swarm Technologies (CI03)
PI: Christopher Rouff - SAIC
Research Team: Walt Truszkowski (GSFC), Mike Hinchey (GSFC), James Rash (GSFC), Amy Vanderbilt (SAIC)
Government POC: Walt Truszkowski - Goddard Space Flight Center (GSFC)
http://sarpresults.ivv.nasa.gov/ViewResearch/56.jsp

Field Programmable Gate Arrays (FPGAs) are an example of Programmable Logic Devices. Programmable Logic (PLC, FPGA, ASIC) devices are hybrids - hardware devices that are designed and programmed like software. As such, they fall in an assurance gray area. Programmable Logic is usually tested and verified as hardware, and the software aspects are ignored, potentially leading to safety or mission success concerns. This technology has both the potential to be key to mission success as well as a potential challenge to mission success.

Space missions have constraints of weight, power requirements, and computer memory. FPGAs, software logic burned to a computer chip, can give us advantages, but the use ups the stakes. There have been many missions saved because controllers on the ground have been able to upload a software patch or in some other way modify the code controlling the system. With developers seeking to move more functionality to PLDs, it is important to be able to assess the design and development with the same rigor we apply to other components of mission software. We have explored several aspects of the FPGA issue. One initiative that recently wrapped up, *Software Safety Assurance of Programmable Logic*, produced training now available to the NASA community working with FPGAs to improve their abilities and understanding. FPGA Finite State Machine (FSM) Modeling and Analysis and Research and Development of Deployable IV&V Methods for FPGA Applications are being studied to better exercise and analyze these devices to increase assurance that they will not negatively impact mission success.

What's the allure of an FPGA? The Space Shuttle has 5 GPCs General Purpose Computers that require over 600 watts of power and weigh 57 pounds each. Given that it costs between $4729 (LEO) and $23060 (GTO) to put a pound into orbit, it costs us more than $23,000 just to carry the GPCs. Obviously, it would be appealing to trade a bulky box for the same functionality on a computer chip weighing a few ounces and requiring less than a watt of power. The trade-off is assurance and confidence in the system. There are concerns about the life of the FPGAs. While they require less power, they may produce enough heat to have an impact on other systems.

Effective Life-Cycle IV&V of Auto-Generated Software (FI06)
PI: Kurt Woodham – L-3 Titan Communications Corporation
Research Team: Kristian "Sonny" Hammaker, (ISR), Mark Dehlin, (MATRIC)
Government POC: Kenneth Vorndran - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/104.jsp

Software Engineering Research / Developer Collaborations (RII04)
PI: Mike Hinchey - Goddard Space Flight Center (GSFC)
Research Team: Until 1 January 2006, the team was: Mike Hinchey (GSFC), Tom Pressburger (ARC), Larry Markosian (ARC), Luis Trevino (MSFC), Tim Menzies (WVU) and Martin Feather (JPL) Since 1 January 2006, the team has been: Mike Hinchey (GSFC), Tom Pressburger (ARC), Caroline Wang (MSFC), C. Michael Holloway (LaRC), Allen Nikora (JPL), Ken Chen (Johnson), Martin Feather (JPL).
Government POC: Mike Hinchey - Goddard Space Flight Center (GSFC)
http://sarpresults.ivv.nasa.gov/ViewResearch/61.jsp

Infusion of Code Surfer into TCMS Sustaining (RII06)
PI: David Moyer - The Boeing Company
Research Team: Tony Melichar, Pat Duncan, Patrick Barrett, Maria Thomas, Anne Zimmer, Robert Krochmal
Government POC: David Macon - Kennedy Space Center (KSC)
http://sarpresults.ivv.nasa.gov/ViewResearch/138.jsp

Technology Infusion of SAVE into the Common Ground Software Development Process for NASA Missions at JHU/APL (RII06)
PI: William Stratton - Johns Hopkins University / Applied Physics Laboratory (JHUAPL)
Research Team: William C. Stratton, Deane E. Sibol, Mikael Lindvall, Patricia Costa
Government POC: Mike Hinchey - Goddard Space Flight Center (GSFC)
http://sarpresults.ivv.nasa.gov/ViewResearch/121.jsp

Technology Infusion of Source Code Analysis & Error Checking into Mission Planning & Execution SW Tools at JPL (RII06)
PI: Barbara Streiffert - Jet Propulsion Laboratory (JPL)
Government POC: Keith Naviaux - Jet Propulsion Laboratory (JPL)
http://sarpresults.ivv.nasa.gov/ViewResearch/122.jsp

Center of Excellence for Traceability (or Traceability Consortium) (FI06)
PI: Jane Hayes - SAIC & University of Kentucky
Research Team: Alex Dekhtyar, Senthil Sundaram, Ashlee Holbrook, Jody Larsen, David Krieg we had assistance from: Jane Cleland-Huang, Brian Berenbach, Andrea Zisman, Olly Gotel
Government POC: Stephanie Ferguson - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/110.jsp

RESEARCH: Analysis of Defect Data and Defect Detectors

Extending previous work showing that certain defect detectors and their metrics predict defects in code will greatly benefit the Goddard Space Flight Center (GSFC) as well as the entire Agency. This research explores a focused data repository at GSFC to develop data collection and analysis of pertinent software issues.

Pilot projects at GSFC will enable case studies that demonstrate the validity of assumptions about certain defect detectors and their relationship to error prediction. After careful analysis of the process for establishing the data schema of the repository, the data collection and analyses will provide NASA with a much-needed methodology for defect detection and prediction. The research will increase GSFC and NASA enterprise software quality via case studies that yield a means of collecting, analyzing, trending and storing defect data to determine how best to predict errors in code.

Using previous findings in this area, a repository and case studies will be designed specifically for project data at GSFC, establishing a service available to all GSFC projects. A case study of the work itself will enable transfer to all NASA centers of a cost-model for developing and using such a repository, the collected metrics and defect detectors learned from them, effectiveness data on the merits of these defect detectors, the software tools developed as part of this work and guidebooks describing the methodology for using these tools.

Interface Validation for Distributed Software Systems (FI05)
PI: Pavan Rajagopal – L-3 Titan Communications Corporation
Research Team: Nikolay Nikolov (GCS), Jack Smith (MATRIC), Greg Bennett (GCS), Jason Blackhurst (MATRIC), Matthew Link, Embry Riddle
Government POC: Stephen Pukansky - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/74.jsp

Program Model Checking Case Studies and Practitioner's Guide (CI04)
PI: Thomas Pressburger - Ames Research Center (ARC)
Research Team: Masoud Mansouri-Samani, Corina Pasareanu, John Penix, Peter Mehlitz, Owen O'Malley,Willem Visser, Guillaume Brat, Lawrence Markosian, Michael Lowry, Gerald Holzmann (JPL)
Government POC: Thomas Pressburger - Ames Research Center (ARC)
http://sarpresults.ivv.nasa.gov/ViewResearch/59.jsp

Tandem Experiments in Finding Faults During Model-Based Development (CI04)
PI: Kurt Woodham – L-3 Titan Communcations Corporation
Research Team: VAjitha Rajan, University of Minnesota, Jeremy Greenwaldt, Portland State University Ryan Clark, Portland State University, Mats Heimdahl, University of Minnesota, Tim Menzies, Portland State University/West Virginia University
Government POC: Wesley Deadrick - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/62.jsp

Automated Systems Test and Operations Language (STOL) Analysis Tool (FI06)
PI: Jack Smith – MATRIC
Research Team: Jason Blackhurst
Government POC: Stephen Pukansky - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/112.jsp

Criticality Analysis Database (FI06)
PI: Jerry Williams - L3 Titan Communications Corporation
Research Team: Denise Lindsey, Llew Williams
Government POC: Kenneth Costello - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/117.jsp

IV&V Technique for Object Oriented Software Systems (CI03)
PI: Khalid Lateef - L3 Titan Communications Corporation
Research Team: Prof. Joanne Bechta Dugan, University of Virginia, Ganesh J. Pai, University of Virginia.
Government POC: Peter Medley - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/52.jsp

RESEARCH: **Lyapunov Stability Analysis and Online Monitoring** A major obstacle precludes the widespread use of ANNs (Artificial Neural Networks) in navigation and control systems: today's V&V technology cannot meet most of the certification standards that NASA and other federal agencies (such as FAA) impose on these life-critical and mission-critical applications. No existing software V&V method/technique can be applied to systems that contain online learning artificial neural networks. This project will produce a framework for reasoning about adaptive systems. The function of online adaptive systems evolves over time as they improve performance through online learning. Adaptive systems offer the advantage of using judicious learning to react to situations that the designer never individually identified and analyzed.

These systems are attracting increasing attention in application domains where autonomy is an important feature or where it is virtually impossible to forecast all possible combinations of environmental conditions that may arise. Autonomy is important, for example, in long-term space missions where communication delays to ground stations are prohibitively long and the systems' local capabilities must deal with unforeseen circumstances. Experimental success suggests significant potential for neural networks and other soft-computing paradigms in process control applications. This research will help develop autonomous learning as well as learning with confidence. These techniques will help a craft learn how to operate safely in normal states, how to react in failure modes, how to stabilize itself and to learn from the failure.

To verify and validate a network architecture involving a non-deterministic component such as an unsupervised neural network, this research analyzes network performance as scenarios are encountered. Lyapunov analysis has helped in understanding the stability of the nondeterministic nature of neural nets. A system of monitors that yield confidence measures for the dynamic cell structure's (DCS) neural network performance in online implementations has been constructed and a systematic way to approximate recovery times for a neural network that encounters perturbed data has been developed.

Test Coverage Analysis - A Tandem Experiment Using Available Prototypes (FI06)
PI: Pavan Rajagopal – L3 Titan Communications Corporation
Research Team: Ganesh Pai, University of Virginia, Keith Pauley, MATRIC, Connie Heitmeyer, NRL
Ralph Jeffords, NRL, Scott Ranville, Chiastek
Government POC: Judith Connelly - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/114.jsp

Evaluation of Current Requirements Analysis (RA) Tools Capabilities for IVV in the RA Phase (FI06)
PI: Valerie Jones - Galaxy Global Corporation
Research Team: Valerie Jones, Jennifer Murray
Government POC: Jeffrey Northey - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/106.jsp

Use of Information Retrieval and Data Mining Techniques for Requirements Traceability Matrix (RTM) Evaluation (FI06)
PI: Jane Hayes - SAIC & University of Kentucky
Research Team: Alex Dekhtyar, Senthil Sundaram, Sravanthi Vadlamudi, Ashlee Holbrook
we had assistance from: Charlie Broadwater, Pavan Rajagopal, Kurt Woodham, Ken McGill, Frank Huy
Government POC: Stephanie Ferguson - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/109.jsp

Formal Methods Analysis Framework (FI06)
PI: David Owen - ProLogic, Inc.
Research Team: David Owen, Robert Best, Tim Menzies
Government POC: Daniel Solomon - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/111.jsp

Testing Framework for Reproducible Execution &
Race Condition Detection in Real-time Sys (CI05)
PI: Ken Chen - Johnson Space Center (JSC)
Research Team: Eric Wong, UT Dallas, Yann-Hang Lee, ASU
Government POC: Ken Chen - Johnson Space Center (JSC)
http://sarpresults.ivv.nasa.gov/ViewResearch/96.jsp

Empirical Assurance of Embedded Software Using Realistic
Simulated Failure Modes (CI04)
PI: Ted Bennett - Triakis Corporation
Research Team: Paul Wennberg, Triakis Corporation, Ken Chen, (JSC)
Government POC: Wesley Deadrick - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/53.jsp

RESEARCH: **Interface Validation** Large software systems are often developed by multiple parties, with different groups building different parts. The interface between these parts and also between custom-built software and commercially available components (often called COTS software Commercial Off The Shelf) is an area of potential concern.

Given the way components are built and tested it is possible for all the parts to work, but for the complete system to have unexpected problems working together. Imagine trying to build a bookcase with two other builders when you are building your parts at different times and you don't have a chance to compare notes. What are the chances that someone is just a little off somewhere? In this initiative the researchers explored ways to improve means of performing comprehensive validation of the interfaces between the components, known as Computer Software Configuration Items (CSCIs).

Though the researchers were looking at ISS, the strategies being developed will have application to other missions. As we have seen time and again, there is no such thing as a little mistake. Even in Earth and space science missions, when human life is not at risk, the stakes are still high. Given constraints of time, money and opportunity we cannot afford errors. As we learn from our current missions, we seek to understand and mitigate potential for errors that would hinder our future endeavors.

Developing Formal Correctness Properties from Natural Language Requirements (FI06)
PI: Allen Nikora - Jet Propulsion Laboratory (JPL)
Co-Investigator: Kirk Reinholtz (JPL)
Government POC: Markland Benson - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/116.jsp

Mitigating the Risk of Legacy Software on NASA Spacecraft (FI05)
PI: Andres Orrego - Global Science & Technology, Inc
Research Team: Kristin Adkins (GST), Jesse Fout (GST), Ronald Gore (ISM), Erik Johnson (GST), David Linger (GST), Gregory Mundy (GST), Andres Orrego (GST – PI/PM), John Powell (JPL), Richard Toothman (GST)
Government POC: Gerald Gilley - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/78.jsp

Optimizing IV&V Benefits Using Simulation (CI03)
PI: David Raffo - Portland State University
Research Team: Dr. Wayne Wakeland, Siri-on Setamanit, John Kramer, Bhuricha Sethananda
Government POC: Thomas Robinson - Ames Research Center (ARC)
http://sarpresults.ivv.nasa.gov/ViewResearch/51.jsp

Risk Assessment of Software Architectures (UI04)
PI: Katerina Goseva-Popstajanova (substitute for Hany Ammar) – WVU
Research Team: Walid AbdelMoez, Swetha Konda
Government POC: Lisa Montgomery - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/67.jsp

Software Development Cost: How much? You sure? (CI05)
PI: Jairus Hihn - Jet Propulsion Laboratory (JPL)
Research Team: Karen Lum (JPL), Tim Menzies (WVU), Dan Baker (WVU), Omid Jalili (WVU)
Government POC: Allen Nikora - Jet Propulsion Laboratory (JPL)
http://sarpresults.ivv.nasa.gov/ViewResearch/95.jsp

Toward more realistic software reliability predictions (UI04)
PI: Katerina Goseva-Popstajanova – WVU
Research Team: Margaret Hamill, Xuan Wang, Shiva Somishetty
Government POC: Lisa Montgomery - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/68.jsp

RESEARCH: Real Time Operating Systems A recent success is our work on the robustness testing of a type of COTS software know as Real-Time Operating Systems (RTOS) which are used heavily in mission critical embedded systems. Research to date has included the robustness testing of the Real-Time Executive for Multiprocessor Systems (RTEMS) operating system. RTEMS is an open source realtime operating system commonly used in embedded systems and found on several NASA missions. Preliminary results identified a number of RTEMS directives that may be candidates for concern when used on mission critical systems—functions that don't always fail under execution, only in the presence of certain input parameters. Results provide the IV&V Facility with a means for assuring that NASA flight software using COTS components, such as RTEMS, does not execute in a fashion that could result in a failure in the operating system. This approach provides automated support for this very particular testing. This new capability is being made available to three projects to date. NASA's Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission is one of the three projects.

Based on the results of the testing, an avionics control subsystem for a NASA mission was analyzed for 17 directives found to fail when passed certain parameters. A detailed analysis and trace of the source code was performed to determine the probability of the flight software passing a parameter to RTEMS that would result in a failure as identified by the tests. Four RTEMS directives referenced in the source were found, and further analysis revealed that the flight software would not pass any of the parameters that would lead to failure.

While no issues were identified with the flight software it was possible to provide additional assurance to the developers. This effort provided proof that it is possible to perform such an analysis given the results of the robustness testing. The results of this analysis were communicated to the software developer and were received very well. Preliminary documentation of testing for RTEMS 4.6.6 was passed to the developer to serve a reference for future builds of the flight software. Current work involves identifying and testing VxWorks routines that are implemented in the Gamma-ray Large Area Space Telescope (GLAST) mission. IV&V will continue to support this project and include the evaluation of other RTOS, including VxWorks, and other COTS applications.

The Impact of Dynamic Metrics on Identification of the Failure Prone Parts of the Software (UI06)
PI: Katerina Goseva-Popstajanova – WVU
Research Team: Arin Zahalka, Margaret Hamill
Government POC: Lisa Montgomery - IV&V
http://sarpresults.ivv.nasa.gov/ViewResearch/108.jsp

Improving IV&V Techniques Through the Analysis of Onboard Anomalies (UI06)
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http://sarpresults.ivv.nasa.gov/ViewResearch/119.jsp

Metrics Data Program (FI05)
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Performability of Web Based Applications (UI03)
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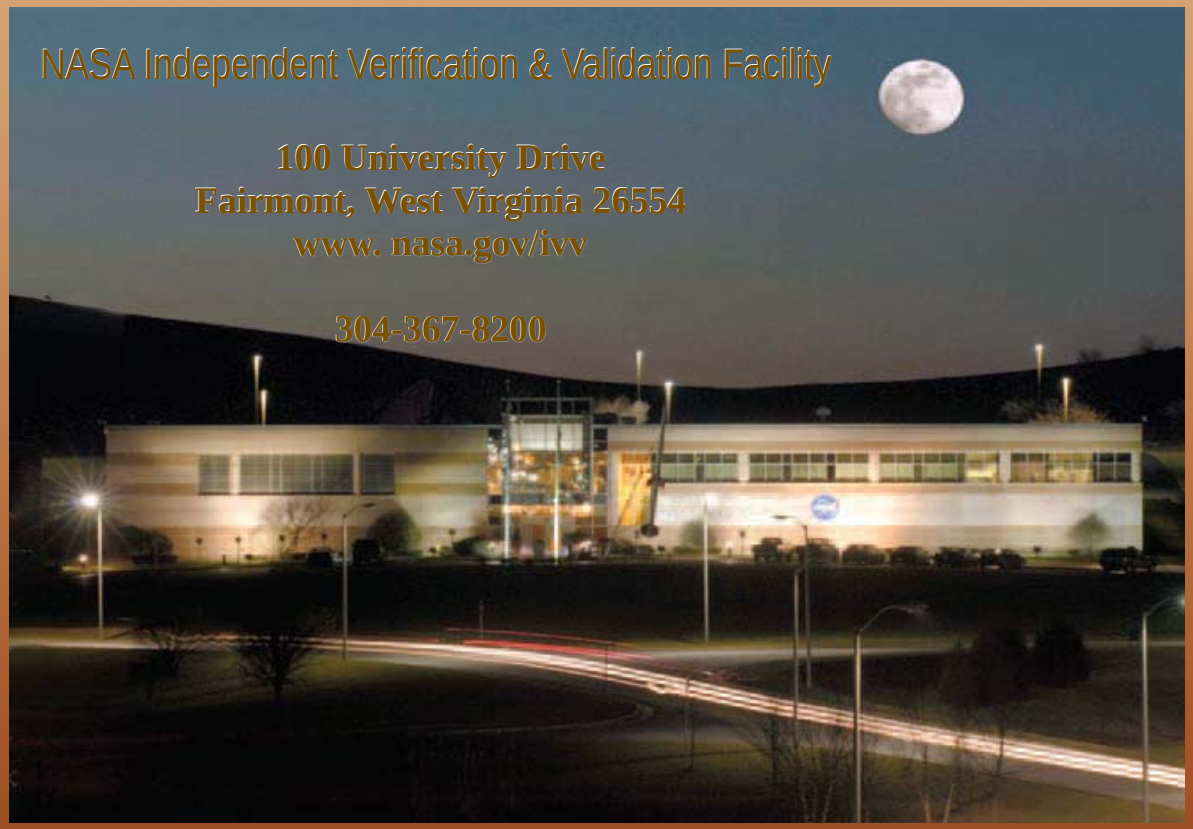
RESEARCH: **Model Checking** is a method to algorithmically verify formal systems—a means to explore the many ways a program may execute. It provides a systematic means to look at operations that can happen at the same time (or seemingly at the same time) and multiple responses based on varying inputs. So, in theory, a model checker can explore all possible execution paths to verify properties of interest. Now, *all* can be a very big number which is why one of the problems model checkers encounter is what is called the state space explosion. What this means is that for large systems there are so many states (locations in the system/program) and so many ways into and out of a state that we run out of computing resources as we try to walk all these paths. While there are several different approaches to combat this problem they all come down to looking at less. And so there is the seemingly contradictory balancing act of looking at less of the system in order to assure more of it.

Model checking can be used both early in the life cycle as well as later in the life cycle. Model checking of software systems early in the life cycle can help analyze requirement specifications and design models. If we can do this, it may let us catch some errors early enough to be mitigated. Because some details are not sufficiently developed until later in the life cycle and also because errors can be introduced into the system along the development cycle, model checking can be useful in catching problems later in the lifecycle as well. Model checking can find defects that would be difficult to find via more traditional testing (manual analysis).

Recognizing the promise of model-checking, as well as the challenges inherent in the approach, there have been a number of research initiatives exploring this domain from different perspectives. Our colleagues at the Jet Propulsion Lab in *Model Checking Artificial Intelligence Based Planners* explored the model-checking tool SPIN first on a small test case and then on a real program model. We have had other researchers looking at other tools and other ways to use model checking. For instance, as the title suggests, the initiative *Model-Validation in Model-Based Development* is considering way to understand if a model is an accurate reflection of a system. The initiative *Program Model Checking Case Studies and Practitioner's Guide* takes a more practical approach to provide assistance in actually using these kinds of tools. These and other related efforts are mature work ready for and undergoing real-world tests on NASA efforts.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