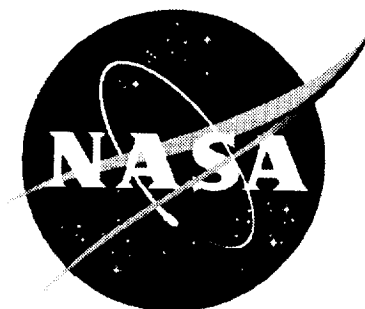


# **NASA Langley Highlights**



**1997**

**NASA/TM-1998-208451**

**National Aeronautics and Space Administration  
Langley Research Center  
Hampton, Virginia 23681-2199**



# Foreword

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The major missions assigned to NASA Langley Research Center are Airframe Systems and Atmospheric Sciences. Langley is also designated the Agency's Center of Excellence for Structures and Materials, in recognition of its long history of research into innovative composites, polymers, metallics, and structures for aircraft and spacecraft. The Airframe Systems mission incorporates a variety of aeronautical areas such as aerodynamics, aerothermodynamics, aircraft mission and system analysis, hypersonic airbreathing propulsion, airborne system and crew station design and integration, and structures and materials. Virtually every American aircraft and spacecraft in operation today incorporates some technology that developed from research originating at NASA Langley. The Center's Lead Program assignments in the NASA Aeronautics and Space Transportation Technology Enterprise, including Airframe Systems, Advanced Subsonic Technology, High Speed Research, and Aviation Safety, assure a continuation of Langley's historic leadership role in national aeronautics research.

Langley's Atmospheric Sciences program began in the 1970's to study potential changes to the atmospheric environment associated with operating proposed advanced aircraft. The program has become a world class producer of innovative research and technology to advance knowledge of atmospheric radiation, chemistry and dynamics for understanding global change. In close collaboration with the NASA Earth Science Enterprise and academia, Langley scientists identify critical atmospheric science issues for research and provide key contributions to national and international assessments of the environment. The resulting advanced technology, remote sensing techniques, atmospheric data sets, and scientific information are widely used by the scientific, policy and educational communities.

Langley's mission is accomplished by performing innovative research relevant to national needs and Agency goals, transferring technology to users in a timely manner, and providing development support to other United States Government Agencies, industry, other NASA Centers, the educational community, and the local community. This report contains highlights of some of the major accomplishments and applications that have been made by Langley researchers and by our university and industry colleagues during the past year. The highlights illustrate the broad range of research and technology activities carried out by NASA Langley Research Center and the contributions of this work toward maintaining United States' leadership in aeronautics and space research. A color electronic version of this report is available at URL <http://larcpubs.larc.nasa.gov/randt/1997/>. For further information about the report, contact Dennis Bushnell, Senior Scientist, Mail Stop 110, NASA Langley Research Center, Hampton, Virginia 23681-2199, (757)-864-8987.



Dr. Jeremiah F. Creedon  
Director

# Availability Information

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The accomplishments in this report are grouped into four categories based on NASA's Strategic Enterprises, including Aeronautics and Space Transportation Technology; Earth Science; Space Science; and Human Exploration and Development of Space. The Aeronautics and Space Transportation Technology Enterprise is further divided into three "Pillars," which are Global Civil Aviation; Revolutionary Technology Leaps; and Access to Space.

The contributions have been screened to avoid disclosure of any export-controlled information; any company-proprietary information or any other "enabling" data from joint NASA-industry programs such as those under Space Act Agreements, focused programs, etc.; or any potentially patentable inventions for which patents have not already been granted.

For additional information, call or E-mail the point-of-contact (POC) that is identified with each highlight. Only a limited number of black and white hard copies of this report have been printed, because the full report is available in color on the internet and can be downloaded from the NASA Langley Highlight Report web page at <http://larcpubs.larc.nasa.gov/randt/1997/>.

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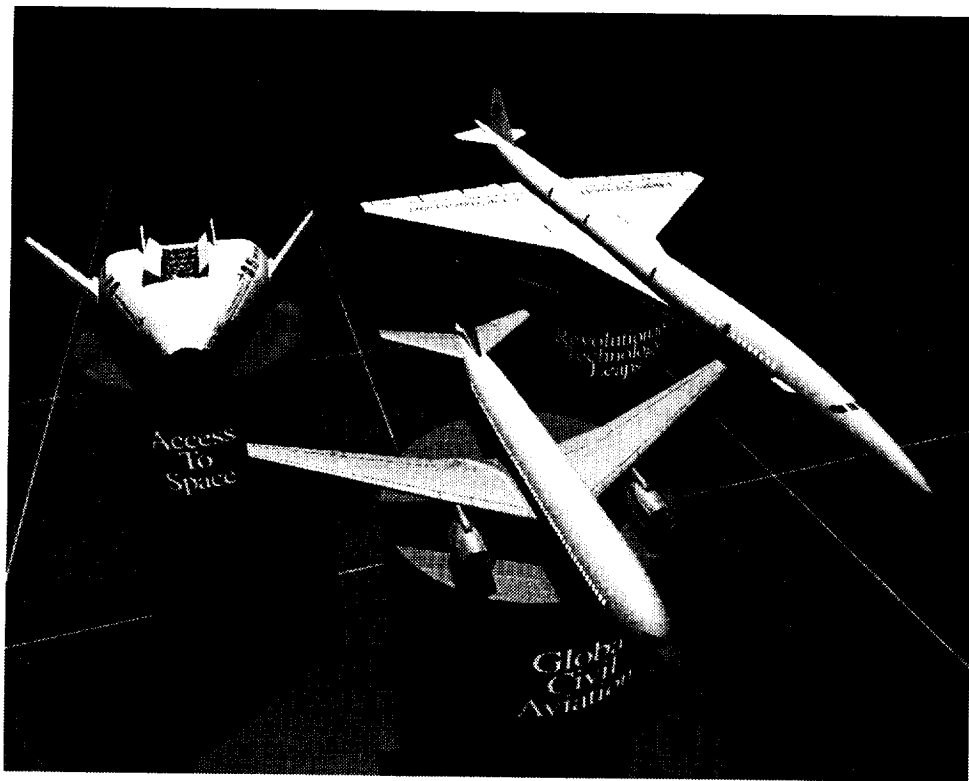
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# Aeronautics and Space Transportation Technology Enterprise



## Three Pillars for Success

Pillar One: Global Civil Aviation

Pillar Two: Revolutionary Technology Leaps

Pillar Three: Access to Space

## **Mission**

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Research and technology play a vital role in ensuring the safety, environmental compatibility, and productivity of the air transportation system and in enhancing the economic health and national security of the Nation. However, numerous factors, including growth in air traffic, increasingly demanding international environmental standards, an aging aircraft fleet, aggressive foreign competition, and launch costs that impede affordable access and utilization of space, represent formidable challenges to the Nation.

The mission of this Enterprise is to pioneer the identification, development, verification, transfer, application, and commercialization of high-payoff aeronautics and space transportation technologies. Through its research and technology accomplishments, it promotes economic growth and national security through a safe, efficient national aviation system and affordable, reliable space transportation. The plans and goals of this Enterprise directly support national policy in both aeronautics and space, documented in "Goals for a National Partnership in Aeronautics Research and Technology" and "National Space Transportation Policy." This Enterprise works in alliance with its aeronautics and space transportation customers, including U.S. industry, the university community, the Department of Defense (DoD), the Federal Aviation Administration (FAA), and the other NASA Enterprises, to ensure that national investments in aeronautics and space transportation technology are effectively defined and coordinated and the NASA's technology products and services add value, are timely, and have been developed to the level at which the customer can confidently make decisions regarding the application of those technologies.

## **Goals**

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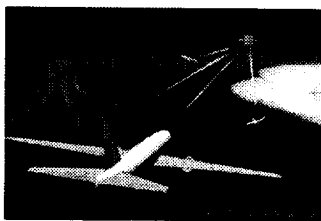
The Enterprise has three major technology goals supported by ten enabling technology objectives and a service goal.

### ***Technology Goals***

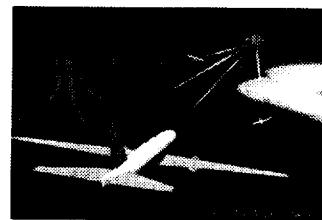
*Global Civil Aviation*—Enable U.S. leadership in global civil aviation through safer, cleaner, quieter, and more affordable air travel.

*Revolutionary Technology Leaps*—Revolutionize air travel and the way in which aircraft are designed, built, and operated.

*Access to Space*—Enable the full commercial potential of space and expansion of space research and exploration.



## Pillar One: Global Civil Aviation



*NASA's objectives for improving air transportation system safety, affordability, and environmental compatibility include technology for a ten-fold improvement in the safety of flight, a 50% reduction in the cost of air travel, and equally aggressive reductions in aircraft noise and emissions over the next 20 years.*

### Aircraft Morphing: The Smart Wing

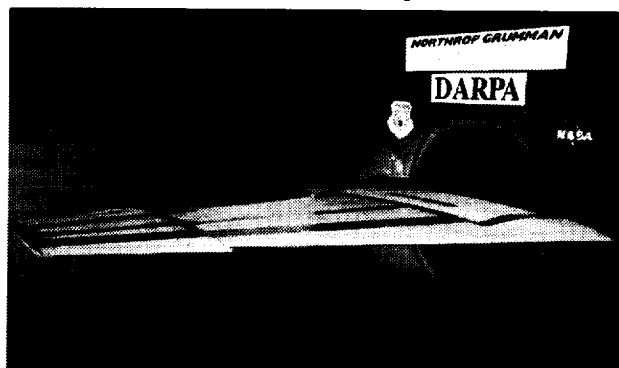
The Aircraft Morphing Program is aligned with Pillar One: Global Civil Aviation, and the fifth national goal of reducing the cost of air travel by 25 percent in 10 years and by 50 percent in 20 years. A primary goal of the Aircraft Morphing Program is to increase the efficiency of aircraft while simplifying aircraft systems and making airplanes easier to produce and maintain. Much of the weight and manufacturing cost of airplanes is in devices that move, referred to as actuated control surfaces. We are looking at new ways to control the flow over aircraft wings in a more efficient and low-cost manner.

The Smart Wing project applies new smart materials to twist and bend airplane wings during flight to morpho the aircraft shape to one that is optimal for different flight conditions. Conventional aircraft are controlled by rigid structures supported on hinges. These surfaces deflect airflow to control the motion of the aircraft, and can be made more efficient because the flow over the wing cannot abruptly change direction around the corners created by such hinges. In addition, hinged devices are driven by hydraulic systems which add to the cost and the complexity of an aircraft.

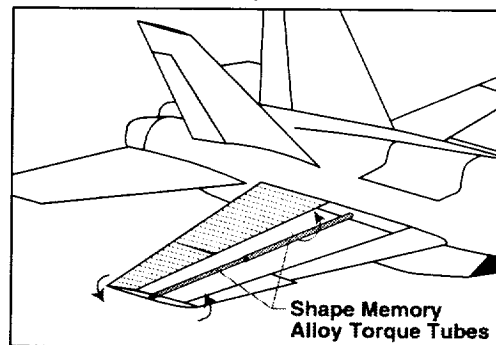
Smart materials are being used to gently bend and twist the wings, which is more like what birds do to control their motion when they fly. Rather than using motors or hydraulic systems to deflect these hinged surfaces, the smart materials are more like muscles which are distributed throughout the wing structure. They become an integral (or embedded) part of the aircraft structure, which makes them more reliable and less costly to maintain. A smart material is one which can change its shape in response to an external command. A special nickel titanium alloy known as a Shape Memory Alloy (SMA) can be trained to remember a specific shape, which it changes back to when

heated by an electric current. If a wire of SMA is stretched, it will grow to a new, longer length. When it is heated with an electric current, it will shrink back to the original, shorter length that it was trained to remember. This is similar to the way a muscle works when it is stimulated by a nerve impulse. By arranging these smart materials in a push-pull fashion, different parts of an airplane structure can be actuated, or made to move.

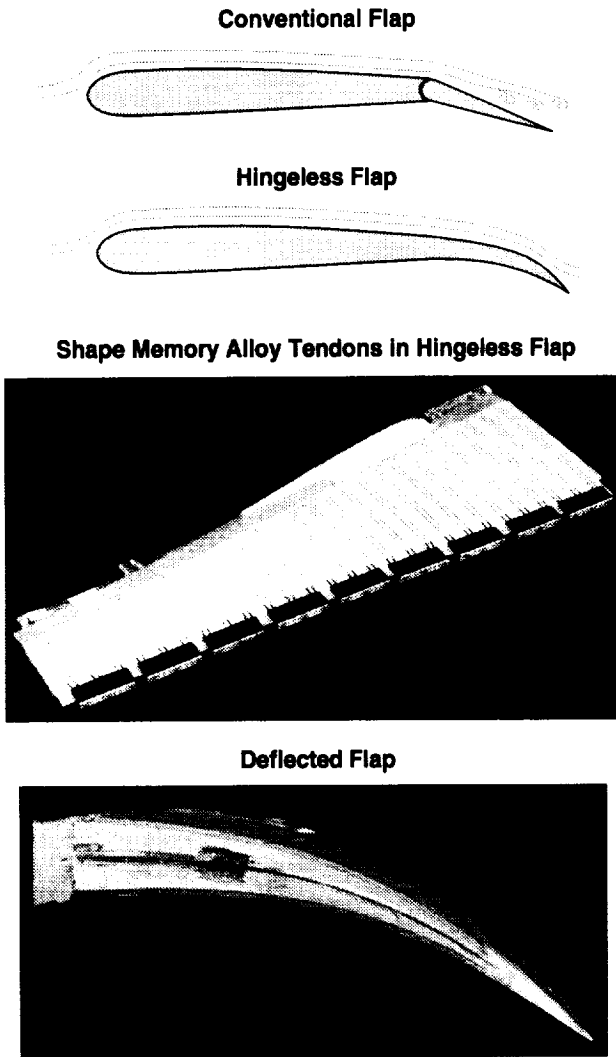
#### Smart Wing in Transonic Dynamics Tunnel



#### Wing Twist



**Figure 1. Smart wing in tunnel (top) and wing twist (bottom).**



**Figure 2. Types of flaps (top), shape memory alloy tendons (middle), and deflected flap (bottom).**

Several smart concepts are being studied in this program. The first concept uses tubes of SMA material to twist the wing from root to tip (see bottom of figure 1). Four-inch long SMA tubes were manufactured using special machining processes and trained to twist (or produce torque) when heated. Thus the tubes are referred to as torque tubes. The torque tubes were attached to stainless steel shafts that were placed in the center of a wing. When the torque tube is actuated, the flexible wing structure twists along its span. This action increases the angle of the tip of the wing, thereby increasing the lift force on the wing. The structure is designed so that when the torque tube cools, the wing returns to its previous shape. In total, two SMA torque tubes were used in the smart wing.

The torque tubes twisted the wing 1.25 degrees and increased the ability of an aircraft to roll by 8%. The second concept is called a hingeless control surface. SMA wires or tendons are stretched, and then embedded in the top and bottom surfaces of a flap (figure 2). When electric current is applied to the SMA tendons on the bottom of the wing, those tendons shrink and bend the surface downward (see bottom right for deflected flap). Electric current applied to the SMA tendons on the top of the wing bend the surface upward. The system is designed so that if power is not applied, the flap remains in a neutral, or undeflected configuration. Tests of the hingeless surface showed an 8% increase in lift over conventional wings.

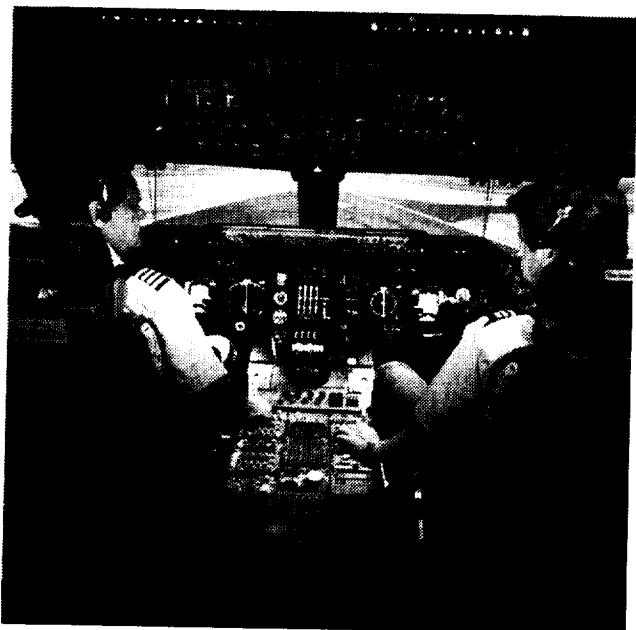
The Smart Wing project is jointly supported by the Defense Advanced Research Projects Agency, NASA Langley Research Center, Air Force Wright Laboratories, and the Naval Research Laboratories. DARPA funding is supporting the prime contractor, Northrop-Grumman and subcontractors including Lockheed Martin Astronautics and several universities and small companies. Two 16%-scale F-18 E/F wing models with embedded smart structures were built and wind-tunnel tested in the NASA Langley 16-foot Transonic Dynamic Tunnel (top image of figure 1). Smart structures and materials technologies that can twist or bend a wing on command will provide innovative capabilities to future military and commercial fixed wing vehicles and rotorcraft.

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## Aircraft Flight Dynamics and Control

Fortunately, commercial pilots are not often faced with flying extreme maneuvers or during upset phenomena such as icing, wake vortex, or wind shear encounters. However, it is during these unusual circumstances that many accidents occur. NASA, along with the FAA and industry, are committed to developing technology that can significantly lower the aircraft accident rate. The first of NASA's technology goals is to "Reduce the aircraft accident rate by a factor of five within 10 years, and by a factor of ten within 20 years."

As a key element of the NASA Safety initiative, NASA has developed the Total Aircraft Management Environment (TAME) Program to address issues associated with adverse environments. An important element of this program includes accurate simulation training to ensure pilot preparedness. Pilots can gain valuable experience by spending time in aircraft simulators (shown in figure 3) where they can practice flying under unusual circumstances which they do not



**Figure 3. TAME cockpit simulator.**

often experience in many hours of actual flight time. However, to make simulation training valuable, it must simulate exactly what the aircraft would do in the same circumstances, with the same pilot input.

Researchers at NASA Langley Research Center have developed methods to guarantee that what the pilot experiences in the simulator is exactly what would be experienced in the actual aircraft. Tests in wind tunnels have been completed and the data analyzed so that the aerodynamic forces can be modeled mathematically and used to produce the realistic simulations. These uncertainty models, developed from experimental data, can also be used to develop new control laws for increased stability for the aircraft themselves during flight in these extreme conditions. Increased control law stability and performance will enable safe and efficient operation of transport and high-performance aircraft.

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### **Futuristic Airframe Concepts and Technologies**

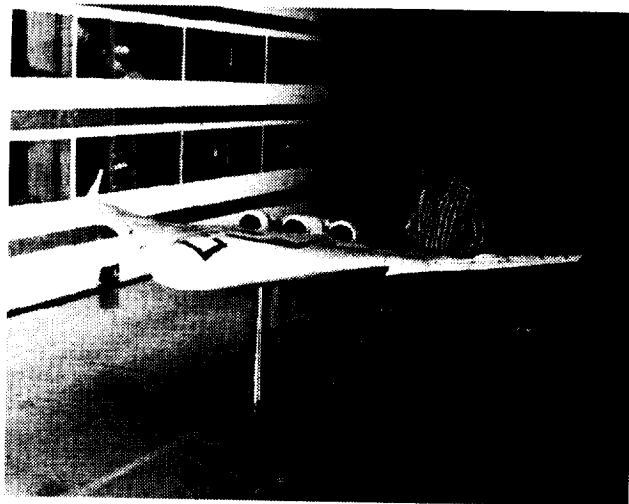
One of the Global Civil Aviation goals is to reduce the cost of air travel by 25% within 10 years and by 50% within 20 years. Revolutionary subsonic transport aircraft configurations can provide potentially dramatic reductions in the cost of air travel by reducing the weight and required fuel which can significantly reduce

the aircraft ownership and operating costs. The Futuristic Airframe Concepts and Technologies Program (FACT) addresses barrier technology that inhibit the development of a new generation of subsonic transport aircraft with particular emphasis on technologies required by subsonic commercial/cargo revolutionary configurations that can significantly reduce the cost of air travel while also decreasing noise and emissions.

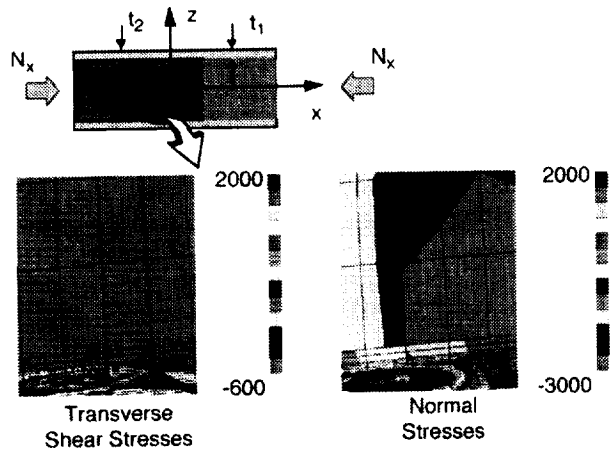
The FACT Program addresses barrier technology in structures, materials, aerodynamics, airframe/propulsions integration, and acoustics to significantly expand design options for future subsonic transports. The technical approach involves developing and validating improved analysis and advanced technologies and concepts integrated with ground- and potentially flights experiments. The program also experimentally investigates unconventional configurations such as the blended wing configurations, which have been shown by trade studies to meet or significantly contribute to the reduction in cost of air travel goal.

In 1997 the first of a series of wind tunnel tests was conducted on an unconventional configuration, a blended wing body configuration, that has the potential to significantly contribute to the reduction in cost of air travel goal (figure 4). Ride quality and handling qualities are critical issues for these types of configurations. These tests showed that controlling the unconventional configuration is possible but will require an automated system onboard the aircraft.

Composite sandwich structural panels offer lightweight structural concepts with the potential for



**Figure 4. Wind tunnel test of unconventional configuration.**



**Figure 5. Results of stress analyses.**

low-cost manufacturing which will enable an unconventional configuration, like a blended wing body, to significantly contribute to the reduction in cost of air travel goal. In 1997 detailed stress analyses were conducted on composite sandwich panels where the facesheet of the panel has local discontinuities—changes in thickness, to identify potential critical design features for blended wing body cover panels. The results of the detailed stress analyses are shown in figure 5 and indicate the change in stresses which must be accounted for in design.

(J. Funk, 757-864-3092; j.g.funk@larc.nasa.gov)

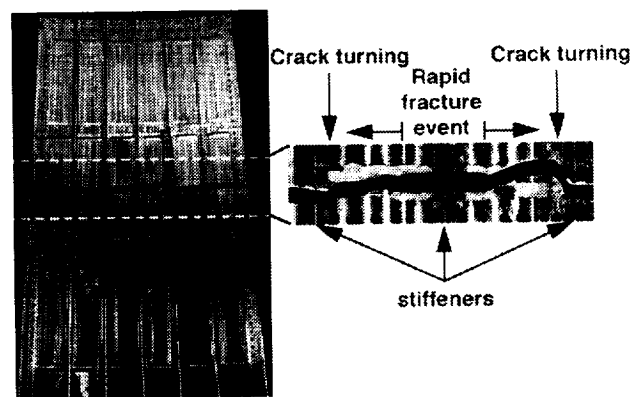
### Integral Airframe Structures

The airframe industry has identified reductions in the ownership cost of airplanes as a critical factor in reducing the cost of air travel— one of the goals of the Global Civil Aviation Pillar. In support of this goal, the Integral Airframe Structures (IAS) Program will develop advanced technologies that may be used by U. S. aircraft industry to enable significant cost reductions in manufacturing integral metallic aircraft fuselage structure. IAS is a joint program between Boeing, Northrop Grumman, Lockheed Martin, Alcoa and NASA LaRC.

The airframe industry has identified reductions in the ownership cost of airplanes as a critical factor in reducing the cost of air travel— one of the goals of the Global Civil Aviation Pillar. Today's airframe designs are typically riveted aluminum skin and stringer construction, a structural concept dating from the 1940's. This process utilizes a very high number of detail parts and tools and is highly refined and optimized. Metallic

structures with integrally machined stringers promise significant cost reductions over traditional built-up structures due to reduced fastener count, reduced detail part count, reduced materials cost, simplified assembly, reduced joints and reduced weight. Today metallic integrally stiffened structures are used on a limited scale because of embedded design practices, an evolutionary design approach, and damage tolerance design practices which rely on discrete parts for fail safety. Recurring manufacturing costs of airframe structure is a key component of ownership cost, and recent advances in metallic materials processing technology indicate that significant reductions (30–50 percent) in manufacturing costs are possible through the use of large integrally stiffened structural components. However, there are significant technical challenges that must be overcome before these cost savings can be realized. These challenges include scale-up of advanced metallic materials processing technologies, and the durability and damage tolerance of large integrally stiffened structural components. The IAS program is developing and demonstrating the technologies required to meet these challenges.

In 1997 panels were evaluated in collaboration with McDonnell Douglas Aerospace to demonstrate the damage tolerance of integrally stiffened structure. Two curved panels, approximately 2.5 ft. by 5 ft. were fabricated with curvature and stiffener spacing that represented typical airframe fuselage structure. The panels were fully machined to produce integral stiffeners, thus requiring a substantial reduction in number of parts over conventional construction, and were tested to demonstrate how a growing crack interacts with the stiffeners. In Figure 6, the integrally stiffened panel is shown with a magnified portion of the photograph showing how the crack turned at the stiffeners. The integrally stiffened panel was able to support the



**Figure 6. Integrally stiffened 2096 curved panel.**

required load for a safe design. Future work will include building larger panels with more advanced technology, and development of the cost and performance.

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## **Error-Proof Flight Deck**

Today, flying is the safest of all major modes of transportation. However, if air traffic triples as is predicted, today's low accident rate will not be good enough. More aircraft in the sky will mean more accidents, unless something is done. NASA, along with partners in the FAA and industry, is committed to address this issue. The first of NASA's technology goals is to Reduce the aircraft accident rate by a factor of five within 10 years, and by a factor of ten within 20 years.

Since 1959, more than 70 percent of all known hull-loss accidents for the U.S. commercial jet fleet have been attributed to "flight crew error." Most often these "flight crew errors" cannot be traced to a single incorrect action or inaction by a crew member, but are actually due to a combination of circumstances which come together to cause the error and therefore the accident or incident. The way in which the human performs is difficult to understand and predict; therefore, designing flight decks to best help the flight crew perform their job is very difficult. Some of the interrelated deficiencies in the current aviation system which exacerbate the human performance problem are:

- Insufficient communication and coordination among various organizations within the airspace system;
- Processes used for design, training, and regulatory functions inadequately address human performance issues;
- Insufficient criteria, methods, and tools for design, training, and evaluation relating to human performance; and
- Designers, pilots, operators, regulators, and researchers do not always possess adequate knowledge and skills in certain areas related to human performance.

The diversity and complexity of the human performance problem will require more than point solutions to individual problems. A *systems approach* is needed to address these interrelated problems to produce a flight deck that not only decreases the likelihood of human errors, but reduces the consequences of these errors if they are made.



**Figure 7. Error-Proof Flight Deck.**

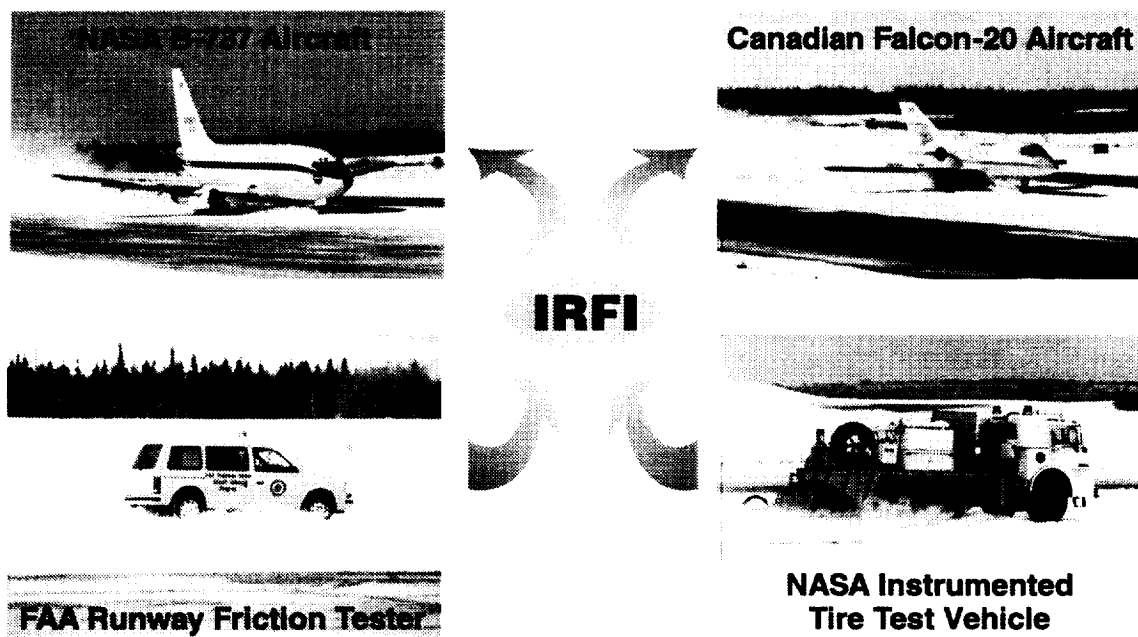
Researchers at NASA Langley Research Center are making the first steps at designing an Error-Proof Flight Deck. As an initial step, a top-down flight deck conceptual design, with traceability to human-centered design guidelines and philosophy has been developed. Some of the attributes of such an error-proof flight deck design are the following: better pilot awareness by reflecting his mental models in design and providing information at the level of usage; improved pilot engagement by increasing his involvement with the task without increasing workload; involved control over all critical flight parameters (not just override capability); clearly defined roles, functions, and responsibilities of the pilot and co-pilot in terms of the mission (instead of in terms of the equipment); appropriately integrated information; and integrated training with the flight deck design. A conceptual depiction of the flight deck with integrated displays is shown in figure 7.

The general approach being taken in this effort is one of iterative top-down design and iterative evaluation. Each iteration provides more depth and breadth both in the definition of the concept and the evaluation of the concept. During each iteration, representatives from industry, the airlines, and the pilot community will be consulted to provide input for both the design and the evaluation. As the design matures, industry will have a greater involvement to insure that practical details have not been overlooked and to increase technology transfer.

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## **Winter Runway Friction Programs**

The Airframe Airworthiness Assurance (AAA) program is developing key safety technologies such as runway friction improvement. NASA, the Federal Aviation Administration, and Transport Canada have



**Figure 8. Joint NASA/TC/FAA Winter Runway Friction Program—Development of International Runway Friction Index (IRFI).**

teamed on a five year winter runway friction investigation to enhance airport ground safety and help relieve airport congestion during bad weather. This effort, the Joint Winter Runway Friction Measurement Program, includes braking tests with instrumented aircraft and ground friction measuring vehicles on a variety of dry, wet, snowy and icy runway conditions. The program contributes to two of NASA's pillar goals: reducing the aircraft accident rate by a factor of five within 10 years; and while maintaining safety, triple the aviation system capacity, in all weather conditions, within 10 years.

Most of the tests were performed at North Bay, Ontario. Two winter test seasons have involved four aircraft and 12 different ground vehicles. Aircraft tested include NASA's B-737, FAA B-727, NRC Falcon-20, and a de Havilland DASH-8. Different friction measuring ground vehicles—van, trailers and modified cars—took readings under similar runway conditions for comparison with each other and the braking performance of the instrumented aircraft. Surface conditions were artificially varied to expand the range of data collected. A methodology was established to harmonize ground vehicle friction measurements to accurately determine aircraft stopping performance under adverse weather conditions. The outcome of this program, as visualized in figure 8, is the establishment of an International Runway Friction Index (IRFI). The IRFI is anticipated to become a standard criterion used by airport operators to assess the condition of a runway under winter

conditions. Safe take-off and landing decisions will then be facilitated by use of the index.

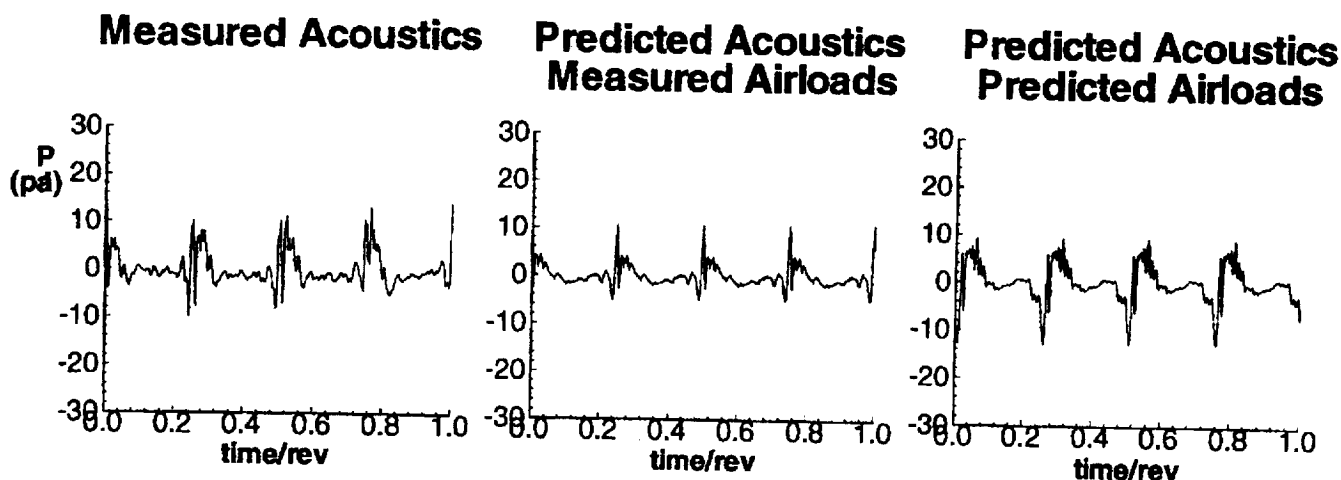
The research will also help industry develop improved tire designs, better chemical treatments for snow and ice, and runway surfaces that minimize bad weather effects. In a non-aerospace application, much of the equipment being used to monitor runways is being used to measure highway pavement friction performance. In areas with high accident rates, pavement textures can be modified, on the basis of friction measurements, to improve the safety of automobile travel. (T. J. Yager, 757-864-1304; t.j.yager@larc.nasa.gov)

### **Rotorcraft Noise Prediction**

Ensuring environmental compatibility of aviation systems is a primary NASA mission, and aircraft noise is an environmental concern. In particular, noise is typically one of the more frequent complaints heard from the community in regard to rotorcraft operations. To address this concern, NASA has undertaken a rotorcraft noise reduction research program.

Noise generated by rotorcraft can be quite annoying to the surrounding community. There are two different ways to reduce the noise that rotorcraft radiate to the ground. One way is to design quieter rotor systems, while an alternate approach that can even be applied





**Figure 9. A comparison of measured and predicted rotor noise data.**

to existing rotorcraft is to change how the pilot operates the vehicle so as to reduce the noise exposure to the community. In either case, prediction of the noise generated by the rotorcraft is the key to success. The ability to predict the noise for a new rotorcraft while still in the design phase will permit inclusion of noise as a design parameter. This has not been possible in the past, since previous noise prediction models were not very accurate. Meanwhile, noise prediction is closely coupled with noise abatement activity as well, to better develop low-noise flight profiles for existing designs. To provide the capability to accurately predict rotor noise, NASA Langley is developing the TiltRotor Aeroacoustic Code (TRAC).

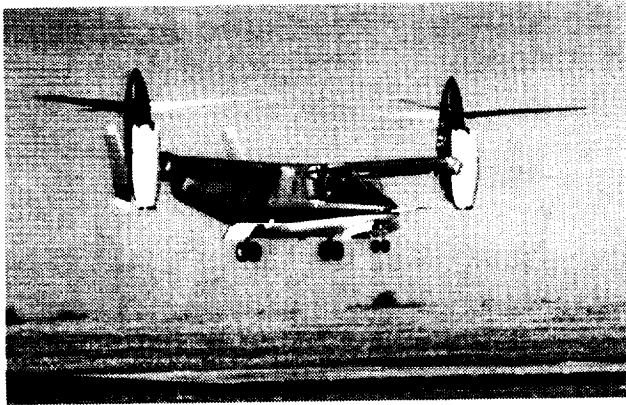
In order to predict rotor noise, it is first necessary to predict the aerodynamics of the rotor blades as they rotate. Rotor blades are like small rotating wings that provide both the lift and the forward movement for a helicopter. Because they rotate, the blades see fluctuations in lift, and it is these fluctuations that produce the noise. To predict the rotor noise, TRAC couples aerodynamic and acoustic modeling in one combined system. A typical result from TRAC is depicted in Figure 9, which compares TRAC noise predictions with acoustic measurements from a Sikorsky model rotor tested in a wind tunnel. The figure shows measured acoustic time histories compared to prediction using measured rotor airloads and predicted rotor airloads. This shows that TRAC is capable of predicting the noise to within at least 2 to 3 dB of that measured. This work was done by NASA Langley working in conjunction with Bell Helicopter Textron Inc., Boeing Helicopter, McDonnell Douglas Helicopter Systems, and Sikorsky Aircraft.

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### Tiltrotor Noise Abatement

An increasing number of U.S. airports, particularly in the Northeast, are rapidly approaching (or have already reached) their capacity with respect to the maximum number of daily aircraft operations. Many of these valuable slots are used by commuter aircraft flying fairly short routes with relatively few passengers, which significantly limits the total number of passengers that can use a congested airport each day. Tiltrotor aircraft, with their unique capability to take off and land vertically while flying like an airplane during cruise, provide a potential alternate means of transportation that could link major cities without requiring runways, thus alleviating some of the demand on airports. The goal of the Civil Tiltrotor element of the Aviation Systems Capacity Program, led by Ames Research Center, is to develop the most critical vehicle technologies for a civil tiltrotor. Langley plays a key role in supporting CTR technology in the area of noise reduction.

Noise generated by large (40 passenger) tiltrotor aircraft is a potential barrier issue for civil market penetration. With its distinctive impulsive character, the (whop-whop) noise generated by all rotorcraft, including tiltrotors, can be quite annoying to the surrounding community. There are different ways to reduce the noise that rotorcraft radiate to the ground. One way is to design quieter rotor systems. However, this approach can be both time-consuming and costly, and may have an adverse impact on the aircraft's operational capabilities. An alternate approach that can even be applied to existing rotorcraft is to alter how the pilot operates the vehicle so as to reduce the noise exposure to the community. For conventional



**Figure 10. XV-15 hovering at test site near Waxahachie, TX.**

helicopters, this typically involves alternate combinations of airspeed and descent angle. (While a commercial airplane usually descends at a three-degree angle, rotorcraft can easily descend at angles of 12 degrees and beyond.) Because their propellers can be positioned anywhere from a helicopter-like configuration to a propeller, tiltrotor aircraft have the additional option of varying the propeller angle to reduce noise. To quantify the potential benefit of tiltrotor noise abatement operations, a joint NASA Langley/Bell Helicopter/Army XV-15 Terminal Area Operations flight acoustics test was successfully conducted in October–November 1995 at a test site near Waxahachie, TX. A photograph of the aircraft in hover at the test site is shown in Figure 1. A total of 175 data runs were completed, with the primary focus being on descent conditions. Both fixed flight conditions and full simulated approach procedures were flown, with up to 38 microphones being used to directly measure noise footprints on the ground. Because of the use of new digital acoustic data acquisition systems, on-site computations of noise contours were produced during the test. These noise footprints indicated that over 50% reduction in the area exposed to a particular noise level was achieved through modification of flight procedures. This test highlights the noise abatement potential available with tiltrotors. The work was done by NASA Langley working in conjunction with Bell Helicopter Textron Inc.

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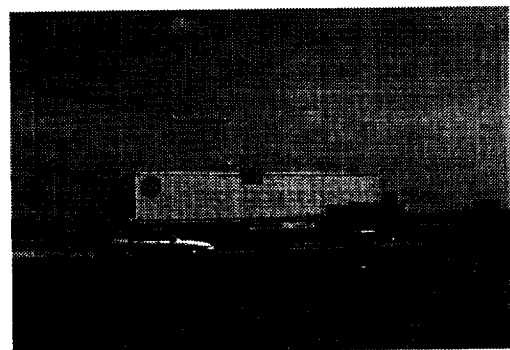
### **Laser Studies to Maximize Airport Capacity**

A pulsed coherent lidar system has been developed to support the Reduced Separation Operations (RSO)

element of NASA's Terminal Area Productivity (TAP) program. The RSO objective is to minimize reductions in airport terminal capacity during instrument meteorological conditions (IMC). Reductions in airport capacity during IMC result from aircraft spacing requirements imposed to avoid exposing aircraft to the hazards of wake turbulence. All aircraft produce wake turbulence which resembles horizontal tornadoes generated off the aircraft wing tips.

Wake turbulence generated by large aircraft can be hazardous to smaller following aircraft during approach and landing. During IMC, air traffic controllers are required to space aircraft in accordance with fixed guidelines based on strength of the wake vortices generated by the leading aircraft and size of the following aircraft. The objective of RSO is to develop a dynamic aircraft spacing system which can utilize near term weather forecasts and models of wake and weather interactions to predict time periods when the fixed guidelines for aircraft separation during IMC can be reduced. The pulsed coherent lidar system will provide the necessary confirmation that actual wake vortex behavior agrees with predictions therefore ensuring safety.

Development of the pulsed lidar transceiver was the responsibility of Coherent Technologies, Inc. (CTI) under a NASA Small Business Innovation Research (SBIR) contract. The transceiver utilizes a solid-state, eye-safe laser operating at a wavelength of two micrometers. The laser operates at 100 pulses per second with a pulse power of approximately 7 millijoules. The pulsed laser beam is expanded through a telescope and directed to a hemispherical scanner which scans the beam across the airport runway. Light reflected from microscopic particles in the air, and shifted in frequency due to the swirling particle motion in the vortex, is detected by the lidar transceiver. These return signals are then analyzed to detect, track and measure strength of the wake vortices.



**Figure 11. Lidar Trailer at DFW Airport.**

Two data analysis systems, one for in-house development and one delivered by CTI under an SBIR contract, are available for processing the lidar return signatures. The integrated system was deployed to Norfolk International Airport for developmental testing in February 1997. During May 1997, the system was deployed to the Volpe National Transportation System Centers Wake Vortex test site at JFK International Airport for comparative testing with a continuous wave lidar developed by the Massachusetts Institute of Technology's Lincoln Laboratory. The accompanying figure shows the system deployed at Dallas-Fort Worth International Airport in September 1997 to support developmental testing of the dynamic spacing system. During this deployment, real-time wake vortex measurements for approximately one thousand aircraft landings were provided to a prototype dynamic spacing system along with measurements of runway cross winds and wind speed and direction versus altitude above ground.

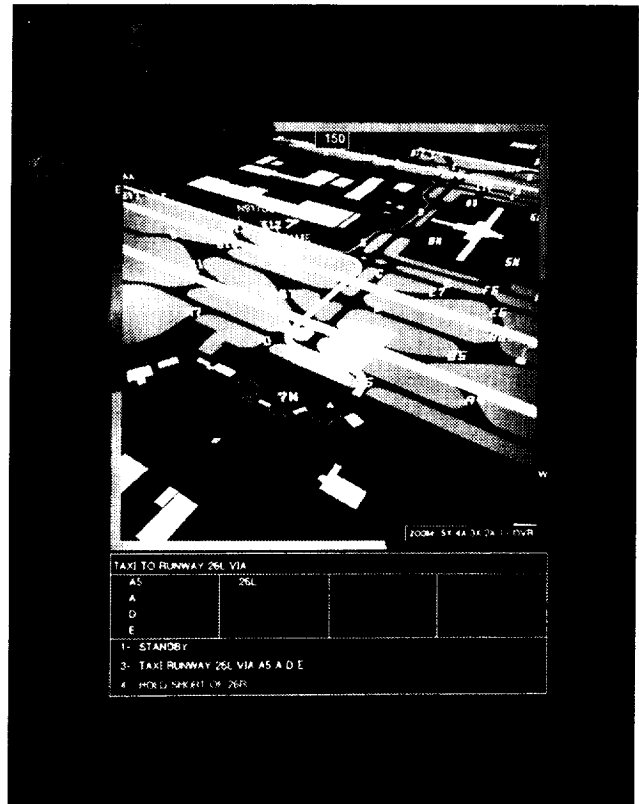
This lidar system development was the subject of an article in the April 1997 issue of *Photons Spectra Magazine* and has resulted in three technical papers presented at the Optical Society of Americas Coherent Laser Radar conferences.

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### NASA Test Concepts for Low-Visibility Airport Operations

In August, NASA Langley tested and demonstrated technology on the runways and taxiways of Hartsfield-Atlanta International Airport that promises to keep traffic moving safely and efficiently day or night regardless of visibility. Dubbed the Low Visibility Landing and Surface Operations program, the research is part of NASA's seven-year Terminal Area Productivity (TAP) program begun in 1994, led by NASA Ames Research Center, Moffett Field, CA. The TAP program is part of the Agency's aviation system capacity program, expected to substantially increase aviation system traffic capacity in all weather conditions. The technology demonstrated in Atlanta is actually many technologies integrated into one air-ground system.

On the ground is a system of surveillance sensors developed by the Federal Aviation Administration and a controller interface developed by NASA Langley. The controller interface allows air traffic controllers to observe surveillance information and to communicate with the research aircraft over a digital datalink in parallel with the normal voice communications. The con-



**Figure 12. Electronic moving airport map (top) and virtual reality runway taxiway (bottom).**

troller is also automatically informed via this computer link if the aircraft deviates from its approved path.

Onboard NASA's Boeing 757 research aircraft, the cockpit display system is an integration of two subsystems, the Roll-Out Turn-off guidance system developed at Langley and the Taxiway Navigation and Situation Awareness display developed by Ames. These systems allow the flight deck crewmembers to safely and efficiently perform landing roll-out, turn-off,

and taxi to the ramp in any visibility or at night using supplemental guidance and situational awareness information provided on two display devices. Upon contact with the ground, the pilot's aircraft position and that of other aircraft are shown on an electronic moving map of the airport on the instrument panel. The glass visor, or head-up display, shows the edges of the runway and taxiway with a series of computer-generated cones in a virtual reality manner.

A combined ground and airborne system can reduce the growing number of ground accidents and close calls by increasing the situational awareness of both pilots and controllers. Additionally, the digital datalink greatly eliminates the possibility of miscommunication between controller and pilot.

Fifty-three flight tests and demonstrations were completed at Hartsfield-Atlanta. The system was demonstrated to various airline and industry executives, officials of the FAA and other government agencies. This testing resulted in nearly 1400 minutes of data that will be used to assess the individual technologies employed and the overall system performance. Results of this assessment will be published in the coming months. Comments from the visitors and the test subjects were overwhelmingly positive and included suggestions for improvements that will be considered as the research continues (see figure 12).

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### **The Advanced Stitching Machine: Making Composite Wing Structures of the Future**

NASA's Advanced Stitching Machine is located at the Marvin B. Dow Stitched Composites Development Center—a new Boeing facility that will produce low-cost composite wing structures. Americans have always associated metal airplanes with strength. However, aircraft designers today are turning to composite materials to meet the growing challenge of maintaining safety and economy for commercial air travelers. Anticipating this challenge, NASA and Boeing have joined forces under the Composites element of the Advanced Subsonic Technology Program to make large composite airplane structures a reality.

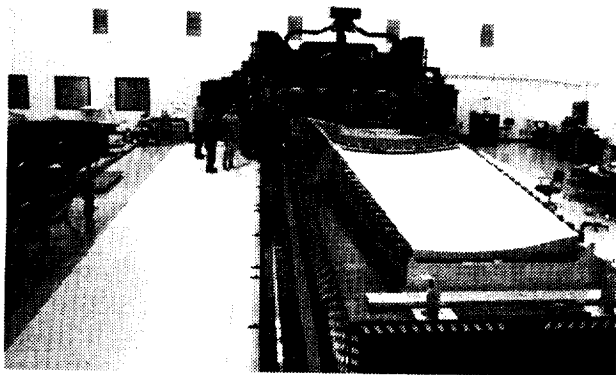
The Composites element aims to reduce air travel costs through the use of composite materials on commercial aircraft. The Advanced Stitching Machine (ASM) was designed and built to aid in making large structures out of composites. The program will also help accomplish one of NASA's new technology goals for aeronautics—to reduce the cost of air travel by

25 percent within 10 years, and by 50 percent within 20 years.

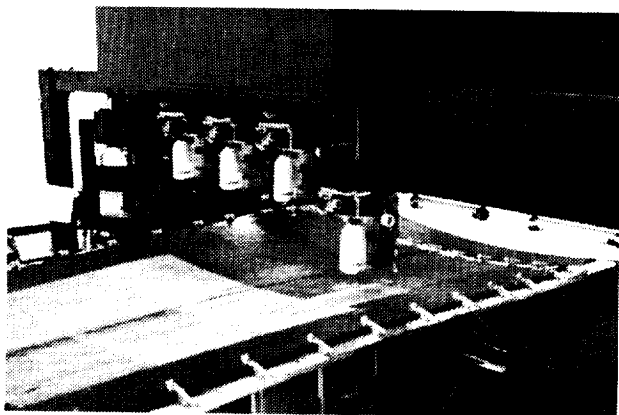
NASA's early composites research provided the aircraft builders with important technology but the industry lacked the confidence to use laminated composites to manufacture wing and fuselage structures. The barrier issues were high cost and low damage tolerance. Various types of textile composites were thoroughly tested but it was stitching combined with resin film infusion (RFI) that showed the greatest potential for overcoming the cost and damage tolerance barriers to wing structures. Assembling carbon fabric preforms, (pre-cut pieces of material), with closely spaced through-the-thickness stitching provided essential reinforcement for damage tolerance. Also, stitching made it possible to incorporate the various elements—wing skin, stiffeners, ribs and spars—into an integral structure that would eliminate thousands of mechanical fasteners. Although studies showed that stitching had the potential for cost-effective manufacturing, the critical need was for machines capable of stitching large wing preforms at higher speeds.

NASA awarded Boeing a contract to develop a large machine capable of stitching entire wing covers for commercial transport aircraft. This high-speed, multi-needle machine is known as the Advanced Stitching Machine (ASM). The largest of the demonstration sections was a 12-ft. long wing stub box which was fabricated at Long Beach, CA, and tested at NASA Langley Research Center in July 1995. The wing stub box demonstrated that the stitching/RFI concept could be used to make the thick composite structures needed for heavily loaded wings. The successful test of the stub box proved the structure and damage tolerance of a stitched wing.

The ASM (see figure 13) features high speed stitching capability with advanced automation allowing it to stitch large, thick, complex wing structures without manual intervention. Equipped with four stitching heads, this massive machine is able to stitch one-piece aircraft wing cover panels 40-feet long, 8-feet wide and 1.5-inches thick at a rate of 3,200 stitches per minute. The stitching heads also offer machine tool precision, stitching at 8 stitches per inch with a row spacing of .2 inches. It features a pivoting or walking needle mechanism and needle cooling system which prevents excessive needle bending and associated temperature build-up in the needle. In addition, to maintain desired stitching speeds, an automated thread gripper and cutting mechanism was developed. A technological marvel, the ASM has computers controlling 38 axes of motion. The computers are also used to simulate and confirm the stitching pattern on



Full View of ASM



Closeup of Stitching Heads

**Figure 13. Advanced Stitching Machine (ASM) at Boeing in Huntington Beach, CA.**

the 50-foot bed of the ASM. A laser projection system is used to precisely locate the wing skin on the lift table surface before stitching begins. This same aerospace precision is used to locate secondary materials, like the stiffeners, for stitching. The movements of the stitching heads are synchronized with each of the fifty lift tables it takes to control stitching over the contoured shapes of the wing panels. The lift tables are used to support the dry fabric preforms as they are stitched. Live-feed cameras are mounted to let operators monitor stitch formation for real-time quality assurance. The machine gantry operates on precisely aligned rails that are 75 feet long. In total, the machine measures 75 feet long, with specialized machinery stretching 20 feet below ground and 20 feet above ground.

The ASM is capable of stitching wing cover panels in one, two-shift operation saving days over conventional composite manufacturing processes. Cost analyses indicate that a reduction of 20 percent in cost can be achieved over equivalent wings built from aluminum. This, together with the reduction in weight, translates to a much improved competitive position for airlines in the global market and ultimately a reduction in future air travel costs.

The ASM is an integral part of the stitched/RFI composites manufacturing process. With through-the-thickness technology, the ASM's stitching heads can penetrate through textile preforms 1.5" thick. This type of stitching increases damage tolerance and load capability especially when assembling and binding secondary materials—stiffeners, spar caps and intercostal clips—onto the skin. Stitching materials together is also faster than drilling holes and assembling the 80,000 metal fasteners found on an aluminum wing. Removal of this excess metal decreases the weight of the wing and eliminates the problems of fatigue or corrosion of the metal fasteners. When the stitching is complete, the still flexible wing skin panel is put into an outer mold line (OML) tool that is the shape of the outside surface of the wing. A film of resin is laid on the OML form, followed by the composite skin panel and the tools that will define the inner mold line. These elements are put into a plastic bag from which the air is drawn out, creating a vacuum. The materials are then placed in an autoclave, where heat and pressure are applied to let the resin spread throughout the carbon fiber material. After heating to 350 degrees for two hours, the wing skin panel takes on its final hardened shape.

The panels currently being stitched on the ASM will eventually be used as test articles in a full-scale ground test of a composite wing for an airliner. A test of this forty-foot semi-span wing will take place at NASA Langley's Structures and Materials Laboratory in 1999. The tests will simulate various levels of damage to ensure that the composite wing meets FAA standards.

Boeing named its new Stitched Composite Development Center after NASA Langley researcher Marvin B. Dow in honor of his contributions to stitched composites research and, specifically, to the Advanced Stitching Machine (ASM). Dow spent the last 25 years of his 40-year NACA/NASA career in pursuit of the application of advanced composite materials on commercial transport aircraft. He is the first NASA employee honored in the naming of a corporate facility.

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## THUNDER

Thin Layer Composite Unimorph Ferroelectric Driver and Sensor (THUNDER) is a new ultra-high displacement actuator/sensor developed at Langley Research Center. When used as an actuator the THUNDER technology significantly improves the state-of-the-art piezoelectric (crystal structures which can generate electricity when stressed or which conversely will move when voltage is applied to the crystal structure) technology and provides a high level of movement not seen before in piezoelectric devices (Fig. 14). The amount of force moved and the amount of movement can be traded to obtain a significant increase in movement over state-of-the-art piezoelectric devices. THUNDER technology is applicable to high performance sensor applications such as microphones, non-destructive testing, and vibration sensing. THUNDER technology is currently being researched as a noise reduction device for aircraft engines. THUNDER actuators manufactured using the THUNDER technology are reliable and have been lab tested to beyond a billion cycles without failure. The electrically insulated, highly efficient actuator can be operated in a vacuum, in liquids, and in the upper atmosphere. THUNDER technology is versatile and rugged enough to allow for its use in harsh environments making it applicable to hundreds of commercial applications.

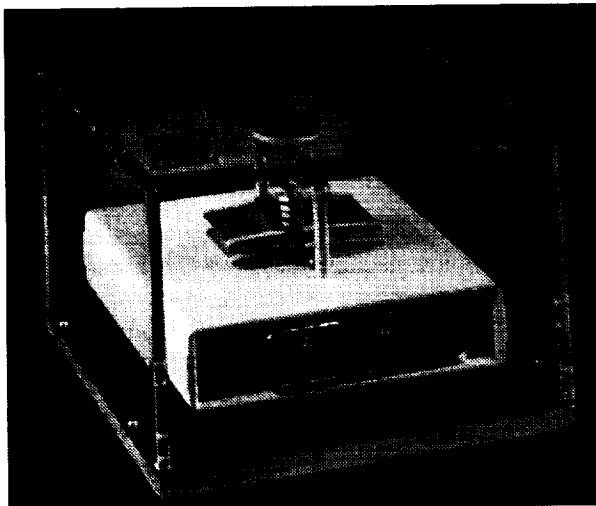
The fabrication process of wafers using the THUNDER technology is uncomplicated and allows for the manufacture of virtually any size and thickness. Initially, electrical contacts are deposited or plated on the active areas of conventional piezoelectric wafers. Next, alternating layers of adhesive and aluminum foil

are placed on one side of the piezoelectric wafer. The package is vacuum bagged on a flat fixture and placed in an oven for processing at a moderate temperature. After removal from the oven the wafers are domed or curved during the cool down process utilizing the difference in thermal expansion rates of the various materials (layers).

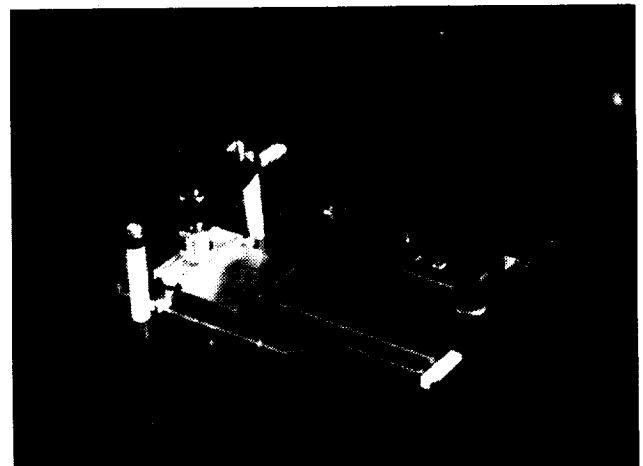
The effectiveness of the THUNDER technology can be attributed to several factors including the fabrication process where any geometrical size and shape can be created to improve the mechanical performance of the device, the mechanical advantage due to the flexibility of the device with the use of metal foils used in processing, and the radial expansion created by the pairing of preselected thermally mismatched materials.

The principal applications of the THUNDER technology at Langley Research Center have been audio tone generation, noise cancellation, pumps, motors, and positioning systems (Fig. 15). Other applications for which the technology can be used are microphones, fluid metering and control, beam and pipe stiffeners, auto focus mirrors, fans, voltage source, air-foil shaping, agitation, and ultrasonic cleaning. All of the potential applications have not been discovered or developed. The THUNDER technology has a known field of use in 24 major categories. The technology is entirely a Langley Research Center invention. Currently a number of industrial partners are developing products that use THUNDER technology. Langley Research Center strives to match potential manufacturers with identified NASA proprietary technologies available for licensing and commercialization. Recipient of a 1996 Research and Development 100 Award, there have been 13 invention disclosures submitted on THUNDER technology and 1 patent granted.

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**Figure 14. Stacked (THUNDER) device.**



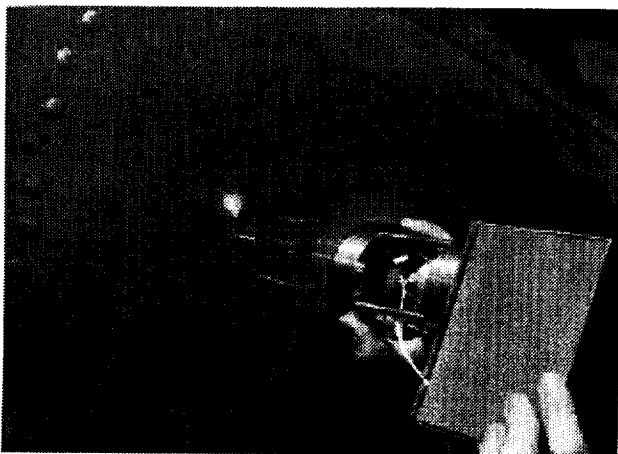
**Figure 15. Laser positioning system.**

## Flux-Focusing Sensor and Rotating Probe Method for Rivet/Fastener Inspection

NASA's Airframe Structural Integrity Program—the Aging Aircraft element of the Advanced Subsonic Technology Program—is focused on developing advanced integrated technologies to economically inspect for damage and to analytically predict residual strength of high time airplanes. As part of this effort, NASA Langley Research Center has developed several instruments based on a novel electromagnetic probe.

One of these instruments, the flux-focusing eddy current sensor and rotating probe offers significant advancement in the detection of fatigue cracks under rivet heads. The probe consists of two concentric coils - outer (drive) and inner (pick up) coils - separated by a ferrous, thin-walled tube, called the flux-focusing lens. This lens isolates a high-turn pick-up coil from the excitation coil. The device's unique driver-pickup coil configuration produces a zero output voltage when unflawed material is inspected. In the presence of a flaw or crack, a large output voltage is recorded. The signal offers the instrument operator an easy method for detecting and locating a flaw. The lens also simplifies inspections and increases detectability of fatigue cracks under circular fasteners in high conductivity materials.

The device (see figure 16) enables parts to be rapidly scanned, monitoring only the amplitude of the pick-up coil signal. The device can detect flaws under fastener heads and in the conducting material. Flaw



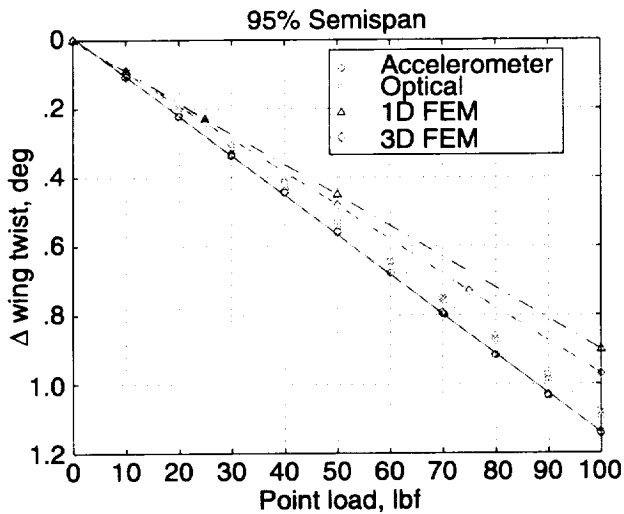
**Figure 16. NASA developed prototype of Rotating Head, Self-Nulling Eddy Current Probe for detecting fatigue cracks in aircraft structures.**

sizing and location can be easily determined from the instrument's output. The instrument has been used to detect small cracks hidden under rivet heads. Test results have proven that the probe is capable of detecting 0.032" long fatigue cracks under fasteners with a 90% certainty. Features of the technology include detection of fatigue cracks in conducting materials; requires minimal instrumentation; requires no calibration (self-nulling) or reference standards; provides a clear, unambiguous signal; producible at low cost (less expensive than existing devices); and portable. A patent application has been filed.

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## Calibration/Validation of Methods for Predicting Static Aeroelastic Deformations of Wind Tunnel Models

The accurate prediction of wind tunnel model static aeroelastic deformations caused by aerodynamic forces acting on elastic wind tunnel models is becoming increasingly important for transonic testing of advanced low wing transport configurations. Computational methods such as the finite element method (FEM) need to be calibrated and validated in order to ensure accurate predictions of the static aeroelastic deformations of typical transonic wind tunnel models. Extensive calibration/validation of FEM predictions has been carried out in a McDonnell Douglas/NASA cooperative study using a novel wind-off wind tunnel model static loading experiment and wind-on optical wing twist measurements obtained during a wind tunnel test in the National Transonic Facility (NTF) at the NASA Langley Research Center. For the static wind-off loading experiment, a single point load was applied to the model at the 95% semispan station at the elastic axis while the model was mounted in the test section at the NTF so that optical wing twist measurements could be recorded for comparison in the same experimental arrangement as used for wind-on. An accelerometer attached to the wing tip tang served as reference for the wing twist measurements. The good agreement (5%) between the optical measurements and reference accelerometer increased the confidence in experimental wing twist measurements needed to validate FEM predictions obtained with wind-on (see figure 17). Further validations were carried out by McDonnell Douglas Corporation using a Navier-Stokes CFD flow solver to calculate wing pressure distributions about several aeroelastically-deformed wings for comparison with NTF experimental data. Results were found to be in good overall agreement with experimentally measured values. Including the



**Figure 17. Wing twist measurements made by accelerometer and optical techniques compared with 1-D and 3-D finite element method (FEM) predictions at the 95% semispan from a wind-off static loading experiment in the National Transonic Facility test section.**

predicted deformations significantly improves the correlation between CFD predicted and experimentally measured wing surface pressures. Details of this effort can be found in a joint McDonnell Douglas/NASA paper entitled, "Static Aeroelastic Analysis of Transonic Wind Tunnel Models Using Finite Element Methods" (AIAA paper 97-2243) written by J. R. Hooker, A. W. Burner, and R. Valla presented at the AIAA Applied Aerodynamics Conference in Atlanta, Georgia, June 1997.

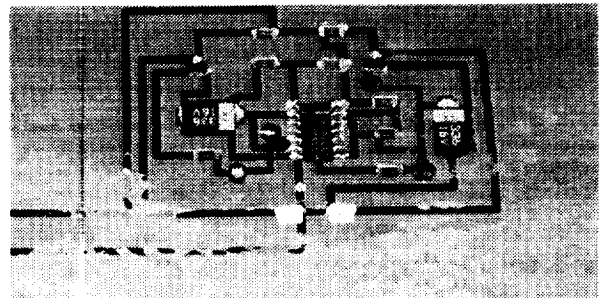
(A. W. Burner, 757-864-4635; a.w.burner@express.larc.nasa.gov)

### Flexible Circuits And Cables Utilizing LaRC™-SI

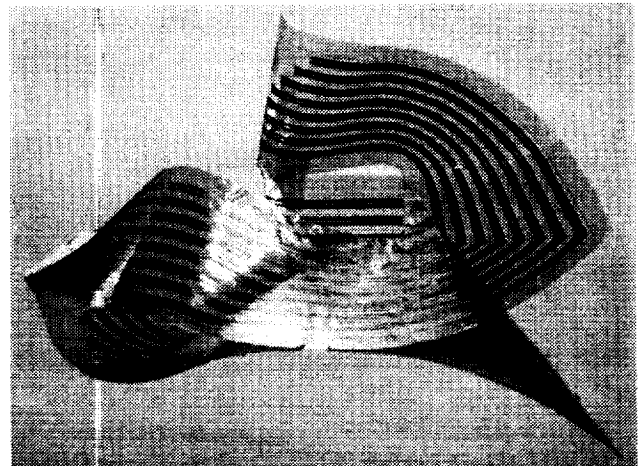
Future electronic systems for aeronautical, space, and consumer applications will be smaller and lighter, will require more efficient circuitry, and will have to survive harsh environments. As these systems become increasingly more complex, the requirements will demand high density circuitry and higher layer count (multilayer) circuits. To meet these needs in the global civil aviation arena, designers will increasingly rely on lightweight multilayer flexible circuits and cables made from high performance materials in an effort to improve air transportation affordability through low cost materials and structural concepts.

Flex circuits have been produced on numerous materials from aramid paper to polyester and polyimide film. Polyimide film, because of its high performance characteristics, is generally the choice material for military and aerospace applications. Adhesives play an active role in fabricating multilayer circuits and are used to bond the conductor and cover layers to the polyimide film as well as to bond the patterned films together to form a multilayer circuit. While adhesives are used to fabricate multilayer flex circuits, they often create disadvantages such as the necessity for additional materials, higher processing costs, thermal mismatch between materials, greater Z axis expansion, and a less flexible, higher end weight product.

Technologists and engineers at NASA Langley Research Center (LaRC) have developed a self-bonding polyimide material known as LaRC - Soluble Imide (LaRC™-SI) which affords a means of fabricating multilayer flex circuits (Fig. 18) and cables (Fig. 19) without the use of adhesives. Many advantages can be achieved by fabricating flexible single and multilayer



**Figure 18. Adhesiveless Multilayer Flex Circuit.**



**Figure 19. Polyimide Flexible Cable.**



circuits and cables without the use of adhesives. Utilizing the LaRC™-SI polyimide material enables self-bonding multilayer flex circuits and cables to be made thinner, with an overall lighter end weight, and without the problems of wrinkling and voids. Flex circuits and cables are no longer limited to the environmental and temperature constraints of previous circuits and cables which used adhesives. Fabricating multilayer flex circuits and cables with self-bonding film is a cost effective way to produce circuits with less processing time, capital investment, and materials costs. LaRC™-SI won the Research and Development 100 Award in 1995 and there have been several associated invention disclosures and several published papers. Companies or universities studying/utilizing LaRC™-SI include Dominion Resources (Virginia Power), Hess Incorporated, Tayco Engineering Incorporated, University of Pittsburgh, and Georgia Tech Research Institute.

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### **Development of New Polymers with Desired Physical Characteristics: A New Approach**

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Increasing emphasis on easy processing and good fracture toughness of composite matrix resins for aerospace structures has provided a strong impetus to develop high performance polymers. Currently available thermosetting polyimides are generally easy to process, but are brittle. Thermoplastic polyimides, on the other hand, are tough but difficult to process. Combining these two types of polymers would be expected to lead to tough and easy to process high performance Semi-Interpenetrating Polymer Networks (S-IPN). The constituent polymers in these networks interpenetrate into each other's chain structure, without forming any chemical bonds. Based on this concept, we synthesized a series of S-IPN's by combining recently developed Langley thermosetting and thermoplastic polyimides in various weight ratios.

Positron Annihilation Spectroscopy (PAS) was employed to monitor morphological characteristics of several S-IPN systems containing variable weight percent ratios of thermosetting and thermoplastic polyimides. PAS involves injection of fast positrons (antiparticles of electrons) in the test samples. These positrons thermalize quickly and subsequently annihilate with the molecular electrons at the ends of their ranges. Their survival times (lifetimes) and the widths of annihilation photon lines depend on the number and velocity distributions of the molecular electrons with which they annihilate. These lifetimes and annihilation

photon widths provide direct information about the defect structure in the test samples. This defect structure strongly affects the physical and mechanical properties of the polymeric materials. As a result of PAS measurements, two very interesting features were noted:

(1) The density of the S-IPN samples goes through a maximum at 50:50 weight composition, indicating the importance of electrostatic interactions between the constituent polymers; and

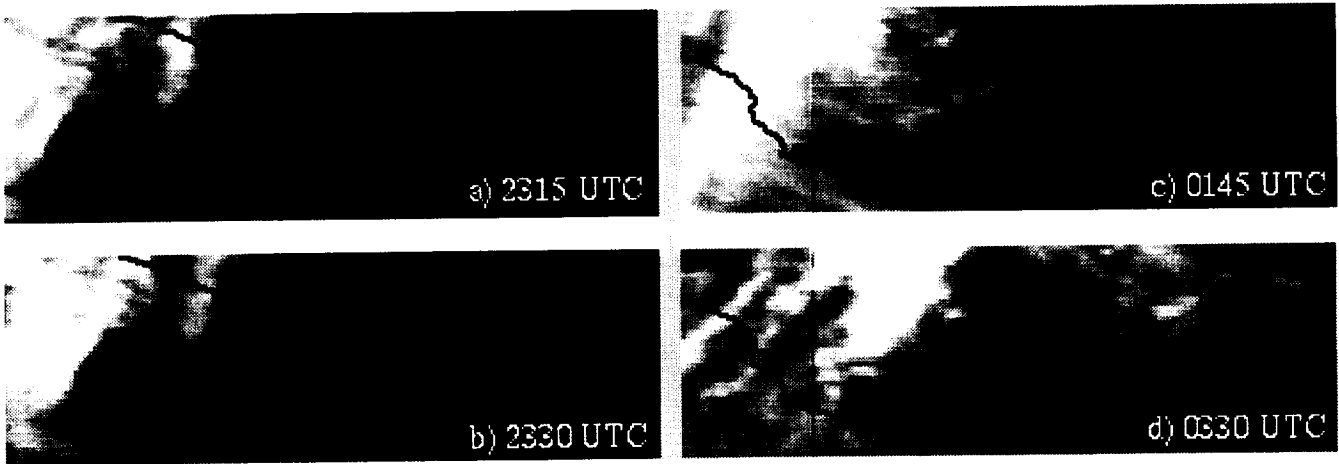
(2) The dielectric constant of the samples depends on their free volume fractions, exhibiting strong composition dependence. These results indicate that S-IPN materials are not merely solid solutions of the constituent polymers. Their non-linear characteristics dictate that both steric and electrostatic forces are needed to explain the observed relations between the density, dielectric constant and the chemical composition of the samples. These results suggest that S-IPN materials with desired physical properties may be synthesized by selecting one member of the network to have pronounced non-spherical charge distribution along its chains, while the charge distribution in the other member is essentially isotropic. Several papers have resulted from this work.

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### **Increasing Cloud Cover from Contrails**

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Commercial and military jet aircraft operate in the upper troposphere, a portion of the atmosphere that is very clean compared to the boundary layer where most air pollutants generally form and persist. As part of the effort to monitor anthropogenic effects on the environment, the Subsonic Assessment (SASS) Program, part of the NASA Atmospheric Effects of Aircraft Program (AEAP), is examining the impact of increased air travel on the troposphere and lower stratosphere. Through their exhaust, aircraft produce a variety of gaseous compounds in addition to water vapor and aerosols. One of the most visible and, perhaps, most important effects of high-altitude air traffic is the production of condensation trails or contrails. In many instances, these artificial clouds are linear streaks in the sky that may rapidly dissipate or, in the proper conditions, persist and grow. If they persist, contrails will act like natural cirrus clouds by reflecting solar radiation causing cooling or trapping infrared radiation from the surface causing a greenhouse-type warming. The net effect, warming or cooling, depends on many factors such as lifetime, thickness, and size of the cloud's particles. Thus, it is important to measure these aspects of contrails.



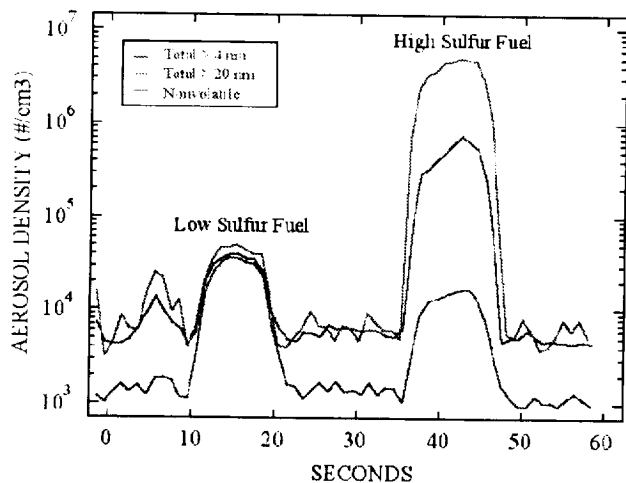
**Figure 20. Development of cirrus cloud from oval contrail generated by NASA DC-8 exhaust during May 12, 1996 SUCCESS flight off coast of California as observed in GOES 4-km infrared images.**

Because contrails form at high altitudes, they tend to move at high speeds making them difficult to track. They also tend to form in the vicinity of natural cirrus so distinguishing them from natural cirrus is difficult. During the Spring of 1996, SASS sponsored the SUB-sonic aircraft: Contrail and Cloud Effects Special Study (SUCCESS) field experiment over the western US. During a May 12 SUCCESS flight off the coast of California, the NASA DC-8 produced a 100-km long oval-shaped contrail in clear air at an altitude of 10 km. This contrail quickly became visible in the 4-km resolution Geostationary Operational Environmental Satellite (GOES-9) imagery. The contrail continued to grow and spread as it traveled across California before dissipating over the Sierra Nevada Mountains more than 5.5 hours after it first formed. Analyses of the GOES data taken every half hour reveal that it covered nearly 5,000 km<sup>2</sup> approximately 3 hours after it formed. Its particles grew from very small sizes to those similar to natural cirrus in a few hours. The contrail's oval shape facilitated the observation of its conversion to a cirrus cloud. A ground observer would have difficulty recognizing this cloud as a contrail. These results are the first to show the formation of a persistent contrail followed by its advection to a different area while it changed into an ordinary-looking cirrus. How often this process occurs and how much cloud cover is being increased by contrails remain important questions for continuing SASS research. It is clear, however, that contrails can have a significant effect on cloud cover.

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### The Role of Jet Fuel Sulfur Contaminants in Controlling Aircraft Aerosol Emissions

Typical jet fuel contains about 500 ppm (parts per million) sulfur (S) as an impurity and levels up to 3000 ppm are allowed under current specifications. A portion of this is expected to be oxidized during combustion to form sulfuric acid which can not only condense onto the aircraft soot emissions but may undergo binary homogeneous nucleation with water to form new particles. These particles can, in turn, perturb heterogeneous chemical processes in the atmosphere or alter cirrus cloud frequency or radiative properties, thus impacting climate. Classical combustion and plume models generally predicted that less than 1% of the fuel sulfur in jet fuels would be immediately converted to acid, the remainder would be released as SO<sub>2</sub> which would have little impact upon the large reservoir of this species present in the atmosphere from natural (i.e., volcanoes and biogenic activity) and other anthropogenic sources. This perception was challenged recently when very high concentrations of small, volatile particles were measured in the exhaust plume of a Concorde aircraft flying in the lower stratosphere. If the particles were indeed sulfate, the observations implied that 12 to 45% of the fuel sulfur was converted to H<sub>2</sub>SO<sub>4</sub> in the near-field behind the aircraft. Such efficient conversion rates with accompanying high rates of aerosol formation could pose a significant perturbation particulate sulfate concentrations in the upper troposphere and lower stratosphere.



**Figure 21. Plot of aerosol concentrations recorded at cruise altitude during penetrations of the NASA Langley B757 exhaust plumes as 70 ppm S and 700 ppm S fuels were being burned in the left and right engines respectively. The total fraction of particles includes both sulfate and soot aerosols whereas the nonvolatile fraction is composed primarily of soot.**

In order to investigate whether the volatile particles observed in the aircraft exhaust plume were indeed composed of sulfate and to quantify the fraction of fuel sulfur released as sulfuric acid, the NASA Atmospheric Effects of Aviation Program (AEAP) performed a carefully controlled fuel sulfur experiment during the April-May, 1996 SUCCESS (Subsonic Assessment: Cloud and Contrail Effects Special Study) mission in Salina, Kansas. During the tests, the Langley B757 center and left wing tanks were fueled with Jet A containing about 70 ppm S whereas its right wing tank was filled with the same fuel containing an additive which brought its sulfur content up to about 700 ppm. The aircraft was then flown in a racetrack pattern at cruise altitudes where it was followed closely (0.05 to 1 km) by a small twin-engine jetliner which had been instrumented by Langley and Air Force scientists with a suite of trace gas and aerosol sensors to monitor exhaust emissions. The B757 alternated burning the low or high sulfur fuels in both engines or low sulfur fuel in the left engine and high sulfur fuel in the right. Exhaust plume data were recorded over a range of atmospheric conditions and aircraft operating parameters, however, as illustrated in Figure 21, much higher

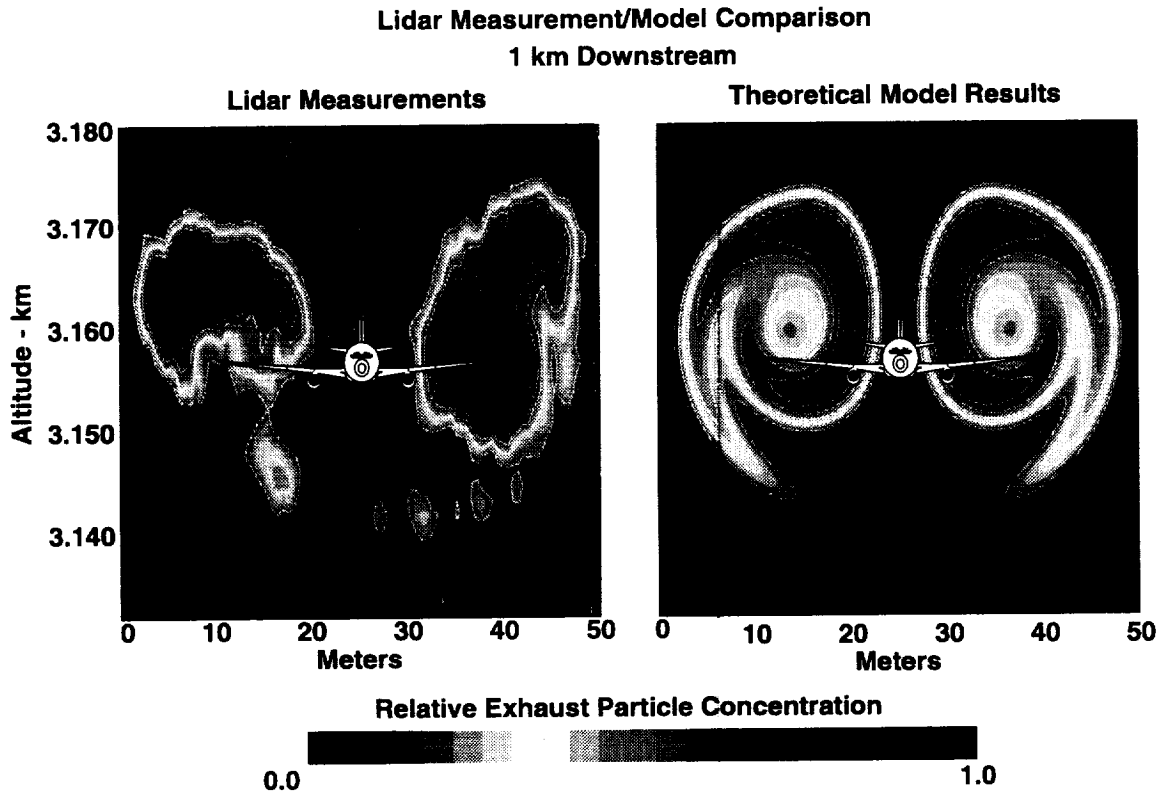
concentrations of volatile particles were consistently observed in the case where high sulfur fuel was used. Average emission indices of about  $2 \times 10^{16}$  and  $1 \times 10^{15}$  volatile particles per Kg of fuel burned were calculated for the high and low sulfur fuels, respectively. These values coupled with concurrently recorded aerosol sizing information and gas phase sulfur measurements indicated that 15 to 30% and 6 to 9% of the sulfur impurity in the high and low fuel S cases, respectively, were oxidized directly to sulfuric acid in the near-field behind the aircraft. These findings coupled with those recorded in the Concorde wake have forced scientist to reexamine their theoretical understanding of combustion processes and to evaluate the possible impact of increased air traffic upon atmospheric processes.

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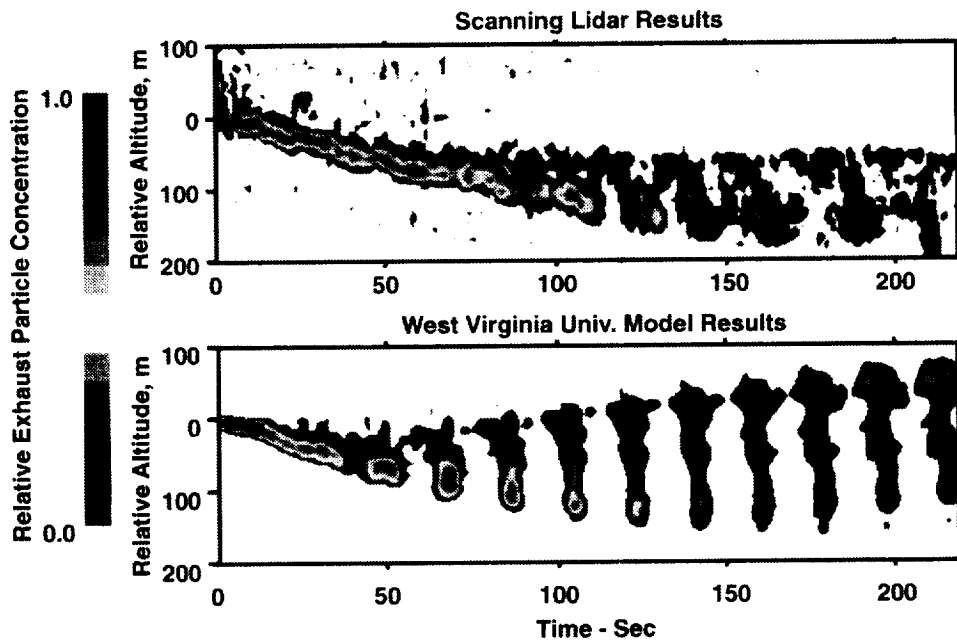
### Ground-Based Lidar Observations of Boeing 737 Exhaust Particles in the Near Field

It is expected that subsonic aircraft traffic will increase dramatically over the next decade, and there is growing interest in the development of supersonic transport aircraft as well (e.g. NASA's High Speed Civil Transport). As a result, more attention is being directed at the potential effects of exhaust products from these aircraft on chemical and radiative processes in the Earth's atmosphere. A hierarchy of computer models is currently being developed to study these processes. An important element of this hierarchy are fluid dynamics models being developed by Continuum Dynamics, Inc. (CDI), of Princeton, New Jersey, and by West Virginia University (WVU) describing how exhaust interacts with the aircraft wingtip vortices and ultimately is mixed into the free atmosphere. Data to test the validity of these models have been collected using ground-based lidar (laser radar) systems at the Langley Research Center during overflights of the Langley Boeing 737 Transport Systems Research Vehicle (TSRV). These data consist of high-resolution two-dimensional measurements of lidar backscatter from the exhaust particles produced by the TSRV. Because the exhaust particles are very small, they serve as excellent tracers of air motion in the aircraft wake.

The left panel of figure 22 shows a cross-section of 532-nanometer lidar data, presented in terms of relative exhaust particle concentration, obtained during a



**Figure 22. UNIWAKE fluid dynamics model. (Note: Figure is in color on internet version of this report.)**



**Figure 23. West Virginia University fluid dynamics model. (Note: Figure is in color on internet version of this report.)**

March 1996 overflight of the TSRV. These data were obtained at a distance of approximately 1 kilometer downstream of the aircraft and has vertical and horizontal resolutions of about 3 meters and 2 meters, respectively. Results from the UNIWAKE fluid dynamics model developed by CDI, shown in the right panel of the first figure show many of the same flow features as do the lidar data. The top panel of figure 23 shows 1064-nanometer scanning lidar data, again in terms of relative particle concentration, obtained also during the March 1996 experiment. The data have been integrated horizontally through the two exhaust plumes of the TSRV, and the initial time denotes when the aircraft passed directly over the lidar site. The TSRV was trav-

eling at a speed of about 100 meters/second; hence the 100-second time mark corresponds to a downstream distance of about 10 kilometers. The bottom panel of the second figure shows comparative results from the WVU fluid dynamics model. Again, the model results capture the features of the data very well, in particular the drop in exhaust plume altitude with time and the formation of cell-like structures downstream of the aircraft. These lidar data are providing the fluid dynamics modeling groups a detailed quantitative look at the evolution of in-flight aircraft exhaust plumes under controlled conditions that can be used to test their simulation codes.

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## Pillar Two: Revolutionary Technology Leaps

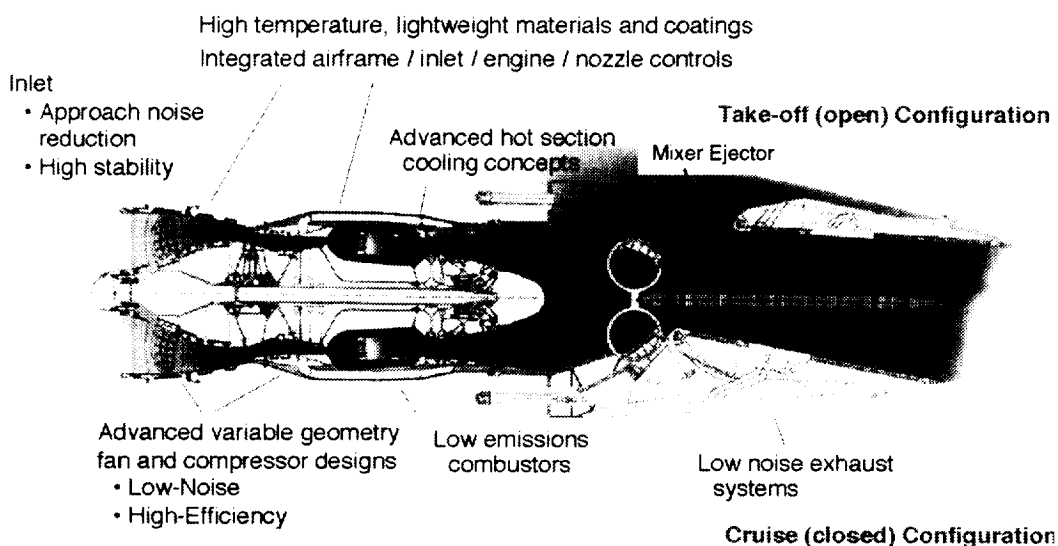


*NASA will pioneer high-risk technology for revolutionizing air travel and the way in which aircraft are designed, built, and operated. Reducing overseas travel time by 50%, expanding the general aviation market, and decreasing aircraft concept-to-certification cycle time by 50% are the technology goals.*

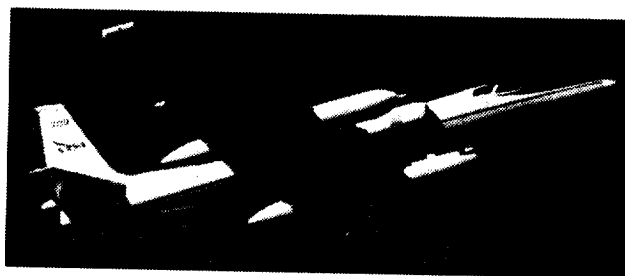
### High Speed Research Program

The Phase II High-Speed Research Program has three primary technology areas—Propulsion, Airframe, and Systems Integration—all focused toward establishing the technology foundation to support the U.S. transport industry's decision for production of an environmentally acceptable, economically viable supersonic transport aircraft. The general approach is to expand on the progress made in the Phase I program, such as the low emission combustor and the high-lift aerodynamic design, and in parallel, manage the Critical Propulsion Components (CPC), Enabling Propulsion Materials (EPM), Aerodynamic Performance, Airframe Materials and Structures, and Flight Deck elements of the Phase II program. NASA works with Boeing on airframe technologies, Pratt & Whitney and General Electric on propulsion technologies, and Honeywell on the flight deck.

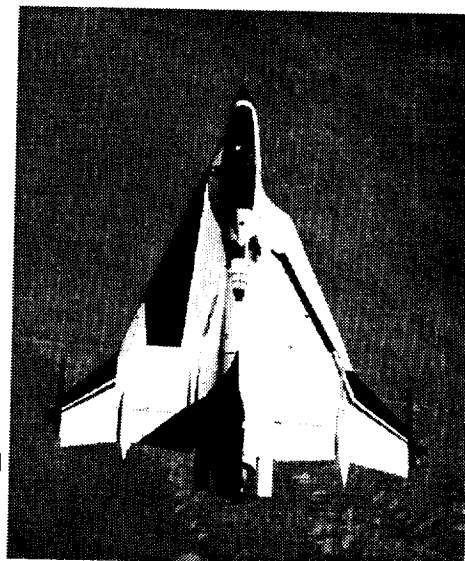
The primary noise source for takeoff is from the high-speed, hot engine jet exhaust. The turbojet cycle used in the Concorde has excellent supersonic performance but also has high noise, as opposed to high-bypass-ratio turbofans used by subsonic commercial transports designed for subsonic performance and low noise. A compromise cycle called the mixed-flow turbofan has been selected for the HSR technology development. Although this cycle does have a moderate bypass ratio to slow the jet, a mixer-ejector nozzle must also be included to further reduce noise. This nozzle entrains outside freestream air which is mixed with the core jet exhaust resulting in a slower and cooler exhaust jet that reduces noise by 16 decibels out of approximately 120. During supersonic cruise, external air entrainment is not required, thus eliminating the drag and reduced efficiency associated with the noise suppression mode. Small-scale nozzle wind-tunnel tests have demonstrated the noise attenuation



**Figure 24. Mixed-Flow Turbofan Engine Concept.**



- Supersonic laminar flow was achieved at Mach 2.0 with integrated suction levels close to design levels.
- Data analyses tools were successfully applied to calculate suction distributions and boundary-layer stability characteristics from flight data.
- Analyses to date are consistent with design tool predictions.
- SLFC has the potential to improve the aerodynamic performance of the High Speed Civil Transport by 10%, thus reducing the gross weight by 6%.



**Figure 25. ER-2 (top) and F-16XL supersonic laminar flow flight experiment (bottom).**

while meeting performance requirements. To keep nozzle weight at a minimum, advanced materials and manufacturing processes are being developed including thin wall castings of superalloys for the mixer, gamma titanium aluminides for the flap, ceramic matrix composite acoustic tiles for reducing mixing noise, and thermal blankets to protect the nozzle backside materials.

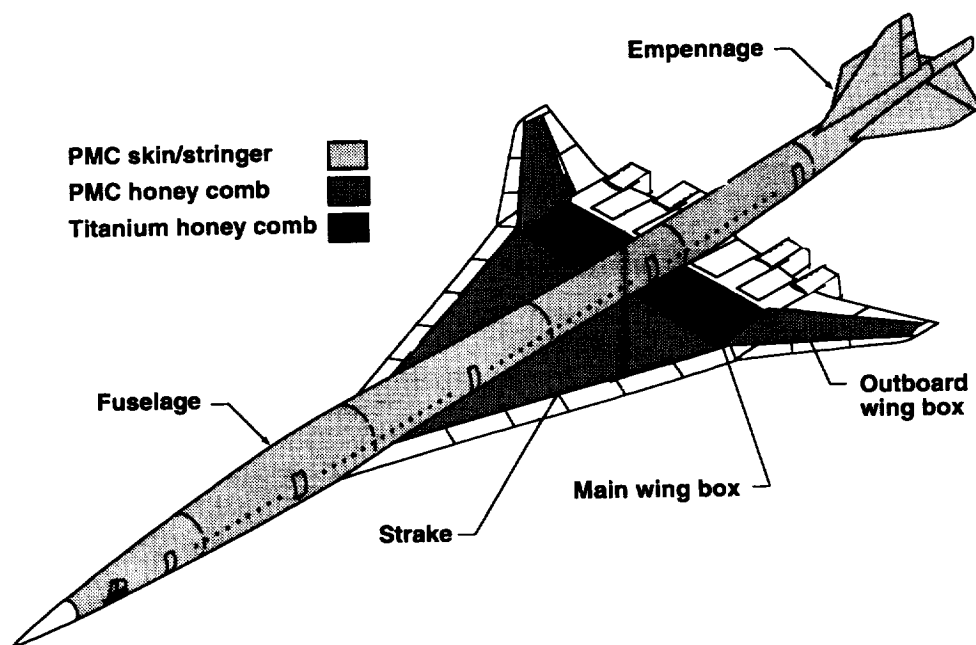
High-altitude atmospheric radiation is of galactic or solar origin. Galactic cosmic rays are complex, heavy ions of high energy and penetrate deep into the Earth's atmosphere. Solar cosmic rays are generated by solar flares and are less penetrating, but may be very intense over short periods of time. Secondary neutrons are generated in the atmosphere by both sources and can be biologically damaging depending on the dosage.

At supersonic cruise altitudes, the radiation dose is double that of a subsonic airliner flying at 40,000 ft. But because the trip time is halved, the total trip dosage is approximately the same. The only concern is with the exposure levels of the flight crew, especially pregnant members. Radiation exposure can be man-

aged by crew rotation scheduling based on validated radiation prediction methods and measurement.

Currently, there are substantial uncertainties in the knowledge of the radiation in the upper atmosphere and changes in latitude where radiation is higher at the poles because of the magnetic field of the Earth. The National Council on Radiation Protection and Measurements has identified the critical scientific questions that must be answered to provide a sound scientific basis for atmospheric radiation prediction. An ER-2 has been equipped with a suite of instruments provided by an international team for characterizing the radiation environment. The solar minimum environment (maximum radiation) is currently being measured and future flights will be able to map the solar cycle effects.

Aerodynamic research is providing potential concepts and validated analytical design and optimization methods for airplane configuration development and ride quality enhancement. These design methods will be used for drag reduction and for predicting aeroelastic stability and control characteristics which are necessary for the design of safe, controllable, and economically viable HSCT configurations.



**Figure 26. High speed research baseline structural concepts.**

A method to achieve high-speed drag reduction is laminar flow control. Already, significant drag reductions have been demonstrated with supersonic laminar flow control (SLFC) at Mach 2.0 on an F16-XL at NASA Dryden Flight Research Center. Supersonic laminar flow was achieved with a left-wing glove with 10 million laser-cut holes through which a suction system controls the laminar boundary layer to prevent turbulence. Data analyses tools were successfully applied to calculate suction distributions and boundary-layer stability characteristics from flight data. Supersonic laminar flow control has the potential to improve the aerodynamic performance of the HSCT by 10 percent, but has been dropped from the program because further technology demonstrations of the subsystems, wing skin with holes through high-temperature composites, and a longer chord demonstration of laminar flow are required to reduce risk for application to a commercial airplane.

The fraction of the operating empty weight for airframe structure is much smaller for a supersonic transport than for conventional subsonic commercial vehicles. This requires the use of innovative structural concepts and advanced materials to satisfy this stringent weight requirement. The operating environment is also more severe because of the high temperatures associated with the aerodynamic friction heating caused by supersonic cruise speeds.

To reduce weight of the fuselage, outboard wing, strake and empennage, and polyimide carbon fibers

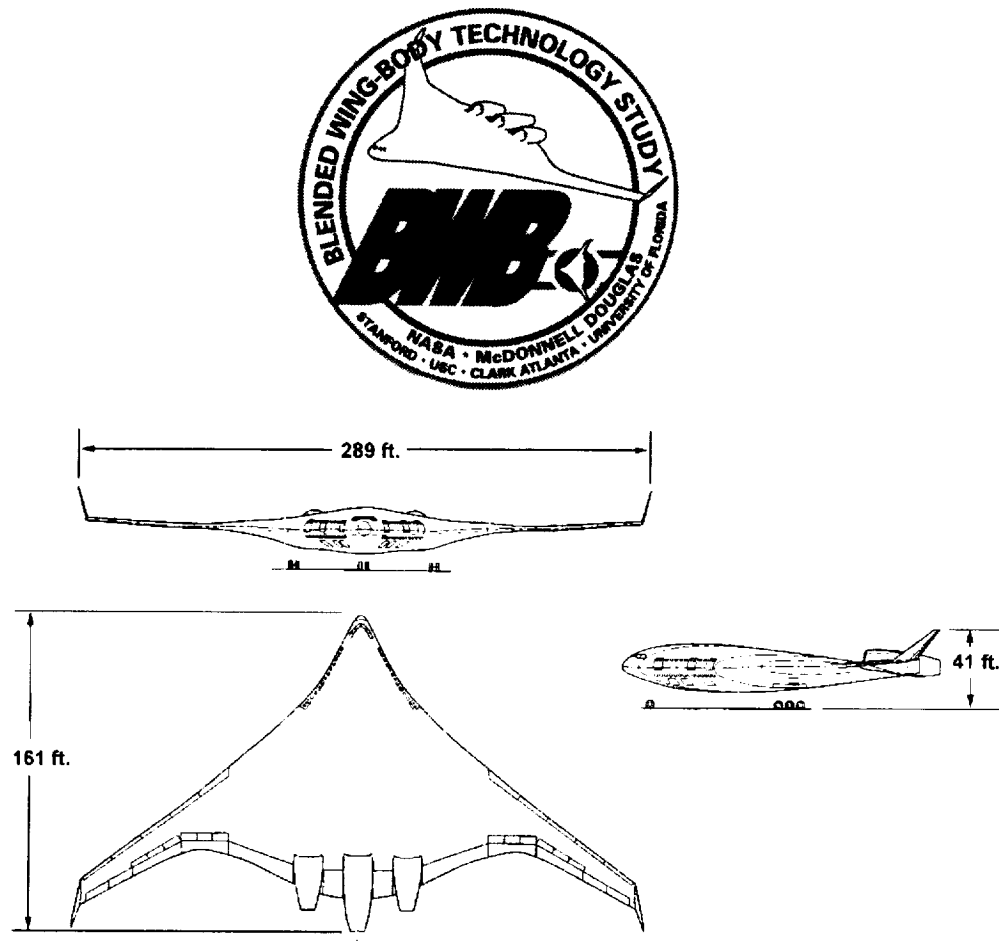
matrix composites (PMC) are being developed. A NASA patented polyimide resin called PETI-5 when combined with a vendor produced IM7 fiber has demonstrated mechanical properties greater than bismaleimides at 350°F. Currently only a "wet" prepreg is available for laboratory hand layup structures that require long cure times at high pressure in autoclaves to remove the volatiles. Dry prepreg is being developed that potentially has more affordable manufacturing processes such as resin film infusion and in situ robotic layup. Durability isothermal tests after 35,000 hours of a PMC show no degradation, and PETI-5 has over 5,000 hours. Thermal mechanical fatigue tests that simulate the flight mechanical and thermal loads have been started. Because it takes seven years to complete one lifetime, accelerated testing and analytical techniques are being developed for screening enhanced PMC resins.

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### **Blended-Wing-Body Technology Study**

The Advanced Concepts for Aeronautics Program was established by NASA to provide an opportunity for NASA, U.S. industry and universities to develop high technical risk/high potential benefit aeronautical concepts. A part of the Advanced Concepts for Aeronautics Program, the Blended-Wing-Body (BWB) Technology Study is a 3-year technology development



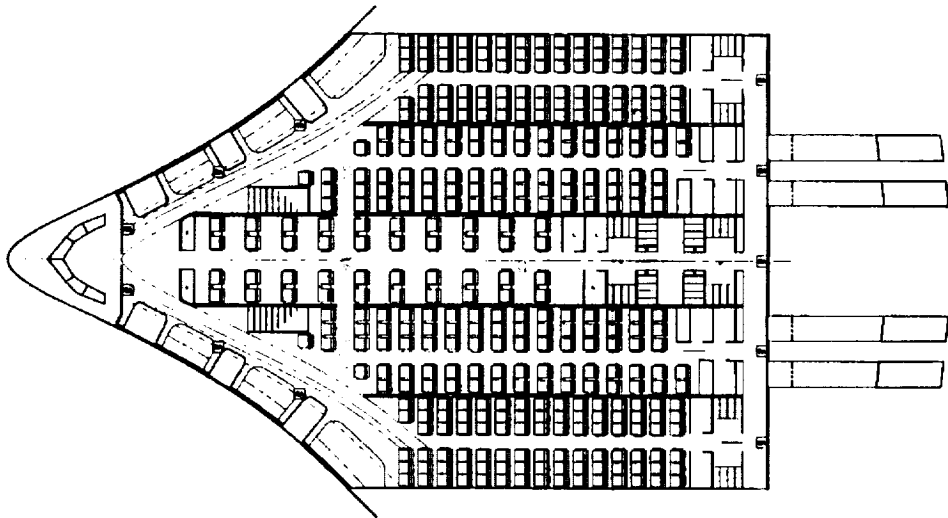


**Figure 27. Blended-Wing-Body Team Logo and 3-View.**

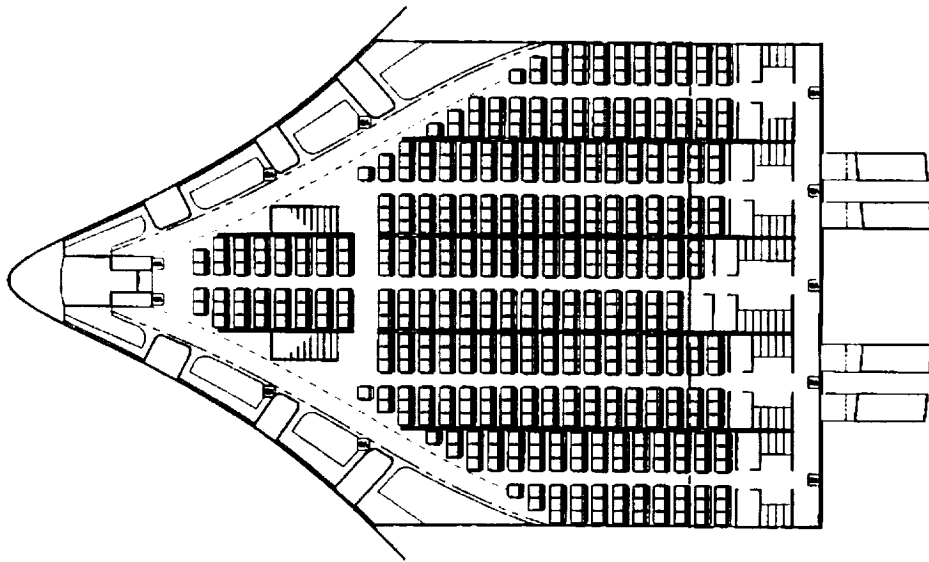
program to assess the technical and commercial viability of an advanced, unconventional aircraft configuration. The research team consists of McDonnell Douglas in Long Beach (now Boeing Phantom Works), Stanford University, University of Southern California, University of Florida, Clark-Atlanta University, and NASA Lewis and NASA Langley Research Centers. This unique transport concept simultaneously addresses the safety, emissions, noise, capacity, and cost technology goals of the Global Civil Aviation pillar, and also the tools/x-plane/design cycle goal of the Revolutionary Technology Leaps pillar of the NASA Three Pillars for Success platform.

Worldwide air travel passenger demand, measured in revenue passenger miles, is expected to triple within the next 15 to 20 years. Historically, the number of aircraft, aircraft passenger capacity, and the number of aircraft operations have all increased to accommodate the growing number of passengers; however, airports

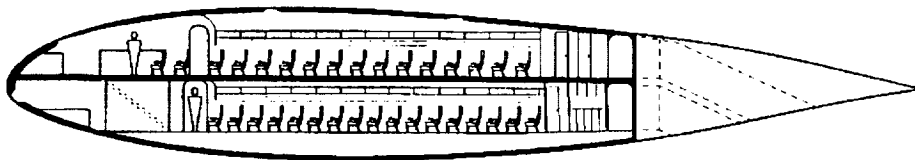
and the airspace system are becoming saturated. Besides the beneficial effect on air traffic system congestion, larger aircraft have also been the airlines' main means of reducing operating costs, since carrying more passengers on fewer planes is a proven way of reducing costs. Very Large Subsonic Transport (VLST) concepts like the BWB are simply defined as intercontinental-range aircraft that carry more than 600 passengers. Due to their size, VLST aircraft inherently reduce the number of required aircraft operations and the cost per passenger mile. The Boeing 747, which carries over 400 passengers in some configurations, is the closest thing to a VLST that currently exists. NASA is interested in VLST aircraft because of their potential effect on the Three Pillars technology goals, especially with respect to reduced cost and increased capacity. In addition to passenger applications, civil and military cargo aircraft operators are very interested in the economy of scale that is inherent in VLST concepts.



**Figure 28. Upper Passenger Deck.**



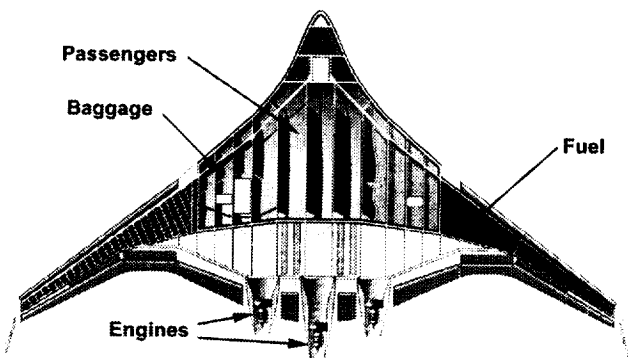
**Figure 29. Lower Passenger Deck.**



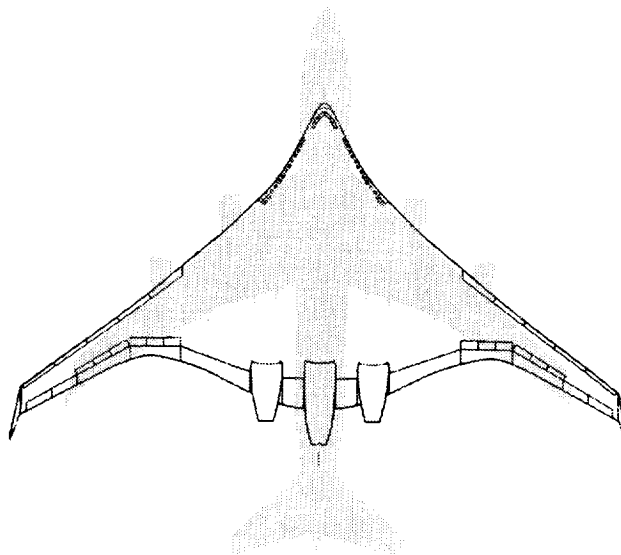
**Figure 30. Passenger Deck Cross Section.**

The BWB is a VLST concept with a design payload of 800 passengers, 560-mph (Mach 0.85) cruise speed and 7000 nautical-mile range. To minimize the required aircraft surface area per passenger, the BWB synergistically combines a rigid, wide airfoil-shaped fuselage with high aspect ratio wings and semi-buried engines. The design has two full passenger decks with a typical long-range, 3-class seating arrangement within the thick centerbody. Baggage and cargo is carried between the passengers in the centerbody and fuel in the outboard portion of the wing. The estimated takeoff gross weight of the aircraft is 823,000 pounds (about 3/4 composites, 1/4 metal), and it uses three 60,000-pound class turbofan engines. The engines are located on top of the wing, aft of the passenger compartment. This works very well for balance, but also has several beneficial side effects. The turbines and compressors are completely clear of the main structural elements, pressurized compartments, and fuel, which can improve safety. The large fans on the high bypass-ratio engines are shielded from the ground by the centerbody, which will improve the noise characteristics for people on the ground. For comparison, note that the BWB has a 60-foot wider wingspan and a 70-foot shorter length than the Boeing 747-400, which carries about half as many passengers, weighs about 6-percent more, and uses four 60,000-pound class engines.

Because the BWB configuration is such an extremely integrated design, a multidisciplinary optimization (MDO) process has been utilized extensively to address technical issues in configuration design, aerodynamics, structures, propulsion, and flight mechanics. NASA and industry systems analyses of this configuration indicate significant cost and performance benefits over projected conventional concepts using similar technologies: 21-percent increase in lift-to-drag



**Figure 31. Blended-Wing-Body Structure and Major Components.**



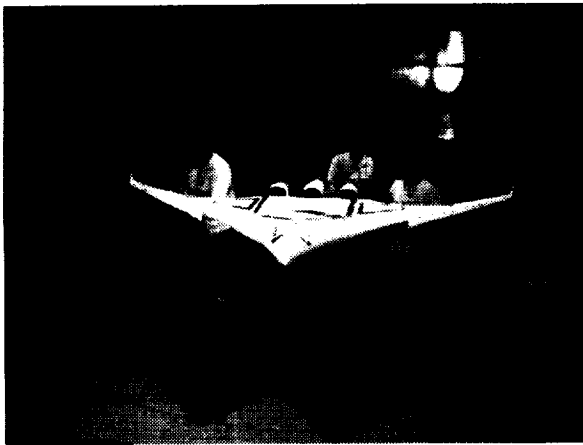
**Figure 32. Blended-Wing-Body versus 747-400.**

ratio, 17-percent decrease in fuel consumption, 6-percent decrease in maximum takeoff weight, as well as a 12-percent decrease in operating costs. Note that the potential benefits are much greater if compared to today's aircraft (e.g., per passenger mile, fuel consumption is 1/3 that of current jumbo jets). Many challenges must be addressed before these outstanding benefits can be achieved. Major challenges include development of structurally efficient passenger cabins that carry pressure loads in bending, thick transonic airfoil definition (including the effects of cabin deformation), optimized propulsion/airframe integration, aircraft systems integration (e.g., power, controls, deicing), passenger emergency egress, ride quality, and interfacing with the existing infrastructure (e.g., taxiways, jetways, gates). These challenges are not unique to the BWB but apply in varying degrees to virtually all VLST concepts.

The BWB Technology Study included extensive performance and weights analyses at the conceptual design level. Computer models of the aircraft were generated then analyzed, and the process was iterated until all constraints were met. Economic and manufacturing models were of great importance in this study, and the cost reduction goal of the Three Pillars for Success platform became a primary comparison metric for the benefits of the design. Basic structural concepts were examined, particularly for the pressurized passenger cabin, then a global finite element model (FEM) was developed. The FEM was used to



**Figure 33. High-Speed Model.**



**Figure 34. Low-Speed Model.**

determine overall structural load paths, complete basic structural sizing, compute aeroelastic stability derivatives, and check initial centerbody and wing weights. Computational Fluid Dynamics (CFD) models were created and analyzed to determine the maximum transonic cruise speed for the thick airfoil and to examine stability and control derivatives. High-speed wind tunnel tests in the National Transonic Facility demonstrating transonic cruise of thick airfoils (in partnership with the Integrated Wing Design element of the Advanced Subsonic Transport Program) were conducted to provide confidence in the CFD results. Low-speed wind tunnel tests to determine stability derivatives and identify possible handling quality deficiencies were conducted with an 11.5-foot wingspan (4-percent scale)

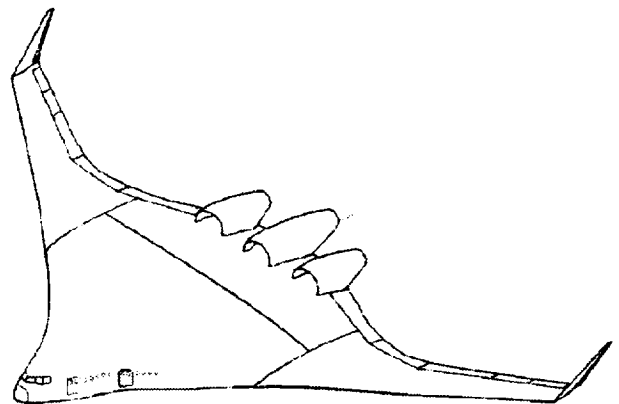
model in the 14 x 22-Foot Subsonic Tunnel. In addition, Stanford University researchers flight-tested an instrumented 17-foot wingspan (6-percent scale) radio-controlled model of the BWB to study flight control options and verify low-speed stability and control derivatives.

Some future research efforts within NASA, industry and academia continue to develop the BWB. The Futuristic Airframe Concepts and Technologies (FACT) program is using the BWB Technology Study as groundwork to investigate in more depth some of the structural, stability and control, and aerodynamic challenges discussed above. Stanford will continue the multi-disciplinary optimization and flight-test research initiated under the technology study. The University of Southern California will refine the engine inlet design using their water tunnel facility. Industry will continue to evaluate the economic viability of the concept.

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**Figure 35. 17-Foot Flying Model.**



**Figure 36. Blended-Wing-Body Isometric View.**

## Highways in the Sky

NASA has launched a national effort to support the revitalization and competitiveness of the U.S. general aviation (GA) industry. Under the General Aviation Element of the Advanced Subsonic Technology Program Office, the Advanced General Aviation Transport Experiments (AGATE) Consortium seeks to revitalize U.S. general aviation through the rapid development and fielding of new technologies for a small aircraft transportation system. The system provides a point-to-point, on demand, personal air transportation system that is competitive in cost and safety with alternative travel modes. A safe and affordable small aircraft transportation system infrastructure brings the mainstream of business, commerce, trade, tourism, health care, and education opportunities to the Nation's small communities and rural areas. These areas will benefit from the "highways in the sky" as America benefited from the Interstate Highway System. The general aviation industry will benefit through new jobs in manufacturing, operations, training, sales and service, and related air transportation infrastructure.

Starting with NASA Aeronautics seed funding of \$63 million in 1994, NASA, the FAA, the Small Business Innovation Research Program (SBIR), industry, and universities have pooled nearly \$200 million in combined resources among 39 cost-sharing partners. About 30 other partners have joined the effort as non-cost-sharing, supporting members of the AGATE Consortium, for a total of nearly 70 members.

Early AGATE success stories illustrate the power and benefits of joint government-industry R&D collaboration in strategic alliances. Members of AGATE have very rapidly converged on several standards for various technologies and capabilities. In some of these cases, the general aviation industry has struggled for years to accomplish such industry consensus.

The 1996 Olympic Summer Games in Atlanta provided the backdrop for one of these early success stories. In partnership with the Atlanta Vertical Flight Association, Helicopter Association International, Georgia Tech Research Institute, NASA, and eight AGATE member companies developed the world's first free-flight system for use in Atlanta. Working together

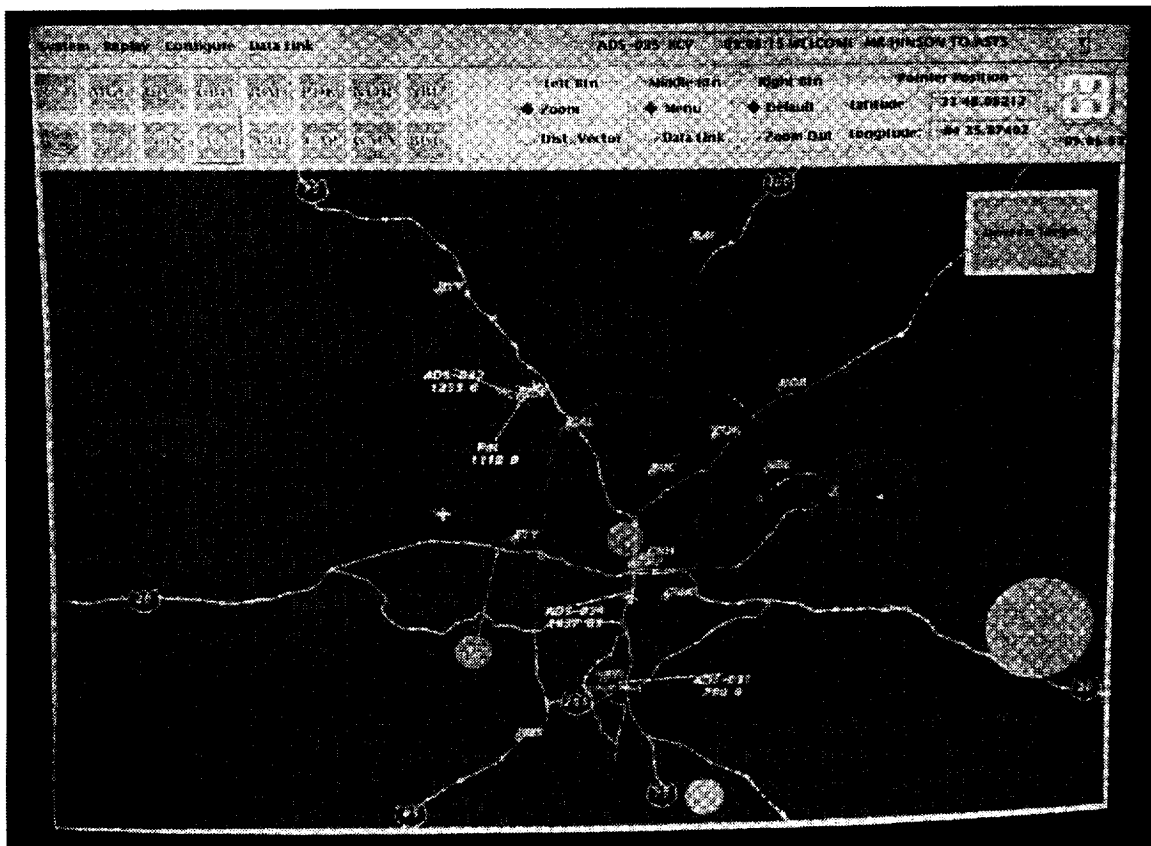


Figure 37. "Highways in the Sky" System.

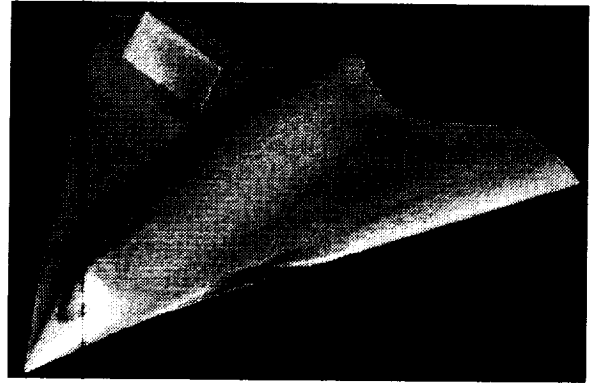
under the FAA-led Operation HeliStar, the team created a "highways in the sky" capability. This "highway in the sky" system was installed in 50 aircraft and an additional 60 units were produced at the request of the White House to meet requirements for special security forces. The system provided public and private sector aircraft with free-flight access to the restricted airspace during the Olympics. Satellite-based navigation, digital radio datalink communications, and advanced flat panel displays technologies were integrated to produce a communication/navigation/surveillance system providing pilots and controllers with graphical traffic, weather, moving maps, and Olympic venue status information in real time (see figure 37). The effort was accomplished in less than 7 months with a joint government-industry investment of less than \$2 million. The commercial cargo operators using the system in Atlanta estimate that over \$20 million was generated in revenues that would have been lost without the Heli-STAR technologies. The Atlanta Olympics project set the stage and accelerated the pace for modernization of the nation's emerging air traffic management free-flight system.

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### Rapid CFD for Preliminary Design of High-Performance Aircraft

NASA has initiated an effort to reduce the design cycle time for high-performance aircraft by 50% to save both time and money. One important and time consuming part of the aircraft design process is the prediction of the aerodynamic forces and moments for a particular aircraft configuration. Traditionally, aerodynamic data have been obtained by testing models in wind tunnels and by utilizing several different types of computer methods, each with different levels of accuracy, computer run times, and individual skill.

The overall aircraft design process is initiated by a team of engineers who develop a number of promising aircraft concepts to meet a specific mission, then compute the aerodynamic forces and moments on each aircraft concept with simple linearized theory computer methods. The linear methods are extremely fast in terms of analysis turnaround time, but they lack in accuracy, particularly for flows that exhibit nonlinear characteristics. Although the linear theory predictions are not as accurate as designers would like, they are the only numerical predictions that can be obtained fast enough for a large number of promising concepts to be quickly evaluated and reduced to a few very



**Figure 38. CFD with adaptive gridding.**

good concepts. This initial phase of the aircraft design process is referred to as the conceptual design phase.

The next phase of the aircraft design process is the preliminary design phase where a reduced number of aircraft concepts are analyzed in much greater detail. This phase initiates a number of expensive wind tunnel models and analyses by sophisticated computer methods that engineers collectively refer to as Computational Fluid Dynamics or CFD methods. Information from both the wind tunnel and CFD are used in a complementary manner to create a thorough understanding of the aerodynamic characteristics of a single aircraft configuration.

One approach to achieving NASA's goal of reducing aircraft design cycle time by 50% is increased reliance upon CFD methods. The barriers to this approach are generally the computer run time and the high skill levels and hours of labor required of the engineers who use CFD methods. However, extremely capable computers referred to as workstations are now widely available in the aerospace industry, so that the primary barrier is now becoming an engineer's skill level and labor hours. This problem is being addressed through a relatively new computer software technology based on adaptive gridding.

CFD methods require a grid, which is a network of connected points on the surface and in the space surrounding the aircraft geometry, to compute the forces acting on the aircraft surfaces. The development of this grid is generally the largest component of labor hours in the process of obtaining a CFD solution, and also requires a high skill level. Research is underway now to fully automate grid generation for one class of CFD methods. The attached figure 38 displays the results from a CFD method with adaptive gridding for an advanced high-performance aircraft concept at high angle of attack. This solution, including grid generation

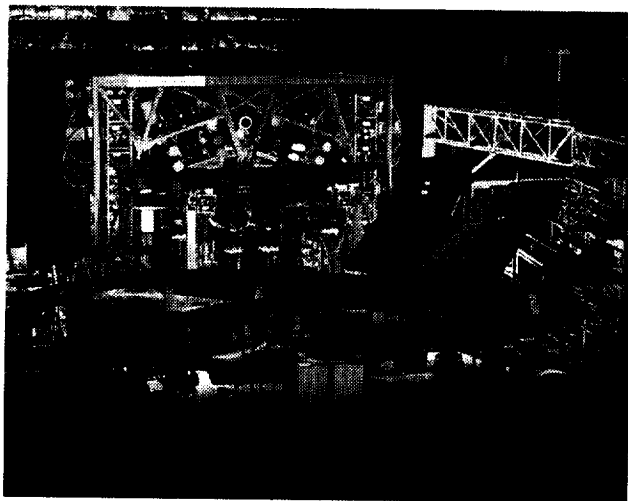
and flow solution based on the Euler formulation, required about 1 day to achieve. This is a notable achievement since a week or more was required to accomplish the same result only a few years ago. Future work will improve adaptive grid technology so that a number of Euler CFD solutions can be obtained in a single day, and then this technology will be applied to the more accurate CFD methods that are based on the Navier-Stokes formulation.

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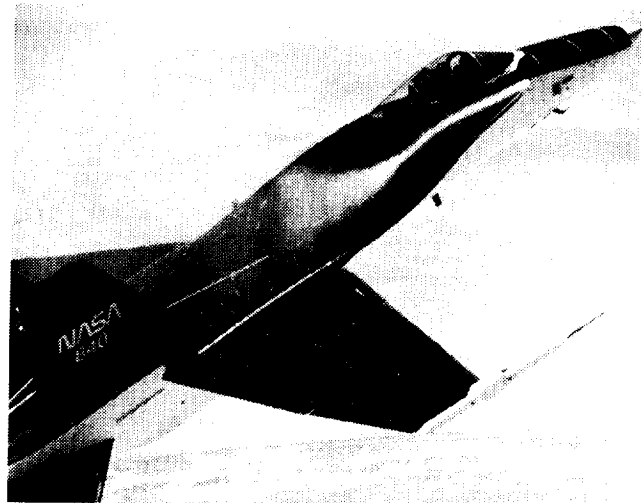
### Buffet Load Alleviation System for High-Performance Aircraft

High-performance aircraft are required to fly at high angle of attack for air combat maneuvering. At high angle of attack conditions, the air flow over the top surface of the aircraft separates from the aircraft to form powerful vortices that are extremely turbulent. The turbulence of the vortices on vertical tails creates a rapid and severe shaking motion that is called buffeting, which can ultimately cause structural failure after several thousand flight hours. The effects of buffeting are sufficiently severe that multi-million dollar aircraft are permanently grounded after reaching this flight time limit unless extensive and costly repairs are completed.

The United States, Canada, and Australia have joined together to develop a system that can solve the vertical tail buffeting problem for the F/A-18 aircraft. The F/A-18 is manufactured by the McDonnell-Douglas Corporation (now Boeing) and is operated by



**Figure 39. F/A-18 Buffet Loads Test Facility.**



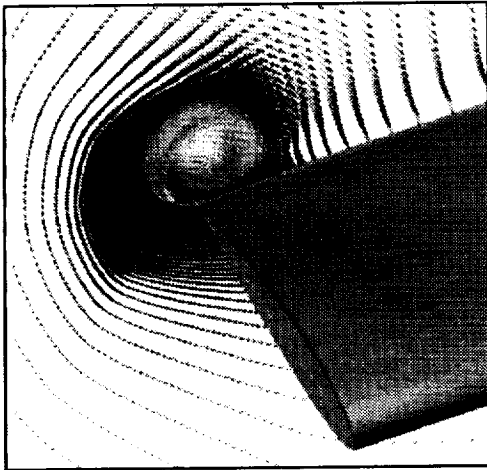
**Figure 40. Flow visualization test.**

the armed forces of these three countries. NASA has participated in this multi-national effort by utilizing the Transonic Dynamics Tunnel at Langley Research Center, and the Center's resident expertise in buffeting alleviation to develop an active buffet load alleviation system for the F/A-18 vertical tails. The term active means that the buffet load alleviation system detects the occurrence of buffeting through a series of sensors installed inside the vertical tail, then commands piezoelectric actuators to respond in a predetermined manner that significantly reduces the structural response of the vertical tail to buffeting. When successfully done, the vertical tail has a significantly greater fatigue life and therefore the lifetime of the aircraft is extended. Preliminary testing of the active vertical tail buffet load alleviation system on an actual F/A-18 aircraft has been completed at the Aeronautics and Maritime Research Laboratory (AMRL) in Melbourne, Australia (see figure 39). This test program demonstrated that the vertical tail buffet load alleviation system operates properly for selected flight conditions. More extensive testing will be conducted to test the system for a wider range of flight conditions.

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### Vortex Breakdown Prediction

The Airframe Systems Concept to Test (ASCOT) Program is a base research and technology program under the Airframe Systems Program Office that focuses primarily on the pillar goal of providing next-generation design tools to increase design confidence, and to cut development time for aircraft in half. Within the area of aircraft design, a consideration for new



**Figure 41. Validation computations accurately predict vortex breakdown location.**

designs is the generation of trailing vortices (invisible, thin, tornado-like cones) off aircraft wing tips. During heavy traffic around airports, these vortices are potentially hazardous because trailing vortices can persist for miles following an aircraft until vortex breakdown occurs (the sudden instability and disappearance of organized vortical flow). These wing tip vortices and their breakdown are difficult to predict and currently rely on empirically-based estimations. In an effort to put more science into the prediction of vortex breakdown, a study was conducted under a NASA-sponsored university grant by Dr. T. Sarpkaya of the Naval Postgraduate School to look into the critical aspects of calculations for vortex flows and vortex breakdown. More accurate, reliable computational methods for vortex breakdown prediction would provide the airframe manufacturers with a tool to design transport vehicles more confidently and efficiently. The overall benefit would be savings in development cost and time while expanding design space options for new, improved configurations.

In this pioneering study of the fundamental vortex breakdown mechanisms at large-scale conditions, detailed building-block experiments were conducted in controlled laboratory conditions corresponding to the points of vortex breakdown and were used as benchmarks for computational accuracy. Computational simulations of these experiments were made for a range of turbulence models. Turbulence models are mathematical representations of the small-scale fluctuations in the fluid, such as occur when a smoke plume from a smokestack undergoes rapid mixing after a run of smooth (or laminar) flow. Turbulence modeling is one

of the weak links in the current capability to predict accurately the vortex hazard from aircraft. Of the models investigated, the class of models known as Reynolds-stress turbulence models gave much more accurate calculations than any of the other methods, in this case yielding significantly better prediction of the breakdown location. A sample of the vortical flow-field computations is shown in the accompanying figure. These encouraging results have spurred interests from the Boeing Commercial Aircraft Group because of the fundamental information now available on the detailed characteristics of turbulent vortex breakdown flows and because the potential exists to improve prediction methods for large-scale aircraft wake hazard effects. Further technical interchange is ongoing between NASA and Boeing on the mechanics of vortex breakdown.

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### **Airborne Observations of Aircraft Aerosol Emissions**

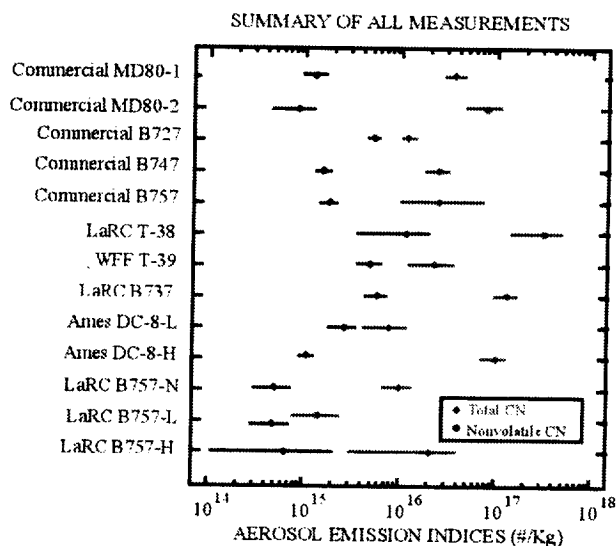
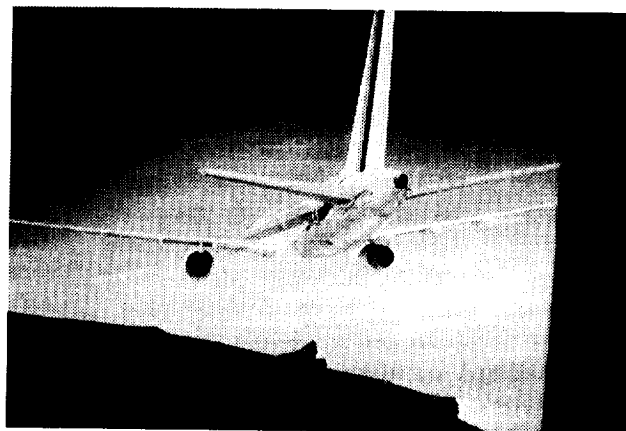
Although aircraft account for only a small fraction of the total global consumption of fossil fuels, the majority of their emissions are injected directly into the upper troposphere/lower stratosphere where residence times are long and background concentrations are low. Consequently these emissions, which include CO<sub>2</sub>, H<sub>2</sub>O, reactive trace gas species and aerosols, may influence climate by perturbing ozone chemistry or atmospheric radiative properties via direct absorption/reflection of light or by modifying cirrus cloud amount or properties. However, the exact nature and quantity of aircraft emissions released at cruise altitudes and the extent to which they impact atmospheric processes is poorly defined and understood. Thus, NASA has instituted the Atmospheric Effects of Aviation Program (AEAP) both to assess the climatic implications of the current subsonic fleet and to develop models for evaluating the environmental impact of future aircraft technologies and emission scenarios.

Langley recently participated in two AEAP-sponsored airborne field missions focused upon gaining a better understanding of aircraft emissions and their atmospheric effects: the January-February, 1996 SNIF-II (Subsonic Assessment: Near-field Interactions Flight) Experiment based at Wallops Island, Virginia, and the April-May SUCCESS (Subsonic Assessment: Cloud and Contrail Effects Special Study) mission conducted from Salina, Kansas. During these experiments, a small twin-engine jetliner, instrumented with a suite of aerosol, trace gas, and meteorological sensors, was used to probe wake/plume physical/



chemical characteristics at aircraft separation distances of 0.1 to 20 km and at altitudes ranging from the surface to 13 km. In particular, in-plume concentrations of volatile (less than 290°C) and nonvolatile particles were examined both as a function of aircraft operating parameters and environmental conditions. Observations were recorded during highly coordinated tandem flights as well as transits of east coast and mid western jetways. In total, over 1000 plume crossings were accomplished behind a variety of aircraft, including B-727, B-737, B-747, B-757, DC-8, T-38, T-39, and MD-80 jet-liners. As shown in Figure 42, these aircraft were observed to produce  $0.5 - 10 \times 10^{15}$  nonvolatile (presumably soot) particles  $\text{Kg}^{-1}$  of fuel burned. These were typically 20 to 100 nm (nanometers,  $10^{-9}$  meters) in diameter and their numbers varied as a function of aircraft type and age along with engine operating parameters but not significantly with atmospheric conditions or plume age. Highest concentrations were found in the wakes of aircraft with older engine technologies (i.e., the LaRC B737 and T-42) and when aircraft were operating in low power conditions. In addition to the soot emissions, much larger numbers of a volatile aerosol component were observed. These particles were, except under contrail producing conditions, typically under 20 nm in diameter and their numbers varied as a function of atmospheric conditions, plume age, and fuel sulfur content. Their emission indices ranged from 0.1 to  $40 \times 10^{16}$   $\text{Kg}^{-1}$  fuel burned (Figure 42). These unique observations suggest that a surprisingly high fraction of fuel sulfur species are converted directly to sulfuric acid either inside aircraft engines or within 0.2 seconds of release to the atmosphere. Though the observed levels of soot emissions are estimated to have only a minor impact on atmospheric aerosol loadings, a future fleet producing such high concentrations of sulfate aerosols could present a significant perturbation to cloud formation and heterogeneous chemical processes in the upper troposphere/lower stratosphere.

Figure 42 shows a summary of aircraft aerosol emission indices recorded in < 2 minute old exhaust plumes of commercial airliners and NASA research aircraft operating at altitudes above 7 km. The total condensation nuclei (CN) concentrations, which include both soot and sulfate particles, were determined using an instrument sensitive to particles > 4 nm in diameter whereas the nonvolatile, primarily soot, fraction was found by heating air samples to 200 to 300°C, then counting the remaining particles with



**Figure 42. Photograph of the NASA Ames DC-8 aircraft taken at 10 km altitude from aboard the Wallops T-39 during near-field sampling of the lead aircraft's right inboard engine exhaust plume.**

an instrument sensitive to aerosols > 20 nm in diameter. The commercial aircraft were observed during routine flight operations at separation distances of > 8 km. Data were obtained in the wake of the NASA aircraft under a wide range of separations, flight conditions, and fuel sulfur concentrations. The suffixes -L, -N, -H attached to the DC-8 and B757 labels indicate low (~70 ppm), nominal (~500 ppm) and high (~700 ppm) fuel sulfur concentrations.

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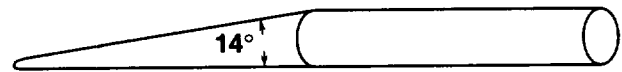
## Measuring Turbulence in High Speed/High Temperature Flows

A device to measure turbulence in high-speed/high temperatures flows equal to or exceeding five times the speed of sound has been developed, fabricated, and tested. This device is a high temperature probe containing a thin-film micro-sensor capable of withstanding high temperatures of up to 1,300 degrees Fahrenheit. These hot-film probes have displayed excellent durability and moderate frequency response characteristics in the initial high-speed and high temperature flow tests conducted in LaRC wind tunnels. This new type measurement device could prove to be a next generation design tool for advanced experimental high speed aircraft. Flow conditions in high speed/high temperature test facilities have to be recorded, studied, and modeled to fully understand the data derived from these test facilities, therefore increasing design confidence and reducing the design cycle time for new aircraft.

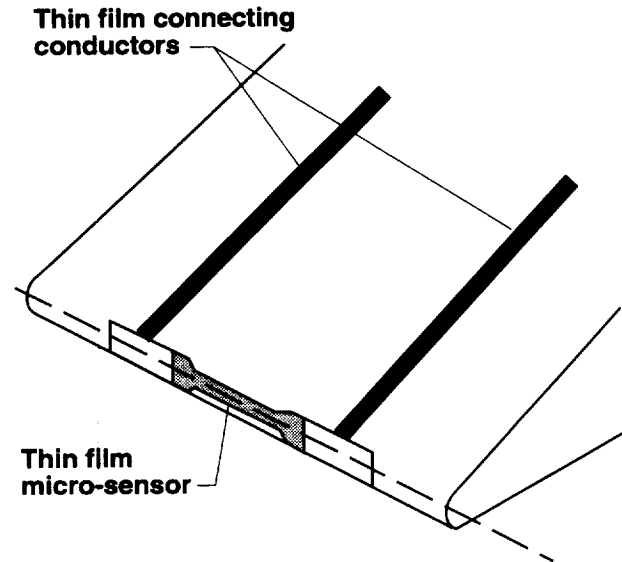
The probe is constructed by shaping a piece of aluminum oxide into a wedge (figure 43). The substrate is wedge shaped so as to minimize flow disturbances created by the probe itself. An easily etched metal such as copper is deposited on the end of the wedge. A reverse image of the sensor shape is formed in the copper by photographic techniques and wet chemical etching to form a lift-off mast. A very thin metal film capable of withstanding very high temperatures is deposited on to the probe surface in the areas not protected by the mast. (The metal used in this case was Iridium.) The copper mast and excess Iridium are removed by wet chemical etching resulting in a mast defined Iridium metal sensor (figure 44). Previously deposited metal conductors on the edges of the aluminum oxide substrate are then connected to gold or platinum conductor wires for transition to coaxial cable (figure 45).

Turbulence measurements in high-speed flows have historically been obtained by hot-wire anemometers (the use of thin-wire conductors to measure air flow based on the cooling effect of the moving air over the sensor wire). However, high stagnation temperatures, high dynamic pressures, and flow contaminants severely limit the life of hot-wire elements in hypersonic flow. Non-intrusive techniques such as laser-Doppler and particle-image velocity measurements also are limited when applied to hypersonic flow. Hot-film probes may prove to be a more practical approach to solving this difficult measurement problem. A patent has been granted for the Micro-Sensor Thin-Film Anemometer.

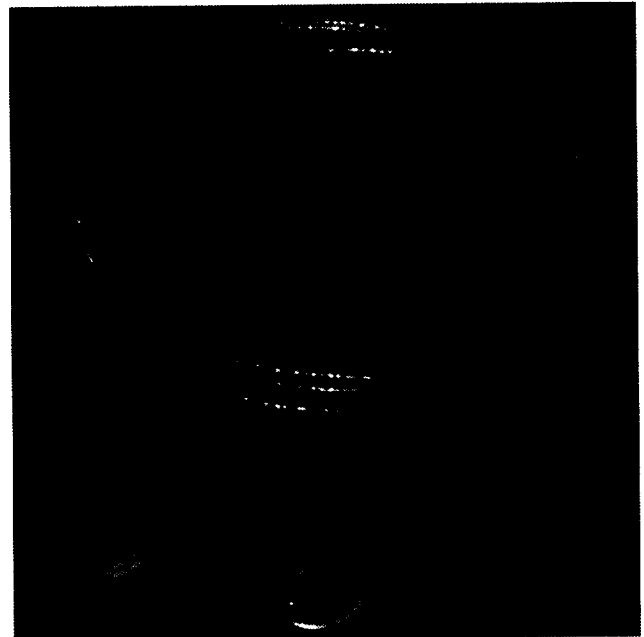
(P. Hopson, 757-864-54741; pson@larc.nasa.gov)



**Figure 43. Half Wedge Probe (Side View).**



**Figure 44. Half Wedge Probe (Front View).**



**Figure 45. Flow Dynamics Probe.**

## Improved Efficiency and Accuracy of Wind Tunnel Balance Analysis

In order to verify and improve aircraft safety and performance, aircraft models are tested in wind tunnels that simulate conditions the aircraft will experience in flight. An important piece of wind tunnel hardware is known as the *strain-gage balance* (Figure 46), which connects the aircraft to the wind tunnel support structure. This high-precision hardware measures the forces, using strain-gages, that act on the aircraft under operating conditions. These forces can then be used to assess the ability of the aircraft to safely function under flight loads.

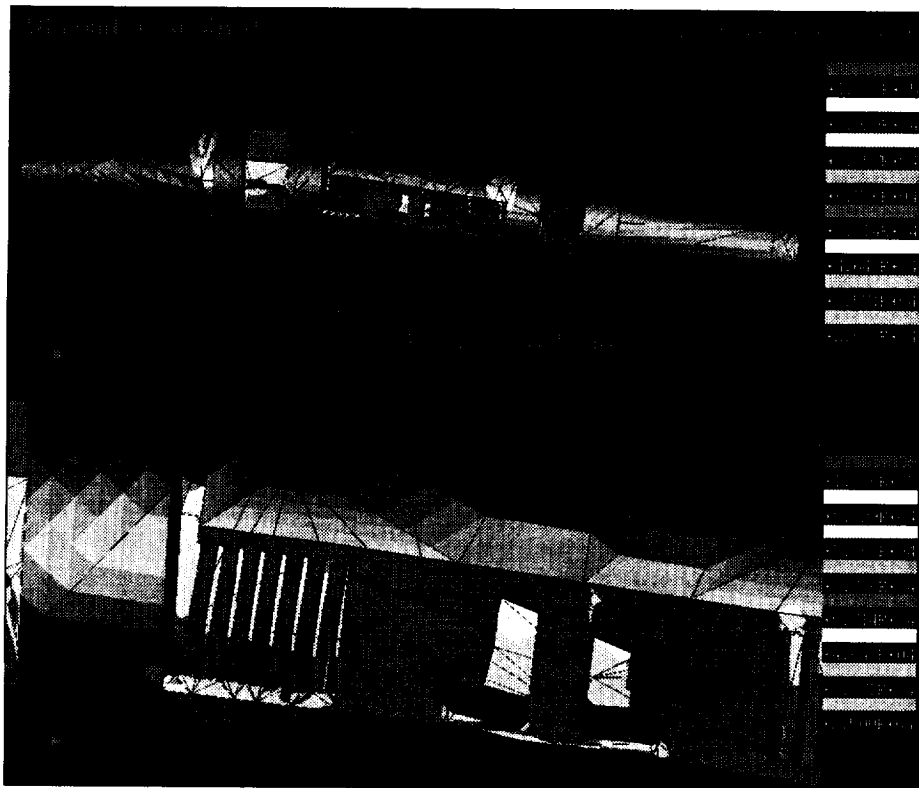
In the past, designing these complex strain-gage balances was time consuming. The intricate cuts in the hardware made it difficult to build accurate computer models, which forced structural analyses to be performed by hand. Now, however, software tools exist to accurately model the balances, which can substantially reduce design time while increasing confidence in the balance's capabilities.

The effectiveness of new software tools to quickly and accurately analyze strain-gage balances for use in wind tunnel testing was demonstrated and a paper



**Figure 46. CAD model of strain-gage balance.**

entitled *Finite Element Analysis of a NASA National Transonic Facility (NTF) Wind Tunnel Balance* was presented at the *International Symposium on Strain-Gage Balances* in October 1996. Computed strains compared very well with measured strains as shown in Table 1.



**Figure 47. Analysis results for NTF wind tunnel balance.**

**Table 1. Summary of Measured and Computed CAD Model Strains for a Natural Transonic Facility Wind Tunnel Balance**

Load Case	Applied Load	Measured Strain (microstrain)	Analysis Strain (microstrain)	% Difference
Axial Force	700 lbs	499.5	489.3	-2.0
Normal Force	5,000 lbs	720.4	719.0	-0.2
Side Force	4,000 lbs	767.0	774.1	0.9
Roll Moment	8,989 in-lbs	433.3	402.3	-7.2
Yaw Moment	6,480 in-lbs	436.1	483.1	10.8
Pitch Moment	13,000 in-lbs	641.6	644.7	0.5

As a result of this work, strain data can now be predicted and used in the design cycle to identify high stress areas (Figure 47) so that design changes can be made to optimize balance performance. In addition to accurate strain prediction, the current software tools can cut the time to assess a balance design from a few weeks to one or two days. This increased efficiency improves NASA's ability to deliver quality services and effectively meet customer commitments.

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### Modern Design of Experiments for Wind Tunnel Testing

The experimental testing technology community at NASA Langley Research Center is developing 21st-Century wind tunnel test techniques that have been shown in early trials to cut wind-on test time and related costs in half while increasing the precision of experimental results. This reduction in test-time translates directly into reduced design cycle time for new aircraft and also significantly cuts aeronautical research costs. Increased precision enables aeronautical researchers to see subtle but potentially important effects in their data that can go undetected with conventional testing methods.

Wind tunnel testing is a very expensive and time-consuming activity. Consider the electrical power required by the huge wind tunnel fan motors that move air at modern aircraft flight speeds. The electricity consumed by wind tunnel testing at Langley Research Center is so great, for example, that it requires daily coordination with electric utility authorities to avoid "brown-outs" in the local community. Langley's 80-megawatt 16-Foot Transonic Tunnel is operated at night, when municipal power consumption is at a minimum. During the day, it must coordinate its operating schedule with other large wind tunnels to limit the total

electrical consumption to levels that the power company can provide. Other Langley tunnels also consume large amounts of electrical power and must also coordinate their operations with each other and the local power utility. The cost of all of this electricity is considerable.

Some tunnels also have to be operated at extremely cold temperatures—more than 250 degrees F below zero typically—to reproduce conditions that a full-scale airplane encounters in flight. Liquid nitrogen is used to cool these "cryogenic" tunnels. It is very expensive to produce and it is consumed at a rate that is measured in tons of nitrogen per day during a typical test. The cooling costs in such tunnels typically dwarf even the electric power costs. It is not uncommon for a single test in a cryogenic tunnel to cost a million dollars or more, for example.

The time it takes to develop and validate a new aircraft design is an even greater consideration than the operating costs of modern wind tunnel testing for an aerospace industry that competes in a global economy for market share with ever-tougher foreign competition. Wind tunnel testing consumes a large portion of the total design cycle. Data acquisition strategies in common use today specify that thousands of data points be recorded in a typical wind tunnel test. Such tests often go on for weeks and months at a time. The time and effort to analyze such large volumes of data are considerable, and also add significantly to the design cycle.

Because the cost in both money and time is so great in wind tunnel testing, Langley Research Center is revisiting the entire wind tunnel testing process. As part of this effort, a new test design strategy is under consideration that does not simply represent an incremental improvement in the data collection methods traditionally used in wind tunnels at Langley and elsewhere, but embodies an entirely new experimental testing philosophy and approach. The method is

focused on certain formal principals of rigorously designed experiments that have been successfully applied to increase the productivity of countless industries in the United States and abroad, most notably in Japan.

We can contrast two approaches to increasing productivity in wind tunnel testing. One approach in common use today is to first allocate a fixed budget of resources to the test (tunnel occupancy time, electricity, liquid nitrogen, labor hours, etc.), and then to design experimental procedures which maximize the volume of data that can be extracted, given this level of resources. The effort is directed toward getting as much “bang for the buck” as possible. Productivity is measured in terms of data points per day or other such metrics. In short, this method focuses on high-volume data collection to maximize the “bang” for a given number of “bucks”.

Practitioners of the new designed-experiments approach also want to increase the “bang for the buck” but focus initially on the “bang” rather than on the “bucks”. The new method seeks to increase productivity not by maximizing data volume for a fixed resource budget, but by clearly identify a quantifiable test objective and then seeking to achieve that objective with the fewest resources possible. In short, this method seeks

to maximize the “bang for the buck” by minimizing the “bucks” needed to achieve a given “bang”.

To illustrate the difference in approaches, consider a researcher who is interested in measuring the drag on some wind tunnel model. By conventional methods the researchers would organize the test to record as many measurements of drag as possible in the time allowed, given a fixed budget of consumables such as electricity and liquid nitrogen.

Were the researchers to use the designed-experiments approach, he or she would focus first on the desired technical outcome of the test rather than on the deployment of fixed assets to maximize data volume. For example, the resources required to adequately define the drag characteristics of the model depend on such factors as the noise levels in the tunnel and the degree of precision required in the test results. These and other factors are considered early in the design of the test, and the resource budget is then based on the minimum number of data points required to characterize the drag with the required level of precision.

With this orientation, it has become clear that the volume of data (and thus the test time and cost) to achieve a precisely articulated technical objective can

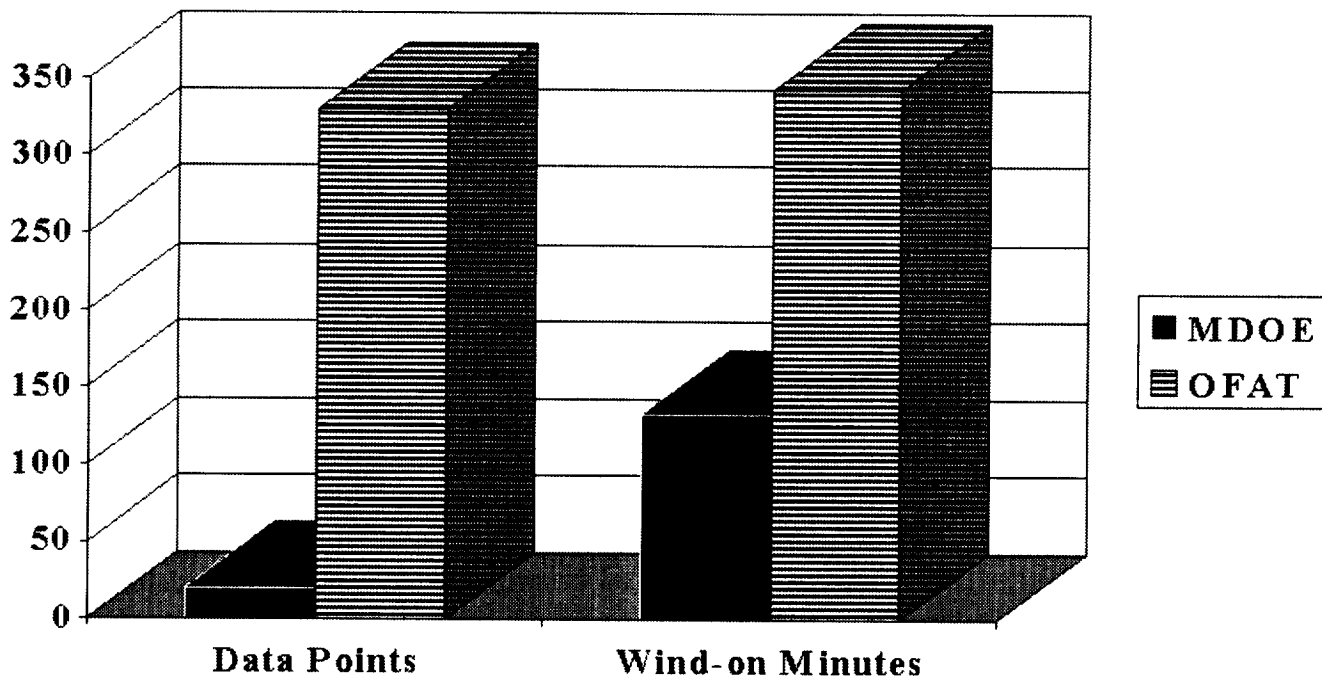


Figure 48. Results of MDOE and OFAT analysis.

be much less than when the scope of the data acquisition activity is resource-driven. The first time the method was applied in a wind tunnel test at Langley Research Center, it resulted in more than a 60% reduction in wind-on minutes compared to a similar test conducted in the classical tradition. The attached figure 48 compares the results of the new method (MDOE) and the conventional method (OFAT) in terms of data points and wind-on minutes. Similar savings have been demonstrated in other tunnels at Langley.

The requirement imposed by this method to clearly define technical objectives early in the design of an experiment has obvious beneficial consequences quite apart from the resource savings. When the researcher has quantified specific objectives early in the design of the experiment and achieved a clear consensus as to the criteria by which successful completion of these objectives will be recognized, it is much more likely that there will be a successful technical result than if the work is done from such common general objectives as, "to study model XYZ", or "to learn as much as possible about phenomenon ABC".

Another benefit of the designed-experiment test strategy is that in order to minimize the volume of data needed to achieve a given result, it imposes a certain underlying mathematical structure on the sequence of data points to be acquired. It turns out that this resource-minimal structure also maximizes the amount of information that each data point carries by reducing the experimental uncertainty associated with each point. The result is higher precision in the technical result and thus a greater sensitivity in the experiment that enables the discovery of subtle effects in the data that can be easily overlooked by conventional means.

The method of formally designed experiments also identifies and corrects for certain systematic facility effects that complicate the comparison of data acquired on the same test model at different times in a given tunnel, or in different tunnels. This further increases the resolution of test data, enabling even more subtle effects to be identified. Also, in contrast with common wind tunnel practices today, the new method explicitly accounts for interactions among test variables that exist when the effect of one variable depends on the level of another. For example, angle of attack may have a different effect on lift at one value of Reynolds number than another. Such interactions can be difficult to quantify with classical test methods, but the designed-experiments approach is explicitly tailored to find significant interactions between all pairs of variables in a test and to quantify their contributions to

the response variables of interest (forces, moments, pressure distributions, etc.)

In summary, NASA Langley Research Center is investigating a new way to do wind tunnel testing based on a modern design of experiments approach that has gained widespread acceptance in many other scientific and industrial applications in the U.S. and abroad. The new method has been demonstrated in early wind tunnel testing to reduce wind-on minutes and the associated cost of consumables by as much as 50% or more. It has also been shown to produce greater precision, smaller error, and additional insights into the highly interactive relationships that are typically investigated in wind tunnel testing.

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### **Using Information Technology to Make Wind Tunnel Data More Useful and Accessible**

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Langley's (LaRC) wind tunnels are critical and unique national aeronautics research facilities. These facilities are not only used by NASA but by major US aerospace companies such as Boeing and Lockheed-Martin and by the US military. LaRC has initiated an extensive reengineering effort to upgrade and improve the wind tunnels. The goal is to reduce cost and improve productivity in the order of 30% over the next few years. Improving the productivity of the wind tunnels is critical to reduce the overall aircraft design cycle. One of the most effective methods to reduce cost and improve productivity is through the proper utilization of modern information technologies.

Conventionally, information about a given wind tunnel test has been created, reduced, and managed at the wind tunnel site. Documentation (test "logbooks") was hand written and kept by test engineers in their offices. If researchers wanted copies of the logbooks off site, copies would be made and mailed. Data files were written to tape and mailed to customers. With the availability of the Internet, e-mail could be used to transfer typed documents. Although e-mail was superior to fax or paper mail, disparate e-mail systems, and no common standard for binary enclosures created difficulties. Data files could be transferred electronically, but special privileges, skills, and effort were required to effect the transfer. A new concern arose that data transmitted over the Internet could end up in the wrong hands, thus compromising security. Protecting the data required additional skills and effort. Recognizing its value, wind tunnel engineers wanted to use modern information technology to move from

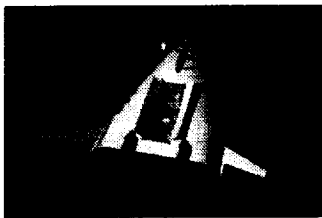
words on paper to a multimedia document including pictures, animations, plots, sounds, etc. The World Wide Web (WWW) looked promising for reading such documents, but tools were not available for easily creating documents and posting them to a WWW server. Also, the WWW did not support encryption acceptable to the Government. The Book Builder software was specifically designed by LaRC's Information Systems and Services Division to solve these problems; it provides user friendly tools for easily creating multimedia documents and posting them to a WWW server as well as supporting encryption (i.e. protection) acceptable to the Government.

The Book Builder client allows the user to transmit a virtually limitless variety of multimedia documents to a Web server, requiring no more skill than that required for ordinary word processing and e-mail. The Book Builder server receives the documents and automatically posts them to a Web server. It also automatically constructs an index page that links the documents

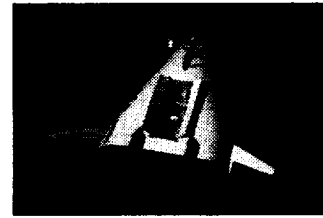
together and presents the collection as an organized Web site. If security is required, the Book Builder handles encryption transparently to the user. Wind tunnel test engineers have found the system so easy to use that they actually create test logbooks as the test is progressing. Engineers can remotely monitor this information almost immediately, thus reducing the number of on-site engineers needed to conduct the test.

The Book Builder has been adopted as an integral part of the LaRC Wind Tunnel Reengineering program. Used in most LaRC tunnel control rooms to produce "Electronic Logbooks," the Book Builder has for the first time made output from the test immediately available to remote researchers. Remote engineers at NASA's Ames Research Center (ARC), Boeing, and Lockheed-Martin depend on the Book Builder for pre-test planning and for feedback to the test site. Over 55 tests have used the Book Builder.

(K. H. Jones, 757-864-6720; k.h.jones@larc.nasa.gov)



## Pillar Three: Access to Space



*Low-cost space access is the key to unleashing the commercial potential of space and greatly expanding space research and exploration. Through integration of aeronautical principles with commercial launch vehicles, a ten-fold reduction in the cost of placing payloads in low-Earth orbit is anticipated within the next decade. An additional ten-fold cost reduction in the decade beyond is the far-term goal for low-cost space access.*

### Hyper-X Program

Revolutionary Technology Leaps and Access to Space are two of the three Pillar Goals for NASA's Aeronautics and Space Transportation Technology Enterprise. The Hyper-X program supports both. The Hyper-X program is opening the speed and altitude boundaries of atmospheric flight and could provide the revolutionary propulsion and other systems required to significantly reduce the cost of access to space. Future aeronautics and space access systems must be able to accomplish their design missions while being affordable for both their initial acquisition and for continuing operations. As a step toward opening the frontiers of atmospheric flight and reducing the cost of access to space, NASA has embarked on the Hyper-X program which will, for the first time ever, fly air-breathing dual-mode scramjet-powered research vehicles at speeds up to 10 times the speed of sound (Mach 10). The first flight, at Mach 7, is planned for January 2000.

1997 was the start-up year for the program. The Langley Research Center is the Lead Center and is also responsible for Hyper-X technology development while the Dryden Flight Research Center manages the Hyper-X flight project. In early 1997, contracts were awarded to a team led by the MicroCraft Corp. (Boeing North American, GASL, and Accurate Automation Corp.) for the final design and fabrication of the Hyper-X Research Vehicle (HXRV) and research vehicle-to-booster adapter (see fig. 49) and to the Orbital Sciences Corp. for the Hyper-X Launch Vehicle (HXLV).

The HXRV and HXLV preliminary design reviews (PDR) have been held. Joint Langley and Dryden teams reviewed and approved the HXRV and HXLV conceptual designs and authorized the start of detail design, long-lead materials and systems procurement, and the start of vehicle, adapter and booster fabrica-

tion. The successful completion of the PDR's leads to the delivery of the Mach 7 engine to Langley for tests in the 8-ft. High Temperature Tunnel in 1998, to the delivery of the Mach 7 HXRV and HXLV to Dryden in 1999 and to the Mach 7 flight in January 2000.

Government deliverables were included in the HXRV contract to expedite the first flight and minimize overall program risk and cost. 100 percent of the deliverables were supplied on time by the Langley and Dryden team. They include HXRV airframe and engine geometry, aerodynamics (including engine performance), forces and loads, limited detailed structural design, and candidate flight control laws. Langley contributions (items being fully utilized by the contractor) include the detailed structural design for the Mach 7 scramjet (supersonic combustion ramjet) engine, control laws for the research vehicle, engine and stage separation sequence, and the aerodynamic and loads database. Over a thousand wind tunnel tests of a dozen models have been conducted at Langley in support of aerodynamic and propulsion design and database development. Extensive computational fluid dynamics (CFD) support for the vehicle final design also has been provided (see fig. 50). This support includes aerodynamic forces, moments and loads, especially for the HXRV contractor's modified stage separation design. Personnel from many Langley organizations are also working to solve challenging Hyper-X design issues such as HXRV wing and tail design.

HXRV and HXLV fabrication started in September 1997. A major series of stage separation wind tunnel tests was conducted at the Air Force Arnold Engineering and Development Center in November and December. The HXLV critical design review was successfully completed in December 1997. Fabrication and testing continued in 1998.

(V. L. Rausch, 757-864-3736; v.l.rausch@larc.nasa.gov)



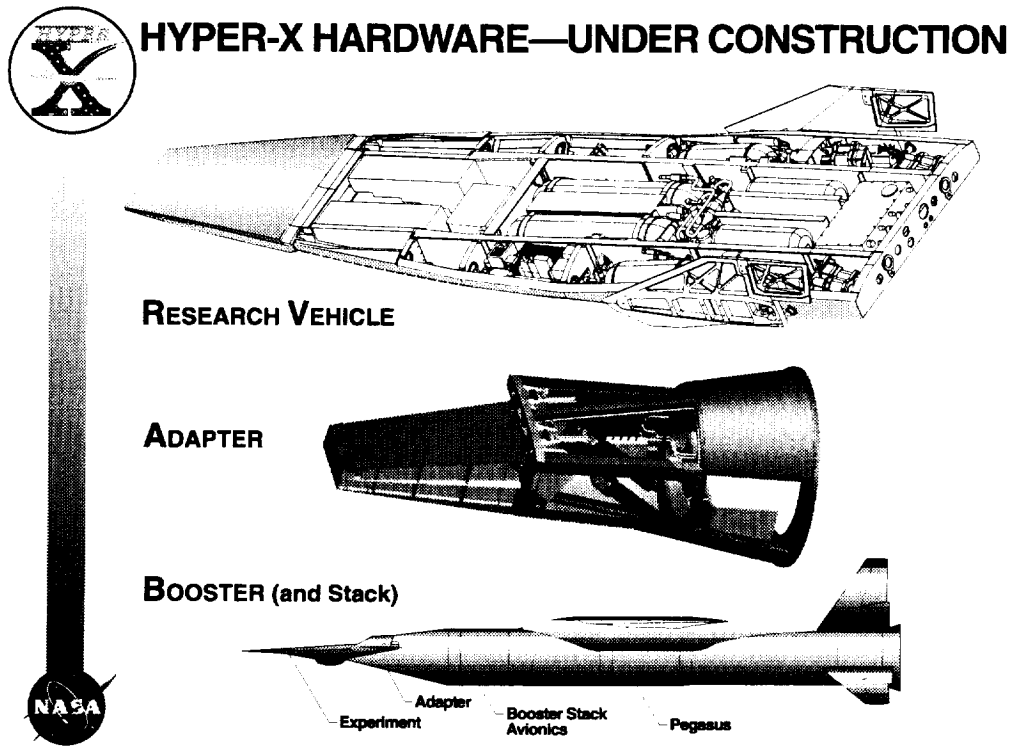


Figure 49. Vehicle, adapter, and booster stack pictures.

HYPER-X GOVERNMENT DELIVERABLES—QUALITY PRODUCTS ON TIME

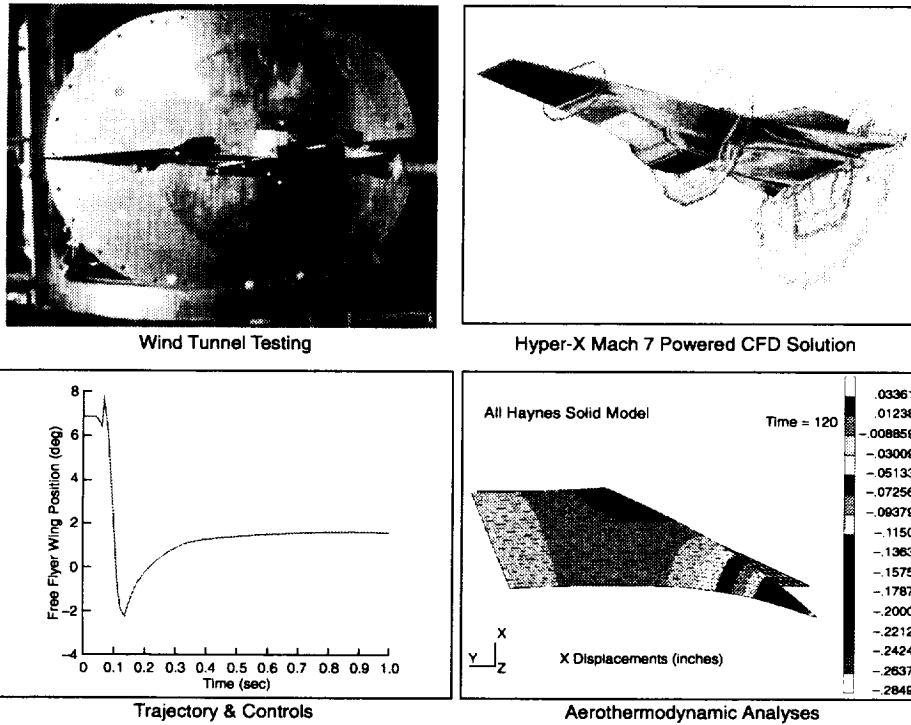


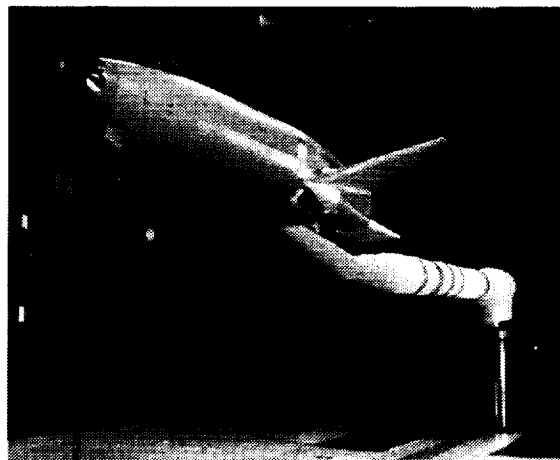
Figure 50. Montage showing government deliverable examples/activities.

## Langley X-33 Program

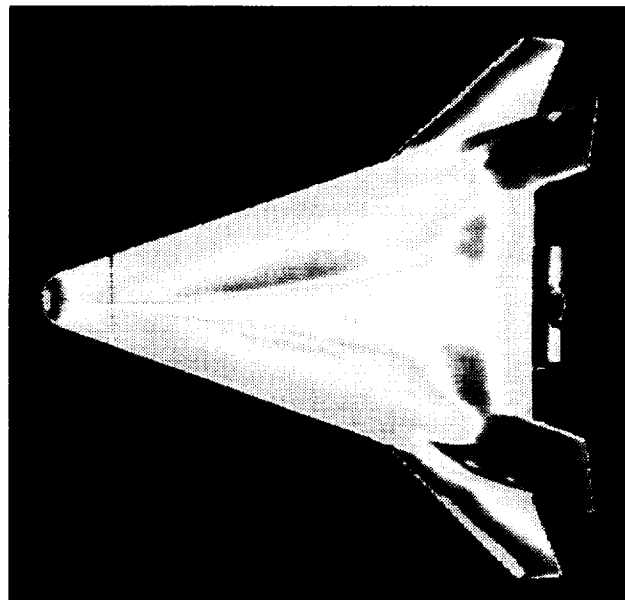
Affordable access to space is one of the three pillars of success for NASA's Aeronautics and Space Transportation Technology Program. For the United States to have affordable access to space and to remain competitive in launching spacecraft, a launch system that greatly reduces the cost required to put a pound of payload into orbit is required. Such a launch system must be light-weight, robust, require little inspection and maintenance, and be designed with low-cost operations as a major design feature. As a step towards enabling the full commercial potential of space by reducing the payload cost to low Earth orbit by an order of magnitude, NASA has embarked on a Cooperative Agreement with Lockheed Martin Skunk Works to develop, manufacture, and flight test the X-33 advanced technology demonstrator vehicle. Following successful flight tests of the X-33 in 1999, a decision could be made by the Nation to proceed with the development of an operational reusable launch vehicle (RLV) that could replace the Space Shuttle.

As part of the NASA Cooperative Agreement to develop the X-33 flight test vehicle, Langley has several task agreements with Lockheed Martin Skunk Works in the general areas of aerothermodynamics, structures, materials, and vehicle systems analysis. In order to determine the final vehicle shape, to determine how it will fly, and to design its protective outer surface to withstand the high heating experienced during entry, the aerodynamic flight and heating characteristics must be obtained. Within the past year, eight Langley facilities were utilized to obtain aerodynamic performance and heating information for early versions of the X-33 lifting-body concept, from subsonic to hypersonic speeds. Selected results are discussed here.

X-33 low-speed aerodynamic characteristics, as well as ground effects on the aerodynamics when approaching a runway for landing, were obtained in the Langley 14x22-Foot Subsonic Tunnel (see figure 51). Extensive configuration development testing was performed in the Langley 22-Inch Helium Tunnel to determine the appropriate body shape, fins, and body flaps to enable the vehicle to fly at hypersonic speeds. Hypersonic aerodynamic heating data were obtained in the Langley 20-Inch Mach 6 Tunnel (see figure 52). All together, these and other tests have contributed to the selection of the final vehicle configuration, the determination of the vehicle surface temperatures expected in flight, and the definition of the thermal protection system for the vehicle.

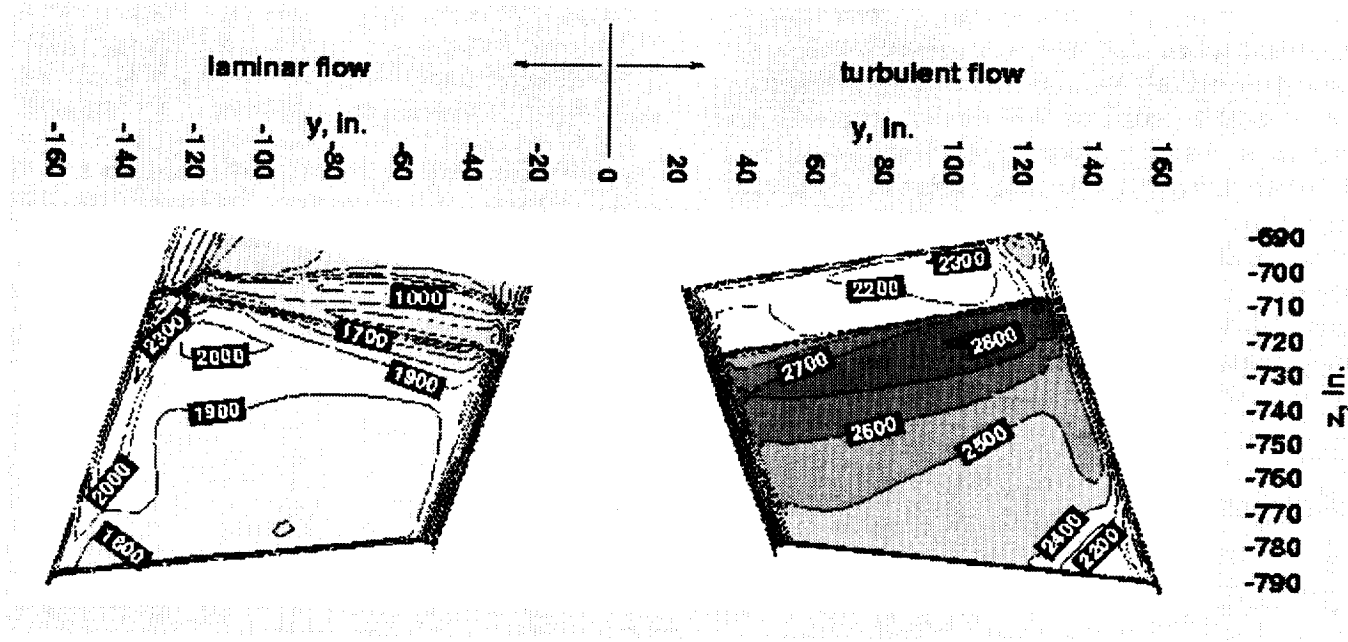


**Figure 51. X-33 ground-effects model testing in 14x22-Foot Subsonic Tunnel.**



**Figure 52. X-33 heat-transfer data measured using the thermographic phosphor technique in the 20-Inch Mach 6 Tunnel.**

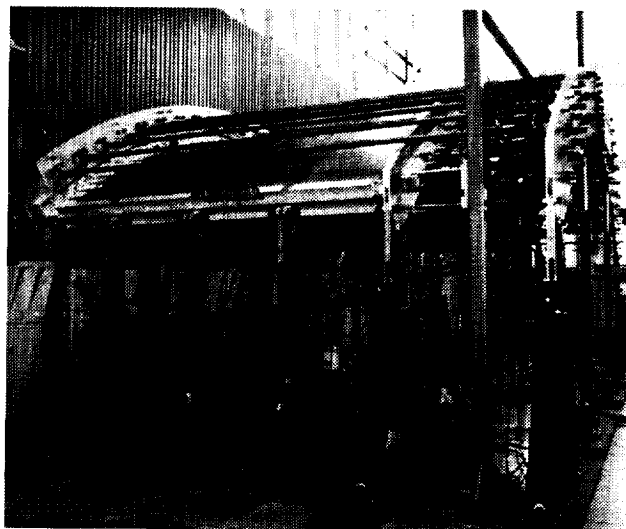
In addition to obtaining experimental data in wind tunnels, computational fluid dynamics (CFD) analyses have been used to compute the flow around the X-33 lifting body during the hypersonic and supersonic phases of entry flight. This work used engineering techniques to populate the aerodynamic heating data base, as well as "benchmark" analysis tools for high fidelity definition of the vehicle's aerothermodynamic performance. The Langley Aerothermodynamic Upwind Relaxation Algorithm (LAURA) code was used



**Figure 53. Comparison of predicted surface temperatures (Fahrenheit) on the X-33 body flap, for laminar and/or turbulent flow conditions, at peak-heating point of flight trajectory.**

for these "benchmark" analyses. The "benchmark" solutions have been used specifically to help define the thermal protection system materials, to assess the impact of flow impingement on the aerospike engine nozzle, to define the heating environment of the body flaps (see figure 53), and to determine the aerodynamic characteristics of the vehicle at peak heating conditions. All computations included the effects of reacting gas chemistry, surface catalysis, surface emissivity, and laminar or turbulent flow. Results of the aerospike engine flow impingement study demonstrated the need to actively cool the engine nozzle during the entry phase of flight.

To develop a light-weight, cost-effective RLV, studies have shown that the use of graphite composites for primary structure is essential. A large, full-scale structural component representative of a section of an inter-tank for a future RLV has been designed, fabricated and tested as a part of a cooperative agreement between NASA and an RLV industry team. The test component was designed and fabricated by a Boeing North American/Northrop Grumman team and tested by NASA Langley Research Center. The test article, 10-feet long and about 22-feet wide (see figure 54), consisted of a hat-stiffened shell skin with five ring frames and represented a cylindrical section (inter-tank) between large propellant tanks in an RLV. The skin, hat stiffeners, and the central ring frames were fabricated using an advanced high-temperature graph-



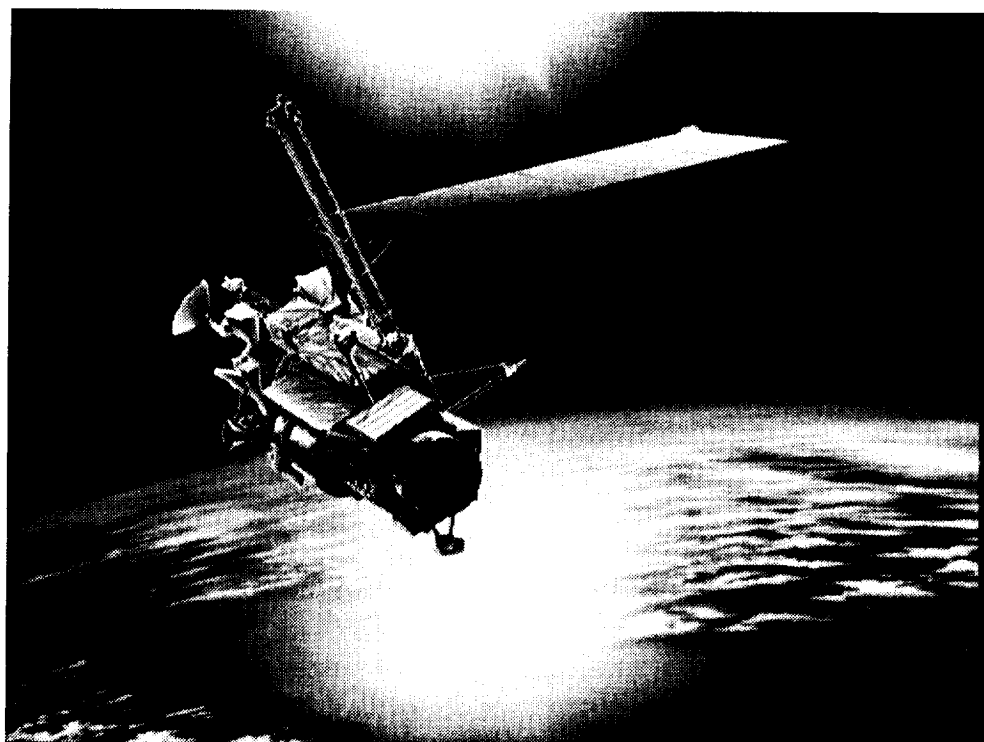
**Figure 54. Full-scale RLV intertank segment testing conducted in the Structures and Materials Laboratory.**

ite/bismaleimide composite. The test article was loaded to failure by applying a uniform compression load to the component using 21 hydraulic jacks equally spaced along the circular arc of one of the end ring frames to simulate the critical vehicle launch conditions. The test article performed as expected until structural failure occurred at a load of approximately

500,000 lb or 1.08 times the design limit load. The expected failure load was approximately 750,000 lb., based on analysis and sub-component test results. Initial inspection indicated that the hat stiffeners separated from the skin, which resulted in the skin buckling between two of the inner ring frames at a lower load than expected. Sub-element tests conducted to determine hat stiffener pull-off and crippling loads for identical shell construction showed much higher values than that obtained in the full-scale component test. Preliminary conclusions are that scaling-up the process for

the secondary bonding of the hat stiffeners to the panel skin on the full-scale test article did not result in strengths as good as those obtained with the sub-element test specimens. Sub-component test specimens have been cut from undamaged sections of the test article and will be tested to determine the stiffener pull-off loads for the full-scale structure. Fabrication techniques will be evaluated to determine improvements that will result in better structural components. Minor adjustments in the fabrication procedure could result in a significantly higher structural load capability. (D. Throckmorton, 757-864-4396; d.a.throckmorton@larc.nasa.gov)

# Earth Science Enterprise



## Upper Atmosphere Research Satellite

Langley's Halogen Occultation Experiment (HALOE) was launched on the Upper Atmosphere Research Satellite (UARS) spacecraft September 12, 1991 as part of the Earth Science Enterprise.

## **Mission**

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NASA's Earth Science Enterprise is dedicated to understanding the total Earth system and the effects of humans on the global environment. The Enterprise is pioneering the study of Global Change; many of the capabilities presently being developed will be needed indefinitely, and today's program is laying the foundation for long-term environment and climate monitoring and prediction.

To preserve and improve the Earth's environment for future generations, governments around the world need policies based upon the strongest possible scientific understanding. The unique vantage point of space provides information about the Earth's land, atmosphere, ice, oceans, and biota that is obtainable in no other way. In concert with the global research community, the Earth Science Enterprise is developing the understanding needed to support the complex environmental policy decisions that lie ahead.

The purposes of the Earth Science Enterprise are to:

- Increase understanding of the Earth as an integrated system
- Observe and characterize the entire Earth system using satellites, aircraft, and associated research systems
- Characterize and understand natural and human-induced change on global and regional scales with an initial emphasis on climate change
- Help identify and predict the consequences of these changes for human health and welfare
- Contribute to the creation of wise and timely environmental policy

To accomplish these purposes, the Earth Science Enterprise will employ the following strategy:

- Promote extensive international collaboration
- Cooperate with other Federal agencies
- Contribute to national and international assessments of the environment
- Strengthen environmental education and public awareness
- Make data, information, and understanding widely available through the National Information Infrastructure
- Seek or develop advanced technologies that lead to new science investigations or reduce program cost
- Transfer relevant technologies to industry in order to strengthen American economic competitiveness

The ultimate beneficiaries of the Earth Science Enterprise are the present and future generations of the people on Earth. The primary customers are those who use environmental information to make decisions, especially national policy makers in the Administration and Congress and their international counterparts. The world science community also uses Earth Science Enterprise data and information—to produce assessments, forecasts, and analysis and to develop new understanding.

## HALOE Observations of the Arctic Stratosphere During Spring of 1997

During March and early April of 1997, the HALOE (Halogen Occultation Experiment) instrument on the Upper Atmosphere Research Satellite (UARS) obtained measurements in the Arctic stratosphere of ozone ( $O_3$ ) and a number of other important gases. In late March, HALOE observed low levels of  $O_3$  and hydrogen chloride (HCl), high levels of nitrogen species ( $NO$  and  $NO_2$ ), and normal levels of water vapor ( $H_2O$ ) when compared with climatological values. Daily hemispheric distributions of these constituents (figure 55 shows the  $O_3$  and HCl mixing ratios) were produced by a trajectory mapping technique using meteorologically-analyzed wind fields. Analysis of these data indicated that the lower stratospheric polar vortex was chemically perturbed during this period. The combination of low  $O_3$  and low HCl values are consistent with a shift in the partitioning of chlorine from "reservoir" species, where it is effectively sequestered, to active species, which destroyed  $O_3$  over the course of the winter.

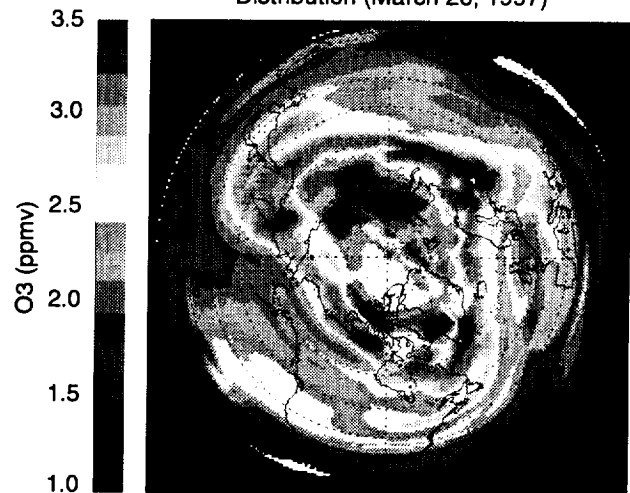
(R. B. Pierce, 757-864-5817; r.b.pierce@larc.nasa.gov)

## SAGE II Upper Troposphere Aerosol Climatology

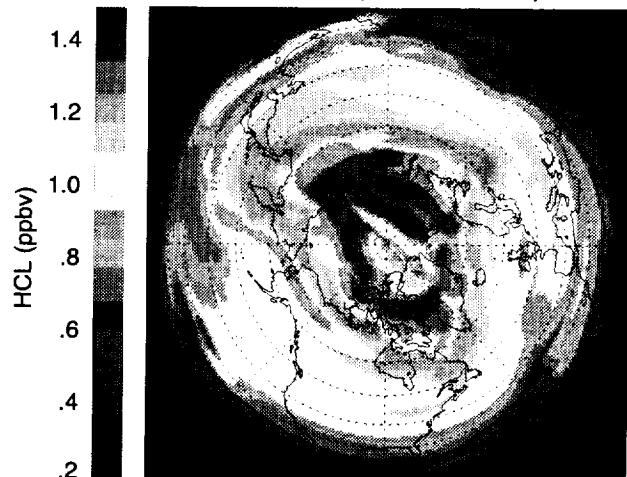
Small suspended particles, or aerosols, in the upper troposphere are not easily measured from satellite platforms, and have only occasionally been probed by instrumented aircraft and balloons. Although their behavior is much less well documented than their stratospheric or lower tropospheric counterparts, upper tropospheric aerosols are nevertheless important to our understanding of global change. When aerosol optical density is high, they may have a significant direct impact on the Earth's climate by scattering and absorbing solar and terrestrial radiation. They also may impose an indirect radiative forcing on the Earth-atmosphere system through the modification of cloud properties and processes. This latter effect is not well quantified, but is of considerable potential significance in the upper troposphere where aerosols have lifetimes of a few weeks.

Measurements from the Langley spaceborne instrument Stratospheric Aerosol and Gas Experiment II (SAGE II) have been used to develop the first global climatology of aerosols in the upper troposphere. Cloud-contaminated observations were filtered out of the measurements, which were accumulated over the periods 1985-1991 and 1993-1996 and averaged by season. Data from the 1992-1993 period were

480k Trajectory Mapped HALOE  $O_3$  Distribution (March 26, 1997)

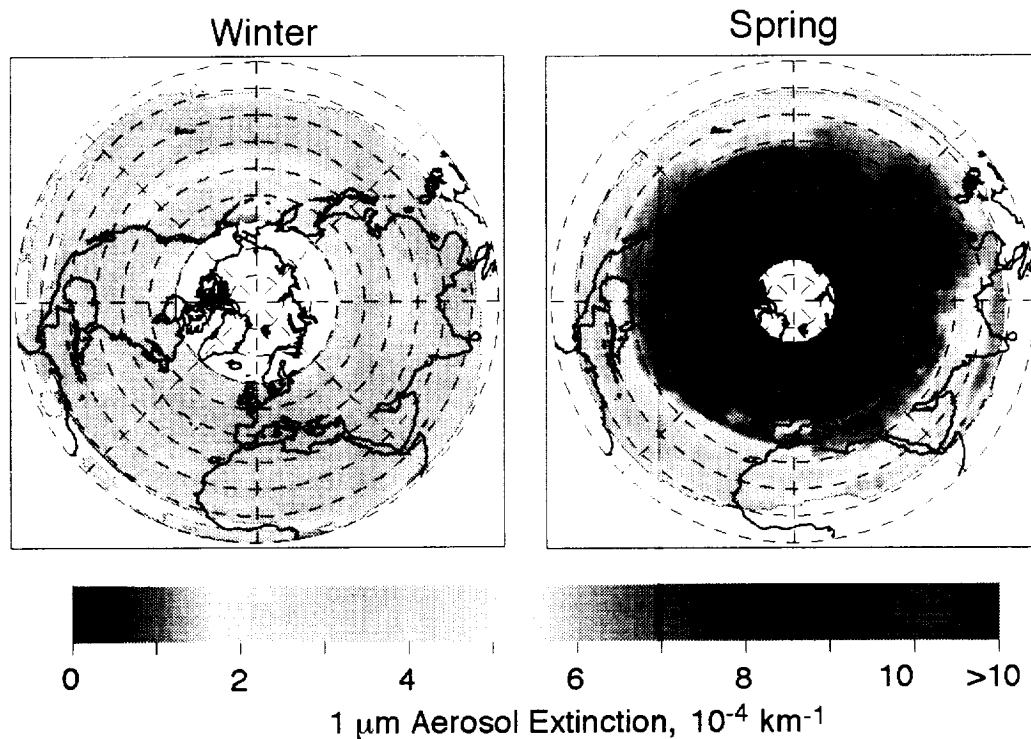


480k Trajectory Mapped HALOE HCl Distribution (March 26, 1997)



**Figure 55. Orthographic projection of trajectory mapped 480k (approximately 20km) HALOE observations of ozone mixing ratio (ppmv) and HCl mixing ratio (ppbv) valid at 00Z on March 26, 1997. Low  $O_3$  and HCl mixing ratios (less than 1.5 ppmv and 0.6 ppbv respectively) are found within the Arctic polar vortex, which is delineated by a collar of higher  $O_3$  and HCl mixing ratios (greater than 3.0 ppmv and 1.2 ppbv respectively). (Note: Figure is in color on Internet version of this report.)**

excluded because the presence of aerosols from the June 1991 Mount Pinatubo eruption made the identification and removal of cloud-contaminated events



**Figure 56. SAGE II Tropospheric Aerosol Analysis (6.5 km) (1984-1991, 1994-1997). (Note: Figure is in color on internet version of this report.)**

problematical. The accompanying figure shows the climatological average aerosol extinction coefficient at an altitude of 6.5 kilometers for winter and spring in the Northern Hemisphere. The data show a pronounced increase in aerosol at this altitude in spring compared to winter. This finding is somewhat unexpected because other observations indicate that the level of aerosol production at the Earth's surface is quite similar during winter and spring. The springtime aerosol enhancement may be due to in situ production of new particles resulting from more vigorous convective vertical transport during spring. Pre-existing aerosols produced at the surface are easily removed from the atmosphere by precipitation in the lower troposphere. Convection, however, can quickly loft water-soluble aerosol precursor gases into the upper troposphere, where the aerosols can then nucleate from the precursor gases, disperse meridionally, and accumulate because there is less precipitation.

(C. R. Trepte, 757-864-5836; c.r.trepte@larc.nasa.gov)

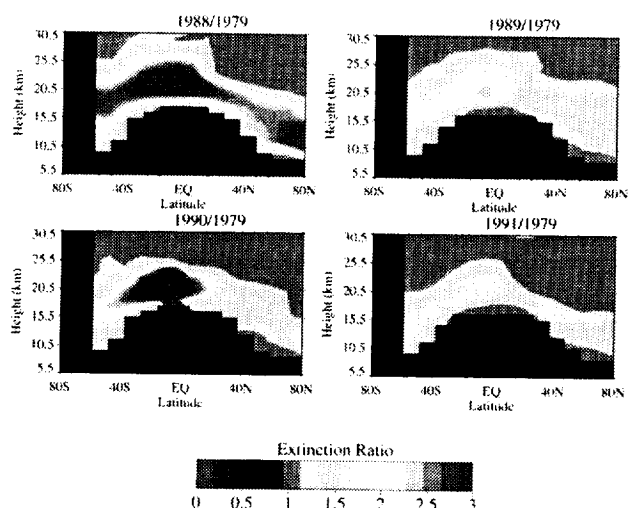
### Changes in Stratospheric Aerosols from 1979 to 1991

Measurements and theoretical advances over the past decade have shown that atmospheric chemical

cycles are significantly altered by heterogeneous (mixed-phase) reactions occurring on suspended particles. For example, the Antarctic ozone hole forms as a result of chemical reactions involving chlorine and nitrogen species that occur on the surface of polar stratospheric cloud particles. Stratospheric sulfate aerosols have been shown to cause similar chemical perturbations as well, particularly after major volcanic eruptions such as that of Mount Pinatubo in June 1991, when significant aerosol-catalyzed ozone loss occurred around the globe. It is thus crucial to characterize the global distribution of these aerosols and to establish if their levels are being influenced by human activity.

Measurements by the Langley spaceborne instruments SAGE (Stratospheric Aerosol and Gas Experiment) from 1979-1981, and its successor SAGE II from 1984 to the present, have been used to characterize changes in stratospheric aerosols occurring between 1979 and 1989-91 (prior to the Mount Pinatubo eruption). These time periods have often been referred to as background, or non-volcanic periods because aerosol levels were lower than at any other times in the modern measurement era. Scientific papers published in the past several years reported that aerosol levels at 41°N were 30-50%





**Figure 57. Aerosol Extinction Ratio Using SAGE II. (Note: Figure is in color on internet version of this report.)**

higher in 1989 than in 1979 and further suggested that the aerosol increase might have been caused by increased sulfur injected into the atmosphere by high-altitude commercial aircraft.

The accompanying figure shows the ratio of aerosol extinction measured by SAGE II during Northern Hemisphere spring in each of the years 1988, 1989, 1990, and 1991 to that measured by SAGE in 1979. Clearly, aerosol levels were higher in the latter years, and the increase observed near 41°N agrees well with the previously published in situ measurements. However, the irregular latitudinal pattern observed from space shows clearly that the stratospheric aerosol layer had not reached a uniform non-volcanic state in 1989-1991, but instead was under the continuing influence of the tropical volcanic eruptions of El Chichon (1982), Nevado del Ruiz (1985), and Kelut (1990). The SAGE results indicate that any underlying aerosol trend due to aircraft activity is much smaller than estimated previously and also reinforce the need for an accurate global aerosol database, since measurements collected at a single site can be interpreted incorrectly.

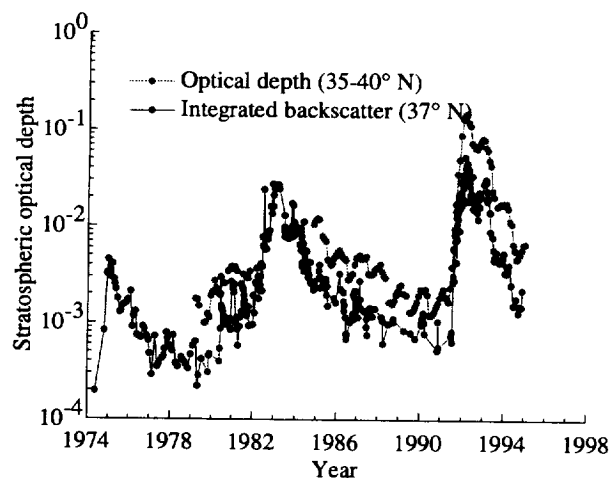
(L. W. Thomason, 757-864-6842; tomason@sisyphus.larc.nasa.gov)

### Stratospheric Aerosol Loading Approaching Level Last Observed in 1979

Atmospheric chemical cycles are influenced substantially by heterogeneous, or mixed-phase reactions occurring on or within suspended cloud particles and

aerosols. The most prominent example of this is the Antarctic ozone hole, which forms annually during spring as a result of chlorine and nitrogen species reactions catalyzed by polar stratospheric clouds. Another example is the significant ozone loss that occurred at midlatitudes following the Mount Pinatubo volcanic eruption in June 1991, which is thought to have resulted from heterogeneous reactions catalyzed by the large amount of stratospheric sulfate aerosol produced by that eruption. There is concern that the non-volcanic background stratospheric aerosol loading, and thus the risk of ozone depletion, might be rising due to human activity. Exhaust aerosols from commercial aircraft are of special interest since air traffic has increased steadily in recent years and is expected to grow at a rate of about 5% per year over the next two decades. Reports published prior to the Mount Pinatubo eruption showed that stratospheric aerosol levels at Northern Hemisphere midlatitudes increased by 30-50% between 1979 and 1989, and suggested that the increase was linked to a similar rise over that time period in aircraft fuel consumption.

Measurements collected since the 1970s by Langley Research Center remote sensors are being used to study the long-term behavior of stratospheric aerosols and to delineate natural variability from possible human influences. The accompanying figure 58 shows stratospheric optical depth (extinction integrated upward from the tropopause) at a wavelength



**Figure 58. Stratospheric optical depth measured in the 35-40°N latitude band by SAGE (1979-81) and SAGE II (1984-1997), and integrated stratospheric aerosol backscatter measured at NASA Langley (latitude 37°N) from 1974-1997.**

of 1 micrometer measured in the 35-40°N latitude band since 1979 by the Langley SAGE (Stratospheric Aerosol and Gas Experiment), and SAGE II spaceborne instruments, along with integrated stratospheric aerosol backscatter at a wavelength of 0.6943 micrometer measured from 1974-1997 by a ground-based lidar system at Langley (37°N). Changes in these quantities reflect changes in the total amount of aerosol material in the stratosphere. Both data records show that there was indeed an increase in aerosol loading from 1979 to 1989, but they also show that loading in 1997 had dropped below that observed in 1989 and was approaching the 1979 minimum. Thus, the stratospheric aerosol layer in 1989 was not in a background non-volcanic state, but instead was still being influenced by the earlier volcanic eruptions of El Chichón (1982) and Nevado del Ruiz (1985). Any underlying aerosol trend due to aircraft or other human activity is certainly smaller than estimated from the 1979-1989 change, and the 1997 data suggest that there may be no trend at all.  
 (L. R. Poole, 757-864-2689; l.r.poole@larc.nasa.gov)

## Lidar Atmospheric Sensing Experiment (LASE)

Sponsored by the Earth Science Enterprise, LASE supports advancing and communicating scientific knowledge and understanding of the environment. The objective of LASE is to develop and demonstrate advance water vapor DIAL technology and techniques as a precursor to the development of a spaceborne water vapor DIAL system. LASE is an airborne instrument that conducts important atmospheric investigations of water vapor, aerosols, and clouds as part of coordinated NASA field experiments. In 1996, LASE successfully deployed out of the Wallops Flight Facility on an ER-2 aircraft during the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX). The major goal of TARFOX was to reduce the uncertainties in the effects of aerosols on climate.

The LASE Instrument (see block diagram, figure 59) provided invaluable real-time profiles of aerosols that were used to locate critical altitudes for

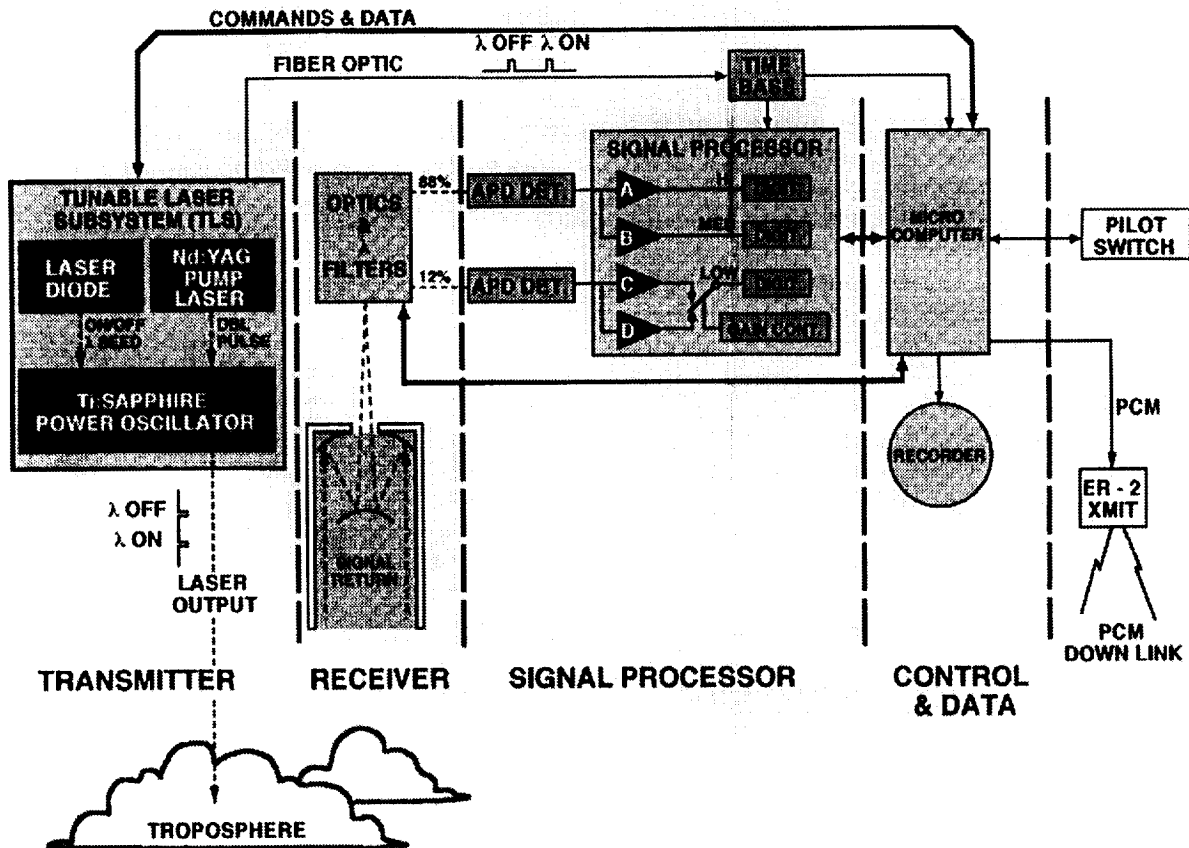


Figure 59. LASE System Block Diagram.

intensive sampling of aerosols. Additionally, LASE provided water vapor and cloud data for post mission analyses.

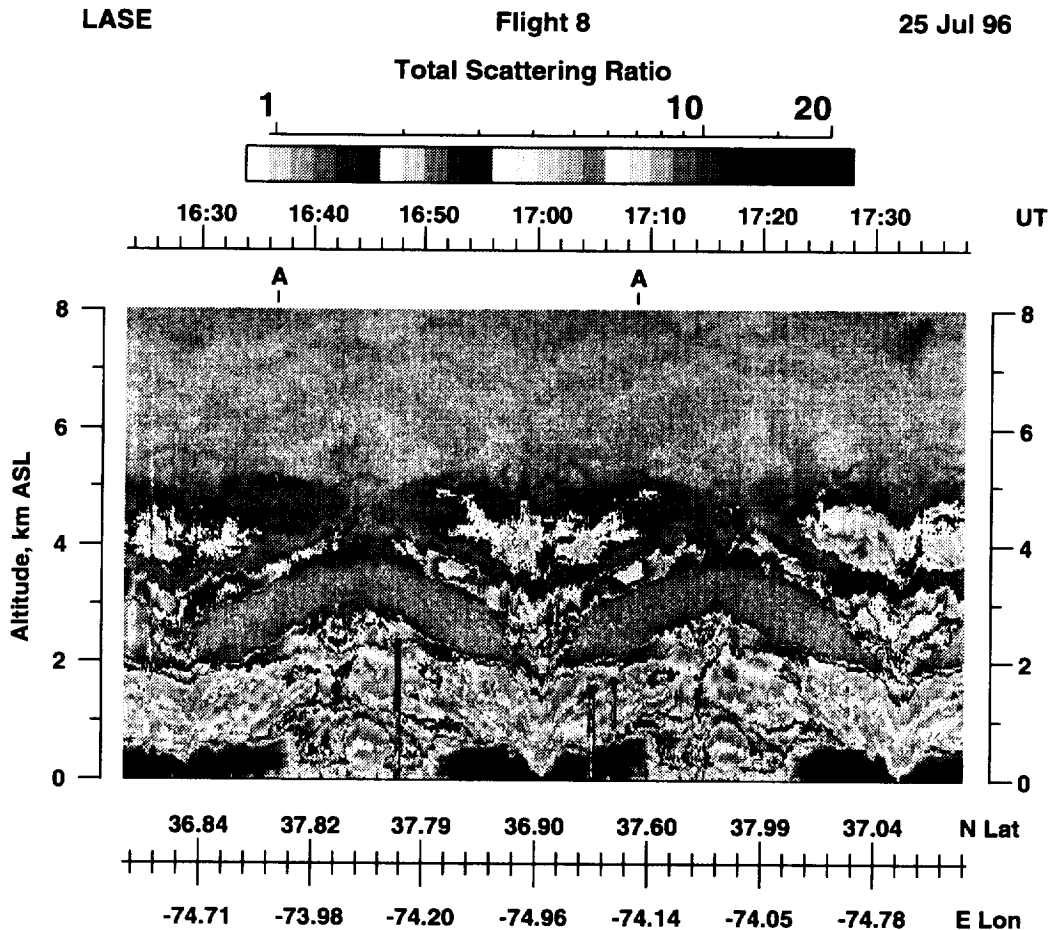
Alliances, partnerships, and customers include National Oceanic and Atmospheric Administration, University of Washington, United Kingdom Meteorological Research Flight, the International Global Atmospheric Chemistry Project community, NASA Ames, and NASA Goddard.

(A. S. Moore, 757-864-7094; a.s.moore@larc.nasa.gov)

### LASE Measurements of Anthropogenic Aerosols

NASA Langley Research Center (LaRC) has developed an advanced laser remote sensing system called LASE (Lidar Atmospheric Sensing Experiment) for the

measurement of atmospheric water vapor and aerosol distributions. The LASE system was flown from a high altitude NASA ER-2 aircraft during the Tropospheric Aerosol Radiative Forcing Experiment (TARFOX) conducted from the NASA Wallops Flight Facility (WFF) during July 1996. The objective of TARFOX was to evaluate the impact of anthropogenic aerosols on the Earth's radiation budget. The TARFOX field experiment employed a number of aircraft to do in situ sampling of the aerosol laden air along with radiation measurements from airborne, satellite and ground-based radiation sensors to study the impact of the urban aerosols on Earth's radiation. The LASE system was used to map the altitude distributions of anthropogenically produced urban aerosols that were advected by air motions onto the oceanic region near WFF. The LASE system provided the geographic location and altitude of urban plumes to the in situ air sampling aircraft. The LASE system conducted a total of 9 flights



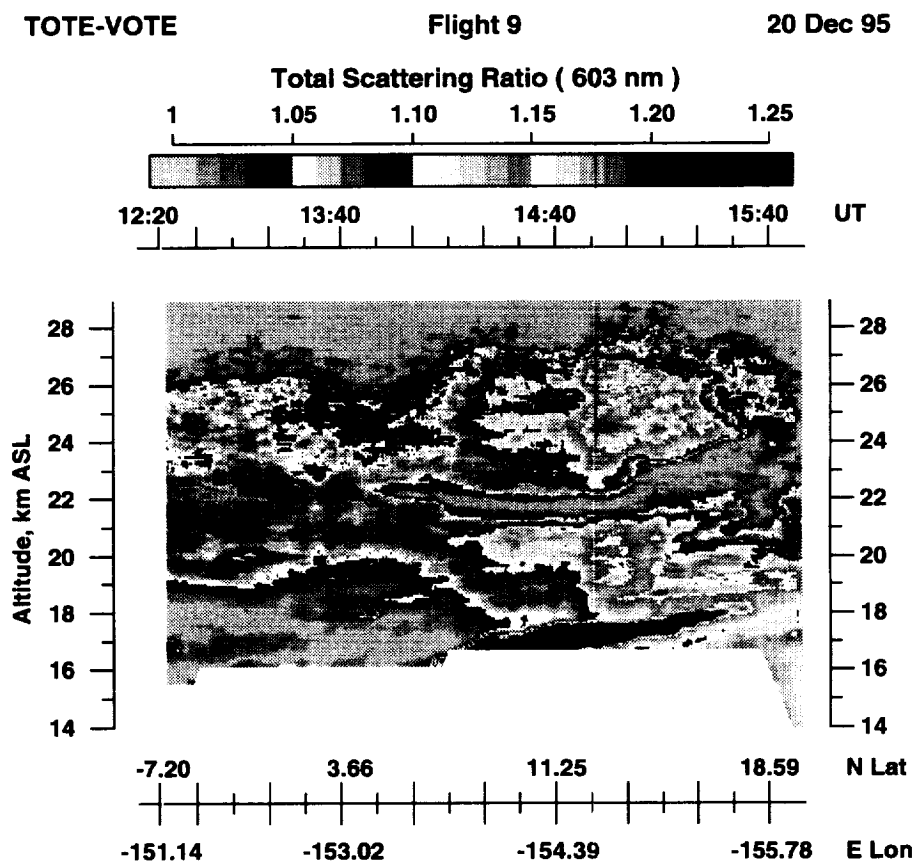
**Figure 60. LASE measurements of atmospheric scattering by urban aerosols in the Eastern Oceanic region near NASA WFF. (Note: Figure is in color on internet version of this report.)**

during July 10-26, 1996 and provided information with respect to the structure and distribution of the urban aerosols. The LASE system also measured water vapor distributions that are needed in the calculation of the infrared radiation fluxes in the atmosphere. An example of the distribution of urban aerosols in the lower atmosphere observed near WFF on July 25, 1996 is depicted in Figure 60. The data obtained by the LASE system is being analyzed and these will be used, in conjunction with other measurement and analyses conducted during the TARFOX field experiment, to study the impact of urban aerosols on the Earth's radiation budget. The LASE system continues to demonstrate its advanced sensor capabilities suitable for use in a number of important atmospheric process studies including hurricane development, atmospheric boundary layer studies, cloud formation and other radiation budget studies. To permit the use of LASE in a number of major NASA field programs it is currently being reconfigured to fly on other NASA aircraft like the P-3 and the DC-8.

(E. V. Browell, 757-864-1273; e.v.browell@larc.nasa.gov)

### Airborne LIDAR Investigation of Transport in the Lower Stratosphere During the TOTE/VOTE Field Experiment

The NASA Langley Research Center's airborne Differential Absorption Lidar (DIAL) system was flown in NASA's Tropical Ozone Transport Experiment/Vortex Ozone Transport Experiment (TOTE/VOTE) to examine the horizontal transport of stratospheric air into and out of the Arctic polar vortex and between the tropical stratospheric reservoir and mid latitudes. The tropical stratospheric reservoir extends between about the 20 degree north and south latitudes in the winter hemisphere and between the 25 degree latitudes in the summer hemisphere, and, like the polar vortices, has effective dynamical barriers to transport of air. It is important to understand such transport because it is key to determining how chemical changes in one region, such as ozone depletion in the polar regions or aircraft emissions in mid-latitudes, affect the chemical balance in other regions. A related objective was to



**Figure 61. TOTE/VOTE measurement with Airborne DIAL of Scattering ratio. (Note: Figure is in color on internet version of this report.)**

see how well meteorological data can be used to predict atmospheric transport in thin layers or filaments.

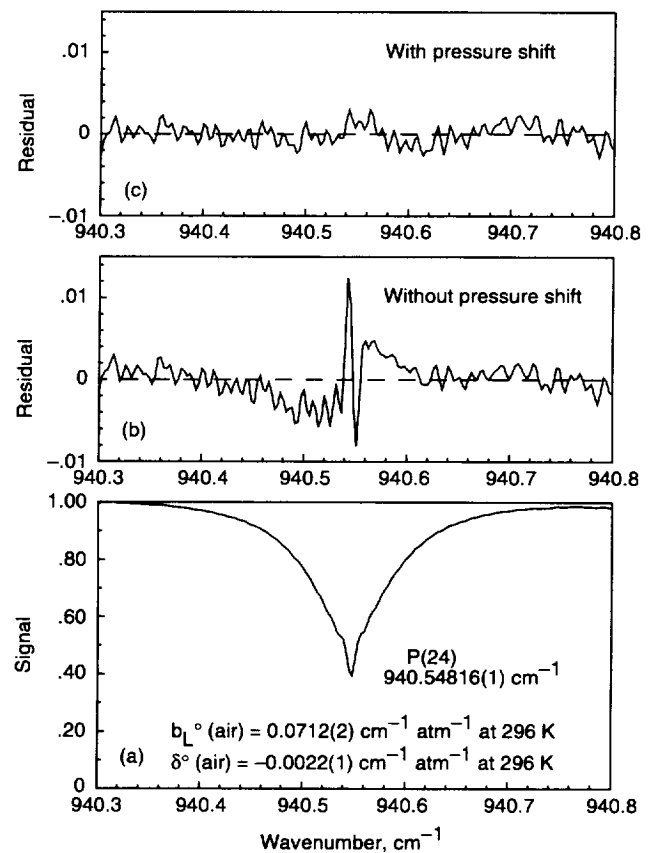
TOTE/VOTE was conducted in the Arctic and Tropical Pacific regions from December 1995 to February 1996, and the airborne DIAL system was flown on the NASA DC-8 along with nine other in situ and remote measuring instruments. The DIAL was used to measure high vertical resolution profiles of ozone and aerosols across the Arctic polar vortex, in the mid-latitude stratosphere and in the tropical stratospheric reservoir. These data demonstrated that ozone and aerosols were being advected across the dynamical boundaries of these regions. The DIAL data have been used in conjunction with meteorological modeling results to show that the predicted thin dynamical filaments were occurring. Figure 61 shows evidence of these thin filaments observed in the DIAL ozone and aerosol data. In addition, the DIAL system demonstrated its capability for making correlative ozone profiles for comparison with ground-based DIAL and space-based stratospheric ozone measuring instruments. This capability will be useful as new passive and active satellite instruments are deployed.  
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### Laboratory Studies of Carbon Dioxide Infrared Laser Bands

The infrared "laser bands" of carbon dioxide are used for atmospheric remote sensing by passive techniques such as solar absorption spectroscopy and by active techniques such as differential absorption lidar. Detailed knowledge of the infrared spectra of carbon dioxide and other atmospheric gases absorbing in the same spectral region is necessary for accurate remote sensing measurements.

A high-resolution laboratory spectroscopic study of absorption lines in the carbon dioxide laser bands of has been performed to examine how these lines are broadened and their positions are shifted by increasing pressures of air or nitrogen (see figure 62).

This study, covering 46 spectral lines in each of the two laser bands, represents the most complete set of pressure broadening and shift measurements thus far reported, including the first known measurements of air-induced line shifts, for these bands. The results show that pressure-induced line shifts due to air or nitrogen are not insignificant and should be taken into account when the carbon dioxide laser bands are used for remote sensing in an environment containing these gases. An article reporting this research has been

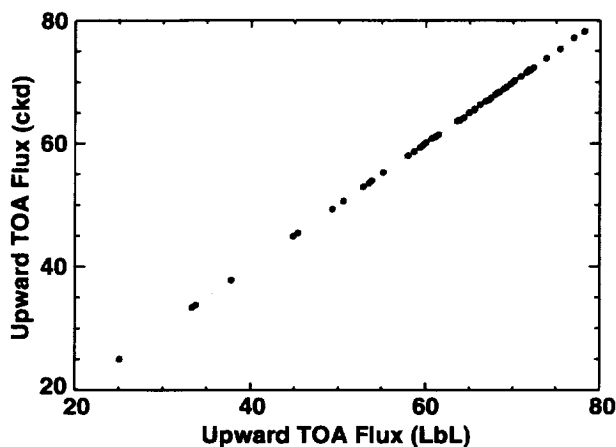


**Figure 62. A carbon dioxide "laser band" line (a) appearing in a high-resolution infrared absorption spectrum of the Earth's atmosphere recorded by a spectrometer on the ground looking up at the sun. Upper panels show magnified differences between the measured spectrum and calculated spectra ignoring (b) and including (c) the air-induced line shift.**

published in the March-May 1998 issue of the *Journal of Quantitative Spectroscopy and Radiative Transfer* (Vol.59, pp. 137-149).  
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### Accounting for Molecular Absorption in the Spectral Range of the CERES Window Channel

Establishing the radiative effect of molecular absorption (emission) in the atmosphere is essential to the proper interpretation of satellite measured radiances. Since satellite instruments produce prodigious



**Figure 63. Comparison of outgoing TOA clear-sky fluxes as computed by the correlated *k*-distribution (ckd) and line-by-line (LbL) models. The values have been computed for the spectral range of the CERES window channel, with the response function being taken into consideration. The units are given in  $\text{Wm}^{-2}$ .**

amounts of data, and since the strength of the atmospheric molecular absorption can be highly dependent upon wavenumber, an initiative has been undertaken to construct fast yet accurate parameterizations that will account for the molecular absorption located in the spectral ranges of several satellite radiometers. Of particular interest to Langley researchers has been the production of parameterized routines to represent the molecular absorption located within the spectral range from  $835$  to  $1250 \text{ cm}^{-1}$  ( $8$  to  $12 \text{ m}$ ), an interval which corresponds to the Clouds and the Earth's Radiant Energy System (CERES) window channel. The CERES endeavor is a critical part of NASA's Earth Observing System (EOS), with the top of the atmosphere (TOA) radiances measured by the CERES window channel being vital to the retrieval of the surface radiation budget. CERES window channel measurements also provide a measure of the trace gas radiative forcing under clear sky conditions. Recent anthropogenic activities have led to substantial increases in several trace gas abundances, such as:  $\text{CO}_2$ ,  $\text{N}_2\text{O}$ ,  $\text{CH}_4$ , and the CFC's, emphasizing the need to understand the radiative forcing of these trace gases. Additional information gathered by the CERES instrument is crucial for advancing our understanding of cloud-radiation interactions, specifically the impact of cloud feedbacks upon the radiation balance of the Earth. Furthermore, CERES data are extremely important for detecting, monitoring, and understanding

the processes responsible for the variability of the climate on both regional and global scales.

Because of its efficiency and accuracy, the correlated *k*-distribution procedure has proven to be the ideal parameterization for calculating the molecular line absorption, especially when encountering non-homogeneous paths. Furthermore, the correlated *k*-distribution procedure can be directly incorporated into radiative transfer routines that consider multiple scattering, as well as absorption, by clouds and aerosol particles. To account for the atmospheric absorption attributed to the water vapor continuum located within the spectral range of the CERES window channel, an empirically derived, yet highly accurate parameterization of the CKD—2.1 continuum code has been developed. Once created, the parameterized continuum procedure was then incorporated into the correlated *k*-distribution routines. Extensive comparisons with reference line-by-line calculations have revealed that the correlated *k*-distribution routines yield very accurate representations of the combined molecular line and continuum absorption located within the wavenumber range of the CERES window channel (see Figure 63). Thus, the present correlated *k*-distribution routines will facilitate the understanding of the processes affecting the TOA radiances measured by the CERES window channel instrument.

The correlated *k*-distributions which have been constructed for the CERES window channel are available from the author by request. Alternatively, the correlated *k*-distribution routines for the CERES window channel as well as several other satellite channels may be accessed at <http://aquila.larc.nasa.gov:8080/>. (D. P. Kratz 757-864-5669; d.p.kratz@larc.nasa.gov)

### Detecting Multilevel Clouds from Satellites

There is a large uncertainty in the ability of current global circulation models to correctly describe global cloud cover. Without an accurate parameterization of cloud cover, the models will incorrectly estimate the Earth's radiation budget. Clouds are often observed to occur in simultaneous layers in the vertical direction, i.e., multilayered clouds are common. Multilayered clouds affect both the top of atmospheric, within atmosphere, and surface fluxes. A fuzzy logic classification methodology was developed to discriminate between clear-sky and clouds in satellite imagery. The method was applied to  $32 \times 32$  pixel arrays, or samples, of 1.1-km Advanced Very High Resolution Radiometer (AVHRR) data.

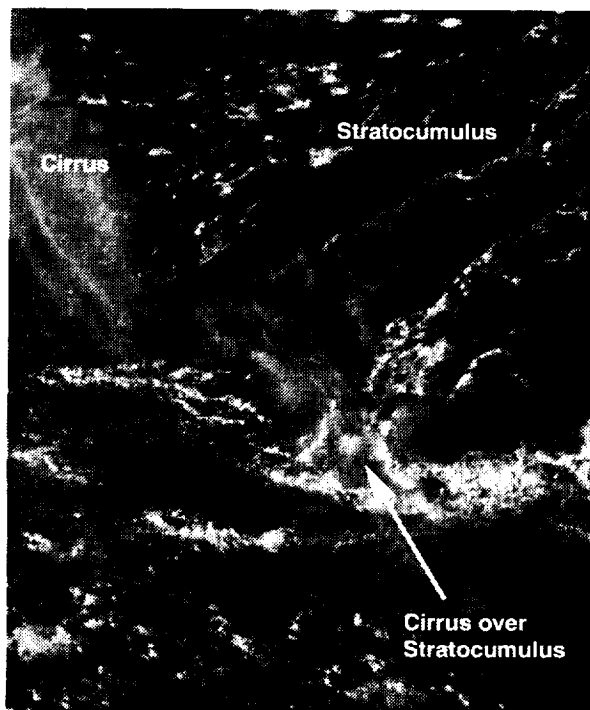
If clouds were present within the sample, the classifier further discriminated between single-layered and multilayered clouds. To achieve these goals, a set of eight fuzzy logic classifier (FLC) modules was derived based broadly on air mass type and surface type (land or water). Basically, air masses are pools of air, having areal extents on the order of thousands of kilometers, that exhibit nearly homogeneous characteristics, such as humidity and temperature. The air masses defined in this study are Equatorial over land, marine Tropical over land, marine Tropical/Equatorial over water, continental Tropical over land, marine polar over land, marine polar over water, continental polar over land, and continental polar/Arctic over water. Derivation of air mass type is performed using gridded analyses provided by the National Centers for Environmental Prediction (NCEP).

The fuzzy logic technique is a "supervised" classification scheme, meaning the classifier must be trained

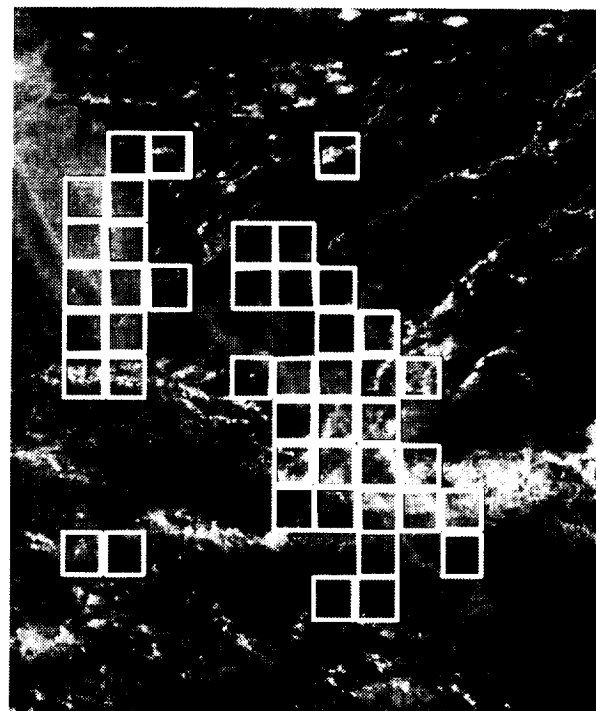
to identify each class based on samples manually labeled by an expert. The accuracies of the eight classification modules were calculated by dividing the number of correctly classified samples by the total number of manually labeled samples of clear-sky and single-layer clouds. Individual module classification accuracies ranged from 85% (marine polar over water) to 91% (continental polar over land). Single-level cloud samples misclassified as multilayered clouds range between 0.5% (continental polar over land) and 3.4% (marine polar over land) for the eight air mass modules. Classification accuracies for a set of labeled multilayered cloud samples range between 64% and 81% for six of the eight air mass modules (excluded are the continental polar over land and continental polar/Arctic over water modules, for which multilayered cloud samples are difficult to find).

The accompanying figure illustrates the application of the fuzzy logic classifier to a scene recorded by the

Scene recorded on 31 January, 1993 over the central Pacific Ocean by the NOAA 11 AVHRR imager



Fuzzy logic classification of pixel arrays containing multiple cloud layers



**Figure 64. NOAA-11 AVHRR image recorded on January 31, 1993 over the central Pacific Ocean. (a) A false color composite image is formed from the 0.63-micron, 0.83-micron, and 11-micron data in the red, green, and blue guns, respectively. The ocean surface is dark, low-level clouds are bright yellow, and cirrus is white/blue. (b) Superimposed over the image are white boxes corresponding to 32 x 32 arrays of 1-km resolution data that were found to contain multilayered clouds as determined from application of the fuzzy logic classification analysis. (Note: Figure is in color on internet version of this report.)**

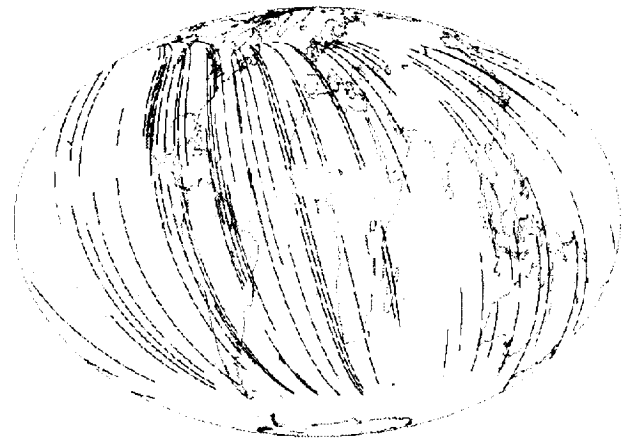
AVHRR on January 31, 1993 over the central Pacific Ocean. In this scene, thin cirrus overlies broken low (stratocumulus) clouds; the ocean surface is dark. For a portion of the image, the classifier was applied to 32 x 32 pixel arrays. The arrays determined by the classification scheme to contain multilayered clouds are outlined by the white boxes. Overall, the fuzzy logic methodology appears to be an excellent approach to classifying both single-layer and multi-layer clouds over a variety of surface types. The application of this technique in general circulation models should improve our ability to model the climate and, ultimately, predict global changes.

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### Observation by LITE of the Global Distribution of Subvisible Cirrus

The Lidar In-space Technology Experiment (LITE) was flown on Space Shuttle Discovery as part of the STS-64 mission and acquired data during the period September 10-19, 1994. The orbital inclination of the STS-64 mission provided observations between latitudes of 57 degrees North and 57 degrees South. Among the many cloud and aerosol phenomena observed by LITE were extensive layers of thin clouds in the vicinity of the tropical tropopause. These observations are particularly interesting in that they provide the first observation of the distribution and spatial structure of subvisible cirrus clouds on a global scale. Thin, high clouds produce a warming in the upper portion of the troposphere due to the absorption of thermal radiation emitted from the Earth's surface and the lower atmosphere. Even very thin cirrus may produce perturbations of the temperature profile of the upper troposphere that are sufficient to affect atmospheric circulation and the exchange of air between the troposphere and the stratosphere.

Lidar provides much more sensitive detection of tenuous cloud and aerosol layers than do passive satellite instruments. LITE had sufficient sensitivity to detect cirrus layers with optical depths greater than about 0.001. This sensitivity is roughly two orders of magnitude better than obtained from passive satellite instruments. During the LITE mission, extensive layers of thin cirrus were observed near the tropical tropopause. The optical depth of these clouds is on the order of 0.01, meaning they are typically not observable either by satellite instruments or visually from the ground. The cirrus layers were observed to occur in thin sheets with a thickness of as little as a few hun-



**Figure 65. Plot of LITE nighttime orbit segments indicating locations where clouds with tops above 15 kilometers were observed and the type of cloud observed. Green indicates either a deep convective cloud or cirrus with a depth of more than 1 kilometer. Red indicates cirrus less than 1 kilometer deep. Purple indicates a layer of thin cirrus appearing as a distinct, separate layer above a deep convective system. (Note: Figure is in color on internet version of this report.)**

dred meters in many cases, but horizontal extents of hundreds to thousands of kilometers.

Figure 65 illustrates the global distribution of this subvisible cirrus in relation to thicker, more optically dense cirrus occurring near the tropopause. The subvisible cirrus is often observed in the vicinity of thunderstorm anvils. However, there are also numerous observations of subvisible cirrus located far from any possible convective sources. Further, subvisible cirrus is observed in locations characterized by the large scale sinking of air in the middle troposphere; conditions where suppressed cloud formation would be expected. These observations imply either the long-range transport of ice near the tropical tropopause or in situ formation of tenuous ice clouds due to large-scale rising air motions in the upper part of the troposphere. The observed distribution of these clouds thus has implications for the processes controlling the formation and dissipation of clouds near the tropical tropopause. Investigation of the quantitative characteristics of these clouds is now being pursued.

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## Reflection of Sunlight by Real Cloud Fields

NASA's Earth Science Enterprise is an effort to understand the complex Earth system in which we live. One key component of this system is the Earth's interaction with the Sun, from which all energy comes. This energy exchange occurs principally in two modes: shortwave energy (sunlight input and reflection back to space) and longwave energy (heat loss to space). The reflection of sunlight is modelled quite simply in current global climate models, due to limitations on the size of available computers. This simple, plane parallel (PP), model of albedo (reflection of sunlight) has been shown by researchers to be a potential source of error in climate models. The diagram illustrates the source of this error: the PP model assumes a light ray stays in a single horizontal column as it traverses a cloud. In nonuniform cloud fields, this model results in more energy being reflected by thick cloud elements (orange line) than there should be (yellow line).

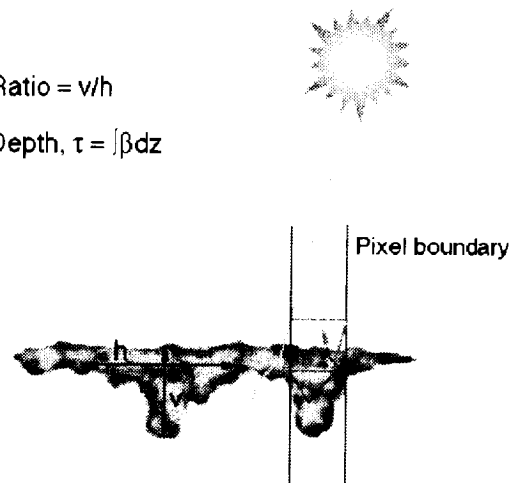
Work has been undertaken in Langley's Atmospheric Sciences Division, using a state-of-the-art three-dimensional shortwave energy transport computer code developed by K. F. Evans at the University of Colorado, to examine the reflection of sunlight by real cloud fields in detail. Forty five fields of low clouds over ocean were studied. The results confirm that the simple plane parallel model of albedo can lead to large bias errors for scattered and broken cloud fields; and errors of the order of 10 percent even for more uniform, overcast cloud fields (see table). A more sophisticated method of computing albedo, the independent pixel approximation (IPA), uses narrower columns and thus provides a better model of the variability of the cloud field. The IPA is shown to have much smaller errors. Even though these errors can still be significant for certain types of cloud fields, the resultant improvement in albedo estimation using IPA for climate models is significant. The table summarizes the errors from the two models for different types of cloud fields and for overhead versus slant sun.

	Scattered	Broken	Overcast
Overhead Sun			
PP Bias Error	40%	22%	12%
IPA Bias Error	2%	0.3%	-0.3%
Slant Sun			
PP Bias Error	35%	20%	9%
IPA Bias Error	-4%	-0.8%	0.6%

## Cloud Model

Aspect Ratio =  $w/h$

Optical Depth,  $\tau = \int \beta dz$



**Figure 66. Actual path of a light ray in a cloud (yellow line), compared to its path in a simple one-dimensional model. (Note: Figure is in color on Internet version of this report.)**

The results of this work have been made available to the climate modelling community and other researchers via a journal article published in the June, 1997 issue of the *Journal of the Atmospheric Sciences*. This article is available via the Internet at <http://techreports.larc.nasa.gov/ltrs/PDF/1997/jp/NASA-97-jotas-lhc.pdf>.

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## Airborne In Situ Measurements of Ozone in the Pacific

This research task provides support to NASA's Global Tropospheric Experiment (GTE) through (1) in situ aircraft measurements of ozone, carbon dioxide, and aerosols during field expeditions, and (2) analyses of multi-discipline GTE aircraft and chemical data bases. GTE, a major part of NASA's Tropospheric Chemistry Program, focuses on documenting and understanding (1) biological sources of atmospheric chemical species, (2) reactions, distributions, and long-range transport of chemical species, and (3) processes in the troposphere that result in conversion, redistribution, and removal of atmospheric chemical species. These goals are accomplished by aircraft sampling campaigns in remote regions of the world.

One region of major concern to atmospheric chemists is the Pacific Basin (see figure 67). The Basin extends 18,000 km in the east-west direction (Peru to Borneo) and 13,000 km north-south (Alaska to New Zealand), covers 35% of the Earth's surface, and represents 50% of ocean surface. From the perspective of the global tropospheric chemist, the Pacific Basin (1) is a very large reaction vessel with numerous important (in terms of chemical processes) meteorological features, e.g., the Inter-Tropical and South Pacific Convergent Zones—ITCZ and SPCZ; (2) is a continual source of clean, pristine air to the Northern Hemisphere; and (3) possesses over 50% of the world's atmospheric oxidative capacity (i.e., potential for removal of atmospheric contaminants). The tropical Pacific and regions south have long been considered, in modeling and climate studies, to be a source of clean, pristine tropospheric air. In particular, the

Pacific Tropics with its hot, humid, and large atmospheric oxidative capacity has been referred to as "the lungs of the world." Should the Pacific Basin show signs of increased pollution as a result of man's activities, there are concerns as to the impact on the oxidative capacity of the tropics and the effect on world climate and pollution (e.g., acid rain, global warming).

The GTE Pacific Exploratory Missions (PEM) have been conducted over the past 5 years to study man's impact on these Pacific Ocean regions. Continuing analyses of the PEM data bases are showing that the Pacific Basin is not the pristine, undisturbed, clean air region of years past, but is being impacted by man's activities. Recent analyses of PEM West data show that Asian outflow has a dominant influence on air quality in the northern (Equator to 40 degrees north) Pacific Basin. The top insert of the figure shows ozone

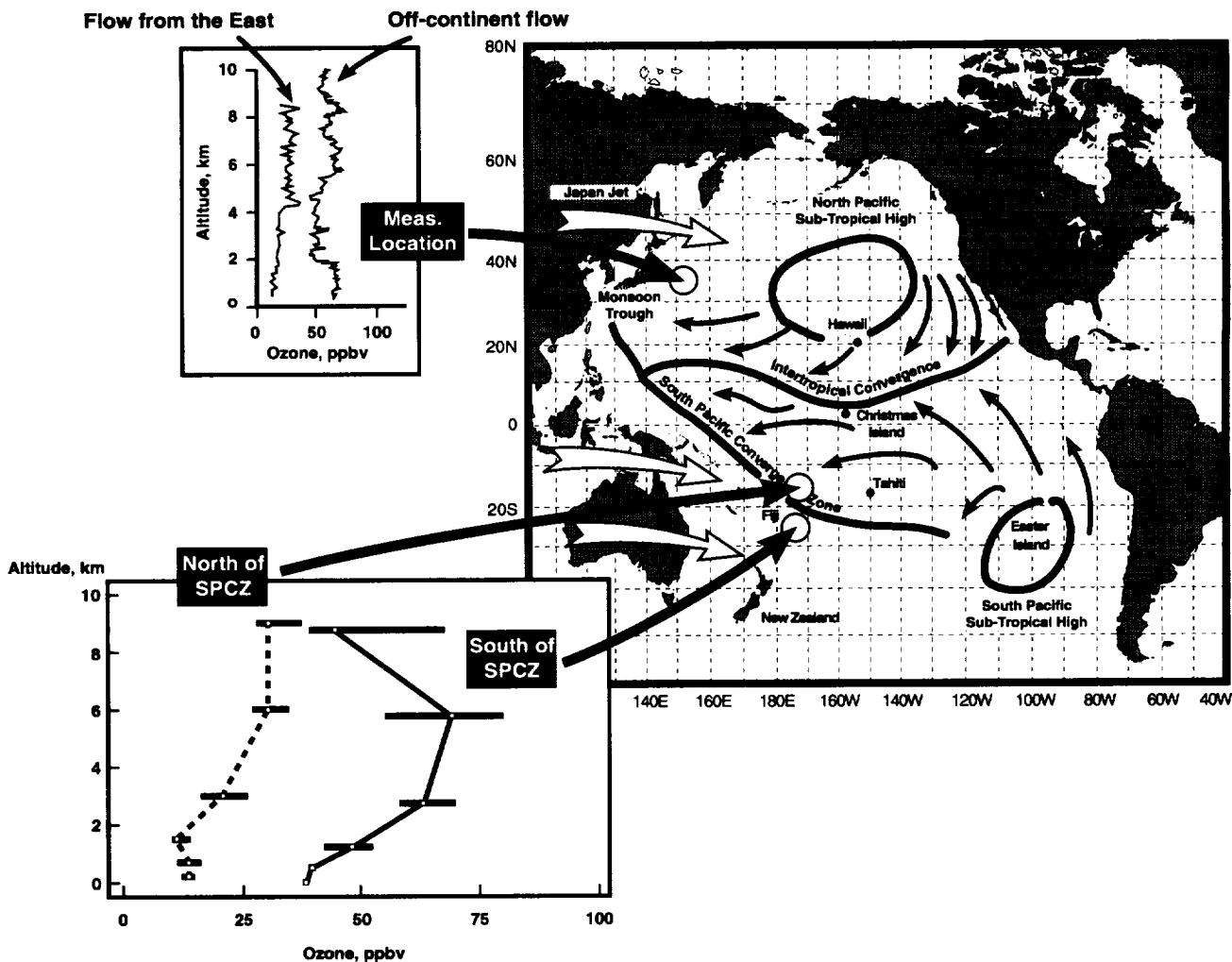


Figure 67. GTE Pacific Exploratory Mission Study Area.

measured aboard NASA's DC-8 aircraft 800 km east of the Asian Continent. The ozone data serve to illustrate the impact of Asian emissions in the region. Ozone production at this site is almost doubled when air flow is off-continent. Other PEM West data indicate that Asian emissions can still be photochemically reactive and produce ozone, as far east as the West Coast of the U.S.

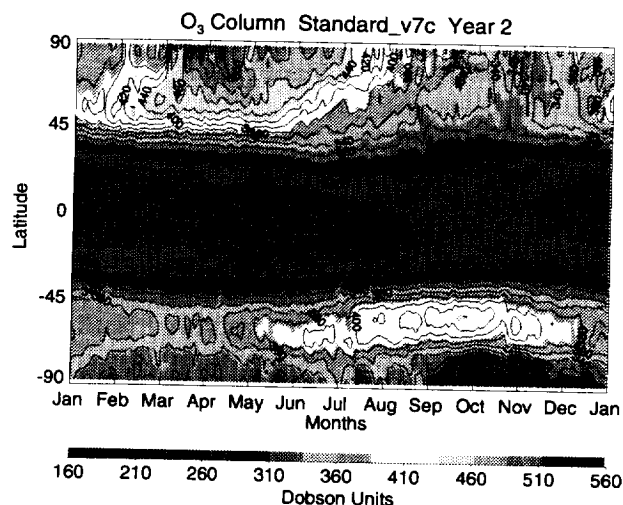
The lower insert to figure 67 shows ozone from the 1996 PEM Tropics expedition. PEM Tropics focused on the southern Pacific Basin with emphasis on documenting air chemistry in these data sparse regions and understanding the importance of the ITCZ and SPCZ in the chemistry of the region. As illustrated in the insert, ozone concentrations south of the SPCZ are much higher than north. All PEM Tropics results clearly show that South Pacific regions, especially those south of the SPCZ, are being impacted by biomass burning from various sources including transport from as far as Africa. Aircraft flights south of the SPCZ consistently showed air elevated in concentrations of species with known biomass burning sources and with air mass back trajectories traceable to active biomass burning sites.

PEM mission data show that the vast Pacific Region (north and south of the Equator) is being impacted by man's activities. The degree to which these activities are affecting the oxidative capacity of Pacific tropical regions is the focus of several on-going PEM Tropics Science Team studies.

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### **The Langley IMPACT Model— An Atmospheric General Circulation Model with Coupled Chemistry**

An annual cycle simulation has been conducted with the LaRC IMPACT model. The IMPACT model is an atmospheric general circulation model (GCM) with interactively coupled chemical, radiative, and dynamical processes. The model domain includes the troposphere and stratosphere extending from the surface to approximately 60 km. The chemistry formulation in the model includes heterogeneous chemical processes on both polar stratospheric clouds and sulfate aerosols in addition to a comprehensive treatment of gas-phase chemistry. The model successfully simulates many observed features of the stratospheric circulation and the distribution of trace constituents, including the formation of the Antarctic ozone hole and its subsequent breakup during the final warming. The simulated distributions show very good agreement with the



**Figure 68. Zonally-averaged total column ozone (Dobson Units) as a function of latitude and time calculated by the LaRC IMPACT model. (Note: Figure is in color on internet version of this report.)**

ments onboard the Upper Atmosphere Research Satellite. The seasonality of the ozone distribution as simulated by the model is depicted in the figure below showing total column ozone as a function of latitude and time. Features of note include: the high-latitude maximum in late Northern Hemisphere spring; the broad tropical minimum; the maximum at middle latitudes in Southern Hemisphere winter/spring; and the Antarctic ozone hole, all of which are in good agreement with observations.

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### **Biogenic Soil Emissions of Nitric Oxide and Nitrous Oxide from Fertilized Fields**

Nitric oxide (NO) and nitrous oxide (N<sub>2</sub>O) are key gases in the chemistry of the troposphere and stratosphere and in global climate. The troposphere, stratosphere and global climate, and how they are changing with time due to human perturbations are areas of great interest to the NASA Earth Science Program. Nitric oxide leads to the photochemical production of nitric acid and ozone in the troposphere. In the stratosphere, nitrous oxide is photochemically transformed to nitric oxide, which leads to the chemical destruction of stratospheric ozone. In addition, nitrous oxide is a greenhouse gas, with a greenhouse warming potential 200 times greater than carbon dioxide on a molecule-to-molecule basis. Atmospheric levels of both nitric

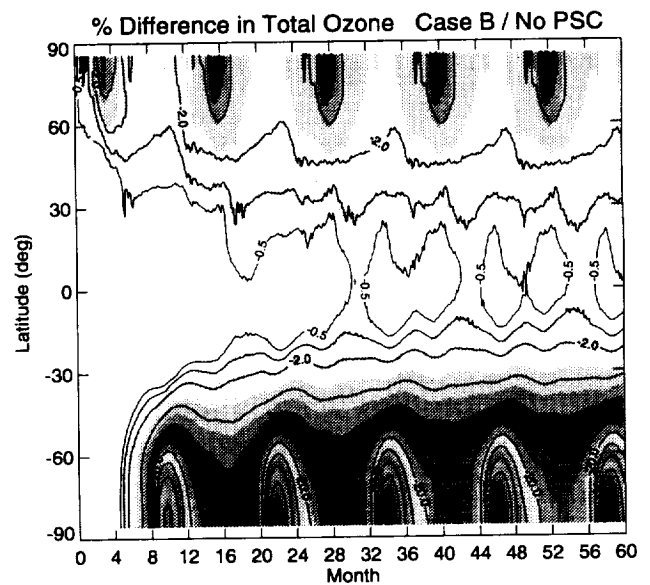
oxide and nitrous oxide appear to be increasing with time. In the case of nitrous oxide, we do not understand the reasons for this increase. A major source of both nitric oxide and nitrous oxide is biogenic production by various microorganisms in the world's soils. There is very little information on the production of these gases in highly fertilized agricultural soils. For this reason, the U. S. Environmental Protection Agency, in cooperation with North Carolina State University, the University of Maryland, the National Center for Atmospheric Research, NASA, NOAA, and Argonne National Laboratory established a field measurement program to investigate the emissions of these gases from an agricultural site in North Carolina. Langley researchers were selected to obtain simultaneous measurements of soil emissions of nitric oxide and nitrous oxide. The measurements were obtained during the growing seasons of 1995 and 1996. In addition to measurements of biogenic soil emissions of nitric oxide and nitrous oxide, measurements of soil temperature, soil moisture, soil nitrate, and soil ammonium were obtained. The measurements of these soil parameters have permitted an investigation into the parameters and processes that control the biogenic soil emissions of these environmentally important gases.

The Langley measurements showed that over a wide range of soil parameters, the emissions of nitrous oxide always exceeded the emissions of nitric oxide. The nitric oxide emissions ranged from less than 1 to 175 ng N m<sup>-2</sup> s<sup>-1</sup> and the nitrous oxide emissions ranged from less than 1 to 1800 ng N m<sup>-2</sup> s<sup>-1</sup> (1 ng = 10<sup>-9</sup> g). Nitrous oxide emissions maximized for high soil moisture conditions (>30% soil saturation), while nitric oxide emissions maximized for very low soil moisture conditions. These measurements will provide insights on the microbial processes responsible for the production of these gases. Preliminary calculations indicate that about 1.5% of the applied nitrogen fertilizer is transformed to nitric oxide and nitrous oxide emissions. The exact amount is a complicated formula that depends on soil temperature, moisture, nitrate, and ammonium. Fertilized agricultural fields may be the source of increasing atmospheric levels of nitrous oxide. Worldwide nitrogen fertilizer application has increased from about 10 Tg N in 1960 to over 90 Tg N in 1994.

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## Polar Ozone Depletion: A Three-Dimensional Chemical Modeling Study of its Long-Term Global Impact

The Antarctic ozone hole has been observed since the late 1970s. This spectacular decrease in ozone during springtime is now largely understood to be the result of the human induced release of chlorine containing gases (e.g., chlorofluorocarbons), their subsequent breakdown in the stratosphere, and the formation of active chlorine species during the cold Antarctic winter. These chlorine species lead to a rapid decrease in ozone during southern springtime with the return of sunlight. In contrast, observed downward trends in stratospheric ozone at midlatitudes during the last two decades remain poorly understood. Measurements made by satellite instruments suggest that midlatitude ozone in the lower and mid-stratosphere is being reduced at a rate of approximately 2% per decade.



**Figure 69. Percent difference in column integrated, zonally averaged ozone between the simulation with polar stratospheric cloud (PSC) chemistry and the no PSC simulation. Negative numbers represent ozone decreases.**

One possible explanation that relates these midlatitude ozone trends to the Antarctic ozone hole is the so-called 'dilution effect'. Dilution of the midlatitude air occurs as a result of the export of ozone-poor air from the ozone hole following the breakup of the southern polar vortex during the seasonal transition in the stratosphere. This dilution could create a deficit in ozone which might persist because the chemical replenishment of ozone in the lower stratosphere requires time scales on the order of a year. If the deficit persists until the next Antarctic spring, the effect might be cumulative and have consequences for the global ozone budget.

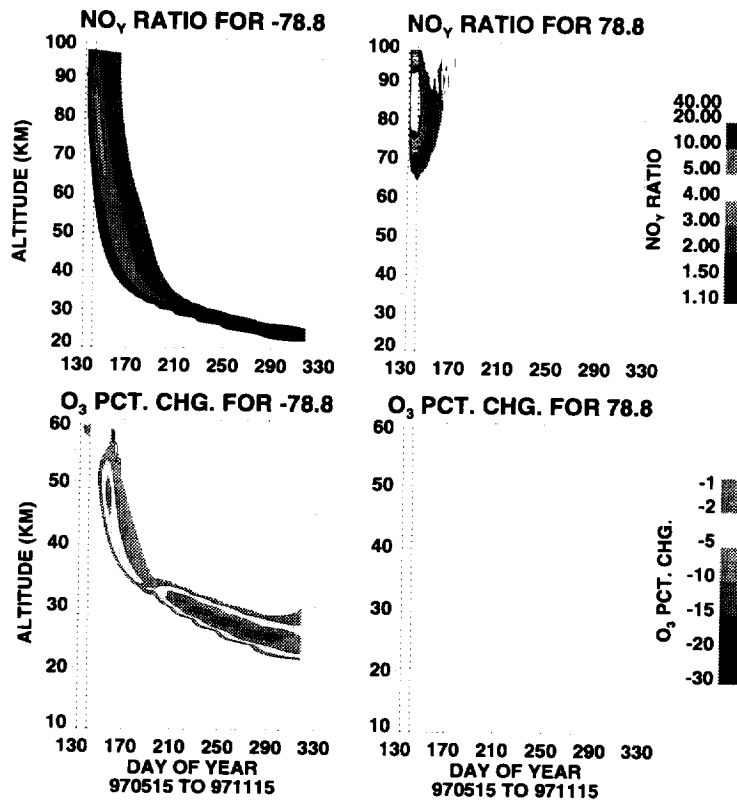
The potential for this ozone dilution to affect midlatitude ozone was explored by utilizing the NASA Langley Research Center three-dimensional chemistry-transport model. The model revealed that ozone is transported equatorward following the breakup of the polar vortex to approximately 20S latitude by the first southern summer following the springtime ozone hole as shown in the figure. A residual ozone depletion of 9% remained by the springtime of the second year. In subsequent years, the model showed that the southern ozone hole itself continued to increase in depth with each succeeding annual cycle.

These model results show that a potential exists for a long-term accumulation of ozone loss in the southern polar region and a gradual increase in the global impact of polar ozone depletion. Comparison with satellite and ground-based observations of ozone trends at midlatitudes suggests that while ozone dilution does not account for the total magnitude of the decadal trends in midlatitude ozone, it may be a contributing factor in its explanation.

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### Solar Atmospheric Coupling by Electrons (SOLACE)

It has been proposed that a coupling between the Sun and the Earth's middle atmosphere exists driven by the precipitation, into the atmosphere, of high energy particles (electrons) stimulated by fluctuations in the solar wind speed. The expected result is the production of nitrogen oxides (NO<sub>y</sub>) between 70 and 100 km which descend to the stratosphere in the wintertime hemisphere affecting global ozone. During May 1997, one such event was observed by instruments which measured both the enhancement of the



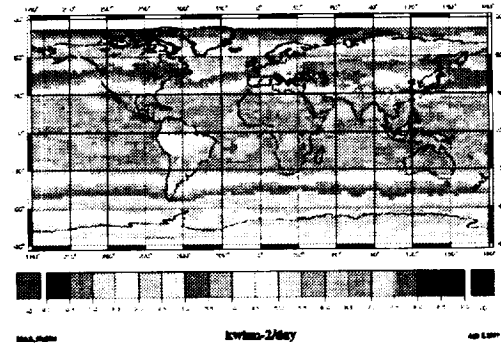
**Figure 70. Electron Flux Enhancement Resulting in NO<sub>y</sub> and O<sub>3</sub> Changes. (Note: Figure is in color on internet version of this report.)**

electron fluxes and the increases in nitric oxide (NO) formed. Increases in NO by factors of 10-30 were observed during this event in both hemispheres near 100 km altitude and at latitudes where particle precipitation occurs. These observations confirm that such a coupling exists. Model simulations of this event indicate that the NO<sub>y</sub> formed can be transported to the stratosphere and lead to reductions of stratospheric ozone near 25-35 km and at mid to high latitudes. The attached figure illustrates, at two latitudes (78.8°N and 78.8°S), the ratio of NO<sub>y</sub> with the event included to NO<sub>y</sub> absent such an event, and the percentage reductions of ozone as a result of the event. In the southern hemisphere, the descent of the NO<sub>y</sub> with the ozone destruction is clearly evident. In the northern hemisphere, there is upward motion during this period, and the NO<sub>y</sub> is photochemically destroyed. Such events occur continually with varying intensity and represent a solar-terrestrial coupling mechanism capable of altering stratospheric ozone levels.

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### Langley Solar Energy Data Helps Feed and Power the World

Samuel Pierpont Langley, the great pioneer of aeronautics and atmospheric science, was a strong believer in the economic advantages of solar power. He developed an early device to measure solar power, and said; "there is an immense fund of possible mechanical power still coming to us from him [the Sun] which might be economically utilized. ... Whoever finds the way to make industrially useful the vast sun-power now wasted on the deserts of North Africa or the shores of the Red Sea, will effect a greater change in men's affairs than any conqueror in history has done" Continuing in the tradition of the man who gave us our name, NASA-Langley researchers play important roles in the three Earth Science priority areas concerned with energy and/or the environment at the Earth's surface. Satellite data as well as ground site measurements are critical to this research. Key research projects have been the Earth Radiation Budget Experiment (ERBE), World Climate Research Program Surface Radiation Budget (WCRP/SRB), and the Clouds and Earth Radiant Energy System (CERES). During 1997, a portion of that scientific data has been converted to Surface Solar Energy (SSE) parameters that are useful to the solar and renewable energy industries. The global, satellite-derived SSE data set contains 52 monthly-averaged values developed under consultation with the DOE National Renewable Energy Laboratory (NREL). These values, an innova-

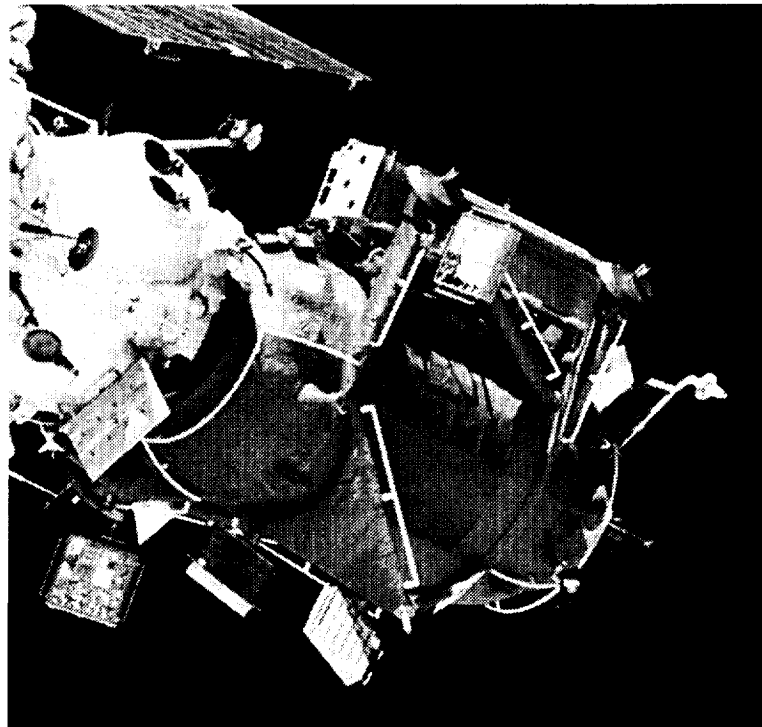


**Figure 71. Average Total Horizontal-Surface Down (March 1985-1988). (Note: Figure is in color on Internet version of this report.)**

tive synthesis of the WCRP/SRB data set and International Satellite Cloud Climatology (ISCCP) cloud data, provide our research results in ways most useful to solar power industries. The SSE data set is internationally accessible at [http://eosweb.larc.nasa.gov/DATDOCS/Surface\\_Solar\\_Energy.html](http://eosweb.larc.nasa.gov/DATDOCS/Surface_Solar_Energy.html). Graphics can be printed from the web site. The figure depicts solar power at the surface of the Earth for an average July. This data set is invaluable to industry, specifically in remote areas of the world where ground measurement data is inadequate or missing. The SSE data set can be used alone, and in conjunction with ground measurement data (available from NREL), to justify funding and to size solar energy systems. In addition, this data may also be incorporated into programs created for professional and educational purposes, which are then used for sizing new systems. With help from NASA-Langley, S. P. Langley's vision of a great "change in men's affairs" is taking place. Solar Cookers International, a non-profit organization, used the SSE data in negotiating funding to place solar cookers in several refugee camps around the world. Sun Frost, a small business producing energy efficient refrigeration systems, used the data for sizing solar energy systems to operate more reliable and less expensive vaccine storage refrigerators. These refrigerators will be placed in equatorial regions of the world where electricity is not readily available. Consultants on Household Uses of Solar Energy (CHUSE), is providing SSE data set values to a professor of archeology for her dig in the Andes of Argentina. She intends to use solar cookers, since there is little biomass available for fuel. Boeing, Advanced Power Programs, can use the SSE data set to assess regional placement of Solar Two, a large-scale solar power plant.

(A. B. Carlson, 757-864-7050; a.b.carlson@larc.nasa.gov)

# Human Exploration and Development of Space Enterprise



## Mir Environmental Effects Payload (MEEP)

MEEP consists of a family of four science experiments; the Passive Experiment Carrier (PEC), the Polished Plate MicroMeteoroid and Debris (PPMD), the Passive Optical Sample Assembly I and II, and the Orbital Debris Collector (ODC), which are deployed on a common carrier.

## **Mission**

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To open the Space frontier by exploring, using and enabling the development of Space and to expand the human experience into the far reaches of Space.

## **Purpose:**

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To improve the quality of life on Earth, to inspire and motivate our citizens, and to bind people together.

## **Goals:**

---

- Prepare to conduct human missions of exploration to planetary and other bodies in the solar system;
- Use the environment of space to expand scientific knowledge;
- Provide safe and affordable human access to space, establish a human presence in space, and share the human experience of being in space; and
- Enable the commercial development of space and share HEDS knowledge, technologies, and assets that promise to enhance the quality of life on Earth.



### **Gas Permeable Polymer Materials (GPPM)**

The objective of Gas Permeable Polymer Materials (GPPM) is to study the effects of polymerization in a low gravity environment. The enhancement of physical properties such as oxygen gas permeability and structural stability which may occur during the low gravity polymerization will create a material extremely well suited for the manufacture of contact lenses and other applications and is unobtainable by other methods. GPPM was successfully launched on May 19, 1996. Data distribution was successful, and analysis is continuing. Alliances, partnerships, and customers include Paragon and Old Dominion University.

(J. C. Fedors, 757-864-3771; j.c.fedors@larc.nasa.gov)

### **Photogrammetric Appendage Structural Dynamics Experiment (PASDE)**

The Photogrammetric Appendage Structural Dynamics Experiment (PASDE) is an experiment to mitigate technical risk and cost associated with passive, on-orbit measurement of spacecraft appendages for the International Space Station Program (ISS). The experiment will demonstrate a photogrammetric method for making appendage structural measurements, provide engineering data on solar array designs expected to be used on the ISS, and verify that routine on-orbit spacecraft operations provide sufficient excitation for structural response testing.

On-orbit measurement of spacecraft structural responses are often desired or necessary for structural verification and loads prediction. Typically, acceleration response time-history data is collected and processed on the ground. From this data, structural dynamic characteristics (structural mode frequencies, damping, and mode shapes) can be determined. PASDE successfully photogrammetrically characterized the structural dynamics of a Mir solar array during a Shuttle docking (STS-74, November 1995). The data produced by PASDE is currently being reviewed by the ISS Program to assist in the design of ISS solar arrays.

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### **Enhanced Dynamic Loads Sensors (EDLS)**

EDLS is a crew motion force measurement instrument that is designed to obtain a statistical understanding of the impact crews will have on the microgravity environment of the International Space Station (ISS).

The primary purpose of EDLS is to provide the ISS design engineers with the force and moment range and frequency content of crew motion during the normal performance of duties on long-duration missions. The secondary purpose is to quantify crew adaptation (learning curve) to a micro-gravity environment.

Specific flight objectives include the high-resolution measurement of crew forces and torque transmitted to the Mir Space Station through Intra-Vehicular restraints (handholds and foot restraints) in multiple high activity work areas, and the periodic measurement of crew forces employed in the conduct of repeated, prescribed motions. EDLS was successfully installed and rendered operational on the Russian Mir/Priroda Module in April 1996.

Data was retrieved in August 1996 on STS-79 and is currently being analyzed.

Alliances, partnerships, and customers include the Office of Space Flight, Russian Space Agency, and MIT.

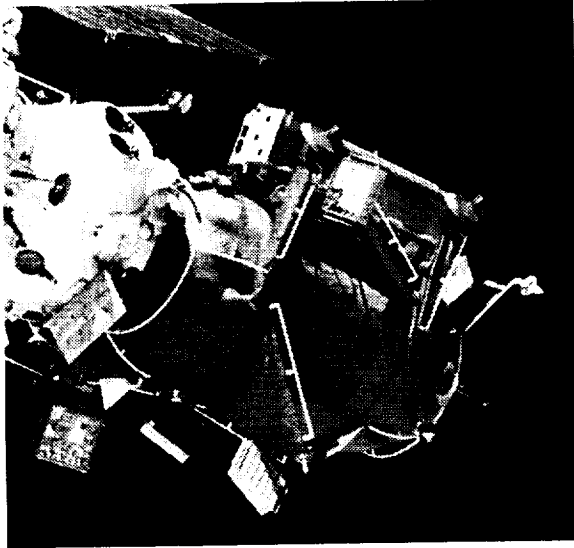
(J. C. Fedors, 757-864-3771; j.c.fedors@larc.nasa.gov)

### **Mir Environmental Effects Payload (MEEP)**

MEEP consists of a family of four science experiments which are deployed on a common carrier (see figure 72).

The Passive Experiment Carrier (PEC) is designed to provide a common carrier for the MEEP environmental risk mitigation science experiments and provide a common interface to the Shuttle and the Mir.

The Polished Plate MicroMeteoroid and Debris (PPMD) is designed to assess and characterize the



**Figure 72. Mir environmental effects payload.**

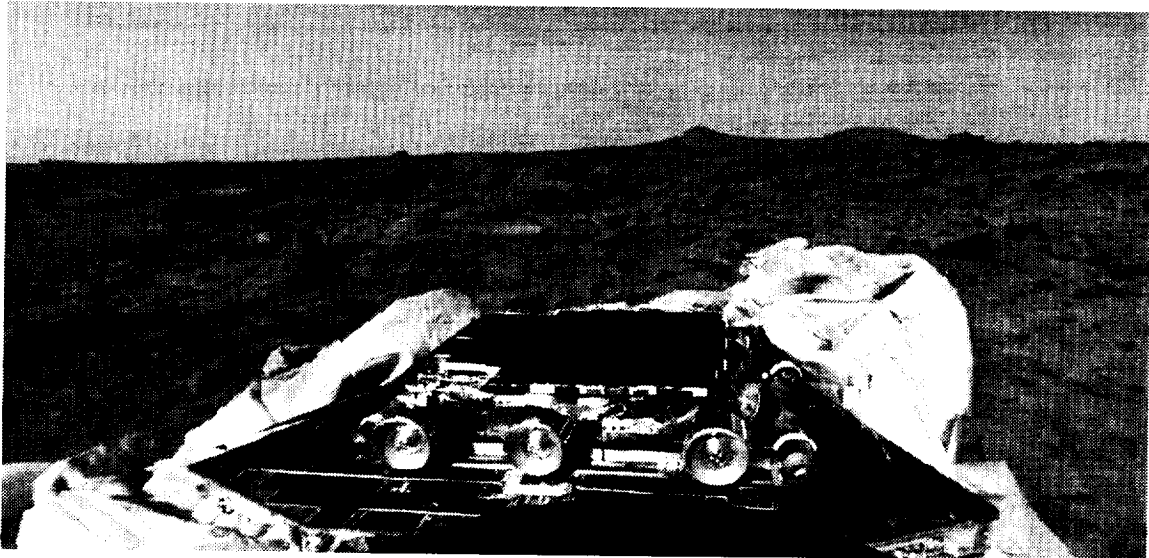
natural micrometeoroid and the man-made debris environment in the Mir high inclination orbit.

The Passive Optical Sample Assembly I and II are designed to assess the magnitude of molecular contamination on the ISS critical surfaces and quantify the performance and degradation rate of candidate/baseline ISS exterior surface materials.

The Orbital Debris Collector (ODC) is designed to capture hypervelocity particles in the Mir environment and return them to earth to determine their composition.

MEEP was successfully launched and deployed in March of 1996, on STS-76, and returned to earth for analysis. Partners and customers include the NASA Office of Space Flight, Russian Space Agency, Boeing, and NASA Marshall Space Flight Center.  
(G. Stover. 757-864-7097; g.stover@larc.nasa.gov)

# Space Science Enterprise



## Mars Pathfinder Atmospheric Entry Simulation

The primary objective of the Pathfinder mission was to develop and demonstrate a low-cost, reliable system for landing on the Mars surface. A six-degree-of-freedom atmospheric flight dynamics simulation was developed at Langley and applied by members of the Pathfinder operations navigation team to ensure successful parachute deployment of the spacecraft. The last planetary missions to land on the surface of Mars successfully were the Mars Viking spacecraft, which were managed by NASA Langley during the 1970's.

## **Mission**

---

- Solve Mysteries of the Universe
- Explore the Solar System
- Discover Planets Around Other Stars
- Search for Life Beyond Earth

## **Enterprise Goals:**

---

1. Establish a virtual presence throughout the solar system, and probe deeper into the mysteries of the Universe and life on Earth and beyond.
2. Pursue space science programs that enable and are enabled by future human exploration beyond low-Earth orbit.
3. Develop and utilize revolutionary technologies for missions impossible in prior decades.
4. Contribute measurably to achieving the science, mathematics, and technology education goals of our Nation, and share widely the excitement and inspiration of our missions and discoveries.

## **Science Goals:**

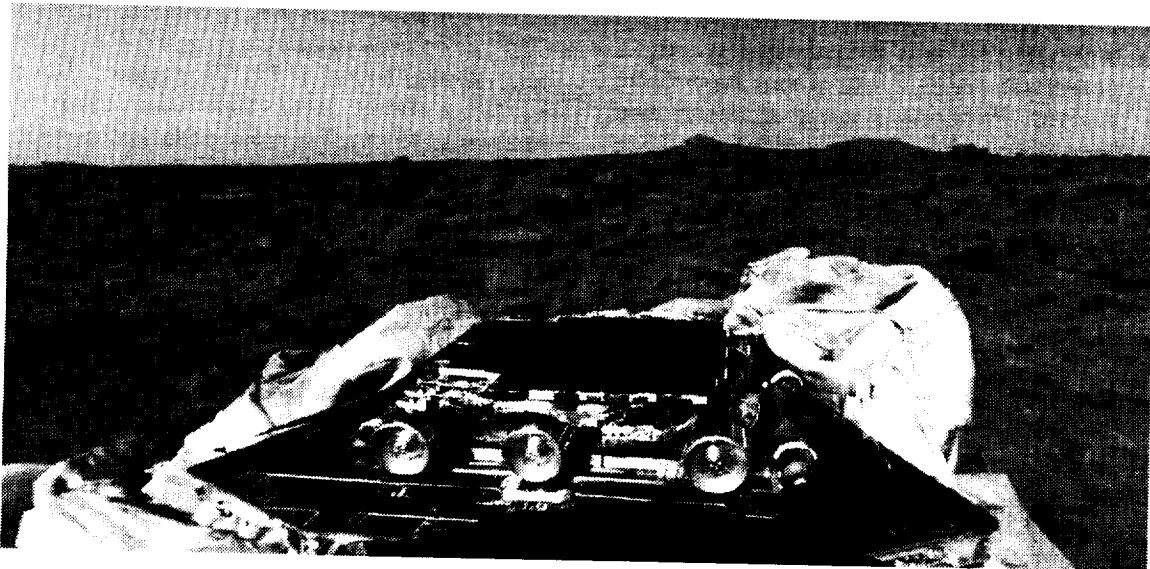
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1. Understand how structure in our Universe (e.g., clusters of galaxies) emerged from the Big Bang.
2. Test physical theories and reveal new phenomena throughout the Universe, especially through the investigation of extreme environments.
3. Understand how both dark and luminous matter determine the geometry and fate of the Universe.
4. Understand the dynamical and chemical evolution of galaxies and stars and the exchange of matter and energy among stars and the interstellar medium.
5. Understand how stars and planetary systems form together.
6. Understand the nature and history of our Solar System, and what makes Earth similar to and different from its planetary neighbors.
7. Understand mechanisms of long- and short-term solar variability, and the specific processes by which Earth and other planets respond.
8. Understand the origin and evolution of life on Earth.
9. Understand the external forces, including comet and asteroid impacts, that affect life and the habitability of Earth.
10. Identify locales and resources for future human habitation within the solar system.
11. Understand how life may originate and persist beyond Earth.

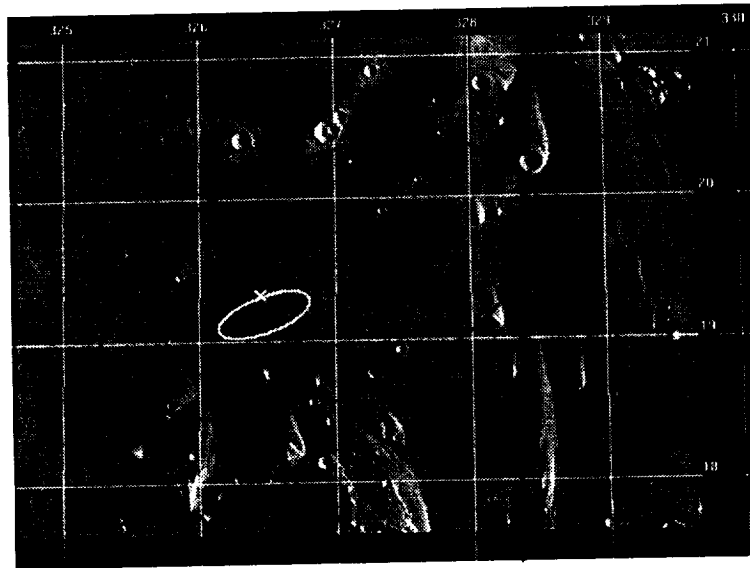
## Mars Pathfinder Atmospheric Entry Simulation

On July 4 1997, the Pathfinder spacecraft ushered in a new era of planetary exploration by successfully landing on the surface of Mars. The primary objective of the Pathfinder mission was to develop and demonstrate a low-cost, reliable system for landing on the Mars surface, shown in Figure 73. In addition to this engineering objective, a focused set of science investigations were performed and several technology elements required for further exploration of Mars were demonstrated. The Pathfinder spacecraft utilized a low-cost EDL (entry, descent, landing) strategy to survive its flight through the Mars atmosphere. Four deceleration mechanisms (aeroshell, parachute, solid-rockets, and airbags) were used to slow the spacecraft from its interplanetary approach velocity to a final velocity of zero. The aeroshell encountered a peak heat rate of approximately  $100 \text{ W/cm}^2$  and a peak deceleration of 16 g's during entry. The parachute was unfurled 171 seconds past the entry interface. This was followed by release of the forebody heatshield and extension of the bridle. A radar altimeter was then used to infer the descent rate and determine the appropriate time of airbag inflation and solid-rocket ignition. After the solid-rocket motors were fired to delete the remaining vertical velocity, the bridle was cut at an altitude of 21 m. The spacecraft then fell to the surface, bouncing more than 15 times before coming to rest.

A six-degree-of-freedom atmospheric flight dynamics simulation, developed at NASA Langley Research Center, was applied by members of the Pathfinder operations navigation team to ensure successful parachute deployment and estimate the Pathfinder landing site during the final entry preparations. This simulation had also been used by the Pathfinder Project Office to assess the impact of off-nominal conditions on the flight system. Outputs from this simulation were used in the design of the Pathfinder heatshield, EDL flight software, and to define numerous hardware. The NASA Langley simulation was based on the application of the six-degree-of-freedom version of the Program to Optimize Simulated Trajectories (6D POST) from the atmospheric interface to parachute deployment. The three-degree-of-freedom version of POST was then used to simulate the descent and landing mission phases. Atmospheric density and pressure profiles derived from Hubble Space Telescope and Earth-based microwave measurements of the Mars atmospheric temperature were employed. Updates to this atmosphere were performed during interplanetary cruise as part of the entry operations procedure. An aerodynamic model developed at NASA Langley from a combination of computational fluid dynamic calculations and existing wind-tunnel and ballistic-range data was employed. This aerodynamic database was valid from entry (in the free molecular flow regime) to parachute deployment. After parachute deployment, aerodynamic drag predictions from Pioneer Aerospace (the parachute manufacturer) were used.



**Figure 73. Pathfinder spacecraft on Mars, July 4, 1997.**



**Figure 74. Mars Pathfinder pre-entry landing site prediction and post-landed estimate.**

During Pathfinder entry operations, the NASA Langley EDL simulations were coupled with the JPL orbit determination software for use by the navigation team to update atmospheric flight estimations. Changes in Pathfinder's estimated atmospheric flight were expected as a result of improved estimates of the atmospheric model and atmospheric interface state vector as the spacecraft approached Mars. By modifying the entry, descent, and landing flight software parameters, the ground controllers could inform the spacecraft of its most likely atmospheric flight conditions. Without this update capability, the likelihood of a successful entry, decent, and landing (particularly, a successful parachute deployment) would have been adversely affected. Pathfinder's entry, descent, and landing software was designed to autonomously guide the spacecraft from cruise-stage separation to a successful landing based on these ground-supplied parameters. Post-flight evaluation of the accelerometer flight data indicates that the parachute was deployed within 2% of the target dynamic pressure and Mach number.

The operations navigation function was most critical in the 36 hours preceding entry, descent, and landing. As Pathfinder approached Mars, small changes in its predicted landing site were expected as a result of increased state knowledge and Mars ephemeris errors. In this period, four opportunities to update the

entry, descent, and landing software parameters and two opportunities to perform a contingency trajectory correction maneuver existed. This final navigation function ended at approximately 6 am PDT on July 4 (4 hours before entry). As the spacecraft approached Mars, the navigation team refined its landing site predictions. The predicted three-sigma landing obtained just prior to entry is shown in Fig. 74. This is the smaller ellipse shown to lie within the larger preflight science requirement ellipse. The predicted landing footprint is approximately 40 x 15 km, centered on a landing site of 19.15 deg N latitude, 33.51 degree W. The landing site determined by the Pathfinder science team is also shown in Fig. 74, denoted with an X. This landed estimate was determined using the lander images to triangulate from observed surface features (craters, knobs, and peaks). The science team estimate (19.33 deg N latitude, 33.55 deg W longitude) placed the spacecraft just 27 km from the navigation target, the center of the science requirement ellipse. A 5 km discrepancy exists between the final pre-entry landed predictions and post-flight position reckoning. A majority of this error is a result of map-tie errors where the Mars surface features were not accurately reflected in an analytical latitude/longitude map. Additionally, post-flight reconstruction analysis has indicated that the spacecraft bounced/rolled as much as 1.5 km before the airbag system stopped.  
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# Technology Partnerships



## Low Temperature Oxidation Catalyst

Catalysts have been developed which can convert the toxic gas carbon monoxide (CO) to nontoxic carbon dioxide (CO<sub>2</sub>) at low (under 100°C) temperatures, and have a variety of commercial applications including making home environments safer.

### Summary of Langley Technology Partnerships

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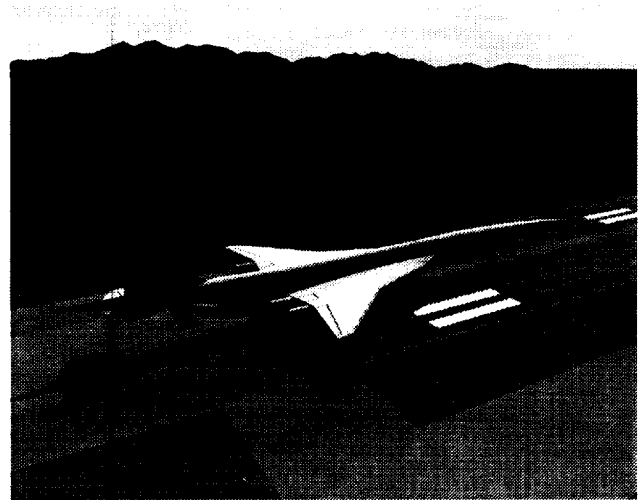
The President, Congress, and the NASA Administrator are emphasizing the value of NASA's research and technology base to U.S. industry in helping to increase industrial competitiveness, provide jobs, and improve the quality of life and the balance of trade. The taxpayers' investment in NASA is an investment in the international competitiveness of U.S. industry through partnerships which take NASA advances and make them available to U.S. industry. Emphasis is being placed both on technology for applications with the aerospace industry and on technology transfer with non-aerospace industry. Relationships are formalized with different agreements, such as patent or copyright licenses and/or Space Act Agreements resulting in benefits to the partner and to the NASA mission. NASA owns approximately 3,000 patents. Although some of these R&D innovations have found their way into industrial spin-offs, most are untapped national treasures. Technology partnerships are key to disseminating information about innovations and promoting their use and industry-led commercialization.

Langley facilitates technology partnerships for the Center, with the primary goal to encourage broader utilization of Langley-developed technologies in the American industrial community.

Implementation of the Center's Technology Transfer and Commercialization Program includes the Center's processes for early identification of technologies of high commercial potential; promoting the expedient transfer of new technologies to the commercial sector; achieving the non-aerospace uses of Langley technology by identifying potential technology applications and creating teams of non-aerospace customers and Langley technologists to accomplish the transfer process; coordinating the Langley program with appropriate NASA Headquarters offices, other NASA centers, and other government agencies; and supporting the technology transfer process for Aerospace customers.

Some examples of Langley successes in commercialization are:

- PETI-5—Scientists at NASA's Langley Research Center developed a high temperature resin called PETI-5. The composite was recently selected for use in a U.S. supersonic civil airliner expected to be built early in the next century (figure 75). A panel studying new technologies has chosen this NASA-developed, high-performance composite material as one of the 100 most technologically significant new products and processes of 1997. The 75 member panel worked

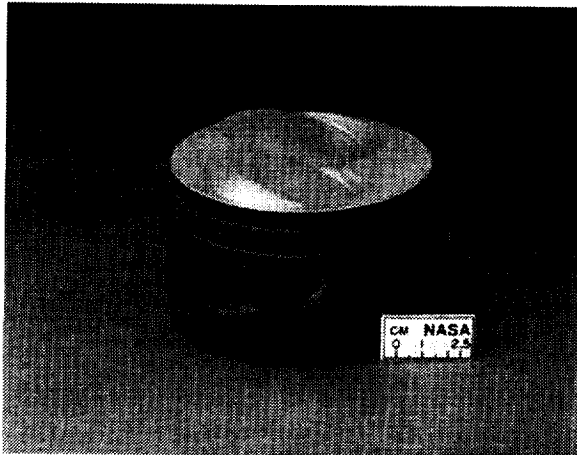


**Figure 75. Next-generation supersonic passenger jet.**

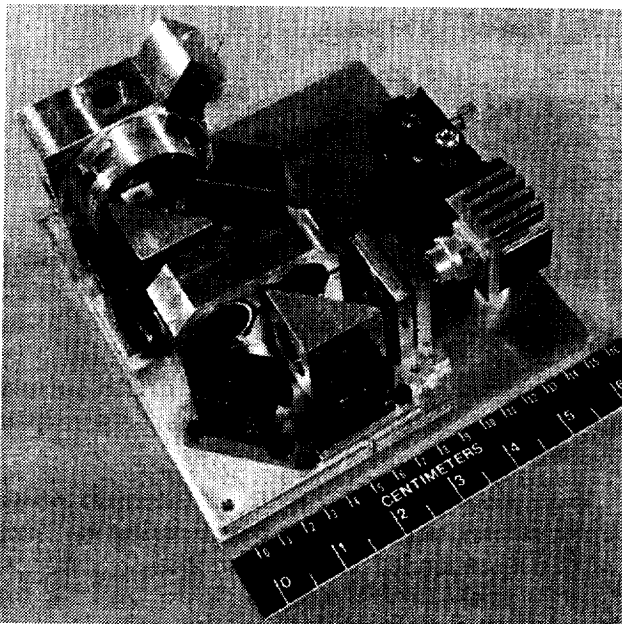
on behalf of the *Research and Development Magazine* to select PETI-5 for this international honor. This technology has already been transferred to industry with licensing agreements to four different companies.

- CARBON-CARBON PISTONS—Under a joint project with the United States Army, NASA determined that it was feasible to fabricate pistons with carbon-carbon materials (figure 76). These pistons are being considered for high performance commercial applications (motor racing). Pistons used in high-performance internal combustion engines are usually made of aluminum alloy. However, carbon-carbon—a tough, heat resistant, space age material consisting of carbon fibers embedded in a carbon matrix—offers significant weight savings and much higher temperature capability and dimensional stability over aluminum. Carbon-carbon also has self-lubricating properties and is non-galling. With these advantages, engine performance improvements and emissions reductions are possible which would not be attainable using aluminum piston technology. This NASA technology has been licensed to Hitco Technologies in California.
- GAS FILTER CORRELATION RADIOMETER (GFCR)—A sensor, originally developed to measure gases in the Earth's atmosphere from an aircraft or satellite (figure 77), now offers an economical solution to many ground-based monitoring applications. MERCO Inc., an air quality consulting firm, has licensed Langley's remote gas sensor. Under the agreement, the sensor will





**Figure 76. Carbon-carbon piston.**



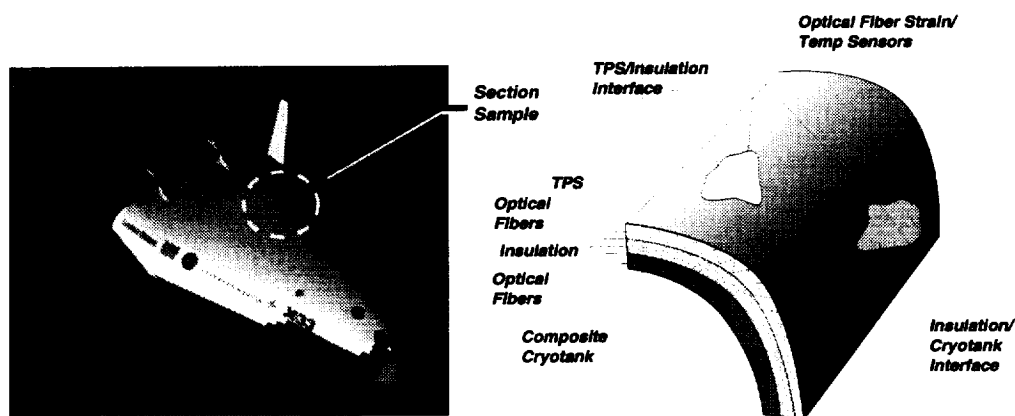
**Figure 77. Gas filter correlation radiometer (GFCR).**

be used to monitor gaseous pollutants from petroleum refineries and chemical manufacturing facilities. GFCR accurately measures concentrations of key gas species, including carbon monoxide, methane and nitrogen oxides. The device relies upon electro-optical techniques, rather than mechanical techniques, to switch its internal optical paths. This offers distinct advantages such as a faster response rate, higher reliability, lower weight and a more compact design.

- **FIBER-OPTIC STRAIN SENSOR**—NASA researchers have developed a fiber optic based distributed strain sensor (figure 78) to be used as part of a Vehicle Health Monitoring system (VHM) for sensing cracks, deformations, temperature fluctuations and gas leaks of aerospace vehicles and structures. The system will help determine the vehicle's global state of health thus reducing unnecessary inspections and therefore reduce life cycle costs. The strain and temperature sensors were tested on a prototype composite liquid hydrogen fuel tank and a scaled up version will fly late 1999 on Lockheed Martin's Reusable Launch Vehicle (RLV) demonstrator, X-33. The strain sensor technology received the 1997 Discover Award for Technological Innovation in the Aviation & AeroSpace Category. This award was one of the 35 finalists selected out of approximately 4,000 innovators.

- **LOW TEMPERATURE OXIDATION CATALYST**—Catalysts have been developed (figure 79) which can convert the toxic gas carbon monoxide (CO) to nontoxic carbon dioxide (CO<sub>2</sub>) at low (under 100°C) temperatures. The original catalyst was developed at Langley for the regeneration of CO<sub>2</sub> in space-based CO<sub>2</sub> lasers, but it and other closely related catalysts have been found to have very significant non-aerospace applications as well. In addition to the many non-aerospace applications already reported in the past, there have been new applications of this family of oxidation catalysts to (1) the monitoring and conditioning of exhaust gases from automobiles and other internal combustion engine powered machines (AirFlow Catalyst Systems, Inc. of Rochester, NY, and STC Catalysts, Inc. of Hampton, VA), and (2) the sensing/monitoring of CO and other gases in work and home environments (American Gas & Chemical Company, Ltd., of Northvale, NJ). Joint development activities between Langley and these companies are making substantial progress towards pre-production prototypes and initial products in both application areas are expected to be available by the end of 1998. STC Catalysts, NASA's patent licensee for CO<sub>2</sub> laser applications of the catalysts, had a NASA technology-based product available for sale in June 1996, and has since sold almost 100 of these catalyst products.

Other examples of Langley technology partnerships include advanced polymer materials; new technology for digital mammography; LARC™-SI; the personnel locator; medical technology for use in



**Reusable Launch Vehicle (RLV)**

**Smart Structure Attributes**

- Large Area Detection Of Cold/Hot Spots Due To Cryoinsulation/Tank/TPS Damage
- Full Field Strain Measurement On Cryotank And Primary Structure
- Low Weight/Size Impact on Vehicle

**Figure 78. Distributed sensing for integrated vehicle health monitoring (IVHM).**



**Figure 79. Low temperature oxidation catalyst.**

dentistry, head trauma, assessing mental concentration, etc.; new carbon-carbon materials; and others.

There were 124 Invention Disclosures, 72 patent applications, and 35 patents granted from NASA Langley Research Center Programs during fiscal year 1997. There were 16 executed licenses, bringing the Langley total to 54. Thirty-nine Space Act Agreements were signed, with 26 representing non-aerospace industries.

There were also 58 SBIR (Small Business Innovation Research Program) contracts funded at the Phase I level and 24 funded at the Phase II level, representing small businesses across the nation. Over the past year, Langley received almost 400 inquiries about NASA developed technologies.

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