NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WEATHER PROGRAMS

The National Aeronautics and Space Administration (NASA) Headquarters Weather Support Office has continued to improve NASA's weather support capabilities for both manned and unmanned space launch vehicles. It is expected that these improvements will strengthen and enhance the information provided to the ground-based decision-makers and astronaut observers to insure that NASA achieves the best operational posture for Space Shuttle launches and landings. The goal of the operations program is to provide the specialized meteorological data needed by operational forecasters at Cape Canaveral Air Station of Kennedy Space Center (KSC) and Johnson Space Center to support the Space Shuttle program. The focus is on detecting and forecasting the mesoscale weather events which strongly impact Shuttle ground processing, launches, and landing operations.

OPERATIONS

The goal of the National Aeronautics and Space Administration (NASA) operations program is to provide the specialized meteorological data needed by forecasters at Cape Canaveral Air Station and the Spaceflight Meteorology Group at Johnson Space Center (JSC) to support the Space Shuttle and Expendable Launch Vehicle programs. The focus is on detecting and forecasting the mesoscale weather events that strongly impact ground processing, launch, and landing operations. The NASA Headquarters Weather Office was closed in FY 1998 and the responsibilities transferred to the Kennedy Space Center (KSC) Weather Office.

This goal requires exploitation of the latest technology. The Applied Meteorology Unit (AMU), collocated with the Air Force's Range Weather Operations, provides a facility to evaluate and, if warranted, transition new meteorological technology into operations. For instance, the AMU strives to develop techniques and systems to help predict and avoid the impacts of KSC's frequent mesoscale summer thunderstorms which endanger the ground processing, launch, and landing operations of the American Space Program—Space Shuttle, DOD, and commercial. Special attention has been given to evaluating mesoscale numerical models. The AMU functions under a joint NASA, Air Force, and National Weather Service Memorandum of Understanding.

Budget items are expected to remain relatively stable between 1999 and 2000. Development of the new toxic model system (Eastern Range (ER) Dispersion Assessment System (ERDAS)) was completed in March 1999. ERDAS will replace the current ER/KSC two-dimensional toxic model with a 4-D model. NASA was the contracting agency for ERDAS development; funding was sent to NASA/KSC by Air Force. Operational implementation will occur slowly as the day to day capabilities and limitations of ERDAS are evaluated and documented. Development of the Advanced Algorithm for the Lightning Detection and Ranging (LDAR) system will finish in FY 1999. The new capability was used to develop a cost-effective method to transfer LDAR data to JSC.

Development of the Very Short Baseline LDAR system has encountered technical challenges and will be extended into FY 2000. After development, the technology will be transferred to a commercial firm which is currently working under a Space Act Agreement with NASA to commercialize LDAR. A new Airborne Field Mill (ABFM) data gathering program is under study at KSC. KSC has already forwarded $100K to Marshall Space Flight Center (MSFC) to build field mills for the program. In FY 1999, approximately $100K will be spent to install the mills, certify the system, and pay for flight hours to gather data at Kwajalein in conjunction with a NASA field experiment. Pending the results of this field experiment, NASA will consider a separate data gathering program at KSC/Eastern Range. The operations budget will decrease 25 percent in FY 2000 only because the $1.1M renovation of the 500 foot weather tower will have been completed. A major project to procure visibility sensors in the data sparse area west of KSC was begun in FY 1999 and will finish in FY 2000. Forecasts and observations for KSC are provided by Air Force meteorologists and contractors. KSC cost shares with the Air Force the expense of operating and maintaining (O&M) the Eastern Range's extensive meteorological network—KSC contributes 40 percent.

SUPPORTING RESEARCH

The supporting research activities are sponsored by the NASA's Earth Science Enterprise (ESE). The purpose of the ESE is to understand the total Earth system and the effects of natural and human-induced changes on the global environment. Earth science is pioneering the new interdisciplinary field of research called Earth system science, born of the recognition that the Earth's land surface, oceans, atmos-

phere, ice sheets and biota are both dynamic and highly interactive. It is an area of research with immense benefits to the nation, yielding new knowledge and tools for weather forecasting, agriculture, water resource management, urban and land use planning, and other areas of economic and environmental importance. In concert with other agencies and the global research community, Earth science is providing the scientific foundation needed for the complex policy choices that lie ahead on the road to sustainable development. Earth science has established three broad goals:

- Expand scientific knowledge of the Earth system using NASA's unique capabilities from the vantage points of space, aircraft and *in situ* platforms
- Disseminate information about the Earth system
- enable productive use of Earth science program science and technology in the public and private sectors.

The ESE has evolved from what was previously called the Mission to Planet Earth Enterprise.

STRATEGY FOR ACHIEVING GOALS

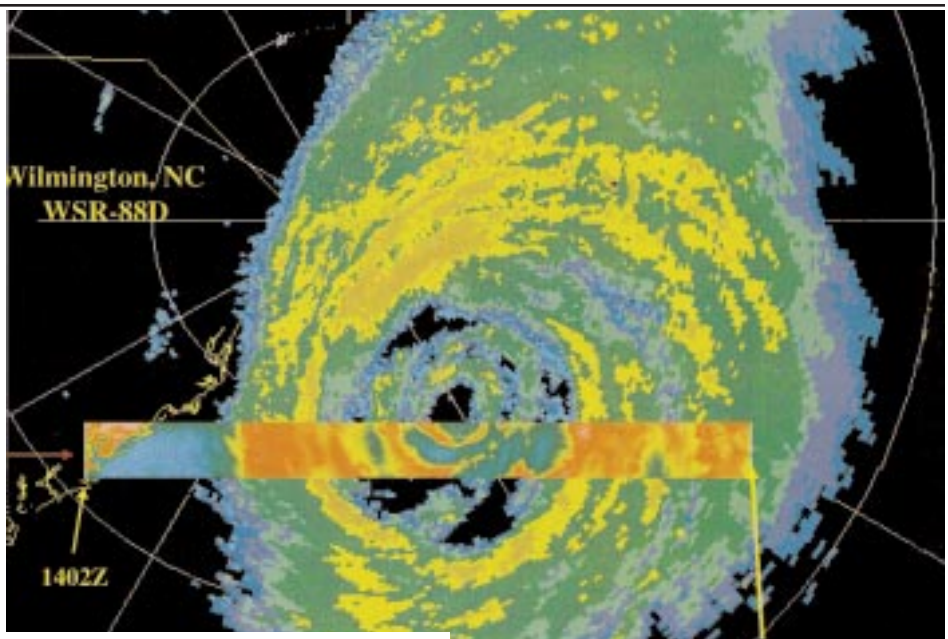
The pursuit of Earth system science would be impractical without the continuous, global observations provided by satellite-borne instruments. Earth science comprises an integrated slate of spacecraft and *in situ* measurement capabilities; data and information management systems to acquire, process, archive, and distribute global data sets; and research and analysis projects to convert data into new knowledge of the Earth system. Numerous users in academia, industry, federal, state, and local government tap this knowledge to produce products and services essential to achieving sustainable development. Earth science is NASA's contribution to the United States Global Change Research Program (USGCRP), an interagency effort to understand the processes and patterns of global change.

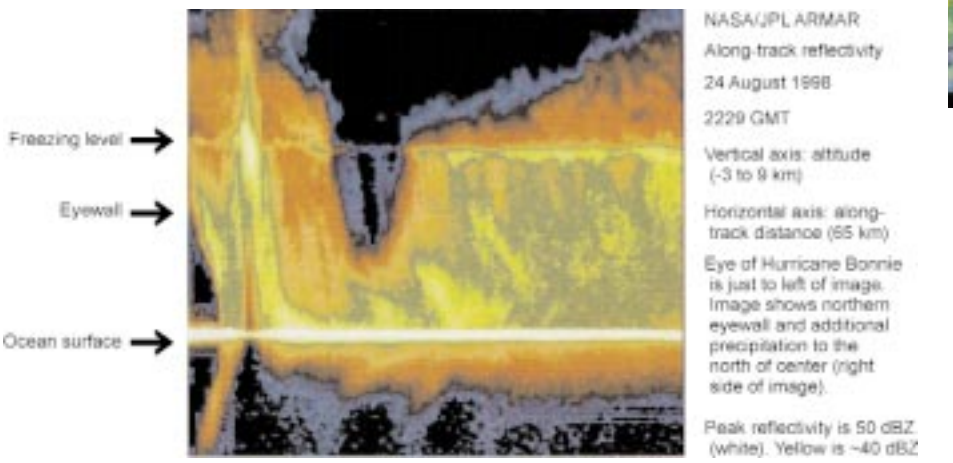
The Earth Observing System (EOS), the centerpiece of Earth science, is a program of multiple spacecraft (the AM, PM, Chemistry, Landsat-7, and follow-on and supporting technology) and interdisciplinary science investigations to provide a data set of key parameters needed to understand global climate change. The first EOS satellite launches will begin in 1999. Preceding the EOS were a number of individual satellite and Shuttle-based missions which are helping to reveal basic processes. The Upper Atmosphere Research Satellite (UARS), launched in 1991, collects data on atmospheric chemistry. The Total Ozone Mapping Spectrometer (TOMS) instruments, launched in 1978, 1991, and 1996, measure ozone distribution and depletion. Two TOMS instruments were launched in 1996, one on the Japanese Advanced Earth Observing System (ADEOS) mission and the other on a dedicated United States Earth Probe. France and the United States collaborated on the Ocean Topography Experiment (TOPEX/Poseidon), launched in 1992, to study ocean topography and circulation. The NASA Scatterometer (NSCAT) mapped ocean winds for one year prior to an on-orbit failure of the Japanese ADEOS-I. In 1997, the Tropical Rainfall Measuring Mission (TRMM) was launched to provide the first-ever measurements of tropical precipitation on a global scale.

Complementing EOS, under the Earth Probes Program, will be a series of small, rapid development Earth System Science Pathfinder (ESSP) missions to study emerging science questions and to use innovative measurement techniques in support of EOS. The first two ESSP missions, Vegetation Canopy LIDAR (VCL) and Gravity Recovery and Climate Experiment (GRACE) are scheduled for launch in 2000 and 2001, respectively. The next ESSP missions were selected in December 1998. NASA has chosen for development one primary and two alternate small spacecraft missions. The Pathfinder Instruments for Cloud and Aerosol Spaceborne Observations - Climatologie Etendue des Nuages et des Aerosols (PICASSO-CENA) mission, co-led by NASA's Langley Research Center and the Institut Pierre Simon Laplace, Paris, France will be the next ESSP mission scheduled for launch in 2003. In addition, NASA has chosen two additional missions, CloudSat and the Volcanic Ash Mission (VOLCAM), for further study at the present time. Based on the study results, NASA may select one of these missions for full development and the other as the alternate mission. Continuing with the recommendation from the 1997 Earth Science Biennial Review, a process is currently under way to define concepts for science and applications missions in the post-2002 time frame. In developing its measurement/mission strategy, the ESE desires to reduce the risk to overall program objectives from any single mission failure by developing smaller, less expensive missions and implementing shorter development cycles from mission definition to launch. The objectives are to further develop the scientific measurement strategy implemented in the first series of EOS satellite missions and to take advantage of the latest instrument technologies. Shorter development times will allow more flexible responses to current and evolving scientific priorities and more effective uses of the latest technologies. In accordance with this philosophy, the implementation of each future mission in the ESE flight program will be based on a competitive selection of instrument payloads and implementation options. It is important, under this new approach, that instrument technology developments be conducted largely before the relevant mission payload selection. A science and applications-based flight mission profile is indispensable to guide these pre-mission technology developments.

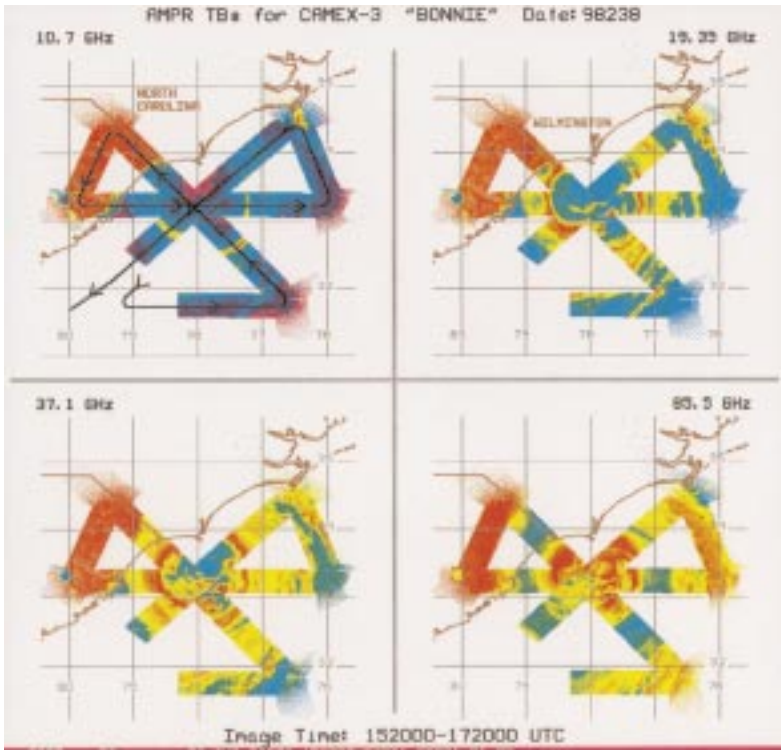
NASA
Hurricane Research Activities

Swath of AMPR data at 37.1GHz. ER–2 flight track begins at the western end at 1402Z, and proceeds due east ending at 1432. Note the excellent correlation of rain banding in the western wall cloud and into the eye which as this time was exhibiting a double eyewall structure.





Airborne Rain Mapping Radar image of Hurricane Bonnie from NASA's DC-8.



Passive Microwave Images from multiple passes on NASA's ER-2 research aircraft.

Figure 3-NASA-1. NASA Hurricane Research activities.

We have obtained a first round of ideas from the science and applications communities for post-2002 mission concepts and are using them to build a nominal multi-mission profile for Earth observation satellite missions in the 2003-2010 time frame.

The purposes of the multi-mission profile are:

- To guide science and application research investments in preparation of the missions;
- To guide ESE technology investment in preparation of the missions; and
- To constitute the basis for discussion with potential commercial and international partners having missions in that time frame for potential cost sharing, collaboration, and partnerships.

The ESE intends to refresh periodically this nominal mission profile through similar consultations with the Earth system science and applications communities. We do not intend to create a 10-year queue of missions, but to promote a theme or focused area at a time leading to selection of one or two missions in each cycle.

Data from Earth science missions, both current and future, will be captured, processed into useful information, and broadly distributed by the EOS Data Information System (EOSDIS). EOSDIS will ensure that data from these diverse missions remain available in active archives for use by current and future scientists. Since these data are expected to find uses well beyond the Earth science research community, EOSDIS will ultimately be accessible by environmental decision-makers, resource managers, commercial firms, social scientists and the general academic community, educators, state, and local government-anyone who wants the information.

Following the recommendation of the National Research Council, NASA is exploring the creation of a federation of Earth science information partners in academia, industry, and government to broaden the participation in the creation and distribution of EOSDIS information products. As a federation pilot project, 24 organizations were competitively selected in December 1997 to become Earth Science Information Partners (ESIPs) to develop innovative science and applications products.

The intellectual capital behind Earth science missions, and the key to generating new knowledge from them, is vested in an active program of research and analysis. Over 1,500 scientific research tasks from nearly every United States state are funded by the Earth science research and analysis program. Scientists from seventeen other nations, funded by their own countries and collaborating with United States researchers, are also part of the Earth science program. These researchers develop Earth system models from Earth science data, conduct laboratory and field experiments, run aircraft campaigns, develop new instruments, and, thus, expand the frontier of our understanding of our planet. ESE-funded scientists are recognized as world leaders in their fields, as exemplified by the award of the 1995 Nobel Prize in chemistry to the two scientists who investigated the threat of cholorfluorocarbons to upper atmospheric ozone. The research and analysis program is also the basis for generation of application pilot programs that enable universities, commercial firms, and state and local governments to turn scientific understanding into economically valuable products and services.

The first Earth Science Research Plan was published in 1996. The plan laid out a strategy for study in five Earth system science areas of maturing scientific understanding and significant societal importance: land-cover and land use changes; short-term climate events, natural hazards research and applications; long-term climate change research; and atmospheric ozone research. The plan also outlined some twenty related areas of research which round out the Earth science contribution to Earth system science.

The challenges of Earth System Science, sustainable development, and mitigation of risks to people, property and the environment from natural disasters, require collaborative efforts among a broad range of national and international partners. As mentioned above, the USGCRP coordinates research among ten United States government agencies. NASA is by far the largest partner in the USGCRP and providing the bulk of USGCRP's space-based observational needs. NASA has extensive collaboration with the National Oceanic and Atmospheric Administration (NOAA) on short-term climate event prediction. The ESE is the responsible managing agent in NASA for the development of NOAA's operational environmental satellites. NOAA, NASA, and the Department of Defense (DOD) jointly work to achieve the convergence of civilian and military weather satellite systems. NASA collaborates with the United States Geological Survey (USGS) on a range of land surface, solid Earth and hydrology research projects. NASA, NOAA, and USGS collaborate in the Landsat-7 program; NASA, DOD, and USGS are working together on a third flight of the Shuttle Radar Laboratory modified to yield a digital terrain map of most of the Earth's surface. NASA participates in the World Climate Research Program, the International Geosphere/Biosphere Program, and the ozone assessments of the World Meteorological Organization.

International cooperation is an essential element in the Earth science program. Earth science addresses global issues and requires international involvement in its implementation and application. Acquiring and analyzing the information necessary to address the science questions is a bigger task than a single nation can undertake. Furthermore, the acceptance and use of

the scientific knowledge in policy and resource management decisions around the world require the engagement of the international scientific community. Global data and global participation are needed to devise a global response to environmental change. In addition, integrating our complementary science programs can result in fiscal benefits to the NASA program. For this reason, NASA has sought and nurtured international partnerships spanning science, data and information systems, and flight missions. Most of Earth science's satellite missions have international participation, ranging from simple data sharing agreements to joint missions involving provision of instruments, spacecraft, and launch services. In the past three years, over 60 international agreements have been concluded and more than 40 more are pending. In some capacity, Earth science programs involve international partners from over 35 nations, including Argentina, Armenia, Australia, Belgium, Brazil, Canada, Chile, China, Denmark, Egypt, France, Germany, India, Israel, Italy, Japan, Mongolia, Russia, South Africa, Ukraine, and others.

While our mission, goals and objectives remain unchanged, our implementation approach continues to evolve. We remain guided by key over-arching Earth science questions while we refine the contributing, lower level questions in response to recent science results. We are using these science questions to drive our technology investment decisions. We have begun the process of identifying post-2002 mission concepts based on how much a given concept contributes to answering a specific science question.

During FY 2000, our first priority is to ensure the success of the Landsat-7 and AM-1-1 missions and that a viable data management system is in place to support the data flow from these missions. We must also sustain support for our other flagship EOS PM, Chemistry, Ice, Cloud, and land Elevation Satellite (ICESat) missions, and sustain Earth Science System Pathfinders (ESSPs) at a viable level.

In addition to ensuring a robust science program, the FY 2000 budget initiates a vigorous Advanced Technology program that supports development of key technologies to enable our future science missions. In addition to our baseline technology program that includes NMP, Instrument Incubator and HPCC, an Advanced Technology Initiative will identify and invest in critical instrument, spacecraft and information system technologies. The ESE will lead the way in the development of highly capable, remote and in situ instruments and the information system technologies needed to support coupled Earth system models. Together, they will enable affordable investigation and broad understanding of the global Earth system.

The ESE will emphasize the development of information system architectures to increase the number of users of Enterprise information from hundreds to tens of thousands, with the goal of providing easy access to global information for science, education and applications. Finally, ESE will work in partnership with industry and operational organizations to develop the capabilities and infrastructure to facilitate the transition of sustained measurements and information dissemination to commercial enterprises.

ESE's technology strategy seeks to leverage the entire range of technology development programs offering benefits in cost, performance and timeliness of future Earth science process and monitoring campaigns. ESE's strategy is to establish strong links to other government programs in order to maximize mutual benefit to use open competitions for ESE-sponsored technology programs to attract the best ideas and capabilities from the broad technology community, including industry and academia.

Technology efforts will be made in the following areas:

- Advanced instrument and measurement technologies for new and/or lower cost scientific investigations;
- Cutting-edge technologies, processes, techniques and engineering capabilities that reduce development and operations costs and that support rapid implementation of productive, economical, and timely missions;
- Advanced end-to-end mission information system technologies, technologies effecting the data flow originating at the instrument detector through data archival, for collecting and disseminating information about the Earth system and enabling the productive use of Enterprise science and technology in the public and private sectors.

From FY 2000 on, ESE will increase emphasis on a viable Applications, Commercial and Education program that will bridge our focused research R&A and mission science investments with the Commercial Remote Sensing Program towards addressing key environmental problems of societal relevance.

The EOS AM-1 will be launched in 1999. This mission will provide key measurements that will significantly contribute to our understanding of the total Earth system. The AM-1 instrument complement will obtain information about the physical and radiative properties of clouds, air-land and air-sea exchanges of energy, carbon, and water, measurements of trace gases, and volcanology.

Landsat-7 is also scheduled for launch in 1999. Landsat-7 will carry a single instrument, the Enhanced Thematic Mapper Plus (ETM+), which will make high spatial resolution measurements of land surface and surrounding coastal regions. This mission will provide data continuity with previous Landsat measurements. Landsat data is used for global change research, regional environmental change studies, and other civil and commercial purposes.

With the EOS main missions, such as AM-1 and Landsat-7 that will be launched in 1999, NASA will begin to turn flight data into information. In addition to the EOSDIS that will produce data products for a wide range of users, NASA is engaging in a variety of activities to extend the utility of Earth Science data to a broader range of users such as regional Earth science applications centers, Earth science information partners, and efforts are under way to fuse science data, socio-economic data and other data sets that can be "geo-referenced" in readily understandable data visualizations. The first of two cooperative missions with the Russian Space Agency (RSA), the Meteor-3M(1) Stratospheric Gas and Aerosol Experiment (SAGE III) mission, is planned for launch in 1999. This mission will collect global profiles of key gaseous species from the troposphere to the mesosphere. The science team will investigate spatial and temporal variability and investigate the effects of aerosols and clouds on the Earth's environment. The Russian METEOR-3M(2) spacecraft is planned to carry the last planned TOMS into orbit in 2000, providing continuity in the essential measurement of the total column of ozone in the stratosphere. However, due to Russian indications that they cannot meet this launch date, NASA is exploring other options.

Five commercial data purchase contracts were awarded in 1998 through the Commercial Remote Sensing Program. Data products will be developed and delivered over the next two years.

The QuikScat spacecraft is ready for launch and is awaiting a launch opportunity. The planned launch in December 1998 was delayed pending the results of the investigation into the failure of a USAF Titan IV launch vehicle earlier in 1998 and related issues with the Titan II. QuikScat, carrying instruments to collect sea surface wind data, will fill the gap in such critical data between ADEOS 1, which failed in June 1997 after seven months on-orbit, and ADEOS II. The availability of components of the Seawinds instrument originally planned for launch on Japan's ADEOS II was accelerated to fly on QuikScat. At present, QuikScat is scheduled for launch in late April 1999. Japan has yet to decide on the timing and form of an ADEOS II mission (or missions), but Earth Science still intends to fly a Seawinds instrument in that context as the follow-on instrument to QuikScat. This will enable continuity of the ocean winds data. In parallel to this development effort, a data buy solicitation for ocean and wind vector data was completed.

Other planned Earth science launches include the Active Cavity Radiometer Irradiance Monitor Satellite (ACRIMSat) and the Hyperspectral EO-1 mission in 1999.

The measurements to be made by these and other future Earth science missions as well as current on-orbit missions provide data products that are used extensively in the Earth science program. These activities are providing an ever increasing scientific understanding of global environment and the effects.

AVIATION WEATHER RESEARCH

NASA is performing research that will substantially improve the display of weather information in the cockpit, will provide dramatic improvements in synthetic vision (electronic vision aids to see at night in poor visibility), turbulence detection and icing protection. The research applies to commercial aviation as well as general aviation. Some of the research makes extensive use of data from the Global Positioning System (GPS) satellite network.

Aviation Safety Program

NASA's Aviation Safety Program is aggressively pursuing three primary areas:

- Aviation Weather Information Distribution and Presentation: This includes combining the inputs from a variety of sources of weather data into a convenient, cockpit display that is simple and easy for the pilot to comprehend. It will likely be a multifunction flat panel display that will display all forms of weather, terrain and traffic hazards. The Advanced Air Transport Technology element is contributing the early work here in hazard avoidance displays and planning.
- Synthetic Vision in the Cockpit: This is the development of electronically enhanced vision which "fuses" the inputs from television, infrared, Lidar, and radar sensors into a single head-up-display (HUD) the pilot will look through as he or she looks out the window (Figure 3-NASA-2). This see-through HUD will make the world look like a bright sunny day even when the airplane is approaching a fogged-in airport at midnight--one that would be shut down under today's operating rules.
- Turbulence Detection: This is the develop-ment of aircraft-mounted, forward looking turbulence detectors that look several kilometers ahead of the aircraft using Lidar (and perhaps radar) technology. A suitable cockpit warning device would alert pilots of impending encounters. There is also work in ground based detection.

NASA's Icing Research is pursuing a large number of areas that affect aircraft in flight. Primary examples of this effort are:

The development of icing training videos and other materials will help educate pilots on all aspects of aviation icing.

- The development of improved wind tunnel and analytical techniques to predict icing accumulation patterns on wings, tails and inlets will help designers improve future aircraft and engines.
- Forward looking, aircraft mounted detectors will detect moisture laden

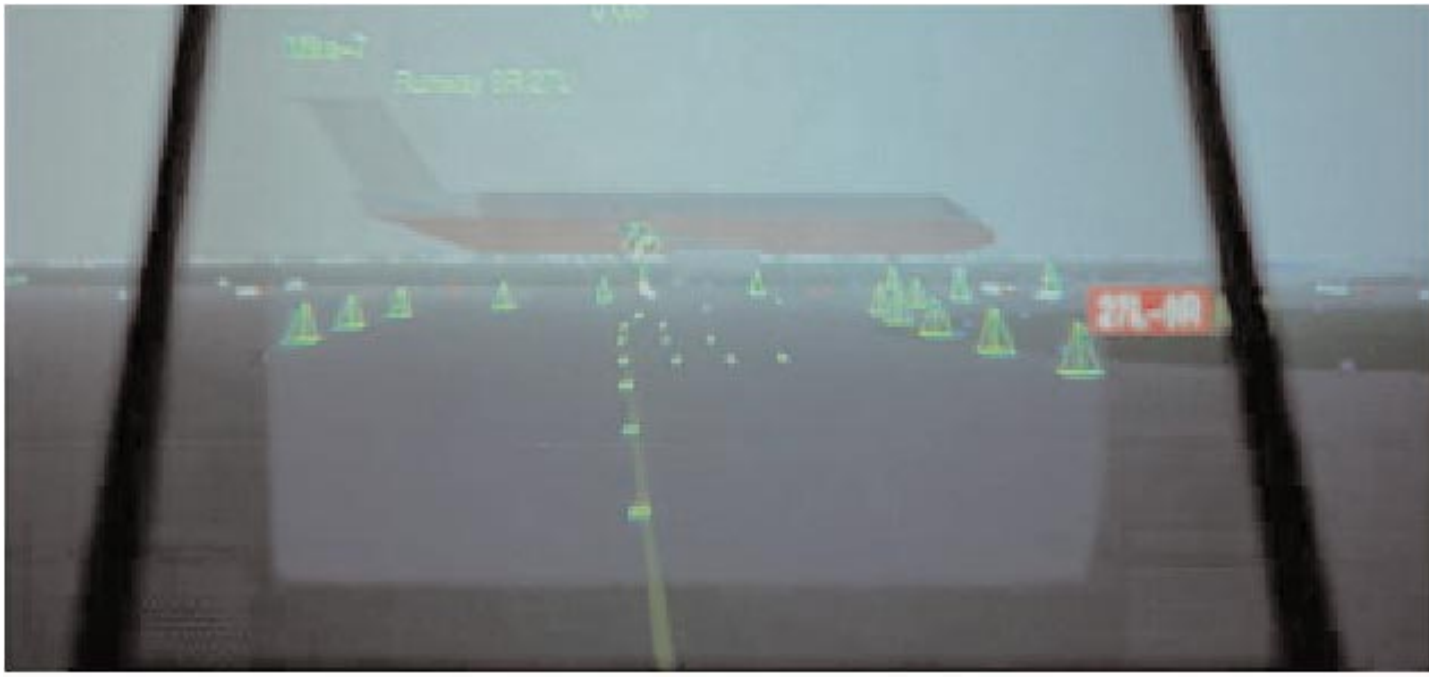


Figure 3-NASA-2. View through NASA Head-up display (HUD).

clouds miles ahead of the aircraft. Adding air temperature, pressure and humidity to the data received from the sensors, on board computers will compute the icing potential of the approaching cloud and will display "high risk areas" to the pilot in an easily read, color cockpit display.

- Sensors that measure the accumulated ice on aircraft in flight will automatically activate, new, low cost de-icing devices that will shed the ice before the aircraft gets in danger.
- The potential for satellite detection of icing conditions is being investigated.

General Aviation

NASA's General Aviation element is actively researching new, low power and low cost pneumatic and electrical ice removal technology. Also in development are low cost displays that graphically show icing weather information so icing conditions can be avoided during flight planning.

Terminal Area Productivity

NASA's Terminal Area Productivity element is contributing via these areas:

- Wake vortex detection to improve the efficiency of aircraft spacing.
- A heads up display that electronically displays the edges of taxiways and runways, shows ground traffic and marks clearance routes to gates and/or runways. All this is overlaid on the pilot's "real world" view out the window while stereo headphones allow the pilot to hear ground traffic from the direction the other aircraft really are. This will be a great aid to vision in poor visibility--especially at unfamiliar airports.
- A look down electronic display shows a bird's eye view of the airport as if the pilot were looking at the airport on a bright sunny day from about 200 feet above the airport. The position of all runways, taxiways, buildings and ground traffic is clearly displayed--as is the exact route the pilot is cleared to take to get to the gate or the runway. Another huge aid to vision in bad weather (Figure 3-NASA-3).

As with virtually all of NASA's aviation research, most of the research mentioned above also helps pilots in good weather too.

Figure 3-NASA-3. NASA's Electronic Moving Map (EMM) of airports.