National Aeronautics and Space Administration

Technologies for Exploration 2006-2007

intelligence report

Advanced Technology Development and Applications

At NASA Ames Research Center's Intelligent Systems Division, we perform mission-driven research and development to enable new system functionality, reduce risk, and enhance the capability for NASA missions.

Exploration is moving forward, the International Space Station and Space Shuttle are fully functional, and Aeronautics is focusing on fundamental advances. Each of these areas requires development and applications of autonomous systems, advanced mission operations, integrated systems health management, and reliable software.

Ames's Intelligent Systems Division is playing important roles providing key and enabling technologies and systems to operate small spacecraft like the LCROSS mission, plan activities for the current and future Mars robotic missions, safely operate the Space Station, and improve the safety of the nation's airspace and aircraft. We are proud to participate in NASA's broad roles in Space and Aeronautics.

Dr. David Korsmeyer
Chief, Intelligent Systems Division
NASA Ames Research Center

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Exploration Research Areas

The Intelligent Systems Division provides leadership in information technology for NASA by conducting mission-driven, user-centered computational sciences research, developing and demonstrating innovative technologies, and transferring these new capabilities for utilization in support of NASA missions.

Located at Ames Research Center, in the heart of Silicon Valley, the division comprises four concentrated areas of computer science and information technology research and development.

Autonomous Systems and Robots

The Vision for Space Exploration calls for closer cooperation between humans and robots than ever before. Creating robust robotic assistants, as well as making key spacecraft systems self sufficient, requires building systems that can adapt their behavior to environments that are complex, rapidly changing, and incompletely understood. Ames Research Center has unique expertise and agency leadership in developing the individual technologies required and integrating these pieces into autonomous systems.

Areas of research and development include adaptive control technologies, control agent architectures, embedded decision systems, evolvable systems, intelligent robotics, adjustable autonomy, distributed and multi-agent systems, goal-level commanding, and planning and scheduling.

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Collaborative and Assistant Systems

As NASA missions become longer and more scientifically complex, so will the ongoing participation of and cooperation between individuals in many different locations. At the same time, human/machine interactions will also become increasingly complex.

The goal of Collaborative and Assistant Systems research is to design new information technologies and collaboration tools that facilitate the process by which NASA engineers, scientists, and mission personnel collaborate in their unique work settings. The research activities in this area focus on applying information management, artificial intelligence, and computer-supported cooperative systems that are more usable, augment human cognition, and facilitate the specialized work of distributed teams in NASA mission settings.

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Discovery and Systems Health

Discovery and Systems Health (DaSH) research focuses on challenges in understanding engineering and science data. Ames is NASA's premier research and development facility in the emerging systems engineering discipline of Integrated Systems Health Management (ISHM), with strengths in system design and engineering, sensor selection and optimization, monitoring, data analysis and management, prognostics, diagnostics, failure recovery, and ISHM human factors.

Scientific data work targets large-scale data analysis problems in data-rich domains such as earth science and cosmology. DaSH is also involved in data analysis and mining for a variety of other NASA missions including aviation safety and security, the Space Shuttle program, and the NASA Engineering Safety Center.

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Robust Software Engineering

The goal of automated software engineering is to increase by orders of magnitude both the quality and the productivity of software engineering. The cross-cutting research done by the Robust Software Engineering (RSE) group draws upon multiple disciplines, including artificial intelligence (particularly automated reasoning and knowledge representation), formal methods, programming language theory, mathematical logic, and advanced compiler methods.

Research is done in the context of NASA applications, both to provide feedback and as a means for making contributions to NASA's goals as projects progress. Current space-related projects include space science code generation and software verification for deep-space missions. Civilian aviation research includes next-generation autocoding technology and high-assurance software design.

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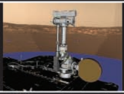

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ISHM

F/A-18 ISHM Technology Demonstration Project

NASA Ames and the Jet Propulsion Laboratory (JPL) have strong competencies in Integrated Systems Health Management (ISHM), particularly in the areas of data fusion, data analysis, monitoring, and diagnosis; however, the lack of test flight opportunities and available test platforms has held back the infusion of these technologies into space and aeronautical missions. To address this problem, a pioneer project was conceived to use an F/A-18 high-performance aircraft at Dryden Flight Research Center as a low-cost proxy to develop, mature, and verify the effectiveness of candidate ISHM technologies. The F/A-18 provided significant advantages over existing test facilities: lower cost, more flights, and deeper integration experience.

- *NASA Dryden contributed significant experience in the development and testing of flight hardware, and also provided flight test support, scheduling, and data download abilities crucial to the project.*
- *JPL developed and integrated Beacon-based Exception Analysis for Multi-missions (BEAM), a software technology that analyzes system data to detect anomalies, classify faults, and track degradation in physical systems.*
- *In addition to managing the project, Ames brought expertise in the areas of model-based reasoning methods and development experience of real-time ISHM systems, specifically the Inductive Monitoring System (IMS), which provides a means to monitor the health of a complex system without the aid of a manually developed model.*

The F/A-18 testbed was used to enhance, integrate, and test existing IMS and BEAM detection algorithms over 23 multi-purpose flights. The aircraft's engines were chosen as the target subsystem for the project. BEAM and IMS individually monitored the performance of both engines throughout the aircraft's flight regime. In addition to demonstrating the ability to detect overt anomalies such as engine shutdown, both algorithms successfully detected subtle differences in engine system performance between training and actual flight data.

This successful cross-center project demonstrated the availability of such a flight test platform using existing F/A-18 test aircraft, flight simulator, bus, processor, and software technologies.

Integrated Systems Health Management for the Crew Launch Vehicle

In order to ensure crew safety during the critical launch and ascent operations of the Ares Crew Launch Vehicle (CLV), NASA needs a highly reliable Crew Abort Fault Detection System. Intelligent Systems Division personnel are working closely with the CLV avionics teams to develop requirements for an on-board Crew Abort Fault Detection System that can detect and confirm all known abort conditions with sufficient time to safely initiate a crew abort.

In 2006 the CLV Fault Detection, Diagnosis, and Recovery (FDDR) team successfully developed a functional failure model of the major subsystems of the CLV which models the behavior of the vehicle, including associated ground systems, under fault conditions. This model will be used to generate requirements and inputs to the system architecture that will improve the capability of the vehicle to prevent and mitigate failures.

In addition to crew abort logic and functional failure analysis work, the Ames team is also involved in other critical efforts related to CLV safety and mission assurance. These include:

- *Ground Diagnostics: Ames is developing a Ground Diagnostics Workstation (GDW) to be deployed at Kennedy Space Center in time for the first flight of the CLV, known as Ares-1. The purpose of this workstation is fault detection for flight vehicles and ground infrastructure during ground tests, as well as data analysis for fleet supportability. The GDW will be certified for support of human flight programs at Kennedy Space Center.*
- *Solid Rocket Motor Health Management: In cooperation with Marshall Space Flight Center, ATK Thiokol, and the Air Force Research Laboratory, Ames has developed algorithms for failure detection and prediction for solid rocket motors (SRM) such as the CLV first stage. These algorithms are based on high-fidelity physics-based models of SRM operation and are designed to operate using data commonly available in production flight hardware. The real-time algorithm will be tested on a subscale SRM during the summer of 2007.*
- *Ares I-X Ground Diagnostics: Ames is leading the development of a ground diagnostics capability for the Ares I-X test flight, in cooperation with Marshall Space Flight Center and Kennedy Space Center. This experiment will process vehicle health and status data during ground tests to predict, detect, and isolate possible failures of several vehicle subsystems.*

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ADAPT

The Advanced Diagnostics and Prognostics Testbed (ADAPT)

As humans venture farther out of low-earth orbit, communications delays make it necessary to migrate health management responsibility for a vehicle or habitat to the crewed system itself. Closer to home, improvements in the safety of current and next-generation aircraft will rely on health management technologies to reduce component and system failures as causal and contributing factors to accidents and incidents. Real-time health management promises improved affordability, reliability, and effectiveness for other complex engineering systems as well. However, it has its own costs in terms of development, power, weight, size, communications, training, and maintenance. New vehicle programs must decide what monitoring and intervention technologies will maximize their return on investment, given mission requirements that balance risk, reliability, and cost.

The Advanced Diagnostics and Prognostics Testbed (ADAPT) is a unique facility designed to test, measure, evaluate, and mature diagnostic and prognostic health management technologies. The testbed has three main goals: 1) assess performance of diagnostic tools and algorithms against a standardized testbed and repeatable failure scenarios, 2) develop prognostic models (performance degradation, remaining life estimation) for subsystems such as the Electrical Power System (EPS), and 3) prototype Advanced Caution and Warning System (ACAWS) algorithms and user interfaces, to characterize which technologies are most appropriate for various faults and contexts.

The initial testbed is functionally representative of an exploration vehicle's EPS. It includes three sets of 100-amp-hr sealed lead acid batteries; battery chargers; a solar panel unit with charge-control regulator; and a controller for power generation, storage, distribution, and monitoring. Data acquisition and control functions are provided by two National Instruments Compact FieldPoint backplanes. Electromechanical and solid-state relays carry power to two load banks, each with two 24 VDC outlets and six 120 VAC outlets. Sensors report temperature, current, voltage, relay position, and light-sensor measurements. The system supports nominal and failure operations of the EPS, for standardized fault configurations or for spontaneous (but repeatable) insertions during system demonstrations.

In a typical EPS test, an antagonist inserts single or multiple faults into the hardware or software configuration, either manually, remotely, or through software scripts. A user—simulating a crew member or pilot—must detect, characterize, and respond to the problem. An observer at a third console monitors the trial and logs real-time data for analysis or retesting. Multi-screen LabView displays—customized for these roles—show the observable or true status and behavior of EPS voltages, currents, and components. Implemented faults include tripped circuit breakers, failed relays (open, closed, or overheating), failed sensors (shorted, open, or stuck), failed AC inverters, and blocked solar arrays. Other faults could include calibration problems, sensor noise, broken wires, failed battery or photovoltaic chargers, overheated or overcharged batteries, and faults in loads.

The primary components under test are the health management applications, not the physical devices of the testbed. The application currently deployed is the Hybrid Diagnostic Engine (HyDE), developed at NASA Ames. It provides online mode tracking, fault detection, and fault isolation to the component level. HyDE itself is a general inference engine, adapted to specific systems by loading a model of the system. In future efforts, other health management applications from industry, academia, and government will be integrated and tested. These techniques may be model-based or data-driven, and may address fault detection, isolation, and recovery (FDIR); prognostics; variable autonomy; or data fusion and diagnostic fusion. Testbed software will evaluate fault detection and isolation times, false and missed alarm rates, precision of fault isolation, and other technical performance metrics.

Future builds will include other subsystems such as Guidance, Navigation, and Control (GNC) and an Environmental Control and Life Support System (ECLSS). ADAPT may also connect to other testbeds through the Internet, to provide a more complete vehicle simulation or a more thorough analysis of human-machine interaction. In particular, ADAPT will interface with the Intelligent Spacecraft Interface Systems (ISIS) and Mission Control Technologies laboratories at Ames, to help refine customer requirements for integration of health management into mission operations.

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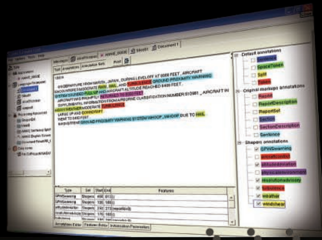

Data Mining

The Intelligent Data Understanding (IDU) Group is developing new text mining algorithms to discover anomalies in free-text reports regarding the systems health and safety of aerospace systems. This work addresses two problems of significant import. The first problem is that of automatically discovering anomalies in tens of thousands of free-text problem reports that are written about an aerospace system. The second problem is automatically discovering recurring anomalies, i.e., anomalies that may be described in different ways by different authors, at varying times and under varying conditions, but that are truly about the same part of the system. The intent of recurring anomaly identification is to determine project or system weaknesses or high-risk issues. The discovery of recurring anomalies is a key goal in building safe, reliable, and cost-effective aerospace systems.

An enormous amount of information regarding aerospace systems exists in the form of structured and unstructured text documents, much of it specifically relating to reports of anomalous behavior of craft, craft subsystems, and/or crew. Mining these text databases can result in the discovery of valuable information regarding the health of the overall system, as well as specific indicators of the health of particular elements in the system.

The IDU Group addresses the problem of discovering anomalies within thousands of free-text reports using two strategies: first, as an unsupervised learning problem where an algorithm takes free-text reports as input and automatically groups them into different bins, with each bin corresponding to a different unknown anomaly category; and second, as a supervised learning problem where the algorithm classifies the free-text reports into one of a number of known anomaly categories.

The IDU Group has been applying these methods to the problem of discovering recurring anomalies in two major two aerospace systems, as well as in benchmark data sets that are widely used in the field of text mining. The first system is the Aviation Safety Reporting System (ASRS) database, which contains several hundred thousand free-text reports filed by commercial pilots concerning safety issues on commercial airlines. The second is the NASA Space Shuttle problem reports as represented in the Configuration Accounting and Reporting System (CARS) data set, which consists of 7440 NASA Shuttle problem reports. Work to date has shown significant classification accuracies on both of these systems, comparing the results with reports classified into anomalies by field experts.

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Vision Workbench

The NASA VisionWorkbench (VW) is a modular, extensible computer vision framework. VW supports a variety of space exploration tasks, including automated science and engineering analysis, robot perception, and 2D/3D environment reconstruction. VW was developed to provide a unified infrastructure for computer vision applications and to help reduce redundant code. Significant emphasis was placed on making the software usable by, and useful to, a wide range of users (from mission scientists to vision researchers) and satisfying the needs of diverse applications.

The VW Core provides basic primitives for processing and manipulating images. The Core is built around an abstract concept of an image that decouples image processing from the underlying representation of the image itself (memory, file, procedure). The framework provides a rapid C++ development environment as well as a flexible, multi-platform system to deploy computer vision applications.

In addition to the Core, VW includes the following modules: Camera (camera models), Cartography (tools for manipulating geospatially referenced images), GPU (accelerated functions using commodity graphics processing hardware), HDR (creating and compressing high-dynamic-range images), Interest Point (tracking and matching interest points), Math (geometric, numeric, and other math functions), and Mosaic (compositing, blending, and manipulating 2D image mosaics).

To date, VW has been used to develop the following NASA computer vision applications: 2D panorama creation from gigapixel data sets, 3D terrain modeling using orbital images (MGS Mars Orbiter Camera, MRO Context Imager, Apollo Panoramic Camera), high-dynamic-range images for visual inspection, and texture-based image matching and retrieval.

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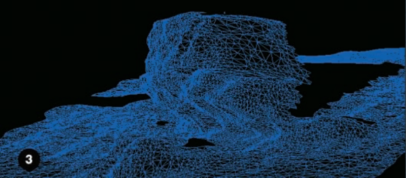


Human Robot Interaction for Space Exploration

The interactions between humans and robots during extended space missions will be unlike anything that NASA has developed to date. At times, robot teams will be remotely operated and supervised by mission control. Robots will also work with astronauts in a variety of team configurations (side-by-side and remote) and a range of control modes.

Basic mission tasks, both in-space and on planetary surfaces, will demand close collaboration between humans and robots. But because cost pressures and other mission constraints (e.g., risk reduction) will keep astronaut teams small, the effectiveness of human-robot interaction (HRI) will have a major impact on the productivity and performance of exploration missions.

Since 2004, the Intelligent Robotics Group (IRG) has been working to improve HRI for space exploration. In particular, IRG is developing tools that enable humans and robots to communicate clearly about their activities and achievements; collaborate to solve problems, especially when situations exceed autonomous capabilities; and coordinate their actions to efficiently perform surface tasks.

Comprehensive Site Survey

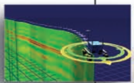
NASA is planning to send humans and robots to the Moon before 2020 to establish a lunar outpost. Comprehensive site surveys will be needed for outpost planning, to prospect for potential resources, and to maximize the capture of new scientific data. If the outpost is established in a polar region, surveys will have to be performed on rugged, steeply sloped terrain and in areas of extended and permanent shadow.

Although orbital images can provide some information, many features will have to be surveyed on the surface. To do this, IRG is developing techniques that combine information from orbital and descent imagery with surface activity by human-robot teams. Two key topics are being addressed: (1) methods for robotic survey (including instrument-based coverage planning) and (2) HRI methods to improve survey performance and efficacy.

With this approach, survey operation can be coordinated from ground control (for precursor exploration missions) and from inside surface habitats or lunar vehicles. A typical work scenario involves multiple robots surveying a site while human operators assess reported finds and provide support (physical and cognitive intervention).

Analog Field Tests

In 2006, an initial system was developed using IRG's K9 and K10 robots and a variety of survey instruments (CHAMP microscopic imager, high-resolution color camera, Mars Underground Mole subsurface sampler). Aerial mapping (to simulate orbital and descent imagery), 3D terrain modeling (to produce digital elevation maps), and resource mapping tests were performed in the Marscape surface analog testbed at NASA Ames. In addition, a framework for integrating multi-robot sensor data and for coordinating multi-robot operations was prototyped.



The system is now being extended to include the CRUX ground-penetrating radar (to characterize subsurface structure), a neutron spectrometer (to assess buried water ice), and a 3D lidar (for topographic mapping). These instruments will be integrated on several K10 robots and used for transect surveys in Haughton Crater (Devon Island, Canada) and other lunar analog sites.

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Global Connection

The Global Connection Project is a partnership between the NASA Ames Intelligent Robotics Group; Carnegie Mellon University; Google, Inc.; and the National Geographic Society. This project seeks to spread understanding of the world's environments and peoples on a global scale by embedding high-definition imagery and hypermedia into the Google Earth browser. The resulting geospatial data can be used for a wide range of applications including education, science, and disaster response.

Since early 2005, Global Connection has been developing overlays for Google Earth that incorporate National Geographic media. By enabling "National Geographic layers," Google Earth users can view hyperlinked content by clicking the yellow rectangle icons, each of which is geo-referenced to National Geographic stories and images. The September 2005 release focused on Africa and included aerial imagery from Mike Fay's "Mega Flyover" of Africa project. The June 2006 release contained over 150 North American sites. Oceania (Antarctica, Australia, etc.) and Europe will follow in 2007.

During Fall 2005, Global Connection rapidly adapted its image alignment and layering tools to support disaster response following Hurricane Karina, Hurricane Rita, and the Pakistan earthquake. The modifications were first made in the days following the hurricanes, when the National Oceanic and Atmospheric Administration (NOAA) took 7,900 high-resolution aerial photographs of the areas impacted by Katrina. Global Connection created overlays in Google Earth to display these images, which were then used by relief and government agencies for coordination and decision making. In recognition of ths work, Global Connection received a 2006 San Jose Technology Museum Award.

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JSC Mission Operations Support

Intelligent Systems Division researchers are developing groundbreaking new technologies that will enable current NASA crews to perform valuable exploration missions, and support future Constellation missions exploring the lunar surface, translunar space, and the surfaces of Near Earth Objects.

XSearch: Information Management for Mission Control

XSearch is an information management system designed to improve NASA flight controllers' ability to access and retrieve the critical information required to monitor and control the International Space Station and Space Shuttle. While much of this information (in the form of notes, action item lists, plans, documentation, etc.) is currently accessible using a patchwork of disconnected tools and databases, XSearch enables search across these data sources using a single web-based interface. In addition, the system identifies cross-referenced and other relevant information that flight controllers might otherwise overlook.

In its initial release, XSearch integrates searches across three key Mission Control Center (MCC) tools: the chits system (used to store mission action requests), the flight notes system (used to store internal flight control team communications), and the anomaly reporting system (used to store mission problem reports). When the text of a search result explicitly references information found in these MCC tools, XSearch presents that information in a convenient cross-reference display. In addition, XSearch compares the text of each search result to all other stored information, attempting to detect and display "similar" information that may be relevant to the flight controller.

Future versions of XSearch will be extended to cover other MCC tools and to introduce new cross-referencing capabilities. The long-term vision is to employ a variety of information extraction methods to build a rich, unifying semantic network structure to integrate disparate MCC information resources.

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Solar Array Constraint Engine (SACE)

As the construction of the International Space Station continues, solar arrays are being added to provide the power needed to support a larger station. These new arrays have more freedom to articulate to enable better tracking of the sun, but they also have more complex constraints that limit the range of safe orientations for the solar arrays, due to structural loads, contamination, and thermal impacts. The limitations on safe orientations impact power generation, requiring operators to balance multiple constraints against power needs. The constraints also complicate fault handling and other aspects of operations.

The Solar Array Constraint Engine (SACE), currently under development in the Intelligent Systems Division, uses intelligent decision-support software to assist power systems flight controllers (PHALCons) with the task of safely operating the new solar arrays on the International Space Station. SACE provides situational awareness, orientation evaluation and optimization, and array operations planning functionality to flight controllers. An initial version of the tool was delivered prior to the December 2006 shuttle flight, during which the first set of new solar arrays was activated. The complete version will be ready in time for the planned August 2007 shuttle flight, when a third set of solar arrays will be activated.

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XBoard

MERBoard is a large touchscreen-based collaborative computer designed to help the Mars Exploration Rover (MER) planning and mission control teams capture, view, and share information during mission planning and surface operations. The basic functionality of each MERBoard includes a whiteboard, a web browser, ubiquitous data space for people and groups, remote access and control, and broadcast capability.

XBoard will utilize and expand on the collaborative MERBoard technology as an assessment for Exploration Mission Operations by establishing a distributed collaboration for full interconnectivity in International Space Station (ISS) planning. XBoard will initially enhance real-time coordination between the planners at the Mission Control Center (MCC) at Johnson Space Center, the Payloads Payload Operations Integration Center at Marshall Space Flight Center, and the Mission Control Center in Moscow.

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Spaceflight Training Management System

Astronauts and ground support personnel require extensive training for spaceflight missions, and it takes an equally extensive hardware and software infrastructure to develop, coordinate, schedule, and keep track of these training activities. The International Space Station, with its 24/7 operation, also requires three full shifts of flight controllers, along with their backups and technical support staff. These training requirements will only increase in the future as the Space Shuttle is retired, the new Crew Exploration Vehicle begins flying, and eventually lunar surface operations begin. Today's infrastructure—while functional—is fragmented, incompletely integrated, and fails to take advantage of the powerful capabilities of modern, web-based applications and software design.

Ames database experts and software developers have now taken over management, maintenance, and development of NASA's spaceflight training management system (TMS). The Ames team plans to fully integrate the separate modules of the current TMS, and migrate all systems and interfaces into a web-based environment. This will eliminate current cross-platform limitations and workrounds; allow for the replacement of older, obsolete hardware; and fully integrate all scheduling, reporting, and curriculum maintenance functions of the system. This redesign and reimplementation will enable cost savings through increased efficiency in managing training schedules and activities, while enabling the Agency to maintain the highest standards for training and qualifying its spaceflight crews and ground controllers.

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Inductive Monitoring System

The success of future space exploration and commercialization depends on safe and cost-effective launch systems and spacecraft. Using techniques and concepts from the fields of model-based reasoning, machine learning, and data mining, Inductive Monitoring System (IMS) software allows near-real-time assessment of the operational health of the monitored system.

Automated health monitoring using tools such as IMS can increase safety by detecting and annunciating minor system anomalies before they develop into major problems.

IMS uses nominal data sets collected either directly from the system or from simulations to build a knowledge base of general classes of expected system values. Sensor values collected from the monitored system are then compared to the nominal classes in this knowledge base. If all values fall in or near the parameter ranges defined by one of the nominal classes, the data is assumed to be nominal data since it matches previously observed nominal behavior. If the values deviate significantly from these classes, the system is behaving in an unusual manner that may indicate a failure or failure precursor. These deviations can be reported to a system operator or autonomous system to prompt evaluation, diagnosis, and corrective action. The IMS knowledge base can also be used for offline analysis of archived data.

The IMS tool has already been used for Space Shuttle anomaly monitoring and analysis, and is scheduled for use on future Shuttle missions. An IMS monitoring application for the International Space Station Control Moment Gyroscope subsystem is currently under development.

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Mission Operations Design and Analysis Tool

Past mission operations have been designed without the benefit of computational models to simulate the ways in which the total work system of people, tools, and facilities dynamically interacts to cause the flow of information and work products. The Ames Intelligent Systems Division has developed a multi-agent modeling and simulation tool for work systems design called Brahms, which has been demonstrated in a variety of mission simulations. Brahms has also been coupled to life support simulations and automation systems, as well as used to drive 3D animations of the work process. In real-time mode, a Brahms system is configured into a service-oriented systems integration architecture that facilitates communication and workflow (a toolkit called Mobile Agents).

In 2006 the Mission Operations Design and Analysis Tool (MODAT) project began work on the design of future operations for the International Space Station and Exploration Missions. The MODAT team is using Ames work systems analysis and design methodology and the Brahms tool to develop an agent-based simulation "proof of concept" model of ISS Mission Operations. The present Intercenter Task Agreement project with JSC applies the Brahms work systems engineering and support capability to Exploration Missions. The project will use ethnographic and agent-based modeling and simulation techniques for two near-term Mission Operations Directorate problems in the Mission Control Center:
1) OCA (Orbital Communications Adaptor) support processes (file transfer between ground and the Space Station) and
2) Gemini activities (multidisciplinary console operations for ISS on weekends).

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OSTPV/EUROPA Integration

In 2006, Johnson Space Center (JSC) and the Ames Intelligent Systems Division began a collaboration to integrate JSC's On-board Short Term Plan Viewer (OSTPV) with the Ames-developed Extensible Universal Remote Operations Planning Architecture (EUROPA). OSTPV is used in Mission Control, by the International Partners, and onboard the International Space Station to visualize the two-week-long Short Term Plans created by other tools such as the Consolidated Planning System (CPS). However, OSTPV does not have the ability to validate plans against mission constraints after modification; these modified plans are routinely adjusted by CPS users, with significant delays in plan validation. With upcoming changes in operating procedures, specifically the introduction of multiple S-Band packet transmission modes, there is increasing need for the capability to edit plans and validate them rapidly inside Mission Control.

Initial efforts consisted of a prototype demonstration of a EUROPA-based planner validating plans in a small S-Band packet transmission problem, followed by a specification of the interface between OSTPV and EUROPA. The resulting tool will allow OSTPV users to edit and validate plans in Mission Control and receive immediate reports of potential conflicts, as well as possible remediations. An integrated prototype tool designed to validate S-Band plans will be delivered during 2007.

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Mission Control Technologies

The Mission Control Technologies (MCT) Project, a collaboration of multiple NASA Centers led by NASA Ames, is building a set of frameworks to enable mission operations software systems to be assembled from flexible collections of components and services. Functions can be shared rather than duplicated between Centers and missions, with customization added as required by mission or operational needs.

In 2005 and 2006, the MCT team worked with Mission Control at Johnson Space Center (JSC) to develop an initial prototype to test the component model and user interface architecture across a representative set of applicable domains (telemetry, procedures, and planning), and a pilot application that was connected to mission data. In 2006, the project's focus shifted to maturing frameworks towards a first deployment for developers, and working with partners at the Jet Propulsion Laboratory (JPL) and JSC on designing the first composable systems, with a focus on International Space Station telemetry and monitoring.

The components will work with both existing NASA telemetry data generation and distribution systems, and the next-generation telemetry services currently under development. They likely will be deployed alongside current telemetry monitoring tools for a period of evaluation, refinement, and extension. Validation is planned at JSC during 2007.

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Small Sat Technologies

NASA's new generation of small but capable spacecraft will depend on Intelligent Systems Division technologies to perform valuable Earth-observing missions; explore the lunar surface; and rendezvous, orbit, and land on the surface of Near Earth Objects and other asteroids and comets.

Polymorphic Control Systems (PCS)

NASA Ames, in collaboration with Carnegie Mellon University, is pioneering a technology for reconfiguring multiple vehicles across their physical boundaries. Polymorphic Control Systems (PCS) uses analysis and synthesis techniques to determine the optimal use of vehicles and their sensors, given a set of mission objectives and available sensors. The goal of PCS is to develop a system which is constantly making these decisions in real time. This allows for automatic trajectory optimization of a multiple-vehicle system, and maximizes its performance if it loses one or more vehicles.

A system of multiple vehicles which is reconfigurable on the fly can enhance the system's robustness to sensor failure. For example, a system of multiple rovers is more resilient if a rover with a broken Inertial Measurement Unit can instantly switch to following another rover using its vision system. If the rover can also choose between following one rover with its vision or using another vehicle's camera to provide state information for a limited period of time, the system will determine which choice will result in achieving the system's objectives the fastest.

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Autonomy for Operations

Flexible, intelligent automation is essential to the success of NASA's planned crewed and robotic missions. Artificial intelligence technology provides robust solutions to systems automation and mission operations coordination, whether for robotic probes at destinations too distant for direct Earth-based control or the increasingly complex systems required for crewed missions.

Autonomy for Operations (A4Ω) is a multi-center project managed by the Intelligent Systems Division at Ames to develop and implement robust automation and coordination technology that can be flexibly applied to exploration mission spacecraft and systems—initially, the Crew Exploration Vehicle (CEV). The Project will also develop the interfaces and infrastructure needed to support complex operations with humans in the loop, as well as the configuration and validation processes necessary for safely and effectively fielding the technology.

A common software core, called the Intelligent Coordination and Automation Software Core (ICASC), will provide the intelligent automation and coordination capabilities. This common core will support system automation, operations coordination, and mission management support. It consists of three primary parts that together provide the ability to sense and determine system state, decide on the most effective and safe course of action, and then robustly and safely execute the decisions made.

- *An executive executes specific commands and externally built plans, and handles any interactions with underlying system interfaces.*
- *A decision-making component, based on planning and scheduling technology, makes decisions and builds plans, while respecting flight rules, constraints, and the impact of actions on the future state of the system.*
- *An integrated systems health-monitoring (ISHM) module monitors the system's states and the commands being executed, identifying faults, possibly through active sensing, and suggesting repair and workaround options.*

Human operators will always have final authority, but the automation can provide services ranging from warnings about unsafe manual operations to fully automated systems operations. This provides an adjustable balance between human operations and automation, easily adaptable to changing conditions or requirements. Adjustable system automation will allow mission crews to work more independently and more effectively, without risking safety. At the same time, crew members can, when needed, take control of the operations, with or without assistance from the automation. Intelligent coordination and mission operations management will help the crew and ground staffs accomplish mission goals in a dynamic environment with limited resources. Crew and ground teams will also always have full insight into plans, activities, and system states.

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Lunar Descent Guidance and Control Architecture

The Guidance, Navigation, and Control (GNC) of the Lunar MicroLander during its final descent phase represents a challenge due to precision landing requirements. Guidance laws ensure minimal fuel usage and feedback control implements the guidance commands while maintaining system constraints. The challenges associated with the MicroLander stem from the limitations of its propulsive units. The main thrusters and reaction attitude control systems are bang-bang in nature. At Ames, in the Intelligent Systems Division, a team is researching various guidance and control schemes to achieve precision landing capability for the Lunar MicroLander.

Towards this end, the following technologies have been developed:

- *A six-degree-of-freedom simulation model with assumed mass distribution, inertia characteristics, main and Attitude Control System (ACS) thruster characteristics*
- *A design of a conservative descent velocity guidance that ensures an altitude-based velocity profile*
- *A phase-plane logic-based ACS attitude control for precise pointing*
- *An adaptive Proportional-Integral (PI)-based ACS attitude control with Pulse-Width-Pulse-Frequency (PWPF) modulation for precise pointing under uncertainties and failures*

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FPGA Digital Circuit Radiation Hardening

The primary radiation risks to digital electronics are single-event-induced bit errors, which can have arbitrarily catastrophic consequences. Researchers of the Adaptive Control and Evolvable Systems (ACES) group are developing an Single Event Effect (SEE) mitigation toolkit, primarily targeting COTS Xilinx FPGAs (e.g., Virtex II or II Pro). The tool has several components: user-logic Single Event Upset (SEU) and Single Event Transient (SET) simulator; circuit analysis scripts based on simulator; implementation of various mitigation approaches in a common framework; automated search/optimization system using that framework; evolutionary sub-circuit design system; and radiation-optimized digital sub-circuit library.

Once developed, the tool set will help in measuring the failure rate of a given FPGA circuit design in a given radiation environment. It will also allow the user to specify arbitrary performance metrics for robust circuit design. These metrics encompass circuit failure rates, multiple failure modes with different costs, circuit performance (speed), and FPGA area usage and power consumption

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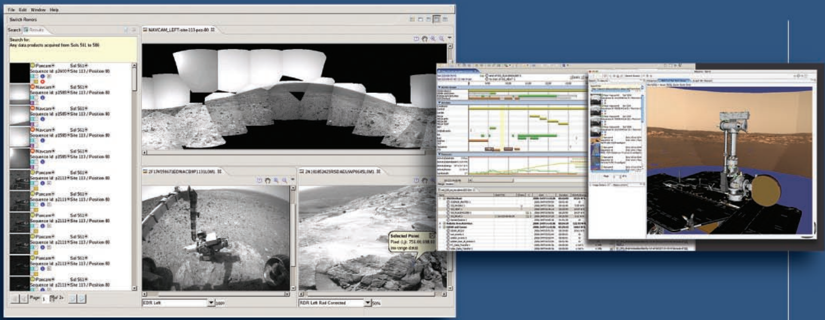

Ensemble & Multi-Mission Operations

The current approach used to develop mission operations software has produced a set of powerful tools that have enabled stunning successes for NASA. But one serious limitation of these tools is that they were developed separately rather than in an integrated fashion. To use a combination of these tools on a mission requires interfaces between systems, and the export or translation of data.

The aptly named Ensemble, a joint Ames/Jet Propulsion Laboratory (JPL) project, is a platform for the development, integration, and deployment of mission operations software that can be reconfigured or upgraded as required during the course of a mission. Based on the popular open source Eclipse application framework and Java-based IDE, an Ensemble product is built from a selection of shared plug-ins, plus a set of mission-specific and tool-specific plug-ins.

Ames plug-ins for planning and scheduling, JPL plug-ins for data browsing and visualization, and Ames plug-ins for manipulating data in a 3D environment can be combined together or with other Ensemble plug-ins and new or legacy services to meet a mission's needs.

Ensemble Architecture

The Ensemble platform methodology is based on five basic tenets:

- *Divide large applications into interoperable and reusable components.*
- *Deliver to a mission only those components it needs.*
- *Allow reconfiguration so the work process can evolve as experience is gained.*
- *Make use of existing software as services that can be called by Ensemble plug-ins.*
- *Use continuous automated build and test systems.*

Data Perspectives and Representations

Ensemble's task-oriented user interface is based heavily upon Eclipse *perspectives*, which define the components that are visible to a user at a particular time. Scientists can downlink data, manipulate it, and create targets from Ensemble's data *browsing* perspective. The *planning* perspective allows activities to be arranged into plans, edited, and linked together with mission or hardware constraints. Custom perspectives that combine new and existing plug-ins are easily defined.

All components use the same data representation, and Ensemble draws upon capabilities provided by Eclipse to document and enforce interfaces between components. The result is an application that feels like a single tool to the user, but draws upon the resources of many development teams. This allows science planning, modeling, activity planning, plan representation, and command sequencing to work together seamlessly. A mission can then easily reuse any component at multiple stages of the operations process. As a multi-mission architecture, Ensemble also supports extensive reuse of components between missions.

Mission Applications

Ensemble plug-ins are used on a range of applications including science data browsing and visualization, planning and scheduling of Mars surface missions, scheduling medical facilities, and control stations for new robotic platforms.

A typical Ensemble application for planning robotic Mars surface operations might perform one or more of the following functions, each with direct user involvement:

- *Search for and display images needed for planning*
- *Enable the user to define a target (for an imaging activity or a traverse activity) by clicking on an image*
- *Define an instance of an activity by selecting from an Activity Dictionary and specifying values of parameters for the instance*
- *Specify temporal relationships among activity instances*
- *Display a timeline of activities and of groups of activities; enable a user to change the scheduled time of activities by dragging items on the timeline*
- *Call upon external models to simulate the plan and display results textually and graphically*
- *Call upon automated planners to schedule activities into legal positions*

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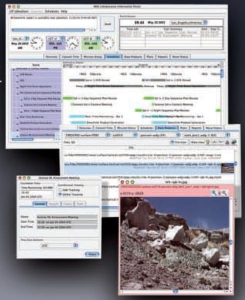
Mission SUPPORT

With the Agency's renewed focus on exploration, division tools and technologies are finding a wide range of application in space and aeronautics missions.



Evolved Antennas for ST-5

The Adaptive Control and Evolvable Systems Group (ACES) developed algorithms to automatically design an X-band antenna for the Space Technology 5 (ST-5) mission. The antenna was evolved to meet a challenging set of mission requirements, most notably the combination of wide beamwidth for a circularly polarized wave and wide bandwidth. The evolved antennas met mission requirements and offered several advantages over the conventional design: lighter, fewer parts, higher bandwidth, and a field pattern that allowed for a wider range of elevation angles. In addition, their development cycle was 33% faster as compared to the conventional design, and new antennas were rapidly evolved to meet new requirements due to an unexpected orbit change. ST-5 was a New Millennium mission comprising three nanosats to study Earth's magnetosphere. This represented the first time an artificially evolved object has flown in space, and was one of the most convincing demonstrations of using artificial intelligence to go beyond optimization and automatically design a challenging, real-world device.

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MER Tools Update

In January 2004 the twin rovers Spirit and Opportunity landed on opposite sides of Mars for what was planned as a 90-day mission. Now in the fourth extension of that mission, they are still exploring and sending back invaluable science data. Mission Operations remains at the Jet Propulsion Laboratory in California, but participating scientists have returned home and are now collaborating remotely, as they will in future long-duration NASA missions.

A mission support application developed at Ames Research Center helps make this distributed operation possible. The Collaborative Information Portal (CIP) is a suite of scheduling and data management tools designed to facilitate long-distance collaboration. To keep the crew up to speed and coordinated, CIP provides a one-stop location for mission team members to find vital information. At any time, on almost any computer, through an interface custom built for the Mars Exploration Rover (MER) mission, team members can quickly access reports, images, daily schedules, and plans that are stored in varied databases. The CIP supports data retrieval, analysis, and understanding for scientists and researchers performing time-critical tasks in an operational science environment. The CIP uses a unique metadata repository for data integration and query. Its Java interface is implemented using time-based and hierarchical navigation tools that present data retrieved via Web Services. This design allows for simple, secure distributed access as well as user customization of information content and presentation. The three-tier architecture (client, middleware, back-end) based on Java 2 Enterprise Edition standards has proved stable and reliable over the years. In the current extended mission, CIP is widely used by the distributed science team as their primary means of reviewing and retrieving the most recent mission data.

The software has exceeded 1,000 sols (Martian days) on both successful mission operations in support of the Spirit and Opportunity rovers without a single critical failure, and will continue to serve this role until the end of the mission.

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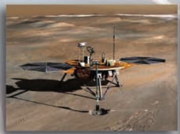
Ensemble for the Phoenix Lander and MSL

NASA's 2007 Phoenix Lander will continue the pursuit of water on Mars on the icy northern pole of the planet. During the course of its 90-sol (Martian day) mission, Phoenix will deploy its robotic arm and dig trenches up to half a meter (1.6 feet) into the layers of 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.

Phoenix will be the first surface mission to return data from either polar region, providing an important contribution to the overall Mars science strategy "Follow the Water." The Phoenix Science Interface tool is based on the Ensemble platform, using components from Ames and the Jet Propulsion Laboratory.

The Mars Science Laboratory (MSL), scheduled to launch in the fall of 2009, is a rover designed to collect Martian soil samples and rock cores and analyze them for organic compounds and environmental conditions that could have supported microbial life now or in the past.

Although it will inherit some design elements from the Mars Exploration Rover (MER) mission, the MSL rover is significantly larger than the MER rovers and will carry state-of-the-art science



instruments for acquiring information about the geology, atmosphere, environmental conditions, and potential biosignatures on Mars. The Ames/JPL Ensemble platform has been baselined for the mission's activity planning function during the surface operations phase of at least one Martian year (687 Earth days).

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Intelligent Flight Control

NASA conducted a series of flight tests of the Intelligent Flight Control System (IFCS) in 2006 under the direction of the Aviation Safety Program. The tests were conducted for a project that addresses the needs of NASA and the U.S. aerospace industry for control systems that can efficiently optimize aircraft performance under both normal and failure conditions. Major control surface failures greatly hinder the ability of a pilot to recover control of an aircraft and in some instances can result in complete loss of control in flight.

The central focus of IFCS is the state-of-the-art direct adaptive neural networks developed by the Intelligent Systems Division. These networks were integrated with flight control algorithms to correctly respond to changes in aircraft stability and control characteristics, and to adjust to maintain the best possible flight performance during an unexpected failure.

Tests were conducted on a modified F-15 aircraft that had additional flight control surfaces (canards) added in order to simulate failure. During the tests, the angle-of-attack feedback to the canards was modified to create a destabilizing condition. IFCS behaved as predicted in the presence of real-world turbulence and noise to correctly compensate for the failure. Tests were also performed by locking one of the horizontal aft control surfaces (stabilators) in a biased (frozen) position. The goal of these tests was to evaluate how well the direct adaptive neural networks helped ensure a safe, in-flight failure recovery. With the direct adaptive neural networks turned on, the pitch rate of the aircraft more closely followed the pilot's pitch commands than when the neural networks were turned off.

Plans are currently in place for additional testing in the first quarter of 2008 as part of Aviation Safety's Integrated Resilient Aircraft Control Project to examine the ability of enhanced neural networks to compensate for larger destabilizing effects and more challenging failures. Both canard and stabilator failures will be examined at fight conditions approaching Mach 0.9 (nine-tenths the speed of sound). Each failure will be performed separately, with increasing severity, to complete the validation of IFCS.

Intelligent Flight Control is a collaboration between NASA Ames Research Center; NASA Dryden Flight Research Center; Boeing Phantom Works, St. Louis, Missouri; the Institute for Scientific Research, Inc.; West Virginia University, Fairmont, West Virginia; and the Georgia Institute of Technology.

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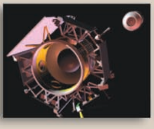
LCROSS Mission Operations

The Lunar CRater Observation and Sensing Satellite (LCROSS) mission will advance the Vision for Space Exploration by identifying the presence of water ice at the Moon's South Pole. LCROSS will use the Lunar Reconnaissance Orbiter launch vehicle's spent Earth Departure Upper Stage as a 2000-kg kinetic impactor that will crash into a permanently shadowed lunar crater and create a nearly 1,000-metric-ton plume of lunar ejecta. The closely following Shepherding Spacecraft will fly through the plume, and send back high-resolution spatial and temporal measurements of the impact, plume, and fresh crater. Earth-based observations will be conducted to support and complement these measurements. Fifteen minutes later, the Shepherding Spacecraft will impact the Moon several kilometers from the first impact. This second impact will be also observed from Earth to provide important information about possible nonuniformity of hydrogen trapped in the shadowed craters.

Intelligent Systems Division personnel are managing the LCROSS Mission Operations team, which consists of members from Ames and NASA's Goddard Space Flight Center (GSFC), along with support from Northrop Grumman. The Mission Operations Center (MOC) at Ames will communicate with the spacecraft through the Deep Space Mission Systems (DSMS) element managed by the Jet Propulsion Laboratory. The GSFC ground terminal will act as a backup Mission Operations Center, and will also provide Flight Dynamics support, coordination with the Lunar Reconnaissance Orbiter Mission Operations Center, and technical support for Goddard-supplied mission operation software.



Ames will be building on relevant mission operations experience with the Lunar Prospector Mission Operations Center as well as other missions. Staff support will come from both Ames and Goddard. Data reduction, science analysis, and science telemetry archiving will be performed by the Science Operations Center (SOC) at Ames.

In addition to MOC management, the Intelligent Systems Division is providing the LCROSS Ground Data System (GDS), an integrated set of ground software, hardware, facilities, and networks that support LCROSS development and mission operations. The Ground Data System includes systems engineering and verification and validation, communication link analysis and scheduling, mission and maneuver design, system-wide operations, activity planning, and navigation.

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NASA Aeronautics Research

As modern aeronautics increases in complexity, so do its requirements for safety and reliability. The Intelligent Systems Division is helping advance modern aviation safety through research in aircraft health management and intelligent adaptive control systems.

Aeronautics Research Mission Directorate Projects

In addition to supporting NASA's Exploration Systems Mission Directorate, the Intelligent Systems Division realized a number of significant accomplishments in 2006 as a result of work funded by the Aeronautics Research Mission Directorate (ARMD), and is currently involved in nine out of ten ARMD projects. The research is primarily focused in three areas: Systems Health, Adaptive Flight Control, and Data Mining.

Systems Health: This research is primarily aligned with the Aviation Safety Program's Integrated Vehicle Health Management (IVHM) and Aircraft Aging and Durability Projects. The IVHM project is tasked with developing technologies that can detect in-flight degradation and damage to aircraft systems early enough to allow for safe recovery. These systems require a combination of software, sensor, and modeling technologies that can work to monitor and diagnose system failures, and mitigate the effects of those failures in flight. Notable achievements in 2006 included the F/A-18 IVHM Technology Demonstration Project, which established the effectiveness of using an F/A-18 aircraft as a testbed for IVHM technologies, and the establishment of the Advanced Diagnostics and Prognostics Testbed (ADAPT) to test and mature diagnostic and prognostic algorithms.

Adaptive Flight Control: This research spans the Aviation Safety and Fundamental Aeronautics Programs. Several projects have requirements for Adaptive Flight Control research to enhance both safety and performance of next-generation aircraft. The projects include Integrated Resilient Aircraft Control (IRAC), Subsonics Fixed-Wing (SFW), Subsonics Rotary-Wing (SRW), and Hypersonics (HyP). The goal of this research is to develop and validate next-generation adaptive flight control systems that can adapt to adverse conditions associated with failures/damage and upsets, and also enhance performance of new aircraft in a variety of flight regimes. This past year saw successful flight tests of the Intelligent Flight Control System on NASA's F-15 aircraft. The tests were a cooperative effort between Ames, Dryden Flight Research Center, Boeing, and the Institute for Scientific Research.

Data Mining: This research spans the Aviation Safety and Airspace Systems Programs. Advanced data analysis and data mining techniques are required to analyze the voluminous historical flight data and identify anomalies and precursors to aviation safety in the National Airspace System. This past year saw the successful development of the sequenceMiner algorithm to analyze large sets of high-dimensional flight sequences and determine anomalies, Mariana to automatically categorize and trend safety incidents, the Recurring Anomaly Detection System (ReADS) to discover potential recurring anomalies, and a variety of anomaly detection methods for continuous and discrete parameters. Data analysis and data mining research also support the optimization of traffic flow management and collaborative decision making, which are essential elements of the Next Generation Air Traffic Management System (NGATS).

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Collaborative Decision System UAV Support

Four days after a successful wildfire survey mission, the Intelligent Systems Division's Collaborative Decision Environment (CDE) was deployed in response to a request from the California Office of Emergency Services for an emergency mission to provide aerial imaging support to the incident command team battling the Esperanza fire in Southern California. The CDE, a prototype tool for enabling distributed planning, situational awareness, and data visualization for unmanned aerial vehicle (UAV) science missions, operated over the full 16-hour flight and connected the widely distributed mission team members.

The NASA/General Atomics Altair UAV used the Autonomous Modular Sensor (AMS)-WILDFIRE, a NASA-developed 12-channel multispectral scanning instrument. The mission flew 20 tracks over the 40,000-acre fire and produced 500,000 lines of scanner data, which were used to automatically create 94 terrain-corrected images and 44 fire-perimeter shape files. The resulting images and shapes were displayed in the CDE, along with a wide variety of other data sources used for decision support and mission planning, such as Real-time Automated Weather Stations (RAWS) weather predictions, satellite heat detection, airspace boundaries and restrictions, and aircraft location.

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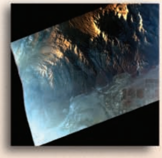

Reliable Software Engineering for Exploration Systems

Reliable software and flight control algorithms are critical to NASA's exploration missions. The goal of the Robust Software Engineering Group's cross-cutting research and development projects is to develop an integrated environment for the efficient development of software and concurrent verification and validation throughout the software design life cycle. This work draws upon several disciplines including artificial intelligence (particularly automated reasoning and knowledge representation), formal methods, programming language theory, mathematical logic, and advanced compiler methods. The techniques are applicable both at the level of design models and at the level of actual source code.

The group works hard to demonstrate the value of adopting software verification tools early in the project life cycle. Compositional and symbolic reasoning are used to verify components and perform automated analysis of multiple program executions at once. SoftwareOrganizer is a semantics-based information repository that can store software artifacts generated throughout the software life cycle. Tools for software verification include C Global Surveyor, a static analyzer that uses abstract interpretation techniques to analyze C programs and find pointer manipulation errors in the code, and JavaPathfinder, a model checker for Java code. The Defect Detection and Prevention tool performs broad, quantitative risk analysis, helping assess risks and plan their cost-effective mitigation. Since qualification of software is a major part of flight software development, and it is expected that in future exploration systems significant portions of the software will be auto-generated from models, the group has developed tools for certifying auto-generated code with respect to a wide range of important safety policies.

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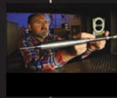
Project Constellation Support



Systems Engineering & Integration Support

The Systems Engineering & Integration (SE&I) Project is a major Level II program within NASA's Project Constellation tasked with generating technical requirements for the Crew Exploration Vehicle (CEV) and Crew Launch Vehicle (CLV). The SE&I project is in turn divided into thirteen Systems Integration Groups, or SIGs, which are tasked with generating requirements in specific technical areas. These SIGs consist of domain experts from around the Agency, who contribute their time and expertise to help NASA define the precise technical requirements that will be passed on to the contractors who build the CEV and CLV.

Many Intelligent Systems Division personnel participated in these SIGs, providing technical expertise in software engineering, verification and validation, systems health monitoring and maintenance, and command and control systems. The Division specifically contributed to three SIGs: Software Avionics Interoperability and Reuse; Command, Control, Communications, and Integration; and Supportability and Logistics/Reliability and Maintainability. The Division will continue to contribute technical expertise to the requirements generation process by supporting the Produceability and Affordability SIG in 2007.

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Project Constellation Data Architectures

NASA's Project Constellation is developing the next generation of spacecraft and launch vehicles for the nation's new vision for space exploration. This ambitious undertaking will require coordinating the creation and flow of information between semi-independent NASA programs, encompassing multiple scientific and engineering disciplines. Crucial information will reside in discrete databases and software applications; in various kinds of documents, including work orders, drawings, procedures and plans; and in the form of tacit knowledge held in the minds of people involved in the project.

Project Constellation initiated the Data Architecture Project in 2006 to develop a framework to enable effective data sharing among the various Constellation sub-projects, organizations, and missions. Teams from multiple NASA Centers collaborated to define consistent, unambiguous standards for representing data and to outline consistent, repeatable processes for data exchange. These unified standards and processes will enable more effective data sharing and knowledge management among the various data producers and consumers in Project Constellation.

Intelligent Systems Division personnel participated in this effort, contributing expertise in data structures, infrastructures, and data management developed through division support of several important NASA missions and organizations, including the 2003 Mars Exploration Rovers, the upcoming 2008 Mars Phoenix Lander, and the Mission Operations Directorate at Johnson Space Center.

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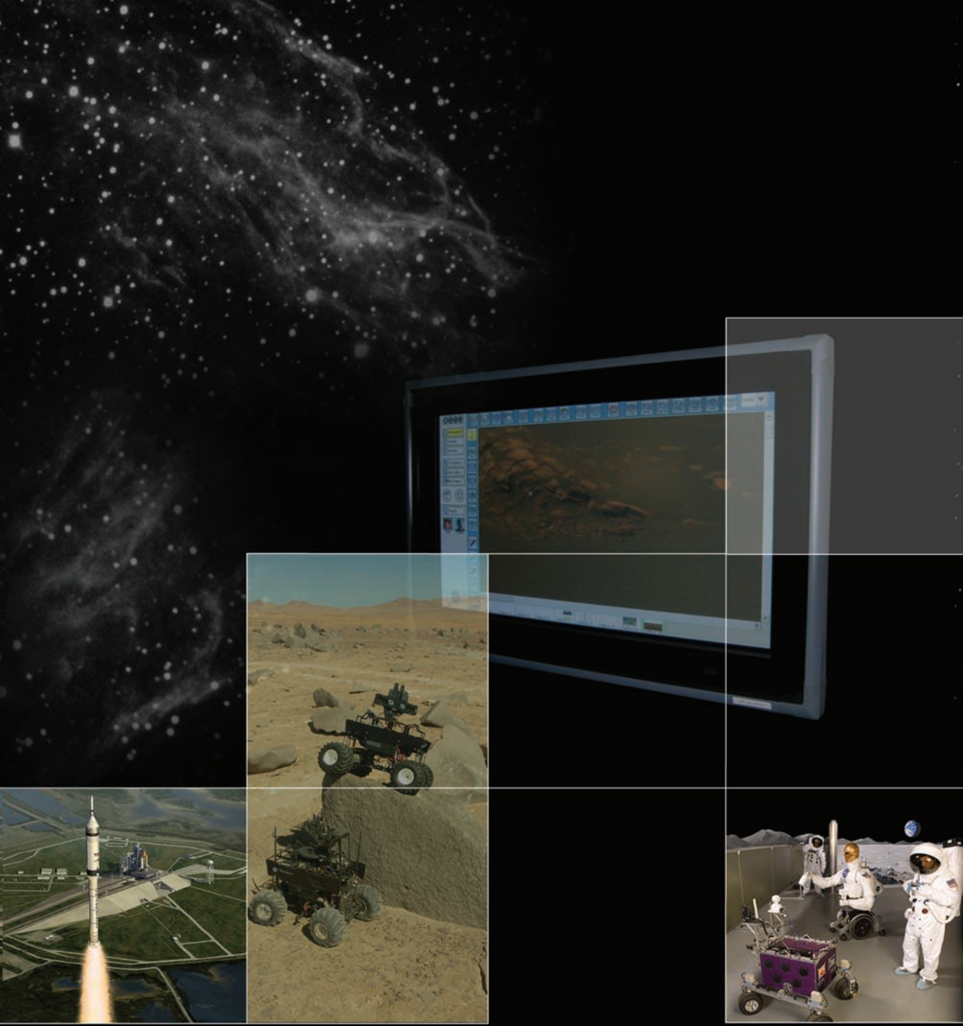

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