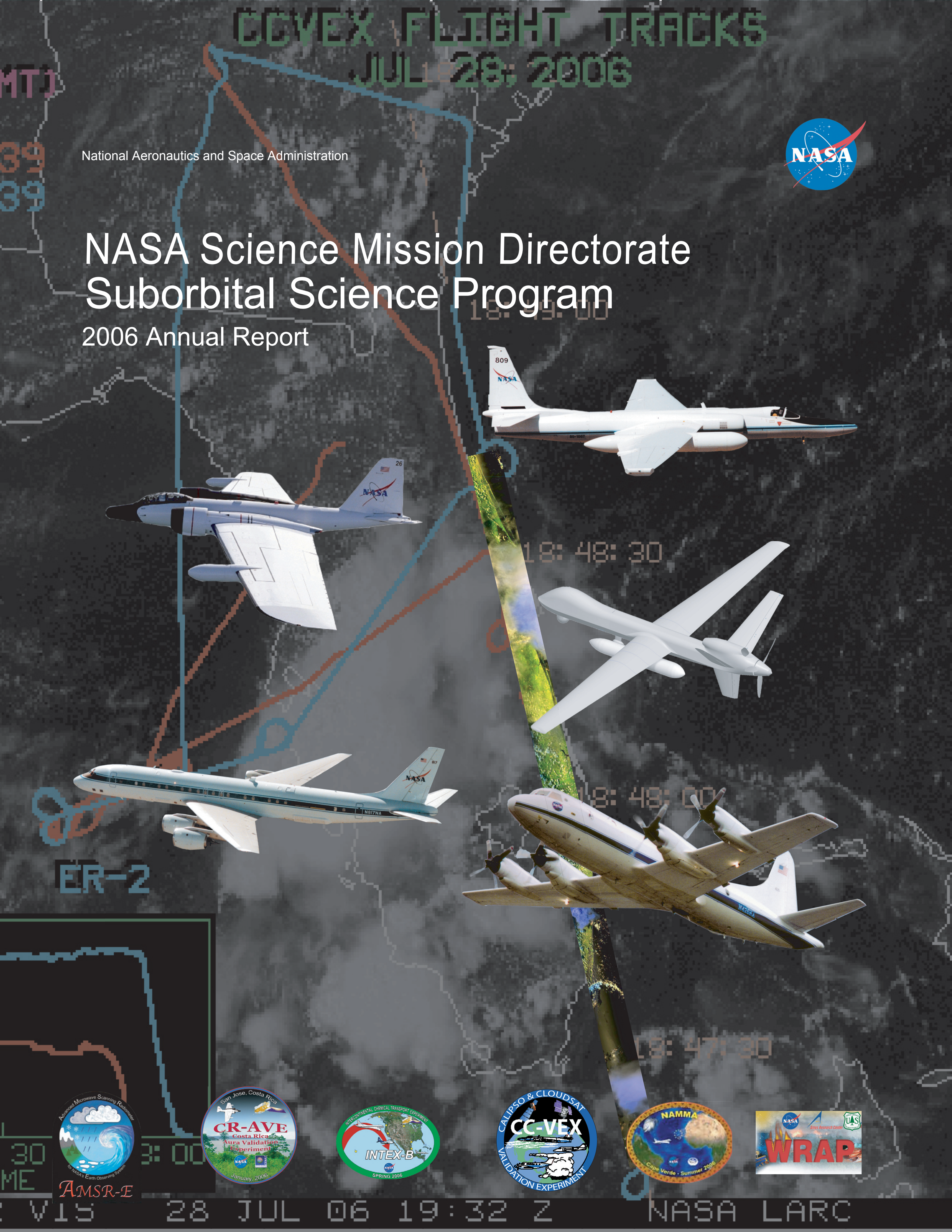
National Aeronautics and Space Administration

NASA Science Mission Directorate Suborbital Science Program

2006 Annual Report



On the cover:

The five principle NASA catalog platforms, from the top: the ER-2 (DFRC), the WB-57F (JSC), the Ikhana Predator-B UAS (DFRC), the DC-8 (University of North Dakota Co-op), and the P-3 (WFF). The background image, from the 2006 CC-VEx experiment, includes plots of flight tracks and altitude profiles from the ER-2 and the WM, Inc. Learjet 35A, overlain on a GOES-12 satellite visible image. Part of the ER-2 flight track includes a segment of the multi-spectral infrared imagery acquired by the MAS instrument during this July 28, 2006 mission. Arrayed across the bottom are logos from the six major airborne science campaigns supported by the Suborbital Program in FY06.

NASA Science Mission Directorate
Earth Science Division

Suborbital Science Program Annual Report 2006

MARCH 2007

http://suborbital.nasa.gov

TABLE OF CONTENTS

Catalog Aircraft

LIST OF FIGURES

LIST OF TABLES

Executive Summary

Earth Science at NASA is a science driven program focused on better understanding the Earth system through global, space-based observations. The Suborbital Science Program plays a key complementary role by providing to the science community unique airborne platforms. What sets the NASA suborbital program apart from other airborne programs are the unique platforms that have been highly modified to make the necessary observations, the breadth of measurement capabilities spanning the full range of science focus areas and the link made between the suborbital and space-based observations. The program fulfills three primary roles, providing: in situ and remote sensing observations of Earth system processes not attainable via space based observation, calibration and validation measurements that allow better understanding of the space based remote sensing observations and a development path for instrument concepts whose final destination is space.

2006 was a very busy year for the Suborbital Science Program. There were seven major field campaigns supporting a wide range of Earth science disciplines from atmospheric composition, hurricane genesis, cryosphere, aerosols and clouds, and disaster response; all linked in various ways to climate change. NASA campaigns covered a wide range of global locations, from the tropical tropopause region in Costa Rica to the frozen ice sheets of Greenland, Alaska and Canada. In addition to the Earth science studies, the first mission conducted on the DC-8, four months after its move to the University of North Dakota, was the Stardust mission, which made a range of visual and spectral observations of the entry of the Stardust Sample Return Capsule. The capsule entered the atmosphere at a higher rate of speed than any previous man-made object in history.

The Stardust mission provided key information on thermal protection system performance, important to NASA's Vision for Space Exploration.

While the DC-8 was flying the Stardust mission, the WB-57 was at KSC supporting the Pluto New Horizon launch, the fastest moving satellite man has yet launched. The WB-57 using the WAVE camera developed for shuttle launches monitored the PNH satellite downrange at 60,000 feet and tracked it from launch to orbit insuring that had an anomaly occurred, the satellite could be imaged all the way to the ocean.

The Costa Rica Aura Validation Experiment (CR-AVE) was conducted in January 2006. With a payload of 29 instruments on the WB-57 aircraft, the mission returned measurements from the tropical upper troposphere/lower stratosphere, an important region of the atmosphere for understanding ozone recovery and impacts of climate change. Also important were key satellite validation measurements often obtained by coordinating the aircraft flight tracks with satellite overpasses, particularly the EOS Aura satellite.

Also providing key satellite validation measurements was the CALIPSO-CloudSat Validation Experiment (CC-VEx). This experiment was conducted with the ER-2 and B-200 aircraft based out of Warner Robbins, Georgia, and NASA Langley, respectively. CALIPSO and CloudSat were on the most recent Earth science satellite launch and are providing important new three-dimensional views of convective cloud systems. CC-VEX provided critical measurements to validate those from space.

The Arctic Sea Ice Mission was conducted in three phases in March 2006 over Alaska, northern Canada, and Greenland. This campaign, using both new and proven instruments on the P-3 aircraft, provided important measurements for validation of the AMSR-E instrument on the Aqua EOS spacecraft and the GLAS instrument on ICESat. The mission also returned important new survey data of the Greenland ice sheet, one of the most important regions of the planet for understanding the impact of global warming

The largest, most complex mission flown in 2006 was the NASA INTEX-B mission conducted in coordination with the NSF MILAGRO mission. This campaign to understand intercontinental transport and transformation of natural and human generated pollution across the Pacific included over 300 scientists, engineers and technical staff in the field in Mexico, Texas, Hawaii, Alaska and Washington State. In addition to the U.S., there was significant participation by Mexico, Canada and Germany. Aircraft involved included the NASA DC-8 and B-200, the NCAR C-130 and the Sky Research Jetstream J-31.

The NASA African Monsoon Multidisciplinary Activities (NAMMA) mission was conducted from Cape Verde off of the western Africa coast in August and September 2006. This major mission was the first ever study focused on obtaining comprehensive measurements to better understand the genesis of Atlantic hurricanes, which are formed by the instability and intensification of the African Easterly Waves coming off the continent. In addition to coordination with satellite data, NASA's TOGA and NPOL research radars, and the SMART-COMMIT mobile research ground station, were deployed to Cape Verde and Senegal. Seven easterly waves were studied along with a number of samples of the Saharan Air Layer carrying significant dust loading from the Sahara desert.

In FY06, NASA continued to demonstrate the use of unmanned aircraft to complement the existing aircraft suite. The NASA Suborbital Science Program assisted the Scripps Institute of Oceanography (UC San Diego) in conducting the first of its kind, multi-UAS mission to the Maldives in the Indian Ocean. Three Manta UAS were flown in a stack formation making simultaneous aerosol and solar radiation measurements in a vertical profile using advanced autonomous avionics to coordinate the aircraft flight tracks in this NSF led experiment.

A second UAS mission was the first significant long duration UAS science flight in the National Airspace over the continental U.S. The Program supported the Wildfire Research and Applications Program (WRAP) funded by the Applied Sciences Division, in working with the U.S. Forest Service to demonstrate the use of unmanned systems for disaster mitigation. The most significant accomplishment of the WRAP project was in response to an emergency request from the California Governor's Office of Emergency Services, for NASA to provide assistance to the California Department of Forestry (CDF) as they were battling a fatal southern California wildfire (known as the Esperanza

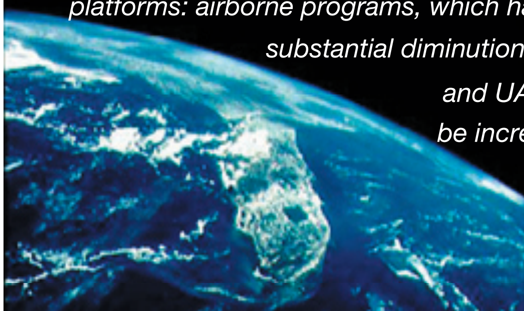
Fire). Using the Altair UAS with a newly developed IR sensor, on board processing, and an end-to-end communication and information delivery system, NASA provided the California Department of Forestry (CDF) critical information on the spreading fire that was used to direct the "boots on the ground" to get the fire contained.

The recently published *National Research Council Decadal Survey for Earth Science* has endorsed and stressed the importance of NASA's Suborbital Science Program. The following is an excerpt from the *Decadal Survey*:

> COMPLEMENTING OBSERVATIONS FROM SPACE
>
> Space-based observations provide a global view of many Earth system processes; however, satellite observations have a number of limitations, including spatial and temporal resolution and the inability to observe certain parts of the Earth. Hence, they do not provide a picture of the Earth system that is sufficient for understanding key physical, chemical, and biological processes. Observations from surface-based (land and ocean) and aerial in situ sensors complement satellite observations through calibration and validation campaigns, and by making critical measurements in places and with accuracy, precision, and resolution that are not obtainable from space. In addition, satellites do not directly observe many of the changes in human societies that are affected by or affect the environment. The requisite Earth information system therefore requires... surface-based and suborbital airborne observations...to complement the observations from space.

In recent years the program has gone through a number of changes, including multiple moves and reduced funding for some of the conventional aircraft, and an initial optimism in the promise of UAS technologies, that has proven to be slower in developing and more expensive than anticipated. The NRC report issued the following recommendation with regard to this situation:

Recommendation:
NASA should support Earth science research via suborbital platforms: airborne programs, which have suffered substantial diminution, should be restored, and UAV technology should be increasingly factored into the nation's strategic plan for Earth sciences



For FY 2007 and beyond, the Program will have a strategic, customer focused plan for investments in aircraft, science support system enhancements, and new technologies. Challenging missions, such as the multi-aircraft Tropical Composition, Clouds and Climate Coupling campaign in Costa Rica, are planned, as well as potential missions UAS compatible sensors selected from the Research Opportunities in Space and Earth Sciences International Polar Year solicitation. New technology demonstrations are scheduled for the planned Ikhana unmanned aircraft system as well as collaborative efforts, such as the Aerosonde hurricane boundary level experiment with NOAA.

Although 2006 saw a number of important and highly visible successes accomplished by the Suborbital Science Program, there is also a need to continually evaluate the program and re-assess the priorities of the program based on science driven requirements.

Introduction

Understanding Earth System processes, how they change, and the potential effect of human activity to that change, continues to be of intense interest to both the general public and the scientific community. In particular, 2006 was a year in which global climate change received increased domestic and international attention, and we witnessed a range of social, media, governmental, and scientific reactions to what we may be facing in the years to come.

NASA's important role in understanding the Earth System continues through the collection and analysis of data on ozone, carbon dioxide, fires, dust and aerosols, point source pollution, precipitation and storms, including hurricanes, atmospheric trace gases, polar ice, land changes, and so on. While much of this data come from satellites, the data obtained from aircraft, balloons, rockets, and ground stations play an essential role in understanding the geophysical processes and interpreting the satellite information.

The Suborbital Science Program (SSP) at NASA is continuing to play a pivotal role in its support to the nation's science endeavors, and this past year has been a successful one. The program supported multiple earth and space science missions, demonstrated new technologies for science data acquisition, and implemented new management structures to more effectively use its airborne platforms. NASA also completed the first year of a five-year cooperative agreement with the University of North Dakota to operate its DC-8 flying laboratory. The program continues to develop the framework to align assets and investments with the Earth Science Research and Analysis Program strategic science roadmap.

The suborbital program continues to operate by its four principal goals:

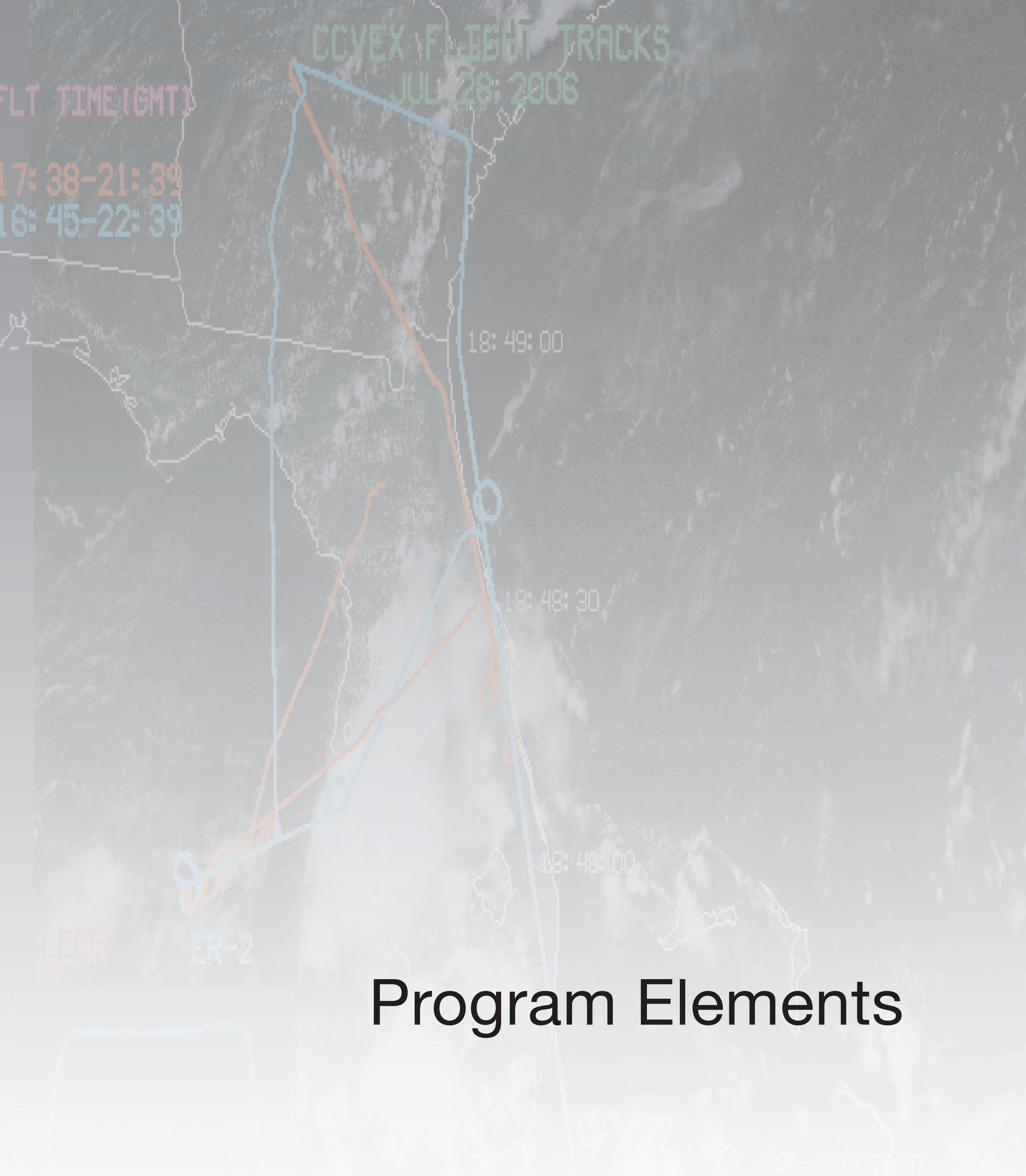
- Support focused science missions that are formulated to implement and follow NASA science roadmaps through competitively selected projects.

- Maintain and evolve an adaptive and responsive suite of platforms selected according to the observational needs and requirements of the science focus areas.
- Infuse new airborne technologies based on advances and developments in aeronautics, information technologies, and sensor systems.
- Transfer proven capabilities to research, operational, or commercial operators as widely available facilities for community-driven experiments or operational decision support systems.

The program is not without challenges, including significant budget limitations and a longer-than-anticipated timeline for UAS technology insertion, but the support to the science community remains strong, in no small part due to the support and dedication of the personnel and organizations across the NASA field centers and their partners that comprise the suborbital team.

The increasing importance of the global climate change issue, the effect of more rapidly changing climate parameters, and the requirement for in situ validation, underscores the need for continued suborbital measurements. Our program couples continued operation of airborne science platforms with the evolution of new technologies, and the collection and evaluation of earth science requirements to forecast future use of its assets. The importance of the suborbital program to the agency's mission was also recently endorsed by the Earth Science Subcommittee of the NASA Advisory Committee (NAC).

In this report, you will find a summary of the significant accomplishments that were achieved in the Suborbital Science Program in fiscal year 2006, and a discussion of where the program is headed over the next several years. The report details program activities in field campaign mission support, technology development, requirements and aircraft catalog management, sensors, airborne science flight requests, and external partnerships.



Program Elements

The Suborbital Science Program (SSP) consists of four program elements which are described in the following sections:

- **Science Requirements and Management**
- **Platform Catalog**
- **New Technologies**
- **Science Instrumentation and Support Systems**

Science Requirements and Management

A continuing goal of the Program is to ensure that the composition of the aircraft catalog and investments in new technologies are directly and clearly traceable to current and planned science mission requirements. Requirements are developed and refined in partnership with the three key stakeholder groups within the earth science community: (1) scientists that need measurements to answer science questions, (2) mission scientists and managers of space flight missions, and (3) technology developers of new observing systems.

Near term requirements are gathered primarily through the online flight request system. (See page 85.) The need for airborne observations related to space-flight missions is tracked using a 5-year plan updated annually and by frequent communications with the NASA Program Managers. For longer term requirements, representatives of the Program attend conferences, review publications, perform interviews and conducts workshops and meetings on specific disciplinary topics. Once science requirements are gathered and properly reviewed, they can provide a critical input to technology development efforts, and ultimately, enable effective management of the aircraft catalog.

5-year Plan

The SSP 5-year plan provides an annual update on the near to mid-term requirements for the program from the agency's science disciplines and flight projects. The most recent plan was developed this past July through inputs from Science Focus Area Program Managers, scientists, and mission managers. Near-term activities primarily consisted of major campaigns in each discipline, sensor development and testing, interagency science campaigns, and future calibration and validation needs for upcoming space missions. A 5-year planning meeting is held each year in the late summer that provides important information on the need to sustain certain platforms while potentially retiring others, and provides input to schedules for the aircraft operational organizations.

Systematic Requirements Analysis for Suborbital Science

Requirements from the NASA Science Mission Directorate (SMD) Earth science focus areas, flight missions, and technology development programs drive the composition of the suborbital program aircraft catalog and the technical performance of sensors and sub-systems. Conferences, publications, workshops, and interviews all provide inputs to science requirements documents. Analyses and reporting on requirements for telemetry, navigation data recorders, multidisciplinary sensors, and science-support systems were conducted during FY06. In addition a requirements summary for the Atmospheric Composition focus area was completed for review, with the other focus area summaries to be completed by the middle of FY07.

Airborne Systems Technology Roadmap

This activity was initiated in the last quarter of FY06 producing a work plan, a working group charter, and a plan for a workshop in the last quarter of FY07. The goal of this activity is to 1) assess the requirements for new aircraft and sub systems within the Earth Science community, 2) recommend technology solutions for the science requirements; 3) provide guidance on the priorities for future development and deployment of suborbital systems. This project is a follow-on from the Civil UAS Assessment activity, and serves to refine promising mission concepts, analyze requirements for aircraft systems, and work with the Science Program Managers to prioritize future technology development and procurements. Subject matter expertise for aircraft and subsystems will be gathered through technical working groups that will be convened to provide guidance on meeting specific capabilities. The final product of this effort will be technology acquisition strategies to ensure capabilities not currently available are met in a timely matter.

Mission Concepts and Management

The Earth Science Project Office (ESPO) at Ames also provides support to the Suborbital Program in requirements analysis, flight request tracking and management (see page 93), and mission concept and science instrument integration development and support. They also manage most of the major Earth Science airborne field campaigns in the Science Mission Directorate.

Platform Catalog

The Suborbital Science Program has successfully implemented a catalog aircraft program element which consists of a mix of NASA-owned aircraft, university operated aircraft, and commercial aircraft. Activities within this program element include flight safety oversight of all aircraft used for NASA earth science activities, and performing analyses and industry calls to assess options for reduced aircraft operations costs. The program element is managed by the Wallops Flight Facility.

In FY06, aircraft in the catalog element flew approximately 1175 hours on eight different platforms. The major earth science missions supported by NASA aircraft included INTEX-B, NAMMA, Arctic 2006, CR-AVE, and CC-VEx. Numerous other missions were conducted on both NASA and non-NASA aircraft during FY06.

For details on individual aircraft, see the “Catalog Aircraft” section, beginning on page 67 in this report.

New Technologies

The New Technologies Project supports the Suborbital Science Program under NASA's Science Mission Directorate. The Project is committed to aggressively pursuing the development of Unmanned Aircraft Systems (UAS) as tools for suborbital Earth Science studies and other civil applications. The mission of the Project is to accomplish flight demonstrations of integrated technology experiments which enable UAS to support Earth Science studies. The scope of this Project includes identifying Earth Science and civil UAS missions, the technologies required for those missions, and the development of selected related technologies thru flight experimentation and demonstration.

During fiscal year 2006, a number of focused projects were accomplished that were only possible through the joint participation of NASA Centers Ames, Dryden, Goddard, Langley, Glenn, Johnson, Marshall, and Wallops. These projects included:

- Completion and initial release of the "Capability Assessment - Earth Observations and the Role of UAS (Unmanned Aircraft Systems)" document.

- Configuration and flight of the Altair aircraft Unmanned Aircraft System (UAS) in support of the Western United States Wildfire flight campaign.

- Procurement and delivery of NASA's Ikhana (MQ-9 Predator-B) unpiloted aircraft system (UAS).

- Development of the UAVSAR flight platform, a Gulfstream III aircraft, that included a Platform Precision Autopilot system and structural modifications to allow installation of the UAVSAR instrument system pod to the belly of the aircraft.

- Supporting the Scripps Institute of Oceanography (University of California, San Diego) field campaign to the Indian Ocean to collect data regarding the role of black carbon in the heating of the atmosphere using Manta UAS aircraft, in stacked coordinated flight formation.

- Over-the-Horizon Communications (OTH) “Suborbital Telepresence” project activities that target affordable and sustainable capabilities to support networks of airborne instruments as components of a future integrated Global Earth Observation System of Systems. The Research Environment for Vehicle-Embedded Analysis on Linux (REVEAL) system continued to support the science community during field campaigns by providing real-time telemetry links between the science aircraft and the ground.

Science Instrumentation and Support Systems

Fig. 1: *The AMS sensor components installed on the lower tray of the new Common Sensor Pod, later flown on the Altair UAS for the Western States Fire missions.*

This element of the Suborbital Program encompasses the development, operation, and demonstration of new and core science instruments, and related science support subsystems. In addition, it provides engineering support for new instrument integrations onto the catalog aircraft, and strives to increase the portability and interoperability of sensors and systems between platforms.

This activity is primarily centered at the Airborne Science and Technology Laboratory, located at the NASA Ames University-Affiliated Research Center, and run in collaboration with the University of California at Santa Cruz. The ASTL has been supporting airborne measurements for the NASA science community for over 20 years. It conducts a range of airborne science support activities, from Instrument design, fabrication, and calibration, to sensor operations, flight planning, and data processing.

Technology Development

A new Autonomous Modular Sensor (AMS) system was developed in FY06 for use on the Altair/Predator-B UAS platform, and in the Western State Fire demonstration missions. This system was designed for extended autonomous operation on a UAS, in a fully-networked environment. The AMS features include re-configurable spectral bands to support multiple science requirements, extensive onboard data processing capabilities,

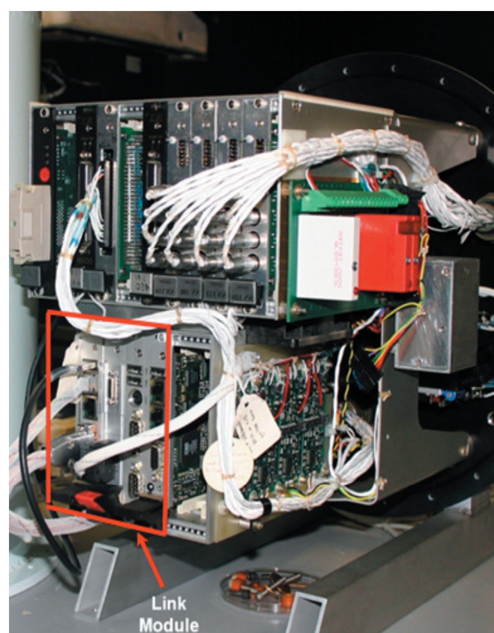


Fig. 2: The UAS Telemetry Link Module, shown here in the lower rack of the AMS data system enclosure.

and full connectivity to high-bandwidth satellite communications systems for real-time applications. After initial testing on the Cessna Caravan, it was installed into the new UAS Common Sensor Pod (Fig.1) and successfully flown on the Altair UAS fire missions.

Fig. 3: The CAR instrument installation in the nose of the J-31 aircraft. The entire forward section of the nose rotates to scan from the zenith to nadir directions.

An outgrowth of the AMS project was a generic telemetry interface module, which can manage high bandwidth data (up to 40 Mbs) from multiple sensors across the sat-com links on Altair, Ikhana, or Global Hawk, to web servers on the ground (Fig. 2). It provides standard interfaces to client sensors on board the UAS, and is designed to be both platform-independent, and transparent to the data users on the ground. It includes programmable processors dedicated to the science payload, which can be used for real-time data reduction, and is intended as a test-bed for future sensor web concepts. During the UAS fire missions it was configured to generate Level-1B and Level-2 data products onboard the aircraft, which were then transmitted to the ground via a 3 Mb/sec Ku-Band sat-com link.

Science support

Extensive engineering support was provided to integrate the MILAGRO payload onto the J-31 aircraft, which involved major modifications to this FAA-certified contract aircraft. The new installations included the Ames Airborne Tracking Sun Photometer (AATS-14), the Solar-Spectral Flux Radiometers, a NAV-Met system, and a special rotating nose-mount for the Cloud Absorption Radiometer (Fig. 3).

ASTL personnel also provided flight planning support and mission logistics for various remote sensing missions on the ER-2, B-200, Caravan, and Twin Otter. Valuable operational experience was also gained with the Altair during the 2006 UAS missions, and several trained engineers are now available to assist with the integration of science payloads on this class of UAS platform.

Sensor Operations

The ASTL operates the MODIS and ASTER Airborne Simulators (MAS and MASTER) in conjunction with the EOS Project Science Office and JPL. These two systems were flown on a total of 56 science missions, including the CC-VEx experiment, and various multi-disciplinary process studies onboard the ER-2, B-200, and Caravan. These instruments are also are made available to the NASA science community through the Flight Request process.

The ASTL also operates a suite of facility assets for the Suborbital Program, including stand-alone precision navigation systems (Applanix POV-AV IMU/DGPS units), the DCS digital tracking cameras, and environmental housings for instrument packaging. The two DCS cameras were flown 37 times in FY06, in support of SMD research, which included an AVIRIS deployment to Puerto Rico (Fig. 4). The POS-AV units flew 48 times, supporting missions on the Altair, J-31, B200, and Cessna Caravan. This utility hardware is available for community use via the Flight Request process.

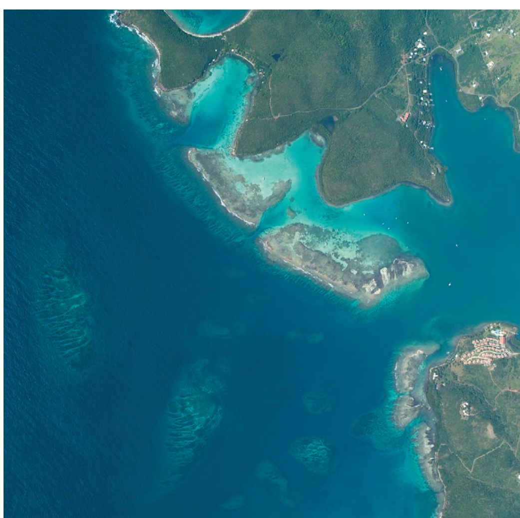


Fig. 4: Cirrus Digital Camera System (DCS) image of La Paguera, Puerto Rico, in support of Coral Reef Bleaching Project

Instrument Calibration

The ASTL Calibration Laboratory is a community resource that is co-funded by the Suborbital Science and EOS programs. It performs NIST-traceable spectral and radiometric characterizations of remote sensing instruments. Recent additions to the lab include a precision transfer radiometer for calibrating radiometric sources, and a high-temperature cavity blackbody. The lab also provides portable radiance sources (integrating hemispheres) and a portable ASD spectrometer to support field experiments. Instruments utilizing the lab this year included the AATS-14 and SSFR radiometers, MAS, MASTER, AMS, and the NASA/UND Space Station AgCam.

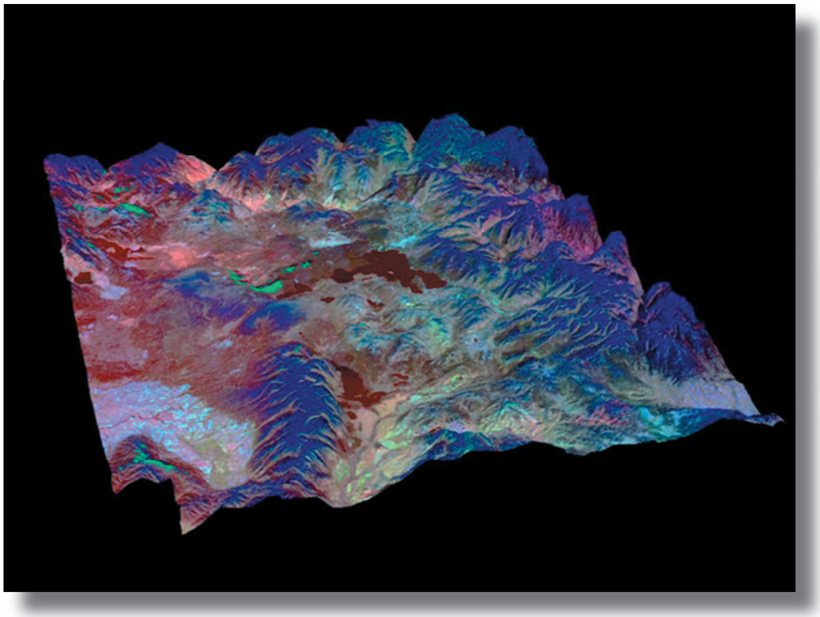
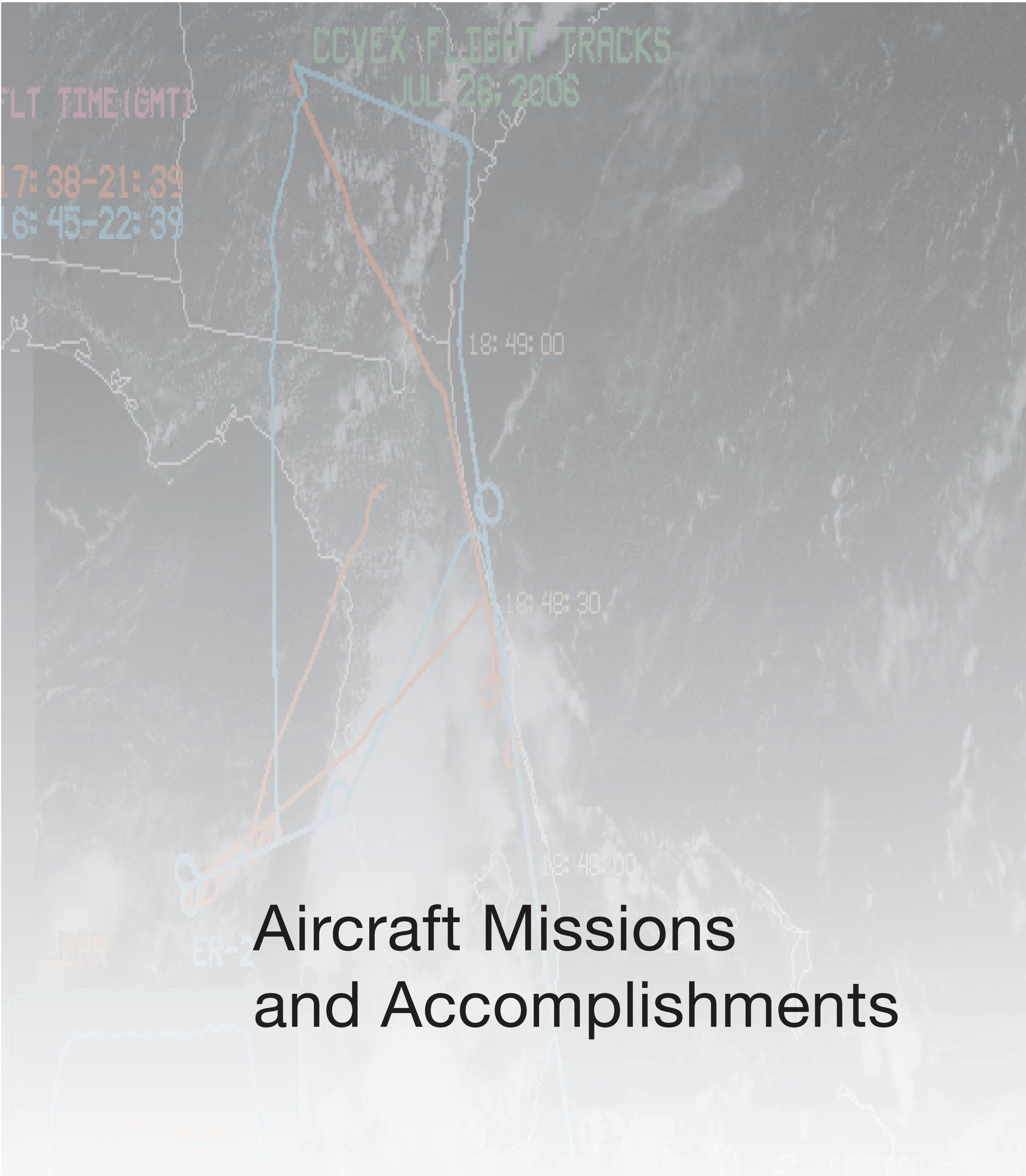


Fig. 5: MASTER data acquired on 25 September, 2006 over Yellowstone National Park. This a mosaic of twelve parallel geo-referenced flight lines, draped over a USGS Digital Elevation Model, and is a statistical representation of five spectral bands ranging from 11.0µm to 0.55µm.

FY07 Planned Activities

Upcoming sensor projects include the implementation of an Ocean Color Imager configuration of the AMS sensor, and a new robust environmental packaging for the DCS cameras. A standardized video tracking-camera package will also be developed for the catalog aircraft. Integration assistance will be provided for new instruments on the Ikhana UAS, in support of IPY requirements and other science missions. A stand-alone version of the telemetry link module for general use on the Ikhana and Global Hawk UAS will be implemented, and plans for a new general-purpose navigation data recorder will be developed in conjunction with the DFRC team.



Aircraft Missions and Accomplishments

CR-AVE

The Costa Rica Aura Validation Experiment (CR-AVE) campaign was conducted from January 14 – February 11, 2006 at the Juan Santamaria airport in San Jose, Costa Rica. The purpose of the mission was to explore the tropical upper troposphere and lower stratosphere (UTLS) portions of the atmosphere, and to provide information for comparison to satellite observations (especially Aura). Interest in the UTLS comes from our understanding that this region has a major impact on both the recovery of the ozone layer and on climate change. Climate change may cause increased temperature and water vapor levels in the tropics. These increases will in turn modify upper tropospheric transport, chemical composition, and clouds, as well as the radiative balance of the UTLS.

The tropical region between 30° N and 30° S latitude comprises half of the Earth's surface, yet is relatively unsampled in comparison to the mid-latitude of the Northern Hemisphere. In addition, observations above typical aircraft altitudes (40,000 feet or 12 km) are even less frequent, making the tropical upper troposphere and lower stratosphere one of the most sparsely sampled regions of our atmosphere.

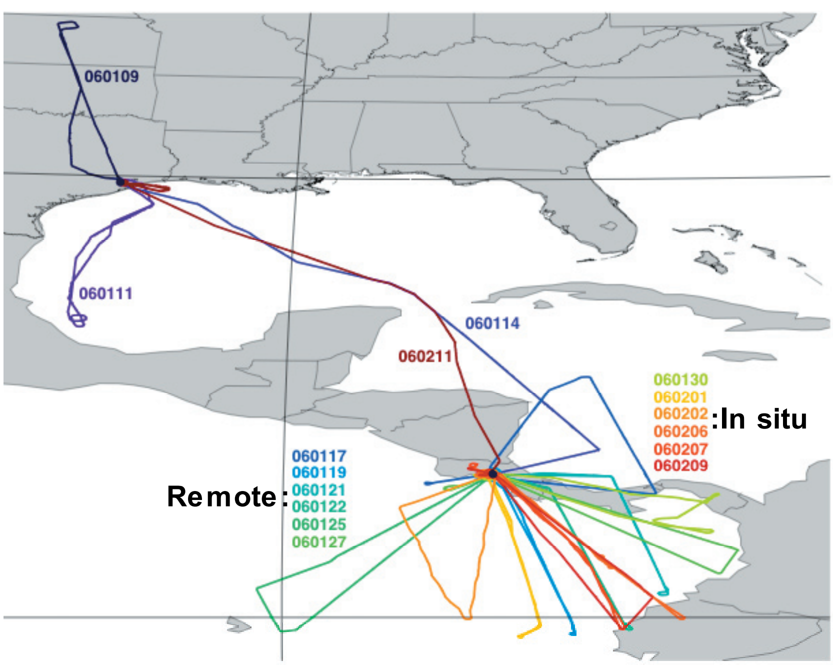


Fig. 6: WB-57 CR-AVE flight tracks

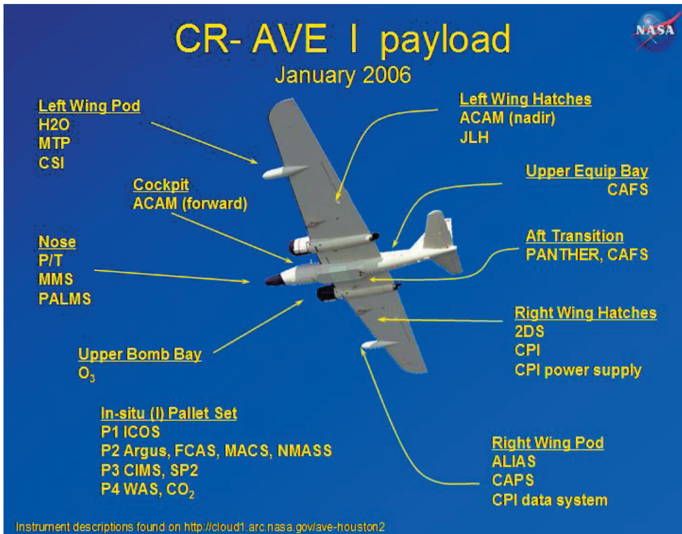


Fig. 7: Remote sensing instrument payload

The scientific objectives of the CR-AVE mission were to: (1) examine the ozone budget at high altitudes of the tropics, (2) measure water vapor, (3) investigate high altitude "sub-visible" cirrus, and (4) measure the size and shapes of cloud ice crystals. Data collected for each of these objectives is used to understand the state of tropical clouds, ozone, and water and their role in climate change

The NASA WB-57F aircraft, with a suite of 29 science instruments, was the primary research platform for CR-AVE. The WB-57F payload included instruments to analyze data related to both ozone recovery and climate change. The payload was divided into two types of science data acquisition, an in-situ air sampling payload, and a remote-sensing payload (see figures 7 and 8). A unique aspect of this mission was the successful change-out of the payload during the middle of the mission at the deployment site. Twelve successful flights were conducted between the two separate payloads, six in-situ and six remote-sensing flights, for a total of 60 flight hours.

Some science highlights from the mission:

- Good correlative measurements were made for TES, MLS, and HIRDLS instrument validation.
- UTLS temperatures were much colder than average, resulting in extensive observations of sub-visual cirrus.
- Observations of water, water isotopes, and VSLS indicates TTL impacted by convection of ice from boundary layer air.
- First observations of black carbon provide basic constraints on GHG radiative forcings.
- Particle observations show that TTL is dominated by neutral organic aerosols while the stratosphere is dominated by acidic sulfate aerosols, a scientific puzzle.

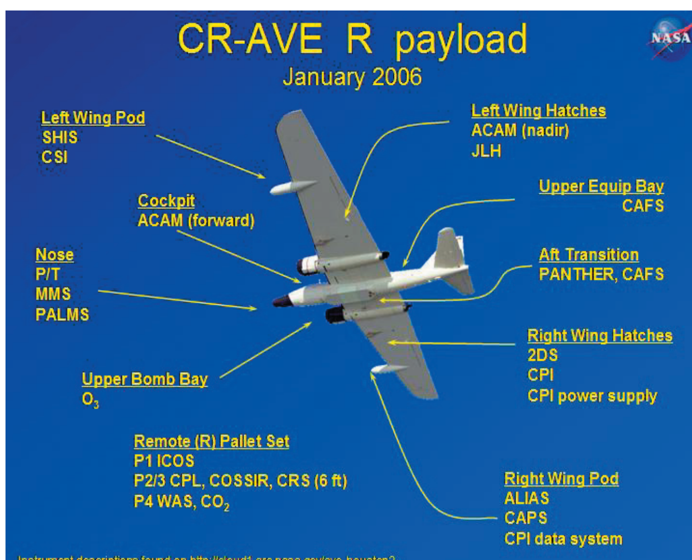


Fig. 8: In-situ instrument payload

- Organic bromine in TTL is dominated by known species (methyl bromide and halons) – therefore, if a major source of Br is being injected into the stratosphere then it must be in inorganic form (e.g., BrO).
- TTL cirrus observations indicate predominance of quasi-spherical, surprisingly large ice crystals.

For more information, the CR-AVE mission web site is located at: http://espo.arc.nasa.gov/ave-costarica2.

Fig. 9: WB-57 Pilot, Bill Rieke, preparing for flight.

Fig. 10: WB-57 nosed into the Presidential Hangar at Juan Santamaria Airport, San Jose, Costa Rica

Stardust Re-Entry

Fig. 11: Image of Stardust capsule re-entry taken with Xybion intensified camera. Photo credit: Dr. M. Taylor, Utah State University.

At 1:58 AM on January 15, 2006, the Stardust Sample Return Capsule entered Earth's atmosphere at 12.8km/s, the fastest man-made object ever to do so. The DC-8 was used as a mid-level airborne science laboratory to observe the vehicle entry to obtain time-dependent data on the radiative heat flux and ablation response of the capsule material.

With an instrument suite consisting of various imagers, photometers, and spectographs, the DC-8 took off from Moffett Field, California, late January 14, and headed to a carefully planned "racetrack" flight path over the Utah desert. The goal was to be "on station" at the exact moment the capsule became visible, and to record it for as long as possible. Through a combined effort of the flight and mission crews, the DC-8 arrived on target at the specified time allowing the science crew to capture the re-entry in its entirety. The Lead Principal Investigator, Dr. Peter Jenniskens of the SETI Institute, reported after landing back at Moffett Field, "We achieved all of our goals. We measured light identified as to come from the hot surface, emissions from the shock, emissions from ablated carbon reacting with the shock, and trace metal atom impurities in what is presumably the heat shield material. We expect to be able to learn from this how well the heatshield performed, what physical processes occur in natural meteors, and how life's first molecules may have originated from comet dust."

The information gathered on the heat shield will be used to build a forensic database for use with future high speed re-entries of various space vehicles by providing a benchmark for the geothermal/thermal protection system (TPS) computational models and predictions of:

- Spectrally and temporally resolved shock layer radiation intensity.
- Surface temperature of the ablator.
- Radiation intensity from ablation products.

Results will be used for comparison between predicted and actual responses, coupled with numerical sensitivity analyses, will be used to asses model accuracy, and will be used to propose additional testing to improve models if important deficiencies are identified.

Funding for the campaign was provided by the NASA Engineering Safety Center (NESC). Investigators from the University of Stuttgart, Kobe University, University of Alaska at Fairbanks, Utah State University, USAF Academy, NASA Ames, and Sandia National Laboratory were represented on the DC-8.

Fig. 12: Stardust Observation Campaign Team

Arctic Sea Ice

Fig. 13: Arctic 2006 Transit Pattern

The Arctic 2006 mission was conducted from March 18-29, 2006 using the NASA P-3 aircraft flying a remote sensing payload over the Arctic and Greenland polar regions. Objectives for each of the three mission phases were as follows:

- Phase 1 primary objectives were to validate the EOS AQUA AMSR-E snow depth on sea-ice product, and assess the sea-ice retrievals from the Ice, Cloud and Land Elevation Satellite (ICESat) Geoscience Laser Altimeter System (GLAS) instrument.

- Phase 2 objectives were to validate the ICESat GLAS and ESA Envisat Microwave altimeter sensors over sea-ice.

- Phase 3 objectives were to conduct aerial topographic mapping surveys over Greenland's ice-sheet surfaces.

Phase 1 was flown over the Alaskan Coast; phase 2 completed ground tracks in the Arctic Ocean adjacent Northern Canada; and Phase 3 covered the Western Coastal region of Greenland. Figure 13 shows the transit pattern from NASA Wallops Island to Spokane, Washington; Fairbanks, Alaska to Thule, Greenland; and Sondrestrom, Greenland, and then back to Wallops Island, Virginia.

The following sensors (and associated institutions) were flown during the mission:

- Snow Radar (University of Kansas) – Ultra-wideband FM-CW radar with a sweep bandwidth from 2-8 GHz. This was the Snow Radar's first flight.

- Polarimetric Scanning Radiometer (PSR) (NOAA ETL/ University of Colorado at Boulder) - covered the AMSR-E range of frequencies (6.9-89.0 GHz) and vertical and horizontal polarizations. An infrared scanning radiometer in the 9.6-11 µm range provided surface temperature.

- Delay/Doppler Phase-monopulse radar altimeter (D2P) (Johns Hopkins University Applied Physics Laboratory) – provided elevation measurements of the snow-ice and the snow-air interfaces.

- Airborne Topographic Mapper 4 (ATM 4), GPS, digital cameras (NASA/Wallops) – obtained high resolution ice surface topography and surface height.

Phase 1 of the mission validated coincident measurements received on NASA's Earth Observation System (EOS) Aqua Advanced Microwave Scanning Radiometer (AMSR-E). Principal Investigators were Dr. Donald Cavalieri and Dr. Thorsten Markus from NASA Goddard Space Flight Center. AMSR-E sea-ice products that were validated included sea-ice concentration, sea-ice temperature, and snow depth on sea ice. Individual sensors aboard the P-3 performed various duties for the validation listed above. A total of six flights were deployed from Fairbanks, Alaska, and were flown near Barrow and in the Bering, Beaufort, and Chukchi seas, totaling 42.5 science data collection hours (see Figure 14).

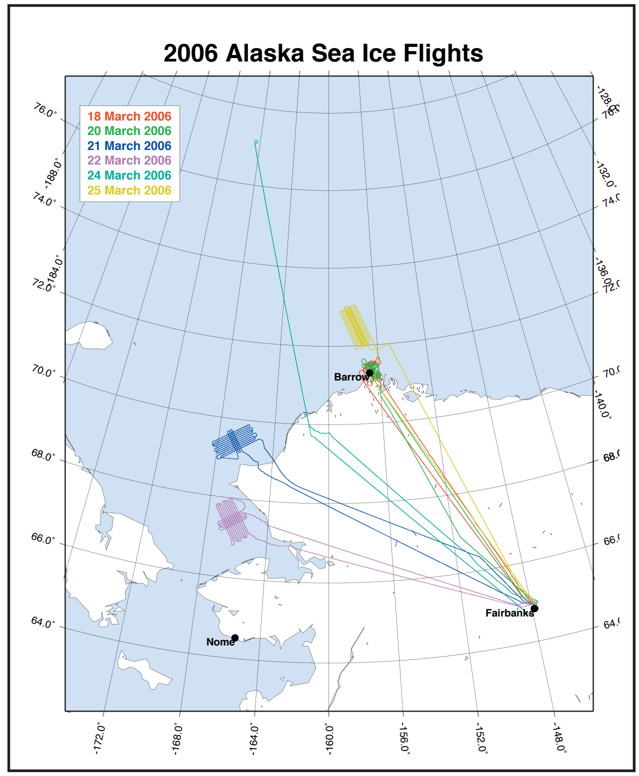


Fig. 14: Phase 1 flights from Fairbanks

Fig. 15: Arctic Sea Ice Science Team

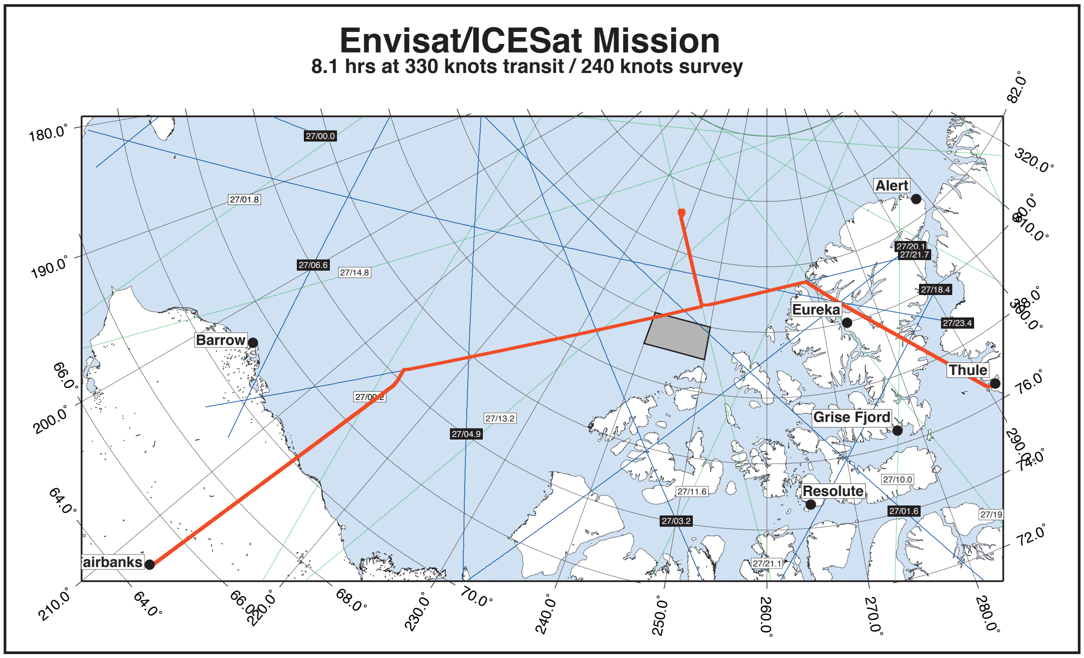


Fig. 16: Thule, Greenland Ramp Flight Path

Phase 2 of the mission, led by Principal Investigator William Krabill from NASA Wallops Flight Facility, validated remotely sensed data acquired by ICESat, and the European Space Agency's (ESA) Envisat satellite. The mission was completed during the transit from Fairbanks, Alaska to Thule, Greenland in 8.1 hours. A notable feature of the Phase 2 flight was that the P-3 flew directly beneath an Envisat overpass and within several minutes of an ICESat overpass. The flight path is shown in Figure 16.

The Phase 3 Greenland flights, also led by Krabill, were designed to aid in the study of the ice sheet mass balance using the ATM4 laser altimeter as the primary instrument. Flight lines were flown at an altitude of 2000 meters along Greenland's Western coastal region. Flight Traverse 1 was flown after an overnight in Thule, Greenland (Figure 17), and Traverse 2 was flown after an overnight in Sondrestrom, Greenland (Figure 18). A total of 6 science flight hours completed Phase 3 of the mission. The ATM4 data will be used to compare data from prior Greenland surveys to aid in determining changes to the Greenland ice sheet mass balance.

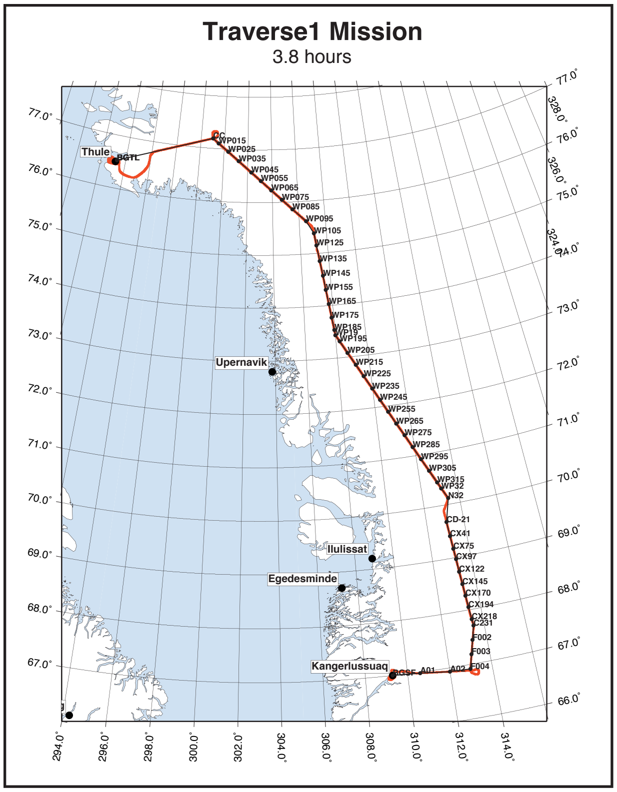


Fig. 17: Phase 3 Traverse 1 over Greenland.

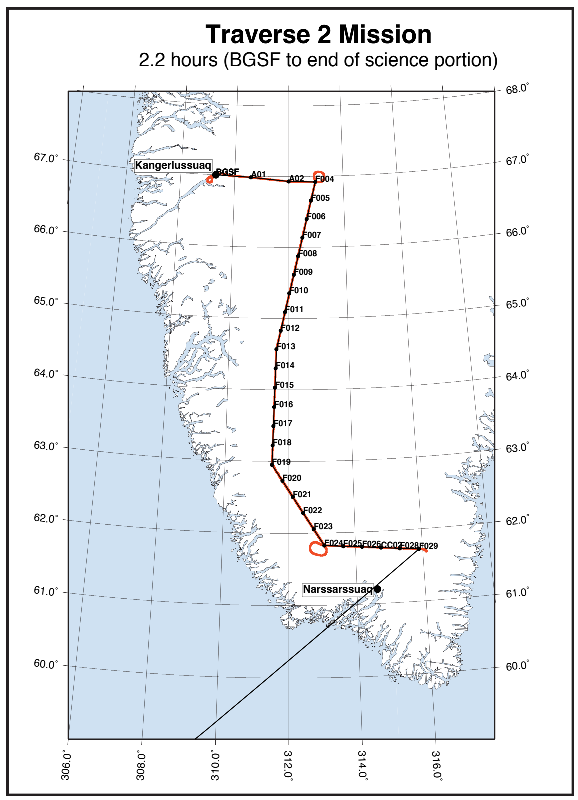
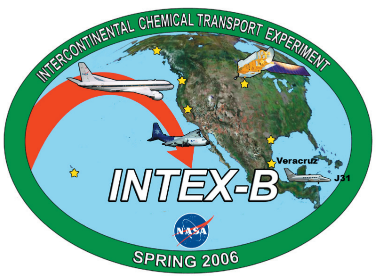


Fig. 18: Phase 3 Traverse 2 over Greenland.

INTEX-B/MILAGRO



INTEX-B

The largest NASA airborne science field campaign in 2006 was the Intercontinental Chemical Transport Experiment (INTEX-B). Sponsored by the Tropospheric Chemistry and Radiation Science programs at NASA Headquarters, and with the partnerships of the National Science Foundation, the Department of Energy, and the countries of Mexico, Canada, and Germany, the campaign obtained significant scientific data to understand the impacts of intercontinental pollution transport on air quality and climate from local to global scales. The lead mission scientist for INTEX was Dr. Hanwant Singh of NASA's Ames Research Center.

The scientific objectives of the mission were to measure:

- Continental Outflow: determine extent and persistence of the outflow of pollution from Mexico.
- Transpacific Pollution: track transport and evolution of Asian pollution and assess implications for air quality and climate.
- Air Quality: relate atmospheric composition to sources and sinks and test chemical transport models.

Fig. 19: Science team contingent deployed to Anchorage, May 2006.

- Aerosol Radiative Forcing: characterize effects of aerosols on solar radiation.
- Satellite Validation: validate space-borne observations of tropospheric composition.

Fig. 20: DC-8 intercomparison flight with NCAR C-130 near Seattle.

The broad scope of the mission included over 300 participants. INTEX-B utilized the NASA DC-8 flying laboratory as well as the Sky Research J-31, a NASA B-200, and the NCAR C-130 aircraft (Fig. 20), with a total of 41 instruments to sample in-situ tropospheric chemistry and provide valuable data to validate NASA's Earth Science satellites, including the Aura satellite. In addition, multiple satellites, ground stations, and models were utilized to achieve mission objectives. The mission encompassed a three-month observation period with deployment sites in Houston, Texas, Veracruz, Mexico, Honolulu, Hawaii, Seattle, Washington, and Anchorage, Alaska.

INTEX-B was also conducted in close cooperation with the Megacity Initiative: Local and Global Research Observations (MILAGRO) mission, a major NSF-led field experiment to study megacity pollution. (See following section for J-31 and MILAGRO.)

INTEX was the first major field campaign for the University of North Dakota, which now operates the DC-8 under a cooperative agreement with NASA. For this mission, the DC-8 completed 17 science flights with a total of 143 flight hours, and took data over significant portions of North America, the Gulf of Mexico, and the northern Pacific (Fig. 21). The J-31, based in Mexico, flew 14 science flights with a total of 44 flight hours. The NASA B-200, also based in Mexico, flew 17 science flights with a total of 52 flight hours. (See next section.)

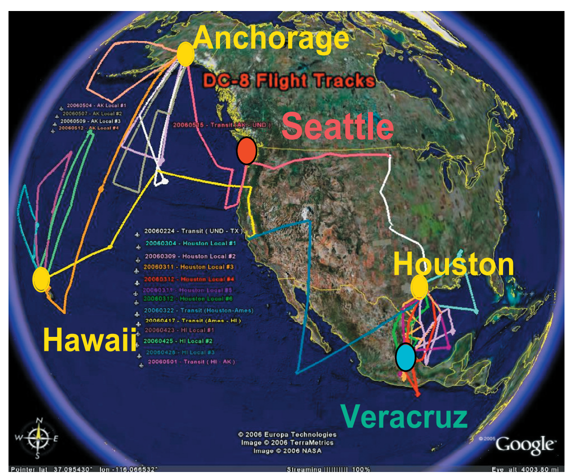


Fig. 21: Summary of DC-8 flight tracks.

The number of personnel, aircraft, and deployment sites for this mission presented significant logistical challenges. During some points in the mission, planes were flying from two deployment sites, while set-up for the next site was simultaneously taking place at a third. At each site, the science teams required lab space, communications and network connectivity, aircraft equipment, shipping of science equipment, meeting space, accommodations, and

Fig. 22: Kulis Air National Guard base in Anchorage, Alaska, puts out the welcome mat for NASA at the final deployment site for the mission.

security access. NASA owes much of its success with the mission to the U.S. Air Force, which provided airlift support, load and logistics support, and hosting NASA aircraft operations at sites in Hawaii and Alaska (Fig. 22).

The INTEX-B experiment is the second phase of a broader NASA project to study the transport and evolution of gases and aerosols across continents and to assess their impact on regional air quality and climate. During INTEX-B, researchers pursued the origins of pollution that ultimately finds its way to North America and affects air in the troposphere, the lower part of the atmosphere in which we live and breathe. This second phase was conducted in April when Asian pollution transport to North America is at its peak. In 2004, the first phase of INTEX explored the makeup and transport of air from the U.S. to Europe during the middle of summer.

Early data analysis provides a view of Asian influences across North America and proves to be far more pervasive than expected. Anthropogenic pollution, smoke from fires, and Asian and stratospheric influences coexist in the troposphere in stratified layers. Important correlative data for Aura satellite validation was also obtained (Figure 23). The science data from the mission are presently being analyzed and will be published in a series of papers in peer reviewed journals over the coming months and years.

More information on the INTEX mission is available at http://espo.arc.nasa.gov/intex-b.

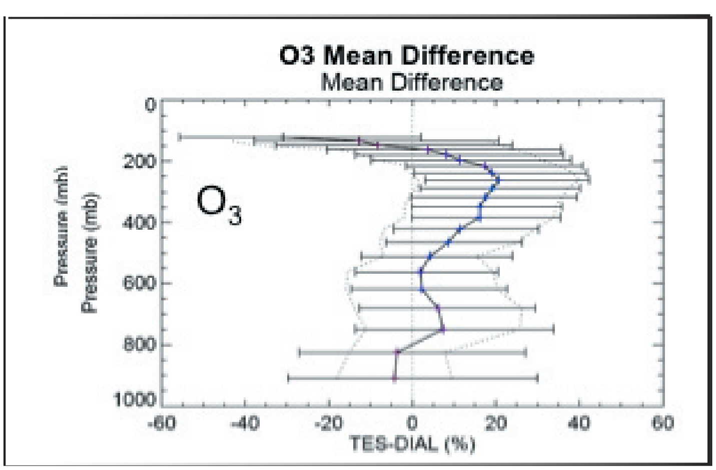


Fig. 23: Comparison of Aura and DIAL ozone profiles.

MILAGRO

In February and March 2006, as part of the INTEX-B/MILAGRO mission, the Sky Research Jetstream 31, and the Langley B-200 loaded with a suite of atmospheric science equipment, deployed to Veracruz, Mexico to measure the properties and radiative effects of aerosols, water vapor, clouds and surfaces.

The specific goals of the mission were to:

- Characterize the distributions, properties, and effects of aerosols and water vapor advecting from Mexico City and biomass fires toward and over the Gulf of Mexico, including aerosol optical depth and extinction spectra.
- Test the ability of Aura, other A-Train and Terra sensors, and airborne lidar to retrieve aerosol, cloud, and water vapor properties.
- Characterize surface spectral albedo and bidirectional reflectance distribution function (BRDF) to help improve satellite retrievals.
- Quantify the relationships between the above and aerosol amounts and types.

Fig. 24: Sky Research J-31 aircraft on the ramp at the General Heriberto Jara International airport, Veracruz, Mexico.

To meet the above science goals, the J-31 carried a payload comprised of the following six instruments: Ames Airborne Tracking Sunphotometer (AATS-14), Solar Spectral Flux Radiometer (SSFR), Research Scanning Polarimeter (RSP), Cloud Absorption Radiometer (CAR), Position and Orientation System (POS), and Meteorological Sensors and Nav/Met Data System (NavMet).

Fig. 25: J-31 Science flight planning meeting at the MILAGRO Operations Center in Veracruz.

Fig. 26: J-31 flight over Mexico City metropolitan area showing local haze and pollution. March 6, 2006.

The J-31 Lead Principal Investigator, Dr. Phil Russell, led the instrument PIs in developing a consensus set of science goals. He coordinated flight planning, including appointment of flight scientists. NASA Ames provided three of the six instruments on-board the J-31 and conducted the instrument integration, including the new installation of the CAR instrument on the nose of the aircraft. The Earth Science Project Office managed the deployment to Verazcruz, and worked with Mexican officials for all aspects of the deployment, including permits, shipping, visas, accommodations, security, ground support, etc.

Planning of this mission was a complex endeavor, requiring close coordination with the many MILAGRO science and operations groups. The J-31 team was able to not only successfully balance science flight objectives among the on-board instruments, but also to coordinate flight plans with the other five U.S. aircraft participating in the campaign (along with additional ground elements), Mexican airspace air traffic restrictions, and coordinate with defined satellite overpass times. Continuously changing conditions over both Mexico City and the Gulf of Mexico required frequent changes to flight paths to maximize science data return. In all, measurements were made on thirteen successful flights out of Veracruz over a three-week deployment period.

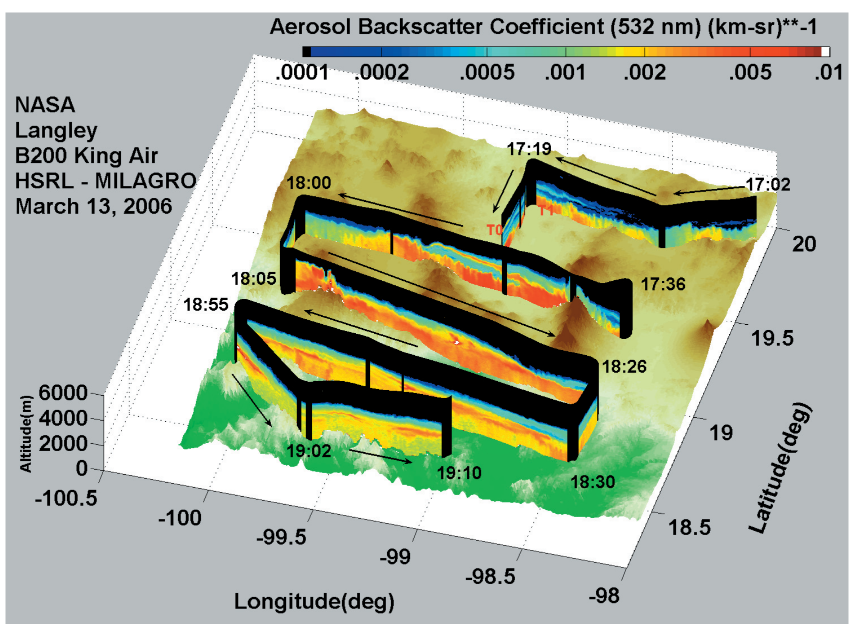


Fig. 27: Three-dimensional rendering of aerosol backscatter profiles acquired with the airborne HSRL from the 13 March MILAGRO flight. This flight was a "raster scan" across and south of Mexico City focused on assessing pollution outflow to the south.

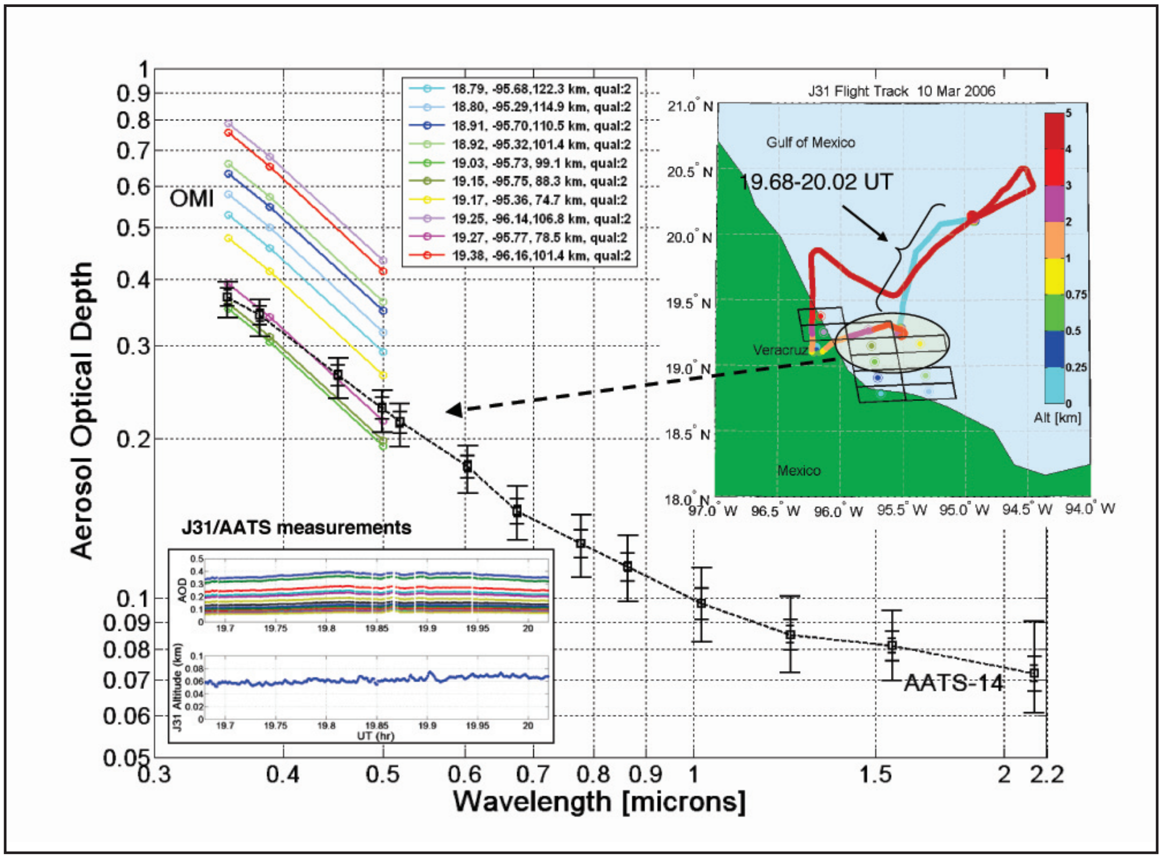


Fig. 28: Comparison of OMI and AATS Aerosol Optical Depth. Corresponding J-31 flight track is shown.

The NASA Langley B-200 also conducted science flights from Veracruz with a suite of aerosol and cloud remote sensing instruments including the new High Spectral Resolution LIDAR (HSRL), the Langley Airborne A-band Spectrometer (LAABS), the Hyperspectral Polarimeter for Aerosol Retrievals, and a digital camera. See Figure 27 for sample HSRL data over Mexico City.

Review of the science data is now underway, including comparisons of aerosol optical depth (AOD) values from the J-31 sunphotometer (AATS) to those from the OMI and MODIS satellite instruments (Fig. 28). Data are being archived in the INTEX-B archive at NASA Langley. Preliminary science results were presented at the first MILAGRO science meeting in Boulder, Colorado, in October 2006, and further science results were presented at the Fall 2006 AGU meeting in San Francisco in December and the INTEX-B science meeting in March 2007.

CC-VEx

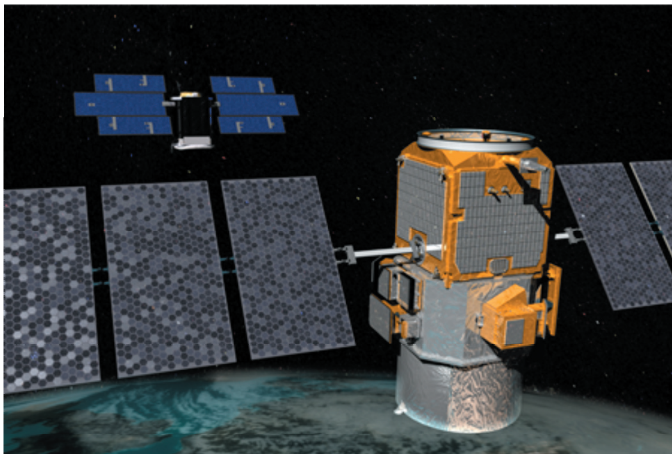
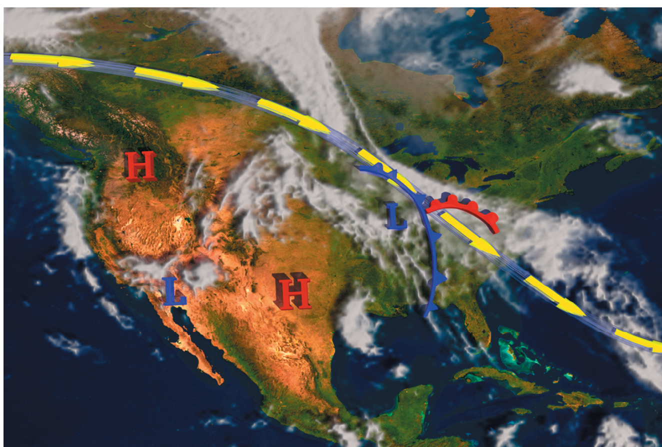


Fig. 29: CloudSat and CALIPSO pairing set a new standard in terms of precision placement of Earth-orbiting satellites. Both satellites look at the same clouds in the atmosphere.

The CALIPSO-CloudSat Validation Experiment (CC-VEx) was conducted between July 24 and August 14, 2006 and was designed to provide coincident observations of cloud and aerosol layers needed to support calibration and validation studies for two new satellite missions: CALIPSO and CloudSat. These missions provide valuable new information on vertical structure and properties of aerosols and clouds needed to improve our understanding of climate, weather, and air quality. They were launched together on a Delta II launch vehicle on April 28, 2006 and placed in formation with three other earth observing satellites into what is commonly known as the “A-Train” satellite constellation. CALIPSO is a joint mission between NASA and the French space agency, Centre National d’Etudes Spatiales (CNES), and its payload consists of an innovative two-wavelength polarization-sensitive lidar, an infrared imaging radiometer, and a wide field-of-view camera. CloudSat is a partnership between NASA, the Canadian space agency, and the United States Air Force, and its payload consists of a state-of-the-art cloud profiling radar operating at 94 GHz.

For initial validation studies, both CALIPSO and CloudSat needed measurements of layers of clouds and aerosols over a range of altitudes and thicknesses with varying composition to compare with the satellite observations. To meet these requirements, three aircraft provided by multiple government agencies were used during CC-VEx: the NASA ER-2, the Weather Modification, Inc LearJet, and the NASA B-200 King Air aircraft. The ER-2 payload included a lidar, radar, and imaging spectrometer with instrument characteristics similar to CALIPSO and CloudSat. The Learjet carried a suite of cloud particle measurements, and the King Air supported a newer lidar design. Flights were designed to fly over different cloud and aerosol features at specific locations timed for coincident satellite overpasses. Base operations for the ER-2 and the LearJet were located at Warner Robbins Air Force Base in Georgia and hosted by the 78th Air Base Wing and the 116th Air Command Wing. Two B-200 flights were conducted from NASA Langley and another from Warner Robbins.

During CC-VEx, 12 comparison flights were conducted by the ER-2, including four at night. The Learjet made seven flights, and the B-200 King Air made three flights. All planned mission objectives were successfully achieved with measurements of thick and thin cirrus, mid-layer clouds, precipitating clouds, clouds with ice, water, and mixed phases, and aerosols (including scenes with thin cirrus) along the satellite track. Early satellite validation studies using CC-VEx observations led to improvements in the quality of CALIPSO and CloudSat data products released in late 2006.



The study of meteorology presents significant challenges to scientists. One of the most challenging aspects is the inherent complexity of weather coupled with its high rate of change. In the case of clouds, scientists seek new insights into how they form, behave, and interact with the Earth's atmosphere. Engineers designed CloudSat and CALIPSO to deliver the data needed by scientists to provide new understanding of how clouds, water vapor, ice particles, and aerosols affect the weather.

Fig. 30

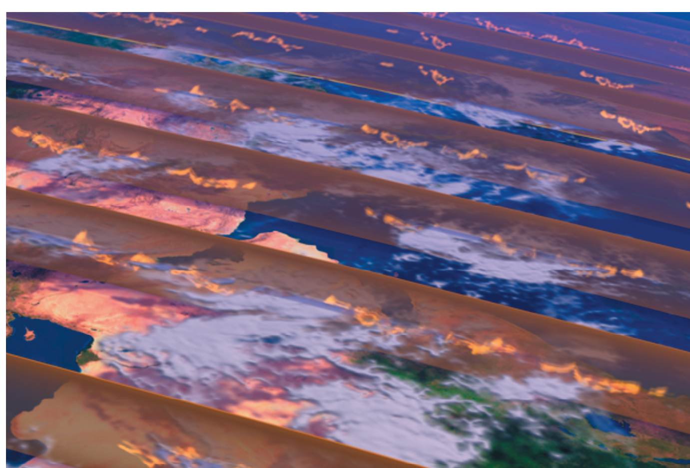


Fig. 31

Manta Maldives AUAV Campaign (MAC)

Fig. 32: A strip of asphalt road serves as a make-shift runway for takeoff during the El Centro shake-down trial.

Scripps Institution of Oceanography conducted a field campaign during March 2006 over the Indian Ocean to investigate the role of the Asian Brown Cloud in Global Dimming. In stacked, three-aircraft formations, UAVs flew below, in, and above the clouds. This enabled the simultaneous measurement of upwelling and down welling radiation fluxes at different altitudes. The campaign also demonstrated use of low cost, light weight, Autonomous Unmanned Air Vehicles (AUAV), miniaturized precision sensors and data management systems, and software for controlling multiple aircraft.

The National Science Foundation, the National Oceanic and Atmospheric Administration, and NASA sponsored the project and recommended that the project team enlist mission project advisors from NASA Dryden Flight Research Center. Dryden Mission Project Managers visited the aircraft manufacturer and operator, Advanced Ceramics Research (ACR), and participated in the shakedown trials at NAS El Centro prior to deploying with the team to the field site on Hanimaadhoo Island in the Republic of Maldives.

A total of eighteen coordinated science missions were completed including 55 sorties and over 120 hours of data acquisition. The automatic flight management system successfully controlled the simultaneous flight paths and speeds of each aircraft such that a cloud structure was observed and sampled with a spatial precision of 20 meters (horizontal).

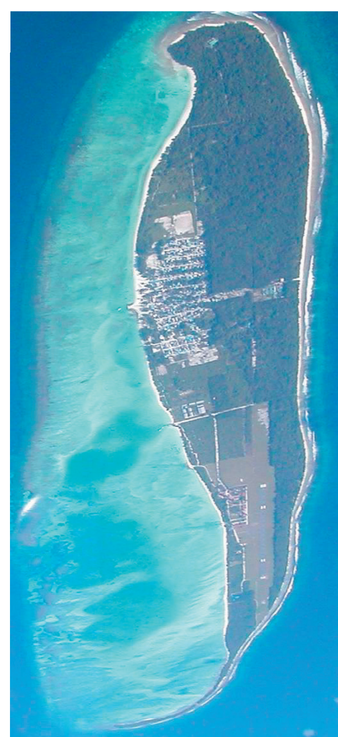


Fig. 33: Hanimaadhoo Island; the airfield can be seen at the bottom and the climate observatory at the top of the picture.

Fig. 34: AUAV on short final approach after a science flight.

Flights were conducted and coordinated with measurements made from the Hanimaadhoo Climate Observatory during the South Asian Monsoon shift.

This use of low-cost UAVs enabled concurrent data collection from spatially separated perspectives. With growing understanding of the risks and capabilities of this class of vehicle, creative new Earth science mission concepts can be anticipated.

Fig. 35: Primary and backup aircraft in their hangar between science missions.

NAMMA

The NASA African Monsoon Multidisciplinary Activities (NAMMA) mission was a major 2006 field campaign based in the Cape Verde Islands, 350 miles off the coast of Senegal, West Africa, designed to study tropical storm systems and the genesis process for hurricanes. The mission was designed to characterize the evolution and structure of African Easterly Waves (AEWs) and mesoscale convective systems over continental western Africa, the formation and evolution of tropical hurricanes in the eastern and central Atlantic, the composition and structure of the Saharan Air Layer (SAL), and whether aerosols affect cloud precipitation and influence cyclone development. Dr. Edward Zipser of the University of Utah was the lead Mission Scientist.

NAMMA utilized the NASA DC-8 research aircraft, with a total of 10 instruments and nearly 100 scientists in the field to sample tropical storm systems and provide valuable data to validate NASA's earth science satellites. The DC-8 was also flown in coordination with NASA's TOGA research weather radar, balloon soundings, and the SMART-COMMIT mobile research ground stations, measuring chemical, optical, microphysical, and radiative properties of the atmosphere.

Fig. 36: NASA DC-8 aircraft on the ramp at the Amilcar Cabral International airport, Sal Island, Cape Verde.

Fig. 37: The NAMMA science team receives a weather briefing by the forecast team. Daily weather forecasts are used in the field to help select the appropriate flight plan and operational constraints.

Some noteworthy highlights of the 30-day mission:

- NASA conducted 13 science flights that sampled seven major waves/circulations, including what is thought to be the genesis of tropical systems Debby, Ernesto, Gordon, and Helene, from mid-August to mid-September of 2006.

- NASA flew a number of dedicated missions studying cloud microphysics and the Saharan Air Layer (SAL). The influence of the SAL and its associated mid-level jet will be studied for years to come with data never before available to the science community.

• NASA provided tropical system formation data which was passed to the National Oceanic and Atmospheric Administration (NOAA) for further definition and study as the systems moved west toward the Caribbean and the North American continent.

Fig. 38: Dr. Jim Podolske of the NASA Ames' Atmospheric Science Branch examines laser absorption spectrometer data of water vapor and carbon monoxide during a NAMMA science flight.

Due to the current media interest in global climate change and the events of the 2005 hurricane season, this mission received extensive media coverage. Subsequent to a NASA news release and press conference on July 26, 2006, the story received wide coverage in all 50 states and around the world, especially from web and print media, including the *New York Times*, *USA Today*, and the *Washington Post*. A profile of the mission was also featured on National Public Radio. International coverage included stories from Australia, Canada, Cape Verde, China, Denmark, Germany, India, Kazakhstan, Malaysia, Netherlands, Nigeria, Portugal, Romania, South Africa, Spain, and the United Kingdom.

The mission was a collaboration between NASA, the NOAA Hurricane Research Division, several universities, the U.S. Air Force, and the Cape Verdean National Institute of Meteorology and Geophysics (INMG). NAMMA was also conducted in close cooperation with the AMMA mission, another major, multi-national (25+ countries) field experiment to study West African monsoons and their effect on water resources and climate in western Africa.

NAMMA was sponsored by the Atmospheric Dynamics and Radiation Sciences programs at NASA Headquarters. Dr. Ramesh Kakar and Dr. Hal Maring are the Headquarters' program sponsors.

Data from the mission are being checked, calibrated, and archived in the NAMMA data archive at NASA Marshall. Review of the science data can then begin. The first NAMMA science meeting is scheduled for the Spring of 2007.

NAMMA web site: http://namma.nsstc.nasa.gov

Fig. 39: Dr. Ed Browell of NASA Langley discusses lidar science onboard the DC-8 with Cape Verdean high school students.

Western States Fire Mission: 2006 Campaign

Fig. 40: Altair in flight with the AMS-Wildfire sensor aboard. The sensor is located in the payload belly pod, with additional science instrumentation capabilities in the aircraft nose.

The Western States Fire Mission (WSFM) 2006 Campaign showcased emerging technologies related to real-time disaster event monitoring using NASA-developed sensing systems, data telemetry systems, improved real-time data analysis technologies, and utility of the Altair UAS platform. The project was a partnership between NASA Ames Research Center, the U.S. Forest Service and the National Interagency Fire Center (NIFC) to develop, integrate, test and demonstrate NASA-derived airborne sensor data into everyday disaster monitoring exercises. The mission demonstration campaign was supported by NASA's SMD, Earth Science Capabilities Demonstration (ESCD) funds and the Disaster Applications Program Manager at NASA HQ (S. Ambrose).

The WSFM team helped develop criteria for an improved line scanner imaging system developed by NASA Ames. The Autonomous Modular Sensor (AMS)–Wildfire was designed to operate autonomously for long-duration flights aboard a UAS. The sensor was designed to use specific thermal channel capabilities for improved fire discrimination. The two thermal channels on the AMS-Wildfire replicate two channels planned for the National Polar-orbiting Operations Environmental Satellite System (NPOESS) VIIRS satellite system. The airborne instrument can therefore operate as a VIIRS simulator to test fire detection algorithm development prior to the satellite launch. The AMS-Wildfire instrument was outfitted in an instrument pod (developed for this mission and other NASA UAS science payloads) to be carried under the belly of the Altair platform (Fig. 40). The pod and instrument are also compatible with the Ikhana UAS platform.

The WSFM campaign was a series of 4-5 flights on the Altair extending through the primary western U.S. fire season during August through September. The mission had specific science objectives and criteria, including coincident under-flight of Aqua and Terra (MODIS) satellites to calibrate the MODIS Rapid Response System (fire detection algorithm in use by USFS). Each mission was designed to demonstrate science data collection for extended duration (>20-hours aloft). Additional mission criteria included long-distance missions in the

National Airspace System (NAS), in-flight revectoring to emerging fire targets, continual monitoring of prescribed fire, real-time data delivery to an Incident Command Center (ICC) and “global sharing” of science aspects of the mission through a newly developed Collaborative Decision Environment (CDE), Decision Support System (DSS).

The WSFM missions had planned to begin the first week of August with an extension of 3-4 weeks (one mission per week) to the end of August/early September time frame. Because the WSFM team was delayed in securing a Certificate of Authorization (COA) from the FAA to operate the Altair in the NAS, the mission was continually delayed until the end of the western U.S. fire season in late September.

An FAA COA for a single Altair mission was granted in late October to operate over a region encompassing Yosemite National Park that was immediately adjacent to the DFRC Range. On October 24 and 25, the Altair flew over the region on a 22-hour mission. The WSFM team successfully collected AMS-Wildfire scanner data from the Altair platform over a few small prescribed fires in the park region and on adjacent National Forest lands. The science team collected multiple AMS-Wildfire scanner data sets, coincident with Aqua and Terra overpasses of these small fire events.

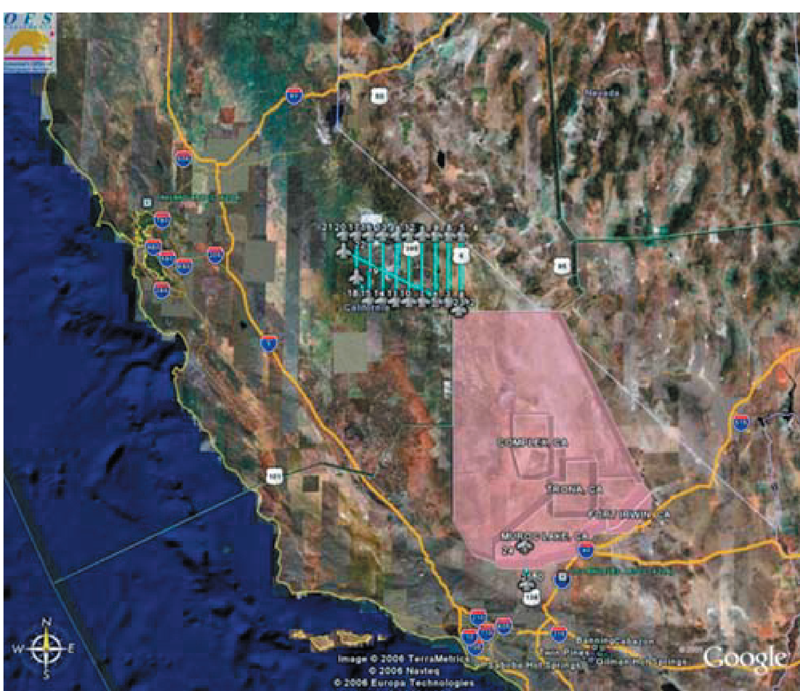


Fig. 41: Image of the real-time screen capture as the Altair left the DFRC Restricted Range and entered the NAS for the first time, heading to Yosemite National Park for the imaging Mission. The planned flight tracks over Yosemite are shown in the graphic as well. The pink colored area is the DFRC Range. The Altair-in-flight icon can be seen at the northern edge of the restricted area, entering the NAS.

The 2007 Western States Fire Mission is being planned as a follow-on to the 2006 campaign, with planned mission flights beginning in mid-July. The new NASA Ikhana platform will be used to perform this mission series.

To access fire data, go to: http://asapdata.arc.nasa.gov/ams

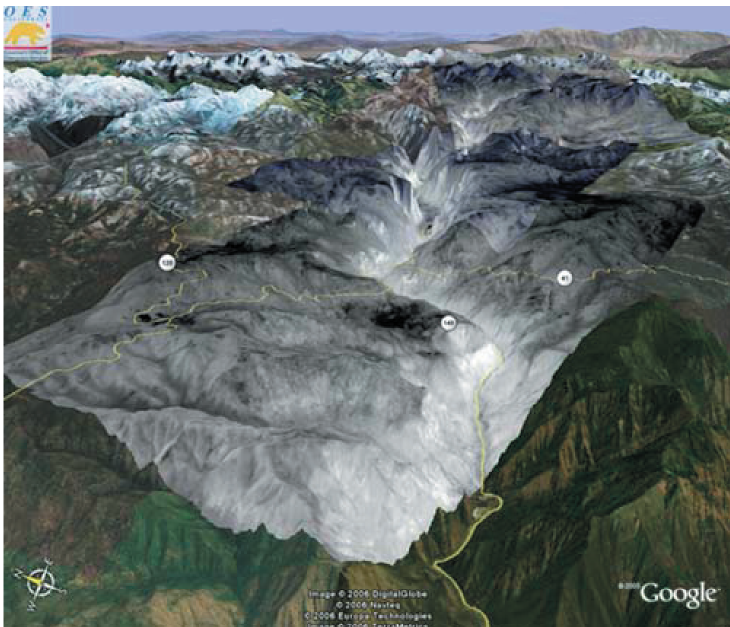
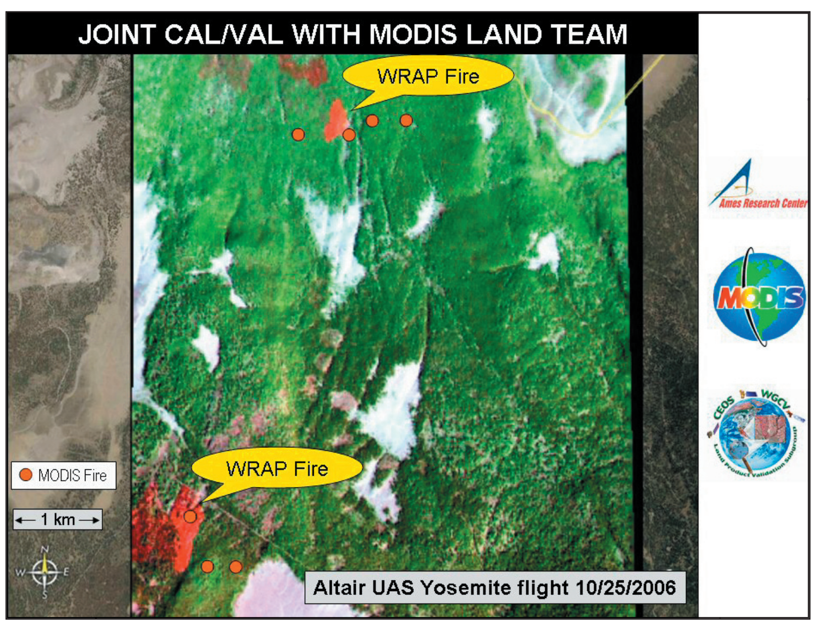


Fig. 42: Three thermal images collected from the AMS scanner operating aboard the Altair UAS during the Yosemite National Park mission. The images are real-time mosaiced and overlain on the GoogleEarth background. The images, collected at night, present a view looking east, up the Yosemite Valley. The data were collected late at night (2:00 AM).

Fig. 43: Calibration/Validation of MODIS Fire Detects with AMS-Wildfire sensor. Data collected by AMS-Wildfire aboard the Altair UAS platform, operating over the Yosemite National Park region in the NAS on October 25th, 2006. Data collected from 43,000 ft. altitude.



Esperanza Fire Support Mission

Immediately following the Yosemite flights in the NAS, a large wildfire in Southern California broke out. On October 27, the team received an emergency request to support the Esperanza Fire from the California Governor's Office and the California Office of Emergency Services (CA-OES). A COA was granted by the FAA and the team reintegrated the AMS-Wildfire scanner on the Altair and initiated a support mission over the Esperanza Fire on October 28 and 29. A 16.6-hour mission was successfully flown over the fire. Real-time fire information and images were collected and distributed via the CDE to the Incident Command Center (ICC) and directly to the CA-OES in Sacramento, California. The ICC used the data to locate escaped fire spots and to deploy teams to take control of those previously unknown events.

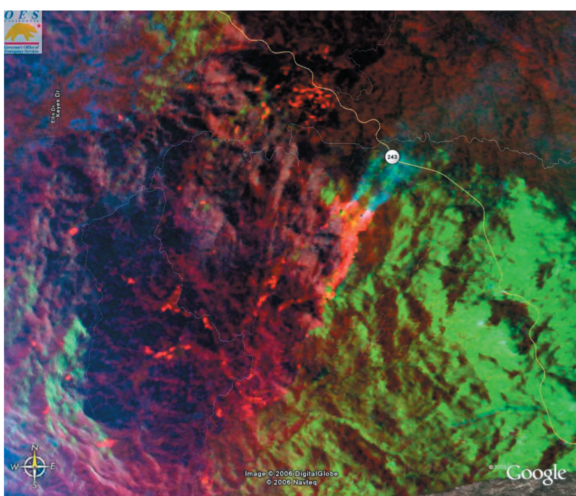


Fig. 44: AMS-Wildfire sensor data collected over the Esperanza Fire, October 28th, 2006 from the Altair UAS operating in the NAS over the fire. The Altair flew at 43,000 ft and the AMS-Wildfire data collected fire-derived information for the 16.6 hours of the mission. Data were geo- and terrain-rectified onboard the UAS autonomously, in real-time, and relayed to the ICC and CA-OES as GEOTIFF files, capable of immediate ingestion into GoogleEarth for visualization and 3-D mapping capabilities.

Technology Development

UAVSAR

UAVSAR Instrument Development

Fig. 45: UAVSAR pod in loading fixture.

NASA's Jet Propulsion Laboratory is currently building a reconfigurable, polarimetric L-band synthetic aperture radar (SAR), specifically designed to acquire airborne repeat track SAR data for differential interferometric measurements that is also designed to be flown from a UAV. Differential interferometry can provide key deformation measurements, important for studies of earthquakes, volcanoes and other dynamically changing phenomena. Using precision real-time GPS and a sensor controlled flight management system, the system will be able to fly predefined paths with great precision. The expected performance of the aircraft's flight control system will constrain the flight path to be within a 10 m diameter tube about the desired flight track. The radar will be fully polarimetric, with a range bandwidth of 80 MHz (2 m range resolution), and will support a 16 km range swath. The antenna will be electronically steered along the flight track to assure that the antenna beam can be directed independently, regardless of the wind direction and speed. Other features supported by the antenna include elevation monopulse and pulse-to-pulse re-steering capabilities that will enable some novel modes of operation. The system will nominally operate at 45,000 ft. (13800 m) flight altitude. The program began as an Instrument Incubator Project (IIP) funded by NASA Earth Science and Technology Office (ESTO).

Fig. 46: UAVSAR pod mounted to GIII aircraft.

UAVSAR Platform Development

As the name implies, this instrument is being designed with the requirement that it be capable of being flown on an Unmanned Aircraft System (UAS).

Fig. 47: PPA hardware in equipment rack.

It was decided early in the project that the instrument should be pod-mounted to allow it to be portable between aircraft. A NASA Gulfstream G-III aircraft was selected as the development support platform and the NASA Ikhana and General Atomics Predator B, as the target UAS. Completed milestones include finishing the Platform Precision Autopilot (PPA) pod, and GIII modification design reviews; completion of the PPA system component assemblies: completion of a precision navigation controller software; completion of all GIII aircraft electrical and structural modifications, and fabrication of two complete UAVSAR pod assemblies. PPA development flights have been initiated and first flight of the UAVSAR instrument is on track for early 2007.

Repeat Pass Interferometry System Development

The objective of this project is to develop and demonstrate technologies required to support Repeat Pass Interferometry (RPI) missions. The team is currently focused on development of a Precision Autopilot System capable of repeatedly controlling the flight track of an aircraft within a specified 10 meter tube. This system will have the capability to conduct RPI measurements with separations ranging from minutes to years. Integrated into this effort is supporting the Jet Propulsion Lab in the flight phase of the UAV Synthetic Aperture Radar (UAVSAR) instrument development. These combined efforts will provide a powerful tool for collecting RPI data.

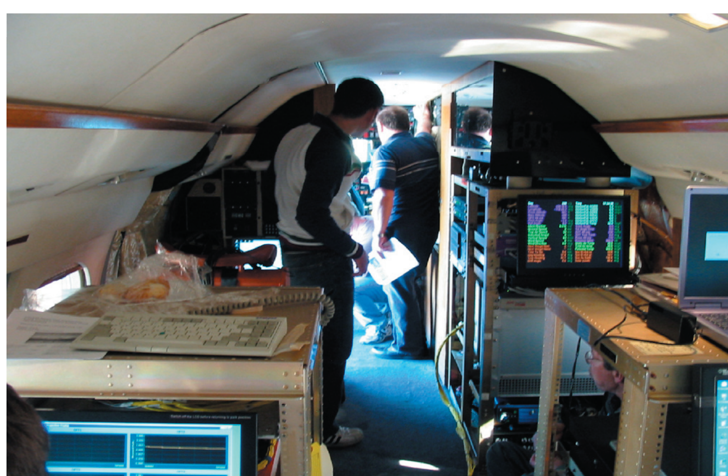


Fig. 48: GIII aircraft interior

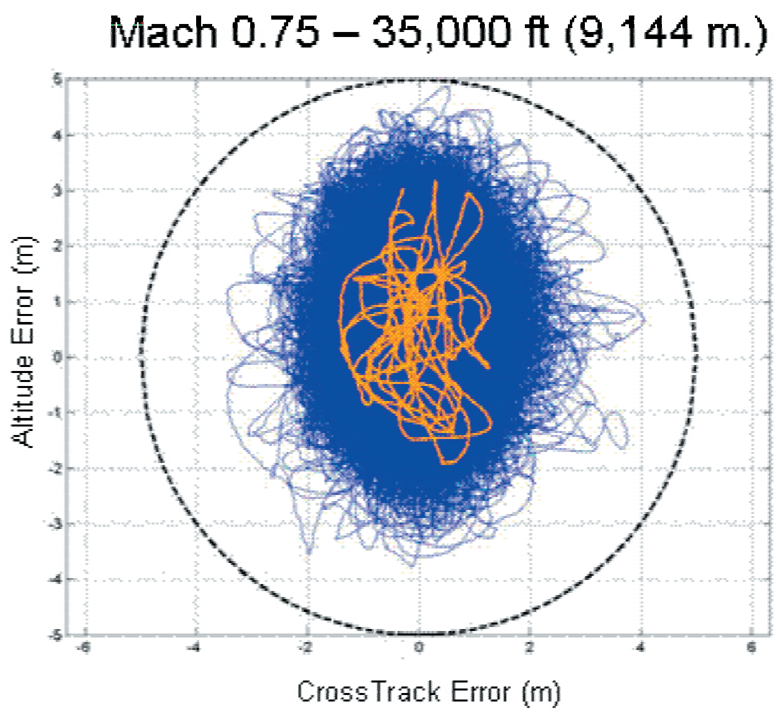


Fig. 49: Performance data results depicting Monte Carlo simulation testing of the Platform Precision Autopilot maintaining the aircraft track within 10 meters of a selected course. This capability will support Repeat pass Interferometry (RPI) data collection.

Ikhana

Fig. 50: Ikhana UAS aircraft on the ramp at Gray Butte, CA.

NASA's much-anticipated MQ-9 Predator-B unpiloted aircraft system (UAS) completed manufacturing and acceptance testing in 2006. The aircraft has been renamed "Ikhana" (a Native American word from the Choctaw language meaning "intelligent, conscious, or aware") to better reflect the intended mission for the aircraft. Based at the Dryden Flight Research Center, the aircraft will begin conducting flights for suborbital science in 2007.

Ikhana can remain aloft for up to 30 hours depending on the mission profile and payload. The aircraft will be capable of carrying up to 1500 lbs. on one of the wing pylon stations, and around 500 lbs. within the avionics bay. The project team completed development of a wing pylon that will be able to carry the pod developed for the Altair Western States Fire Mission. This capability decreases the time required to integrate new payloads and minimize the time required to reconfigure the aircraft between payloads. The project team is developing flexible payload interfaces in cooperation with the science community at several NASA centers.

A standard ground control station (GCS) has also been acquired and has been mounted in a mobile trailer to support local and deployed missions (Fig. 51). Numerous upgrades to this standard control center have been designed and tested in 2006, including 6 engineering monitoring stations and an intercom system. These upgrades will be installed into the mobile GCS in early 2007. Other procurements include a 4.5m mobile Ku-band satellite dish, special aircraft ground support equipment, and a small spares set. Once the Ikhana shipping containers are delivered in FY2007, all equipment required to deploy the UAS to remote sites via ground, sea, or airborne cargo transport will be in place.

The project team also completed the development of an Airborne Research Test System (ARTS) in cooperation with the Institute for Scientific Research that will have the ability to autonomously control the aircraft and onboard payloads. This activity will allow Ikhana to host technology demonstration experiments such as intelligent mission management, intelligent health management, collision avoidance, and precision trajectory. A NASA-led UAS capability assessment has identified these technologies as key to enabling many suborbital science UAS missions.

General Atomics is under contract to complete Ikhana flight control modifications in 2007 that will allow the ARTS to command the aircraft in place of the remote pilot. The project has developed an Ikhana simulation for developing and testing ARTS-based flight experiments, in addition to standard pilot training and mission planning.

An experimenter's handbook is currently being developed that will document aircraft performance, operational limitations, payload interface requirements (network, power, installation options, etc.), payload best practices (materials, wiring, structural design factors, etc.), and environmental requirements (vibration, shock, temperature, humidity, electro-magnetic interference). The Ikhana team also plans to build a mock-up of the avionics bay is also planned to reduce the time required to integrate payloads and prepare wiring harnesses.

The Ikhana project is being conducted in cooperation with NASA's Aeronautics Research Mission Directorate.

Fig. 51: Scientists' work stations within Ikhana's UAS Ground Control Station.

Altair

Fig. 52: Altair in flight with the Wildfire sensor pod installed. In addition to the sensor pod, scientific instruments may be installed in the aircraft's nose equipment bay.

The Altair aircraft, owned and operated by GA-ASI, has been supporting a NASA Unmanned Aircraft System (UAS) Western United States Wildfire flight campaign (see page 46). NASA procured a specially designed pod to carry payloads on Altair or Ikhana (Predator B). The Autonomous Modular Sensor (AMS)-Wildfire sensor system was flown in the new pod and flown over Yosemite National Park in Southern California in late October. The flight was conducted at an altitude of 43,000 feet and duration of 21.3 hours. After the Esperanza fire in Southern California ignited on Thursday, Oct. 26, 2006, in less than 24 hours, NASA was able to fly the Altair with sensor over the 40,200 acre fire. From an altitude of 43,000 feet, the Altair Unmanned Aircraft System's sensors collected and sent 100 images and more than 20 data files containing the location of the fire perimeter over a 16-hour period between October 28 and 29.

DFRC has also demonstrated that UAS's can be flown safely in the National Airspace System (NAS). For a typical flight profile, the Altair would take off or land from GA-ASI, Gray Butte, California, and is currently assisted by a chase plane up to 18,000 feet. The Edwards Air Force Base restricted range was utilized to ascend and descend to and from 43,000 feet. At 43,000 feet the Altair would then transition to and from the NAS. The Federal Aviation Administration (FAA) has issued Experimental Airworthiness Certificates for the manufacture of several UAS airframes and also recognizes government-

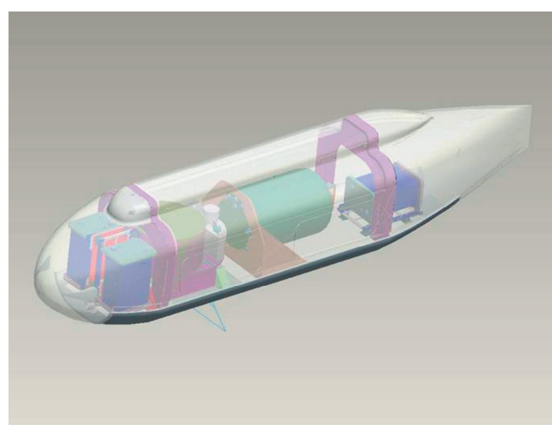


Fig. 53: Sensor pod depicting AMS-Wildfire Sensor installation. Pod tray arrangement allows for efficient reconfiguration of pod to accommodate different sensors and experiments.

issued airworthiness statements (i.e., public aircraft). An FAA recognized Airworthiness Certificate or a Certificate of Authorization (COA) is required in order to fly a UAS in the NAS. The FAA is working on a process to allow third party operations of a UAS in the NAS and is forecasted to be in place by 2012. NASA has discontinued the exclusive Altair lease arrangement with GA-ASI but the UAS can be made available through special contracting with GA-ASI.

SIERRA

In FY2006, the NASA Ames Research Center took ownership of 2 medium-class unmanned aircraft systems from the Naval Research Laboratory under a Memorandum of Understanding (MOU) to conduct joint development activities for sensors and UAS operations. With a gross take-off weight of approximately 450 lbs, and the capability to carry up to 100 lbs of science payload for more than 10 hours, the System Integration Evaluation Remote Research Aircraft (SIERRA) will fill an important niche among UAS's by providing a highly capable science platform that can be operated with less resources than a Predator-class UAS, while carrying a larger payload than Aerosonde-class systems. The SIERRA was designed to be highly modular, allowing for different configurations of wings, tails, and noses, depending on mission requirements. The aircraft will initially be flown in a pusher configuration, with the propeller in the rear, but it can also be configured as a puller. The pusher configuration will be useful for atmospheric sampling missions.

This year the SIERRA UAS team successfully assembled the first aircraft including the procurement of a ground system, design and installation of the electrical systems, development of a concept of operations (CONOPS) and completed engine checkout. Test flights and envelope expansion flights will be conducted in late 2007 with the first science missions taking place in 2008. Future science missions will include remote sensing, in situ sampling, aerosol, and radiation studies.

Fig. 54: SIERRA UAS.

Over-the-Horizon Communications Suborbital Telepresence

Within the Earth Science Capability Demonstration (ESCD) element of the Suborbital Science Program, the Over-the-Horizon Communications “Suborbital Telepresence” project (ESCD/OTH) targets affordable and sustainable capabilities to support networks of airborne instruments that are components of a future integrated Global Earth Observation System of Systems. ESCD/OTH is focused on network connectivity across science platforms to support teleoperation and control of science instruments.

The ESCD/OTH project delivered another noteworthy list of accomplishments this year. The OTH project demonstrated continuously improving global-reach instrument telepresence capabilities through support of six airborne science missions across three platforms (Altair, DC-8, ER-2) and two continents. NASA Dryden leads ESCD/OTH, with NASA Marshall and NASA Ames as contributing partners.

The long-term vision in suborbital networking includes a disruption tolerant network of multiple link technologies. This general scenario necessarily includes line-of-sight and augmented line-of-sight links that do not relay through satellites. This year ESCD completed a feasibility demonstration of high-rate wireless airborne networking using a NASA B-200 and existing telemetry infrastructure that achieved nearly 10 Mbit per second at a range of more than 150 miles. The project subsequently initiated an Advanced Experimental Systems Project under NASA Aeronautics Research Mission Directorate to pursue closure of identified technology gaps in this area.

A summertime education outreach opportunity with Embry Riddle University resulted in the design and construction by undergraduate students of “REVEAL-Lite,” a small REVEAL system for use in battery-operated and volume-constrained environments such as a sailplane.

Onboard technologies alone are not enough to establish suborbital platforms as nodes on a network of Earth observation systems. Ground stations and distribution infrastructure are needed to promote interoperability among platforms, instruments, and data management tools. Significant strides were made this year in developing and demonstrating the ground infrastructure and related tools needed to support networks of instrument payloads aboard airborne platforms. The most visible of terrestrial aspects of the work this year has been the introduction of Google Earth as a network data display client. The ESCD/OTH team introduced NASA airborne science to the integration of live flight track data with the Google Earth client, starting with the Altair/NOAA mission in November 2005. The ability to leverage Google Earth evolved rapidly through the year, culminating in a “Realtime Mission Monitor” used during the NAMMA deployment, and on the Altair Western States Fire Mission. This was particularly useful in a mission like NAMMA since there is interest in tracking the rapidly-changing conditions of tropical cyclogenesis. In all cases, the net-centric realtime displays contributed directly and significantly to the success of each science activity.

The long-term vision for suborbital networking is a disruption tolerant network of multiple link technologies. In addition to satellite communications, this scenario includes line-of-sight and augmented line-of-sight links that do not

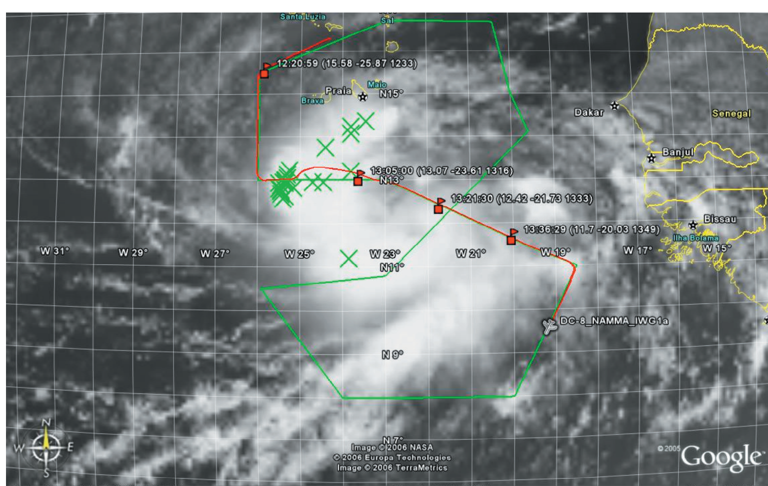


Fig. 55: NAMMA campaign near the Cape Verde Islands off the west coast of Africa. Screen shot of REVEAL provided DC-8 ground track data through Iridium communications satellites.

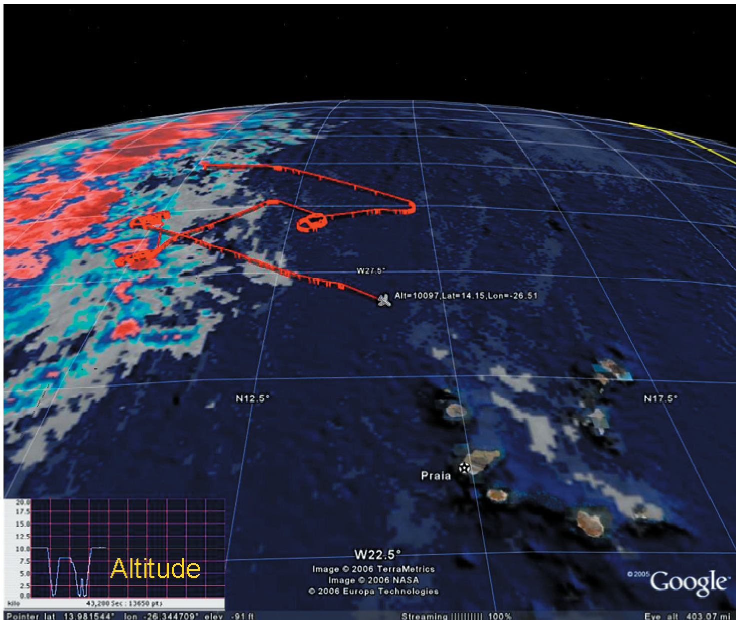


Fig. 56: DC-8 ground track data overlaid on weather satellite imagery and Google Earth provided real-time data to the science community via the Internet.

relay through satellites. To that end, this year ESCD completed a feasibility demonstration of high-rate wireless airborne networking using a B-200 aircraft and existing telemetry infrastructure that achieved nearly a 10 Mbit bandwidth at a range of more than 150 miles. The project subsequently initiated an Advanced Experimental Systems Project under NASA Aeronautics Research Mission Directorate to narrow identified technology gaps in this area.

Finally, ESCD/OTH has been an active participant in the Interagency Working Group for Airborne Data and Telecommunication Systems (IWGADTS). This group was formed in 2005 as a subgroup of the Interagency Coordinating Committee for Airborne Geosciences Research and Applications and targets cross-agency platform system interoperability. The IWGADTS group defined a consensus-driven set of parameters and a format (referred to as a "trivial data feed") for exchanging commonly needed realtime information. All ESCD/OTH activities since August 2006 have offered this format both in the air (where applicable) and on the ground.

REVEAL

The most visible effort of the OTH project continues to be the vehicular system component called the Research Environment for Vehicle-Embedded Analysis on Linux, or REVEAL. REVEAL is a vehicle-independent communication gateway for payload networks offering flexible computing resources and standardized interfaces in a dynamically configurable environment. Originally conceived for sensor web research, the REVEAL systems designed and built by ESCD project have been tailored to the needs of the airborne science community.

The Altair Western States Fire Mission provided an opportunity to demonstrate the flexibility of the system. REVEAL nominally supplied general-use vehicle state telemetry in parallel with health and status telemetry from a particular NOAA instrument for measuring ozone, water vapor, and trace gases. At the start of the historic 20-hour first flight of Altair in the national airspace, situational awareness displays verified that the NOAA "UCATS" instrument was inoperative. REVEAL-based connectivity to the instrument subsequently allowed researchers on the ground to rebuild the NOAA instrument operation software and get it functional again without impacting other activities on the mission.

REVEAL systems can now leverage multiple Iridium modems, and has used as many as a dozen modems in parallel. The communications module on the "Altair-Class" REVEAL system currently supports up to six modems in a compact package. JPL has also implemented protocol enhancements that will enable increased performance and robustness for multiple modems on airborne science platforms. Demonstration of these protocol enhancements are scheduled for FY07.

Planned 2007 activities are dominated by the Tropical Composition, Cloud and Climate Coupling (TC4) experiment. With three or more airborne science platforms performing coordinated measurements, TC4 offers an ideal opportunity to demonstrate an integrated system of observation systems. In addition, efforts are underway to design, build, and demonstrate a "Next Generation Navigation Recorder" that is a REVEAL-based plug-and-play replacement for the recorders on ER-2 and WB-57F.

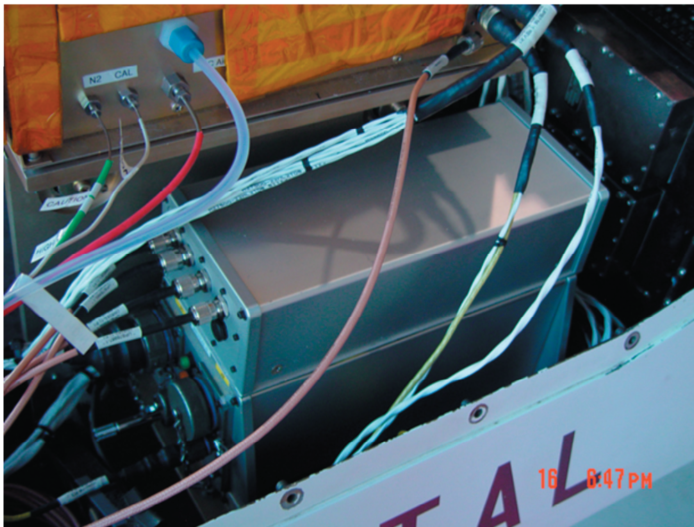


Fig. 57: REVEAL Box

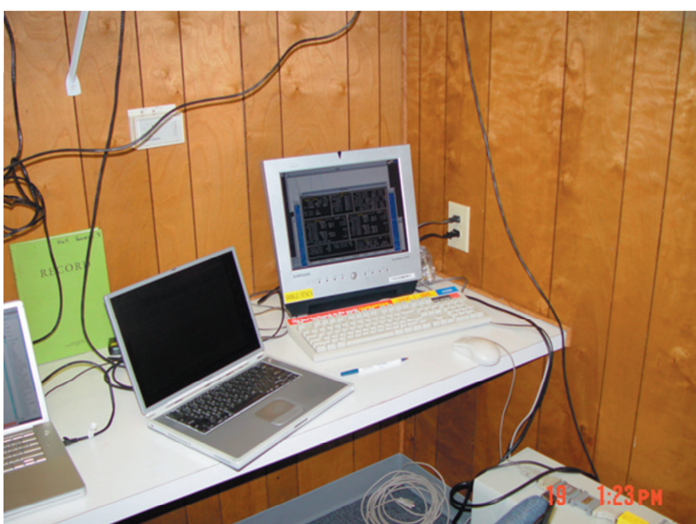
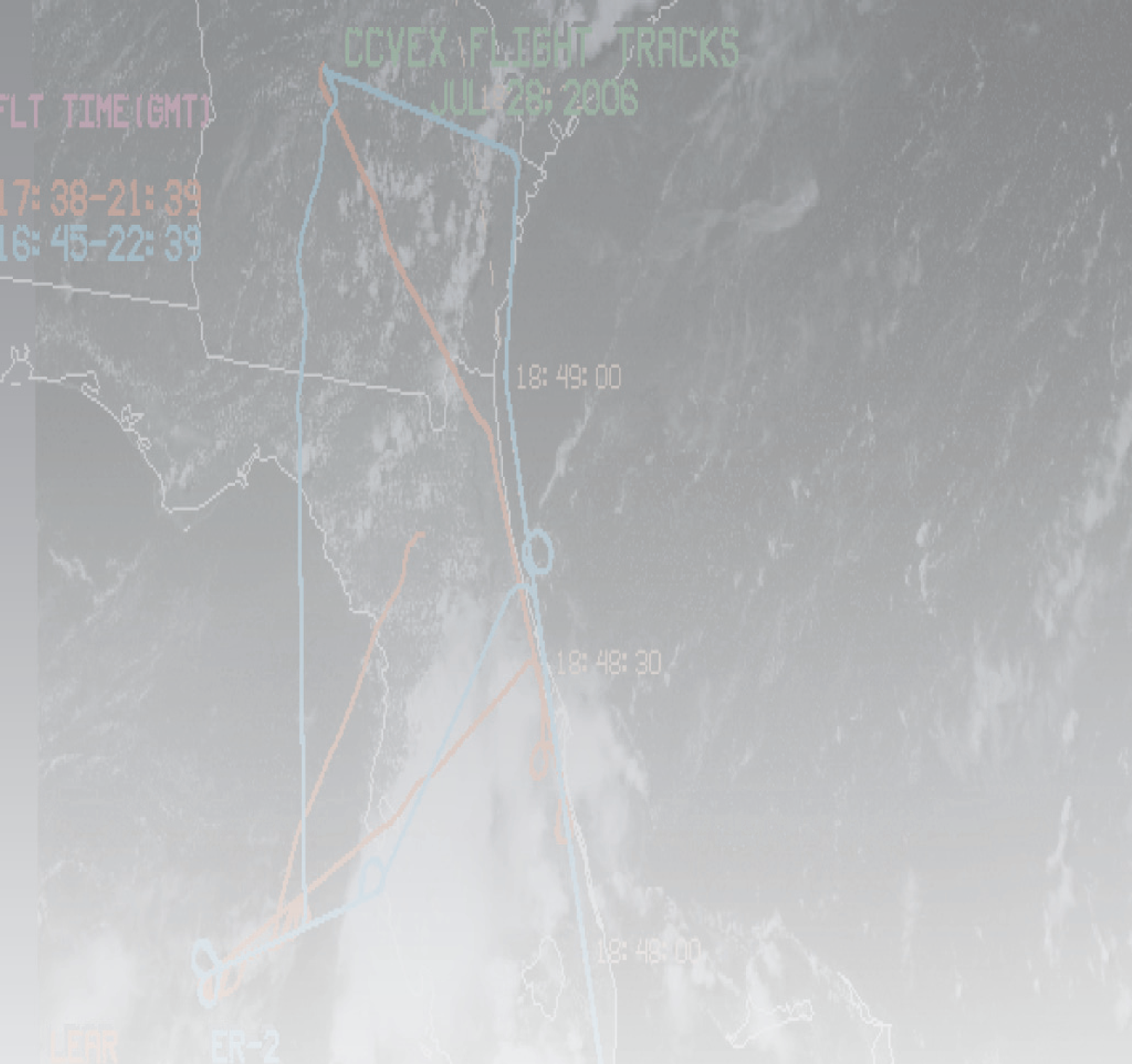


Fig. 58: Serial data stream on computer monitor of UCATS data in NASA Fire Mission Trailer via NASA REVEAL.



Catalog Aircraft

DC-8

The DC-8 Flying Laboratory is based in Grand Forks, ND under a NASA Cooperative Agreement with the University of North Dakota (UND). The oversight of the aircraft operations is with GSFC/WFF. UND has created the National Suborbital Education and Research Center (NSERC) {http://www.nserc.und.edu/} to manage and operate the DC-8.

Fig. 59: DC-8

Three major missions were conducted on the DC-8 under NSERC management in FY06. The first DC-8 mission of the year was the Stardust Hypervelocity Entry mission (p. 27). This flight involved using the DC-8 to fly imagers, photometers, and spectrometers to image the returning Stardust space capsule. This DC-8 mission was supported by the NASA Engineering Safety Center (NESC). The second and most complex DC-8 mission to date was the INTEX-B mission with 28 instruments onboard. INTEX-B was supported by the Tropospheric Chemistry Program. The final mission for the DC-8 in FY06 was the NASA-African Monsoon Multidisciplinary Activities (NAMMA) mission that supported the Weather Focus Area within the Research and Analysis Program. Summaries of these missions are found in other parts of this annual report.

A major goal of the Cooperative Agreement was to open the use of the DC-8 research platform to the general research community, including other federal agencies: the National Science Foundation (NSF) led a Deep Convective Clouds and Chemistry (DC3) Planning Workshop, and NSERC staff presented an option to use the DC-8 for the mid-altitude part of the DC3 mission objectives. A quote from the executive summary of the meeting:

> "The consensus from the workshop was to design DC3 around the NSF G-V and the NASA DC-8 or NSF C-130, with the DC-8 the preferred platform, and to welcome the participation and collaboration of the DOE G-1 and the upcoming NSF/Navy A10, if it is available."

Discussions after the workshop suggested reviewing the capabilities of each of these aircraft.

NSERC also proposed to develop a seminar series to bring airborne research activities to a larger faculty and student audience. NSERC organized a campus wide seminar by Dr. Hanwant Singh that presented the INTEX overall goals and data from INTEX-NA to put the upcoming INTEX-B mission and contribution of the DC-8 in context. We also had principal investigators, who were participating in the mission upload at GFAFB, give presentations on their instruments, data, and how the data was used to contribute to the overall INTEX-B mission science goals. These talks were filmed and are now available on the NSERC web site. Investigators aimed their talks at students that did not have extensive technical backgrounds in instrumentation and airborne science so that they could reach a wider audience. The compilation of these talks could serve as the basis for a seminar class on airborne research, in particular atmospheric chemistry.

The DC-8 supported the program with 264 flight hours during FY06.

WB-57

The NASA Johnson Space Center (JSC) in Houston, Texas is the home of the NASA WB-57 High Altitude Research Program. Two fully operational WB-57 aircraft are based near JSC at Ellington Field. Both aircraft have been flying research missions since the early 1960s, and continue to be an asset to the scientific community with professional, reliable, customer-oriented service designed to meet all scientific objectives.

Fig. 60: WB-57s over Houston, TX.

During January and February, 2006, the WB-57 was deployed to Costa Rica for the Aura Validation Experiment (CR-AVE). The Program integrated and tested 29 instruments in Houston in early January and then flew science flights over 4 weeks in Costa Rica (mid-January through mid-February). The WB-57 was used to gather in-situ data and compare and validate it with Aura satellite data.

Three major new instruments were integrated and flown on the WB-67 in FY06: WAVE, NAST-I, and NAST-M. NAST-M is a suite of passive microwave spectrometers which is used to retrieve temperature and humidity profiles from both clear air and cloudy atmospheres. NAST-I is a scanning interferometer which measures emitted thermal radiation at high spectral resolution between 3.3 and 18 microns. The measured emitted radiance is used to obtain temperature and water vapor profiles of the Earth's atmosphere. WAVE development was sponsored by the Space Operations Mission Directorate (SOMD).

Many test flights of the WB-57 Ascent Video Experiment (WAVE) were conducted and subsequently WAVE was used to track the launch and re-entry of the space shuttle missions STS-121 and STS-115. Video gathered by WAVE of the space shuttle launches and landings helped asses the safety and integrity of the space shuttle during these two highly dynamic flight phases. The WAVE system was instrumental in supporting the Pluto New Horizon mission by monitoring the launch from 60,000 feet (Fig. 61). Had a failure occurred during launch, WAVE would be able to track the satellite to the surface giving the longitude and latitude of the impact location for rapid recovery of the Radioisotopes Thermal

Fig. 61: Image of PNH launch taken with WAVE sensor on board WB-57.

Generators. These missions show how our assets are sued to support other SMD divisions and other Directorates within NASA. Integration and test flights of the National Polar Orbiting Operational Environmental Satellite System (NPOOES) Aircraft Sounder Test Bed (NAST) NAST-Interferometer (NAST-I) and NAST- Microwave (NAST-M) were conducted satisfactorily.

A series of successful Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) flights were conducted during May of 2006. Missions included data collection for three separate principal investigators over several states including Illinois, Wisconsin, Maryland, Nebraska, and Colorado.

The WB-57 supported the Suborbital Science Program for a total of 121.8 hours during the year.

Fig. 62: WB-57 in service bay showing WAVE sensor on aircraft nose.

ER-2

The NASA ER-2 aircraft is based at the NASA Dryden Flight Research Center (DFRC).

Fig. 63: NASA ER-2 over Edwards Air Force Base, CA.

In May, the Large Area Collectors were mounted on ER-2 809 and a successful series of science flights were accomplished from DFRC. There were 27.2 flight hours accomplished in over 4 flights.

Following the Large Area Collector flights, ER-2 809 began a Periodic Phase Maintenance, which carried it through the rest of the year.

After a two year downtime to complete Periodic Depot Maintenance, ER-2 806 began flying check flights in March and was certified mission ready in May.

In the meantime, interest had risen from the CloudSat and CALIPSO satellite teams to use the ER-2 to fly the validation missions for the two satellites. In July, ER-2 806 deployed on its first mission in over two years to Robins AFB with four instruments to validate the two satellites. Flight operations ran smoothly even though science requirements called for a variety of mission conditions for the ER-2. These conditions include flights from daylight clear skies to nighttime convection and thunderstorms. During this deployment all objectives were met and exceeded. The science teams had hoped for 7 flights with 2 during the night. In the end, the ER-2 completed 12 flights, which included 4 night flights. This was an extremely successful deployment for the ER-2. During the entire mission, the ER-2 flew 13 sorties for 64.7 hours.

Upon the ER-2's return, DFRC was contacted by the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) team from the Jet Propulsion Laboratory (JPL). The investigators had some requirements to provide data and were unable to accomplish these missions in a cost-effective manner. Their predicament was taken as a challenge and the needed data and the budget constraints requirements of the science community were met. During this series of flights, 7 sorties totaling 27.2 flight hours were completed in only 14 days. All of these missions were flown from Dryden and the aircraft managed to fly a sortie over targets as far away as Minnesota and Wisconsin, as well as flying a sortie over Yellowstone National Park and imaging over 10,800 square miles in that flight.

Although the year started out slowly for the ER-2 Program, the end of the year concluded with a “bang” and high hopes for upcoming years. During FY06, the ER-2’s flew a total of 54 sorties and 167.9 flight hours. Although this does not compare to the hundreds of hours flown in years past, FY06 marked the first year since FY00 that the ER-2 Program flew more hours than the year before. In conjunction with the powerful ending of FY06, this gives high hopes for the future use of this unique national asset.

P-3

Fig. 64: P-3

The P-3 is based at Goddard Space Flight Center's (GSFC's) Wallops Flight Facility (WFF). The P-3 returned to flight in FY06 after a two-and-a-half year hiatus due to maintenance work. The aircraft flew two missions during FY06.

The first mission was Arctic 2006 which was flown in three phases over the Arctic regions of the Northern and Western Alaskan Coasts, the Arctic Ocean, and Greenland. All mission objectives were met with a total of 84 science flight hours on the NASA WFF P-3 (p. 30).

The RadSTAR-A mission was flown in May-June 2006 to test a newly designed electronic beam steering and digital beam-forming radar. The first flight tests were conducted on the NASA WFF P-3 to collect data over a mixed background of land and ocean utilizing lines that crossed the Delmarva Peninsula. This mission supported the Hydrospheric and Biospheric Sciences Laboratory at GSFC. Successful instrument installation, data collection, and analysis was completed for a total of 5.1 science flight hours. The P-3 flew 123.0 flight hours in support of the Suborbital Science Program in FY06.

Twin Otter

Twin Otter International in Grand Junction, CO participated in three missions during FY06 using their Twin Otter aircraft. The first was the AVIRIS Fall 2005 Campaign during October-November 2005 for the Terrestrial Ecology Program. AVIRIS and the Twin Otter International were then approved to fly a mission over a coral reef bleaching event off of Puerto Rico and the U.S. Virgin Islands in December 2005, supporting the Biological Oceanography Program. In April-May 2006 a Spring AVIRIS campaign was conducted over sites in the western U.S. It also supported REASON CAN objectives and the Terrestrial Ecology Program.

All together, Twin Otter international supported the program on these missions for a total of 199 hours.

Fig. 65: Twin Otter

Jetstream-31

The J-31, owned and operated by Sky Research Inc., is a pressurized, twin-engine turbo-prop aircraft. Capable of international operations, it has a seating capacity of up to nineteen passengers, and a removable oversized cargo pod. Extensively modified to support a variety of sensors and equipment for a multitude of survey and research missions, the J-31 features a wide cabin and standing headroom offering comfort for project operators. Additional features include an observation bubble window and 12.25" hole in the ceiling for upward-looking sensors.

Fig. 66: Jetstream-31

In the spring of 2006, the J-31 conducted a three-week deployment to Verazcruz, Mexico, in support of the INTEX-B/MILAGRO Mission.

For the INTEX-B mission, SKY performed a very complex modification to the nose of the BAe J-31, to accommodate NASA Goddard's Cloud Absorption Radiometer (CAR). The operational deployment of this sensor was a success for both NASA and SKY (p. 34).

In addition to the CAR, the J-31 also flew the NASA Ames' Airborne Tracking Sun-photometer (AATS), Position & Orientation System (POS), and Met Sensors & Nav/Met Data System, Columbia University's Research Scanning Polarimeter (RSP), and the University of Colorado's Solar Spectral Flux Radiometer (SSFR). The aircraft was also flown to support similar instruments for the 2004 and 2005 ICARTT efforts.

The J-31 flew 79 hours in FY06 supporting the Radiation Science and Tropospheric Chemistry Programs.

Cessna Caravan

Fig. 67: Cessna Caravan

The Cessna Caravan, owned by Sky Research, is based in Ashland Oregon, and is used under contract by NASA for low altitude earth science research. Because it is equipped with an Inmarsat sat-com system, it is also used as a UAS-surrogate to test payloads in an autonomous or remote-controlled configuration. The Caravan flew both in support of new instrument development and established instrument science.

In August 2006, MASTER was flown over TeaPot Dome Naval Petroleum Reserve in Wyoming as part of the Carbon Capture Program. These data were used to test the ability of multi-spectral infrared systems to detect Methane and CO_2 under controlled-release conditions.

The Caravan was used to fly the first missions of the new Autonomous Modular Sensor (AMS) UAS system. In April, the inaugural flights for this new system were flown over several local sites. This was done as a risk mitigation for the subsequent missions on the Altair UAS. Later, in June, multiple flights were flown over controlled burns at Fort Hunter Liggett in California. At the conclusion of the burn exercise, AMPI (Airborne Multi-spectral Polarization Imager, an SBIR project) was flown over a variety of San Francisco Bay targets.

The Cavaran's support of the program totaled 28.9 flight hours over the course of the fiscal year.

B-200

The Department of Energy's Remote Sensing Lab in Las Vegas, Nevada operates two King Air B200 aircraft, which are made available to NASA through an interagency agreement.   This past fiscal year, these aircraft flew about 160 hours in support of earth science research.

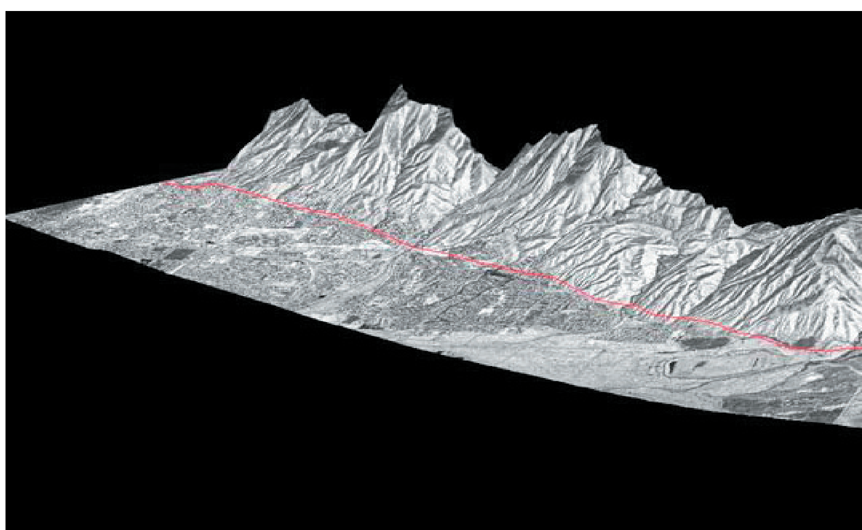
In October 2005, the MODIS/ASTER Airborne Simulator (MASTER) was flown over Catalina Island in support of the ASTER science team. In May 2006, MASTER imagery was collected over several sites in Western Nevada, in support of a study to spectrally and spatially enhance ASTER satellite imagery over a variety of geothermal targets.

In June, an extensive data collection flight series was conducted with the Laser Vegetation Imaging System (LVIS.) Targets included the Sequoia National Forest, Mammoth Mountain, as well as the Ivory Billed Woodpecker Habitat in Arkansas.

In August, the aircraft provided continued and expanded support for the Southern California Fault assessment project. This is an ongoing collaboration between NASA, JPL and UCLA. MASTER data were collected over a series of fault structures. The day/night image pairs provide the means to distinguish subtle mineral composition differences. These differences are used to quantify the cumulative slip history of each fault. (See Figures 69 and 70.)

Fig. 68: B-200

The flight year ended with ASTER modeling over two sites in Colorado. MASTER data were collected over Mt Emmons and Cashin, CO, in an effort to predict ASTER multispectral signatures. These predictions will be used to improve ASTER mapping by modeling spectral spatial scaling of HSI.



Figs. 69 and 70: Daytime MASTER (MODIS/ASTER Airborne Simulator) color infrared composite image (Fig. 69, above), and night thermal infrared image (Fig. 70, below) of Garlock Fault in Southern California.

Aerosonde

The AAI Aerosonde platform is based at NASA WFF. During the past fiscal year, Aerosonde participated in a U.S. Air Force demonstration mission called WeatherScout. It was focused on flying into tropical storms over the Pacific Ocean. They successfully flew into several minor tropical systems. This mission was partially supported by the Suborbital Science Program.

Aerosonde also participated in an outreach activity through the JASON Project, which is part of National Geographic. The Aerosonde's ability to fly into hurricanes was highlighted in two separate filmings at NASA Wallops, the culmination of which was a short demonstration flight with three middle school students and two teachers participating in the activities leading up to the flight. Aerosonde flew a total of 74.0 flight hours in support of the Suborbital Science Program in FY06.

Fig. 71: Aerosonde is launched from catapult mounted onto truck roof.

Flight Requests

Flight Requests

The 2006 calendar year was active for the Flight Request System. There were 110 flight requests in 2006. Forty-six requests were completed, and the rest were rolled over into 2007, withdrawn, or canceled depending upon the availability of resources at the time of the request, or their alignment with NASA science goal and objective priorities. Also, some of the uncompleted requests have been rescheduled for future available aircraft flight periods. Ten different aircraft platforms completed the various flight requests and flew more than 1200 flight hours in all. Three large field campaigns (CR-AVE, INTEX-B and NAMMA) were also successfully conducted this year. The details are listed in Table 1 below.

The flight request tracking database was upgraded with a new Suborbital Flight Request System accessible through the Suborbital Science Program website (http://suborbital.arc.nasa.gov/). The new system is still being refined and will provide a more user friendly flight request submittal form, a better tracking capability and a more flexible system overall.

Aircraft	Submitted	Total Approved	Total Completed	Total Flight Hours Flown
DC-8	13	4	4	264
ER-2	19	12	11	168
WB-57	18	6	5	122
P-3	7	3	3	123
Twin Otter	23	11	10	199
B-200	7	6	6	157
Caravan	3	2	2	29
J-31	3	2	2	79
Aerosonde	9	4	2	74
Altair	8	7	1	73
TOTAL	110	57	46	1288

KEY
Submitted: Flight entered into the system.
Total Approved: All flight requests that have been approved; supported by science and suborbital managers.
Total Completed: Flight requests completed or partially completed.

Table 1: FY06 Flight Request Summary

Collaborations and Partnerships

Collaborations and Partnerships

The Suborbital Program routinely partners with other agencies and organizations to further the goals of the earth science community. NASA continues to lead the Interagency Coordinating Committee for Airborne Geosciences Research and Applications that includes NOAA, NSF, DOE, and NRL in an effort to improve interagency cooperation on the use of aircraft in earth science data collection. The Program also works closely with the University-National Oceanographic Laboratory System (UNOLS) Scientific Coordinating Committee for Oceanographic Research (SCOAR) community in a continuing effort to adopt best practices for managing and scheduling research assets. Below are further details on a number of important efforts in FY2006 that leveraged the suborbital assets of NASA and its partners.

NASA/University of North Dakota (UND) Cooperative Agreement: The cooperative agreement between NASA and UND for the operation of the NASA DC-8 is now in its second year. This collaboration is a test case to explore alternative ways of managing and operating federally owned aircraft. Another goal of this partnership is to broaden the DC-8 user community and to improve outreach related to suborbital science. The National Suborbital Education & Research Center (NSERC) at UND was formed to facilitate this outreach and extend the benefits of the DC-8 laboratory to the larger earth science community. (For highlights of DC-8 operations during FY06 please see page 69 above.)

NASA/USFS Wildfire Research and Applications Project: The Program provided partial support to a project funded under the NASA ESD Applied Science program that partners NASA researchers with USFS remote sensing specialists to explore the use of data from unmanned systems in managing wildfires. The Forest Service has been an enthusiastic collaborator with NASA to improve the science of wildfire management. The Program provided support for refinement of a thermal imaging system, a sensor pod to house the system, and flight hours costs for the Altair UAS. This effort culminated in a successful demonstration of the utility of near realtime fire location information from a long duration UAS.

(For more information on this project see page 46.) This partnership also served to highlight the need for continued collaboration with the FAA to reduce the risks associated with UAS flights in the National Airspace.

NASA/NRL Sierra UAS development: NASA and NRL signed an MOU to collaborate on the development of two mid-class UAS capable of carrying 100 lbs. of payload for over 10 hours. The aircraft will primarily be used to drive sensor development for small classes of UAS, in addition to providing a test-bed for new sensors and advanced UAS operations.

NASA/NOAA/DoE UAS activities: The Program continued efforts to strengthen the relationship between the science activities of NASA, and the operational capabilities required by NOAA. The two agencies partnered effectively on the NAMMA experiment which investigated the genesis of hurricanes off the coast of Africa. The Program also worked with NOAA to plan for a hurricane boundary layer study using the Aerosonde. New measurements are needed to improve hurricane intensity forecasting, and UAS are well-suited for providing measurement such as wind speed, humidity and temperature where it is too dangerous for pilots to fly. Lastly, NASA, NOAA, and DOE have completed a MOU on cooperative development and use of UAS for earth science research, with all but DOE having signed the document as this report went to press.

Science Community Outreach: The Program is an active participant in national conferences and workshops, such as those conducted by the AGU, AMS, and AIAA, and develops displays and other information to communicate the goals, capabilities, and resources of the program.

NSERC presented a poster detailing the capabilities of the DC-8 platform at the recent University-National Oceanographic Laboratory System (UNOLS) Airborne Ocean Science Conference on May 24-25, 2006. The goal was to inform the oceanographic research community on the DC-8 capability.

Community Outreach

As a part of field campaign and flight demonstration support, the Suborbital Program places strong emphasis on communicating its activities and accomplishments to the general public. This year was no exception. The suborbital team actively worked with the public affairs offices at the NASA centers and Headquarters to prepare and distribute press releases, conduct press conferences and interviews, and update public access web sites, so that the science data and operations were accessible to both the scientific community and the public.

Fig. 72: NSERC Director Rick Shetter (left) interviewed by news crew at Kulis Air National Guard Base, Anchorage, Alaska, during INTEX-B campaign.

The Program is an active participant in national conferences and workshops, such as those conducted by the AGU, AMS, and AIAA, and develops displays and other information to communicate the goals, capabilities, and resources of the program. For example, NSERC presented a poster detailing the capabilities of the DC-8 platform at the recent University-National Oceanographic Laboratory System (UNOLS) Airborne Ocean Science Conference on May 24-25, 2006. The goal was to inform the oceanographic research community on the DC-8 capability. Also, the Airborne Science and Technology Lab developed suborbital informational handouts and displays for the annual fall AGU meeting in San Francisco.

Media interest and coverage of NASA's Earth Science activities in 2006 was very extensive and global in scope. From the Stardust mission at the start of 2006 to the NAMMA hurricane mission in Cape Verde in the late summer, the accomplishments of the Suborbital Program and the stories on these missions received wide coverage in all 50 states and around the world. This included local, national, and international radio, television, and print media. In Costa Rica for the CR-AVE mission, NASA held a mission press conference attended by the U.S. Ambassador to Costa Rica. In Cape Verde, a reporter from National Public Radio met with the science team and accompanied them on a science research flight, which was subsequently featured on a radio broadcast. In conjunction with these missions, NASA personnel gave radio and TV interviews, including an interview on Baltimore's WCBM Weather Talk program. Newspaper articles on the missions appeared in the *New York Times*, *USA Today*, and the *Washington Post*. Other local news articles appeared in nearly every state, including in Alaska, Hawaii, Georgia, California, and also in Mexico (and at least 15 other countries). In addition, up to date information on NASA hurricane research and storm status was available to the public at the NASA Hurricane Research page (web site: http://www.nasa.gov/mission_pages/hurricanes).

Fig. 73: CR-AVE press conference in Costa Rica, January 2006. Seated left to right: Mark Langdale, U.S. Ambassador to Costa Rica; Fernando Gutierrez, Former Minister of Science and Technology, Costa Rica; Paul Newman, NASA, CR-AVE Project Scientist; Eric Jensen, NASA, CR-AVE Project Scientist; and Jorge Andres Diaz, CENAT Costa Rica.

Looking Ahead to FY07 and Beyond

Looking Ahead

The Suborbital Science Program continues to move forward, and in moving forward, the focus will continue to be on fulfilling the requirements of our customers and stakeholders, the NASA science community.

Efforts will continue to gather and derive customer requirements from our stakeholders, focus area roadmaps, and the newly-released NRC Decadal Study, and translate these into requirement and planning documents that drive the program, from its organization, activities, and fleet, to its investment portfolio. Studies will also continue to identify new mission concepts, innovative methods, and means to enhance suborbital Earth observations. A workshop to present to the community the findings of recent requirements collection and documentation efforts, and receive feedback, is planned for FY07.

Some challenging Earth observation missions are planned in the 2007-2010 timeframe, including the Tropical Composition, Cloud and Climate Coupling (TC4) and the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) campaigns supporting the Atmospheric Composition focus area, interdisciplinary International Polar Year missions, and follow-on missions for the Weather focus area, such as a second Tropical Cloud Systems and Processes campaign. Also planned are satellite calibration & validation field campaigns in support of the Orbital Carbon Observatory, as well as the "A-train" satellites. As some of the sensor technologies in development mature, such as the UAVSAR, missions are planned to learn and demonstrate and use this new science capability. The program will continue to develop capabilities to support and manage increasingly complex missions, such as international and multi-platform/system campaigns.

To allow the program to commit to these missions, investments in the core aircraft will continue to maintain the fleets' airworthiness and relevance. For the DC-8, these investments include the ongoing "C"-check inspection and maintenance activity, an avionics upgrade for enhanced operational flexibility, and a fuel tank repair and recertification which will allow an additional two hour increase in flight time. For the WB-57, a landing gear upgrade, which will allow use of commercially available aircraft tires, and a gross weight increase study are in work. Future efforts may include a fuel heating study for the ER-2, WB-57, and Global Hawk platforms to prepare for the time when the Air Force source is discontinued, and to increase the science capabilities of these platforms.

To supplement the core fleet, innovative approaches to acquire access to fully flight ready, mission capable aircraft from the commercial sector, or other government agencies, will continue. This aircraft access service to the science community is expected to reduce costs through competition and to reduce programmatic risks by establishing flexible procurement tools that provide quick access to aircraft providers. It also ensures that NASA's safety and airworthiness issues are maintained through oversight by NASA aircraft operations experts. A Request for Bid for these services is scheduled to be released in FY07.

In addition to the aircraft, investments will be made in science support systems. FY07 activities will include preparing four REVEAL systems for the TC4 mission, and other future campaigns, to enhance communications and data sharing between aircraft and ground facilities. Also being studied is a stand-alone version of the AMS telemetry link module which would provide standardized payload connectivity to the broad-band telemetry systems on the Ikhana and Global Hawk UAS platforms, as well as further development of the Ikhana Common Sensor Pod to accommodate generic science payloads. A general-purpose replacement for the aging navigation data recorders on the ER-2 and WB-57 aircraft will be studied, and improvements to the generic digital and video tracking cameras on the catalog aircraft will be undertaken. Efforts to increase payload portability and commonality between platforms will remain a high priority. The Program will also continue to participate in the Inter-agency Working Group for Airborne Data and Telemetry Systems to develop interagency data distribution standards which are being applied to new data systems.

The UAVSAR development effort, a joint project with the Earth Science Technology Office, will continue, and is expected to complete its envelope expansion and engineering check flights in FY07. Also supporting this effort, the Precision Platform Autopilot project will demonstrate the ability to interface the science sensor with the aircraft flight control system to navigate the aircraft and radar system repeatably in a precise flight pattern. The capability is expected to be ready for science demonstration missions supporting the Solid Earth and Interiors focus areas starting in FY08 flying on the NASA G-III and then prepare for transition to the Ikhana.

A new capability to be demonstrated in FY07 is the new Ikhana system, NASA's civilian version of the Predator B UAS. NASA is expected to receive and establish a flight operations capability for Ikhana, , in time to support a summer 2007 Western States Fire Mission. Also in FY07, NASA plans to acquire two Global Hawks (pre-production aircraft models that the Air Force is excessing) for potential future use. The near-term focus will be to continue studies to determine the best approach to make these science mission and programmatically capable aircraft in later years. Finally, the Sierra UAS is expected to go through its flight certification effort.

Upcoming sensor technology projects will include the implementation of an Ocean Color Imager configuration of the AMS sensor and the development of a standardized video tracking-camera package. Integration assistance will be provided for new instruments on the Ikhana UAS, in support of IPY requirements and other science missions. A stand alone version of the telemetry link module for general use on the Ikhana and Global Hawk UAS will be implemented. In FY07-09, the Program will invest in UAS sensors that support International Polar Year activities to help jumpstart UAS missions in the polar regions.

The program will also continue to work with other government agencies to support science of mutual interest. Plans for FY07 include the CLASIC mission, led by the Department of Energy, and a Hurricane Boundary Layer Mission, sponsored by the National Oceanic and Atmospheric Administration, using the Aerosonde to fly at very low altitudes within a hurricane. Also to be completed is a Memorandum of Understanding between NASA, NOAA, and DOE concerning Unmanned Aircraft Systems for Global Observing System Science Research that will facilitate interagency collaborations on future missions and technologies.

Building on the 2006 effort, the Program will work to integrate its flight request process into the 2007 Research in Space and Earth Sciences call for proposals. To ensure the Earth science community is aware of the Program and its capabilities, efforts will continue to participate in science conferences and workshops. The Program will also invest in educational efforts that support, and are consistent with, the Science Mission Directorate's goals and objectives.

The long-term goals of the Program are to maintain and enhance the capabilities described in this report. The Program is committed to continued strategic alignment of its portfolio investments to meet the needs of the science community. A major thrust of the Program will continue to be the evaluation of its assets and investment portfolio to ensure reliability and relevance to SMD's Earth Science needs . Since many of the current Earth Observation satellites are in extended mission status, and follow-on systems are expected to be launched in the next decade, the Program expects continued heavy emphasis on aircraft flights and campaigns for satellite data validation, and a new series of process studies to better understand the Earth system.

The Suborbital Science Program's future is full of challenges and opportunities. The challenges include a very constrained budget and increasingly complex missions for satellite cal/val process studies, and sensor development. The opportunities are grounded by the realization that the Program can make a difference in the lives of everyday people through the science discoveries enabled by NASA's suborbital assets, and that addressing many compelling and complex science questions is made possible through the Program's dedicated people and capabilities.

Appendix A:

Platform Characteristics*

Platform Name	Center	Duration (Hours)	Useful Payload (lbs.)	GTOW (lbs.)	Max Altitude (ft.)	Airspeed (knots)	Range (Nmi)	Internet and Document References
ER-2	NASA-DFRC	12	2,900	40,000	>70,000	410	>5,000	http://www.nasa.gov/centers/dryden/research/AirSci/ER-2/
WB-57	NASA-JSC	6	6,000	63,000	65,000	410	2,172	http://jsc-aircraft-ops.jsc.nasa.gov/wb57/
Proteus	NASA-DFRC	18	2,200	12,500	>60,000	280	1,500	http://www.scaled.com/projects/proteus.html
Gulfstream III (G-III) (mil: C-20A)	NASA-DFRC	7	2,610	45,000	45,000	459	3,400	
DC-8	NASA-GSFC-WFF	12	30,000	340,000	45,000	450	5,400	http:///.nasa.gov/centers/dryden/research/ÅirSci/DC-8/
S-3B, Viking	NASA-GRC	>6	3,958	52,539	35,000	370	2300	http://www.fas.org/man/dod-101/sys/ac/s-3.htm
King Air B-200	NASA-ARC	6.75	2,000	14,000	32,000	221	1883	
P-3B	NASA-WFF	12	16,000	135,000	30,000	330	3,800	http://wacop.wff.nasa.gov
Cessna Caravan	NASA-ARC	5	1500	7,300	27,600	171	1000	http://www.skyresearch.com/
Jetstream-31 (J-31)	NASA-ARC	6	4,000	15,322	25,000	225	1,000	http://www.skyresearch.com/
DHC-6 Twin Otter	NASA-GSFC-WFF	7	5,000	12,000	25,000	160	500	http://www.twinotter.com
Predator-B (Ikhana)	NASA-DFRC	30	3,000	10,000	52,000	171	3,500	
Altair	NASA-DFRC	24	750	7,000	52,000	171	3,400	
Aerosonde	NASA-WFF	30	6	28	20,000	60	1875	http://www.aerosonde.com/
Learjet 25	NASA-GRC	3	7,600	15,000	42,000	452	1,436	http://www.nasa.gov/centers/glenn/testfacilities/learjet.hgml

* The data shown above generally represent demonstrated mission capabilities and may not represent aircraft limits. In most cases, the performance parameters cannot be achieved concurrently.

Appendix B:

Acronyms

A

AATS	Ames Airborne Tracking Sunphotometer
ACCLAIM	Advanced Carbon/Climate LAser International Mission
ACR	Advanced Ceramics Research
AGU	American Geophysical Union
AIAA	American Institute of Aeronautics and Astronautics
AMMA	African Monsoon Multidisciplinary Analyses
AMPI	Airborne Multispectral Polarization Imager
AMS	American Meteorological Society
AMS	Autonomous Modular Sensor
AMSR	Advanced Microwave Scanning Radiometer
ASTER	Advanced Spaceborne Thermal Emission & Reflection Radiometer
AOD	Aerosol Optical Depth
ARC	Ames Research Center
ARCTAS	Arctic Research of the Composition of the Troposphere from Aircraft and Satellites
ARTS	Airborne Research Test System
ASD	Analytical Spectral Devices
ASTL	Airborne Science and Technology Laboratory
ATM	Airborne Topographic Mapper
AVE	Aura Validation Experiment

B

BRDF	Bi-Directional Reflectance Distribution Function

C

CALIPSO	Cloud Aerosol Lidar & Infrared Pathfinder Satellite Observation
CA-OES	California Office of Emergency Services
CAR	Cloud Absorption Radiometer
CC-Vex	CALIPSO-CloudSat Validation Experiment
CDE	Collaborative Decision Environment
CDF	California Department of Forestry
CHAPS	Cumulus-Humilus Aerosol Processing Study
CNES	Centre National d’Études Spatiales
COA	Certificate of Authorization
CO-BALT	Carbon mOnoxide By Attenuation of Laser Transmission
COMMIT	Chemical, Optical, Microphysical Measurements of In-Situ Troposphere
CONOPS	Concept of Operations
CR-AVE	Costa Rica Aura Validation Experiment

D

DC3	Deep Convective Clouds and Chemistry
DCS	Digital Camera System
DFRC	Dryden Flight Research Center
DOD	Department of Defense
DOE	Department of Energy
DSS	Decision Support System

E

ETL	Environmental Technology Laboratory
EOS	Earth Observing System
EPA	Environmental Protection Agency
ESA	European Space Agency
ESCD	Earth Science Capability Demonstration
ESPO	Earth Science Project Office
ESTO	Earth Science Technology Office

F

FAA	Federal Aviation Administration

G

GCS	Ground Control Station
GHG	Greenhouse Gas
GIFS	Geostationary Imaging Fabry-Perot Spectrometer
GLAS	Geoscience Laser Altimeter System
Go-MACCS	Gulf of Mexico Atmospheric Composition and Climate Study
GPS	Global Positioning System
GSFC	Goddard Space Flight Center

H

HIRDLS	High Resolution Dynamic Limb Sounder
HSI	Hyper-spectral Imaging
HSRL	High Spectral Resolution LIDAR

I

ICARTT	International Consortium for Atmospheric Research on Transport & Transformation
ICC	Incident Command Center
ICESat	Ice, Cloud and Land Elevation Satellite
IIP	Instrument Incubator Project
INDS	Intelligent Network Data Server
INMG	Institute of Meteorology & Geophysics
INTEX	Intercontinental Chemical Transport Experiment
IWGADTS	Interagency Working Group for Airborne Data and Telecommunication System

J

JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center

L

LAABS	Langley Airborne A-band Spectrometer
LaRC	Langley Research Center
LIDAR	Laser Imaging Detection & Ranging
LVIS	Laser Vegetation Imaging System

M

MAS	Modis Airborne Simulator
MASTER	Modis/Aster Airborne Simulator
MILAGRO	Megacity Initiative: Local and Global Research Observation
MLS	Microwave Limb Sounder
MODIS	Moderate Resolution Imaging Spectrometer
MOU	Memorandum of Understanding

N

NAC	NASA Advisory Committee
NAMMA	NASA African Monsoon Multidisciplinary Activities
NAS	National Academy of Science
NAS	National Airspace System
NAS	Naval Air Station
NASA	National Aeronautics and Space Administration
NAST-I	NPOESS Aircraft Sounder Testbed Interferometer
NAST-M	NPOESS Aircraft Sounder Testbed Microwave
NAST	NPOESS Aircraft Sounder Testbed
NCAR	National Center for Atmospheric Research
NESC	NASA Engineering Safety Center
NIFC	National Interagency Fire Center
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSERC	National Suborbital Education and Research Center

O

OMI	Ozone Monitoring Instrument
OTH	Over the Horizon

P

POS	Position & Orientation Systems
PPA	Platform Precision Autopilot
PSR	Polarimetric Scanning Radiometer

R

RadSTAR-A	Radiation Synthetically Thinned Aperture Radar-Active
REASON-CAN	(Earth Science) Research, Education & Applications Solutions Network Cooperative Agreement Notice
REVEAL	Research Environment for Vehicle-Embedded Analysis on Linux
RPI	Repeat Pass Interferometry
RSP	Research Scanning Polarimeter

S

SAL	Saharan Air Layer
SAR	Synthetic Aperture Radar
SBIR	Small Business Innovation Research
SCOAR	Scientific Coordinating Commission for Oceanographic Research
SERDP	Strategic Environmental Research and Development Program
SETI	Search for Extraterrestrial Intelligence
SIERRA	System Integration Evaluation Remote Research Aircraft
SKY	Sky Research, Inc.
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SMD	Science Mission Directorate
SSFR	Solar Spectral Flux Radiometer
SQUID	Superconducting Quantum Interference Devices

T

TC4	Tropical Composition, Cloud & Climate Coupling Experiment
TCAS	Traffic Collision Avoidance System
TES	Thermal Emission Spectrometer
TOGA	Tropical Ocean Global Atmosphere
TPS	Thermal Protection System
TTL	Tropical Tropopause Layer

U

UAS	Unpiloted Aircraft Systems
UAVSAR	Unmanned Air Vehicle Synthetic Aperture RADAR
UCATS	UAS Chromatograph for Atmospheric Trace Species
UCLA	University of California, Los Angeles
UND	University of North Dakota
UNOLS	Universal National Oceanographic Laboratory System
USDA	United States Dept. of Agriculture
UTLS	Upper Troposphere and Lower Stratosphere

V

VIIRS	Visible Infrared Imager/Radiometer Suite
VSLS	Very Short-lived Species
VWC	Vegetation Water Content

W

WAVE	WB-57 Ascent Video Experiment
WFF	Wallops Flight Facility
WSFM	Western States Fire Mission