EXPLORATIONS

Engineering Solutions to Problems of National Significance

SUMMER 2003

FROM AUTOMATION TO INTELLIGENT AUTONOMY:
Draper's Achievements in Advancing Autonomy

PRECISION DELIVERY OF AIRDROP PAYLOADS

AUTONOMY FOR UNMANNED AIR VEHICLES

LEADING THE WAY IN AUTONOMOUS SPACE SYSTEMS

DRAPER LABORATORY

Maintaining Diversity in Autonomous Systems Capabilities

The evolution of Draper Laboratory's expertise in autonomous mission management systems can be traced back to its pioneering work during the 1950s and '60s in designing the autonomous guidance, navigation, and control (GN&C) systems for NASA's Apollo spacecraft and the autonomous guidance systems for all the U.S. Navy's undersea-launched ballistic missiles. Over the past two decades, Draper has developed capabilities to provide dynamic mission-level autonomy for unmanned systems, becoming a world leader in autonomous mission planning and decision systems. Recently the Laboratory developed new autonomous modes for vehicle management systems for unmanned systems, including an agile maneuvering capability that allows a vehicle to avoid threats and obstacles autonomously.

In the area of autonomous mission management, Draper pioneered mission planning and decision systems to provide the ability to plan missions dynamically, command subsystems within the autonomous vehicle management system, generate situation awareness, adapt to unanticipated events, and monitor systems and diagnose their failures. The Laboratory has designed autonomous mission management and vehicle management systems for a broad variety of military applications in virtually all operational domains, including weapons systems, aircraft, ground robotics, spacecraft, and undersea vehicles.

The agile maneuvering capability enables the real-time creation of complex trajectories, while maintaining vehicle control system stability. This ability permits autonomous vehicles to operate in environments that are substantially more complex.

Draper's current work in autonomous vehicle management systems, including new autonomous modes, and in mission planning and decision systems is highlighted in this issue of *Explorations*. The range of capabilities being advanced and the variety of systems in which they are being applied demonstrate Draper's continuing commitment to pioneering autonomy technology.

- Neil Adams
Associate Director, IR&D

2003 Draper Prize Awarded to Developers of GPS

The 2003 Draper Prize recipients spoke at the Draper Prize Lecture at the Museum of Science, Boston, on May 6. Pictured in front of the Draper Prize exhibit from left to right are Draper President Vincent Vitto, NAE President Dr. Wm. Wulf, Dr. Ivan Getting, Dr. Bradford Parkinson, and Draper Chairman Dr. John Kreick.

Drs. Ivan A. Getting and Bradford W. Parkinson share the 2003 Charles Stark Draper Prize for their individual efforts toward the development of the Global Positioning System (GPS). The Prize is the National Academy of Engineering's (NAE) most prestigious award for engineering excellence, honoring engineers whose accomplishments have significantly benefited society. The $500,000 Prize was presented to Getting and Parkinson at the NAE's annual awards banquet in Washington, D.C., in February.

NAE President Wm. A. Wulf said, "Many of engineering's great achievements become so much a part of our lives that they are taken for granted. I think

see Draper Prize, pg. 11

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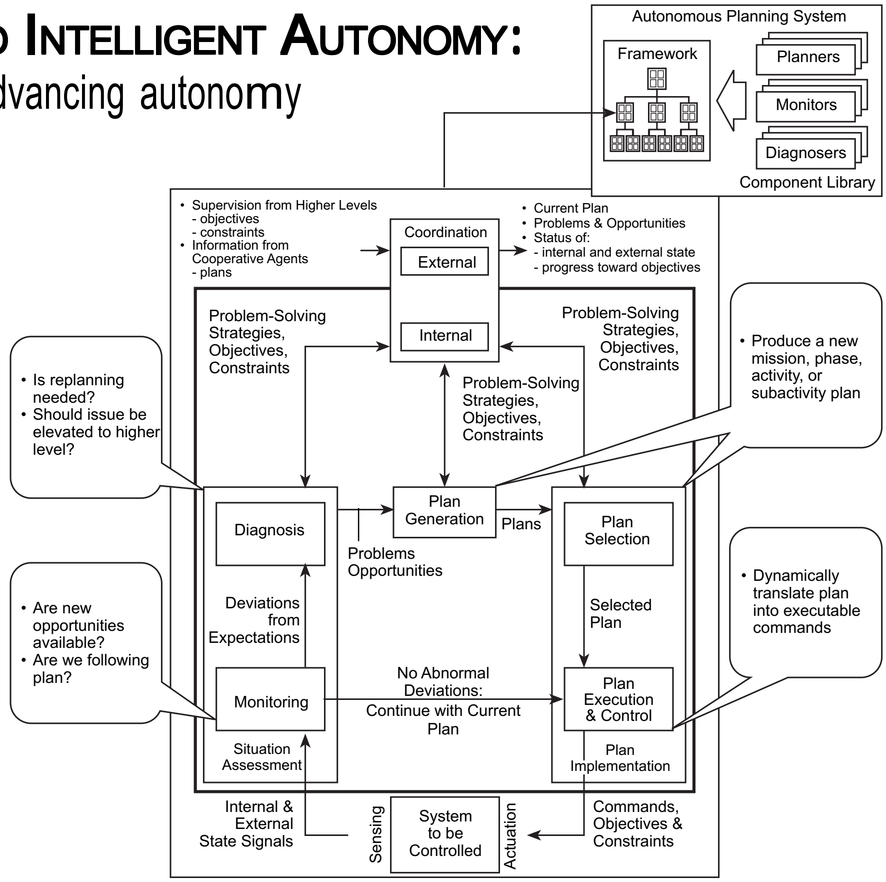
From Automation to Intelligent Autonomy:

Draper's achievements in advancing autonomy

Draper Laboratory's capabilities in autonomy technology have advanced significantly since its early and historic achievements in the 1950s and '60s, when its forerunner, the MIT Instrumentation Laboratory, designed the scripted autonomy systems of early spacecraft and strategic guided weapons. Draper Lab now is developing supervised autonomous vehicle systems and pushing toward truly intelligent autonomy.

Scripted autonomy yields systems that are essentially autopilots, performing preplanned scripts of actions based on anticipated events. Supervised autonomy systems offer more capability, allowing an evolving mission sequence. Intelligent autonomy systems are intended to execute abstract human directives, made capable of doing so by the ability to accommodate or adapt to unplanned events, allowing for evolving mission objectives.

What differentiates between these levels of autonomy is the nature of the human user's control of the system and the location of that control within the system. Human interaction with an autonomous system ranges from basic teleoperation, to assigning the system tasks and assisting it in performing those tasks, or to tasking it and consenting to the actions it proposes as a means to accomplish the assigned task. Draper Laboratory's approach to designing autonomous systems is based on the premise that autonomous systems are an aid to humans rather than a replacement, and such systems achieve autonomy through the incorporation of human-like intelligence in software, focusing on the attributes of planning, perception, adaptation, learning, and diagnosis.



Draper Laboratory's ADEPT Planning Framework

Draper's Autonomous Planning Framework

When designing autonomous systems to help their human operators plan activities, make decisions, interpret sensor data, diagnose problems, adapt to unanticipated events, and improve the system's performance through the learned use of experiential data, Draper engineers draw on the Laboratory's All Domain Execution and Planning Technology (ADEPT). The product of 25 years of experience in designing autonomous systems, ADEPT is a general-purpose dynamic planning software framework that enables a high level of system autonomy for planning across networks and hierarchies with a broad range of human interaction. As an application programming interface, ADEPT supports plan generation, plan monitoring, problem diagnosis, and command execution for a network or hierarchy of mission activities.

ADEPT enables several categories of dynamic planning, including perturbation replanning, bubble-up replanning, negotiated replanning, concurrent abort planning, and rolling horizon replanning. Perturbation replanning is the ability to accommodate small dispersions in planned behavior due to unmodeled or mismodeled dynamics or failures within redundant systems. Bubble-up replanning is the replanning that occurs when a subordinate activity planner cannot solve its problem due to more severe dispersions or the lack of resources (e.g., time, fuel, power, memory). Negotiated replanning is the ability of a superior-level planner to negotiate resources with subordinates to obtain a feasible plan, autonomously moving resources from one activity to another. Concurrent abort planning is used during nominal mission execution to prepare alternative plans in the event of a specific failure that requires a time-critical response from the system to put the vehicle in safe mode or preserve the mission. Rolling horizon replanning is the ability of the planning system to replan over a finite time horizon to be compatible with system computing resources.

For each level of mission complexity, there is an associated level of system complexity required to enable the execution of mission plans. For example, a subsystem mode is used to implement an autonomous behavior, a subsystem or multiple subsystems are used to implement

see Autonomy, pg. 6

ONR MARITIME RECONNAISSANCE DEMONSTRATION PROGRAM

Collecting accurate intelligence is critical for success in any form of armed conflict, and the U.S. Navy's submarine force plays a pivotal role in the nation's reconnaissance efforts. Intelligence, surveillance, and reconnaissance (ISR) is expected to remain a premier mission of the Navy's submarines. The Navy has identified expanding ISR to an Unmanned Undersea Vehicle (UUV) platform as the number one signature capability requirement of the Navy's UUV development and as a crucial part of the ongoing transformation of our naval forces to maintain military superiority in a dynamic world.

Photo courtesy of Naval Undersea Warfare Center, Division Newport

Manta Test Vehicle

> A series of five demonstrations began in spring 2003 and will continue through fall 2004.

Funded as part of the Autonomous Operations Future Naval Capabilities Program at the Office of Naval Research, Draper is teamed with the Naval Undersea Warfare Center, Division Newport (NUWC), and Northrop Grumman Corp. (NGC) to develop the Maritime Reconnaissance Demonstration (MRD) system. The MRD program is focused on dramatically increasing the level of autonomy in UUVs through the development, integration, and demonstration of mission-level autonomous surveillance and reconnaissance for naval organic unmanned undersea systems. Draper is responsible for the design and manufacture of the autonomous mission controller, the integrated vehicle simulation, processor-in-the-loop testing, and support of hardware-in-the-loop testing. NUWC is responsible for vehicle integration, testing, and demonstration range safety, and NGC will develop the ISR sensor package.

The capabilities developed in the MRD program will be demonstrated in-water on NUWC's Manta Test Vehicle (MTV) and 21-inch diameter UUV (21UUV) test vehicles. Over the past decade, Draper has played an active role in the development of these vehicles in the areas of systems engineering, vehicle simulation and hydrodynamic modeling. A series of five demonstrations began in spring 2003 and will continue through fall 2004. They will be of increasing complexity and will take place in the Narragansett Bay and Rhode Island Sound areas.

Under the MRD model, autonomous UUVs must be capable of dealing with mission time variability and multiple mission objectives. During the demonstration itself, the vehicle will be tasked with moving itself to one of a series of collection areas and gathering signal intelligence (SIGINT) data. Potential threats include nonhostile surface traffic and both ground- and air-based hostile threats that are identified with the ISR sensors. When a threat is identified, the vehicle must take appropriate action to avoid the threat, wait in the area, and then attempt to continue collection at a later time. If the autonomous controller determines that the threat level for an area is too high, intelligence gathering is aborted and continued at another collection area. Demonstration objectives involve multiple collection areas and avoidance zones coupled with constraints on time, energy, and vehicle capabilities.

The MRD autonomous mission controller that Draper is developing includes all capabilities for 1) real-time path planning to, between, and from the collection areas; 2) real-time situational awareness and assessment which filters and tracks environmental data and ISR contacts; 3) responding to obstacles, threats, and environmental data assimilated by situational awareness capability; 4) responding to changes in the mission objectives and constraints received mid-mission. Furthermore, MRD guidelines mean that the autonomous controller will need to control the vehicle by issuing guidance commands and sensor operation commands, in addition to being able to determine the urgency of data transmittal during covert operations.

The MRD autonomous mission controller builds on Draper's previous work in DARPA's Autonomous Minehunting and Mapping Technologies (AMMT) Program. Additional capabilities being added for MRD include the ability

PRECISION DELIVERY OF AIRDROP PAYLOADS

Photo courtesy of NASA Dryden Flight Research Center

Guided Parafoil

Since 1994, Draper has been developing ways to increase the accuracy of airdrop delivery of small and large payloads using autonomous guided airdrop systems and unguided parachutes. The Precision Guided Airdrop System (PGAS) program developed an open-architecture autonomous guidance and control (AG&C) capability for parafoil airdrops.

Developed for the Army, Draper implemented a flight version of the AG&C algorithms that was scalable for applications using both small and large parafoils with payloads over a wide range of masses. The AG&C system was the first steerable airdrop system to navigate with the on-board combination of an inertial navigation system (INS) and Global Positioning System (GPS) receiver. A model of the expected behavior of the airdrop system was fused with INS and GPS data in an algorithm that estimated in-flight winds in order to compensate for wind disturbances to the planned parafoil descent trajectory. Additionally, to facilitate development of the AG&C algorithms and to support subsequent flight test analysis, Draper implemented a high-fidelity simulation of the AG&C system and applicable parafoil dynamics as part of the PGAS program. In collaboration with the NASA Dryden Flight Research Center (DFRC), the PGAS algorithms were flight tested using a DFRC-supplied 88-square-foot parafoil with an extensively instrumented 170-pound payload.

Draper performed numerous airdrops with this parafoil system from altitudes of up to 10,000 ft. By the end of the flight demonstration program, the airdrops were performed fully autonomously from aircraft release to touchdown. The PGAS airdrops demonstrated a Circular Error Probable (CEP) for payload delivery of less than 50m through a range of wind conditions. Previously, achieving similar accuracy relied on use of a ground observer with a radio controller near the drop zone (DZ) to command a steerable airdrop system to the DZ.

After successful completion of development and prototype demonstration of the PGAS, the Air Force and Army began joint sponsorship under the New World Vistas program in 2000 of the laptop-based Precision Airdrop System (PADS) that can be carried on-board airdrop carrier aircraft to facilitate in-flight planning of precision airdrops. Draper evolved the PADS planning system from the PGAS system. The PADS planning system makes use of available wind models derived from Air Force global weather forecasts and wind data collected by the carrier aircraft.

The PGAS and PADS programs, combined with other Draper airdrop technology programs, establish a basis for enabling major airdrop operations to be performed safely at high altitude, with confidence that the intended parties will receive the payloads where they are needed. The associated AG&C capability for use on steerable airdrop systems and the PADS on-aircraft planning capability enable users to adapt the airdrop mission plan to actual field conditions up to minutes before release, providing confidence that the payloads will be delivered accurately to the best possible location without a need for post-release descent monitoring by the aircraft crews and without requiring any management of the payload descents by individuals near the DZ.

MRD Cont'd

to avoid nonhostile surface traffic and to operate in complex, dynamic environments such as cluttered, shallow water areas. The mission controller is based on Draper's All-Domain Execution and Planning Technology (ADEPT) approach. In the ADEPT architecture, the problem is broken down into temporal and hierarchical components. Each level contains functions to monitor plan execution, decide when replanning is necessary and formulate a new planning problem, and assign planning problems to planning algorithms to generate a new plan.

MRD will significantly advance the state of the art in UUV autonomy. The demonstrated capabilities will be used to set the standard for future Navy unmanned undersea vehicle programs.

Autonomy, Cont'd

a mission activity, and a system of systems is used to implement a collaborative mission activity.

An overview of projects

Since 1985, the Laboratory has executed more than 75 government-sponsored or internally funded research and development (R&D) projects to advance intelligent autonomy technology in the areas of autonomous planning and decision, navigation and mapping, monitoring and diagnosis, and learning and adaptation. The base of the Laboratory's experience in the many disciplines of intelligent autonomy, coupled with our broad range of research experience from early stage development to prototype autonomous system development, has made the not-for-profit Draper Laboratory a trusted government resource.

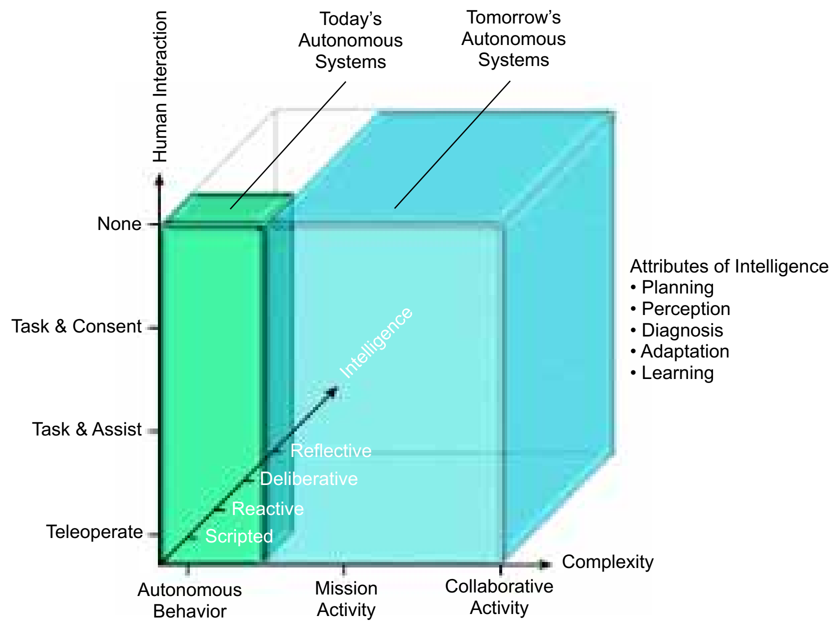
Planning and Decision

Autonomous vehicle systems use planning and decision technology to dynamically plan, schedule, and execute one task in a spectrum of increasingly complex autonomous mission tasks. Draper Laboratory's autonomous vehicle mission controllers are closed-loop planning and decision systems, which allow the system to adapt to unanticipated events. The mission controllers contain plan generation, plan monitoring, plan diagnosis, and plan execution functions. Plan generation is achieved using optimization theoretic or branch-and-bound search methodologies, while monitoring and diagnosis functions employ estimation and computational decision theoretic technologies. Operator interaction is enabled at all levels and for all controller functions. Draper Laboratory's approach to autonomous mission planning and decision has been developed over the last two decades via our participation in numerous R&D programs.

These included development of aircraft flight planning systems for the Defense Advanced Research Projects Agency (DARPA) and the U.S. Air Force, which paved the way for autonomous systems now in use; design and construction of two Unmanned Undersea Vehicles and four mission packages for DARPA; design, development, and simulation of an autonomous abort planning system for NASA Marshall Space Flight Center; and development of wireless communications links to control small robotic vehicles for support of small unit operations.

Learning and Adaptation

The ability to adapt to unanticipated events is critical to increase the mission effectiveness and survivability of autonomous vehicle systems. Systems that can react to pop-up threats, rapidly changing operating conditions or weather, system failures, or new opportunities can operate when communication is not possible or is undesirable.



A 3-Dimensional Representation of Level of Autonomy

From the mid-1980s through the 1990s, Draper Laboratory pioneered learning-augmented flight control, navigation, planning, and failure detection and isolation under Air Force and Navy sponsorship. The Laboratory executed 15 projects during this time period and pioneered early concepts of connectionist learning systems which helped to encode complex nonlinear dynamics in approximating functions. The Laboratory also pioneered several key methods of reinforcement learning, which allow autonomous systems to improve their performance over time by taking advantage of experiential data collected during their missions. Some of the applications of learning explored by the Laboratory included aircraft missile evasion, air-to-air combat, F-15 and F-18 flight control envelope expansion, UUV control envelope expansion, UUV failure detection, and anti-jam GPS operations.

Health and Failure Monitoring

Autonomous vehicle systems often require the ability to detect and isolate system failures to signal the need for adjustment in the vehicle's mission plan or to preserve the vehicle under conditions of extreme failure. Emerging autonomous vehicle systems also may employ health and usage monitoring systems to help in reducing life cycle costs by reducing troubleshooting, maintenance, and diagnostics costs between uses of the vehicle system.

Since the late 1970s, Draper Laboratory has worked problems of autonomous fault detection, isolation, and reconfiguration (FDIR) for reconfigurable guidance, navigation, and control systems, including the Aircraft Restructurable Controls Program, F-8 Avionics FDI, V-22 FDIR, Inertial Upper Stage Inertial System FDI, International Space Station FDI, Military Aircraft

Actuator FDI, and the Navy SH-60 Helicopter Health and Usage Monitoring system.

The Laboratory also has worked on applications of Vehicle Health Monitoring (VHM) for the Space Shuttle Reentry Flight Control System, the Space Shuttle Main Engines, the X-33 Main Engines, the X-34 avionics, helicopter gearbox monitoring, commercial jet airframe monitoring, and Pratt & Whitney gas turbine engines.

The techniques of analytical redundancy developed and implemented include linear and robust detection filtering, hypothesis testing, and maximum likelihood estimation. These techniques continue to form the technical foundation of the monitoring and diagnosis functions within autonomous systems.

Navigation and Mapping

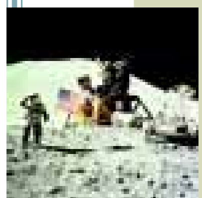
The execution of autonomous vehicle missions often requires the vehicle to determine its location with respect to targets, threats, terrain, and other vehicles. This information provides the situation awareness needed for the autonomous vehicle to navigate within its operating environment and to achieve its mission objectives subject to a set of operating constraints.

Since the 1990s, Draper Laboratory has been building on our expertise in inertial navigation systems (INS) and the Global Positioning System (GPS) to address problems of relative navigation and mapping in complex operating environments. A tightly coupled concurrent navigation and mapping methodology is the general approach used. A navigation and mapping state estimator fuses and filters INS measurements, GPS information, and measurements from one or more relative navigation sensing modalities, such as electro-optic, infrared, radar, sonar, and lidar. The tight coupling of information also allows velocity aiding for enhanced inertial navigation in GPS-denied or intermittent environments.

Ongoing advancement

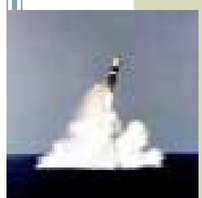
Draper's long heritage in spacecraft autonomous rendezvous, proximity operations, and docking is being leveraged for DARPA and Air Force programs involving autonomous satellite inspection and satellite servicing. Draper is designing and developing the autonomous activity planning, scheduling, and command sequencing required to significantly shorten planning cycles and reduce the operations work force for such missions. Through these and other programs, the Laboratory continues to advance autonomy technology.

Draper's Autonomy Achievements Timeline



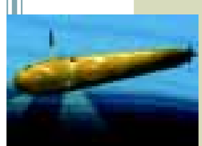
1950s to 1970s:

- Inertial guidance system for submarine-launched Polaris Missile for Navy
- Apollo spacecraft guidance, navigation, and control system for NASA
- Space Shuttle on-orbit digital autopilot for NASA
- Trident missile guidance system for Navy
- Pioneered autonomous failure detection and isolation technology



1980s:

- Trident II missile guidance system for U.S. Navy
- Unmanned Underwater Vehicle for Defense Advanced Research Projects Agency (DARPA)
- Prototype aircraft flight planning system for DARPA
- Autonomous rendezvous and docking technology for NASA
- Pioneered learning-augmented planning and control technology under several AFRL programs



1990s:

- Real-time mission planning for DARPA UUV mine hunting and mapping
- Explosive ordnance disposal robots for Navy
- Micro air vehicle, gun-launched UAV, and tactical mobile robots for DARPA
- Precision Guided Airdrop System for the Army
- Small Aerial Reconnaissance Demo for DARPA and the Army
- X-33 and X-34 autonomous abort planning system for NASA
- Autonomous vehicle agile maneuvering control technology for DARPA

2000s:

- Mission sequencer for DARPA Orbital Express Program
- Mission management system for ONR UUV Maritime Reconnaissance Demonstration Program
- Rendezvous and proximity operations planning for the Air Force XSS-11 Program
- Spacecraft mission assessment and replanning tool for NASA
- Multivehicle autonomous flight planning technology for ONR UCAV Demonstration program
- Multivehicle autonomy for the DARPA/Army UCAR program
- Multivehicle dynamic replanning technology for ONR Intelligent Autonomy Program

AUTONOMY FOR UNMANNED AIR VEHICLES

Helicopter for UCAV Demonstration

Effective autonomous air vehicles, particularly in the combat arena, pose a number of unique capability challenges. These include the ability to perform collaborative, multivehicle in-stride obstacle avoidance and vision-based landing maneuvers in a dynamic environment. Over the last several years, Draper has applied its skills in autonomous system vehicle development, particularly its undersea autonomous vehicle experience, to the air domain.

In 2000 Draper collaborated with Scientific Systems Company (SSC) to begin the Uninhabited Combat Air Vehicle (UCAV) Demonstration Program – a three-step program to demonstrate increasingly challenging autonomous system capabilities for air vehicles.

Step one demonstrated in-stride obstacle avoidance around multiple threats using our autonomous helicopter platform. The autonomous helicopter had to recognize a threat, determine if the threat was relevant to its planned flight path, and then, if appropriate, develop a replan to avoid the threat area.

Step two displayed autonomous multivehicle operations. In this demonstration, two vehicles were sent on individual image retrieval missions during which they had to not only maneuver around terrain obstacles and avoid pop-up threats, but avoid collision with the other vehicle as well. During obstacle avoidance, they had to "discover" each other, determine if a replan was necessary, and then "collaboratively" replan around each other and still complete their individual missions.

The final phase developed and simulated component technologies to demonstrate an autonomous vision-based landing on a moving platform. During this simulated demonstration, the vehicle had to autonomously identify the platform, develop a path to bring itself over the platform, determine the motion of the platform, and then autonomously land on the platform.

Transitioning Draper Autonomy

Building on the success in all three demos, Draper teamed with Lockheed Martin on the DARPA/Army Unmanned Combat Armed Rotorcraft (UCAR) program last year. This multiphase program will lead to a full system design and development program with the Army. During the first phase of this program, Draper completed trade studies to determine the appropriate level of autonomy for the system, the distribution of autonomy among the system elements, and a preliminary concept to support autonomous low altitude flight.

Draper utilized an innovative, quantitative approach to determine the appropriate level and distribution of autonomy for the UCAR system. We traded different autonomy algorithms for each relevant mission activity to examine system level of benefit of independence from human control, coordination, and intelligence, and integrated the analysis results into a force-on-force simulation, in which both the UCAR and its adversary are simulated, to obtain the overall system performance metrics. Our recommended autonomous system design will support individual, group, and multigroup collaborative interaction among each other and with a manned helicopter. The current plans of the program are to apply Draper's ADEPT planning system to support the full level of autonomous mission performance requirements.

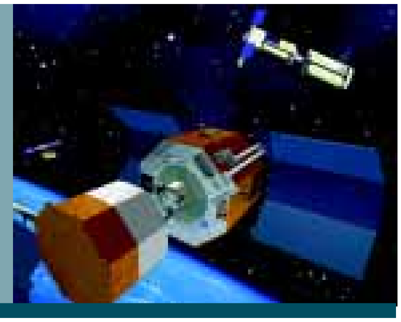
Analysis of several mission vignettes in which aircraft-specific capabilities such as maneuverability were included indicates that the UCAR mission survivability and effectiveness increased significantly with low-altitude flight. The autonomous low-altitude design will be one of Draper's responsibilities for future phases of the UCAR program. Success in low-altitude, nap-of-the-earth flight is dependent upon the ability to maneuver with agility in order to navigate the high number of obstacles and threats. The Lab's agile maneuvering technology will provide us with the ability to take advantage of this mission enabler.

Transforming Autonomy for the Future

While the autonomy technology being utilized by the UCAR program is state-of-the-art, it is still built on existing autonomous system platforms which may prove limiting to future capability advancements. Draper is one of four contractors chosen by the Office of Naval Research Intelligent Autonomy Program, whose goal is to completely transform autonomous system capabilities through the use of higher levels of autonomy. We conceptualized the complete autonomy architecture of the system, including both single and multi vehicle reactive and proactive dynamic replanning using our ADEPT planning system framework and our hybrid control maneuver logic for agile flight.

With the Department of Defense's increasing desire for more capable, reliable, and easier to use autonomous systems, Draper has established itself as a leader in intelligent autonomous system development. Our contracted work and internal investments will continue to lead to increasing levels of autonomy and will help the Lab remain at the forefront of autonomous aerial vehicle development.

Leading in the Development of Autonomous Space Systems



Since the Apollo program, Draper's technical capabilities in autonomy have played a key role in the nation's space systems development. From developing the ability to conduct the Lunar landing mission independent of ground control for Apollo, to today's complex, on-board mission management requirements, Draper has been a leader in creating autonomous space systems.

A current example of Draper's space autonomy work is the Autonomous Mission Manager the Lab is developing for the Defense Advanced Research Projects Agency's (DARPA) Orbital Express Program. Orbital Express will demonstrate the ability to autonomously refuel, reconfigure and repair satellites on-orbit. To do this, a servicing vehicle called the ASTRO must rendezvous, approach, and dock (or mate) with the spacecraft to be serviced. Once mated, ASTRO will provide the needed servicing operation and then withdraw so that the spacecraft can continue operation. DARPA envisions an operational Orbital Express-derived satellite servicing architecture that will revolutionize space operations. The first step to this goal is to demonstrate autonomous operations on-orbit utilizing the Draper Mission Manager.

The Mission Manager carries out Ground Control's objectives or directives by using sequences and related information held in an operations database. The database is executed and monitored fully autonomously, but with a high level of human input into the database creation. This system allows the manager to properly execute the plan, monitor it, and respond to any abnormal conditions. The Mission Manager Executive will control the loading, unloading, starting, interruption, and aborting of sequences per requests from the ground; manage authority-to-proceed (ATP) requests; and enable human supervision to sequences that are autonomously executed on-board the servicing spacecraft. Key elements of the Mission Manager are the Sequencer, Monitor, Contingency Responder, and Resource Predictor.

The Sequencer executes transitions from the current activity to the next, scenario-level mission manager sequences, and low-level element sequences. Low-level sequences will provide GN&C support for nonmated operations, perform fluid transfers, and control the robotic arm for free-flyer capture and avionic system transfers. The Monitor checks the internal health of the ASTRO as well as progress toward the mission objective. The Contingency Responder initiates a contingency action in case of failures or unexpected events. The Resource Predictor manages the communication to the ground to enable positive control over all operations.

In addition to the flight segment, the mission includes a ground segment which will coordinate all activities for the operation of the Orbital Express Demonstration by assembling and verifying sequences for upload to the Mission Manager Flight Segment. It will display both the status of the Mission Manager and the next planned event, as well as list all of the nominal and off-nominal event sequences available for execution during the mission.

The Mission Manager extends Draper's patented Timeliner automated mission sequencing system developed in 1981 for simulating tasks performed on the Space Shuttle.

The Orbital Express Mission Manager uses and extends the Draper-patented Timeliner automated mission sequencing system originally developed in 1981 for use in simulating tasks performed by astronauts aboard the Space Shuttle. In 1992, Timeliner was selected by NASA as the User Interface Language for the space station, and it was installed on the space station's Command and Control Processor and Payload Control Processor. Draper patented the software system in 1998. It was used for the first time on-board the International Space Station on June 10. For Orbital Express, Timeliner will execute and monitor the sequence of events needed to conduct on-orbit rendezvous, docking, and servicing of a given spacecraft.

THE DRAPER FELLOW PROGRAM: A UNIQUE EDUCATIONAL OPPORTUNITY

In fulfillment of the educational directive of its mission, Draper offers an exceptional opportunity to graduate students to gain practical experience in their technical fields while providing full tuition and a stipend. Draper Fellows conduct research for their theses in fields such as aeronautics and astronautics, mechanical engineering, materials science and engineering, and electrical engineering and computer science at Draper Laboratory. A faculty member and a Draper Technical Staff member jointly supervise the research, which must be compatible with a Draper research project.

Formalized 30 years ago when Draper became independent from MIT, the program enabled the Laboratory to retain strong educational ties to MIT by continuing to employ selected graduate students on research projects. More than 600 students have received degrees through study and research at Draper Laboratory. Alumni of this program have become astronauts, professional educators, leaders in industry, high-level military officers, and Defense Department officials.

During 2003/04, the Lab will employ 65 Fellows, most of them MIT students. About 25 percent of the Fellows are civilian government employees or military officers.

Candidates interested in the program should review Draper's education page on the web at www.draper.com.

MEET A FEW OF THE FELLOWS:

2Lt. Krissa E. Arn, USAF
S.M. candidate Mechanical Engineering, MIT
Research area: product design
Draper Thesis Advisor: George Costa

Arn earned a B.S. in engineering mechanics from the United States Air Force Academy and has completed five years of service. Her acceptance into the master's degree program at MIT realized her early ambition and dream to study mechanical engineering at the school.

Arn loves building and racing her projects. At the Academy, she was part of a team that designed, built, and raced a dune buggy vehicle for the SAE Mini Baja Competition. She has built many bikes and raced on the Academy's mountain bike and cycling teams. She also worked one summer at Tyndall AFB in the AFRL Robotics Lab to further develop the Prairie Dog Robot.

She has focused her studies in the product design field. For her master's thesis she is working on the development of a non-contact vibration measurement and analysis system for electronic board testing; the physical contact of common vibration measurement sensors can alter the structure's in-situ properties.

Arn will continue military service as a project engineer and plans to marry a USAF pilot upon completion of the S.M. degree. In the future, she is interested in working for a product design firm.

Tiffany Lapp
S.M. candidate Aeronautics & Astronautics, MIT
Research area: optimal control
Draper Thesis Advisor: Leena Singh

While pursuing a B.S. in aero/astro engineering from the University of Washington with a focus in control law design and analysis, Lapp was one of three elected leads of her senior aerodesign class and lead of the wind tunnel test program for the senior design UAV. She spent three years at the Kirsten Wind Tunnel, part of the University of Washington's Aeronautical Laboratories, testing a variety of vehicles and serving as crew chief for 1.5 years. Two years at Boeing Commercial followed, where she contributed to control law development and engage logic design for the 737NG autopilot, including flight testing for performance evaluation and certification. She is a member of AIAA.

Her research at Draper encompasses real-time outer-loop control of low-altitude, high-speed flight and the associated terrain following and obstacle avoidance. She also is investigating stability and feasibility guarantees as part of her thesis.

Lapp is considering a Ph.D. and possibly a career in research. In addition to her fascination with airplanes and flight, she is interested in bio-engineering and in exploring how her experience in controls might lead to work in the control of biological systems.

David Benson
Ph.D. candidate Aeronautics & Astronautics, MIT
Research area: optimal control & numerical methods
Draper Thesis Advisor: Tom Thorvaldsen

While earning his B.S. and M.S. in aerospace engineering from the University of Colorado at Boulder, Benson worked as a laboratory assistant at the Center for Astrophysics and Space Astronomy while an undergraduate and as a teaching assistant for three courses, aerodynamics and thermodynamics, orbital mechanics, and attitude determination, during his graduate program. For his master's degree he conducted research on periodic control systems for wind turbines.

Benson's focus on controls continues in his doctoral research. With an emphasis in optimal control and numerical methods, he is researching numerical methods for solving optimal control problems in integral form. The new method finds a better numerical approximation to the optimal control problem, which then can be used for improved trajectory optimization.

Benson is interested in research in optimal control of non-linear systems in the field of aerospace engineering. Future career plans include working in control or trajectory optimization for satellites and spacecraft.

2Lt. Luke M. Sauter, USAF
S.M. candidate Aeronautics & Astronautics, MIT
Research area: satellite constellation design
Draper Thesis Advisor: Ron Proulx

A graduate of the United States Air Force Academy with a B.S. in astronautical engineering, Sauter earned distinctions in military, academic, and physical performance and was the top graduate in astronautical engineering in his class. He served as Chief Engineer for the Academy's FalconSat Program 2001-2002 and was a member of the Academy's Flying Team 1998-99.

First in his squadron, he received the Top Gun award for leadership. He wrote and presented papers at AI AIAA and IEEE conferences on Mars surface communications, the Academy's FalconSat program, and microsatellite design. From 1999 to 2001, he also volunteered as a Big Brother in the Academy's chapter of Big Brother and Big Sisters.

As a summer research fellow at JPL in 2001, Sauter helped engineers resolve communication-timing concerns with the 2003 Mars Exploration Rovers and other Mars missions.

His research at Draper encompasses satellite constellation design for the interception of ballistic missiles. He also has provided research assistance on the SPIDR program. Upon completion of his Draper Fellowship next May, Sauter will be directly involved with acquisition programs and management for the U.S. Air Force.

Jillian A. Redfern
S.M. candidate Aeronautics & Astronautics, MIT
Research area: artificial intelligence
Draper Thesis Advisor: Mark Abramson

Redfern was one of the premier Norlin Scholars at the University of Colorado at Boulder where she earned a B.S. in applied mathematics. Norlin Scholars is an undergraduate education program for highly motivated students with strong academic or creative abilities. She was on the dean's list in 1997-1999. She tested a new grating drive design aboard NASA's Weightless Wonder and then ran an education outreach program for elementary and middle school students based upon the experience. She also served as president and treasurer of the university's chapter of the Society for Industrial and Applied Mathematics.

Redfern is interested in AI and its applications to space exploration. Her research at Draper encompasses utilizing artificial intelligence to perform fault diagnosis for the Orbital Express mission. She is also being advised by Brian Williams at MIT's Space Systems Laboratory. She is extending his work in the realm of the Orbital Express mission.

Looking ahead, she would like the opportunity to work with emerging space technologies in the exploration of the solar system, utilizing her scientific background and MIT engineering education.

Draper Prize Cont'd

that, without question, the Global Positioning System is destined for this distinction. It is an achievement that deservedly joins the ranks of previous Draper Prize honors, such as the semiconductor microchip, the jet engine, satellite technology, fiber optics, and the Internet."

The recipients, invited by Draper President Vincent Vitto, gave the annual Draper Prize Lecture at the Museum of Science, Boston, on May 6.

Ivan A. Getting is president emeritus of The Aerospace Corp. In the 1950s he envisioned a system that would use satellite transmitters to pinpoint with extreme accuracy locations anywhere on Earth. After it was shown that GPS could work, Getting became a tireless advocate for making sure the complex system was actually built.

Bradford W. Parkinson was Department of Defense program director for the original definition of the GPS system architecture, as well as for its engineering, development, demonstration, and implementation. He continues to work on GPS at Stanford University, further honing its accuracy and using it to control such things as helicopters, farm tractors, and spacecraft. Parkinson is a member of the Board of Directors of Draper Laboratory.

For more information on the Draper Prize, see Draper's web page, www.draper.com, or the National Academy of Engineering's page, www.nae.edu.

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