# RESEARCH & TECHNOLOGY ANNUAL REPORT

## FY 1990

(NASA-TM-107807) RESEARCH AND TECHNOLOGY ANNUAL REPORT, FY 1990 (NASA) 100 p

N92-30197

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G3/99 0078366

## PREFACE

The purpose of this report is to present the accomplishments of the John C. Stennis Space Center R&T Program for Fiscal Year 1990.

The report includes program activities sponsored by the NASA Offices of Space Flight, Space Station, Space Science and Applications, Commercial Programs, and Aeronautics, Exploration, and Technology.

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For additional information on each R&T subject discussed in this report, refer to the Appendix, which gives the SSC technical contact and telephone number.

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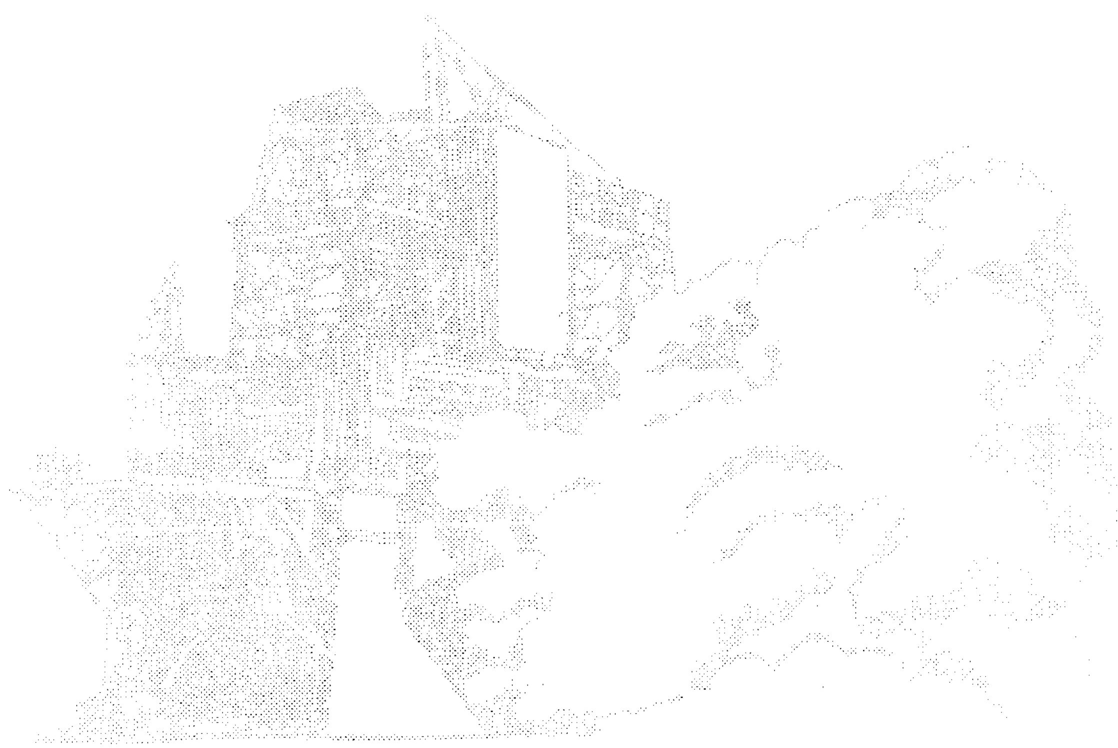
# INTRODUCTION



# INTRODUCTION

The John C. Stennis Space Center (SSC), the second largest in land area of the nine NASA Centers, is responsible for testing the Agency's large propulsion systems, developing supporting test technologies, conducting research in a variety of earth science disciplines, and facilitating the commercial uses of NASA-developed technologies. Because of its accessibility to the Gulf of Mexico and inland waterways and its large land mass with acoustic buffer zone, SSC has supported NASA as the heavy-lift rocket engine test facility from early in the Apollo era to the present period of Space Shuttle Main Engine test and certification.

SSC combines a variety of roles across a broad spectrum of research and technology projects. These activities include remote sensing technology development, earth sciences research, associated data system development, technology development, and the commercialization and transfer of NASA-developed technologies.

The earth sciences research programs at SSC are grouped into two major research areas: forest ecosystems and land-sea interface. The forest ecosystems research examines the forest physiological processes and forest vegetation thermal characteristics. The land-sea interface research involves chlorophyll pigment and suspended sediment mapping, sediment transport, coastal ecosystems, and wetlands biogeochemical flux. The primary data tools and techniques involved with this research are ELAS with data sets from Landsat; the SSC-developed Calibrated Airborne Multispectral Scanner (CAMS), Thermal Infrared Multispectral Scanner (TIMS), and Thematic Mapper Simulator (TMS) remote airborne sensors; and *in situ* data.

The technology development program at SSC has contributed the CAMS, TIMS, and TMS airborne sensors for use in both scientific research and commercial applications efforts at SSC. The SSC has the capability of design, development, fabrication, calibration, operation, and maintenance of these airborne remote sensing systems. In addition, this center of excellence has been expanded in recent years into the development of thermal imagers applied to Space Transportation System (STS) operations at SSC, Kennedy Space Center (KSC), and Johnson Space Center (JSC). These imagers are being used for development testing such as rocket motor testing, along with many other development and operational tests by which systems conditions can be readily determined through non-intrusive thermal imaging technology. The technology development has produced hydrogen and other gas sensors, rocket exhaust plume diagnostic sensors, and radiometry, radar, and electric field measurements.

Commercial programs have been an extremely successful initiative at SSC for the Agency. SSC has the lead role for the Earth Observations Commercial Applications Program, in which significant success can be identified with the environmental sensitivity index mapping, forest resource management, and subsurface gravel detection commercial initiatives. One of the NASA Centers for the Commercial Development of Space is located at SSC.

In addition, the commercial programs at SSC encompass the Small Business Innovation Research Program, for such areas as propulsion and remote sensing technology, and the Visiting Investigator Program. SSC has a significant thrust in developing geographic information systems utilizing remote

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sensing data and the SSC ELAS applications software.

In support of earth sciences research, technology development, and the commercial programs, SSC has a staff dedicated to information systems design and development; operations, analysis, and archiving of remote sensing data; and the continuing maintenance and updating of ELAS and other applications software utilized with the SSC super minicomputers and workstations. SSC provides design, development, and installation of information systems to its eighteen resident agencies on a reimbursable basis.

As the newest NASA Center, SSC confidently accepts the challenge of the new decade and the next century. SSC is strategically positioned for future programs as demonstrated by its support of the Advanced Solid Rocket Motor (ASRM) and Advanced Launch System (ALS) programs.

The maturation of this Center, combined with the variety of assigned roles, contributes to a broad research base for developing technologies to meet future challenges. This report describes the development of such technologies and the associated research.

# EARTH SCIENCES RESEARCH PROGRAM

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# EARTH SCIENCES RESEARCH PROGRAM

The general goal of the earth sciences research program is to obtain a better understanding of the biological, chemical, and physical processes that are crucial to the vitality of ecosystems. Research involves utilizing remotely sensed data acquired by a variety of sensors operated from the ground, aircraft, or spacecraft. Although some studies are site-specific, the overall objective is to gain understanding that would enable modeling from a global perspective. Research is conducted through a team approach with a multidisciplinary staff. Preference is also given to developing joint research projects with university faculty or other external investigators in order to form a team that would be appropriate for the particular research objective being addressed. Collaborative research with external investigators is also facilitated through the Resident Research Associateship program administered through the National Research Council, the summer faculty program, and a summer visiting scientist program.

## FOREST ECOSYSTEMS RESEARCH

### Forest Physiological Processes

Research projects in the Science and Technology Laboratory comprise a continuing effort to determine relationships between the radiative properties of vegetation and its physiological status. Since the radiative properties of forest ecosystems that are found in moist climates are strongly dominated by the radiative properties of leaves, most of this fundamental research is aimed at determining the extent to which leaf radiative properties may indicate physiological status.

#### Fundamental Influences on the Spectral Reflectance of Leaves

Studies of leaf radiative properties that are conducted under controlled conditions in the laboratory continue to be important in the interpretation of plant radiative responses to field conditions. Since previous work conducted at STL suggested that many responses of leaf reflectance to environmental conditions may essentially represent reflectance responses to leaf water content (Carter, et al., 1989), a more complete understanding of the effects of water content on leaf reflectance was needed. During FY89 and FY90, a laboratory study was conducted to observe the direct effects of water content on leaf reflectance, irrespective of reflectance responses to the numerous other influences on vegetation that may occur under field conditions.

Primary effects of water content on the spectral reflectance of leaves were defined as those that are a direct result of the optical properties of water, such as absorption and scattering by water molecules. Secondary effects of water content on the spectral reflectance of leaves were defined as those effects that were not a direct result of the optical properties of water. These included the effects of water content on radiation absorption by other substances in the leaf, such as pigments, as well as effects on reflectance that resulted from relatively wavelength-independent processes such as multiple reflection inside the leaf (Woolley, 1971).

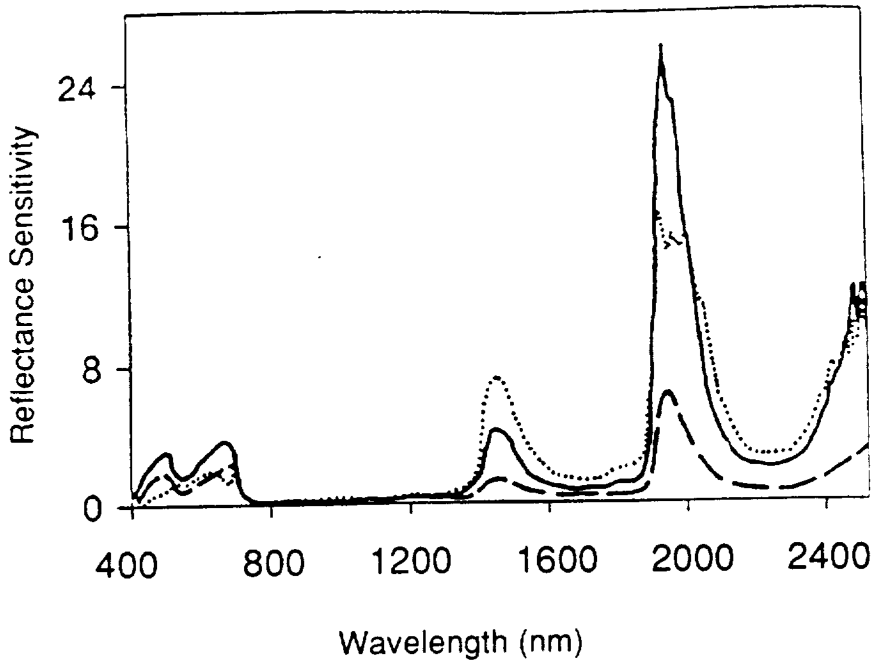
To determine the primary and secondary effects of water content on the spectral reflectance of leaves, leaves of six species were selected to represent a broad range in absolute water content and internal anatomical structure. Selected for study were the two aquatic species *Nuphar luteum* (pond lilly) and *Eichhornia crassippes* (water hyacinth), the broad-leaved trees *Magnolia grandiflora* (magnolia) and *Liquidambar styraciflua* (sweetgum), the grass *Arundinaria tecta* (switchcane), and the needle-leaved conifer *Pinus elliottii* (slash pine). Healthy leaves of each species were collected from sun-exposed sites in the field and returned to the laboratory for reflectance measurements. Spectral reflectances were determined at relative water contents of 100%, 75%, 50%, and 25%, and then at 3-14% (air-dryness), depending upon species.

Although water absorbs strongly and thus would be expected to decrease reflectance at wavelengths near 1450, 1950, and 2500 nanometers, leaf reflectance increased at wavelengths throughout the entire 400-2500-nanometer spectrum as water content decreased. This result indicated that secondary as well as primary effects of water content on reflectance were significant. To better evaluate the relative importance of primary and secondary effects of water content on reflectance, reflectance differences were computed by subtracting the reflectance of the leaf in its turgid state from that of the partially or fully dehydrated leaf. These reflectance differences were then divided by the reflectance of the same leaf in its turgid state to yield the reflectance sensitivity to water content. This sensitivity represents the change in reflectance at a given wavelength in response to a change in water content. (Carter, 1991)

Even though there were large differences among species in leaf thickness, absolute water content, and internal anatomical structure, the wavelength regions of the sensitivity maxima were nearly identical among species (Figure 1). The greatest sensitivities to water content occurred in the infrared spectrum. These sensitivity maxima corresponded precisely to the absorption coefficients of pure liquid water (Curcio and Petty, 1951; Tucker and Garratt, 1977). Thus, high sensitivities in the 1300-2500-nanometer wavelength range were considered to represent primary effects of water content on the spectral reflectance of leaves. The absorptivity of water is quite low at visible wavelengths (Curcio and Petty, 1951), yet sensitivities in this region were appreciable. Thus, these sensitivity maxima represent secondary rather than primary effects of water content on the reflectance of leaves, and result from the effects of leaf water content on absorption by pigments. Leaves in general do not contain substances that absorb strongly in the 700-1300-nanometer region; reflectance at these wavelengths is thought to be affected predominantly by wavelength-independent processes. These would include the potential effects on reflectance of multiple reflections among leaf cellular and subcellular structures.

Although decreased water contents resulted in increased reflectances at 700-1300-nanometer wavelengths, the near-zero sensitivities of reflectance in this region indicated that wavelength-independent effects on reflectance were far less significant than effects that resulted from decreased absorption by water or pigments. Since anatomical structure changed dramatically with water content, and similar results were observed among species representing large differences in leaf anatomy, it is apparent that the influence of leaf anatomy on reflectance is far less important than effects resulting from decreased absorption. Thus, direct absorption of radiation by water was the most significant influence of water content on the spectral reflectance of leaves within the 400-2500-nanometer spectrum. These results demonstrate the predominant influence of water on the spectral reflectance of leaves, and will be useful in the interpretation of reflectance responses measured for plants in the field.

In a separate but closely related study, the potential effects of leaf internal anatomy on the spectral reflectance of




*Sensitivity maxima in the 1300-2500-nanometer range represent primary effects of water content on the spectral reflectance of leaves. Maxima in the 400-700-nanometer range represent secondary effects of water content on reflectance.*

Figure 1. Sensitivity of Leaf Reflectance to Water Content for Leaves of *Arundinaria tecta* (———), *Magnolia grandiflora* (— — —), and *Nuphar luteum* (• • • • • • •)

leaves is being evaluated through the use of nuclear magnetic resonance (NMR) spectroscopy. The NMR spectrum of a leaf may be quite useful in measuring the water content of leaves and detecting anatomical changes (McKain and Markley, 1990). Thus, quantitative measurements of some leaf anatomical features can be made by using NMR. During the summer of 1990, NMR and reflectance spectra were obtained for partially dehydrated leaves at the University of Wisconsin, Madison. These data are currently being evaluated to more accurately determine potential effects of leaf anatomy on spectral reflectance.

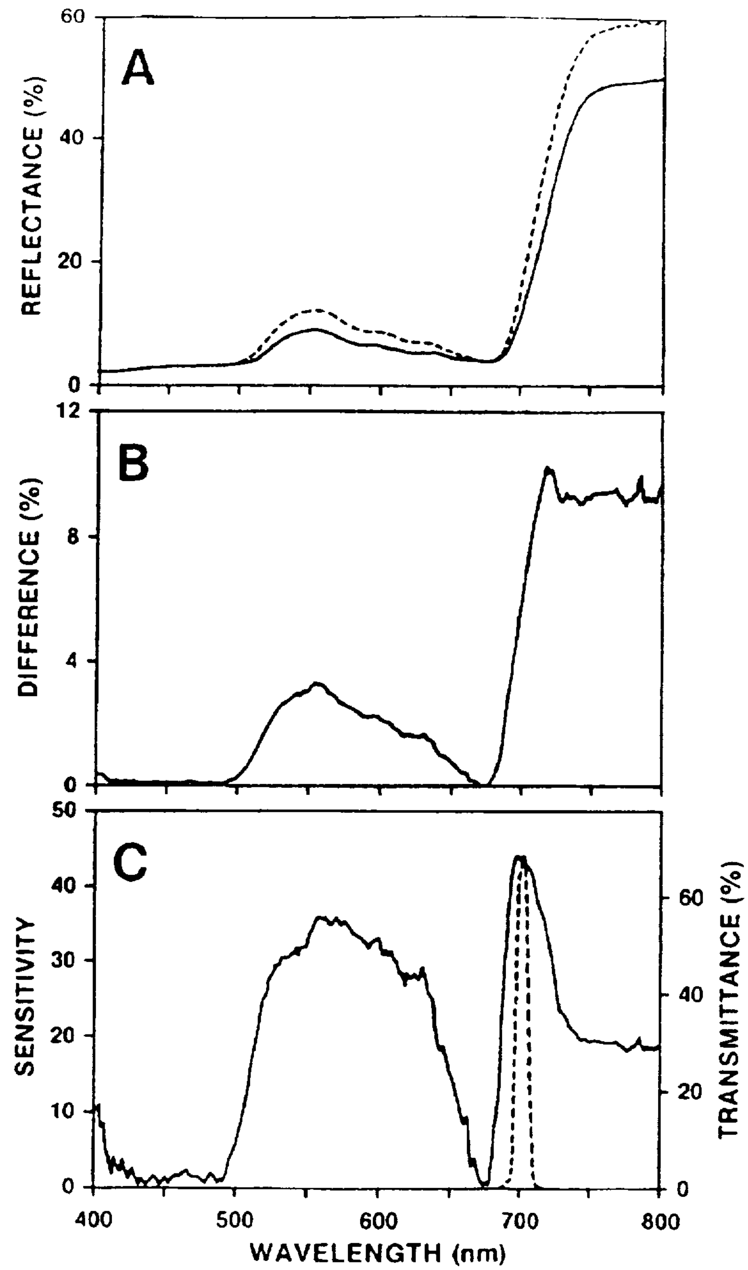
## Spectral Reflectance and Physiological Ecology

In addition to laboratory studies that utilize controlled environments to address the fundamental nature of leaf radiative properties, field studies that determine reflectance responses to a variety of environmental parameters are continuing. One important aspect of this research is determining the extent to which common biological processes may influence the spectral reflectance of vegetation. Previous work in this laboratory has addressed the effects of interplant competition for limited soil resources on reflectance in pine foliage (Carter, et al., 1989). Another biological parameter that appears to significantly affect reflectance in conifers is the symbiotic relationship between soil fungi and the root systems of vascular plants, referred to as mycorrhizae.

Field measurements were obtained during spring 1990 on seedlings of slash pine that had been inoculated with the beneficial ectomycorrhizal fungus *Pisolithus tinctorius*. Reflectances of seedling canopies were measured in the field under full sunlight using the Visible and Infrared Intelligent Spectroradiometer (VIRIS). As is often found for plants subject to unfavorable growth conditions, reflectance in the non-inoculated seedlings was greater than in the healthy, inoculated seedlings (Figure 2, Graph A). Although reflectances were measured across the 400-2500-nanometer spectrum, differences in reflectance between the inoculated versus non-inoculated seedlings were appreciable only in the visible and near-infrared spectra (Figure 2, Graph B). Maximum reflectance sensitivity occurred near the 700-nanometer wavelength (Figure 2, Graph C).

Once spectroradiometry determined that maximum reflectance sensitivity to mycorrhizal infection occurred near 700 nanometers, photographs were taken through a filter having maximum transmittance near 700 nanometers (Figure 3) and the far-red reflectance response to degree of mycorrhizal infection was visualized. Photo A is a panchromatic image of an inoculated seedling (center) and non-inoculated seedlings (left and right of center). Photo B was taken with black and white infrared film and a 10-nanometer bandwidth interference filter centered at 700 nanometers. In this wavelength region, the foliage of the non-inoculated seedlings is much more reflective than that of the inoculated seedling. Photographs using filters centered at 690, 710, 720, and 730 nanometers did not exhibit this difference in reflectance between stressed and healthy seedlings. (Cibula and Carter, 1991)

Investigators have also observed increased far-red/near-infrared reflectance as a response to chemical rather than biologically induced perturbation. A cooperative study between STL and the




*Graph A is the reflectance for seedlings of* Pinus elliottii *that were inoculated (————) or non-inoculated (- - - - - - -) with the beneficial mycorrhizal fungus* Pisolithus tinctorius. *The reflectance difference, Graph B, was computed by subtracting the reflectance for the inoculated seedlings from that of the non-inoculated seedlings. The reflectance sensitivity to mycorrhizal infection, Graph C, was determined by dividing the reflectance difference by the reflectance of the healthy, inoculated seedlings. Peak transmittance of a 700-nanometer interference filter (- - - - - -) corresponded to the maximum reflectance sensitivity.*

Figure 2. Canopy Reflectance Measurements

School of Forestry at Auburn University found that significant increases in far-red/near-infrared reflectance resulted when seedlings of *Pinus taeda* (loblolly pine) were exposed to increased concentrations of atmospheric ozone, as shown in Figure 4 (Carter, et al., 1991). Thus, this photographic method of detecting increased reflectance near the 700-nanometer wavelength may prove to be useful in pre-visual determinations of plant growth conditions.

Studies of reflectance responses to a variety of influences on growth continue to provide useful information regarding their potential use in determining the physiological vigor of vegetation. These studies, together with continued efforts in the measurement of solar-excited fluorescence and its potential relationship to photosynthetic rate (Carter, et al., 1990), are increasing investigators' understanding of the radiative properties that are most informative regarding plant physiological processes and ecosystem function.

## Forest Vegetation Thermal Studies

The need to include information regarding surface thermal processes into global-scale climate models is clearly recognized. However, far more detailed information about the thermal response characteristics of heterogeneous surface types is needed. Unfortunately, the complexity of sampling and analyzing forests and other heterogeneous landscapes has limited research designed to understand the thermal responses of individual components of ecosystems. Even though a substantial amount of thermal variability for hetero-

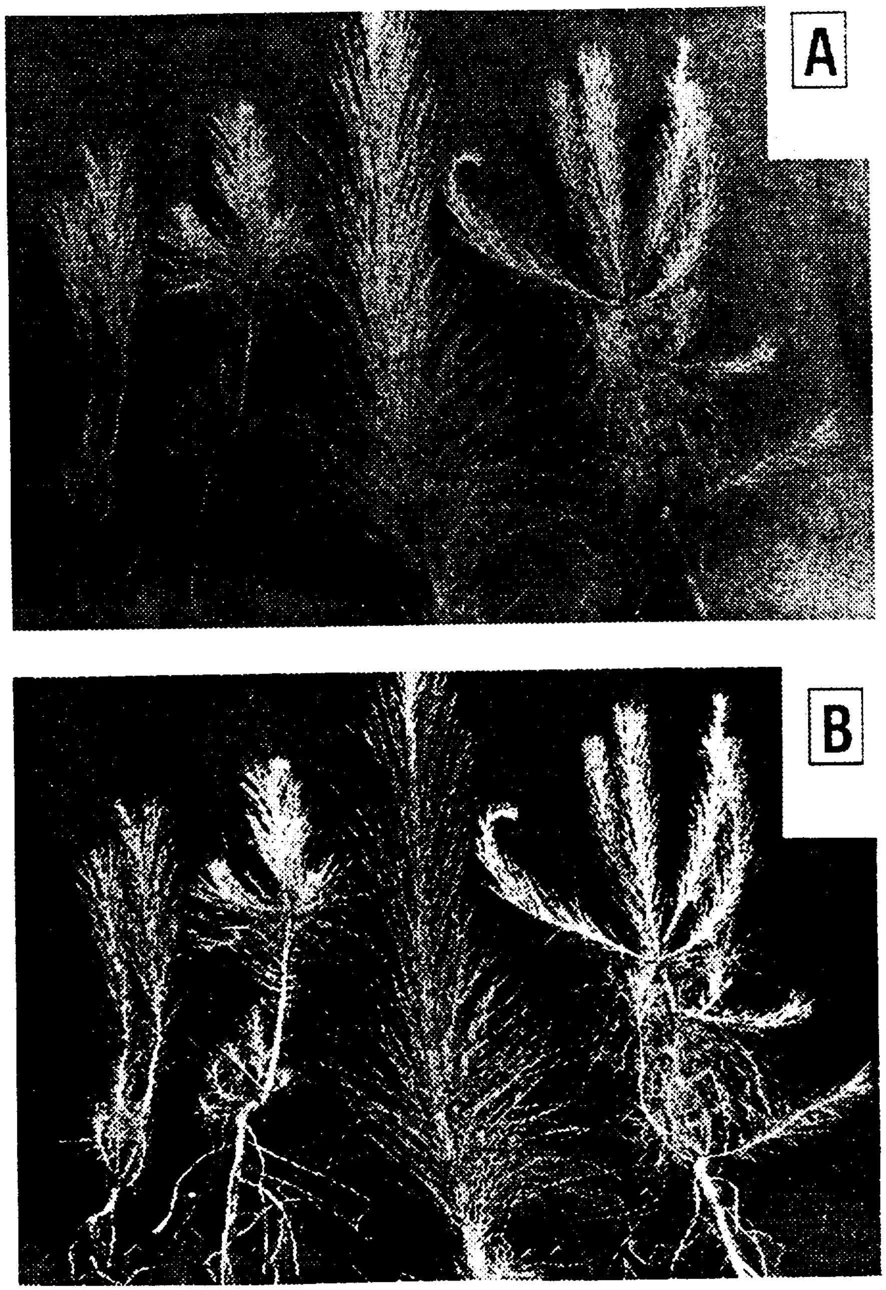



Figure 3. Panchromatic (A) and Far-Red (B) Photographs of Inoculated and Noninoculated Pine Seedlings

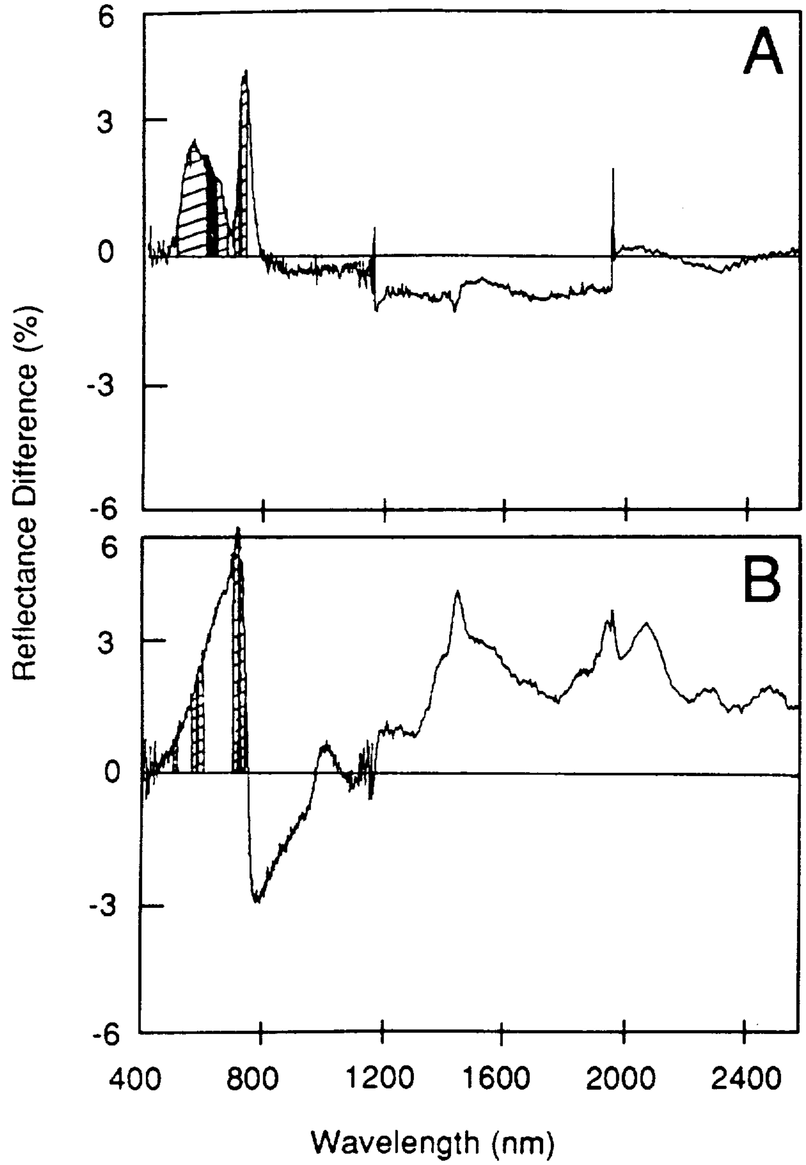
geneous surfaces can be anticipated, quantitative measures of spatial heterogeneity are needed. This would require the thermal remote sensing of surface types and mixtures of types (plants and soils), simultaneously, while they respond thermally to identical atmospheric and radiant inputs.

Using analytical techniques pioneered at STL for the use of Thermal Infrared Multispectral Scanner (TIMS) data to understand energy budgets in temperate forests (Luvall and Holbo, 1989; Holbo and Luvall, 1989), TIMS data acquired over a tropical forest study site in Costa Rica have recently been analyzed to develop a more complete understanding of forest thermal processes.

Analysis of TIMS data revealed considerable variation in forest canopy temperatures in the study area, both within and between forest types. Several factors may contribute to these differences, including changes in microclimate, forest canopy structure, and species composition, although it is difficult at present to separate the relative importance of these factors.

Because of the high spatial resolution of the TIMS, detailed studies of forest edges or other ecotones are possible. Use of canopy temperature transects may be an effective tool for determining edges and minimum patch size and shape needed to minimize the effect of edge on interior forest habitats.

Thermal remote sensing is a potentially powerful tool for examining forest canopy thermal responses on a landscape scale, and is particularly useful in tropical forest where




*Differences were computed by subtracting the reflectances of healthy seedlings from those of ozone-treated seedlings. Darkened and hatched areas represent mean differences that were significant at the p = 0.01 and 0.05 levels, respectively.*

Figure 4. Reflectance Differences for Two Genetic Families of *Pinus taeda* Known To Be Relatively Insensitive, Graph A, or Sensitive, Graph B, to Exposure to Ozone

ground access is difficult. Clearly, knowledge of the spatial distribution pattern of significant aspects of forest energy budgets will contribute to scientists' understanding of the thermal processes, and will enhance the ability to model these processes at landscape and regional scales (Luvall, et al., 1990).

## Tropical Forest Inventory and Monitoring Techniques

During FY90, a literature review indicated that remote sensing techniques coupled with geographic systems and modeling approaches offer an outstanding opportunity to monitor regional ecosystem processes in tropical environments that are undergoing rapid change (Sader, et al., 1990). This comprehensive overview of how remote sensing technology has been applied to tropical forest monitoring over the past 20 years suggests research needs for monitoring the condition and extent of tropical forest. For example, information derived from coarse spatial resolution sensors that have high temporal data acquisition rates, such as the Advanced Very High Resolution Radiometer (AVHRR), are required to accommodate the vast land area included in tropical surveys. Higher resolution sensors, such as Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), aircraft scanners, and mapping cameras, are necessary tools to record the spectral and spatial detail needed to link intensive ecological field studies to the forest community and biome levels. In regions with frequent cloud cover where sensors that operate in the visible and near-infrared have limited utility, active microwave sensors can provide information about the land surface and forest canopy that would otherwise be unobtainable. Additional research and technique development are needed to advance the utility of remotely sensed data for tropical forest monitoring. However, there is sufficient information available to form a basis for implementing a tropical forest monitoring system utilizing sensors currently on-board orbiting satellites complemented with airborne sensors. Implementation of geographic information systems and multistage inventory techniques for tropical forest assessments are suggested as important components of a global tropical forest information system.

### Landsat Thematic Mapper

In another study, forest stand structure and biomass data were collected using conventional forest inventory techniques in tropical, subtropical, and warm temperate forest biomes. The feasibility of detecting tropical forest successional age class and total biomass differences using Landsat TM data was evaluated. The Normalized Difference Vegetation Index (NDVI) calculated from Landsat TM data was not significantly correlated with forest regeneration age classes in the mountain terrain of the Luquillo Experimental Forest, Puerto Rico. The low sun angle and shadows cast on steep north- and west-facing slopes reduced spectral reflectance values recorded by the TM at orbital altitude. The NDVI, calculated from low-altitude aircraft scanner data, was significantly correlated with forest age classes. However, analysis of variance suggested that NDVI differences were not detectable for successional forests older than approximately 15-20 years. Also, biomass differences in young successional tropical forest were not detectable using the NDVI. The vegetation index does not appear to be a good predictor of stand structure variables (e.g., height and diameter of main stem) or total biomass in uneven age, mixed broadleaf forest. Good correlation between the vegetation index and low biomass in even age pine plantations was achieved for a warm temperate study site.

Applications of the NDVI computed from Landsat TM or other satellite systems may be appropriate for forest change detection and other ecological studies in low relief tropical forests (e.g., the Amazon Basin) but should be used with caution in mountainous regions. Topographic corrections may need to be applied in the latter case. This study did not address relationships between NDVI and forest canopy leaf area index, which require different forest data collection techniques than were applied in biomass sampling. The utility of Landsat TM data (NDVI) for studies directed to Leaf Area Index (LAI) estimates and net primary productivity in the tropics is an important area for future research (Sader, et al., 1989).

## Synthetic Aperture Radar

A digital terrain elevation data set was coregistered with radar data for assessing tropical forest stand characteristics. Both raw and topographically corrected L-band polarimetric radar data acquired over the tropical forests of Costa Rica were analyzed and correlated with field-collected tree parameter data to study the stand characteristics. The results of analyses using 18 plots for each of two sites indicated that per-plot bole volume and tree volume are related to Synthetic Aperture Radar (SAR) data, particularly for one site. The topographically corrected SAR data appear to produce the same findings as those of uncorrected data (Wu, 1990).

## Multisensor Data Sets

Concern about the future of tropical forests has led to a demand for geocoded multisensor databases that can be used to assess forest structure, deforestation, thermal response, evapotranspiration, and other parameters linked to climate change. Digital satellite and aircraft images recorded by Landsat TM, SPOT, TIMS, and Calibrated Airborne Multispectral Scanner (CAMS) sensors over the study site in Costa Rica were placed in register using the Landsat TM image as the reference "map." Despite problems caused by relief, multitemporal data sets, and geometric distortions in the aircraft images, registration was accomplished to within ±20 meters (±1 data pixel). A digital elevation model (DEM) constructed from a multisensor Landsat TM/SPOT stereo pair proved useful for generating perspective views of the rugged, forested terrain.

The methodologies developed for this study illustrate how digital satellite and aircraft imagery can be employed in concert to derive X, Y, Z terrain coordinates, stereo images, perspective displays, and representative thematic information about tropical forest areas. In particular, it is anticipated that maps of thermal response and evapotranspiration can be generated for Braulio Carrillo National Park and La Selva Biological Station, and that these data can be applied for future studies of tropical forest environments (Welch, et al., 1990). (Note: This study was conducted at the University of Georgia under contract with the SSC/STL.)

## Guatemala Project

Phase II activities were initiated for an EOCAP project entitled "An Environmental and Archeological Assessment of the Piedras Negras Region of Guatemala and Mexico." Participants in the project include NASA, the National Geographic Society, Mississippi State University, and Geoinformation Services, Inc. The purpose of the project is to provide a practical demonstration of the commercial use of remote sensing/GIS technology for:

- Mapping large inaccessible areas rapidly and effectively.
- Assessing land use changes and their potential environmental impact.

- Developing an archeological predictive model for site location and settlement patterns.
- Demonstrating a cost-effective methodology for assessing environmental impacts.

The study region is located along the border between Guatemala and Mexico. In addition to mapping the current tropical forest cover in this isolated region, the project is also interested in locating unrecorded prehistoric Maya sites. Using remote sensing technology, investigators are attempting to understand how hundreds of thousands of Maya lived for hundreds of years in the delicate rainforests of Central America without destroying the environment. Contemporary practices in land clearing for agriculture and cattle raising are resulting in rapid deforestation on a scale that can only result in regional desiccation. This environmental destruction is causing severe constraints and disease among the current inhabitants.

Understanding whether similar environmental degradation occurred in the past or if successful land management was applied by the ancient Maya will answer many questions regarding contemporary human adaptation. Much of the study area is uncharted and unknown, and may contain some major sites of the Maya civilization.

Landsat TM images have been processed and analyzed. One of these images appeared in the October 1989 issue of National Geographic Magazine. Five-meter TIMS and CAMS data have been acquired during the past year and a database has been developed over the area for predictive modeling. A field trip was recently completed along both the Usumacinta River and into the northern Peten region of Guatemala. A combination of mule trains, boats, jeeps, and hiking was required to reach these areas in order to acquire Global Positioning System (GPS) readings and ground verification data.

The cost effective remote sensing/GIS techniques are being incorporated into Geoinformation Services' operations for expanded marketing of commercial services to agencies and organizations such as the National Geographic Society.

## LAND-SEA INTERFACE RESEARCH

### Chlorophyll Pigment and Suspended Sediment Mapping

During FY90 the National Oceanic and Atmospheric Administration (NOAA) initiated the Nutrient Enhanced Coastal Ocean Productivity (NECOP) Program. A principal objective of NECOP is to clarify the linkages between nutrient loading from the Mississippi River system, phytoplankton production, and the fates of nutrient-enhanced production. A project proposed by the Science and Technology Laboratory, the National Marine Fisheries Service (NMFS), and the Louisiana Universities Marine Consortium (LUMCON) was funded by NECOP to provide large-scale spatial maps of phytoplankton pigment and suspended sediment concentrations. This project will integrate remotely sensed digital data with results from process-related studies performed during acquisition of remotely sensed data.

The general objective of this investigation is to provide large-scale synoptic maps of chlorophyll pigments and suspended sediment associated with the Mississippi River system (Mississippi River and Atchafalaya River) and the Louisiana shelf in support of the specific goals and objectives of the NECOP program. Inherent in this objective is a concerted effort to develop appropriate remote sensing algorithms (atmospheric and bio-optical) and to provide an operational environment in which to support process studies. Specific objectives of the project include:

- Develop effective radiative transfer models for the Calibrated Airborne Multispectral Scanner (CAMS) based on proven reflectance models to distinguish between suspended sediments and chlorophyll pigments.

- Develop a comparative analysis of reflectance models generated using both CAMS and Advanced Very High Resolution Radiometer (AVHRR) data to provide a detailed analysis of the temporal dynamics of the Mississippi River system.

- Characterize the temporal and geographic range of influence of the Mississippi River system by acquiring remotely sensed data during periods of high and low river discharge.

## Background

The Mississippi and Atchafalaya Rivers annually discharge an average of 577 cubic kilometers of fresh water into the northern Gulf of Mexico. Approximately two-thirds is discharged onto the broad shallow shelf west of the Mississippi River delta (Dinnel and Wiseman, 1986) and, because of prevailing winds and topography, is typically transported in a westerly direction. Mississippi River waters are turbid because of high concentrations of suspended lithogenic and biogenic particles (Nelson and Telfry, 1986) and contain high concentrations of dissolved plant nutrients (Fox, et al., 1987). Inputs of dissolved inorganic nutrients, especially nitrogen, from the Mississippi River system can potentially stimulate high biological productivity along the Louisiana-Texas shelf.

The fates of phytoplankton production stimulated by riverborne nutrients are of particular interest for at least two reasons: (1) Large bands of hypoxic water (water containing < 2 milligrams per liter oxygen) have been observed along the coast of Louisiana during the summer months. This hypoxia was initially attributed to phytoplankton blooms that sink and deplete oxygen in the bottom layer (Leming and Stuntz, 1984) but more complete data suggest that the relationships are more complex. (2) Increased nitrogen inputs to the shelf that stimulate carbon fixation by phytoplankton could ultimately result in increased carbon burial in the deep-sea with a concomitant impact on the global carbon budget (Walsh, et al., 1981; but see Rowe, et al., 1986).

Numerous studies have shown that the characteristic time and space scales of phytoplankton variability make shipboard estimates extremely difficult (e.g., Denman and Powell, 1984; Miller and Kamykowski, 1986; Miller and Kamykowski, 1987). Samples acquired using traditional shipboard techniques are limited in their ability to characterize large-scale or regional features. However, the utility of using remotely sensed data for generating large-scale synoptic maps of various biological, chemical, and physical variables has been clearly demonstrated (e.g., Gordon, et al., 1980; Gordon and Clark, 1980; Miller, et al., 1990). The NECOP project will develop large-scale spatial maps of chlorophyll pigments and suspended sediments associated with the Mississippi River plume and the Louisiana coastal shelf region based on remotely sensed data. Digital imagery acquired using the CAMS and the AVHRR are being processed and analyzed to (1) develop an operational approach for providing synoptic temporal/spatial maps of the northern Gulf of Mexico, (2) supplement regional process studies, and (3) provide data relevant to an analysis of the couplings between the Mississippi River system and regional phytoplankton production.

## Data Acquisition

An overflight using the CAMS was completed during July 1990, providing spatial coverage of the Mississippi River delta and Louisiana Bight. The CAMS was flown aboard STL's Learjet 23 at an altitude that yielded a ground resolution of 30 meters. This mission provided data on the plume dynamics during low flow conditions. Simultaneous shipboard measurements were collected aboard the R/V Pelican. To afford maximum utility of shipboard measurements, current position and rudimentary characterization of the Mississippi River plume are required. Enhanced visible band and thermal images from the AVHRR were obtained for all cloud-free days during the field operations. These data were received at the Stennis Space Center in real-time over the Naval Oceanographic and Atmospheric Research Laboratory antennas. AVHRR images were calibrated, geographically referenced, compressed, and transmitted to the Pelican within 12 hours of satellite overpass. Data communications were through a satellite-cellular telephone link that allows a voice and data link to a vessel microcomputer. These images provided location (latitude/longitude and Loran C), depth, and sea surface temperature, thus yielding accurate and current details of the plume.

Continuous measurements were collected using the MIDAS software system (Walser, et al., 1990). MIDAS, which is functionally equivalent to SAIL, represents a well integrated flow-through and computer-based data acquisition system. Continuous measurements are provided from water pumped from an intake position about 1.5 meters below the water surface. The flow-through system includes two Turner Design Model 10 fluorometers for *in vivo* fluorescence and nephelometry, and a thermosalinograph (Seabird CTD system) for temperature and salinity. In addition, a Northstar Loran C and a Li-Cor Quantum Sensor (PAR) are used for earth position and solar irradiance, respectively. Analog signals from all instruments are received by a Zenith 386 PC microcomputer running custom software. Signals are obtained by the microcomputer every 3 seconds, converted to digital values, and stored on magnetic media for retrieval and processing in the lab. The software is characterized by an easy-to-use user interface defined by a custom windowing environment. MIDAS software is also extremely flexible and robust and provides the user with various options and real-time graphics. Numerous discrete samples are obtained from the outflow of the system for instrument calibration. Archived data are preprocessed on a laboratory computer and then ported into the ELAS environment.

## Data Analysis

All digital data will be processed using STL's ELAS image processing environment. A large suite of software modules was developed to process CAMS and AVHRR data to yield data products as required by this investigation. For example, several modules were developed to efficiently integrate the continuous shipboard records derived from MIDAS into CAMS digital imagery (Miller. et al., 1990). This approach provides a large sample size in developing the necessary empirical equations, resulting in good statistical relationships. Statistical analyses are conducted using PC SAS (Statistical Analysis System) and various PC spreadsheet and database management packages.

Estimates of chlorophyll pigments and suspended sediment concentrations are derived from an analysis of digital imagery from a basic reflectance model proposed by Gordon, et al. (1975):

$$R_\lambda = (0.33\ b_{b\lambda})\ (a_\lambda + b_{b\lambda})^{-1} \qquad (1)$$

where R is the irradiant reflectance at wavelength $\lambda$, $b_{b\lambda}$ the backscatter coefficient, and $a_\lambda$ is the absorption coefficient. This ratio of irradiance leaving the water to that entering, when using the red and near-infrared bands of the Coastal Zone Color Scanner (CZCS), AVHRR, and the CAMS, provides data that permit a color vector analysis in highly turbid coastal (estuarine) environments. Reflectance is determined using the equation

$$R = QL_{w\lambda} (E_\lambda \cos\theta)^{-1} \quad (2)$$

where $\lambda$ denotes spectral band (red or near-infrared), Q defines the diffuse irradiance field and is considered a constant, $L_{w\lambda}$ is the water leaving radiance at wavelength $\lambda$, $E_\lambda$ is the extraterrestrial solar irradiance, and $\theta$ is the solar zenith angle. $L_{w\lambda}$ may be decomposed into

$$L_{w\lambda} = (L_{t\lambda} - L_{a\lambda}) / T \quad (3)$$

where $L_{t\lambda}$ is the radiance received at the sensor, $L_{a\lambda}$ is the atmospheric path radiance, and T is the atmospheric transmission coefficient. Note that Equations 1 and 2 are equivalent expressions. Ocean color analysis may be conducted using the equation

$$C_{ij} = R_j / R_i \quad (4)$$

where the color vector $C_{ij}$ is computed as the ratio of near-infrared reflectance (j) to red reflectance (i). This method is based on the absorbance peak of chlorophyll *a* at about 665 nanometers. Because water is strongly absorbing at near-infrared wavelengths, and is unaffected by chlorophyll pigments, an increase in the color vector $C_{ij}$ will typically indicate a commensurate increase in phytoplankton. Furthermore, the near-infrared band will tend to normalize for changes in suspended sediments.

The analysis for suspended sediments uses the equation

$$R_T = R_i + R_j \quad (5)$$

where $R_T$ is the total reflectance for the red ($R_i$) and near-infrared ($R_j$) sensor bands. The models for color analysis and total reflectance require calibration using numerous field sample measurements and effective atmospheric correction for atmospheric path radiance. Significant errors in model prediction may result from inadequate atmospheric correction (Stumpf, 1987; Stumpf and Tyler, 1988).

By applying the methods presented above, this investigation is providing the NECOP program with large-scale spatial maps of chlorophyll pigments, suspended sediments, plume definition, and temporal characteristics, and potentially other constituents directly correlated with the plume dynamics. Because atmospheric correction is a critical element of developing effective and efficient remote sensing algorithms, the comprehensive approach employed by this study may significantly extend the utility of these methods to other regions or environments of varying suspended sediment concentrations and types. It is expected that these data may be directly incorporated into other projects or investigations of the NECOP program.

A detailed comparison is being performed to analyze the coherency between CAMS and AVHRR data. Due to the higher spatial resolution of CAMS data (30 meters vs 1 kilometer for AVHRR) and coordination within shipboard sampling, CAMS serves as the primary data set from which atmospheric and bio-optical algorithms will be developed. However, to establish an operational system that is cost effective, satellite imagery must be considered. The similarities between the CAMS and AVHRR red and near-infrared bands, the success in generating maps of chlorophyll pigments and suspended sediments using both systems, and the frequent overpass cycle of the AVHRR (currently two passes during solar illumination per day) suggest that this approach is reasonable. Therefore, this effort may provide a transition from aircraft to satellite data to monitor the dynamic behavior of a river plume and its effect on the local coastal environment. Further, this effort may provide a logical means of extending the results from this investigation to additional research environments.

## Coastal Ecosystems Study

In 1986, the Science and Technology Laboratory and the University of Puerto Rico (UPR) began a five-year cooperative program. The primary goals of this program include the transfer of NASA technology and research capabilities associated with the acquisition, processing, and analysis of remotely sensed data from STL to UPR, and the establishment of a viable multidisciplinary research program related to an analysis of processes occurring at the land-sea interface. The program plan established that the first three project years (FY86-FY89) would involve the transfer of technology, training, and development of a research program. Project years four and five would therefore involve an integrated multidisciplinary research team to address those research questions formulated and of relevance to the coastal environment of Puerto Rico. The technology and computational capabilities necessary to support such a large-scale research program were successfully transferred to UPR prior to FY90.

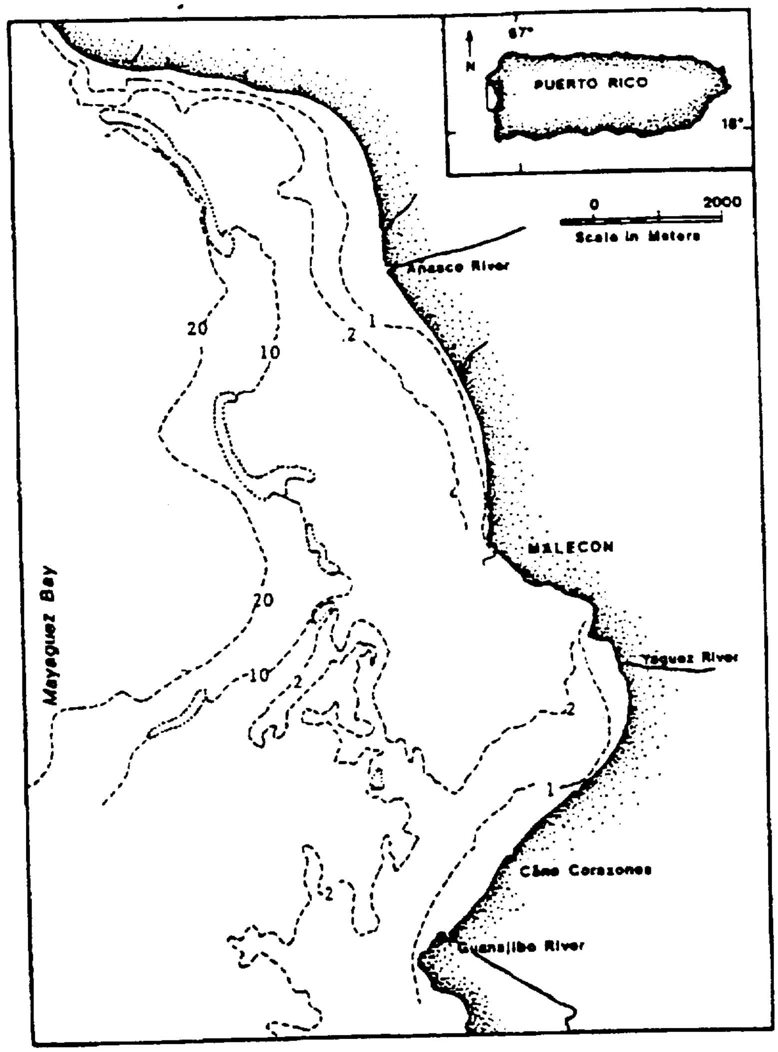



Figure 5. Map of Study Site Showing Bathymetry of Mayaguez Bay and Relative Location of Major Rivers

During FY90, a research project was initiated to analyze the effects of changing coastal landscapes on nearshore biological communities (e.g., phytoplankton and coral). The study site selected is Mayaguez Bay on the West Coast of Puerto Rico (Figure 5). Mayaguez Bay is experiencing a decline in local phytoplankton production, supported fisheries, and, potentially, coral reef communities as a direct effect of increasing sediment discharge into the bay. For example, a major seasonal influx of sediment occurs during sugar cane harvest as large agricultural lands are laid barren and exposed to major flooding. The research project has two major parts focusing on the development of remote sensing techniques to characterize the linkages between land-based processes and coastal phytoplankton production: (1) developing a grid-based model to quantify the influence of landscape pattern (including cover type, spatial arrangement, and drainage basin morphology) on sediment transport to the coastal zone; and (2) characterizing the effects of land-derived sediment, including light attenuation and nutrient source/sink characteristics, on coastal primary production. The major rivers discharging into Mayaguez Bay are the Anasco, Guanajibo, and Yaguez. These rivers have well defined drainage basins that provide a diverse set of landscape types, total volume discharge, and apparent impact on coastal waters. The Guanajibo watershed has been a major focus of activity during the past three project years, in which a preliminary geographic information system has been developed. This GIS contains digitized data layers of soil types, streams, topography, and land cover, and serves as a prototype system for developing a region-wide GIS for integration into the research project.

The participating investigators are faculty and graduate students from the Marine Science, Electrical, and Computer Engineering Departments of the UPR Mayaguez campus, staff of the Terrestrial and Marine Ecology Divisions of the Center for Energy and Environmental Research (CEER), and several research investigators from STL. The research team assembled represents a large complement of both marine and terrestrial scientists.

Remotely sensed data were acquired using the Airborne Ocean Color Imager (AOCI) and the CAMS during January 1990. The AOCI was flown on NASA's ER-2 high-altitude aircraft at an altitude yielding a ground resolution of 50 meters. The CAMS was flown aboard STL's Learjet 23 at various altitudes to yield ground resolutions of 10, 20, and 30 meters. Sensor specifications for the AOCI and CAMS are listed in Tables 1 and 2. Developed as an ocean viewing sensor, the AOCI provided data in direct support of the marine studies, while data acquired using the CAMS provided data to support both marine and terrestrial studies. Complete areal coverage of the west coast of Puerto Rico was obtained. All digital imagery has been calibrated and georeferenced to latitude and longitude. A major effort is now underway to establish accurate atmospheric correction and bio-optical algorithms. Following this work, regional maps of chlorophyll pigments and suspended sediment concentrations will be produced. These results will then be used to integrate model output from the land-based studies to meet the project goal and objectives of assessing the effects of changing coastal landscapes on the nearshore biological communities.

A comprehensive field sampling program was conducted within Mayaguez Bay during each aircraft overflight. Continuous surface measurements of *in vivo* fluorescence, suspended particulate matter (SPM), temperature, and salinity were collected using a flow-through system aboard the R/V Sultana. Solar irradiance was also measured continuously. The flow-through system consisted of a hull-mounted submersible pump located about 1.5 meters below the water surface. All instruments were interfaced to a Campbell data logger for digitization. The data logger in turn was connected to a microcomputer for automated data archiving. Numerous discrete samples were collected for extracted chlorophyll *a*, suspended particulate matter, and dissolved and particulate organic matter. Ship position was recorded every 30 seconds using a hand-held GPS system (Magellan 1000).

Vertical profiles of salinity, temperature, chlorophyll pigments, plant nutrients, and phytoplankton production (light-dark bottles) were collected at select stations from small boats. These data are currently being processed using SAS software to yield horizontal and vertical contours of all measured variables. The data will then be gridded to a scale consistent with scanner resolution for developing *in situ* bio-optical algorithms.

To support the land segment of the joint STL-UPR project, ground truthing was conducted in the western Puerto Rico study area coincidentally with the CAMS and AOCI overflights. The main focus of this ground truthing activity was to obtain a detailed look at land cover types and overall landscape conditions *in situ* with remote sensing data collection as a means for better quantifying how the local landscape affects soil loss into the Guanajibo, Anasco, and Yaquez Rivers. Additionally, this ground truth information is necessary for verification of digital land cover classification accuracy assessment. Digital classification techniques will be applied to the CAMS data acquired at spatial resolutions of 10, 20, and 30 meters as one means for determining how a change in spatial resolution can be used to assess the signifi-

Table 1. Characteristics of the AOCI

| Channel | Central Wavelength (nanometers) | Bandwidth (nanometers) |
|---|---|---|
| 1 | 443 | 20 |
| 2 | 490 | 20 |
| 3 | 520 | 20 |
| 4 | 565 | 20 |
| 5 | 620 | 20 |
| 6 | 665 | 20 |
| 7 | 765 | 40 |
| 8 | 865 | 45 |
| 9 | 1,035 | 65 |
| 10 | 11,500 | 3856 |

**Sensor Specifications**

| | |
|---|---|
| IFOV | 2.5 milliradians |
| Ground Resolution | 163 feet (50 meters) at 65,000 feet |
| Swath Width | 18 nautical miles (33.3 kilometers) |
| Pixels/Scan Line | 716 |
| Radiometric Sensitivity | 10-bit digitization |

Table 2. Characteristics of the CAMS

| Channel | Spectral Coverage (microns) |
|---|---|
| 1 | 0.45 - 0.52 |
| 2 | 0.52 - 0.60 |
| 3 | 0.60 - 0.63 |
| 4 | 0.63 - 0.69 |
| 5 | 0.69 - 0.76 |
| 6 | 0.76 - 0.90 |
| 7 | 1.55 - 1.75 |
| 8 | 2.08 - 2.35 |
| 9 | 10.5 - 12.5 |

**Sensor Specifications**

| | |
|---|---|
| IFOV | 2.5 milliradians |
| Ground Resolution | 32.8 feet (10 meters) at 13,200 feet<br>98 feet (30 meters) at 39,600 feet |
| Swath Width | 7 or 21 kilometers at 13,200 or 39,600 feet |
| Pixels/Scan Line | 700 |
| Radiometric Sensitivity | 8-bit digitization |

cance or importance of specific landscape components, such as the shape or arrangement of land covers adjacent to the three river basins under study.

In conjunction with another research project within the STL, the CAMS data used for analysis of land cover characteristics for the western Puerto Rico study area are also being employed to examine how spatial object identification, size, shape, and arrangement are affected by changing spatial scale. Of principal importance will be understanding how spatial modeling can be advanced using fractal analysis as a means for determining the geometry and pattern of spatial phenomena at different scales. Fractal analysis focuses on the concept of "self-similarity," where regardless of spatial scale, any part of a feature when enlarged is indistinguishable from the feature as a whole. Fractal analysis breaks down this dissimilarity between objects into progressively finer increments called steps. Ultimately, the similarity between objects becomes apparent when observed at finer or greater step increments, depending upon the geometry of the object being measured. Although fractal analysis has been applied to the physical sciences in determining similarities in the shapes of various phenomena, such as cloud formation in meteorology, fractals have not been extensively applied to remote sensing. In concept, fractals appear as an exciting and innovative approach to resolving the problems associated with analyzing landscape spatial characteristics through remote sensing. Because the Puerto Rico CAMS data have been acquired at three spatial resolutions over a very short data collection period, they reside as an excellent data set to compare the sensitivity of different fractal analysis algorithms as affected by the variability in spatial and spectral responses. It is anticipated that this research will provide new insight on how fractal analysis can be of utility as an improved technique for assessing the change in landscape patterns across spatial and spectral scales, which will benefit a wide range of earth science disciplines. This research is being conducted in cooperation with the Department of Geography at Louisiana State University.

## Sediment Transport and Land Loss Processes

The State of Louisiana is experiencing the most critical coastal erosion and land loss problem in the United States. Shoreline erosion rates exceed 6 meters per year in more than 80% of Louisiana's coastal zone, and shorelines impacted by hurricanes may retreat up to 50 meters per year. Louisiana's barrier islands have decreased in area some 40% since 1980. In Louisiana's wetlands, land loss from both natural and human-induced processes is estimated to exceed 100 square kilometers per year. The general public, public officials, and coastal scientists have only recently become aware of the magnitude of the problem and the potential worsening in response from a rapid sea level rise resulting from the greenhouse effect. Most studies of the subject to date have been of local extent and have dealt mainly with an evaluation of changing land-water boundaries, or are primarily descriptive. The processes responsible for land loss and coastal retreat are complex and numerous, and combinations of these processes vary greatly in time and space.

In response to the problem, the Louisiana Geological Survey (LGS) developed the Coastal Protection Master Plan. The plan calls for barrier island restoration, beach nourishment, and implementation of a wetland protection program. To meet the goals of this plan, it was evident that LGS required a synoptic monitoring capability derived from remote sensing technology.

In FY89 a cooperative program between STL, the

Coastal Studies Institute (CSI) of Louisiana State University, and LGS was established. The project is designed to develop strategies and procedures for monitoring processes and responses associated with Louisiana's land loss problem. In addition, an understanding of coastal change is to be developed in the form of process-response models that will help predict future changes in coastal and deltaic plain environments. Specific objects of this project are:

- Provide synoptic monitoring capability to LGS.
- Initiate a remotely sensed database and develop analysis procedures suitable for inputs to plans for long-range planning in the coastal zone.
- Transfer remote sensing and image processing capabilities from STL to CSI and LGS.
- Develop an understanding of the links between process and response, particularly with regard to hydrology/sediment transport, in the coastal zone so that a set of predictive models can be generated.

Multispectral data from the AVHRR and STL's CAMS are being acquired, and three primary study sites have been established: the Mississippi River Delta, Terrebonne Bay, and Atchafalaya Bay. These areas represent different regimes of sediment supply, hydrography, and sedimentalogical processes. A diverse field sampling program provides *in situ* ground truthing during data acquisition using the CAMS. The CAMS is flown aboard STL's Learjet at an altitude yielding a ground resolution of 30 meters. A successful CAMS mission was flown during October 1989 and during March 1990 to represent low and high flow (river discharge) periods, respectively. Discrete samples for suspended sediments are obtained from small boats at the Mississippi River delta and Atchafalaya Bay field stations. Continuous near-surface measurements are acquired using a flow-through system aboard the R/V Pelican within Terrebonne Bay and adjacent shelf. Continuous surface mapping data of *in vivo* fluorescence, temperature, salinity, and suspended particulate matter are collected using the MIDAS software system (Walser, et al., 1990). MIDAS, which is functionally equivalent to SAIL, represents a well integrated flow-through and computer-based data acquisition system. In addition, a Northstar Loran C and a Li-Cor Quantum Sensor (PAR) are used for earth position and solar irradiance, respectively. Analog signals from all instruments are received by a Zenith 386 PC microcomputer running custom software. Signals are obtained by the microcomputer every 3 seconds, converted to digital values, and stored on magnetic media for retrieval and processing in the lab. The software is characterized by an easy-to-use user interface defined by a custom windowing environment. MIDAS software is also extremely flexible and robust and provides the user with various options and real-time graphics. Numerous discrete samples are obtained from the outflow of the system for instrument calibration.

A full suite of AVHRR images has been acquired and archived at CSI during the project period. These images are transferred to STL for data analysis as needed. All digital data will be processed using STL's ELAS image processing environment. A large suite of software modules was developed to process CAMS and AVHRR data to yield data products as required by this investigation. For example, several modules were developed to efficiently integrate the continuous shipboard records derived from MIDAS into CAMS digital imagery (Miller, et al., 1990). This approach provides a large sample size in developing the necessary empirical equations, resulting in good statistical relationships. Statistical analyses are conducted using PC

SAS (Statistical Analysis System) and various PC spreadsheet programs.

Accurate empirical relationships were developed ($r^2 > 0.85$) to translate spectral reflectance measured by the CAMS into quantitative estimates of suspended sediments. CAMS and AVHRR imagery is being processed to yield spatial maps of suspended sediment concentrations and integrated into process/response models. Additional FY90 accomplishments include:

- Supporting data on coastal water levels, river stage, sediment and freshwater discharge, and meteorological conditions have been summarized.
- Models for coastal change in the Atchafalaya-Chenier Plain area have been developed and implications regarding wetlands mitigation procedures explored.
- ELAS has been ported to LGS on a new Silicon Graphics workstation.
- NASA-acquired high resolution aerial photography has been used to study geomorphic evolution of coastal environments.

## Wetlands Biogeochemical Flux

Recent research has reported that trends during the last century indicate significant atmospheric compositional changes in a variety of trace gases. These gases tend to be chemically and radiatively very active and important contributors to the "greenhouse effect" and stratospheric ozone degradation. To better determine the severity of the impact from these increasing levels of trace gases in the atmosphere, researchers must better understand the processes involved in their evolution, and the location of the various sources (and sinks) and their corresponding strengths.

Since anaerobic conditions are important to the genesis of many of these gases, wetlands play a central role as a major source environment. Globally, wetlands exist across a wide spectrum of latitudes but are bimodally concentrated in tropical and northern high latitude regions. While much work has been conducted on the mid-latitudes, a more recent emphasis has begun to focus on these other more geographically significant regions. As the various sources and processes involved in the production of these gases become better understood, progress can be made toward developing improved global monitoring and modeling techniques.

The research conducted by STL is part of a cooperative effort between SSC, Langley Research Center, and a number of university investigators funded by the Wetlands Biospherics Program of the NASA Office of Space Science and Applications administered by the Life Sciences Division. An important component of the joint effort is the synergistic merging of the independent research efforts into regional scale models of gas flux. The objectives of the wetlands biogeochemical flux project at STL are to: (1) examine the capabilities of remote sensing instruments to delineate key wetland vegetation type distribution and extent, determine environmental conditions (e.g., water inundation extent, surface temperature, vegetation stress, etc.), and characterize subsurface soil conditions (e.g., organic vs. mineral content, vertical material stratification, interstitial salinity, etc.); and (2) develop and implement a geographic information system (GIS) for modeling various trace gas fluxes from wetland ecosystems.

The Florida Everglades has been a focal test site representing a subtropical/tropical wetland environment. Two locations in northern Canada have been used to represent high latitude wetlands: 1) the Hudson Bay Lowlands, near Moosonee, Ontario; and 2) the subarctic of Quebec near Schefferville.

The following segments describe the various tasks being conducted under this research program.

## Everglades Methane Flux Modeling

To provide better estimates of methane flux from the Florida Everglades, a simple mechanistic model of methanogens and a spatial model of methane flux were developed. The simple model was used to determine the most important factors in the production of methane, and the spatial model was used to determine the effect of normal and drought periods on methane flux in the Florida Everglades.

The simple model was developed from a competition model of methane bacteria and sulfate reducing bacteria. The model was expanded to include methane oxidizers and oxygen, which can be important in methane being released to the atmosphere. This model included overlying water, an algal mat, a top layer of sediment, and a bottom layer (Figure 6).

Most of the activity of methane production occurs near the surface. This can be attributed to the higher amount of new organic matter decomposing to acetate (the major substrate of methane bacteria) that occurs in the upper sediments as compared to the lower sediments. The lower sediments also produce acetate but at a lower rate.

Methane flux within the model was most sensitive to acetate production. Following in sensitivity were depth of the topmost sediment layer, any parameter that affects oxygen levels in the sediment, and methane oxidation rates. Sensitivity analysis also showed that most of these parameters did not affect methane flux in a linear fashion.

The spatial scale model was based on the hydrology of the Florida Everglades in addition to the previously identified most sensitive parameters (Figure 7). To define the model specifically, the topography of the region was needed, from which slope and aspect through each square kilometer could be determined. This was used to determine water flow rates and direction. More information was obtained from previous research that found five different plant communities (Bartlett, et al., 1989). They believed that the differences in methane flux in these different communities were because of differences in production of organic material. Thus these classifications were reclassified according to this scheme by acetate production.

Everglades National Park personnel provided information on rainfall and water releases into the park from the main water control gates. This information was used to drive the model to simulate conditions in 1988, a relatively normal year, and 1989, a relatively dry year. The result in the normal year was methane being produced relatively evenly throughout the whole area (average rate = 4.7 kilograms/hectare/year), while in the dry year the methane was produced mainly in those areas that remained wet throughout the year. This concentration of methane in the wet areas seemed to produce more methane, but because of the smaller area where methane was being produced, the total flux rate was 20% less (average rate = 3.8 kilograms/hectare/year) than in the wet year. This was similar to the results of the prediction of a previous empirical model comparing wet and dry years (Pelletier, et al., 1990).

## Everglades Inundation Modeling

In order to expand methane modeling efforts conducted with Landsat Thematic Mapper (TM) data to large regional and global scales, it became apparent that other forms of remotely sensed data may be necessary. Advanced Very High Resolution Radiometer (AVHRR) data were chosen because their 1-kilometer resolution made the data more computationally

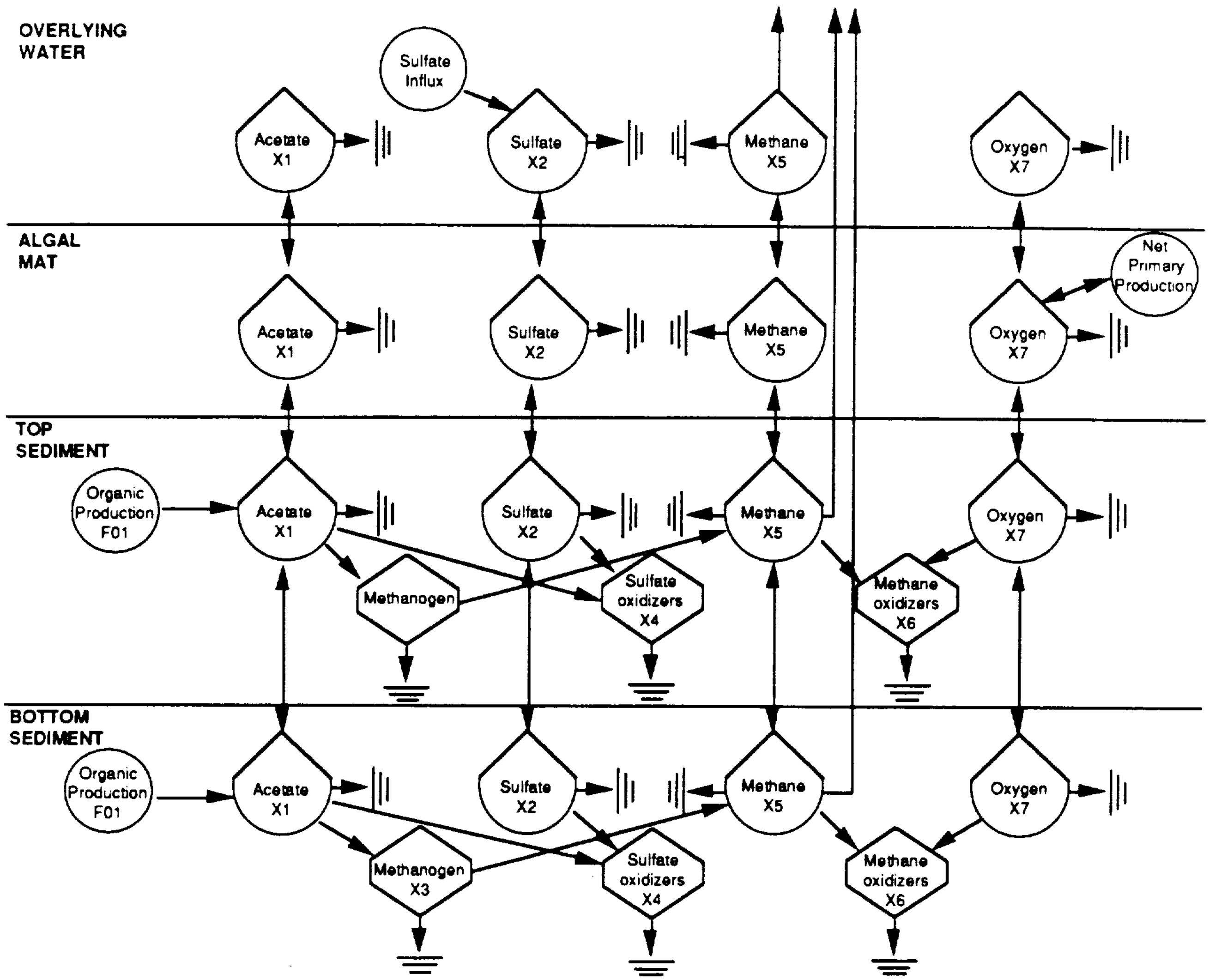



Figure 6. Everglades Methane Flux Model Components

efficient to process for large areas and because the frequent coverage provided improved probability for timely data acquisition in these often cloud-obscured wetland areas.

The monitoring of inundation dynamics in these wetlands at these regional scales is important, and is made possible by the frequent coverage of AVHRR. Non-saturated soils would likely be aerobic and be considered as having negligible methane flux, while areas with shallow standing water or having saturated conditions could be sources of methane. Inundation conditions change with the seasons and can vary significantly from year to year, so proper monitoring of these dynamics in wetness will permit the model to better reflect true and variable conditions.

Selected AVHRR data scenes between 1986 and 1990 were acquired and classified for five classes of inundation status. During the latter part of this time period the Everglades went through a significant dry period (over a three-year period the area experienced a deficit relatively equivalent to one normal year's rainfall). Data were acquired monthly from June 1987 to May 1988 and at significant times during the drought years. Daily rainfall, stage height, and water release data were also collected as a means of ground truthing the data.

Qualitatively, the AVHRR classifications proved to be very effective in delineating the lateral extent of inundation. With the incorporation of ancillary data (e.g., stage height), the AVHRR classifications also appeared to be semi-quantitatively useful in determining the standing water depth (Figure 8). These results are reported in a paper by Pelletier, et al., 1990.

## Canadian Subarctic Methane Flux Modeling

As part of the Global Tropospheric Experiment/Atmospheric Boundary Layer Experiment (GTE/ABLE) program conducted in northern Canada in the summer of 1990, a methane flux modeling test site was established at a subarctic location near Schefferville, Quebec. McGill University (Montreal) operates a research station there and served as home base. Multiple Canadian and American government agencies and universities were involved in the cooperative research.

SSC was responsible for developing a TM classification of land cover types for the Schefferville locale and the larger regional area. A preliminary classification was developed before visiting the site in late August. Upon visiting the site, specific land covers pertinent to methane flux modeling were discerned, including spruce/lichen forest, spruce/moss forest, fen, tundra, fen/bog margins, bare rock, etc. Roads and other means of transportation are sparse in this area, so available aerial photography was acquired to supplement ground truthing activities.

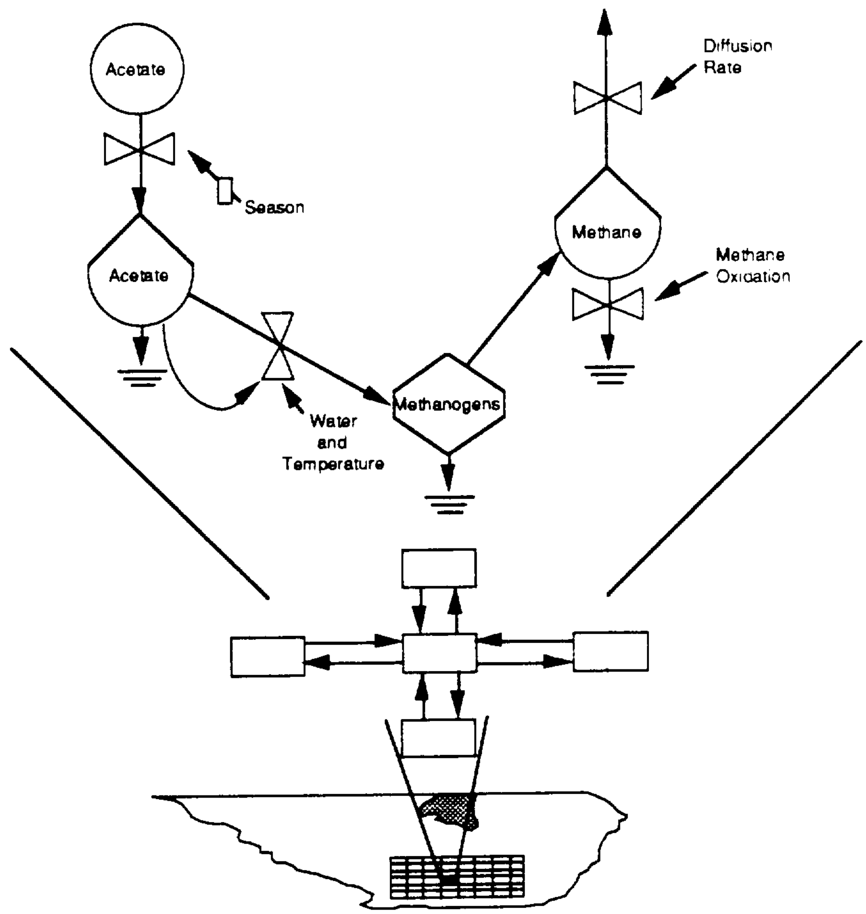
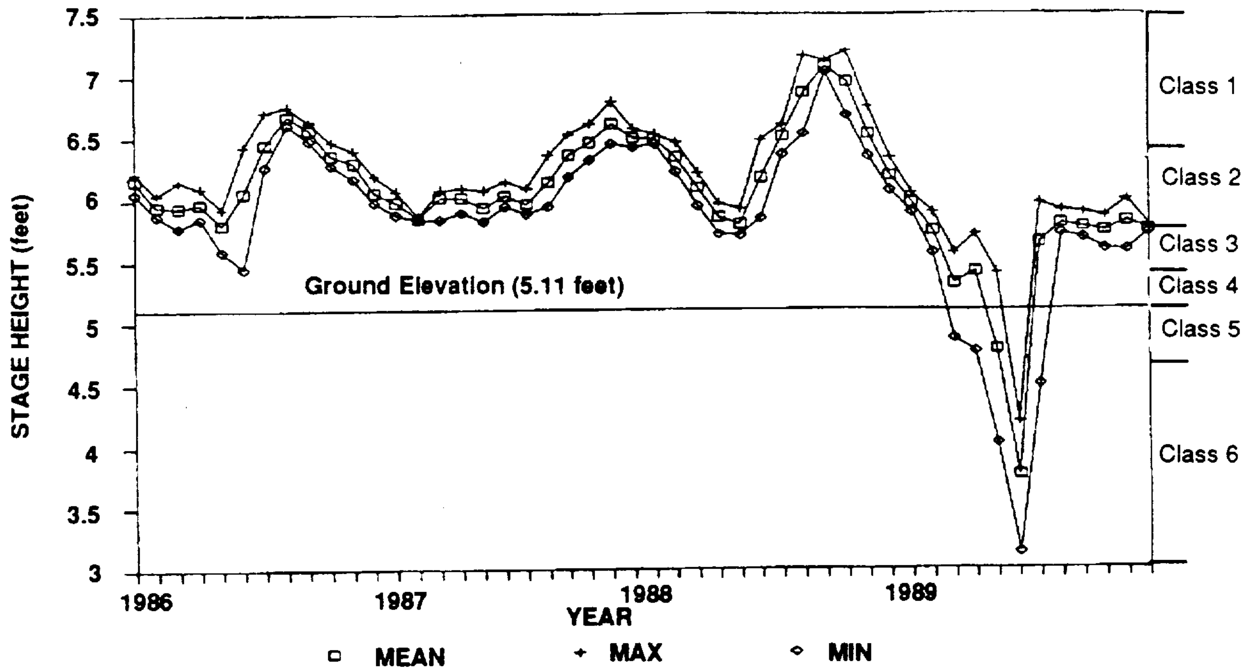



Figure 7. Flux Model Parameters

Since this activity began so near the end of the fiscal year, the major portion of the reassessment of land cover classes will continue into FY91. As with the Everglades methane modeling project, a database with remotely sensed and ancillary data will be established to support extrapolating *in situ* measurements of trace gas flux to larger areas.




*Class 1 indicates significant open water areas with increasing class number corresponding to decreasing wetness. Class 6 indicates non-inundated, likely aerobic conditions.*

Figure 8. Stage Height at Gauge P-33 Compared to AVHRR Inundation Classes Semi-Quantitatively Related to Stage Height

## Hudson Bay Lowlands Peat Profiling

The Hudson Bay Lowlands around Moosonee, Ontario, and west of James Bay were selected as another major test site of the GTE/ABLE program during the summer of 1990. Unlike the Schefferville area, which has hilly terrain, the Hudson Bay Lowlands near Moosonee are relatively flat, expansive bog and fen environments. Four focal research areas were set up along a 100-kilometer transect extending west from James Bay starting with the coastal marsh site, coastal fen site, inland fen site, and finally the Kenoje Lake bog site. Over this distance water chemistry changed greatly and peat depth increased from less than a meter to around 10 meters. SSC's contribution to the program was to investigate the use of low-frequency remote sensing technology to measure peat depth across the study transect. Information about peat depth will provide a better understanding of the total carbon source available if climate changes alter metabolic activity and the production of methane.

Multikilometer transects of airborne (helicopter) ground penetrating radar (GPR) data were collected periodically along the 100-kilometer distance from the coast inland to obtain a regional trend in peat depth and related parameters. Global Positioning System (GPS) data were simultaneously collected from the helicopter to properly georeference the GPR data. Additional 50-meter ground-based transects of GPR data were also collected as a source of ground truthing, as a calibration aid for the airborne data sets, and as a source of higher resolution data for characterizing the strata within the peat. *In situ* peat depth probing and soil characterizations from excavated soil pits were used to verify GPR findings.

Preliminary results from the ground-based data were quite good. Peat depth was determined with the GPR by identifying the interface between the peat and the older, deeper marine clays due to the conductivity differential between them. Limited initial analyses demonstrated that the GPR was also able to delineate stratifications within the peat indicative of denser layers. Simultaneous paleoecological studies have reported that such layers are often composed of woody tissues and other material representative of various past vegetation, including forests.

Airborne GPR data acquisition is very experimental but proved promising from preliminary analysis. Analyses of these data will continue into FY91. These preliminary results are reported in a paper by Pelletier (in press).

## Methanogenic Bacterial Population Studies

The potential risk of global warming has elicited an interest in trace gases such as methane. Although it is a relatively minor constituent in the carbon cycle, methane has been linked with degradation of the ozone layer due to the molecule's ability to absorb in the infrared region. Marshes are a primary source of methane where the gas is typically produced as a result of bacterial metabolism by the methanogens, or methane-generating bacteria. To obtain a preliminary characterization of methane production in the Mississippi Gulf Coast region, sediment cores from salt marsh and estuarine systems are being analyzed for the presence of methanogens. Similarly, *in vitro* methanogenesis is being quantitated by gas chromatography.

Preliminary data indicate relatively low numbers of methanogens in both salt marsh and estuarine sites. Coincident with the low numbers is the reduced level of methane production. It is interesting to note that several factors may be involved, including competition by the sulfate-reducing bacteria. Typically, when sulfate levels are high, this group predominates. Chemical analyses of sediment and interstitial water have revealed high levels of sulfate as well as other relevant ions. Studies are continuing to examine the methanogen populations, with emphasis on seasonal and diurnal fluctuations.

## Coastal Geomorphology

River deltas are very important. Natural resources, both living and geologic, are concentrated in deltas such as that of the Mississippi River in Louisiana. But scientists' understanding of what affects the distribution of sediment and mud, the building blocks of all deltas, is not very good. For coasts like that of Louisiana, recent work indicates that violent summer storms, such as hurricanes, are less important movers of sediment than the passage of winter cold fronts. Testing this idea is the work of a joint NASA/SSC and Louisiana State University team.

This group of researchers has for several years been studying the growth and change of the Mississippi Delta in an Atchafalaya Bay study site. Designed around the CAMS scanner, which is flown on the SSC Learjet 23, their experiments require the integration of dozens of separate aircraft flights over several years. To support the resulting data processing, graphics workstations are being procured. When matching systems are installed at LSU and STL, researchers will be able to visually compare multiple true-color images of georeferenced imagery from disparate acquisitions.

Field work, both marine and on land, has documented the rapid and complex manner in which this delta is growing. The two mouths of the Atchafalaya River are both forming deltas, one disturbed by dredging, the other undisturbed. The sediments have now almost completely filled Atchafalya Bay and are being swept westward, bypassing Marsh Island and building new coastline along the Chenier Plain.

The method of deposition along the plain is complex and still under study. The sediments appear to deposit offshore as a gelatinous layer of mud, which is then driven onshore by winter storms. Each storm event is marked by a basal layer of shell hash and sand, topped by a layer of mud approximately 10 centimeters thick. Each sand/mud layer visually forms a wedge, tapering shoreward. The mud layer, when exposed to air, becomes coherent and resists wave action. It even develops mud cracks and will form cobbles, even though this is a very humid coast.

Future work will document the rate of growth, both in the bay and along the plain. Also, investigators will attempt to determine why Marsh Island is not accumulating sediment. Finally, the team hopes to establish the exact sequence of events that leads to the development of the mud deposition west of the deltas.

## DEVELOPMENT OF TOOLS AND TECHNIQUES

### Jackson State University Project

During FY81, President Ronald Reagan signed Executive Order 12320, the White House Initiative on Historically Black Colleges and Universities (HBCUs). This initiative, which was designed to achieve a significant increase in the participation by HBCUs in Federally sponsored programs, was also designed to further the policy and purposes of the National Aeronautics and Space Act of 1958. The initiative has two purposes. The first is to help achieve research and technology objectives through strengthened capabilities in research, aerospace, science, engineering and management at HBCUs. The second is to develop a larger pool of minority graduate researchers by encouraging the participation of students and faculty of HBCUs in Government-sponsored research and in NASA's educational opportunities and services. In compliance with this initiative, the Minority University Program of the NASA Office of Equal Opportunity Programs (Code U), administers funding of various colleges and universities.

Jackson State University, in Jackson, Mississippi, is the sixth largest Historically Black College/University in the nation, and has the nation's largest minority-based computer science program. Because of its substantial computing capability and expertise, JSU was selected in 1986 as a partner in a NASA program to develop new spatial analysis technologies at an HBCU. The initial efforts were to: (1) develop remote sensing and geographic information system (GIS) technologies at JSU; (2) train faculty, staff, and students in their operations and applications; and (3) begin preliminary research. By mid-1987, the program was initiated and basic directions had been established.

This three-year project entered its third year in FY90. In the first two years of the project, SSC efforts were directed toward providing specialized training for the JSU faculty, students, and staff; increasing the JSU library's holdings; developing an interest in and a means of offering a remote sensing curriculum; and creating a research facility. The third year was to assist in the development of several GISs and their use for various projects. Three main projects were addressed in FY90: International and Community Outreach, Quality of Life Analysis, and Land Use Change Modeling.

## International and Community Outreach

Officials at Jackson State believe that JSU, as the State's only urban university, has an obligation to reach beyond its immediate student body and to assist the larger community. Recognizing the high potential of GIS technologies and acknowledging the relatively low level of awareness of GIS, they believe there is opportunity for useful involvement beyond the campus environment. Therefore, this project is to extend JSU's Center for Spatial Data Research and Applications (CSDRA) expertise to the community, and beyond, by initiating a spatial data management summer program for Jackson public school secondary students.

The GIS concept (and its attendant technologies) is relatively easy to understand, even with rudimentary instruction--the intensive, esoteric training most sciences require to achieve productive conditions is not required for GIS applications. The concepts can be taught at a wide range of educational levels, from secondary students to professionals, and the applications can be appreciated by a diverse audience. With "user-friendy" GIS and remote sensing systems such as ELAS, basic operations can be learned with little difficulty. This was demonstrated by the successful use of ELAS image processing in a 1990 Jackson summer student project in which 11th and 12th graders actually processed Landsat satellite and aircraft data on JSU's campus. SSC and CSDRA presented several hours of instructions on the fundamentals of digital remote sensing analysis, developed daily mission exercises, and loaned "Mission Control" a system.

The program established a six-week GIS/remote sensing workshop for high school juniors and seniors at JSU. JSU hopes the workshop will become a permanent NASA/JSU summer program, with two or three sessions offered each year.

Another program was developed to establish international contacts, to develop an international GIS/remote sensing training program, and to conduct an international research project. Initial contacts were made with the Environmental Research Institute of Michigan (ERIM) at the University of Michigan, which sponsors international remote sensing symposia. At the 1990 symposium, JSU made contacts that led to a memorandum of understanding between JSU and Environmental Systems Research Institute (ESRI). JSU is working with ESRI on a contract with the Defense Mapping Agency to develop a digital world database (Global Environmental Crises GIS Atlas). As part of this project, an extensive digital bibliographic database was compiled by doing an intensive literature search of GIS and remote sensing/image processing in Third World development.

Links with other programs of interest were also made through JSU's participation in NASA's Earth Observing System (EOS) program, the Africa Outreach/Research Center Program of Jackson Mayor Kane Ditto, and a presentation on the CSDRA by JSU's Dr. Bruce Davis at the 23rd International Symposium on Remote Sensing of the Environment held in Bangkok, Thailand.

## Quality of Life Project

"Quality of Life," or QOL, is a vague concept denoting a standard of living dealing with factors beyond wealth. QOL is a lightly regarded, yet highly positive, subject of remote sensing data applications. Digital image processing techniques have not been applied to QOL. The City of Jackson has not been examined intensively through remote sensing data and probably not at all in terms of QOL analysis, particularly from an aerial perspective. Also, a need exists for QOL assessment methodologies.

The NASA Jackson Land Use Project, initiated in 1989, obtained aerial photography and scanner data of Jackson for use in investigating the potential of QOL analysis, using small study sites for testing.

Jackson is undergoing significant social, economic and physical transformations. There are concerns that demographic changes are occurring too rapidly to maintain records and to make policy changes. In remote sensing, quality of life analysis has been attempted with mixed results. Some basic precepts have been presented, but the field is essentially incomplete. GIS seems to be an ideal methodology in such endeavors. GIS and/or remote sensing work performed with QOL emphasis, when employed for analysis of Jackson, should be very useful.

One goal of the Jackson QOL project is to refine the concepts and results from the 1989 research. Using the various data sets acquired and the small study sites, the investigation established the value of integrated approaches, specifically the use of non-image data as support for interpretations. GIS database developments and operations were implemented to form a thorough approach. The basic concepts of using imagery for QOL analysis were explored.

The project also seeks to standardize interpretive and analytical approaches of remote sensing/GIS QOL analysis for southeastern U.S. cities. An index for QOL interpretation was developed. From each neighborhood study site approximately ten interpretation "samples" of residences and surrounding areas were taken, using a coding system of qualitative and quantitative measures to evaluate the social and physical conditions and overall morphology. Worksheets containing morphologic characteristics from the aerial photography were totaled and the results analyzed.

Another goal of the study is to "sample" residents' perceptions of their quality of life. An attitudinal survey was devised and mailed to residents in the study areas to get a measure of quality of life in Jackson. The survey consisted of twenty statements pertaining to residents' perceptions of education, employment, unemployment, elderly citizens' conditions, and public transportation. Three hundred residents were randomly selected from the 1989 Mississippi Polk Directory. Ten neighborhood zones were chosen for the study areas and 30 houses per zone were randomly selected. Results of the analysis will be noted on the survey and index.

## Jackson Land Use Project

The NASA/JSU Jackson Land Use Project in 1989 established preliminary concepts and approaches to assessing land use change detection and analysis of the Jackson metropolitan area. Several study sites remain under investigation and change detection techniques are being applied. Using these general steps, the on-going project will carry the initial developments further by completing a land use map of Jackson, selecting and modifying spatial trend techniques, and applying spatial change analysis to Jackson land use.

The project consists of several tasks, including using ELAS for georeferencing Daedalus airborne scanner and Landsat Thematic Mapper data, merging ARC/INFO data with ELAS data, and using various ELAS modules to detect and characterize land use change.

# TECHNOLOGY DEVELOPMENT PROGRAM

- Advanced Sensor Development Laboratory
  - Sensor Development Support
  - Sensor System Support
    - Calibrated Airborne Multispectral Scanner
    - Thermal Infrared Multispectral Scanner
    - Ice Detection Research and Development
- Thermal Imagery Activity
  - Preliminary Testing of EMU
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- SSC/STL Aircraft
- SSF Payload Simulator Activities
- Gas Detectors
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- Plume Analysis
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  - Advanced Plume Diagnostics Capabilities
    - Flat-Flame Diffusion Burner
    - Spatial Imaging of Plume
    - Application of LIF and CARS Techniques
    - Video Imaging of SSME Plume
    - Electric Field Measurements of Plumes
      - DTF Electric Field Measurements
      - SSME Electric Field Measurements
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  - Diagnostics Testbed Facility
    - Engine Diagnostics Console Development
    - Plume Seeding and Materials Database
  - Expert System Applications to Engine Monitoring
- Radio Frequency Detectors
  - Millimeter-Wave Radiometry
  - Synthetic Aperture Radar
  - Polarimetric Synthetic Aperture Radar

# TECHNOLOGY DEVELOPMENT PROGRAM

## ADVANCED SENSOR DEVELOPMENT LABORATORY

The Advanced Sensor Development Laboratory (ASDL) is responsible for research and development--particularly the design and development of multispectral scanners--and for calibrating, maintaining, and operating NASA/SSC's airborne sensors.

The ASDL is currently housed in a 7,600-square-foot facility accommodating a staff of 11 engineers and scientists. The facility includes laboratories to support associated research and development activities in optical, mechanical, electronic, and overall sensor systems. Additionally, there are specialized laboratories with computer-aided design (CAD) workstations.

The ASDL supports STL's research and commercial programs, which contribute to both NASA and non-NASA programs.

### Sensor Development Support

A significant increase in the ASDL capabilities for the development of airborne multispectral sensors was achieved in FY90, and a study of the ASDL's capabilities was conducted by a senior engineer outside of the SSC community. Primary accomplishments include:

- A microprocessor development system was procured and used to develop a sensor prototype Central Processing Unit (CPU) that can manage sensor housekeeping, interface with aircraft inertial navigation and gyro systems, and manage certain timing and control functions. This prototype CPU is now operational and will support a developed system concept; it should be readily adaptable to other design concepts.

- Research was conducted into current storage devices and supporting interfaces. A helical-scan tape recorder with a small computer system interface was selected as the most appropriate choice for the storage of multispectral sensor data.

- A high-level language program, ASYST, was procured and utilized to develop a computerized sensor analysis and modeling program. The program was used to analyze the Thermal Infrared Multispectral Scanner (TIMS) and the Calibrated Airborne Multispectral Scanner (CAMS) systems to better understand and document their performance parameters. This general-purpose analytical capability can be used to evaluate opto-electronic instrumentation and sensor systems.

- A circuit analysis program was installed and utilized with IEEE 488 bus-supported test equipment to obtain actual TIMS and CAMS preamplifier performance specifications. This new capability is available for evaluation and testing of other instrumentation and sensor systems.

- The mechanical computer-aided design hardware and software capabilities were upgraded to increase system performance. Additionally, the computer-aided engineering (CAE) workstations were upgraded with better performing hardware and more comprehensive software packages.

### Sensor System Support

The ASDL provided calibration, maintenance, and operational support for the TIMS and CAMS and, to some extent, refurbished and modified both scanners. Performance of both

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sensors was significantly improved during FY90.

Sensor technical support also was provided for other organizations, including Ames Research Center (ARC), Naval Oceanographic Office (NOO), Naval Oceanographic and Atmospheric Research Laboratory (NOARL), and Space Remote Sensing Center (SRSC).

The following paragraphs describe specific activities relating to the CAMS and TIMS, as well as to the ground-based Ice Detection System development effort.

## Calibrated Airborne Multispectral Scanner

The CAMS, one of two STL airborne sensors, is a nine-channel imaging system designed and fabricated by SSC/STL. The nine channels provide data in the visible, short wavelength infrared (IR), and thermal IR wavelengths. Onboard sensor reference sources provide data for calibration standards. The composite sensor data are in PCM format and include imagery data, reference data, time, latitude/longitude, ground speed, true heading, and video gain settings. The data are recorded on 14-track, 1-inch, analog magnetic tape.

The CAMS has been used in support of research in various fields, including archeology, coastal geomorphology, tropical forestry, near-shore oceanography, and rocket motor plume analysis.

In FY90, portions of the CAMS optics were refurbished and realigned, and Channel 9 hardware was modified. This resulted in significant improvements in CAMS data.

## Thermal Infrared Multispectral Scanner

The TIMS, the prime SSC/STL airborne sensor, is a six-channel thermal infrared scanning spectrometer. It has onboard reference sources and records data in a format and method similar to those of the CAMS.

For nine years, the TIMS has been supporting missions for both SSC and Ames Research Center, as well as for many non-agency users. In recent years, the TIMS has been used to support the NASA Office of Space Flight activities in assessment of the Rogers Lake Bed condition, support of Shuttle landings, and ground testing assessment of SRM thermal plume profiles.

The original capabilities of the TIMS have been enhanced by modifications performed by the ASDL. During its service tenure, the detector preamps have been significantly improved; the telescope and motor/mirror assemblies have been refurbished; and new black bodies, a gyro, and a new diffraction grating have been installed. Additionally, in FY90, a new detector/dewar was installed. All of this has resulted in the highest quality of data yet acquired by this instrument.

TIMS missions supported research in a variety of disciplines, including geology, archeology, and forestry.

## Ice Detection Research and Development

As a derivative of earlier remote temperature sensing instruments and their application in monitoring the surface temperature of the Space Transportation System (STS) external tank for icing conditions, the ASDL has developed a prototype Ice Detection Sensor based on a commercial platinum-silicide, focal plane array.

This imaging array system has an open spectral range from 1.0 to 5.0 microns, but optical filters are used to create a two-band system operating at 1.5 to 1.8 and 3.0 to 5.0 microns. These bands were selected because of the enhanced ability to detect moisture, frost, and ice on samples of the STS external tank Spray-On Foam Insulation (SOFI).

Multispectral imagery was acquired during varying external environmental conditions on the SOFI samples to determine and optimize a method of discriminating between frost and ice. The statistics of each test category were studied using discrimination procedures based on *a priori* data as well as unsupervised data classification techniques. Image processing algorithms and subsequent enhancements have been developed for near real-time ice detection and discrimination.

A PC-based, menu-driven image processing system with special-purpose plug-in boards has been configured to support the sensor.

## THERMAL IMAGERY ACTIVITY

### Preliminary Testing of EMU

The thermal imagers used by KSC Ice and Debris Team members during space shuttle launches have found use in other areas of research within NASA. One such use was to assist engineers at Johnson Space Center (JSC) in determining Extravehicular Mobility Unit (EMU) surface temperatures during thermal vacuum (T/V) testing of the suit.

Of the 16 crew members who have used the shuttle EMU during extravehicular activities, 9 have reported cold thermal discomfort of the overall body and in the hands. Such problems were thought to be directly linked to the EMU used for space shuttle missions, and until recently there was no effective method for evaluating the thermal insulation of the suit and its components other than contact type temperature sensing devices.

Two theories have been formulated that explain the development of cold extremities. The first theory is that the aluminized Mylar/Dacron multilayer insulation (MLI) in the EMU degrades over time and with high levels of use. This particular theory holds that the Dacron actually "debonds" from the Mylar in areas that undergo frequent flexing and compression (near joints, etc.). This permits the Mylar to develop creases and ultimately to tear, drastically reducing the insulation capability of the garment, and thus permitting heat loss from the inner layers.

The second theory is that the construction of the garment is the cause of the problem. For ease of manufacture, a "stitch through" technique is used on the layers outside of the actual pressure vessel. This means that seams visible on the outer Ortho fabric shell of the EMU are in fact stitched through the Mylar/Dacron MLI, causing a "cold short" at these locations and ultimately resulting in a heat loss.

Current technology in the T/V chamber at JSC relies on the use of contact temperature measuring devices, such as copper-constantan thermocouples, to ascertain suit temperatures at various locations. Although the values obtained through contact means are accurate and precise, the use of such devices has several drawbacks, including the need to be attached to the EMU, the presence of data lines from the thermocouple to the data collection device, the potential for tripping, impairment of movement, etc.

Data produced by the thermal IR imager are in the form of television-like images representing a "picture" of the temperature of a surface at a given point of time, and do not rely on contact with the surface being examined. Display intensity (black and white mode) or color variations (color mode) are related to surface temperature directly through an on-board calibration table.

Direct readout of the temperature at a particular location is available through the use of a set of movable cross hairs.

The unique aspect of this method of data display is that, unlike thermocouples, any point in the entire 15-degree vertical by 20-degree horizontal field of view can be "targeted" at will by the operator to obtain the temperature. The device collects temperature measurements for a particular target at 30 times per second. These images are subsequently assembled and sent out over a video link like a standard TV signal, where they can be stored on videotape and analyzed.

To gain insight into the surface temperature distribution of the EMU and its components, a thermal imager was placed inside T/V Chamber "B" (24 feet in diameter) for use during EMU T/V testing. The location was nearly ideal as it provided a "head on" view of the crew member during both resting (seated) and exercising/working (standing) periods of the T/V test. The location precluded total coverage in one IR imager view, necessitating the tilting of the unit to gather data on the upper and lower torso. Other than this consideration, the vantage point provided coverage of nearly perfect orientation.

The video and control lines of the imager were directed to a control console location on an upper floor of Building 3 to permit control of the unit from a remote location. All imager functions, as well as pan and tilt of the imager mount, could be directed from this vantage point.

Since the absolute temperatures of the surface of the EMU were required, the emittance of the material had to be determined; i.e., the imager had to be calibrated to the EMU surface through a range of temperatures encompassing those to be encountered during operational tests. Emittance is an indicator of the radiation efficiency of a material relative to a theoretically perfect "black body" radiator. This value ranges from a low of 0 to a high of 1.0, and can vary with wavelength. Thus, objects that are good radiators in one wavelength region might be poor ones elsewhere.

To calibrate the IR imager to the fabric of the EMU, three instrumented targets were constructed and placed on a frame in the T/V chamber such that the pan control on the imager mount would permit them to be moved into the field of view of the imager. They consisted of EMU material with thermocouples attached to the surface facing the IR imager. Both shredded and intact insulation were used in a "heated" configuration in an attempt to determine the effect of torn insulation layers. A third target served as a passive source, and gave an indication of the ambient thermodynamic equilibrium surface temperature.

During chamber chill-down, 21 simultaneous thermocouple/IR imager readings of the passive target were taken from between 62.9° F (17.1° C) and -130° F (-90° C), roughly spaced at 10° F intervals. After all the data had been collected, a model was developed that defined the relationship between imager "Level" value and recorded thermocouple target surface temperature. From this model, temperatures were related to imager "Level" value in such a manner that any reading made by the imager could be converted into an absolute surface temperature. Since the data were gathered using a portion of the EMU, the emittance value was automatically factored in, and as long as the imager was operated in a setup mode identical to the one used for calibration data acquisition, absolute temperature readings were possible.

Infrared imager data were collected during the June 22, 1990, EMU T/V test, which lasted nearly 5 hours. All during that time, the IR imager provided information on not only the EMU and all of the specific components, but also on several other items in the chamber as well, such as the Portable Data Acquisition Package (PDAP) and several styles of pip pins being tested.

The data were recorded in both black and white and color versions, with the color materials given to JSC engineers for immediate use in briefings and reviews. The black and white data were retained by Stennis Space Center personnel for analysis at a later date.

Several qualitative aspects of the data gathered warrant mention at this time. First, this test represents the first time that data using the IR imager were calibrated at and subsequently used to make temperature measurements in "space" thermal conditions. This ability demonstrates that devices such as this are adaptable for use on orbiting platforms.

Second, not all of the locations where temporal temperature measurements were made were considered at the beginning of the testing. In fact, some measurements were added after the initial readings had been completed. This ability to "go back" and "add" measurements after the T/V testing had been completed represents one of the strong points of using this technology. Implementation of the test through contact devices would have not only precluded data from these locations, but valuable insight into the thermodynamics of the suit would not have been gained.

Third, suit engineers used the data to perform quantitative assessments of the EMU insulation layer. As to the two theories mentioned earlier, engineers found that compression due to stitching does not appear to be a heat leak problem. The major heat losses are caused primarily by exposed/uninsulated surfaces and other suit penetrations. Shredded insulation did not noticeably affect the heat loss through arms and legs. In addition, comparisons of the Series 4000 (old) and 5000 (new design) gloves were made. The 5000 series gloves were thermally qualified for STS-37 and cold EVAs, based in part on the insight provided by the IR imager.

Fourth, during pre-EMU T/V testing of several flight components, the data provided qualitative (relative) temperatures that permitted the near-real-time modification of the insulation layer of the PDAP, thus preventing it from cooling down past the lower operational limits for the hardware contained in it. This is especially noteworthy as the PDAP is a passive, self-contained device, and the inclusion of heaters would make it too energy-consuming to use easily. Thermal conservation through adequate insulation and thermal isolation mounting was the only practical route open to engineers, and the IR imager provided the insight required to map the entire PDAP and locate areas where improvements could be made.

Finally, engineers concerned with other items tested in T/V conditions (e.g., pip pins) requested temperature estimates of surfaces other than the EMU. This indicates interest in the use of IR data for other applications, thus expanding the user base for such data.

As a conclusion to the effort, the following recommendation was made by JSC engineers: "Adopt the use of infrared camera technology for thermal-vacuum use as a cost savings as well as a means of non-destructive/non-damaging testing of both development and flight hardware. Cost savings are likely when comparing the cost of obtaining continuous thermal mapping IR imaging data with hard-wired instrumentation. In addition, performance of test hardware is more representative without bulky instrumentation interfaces, and the damaging effects of attaching thermocouples is eliminated."

## Thermal Imaging of Cereal Crops

The Space Remote Sensing Center (SRSC) at SSC develops contacts and demonstration projects with the private sector for the application of remote sensing technologies. SRSC requested SSC/STL to demonstrate the feasibility of using thermal imaging systems in small aircraft for aerial survey of cereal crops at the Dekalb-Pfizer Company Agricultural Research Farms in Kansas and Nebraska.

STL personnel used a standard gas-cooled thermal imaging system in a fixture that retrofitted the right-hand pilot position of a Cessna 172 so that this type of aircraft, which normally uses color infrared photographic systems, could fly real-time thermal image surveys. The pilot of the aircraft was in the left front seat and the thermal image systems operator maintained control of the unit from the rear seat.

The demonstration project was the survey of cereal crops, primarily hybrid varieties of corn, so that a determination of genetic variation and environmental stress relationships was made. Data were acquired for these crops at different times of day and at altitudes varying from 25 feet to 7,000 feet.

The results of analysis of the thermal imagery were that crop variety and environmental crop stress were clearly discernible. Further conclusions on the project were that it would be possible to replace color infrared photographic systems with real-time thermal imaging systems that allow for immediate and post-flight analysis of crops, soil conditions, water use, and livestock monitoring.

## SRM Test Monitoring Using Thermal Imaging

In support of the Propulsion Test Operations Office at SSC and the Base Heating Study at Marshall Space Flight Center (MSFC), the SSC thermal imaging equipment was used by SSC/STL personnel in a joint SSC/MSFC project to monitor solid rocket motor (SRM) tests at the Thiokol Test Range in Utah and at the Solid Propellant Test Article (SPTA) test stand at MSFC.

The use of thermal imaging technology was prompted by the desire to utilize the least intrusive methods of acquiring thermal data. Attaching the necessary array of contact thermal and strain sensors to the body of the SRM and Advanced SRM (ASRM) for such tests was thought to be overly involved. The thermal imager proved to have a much more comprehensive and overall monitoring capability than the add-on thermocouple devices presently being used.

The continued use of thermal imagers, however, will require the construction of shock-mounted and thermally shielded units, much like those used in the Shuttle Thermal Imaging project at the launch site at KSC.

The use of the liquid-cooled thermal imager in the Base Heating Study has increased the application of such instrumentation in that particular program. Even before the data from the first SPTA test were distributed, engineers at MSFC had developed even more comprehensive tests for thermal imaging systems of the type utilized for the Base Heating Study. It is apparent that thermal imaging technology reveals thermal planes and boundaries in rocket exhaust plumes with much better definition than that provided by single-point radiometers.

## SSC/STL AIRCRAFT

The SSC/STL Learjet 23 acquired more than 5,977 linear miles of airborne remotely sensed data during FY90. This involved a total of 40 missions with three of the deployments outside the United States.

The aircraft is equipped with instrumentation necessary to provide the housekeeping information for locational and attitude data used in the analysis of the images acquired. Basic operating parameters for the aircraft are altitudes from 3,000 to 41,000 feet above sea level, a range of approximately 1,000 nautical miles, and speeds of up to 450 knots. The sensor system is installed in an open bay area of the aircraft and is accompanied by a Zeiss 9-inch-square format aerial photographic camera. With the sensor systems available on this platform, data may be acquired with resolutions from 2.5 to 30 meters.

Keys to STL's data acquisition program include the ability to rapidly deploy the Learjet and the Laboratory's end-to-end remote sensing capability. On occasion, missions have been requested, scheduled, and flown in less than 24 hours. STL's expertise includes sensor design, development, calibration and maintenance, data acquisition, scientific investigations, data processing, and image analysis software development.

In addition, because of its low operating costs, the Learjet can remain deployed near the target and wait for optimal weather conditions to complete a mission.

## SSF PAYLOAD SIMULATOR ACTIVITIES

SSC/STL continues to develop the Space Station Freedom (SSF) Payload Simulator (PLS) in support of demonstrations on the Operations Management System (OMS) Testbed at the JSC, and Payload Crew Training Complex (PCTC) activities on the MSFC Operations Console Trainer (OCT). The PLS assists in the proof of concept and validation of SSF subsystems design, modeling, and simulations, and provides reduced life-cycle costs in payload operations.

The SSC PLS is a configurable evolutionary software product that simulates attached payloads in support of telescience concepts and resource management. It provides variable data loads for testing network interfaces and data handling and routing on SSF testbeds. The PLS is a menu-driven package written in the Ada program language. By developing this package in Ada and satisfying the requirements of portability, an understanding of portability and real-time capabilities/limitations of the Ada language has been obtained. Development continues on SSC's Ada Program Development System (see Figure 9), with integration and checkout following on appropriate SSF testbed hosts.

The execution of a payload configuration requires a complex multitask implementation that exchanges commands and data with a workstation and/or core systems, and utilizes the communications services provided by the host environment. The PLS generates standardized Consultative Committee on Space Data Systems (CCSDS) data packets of varying rate and length as specified by the user during the creation of the payload configuration. In addition to currently residing in the OMS Testbed and the OCT Workstation Laboratory, the PLS has been integrated into multiple SSF testbeds, including the JSC Data Management System Testbed; the Goddard Space Flight Center Telescience, Platform Management System (PMS), and Star Bus Testbeds; and the Network Protocol Testbed at Reston, Virginia. The PLS was an integral part of the Space Station Information System End-to-End Test Capability.

Current payload simulations are configurable and provide the user with definition and control of a payload's potential data load, data format, logic, and interactions with the Operations Management Application (OMA) on the OMS Testbed, the OCT, or other applications programs. Such control is attained by defining a payload configuration in terms of a finite-state model described with state and transition tables. This model allows the user to define a logical flow of events through the course of a simulated experiment.

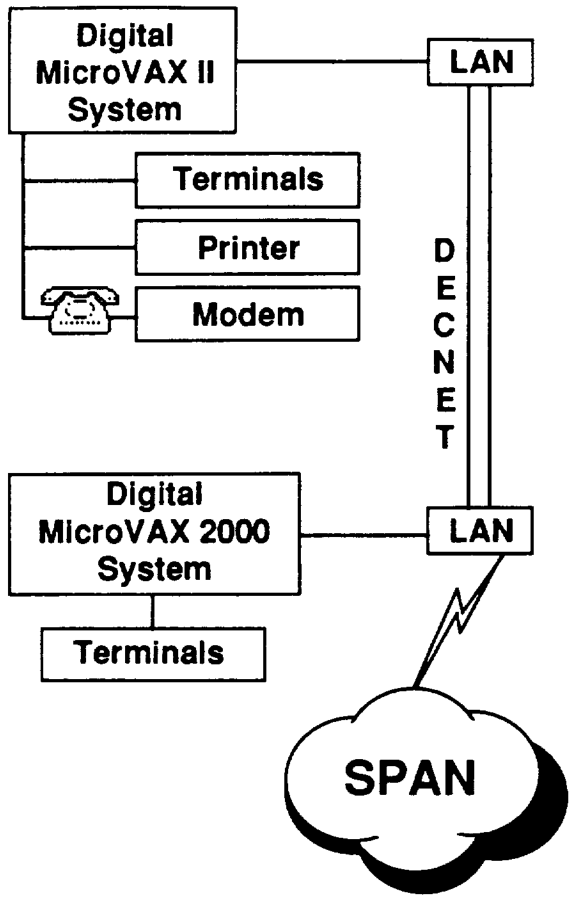



Figure 9. SSC Ada Program Development System Hardware Configuration

Besides providing the user with the ability to select elements of a simple payload configuration, the package provides a self-contained database management system for the creation, storage, retrieval, and installation of named configurations associated with a specified user identification. Configurations are maintained online as disk files, with a linked-list structure providing efficient access.

Execution of the payload configuration opens a dialog with the OMA, the OCT, or other applications programs in which commands are received and acknowledged according to the finite-state model definitions. Execution of an installed configuration generates CCSDS data packets at a specified rate and of a specified length, format, and content in compliance with parameters of the configuration. A multinode capability exists whereby the simulator may send/receive commands or data to/from multiple nodes.

SSC/STL expanded PLS support to an additional NASA installation by releasing a version of the software package in support of the MSFC OCT Demonstration No. 2. The simulator was hosted on a VAX workstation in the OCT Workstation Laboratory to simulate given experiments and to provide on-desk training capability for console operators of the PCTC. The objective of this demonstration was to develop and utilize an interactive tool for the OCT, since resources in the PCTC were in great demand and training activities would be enhanced with such a tool. The PLS was successfully integrated with existing Man Machine Interface tools and Transportable Applications Executive capabilities to provide a common user interface with a flexible payload modeling tool.

Also, SSC/STL published a PLS/MSFC OCT interface control document together with revisions to the PLS requirements, design, and users' guide documents. The PLS release implemented new MSFC OCT requirements, which included upgrades in the simulator's engineering data output capabilities through the utilization of linear ramp functions.

Toward the end of FY90, SSC/STL began Demonstration No. 5 to support a set of operations on the OMS Testbed at JSC. These operations will demonstrate SSF core-system and user activities under the control of an onboard OMS.

Additionally, SSC/STL has begun design efforts to implement the software changes required to interface with communication servers associated with the OMS testbed, and to define and implement three new payloads to enhance the PLS configuration capability.

## GAS DETECTORS

### Hydrogen Gas Sensing Instrumentation

The Smart Hydrogen Sensor Project reached a major milestone with the production and delivery of three units for testing and evaluation for the KSC Engineering Development Laboratory. The Smart Hydrogen Sensor (SHS) Unit is primarily designed for use in hydrogen storage facility or transfer system monitoring.

First conceived at SSC for use in the Space Shuttle Main Engine (SSME) test facilities, the adaptability and quick response of the units yielded new opportunities for potential applications at other NASA Centers. Work continues on the standalone, single-point sensor as well as multipoint array sensor elements. Additional activity using the hydrogen sensor is for development of a hand-held portable unit and a miniature version, using surface mount technology, for potential application as flight hardware.

### Fugitive Gas Detection and Analysis

As NASA's capability to sense the presence of hydrogen improves with the addition of instrumentation such as the Smart Hydrogen Sensor, interests turn to how these data can be more effectively utilized to protect lives and equipment in the component test, engine test, and launch environments. Typically, the data from hazardous gas detection systems are connected to the traditional array of panel meters. Monitoring the status of these instruments places a considerable burden on system operators. Modeling studies conducted during the subject program have led the way to conceptual designs with far more effective fugitive gas detection, hazards analysis, and remediation capabilities.

In FY90, simulations were developed using a hydrogen diffusion model, piping schematics, and oblique-projection graphics that had been tailored for SSC's Component Test Facility (CTF), now under construction. Through the use of these simulations, various methods of data presentation and operator interaction were explored. These simulations ranged in complexity from simple two-dimensional displays of sensor data relative to hydrogen system schematics (Figure 10) to oblique-projection graphics overlaid with displays of hydrogen concentration (Figure 11). Based on these simulations a greater fugitive gas detection efficiency is possible, especially when leak levels are low.

## PLUME ANALYSIS

### SSME Exhaust Plume Diagnostics Project

One approach to managing rocket engine health is to monitor the status of those engine components that are subject to deterioration. When a component wears excessively, the engine's exhaust plume may contain higher than normal concentrations of that particular component's constituent material.

Visual observations of SSME exhaust plumes have shown an occasional flaring that sometimes resulted in test failure or even engine damage. Real-time detection and the immediate interpretation of these events will enhance engine and test facility safety. It has been demonstrated that by monitoring exhaust plume emissions, precursors to many component failures can be detected prior to the actual failure. Additionally, plume emissions provide the earliest information on some SSME component wear and degradation. This information can be used to enhance post-test inspection and certify the engine ready for reuse.

In FY89, a project was undertaken at SSC to provide plume diagnostic monitoring capability for all SSME test firings. By the end of FY90, commercial spectroscopic and video equipment had been installed on all SSME test stands. Optical probes were also designed and fabricated to provide spectroscopic data for each test stand.

Based on SSME plume monitoring data and related technology efforts at the Diagnostics Testbed Facility (DTF), the optimization of these systems is in progress. These efforts will result in enhanced, real-time interpretation of spectroscopic and video plume monitoring data.

Figure 12 shows plume emission data acquired on SSME Firing No. 901-619. The video data (top) show plume streaking that resulted from the erosion of the main combustion chamber baffle. The spectral "waterfall" plots (bottom) identify copper as the major component of the eroding baffle. Precursors of the major streaking event (failure of the baffle) were observed long before visual indications were noted.

The FY91 goals of the plume diagnostics project are to develop recognition criteria of

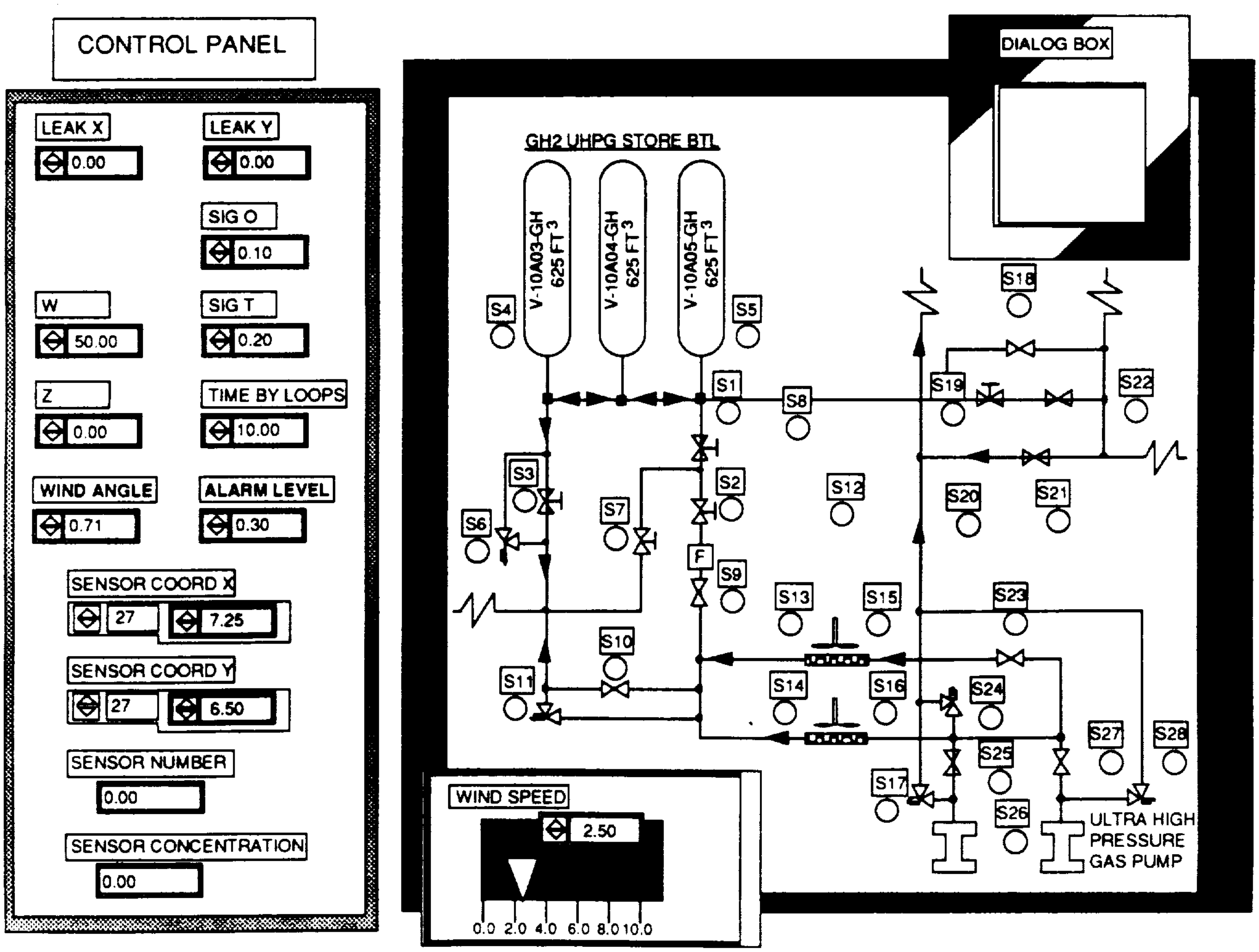



Figure 10. Fugitive Gas Detection System

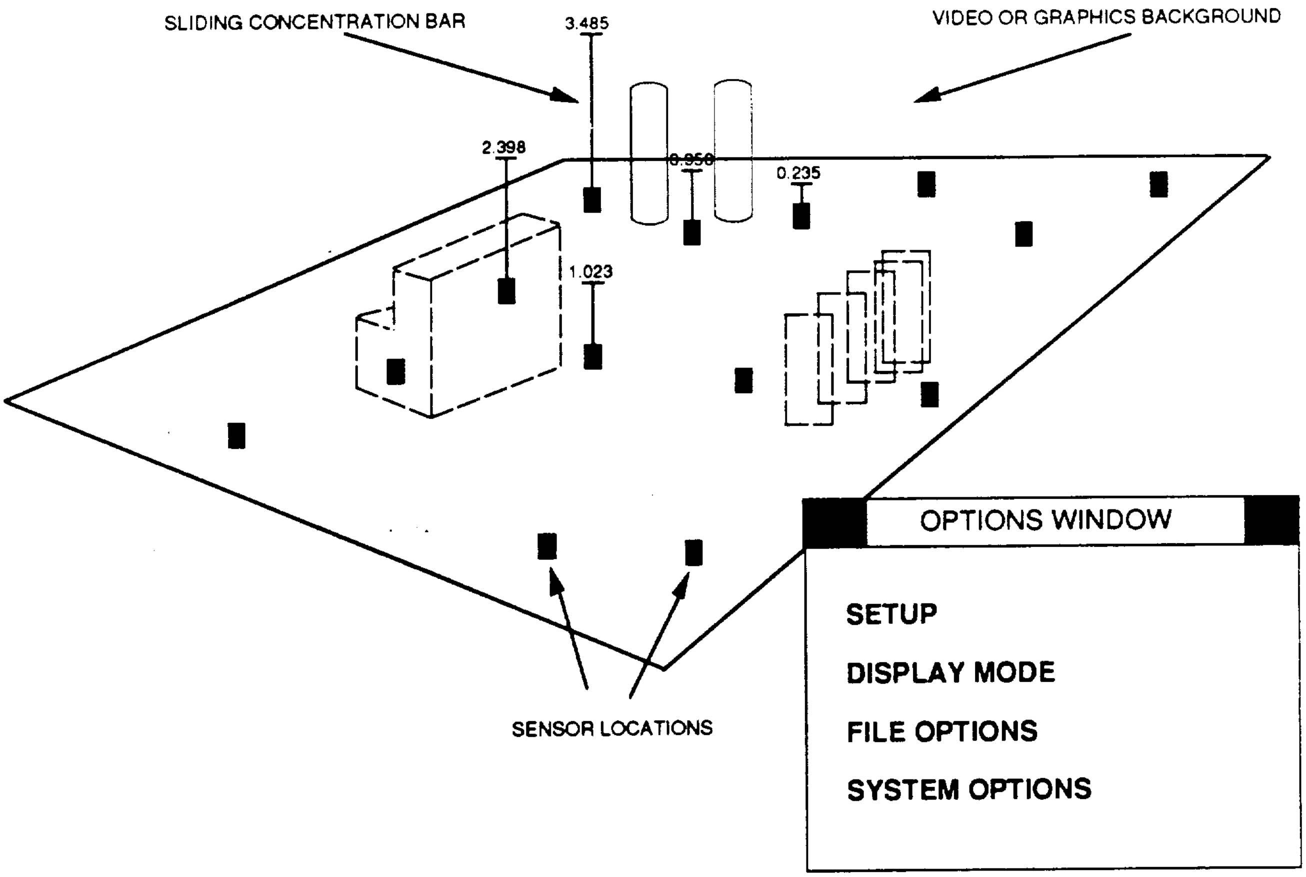



Figure 11. Sliding Bar Sensor Grid Visualization

crucial SSME material emission spectra; establish thresholds for acceptable plume emission parameters; and quantify SSME component wear and degradation. The addition of a real-time display of these data will improve SSME test safety and increase test efficiency. The development of a closed-loop capability for SSME and advanced propulsion system testing are long-range goals of the SSC research and technology effort.

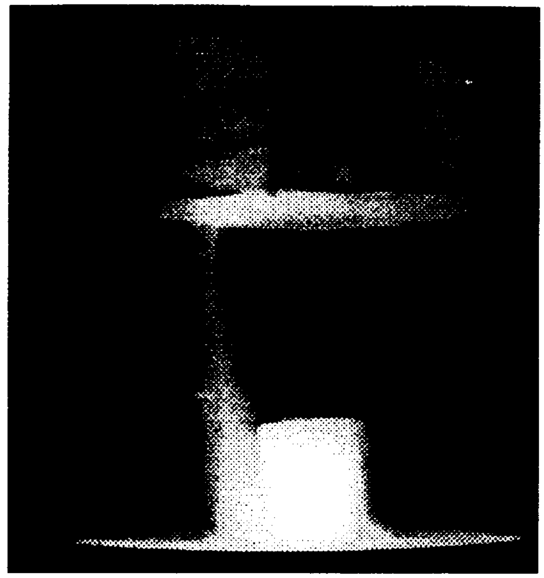
## Advanced Plume Diagnostics Capabilities

Efforts to enhance the existing SSME diagnostics capabilities continued in FY90. In addition to the evaluation of advanced plume diagnostics concepts and the implementation of a flat-flame diffusion burner (FFDB), several advanced concepts and instrumentation were identified as having potential for engine diagnostics at SSC.

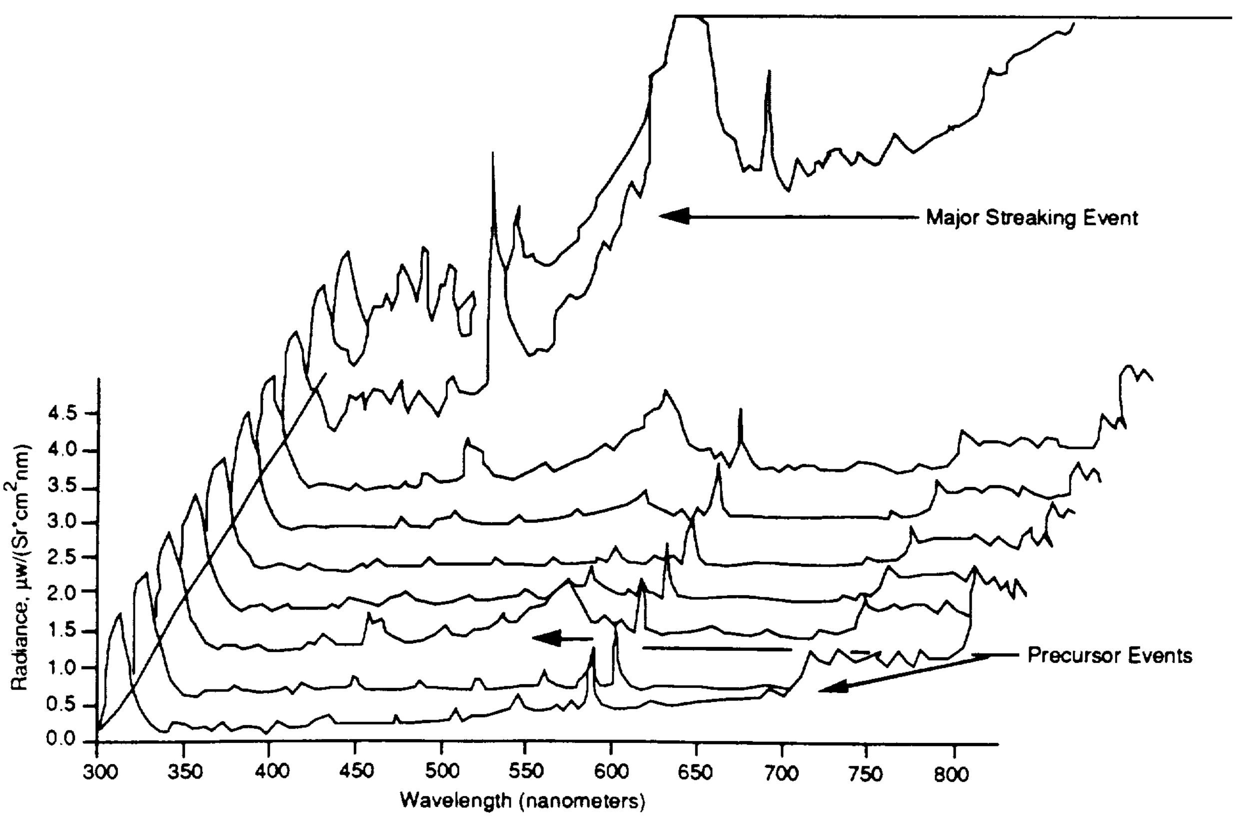
## Flat-Flame Diffusion Burner

As a result of an FY89 study, SSC initiated the installation of an FFDB and a laboratory-scaled, hydrogen/oxygen plume emission source at the DTF in FY90. The goal of this effort is to build a laboratory spectroscopic capability to support current and future engine diagnostics projects at SSC. Its immediate application is in the current plume diagnostic activity with the DTF Thruster (DTFT), as well as on SSME test stands.

In FY90, the FFDB system design was completed, parts specified, and system component procurement initiated. The system, shown in Figure 13, consists of a 0.5-inch-diameter flat-flame, co-flow diffusion burner; gas distribution/control network; computer-based control/monitoring unit;



*a. Digitized frame of plume video data shows streaking from main injector baffle erosion.*




*b. Waterfall plot of plume spectral emissions during baffle erosion event. Major peaks result from copper emissions.*

Figure 12. Plume Emission Data Acquired on SSME Firing 901-619

and a fume hood. The fuel and oxidizer remain isolated until combustion above the burner surface. The combustion products are contained by a nitrogen shroud. An axial feed-tube located at the center of the burner facilitates dopant injection.

At the completion of the FFDB installation in early FY91, a repeatable spectroscopic source similar to that used with the DTFT and the SSME exhaust plume will be available for plume diagnostics at a fraction of the DTF operating cost.

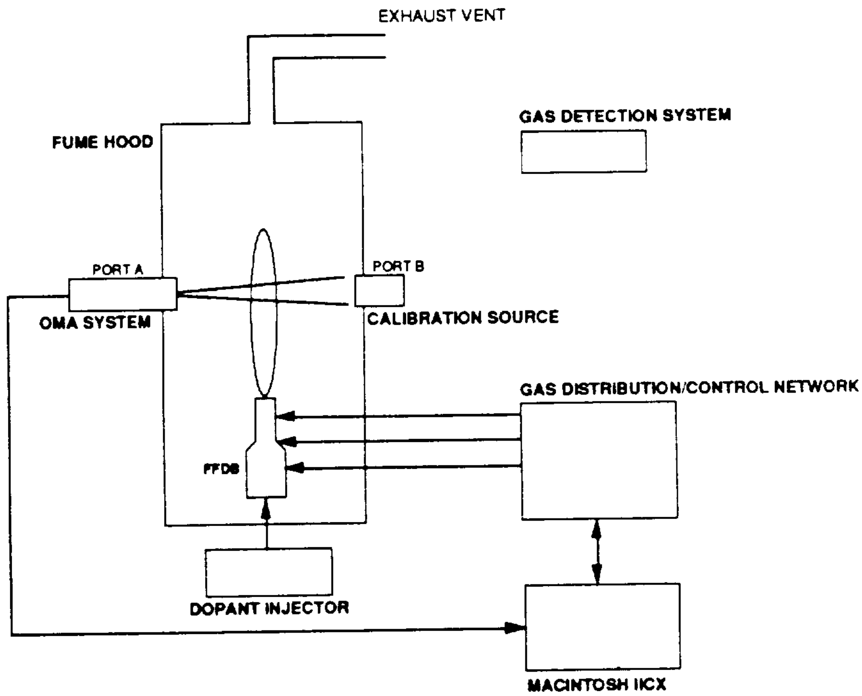



Figure 13. Flat-Flame Diffusion Burner System Schematic

## Spatial Imaging of Plume

Spatial imaging research of plumes was initiated in FY89 and continued through FY90. The intent is to determine if the concept is applicable in SSME diagnostics.

Spatial images of rocket exhaust plumes are acquired with ultraviolet (UV), visible, and IR cameras in order to study the combustion products expected under normal engine operating conditions, as well as those occurring during engine operation anomalies. The objective is to study spatial images of the SSME plume and correlate the changes in the images with the changes in the engine operating parameters. Knowledge of spatial characteristics of the SSME exhaust plume combined with spectral data from Optical Multichannel Analyzer (OMA) systems can provide important information on the health of the engine during ground test and could lead to development of advanced plume diagnostic techniques at SSC.

UV and IR spatial images of the DTF exhaust plume were collected with UV and IR cameras in conjunction with ongoing DTF plume seeding experiments. Digitized frames of those images have been processed and characterized with some success. The visual inspection of unenhanced images, either in UV or IR, did not reveal any reliable information; however, when these images were enhanced by spatial and frequency processing methods, reproducible patterns in both UV and IR images were apparent.

The limited DTF data set precludes any firm conclusions on the differences in seeded and unseeded (baseline) patterns. It is probable that dopants in the seeded DTF exhaust plume did not induce significant patterns due to the present seeding method which results in a nearly uniform distribution of dopants in the exhaust plume.

Spatial images of the SSME plume on the A-1 Test Stand, where streaks had been observed frequently, were acquired during test 901-619. The results from the enhanced digital data show promise sufficient to justify additional research.

## Application of LIF and CARS Techniques

Laser-induced fluorescence and coherent anti-Stokes Raman scattering techniques use actively tuned lasers to excite the specific element of interest in the exhaust plume. This requires precision alignment of a strong laser and a sensitive detector to scan in unison a plume as large as that produced by the DTFT, or even the SSME.

Such detection apparatus and techniques have proven to be very useful for diagnostic measurements in laboratory environments, but further development for large-scale applications outside of controlled environments needs to be addressed. Both techniques have been evaluated analytically by a NASA Summer Faculty member from Mississippi State University and by SSC personnel as to how the techniques can be applied in plume diagnostics.

The detection of metallic species such as molybdenum, hafnium, and tantalum indicates that further research is justified.

## Video Imaging of SSME Plume

One common anomaly in the SSME plume is the appearance of a green streak due to copper ingestation. Such streaking can be recorded in video images during SSME test firings. On January 31, 1990, during Test 901-619 on Engine 0209, camera Position 1 was used to acquire data for spectral analysis.

The analysis of these video images was directed toward two principal areas of interest. The first was to determine if there were other spatial effects associated with this streaking, and the second was to detect variations over time to determine if there were any recognizable events preceding the streaking. The results of the analysis are presented in Figures 14 through 21. (Note: Original photos are in color; black and white half tones used here cannot convey technical data fully, but should illustrate gist of study results. Contact author listed in Appendix for further information.)

Figures 14 and 15 are plots of cross sections through a plume containing a streak. The vertical axes of the graphs represent intensity while the horizontal axes show the position along lines in the images. The part of the image outside the area of the streak is fairly smooth and of low intensity; however, the horizontal cross section seems to indicate the existence of convoluted sinusoidal patterns.

Most of the streaks appear to be solid green, though there were occasionally red streaks. The streak in Figure 14 (Image 0243-2) is an exception, in that it contains a thin yellow core. Because the video frame grabber operates with black and white intensities, the yellow is not apparent in the image; however, this core appears clearly defined in Figure 17, a pseudo-colored version of image 0243-2.

The cross-sectional plot in Figure 16 indicates a Gaussian shape to the streak. Unfortunately, green streaks also show this Gaussian shape (e.g., the streak in Image 0155-2 of Figure 18), meaning that without further study and quantification, a Gaussian profile is not a useful discriminator for distinguishing variations in streaks.

Figure 19 represents Image 0110-1, a plume with no anomalies. With trackball linear mapping, the contrast of Figure 19 was enhanced to make the details of the image more apparent.

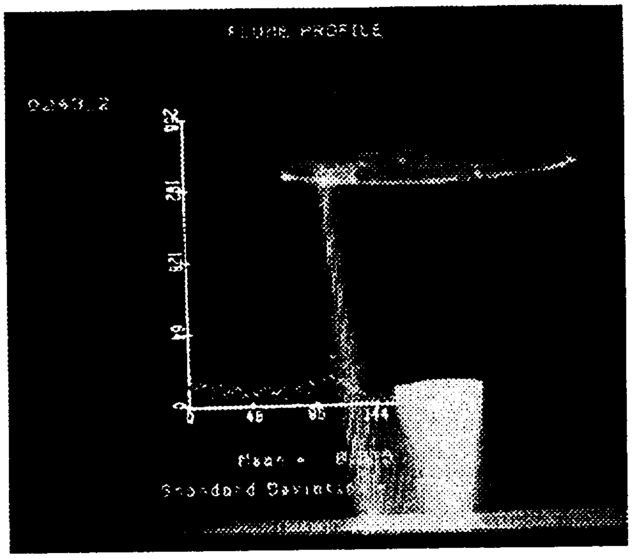


Figure 14. Horizontal Cross-Sectional Profile of Plume with Streak

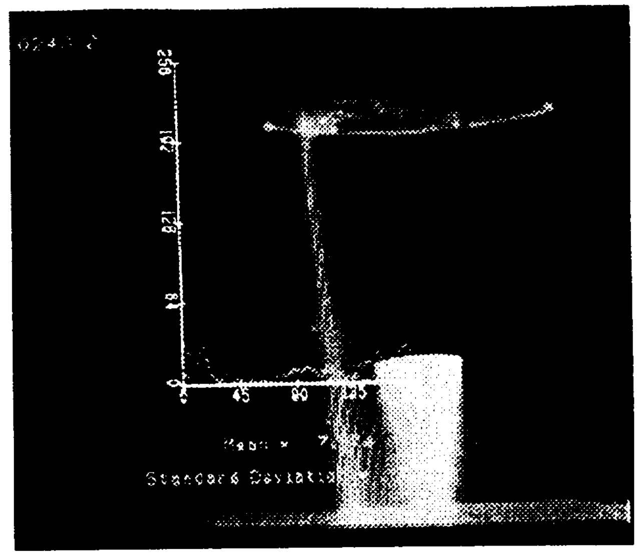


Figure 15. Vertical Cross-Sectional Profile of Plume with Streak

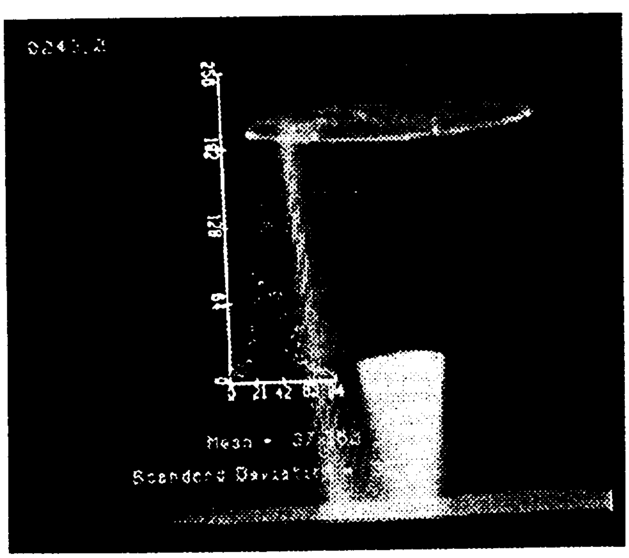


Figure 16. Horizontal Cross-Sectional Profile of Streak with Core

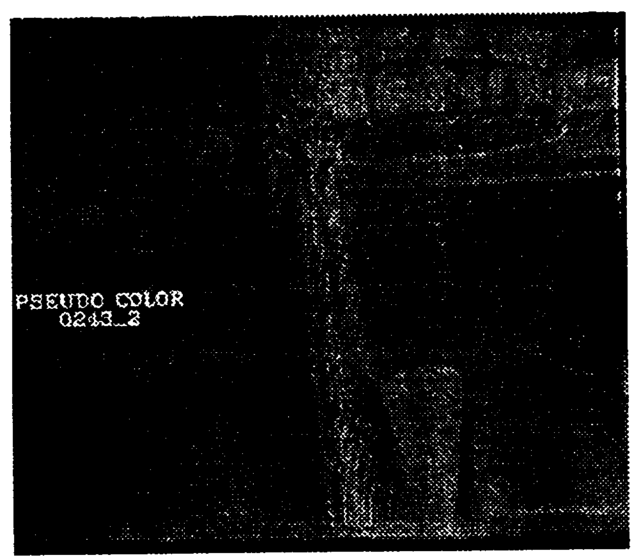



Figure 17. Pseudo-Color Version of Streak with Core

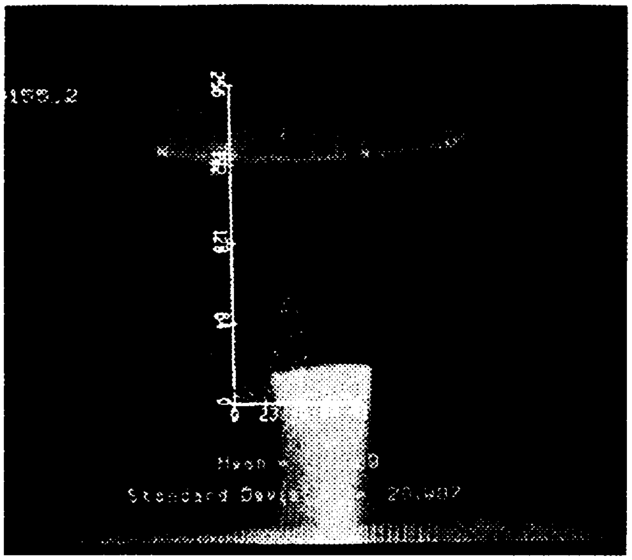


Figure 18. Horizontal Cross-Sectional Profile of Streak without Core

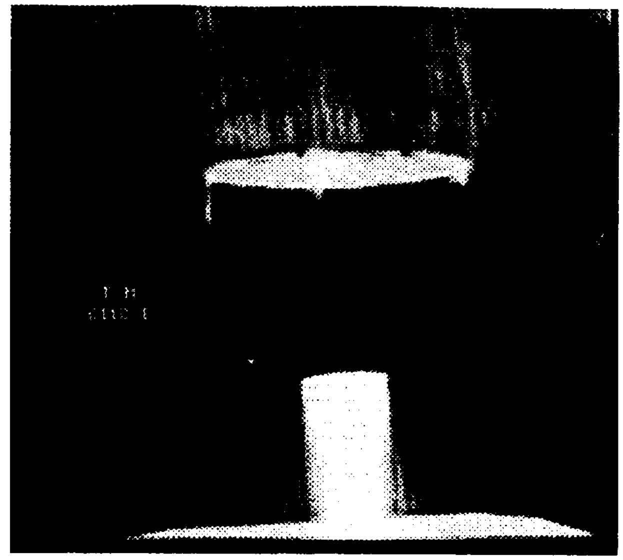


Figure 19. Image of Plume Enhanced by Trackball Linear Mapping

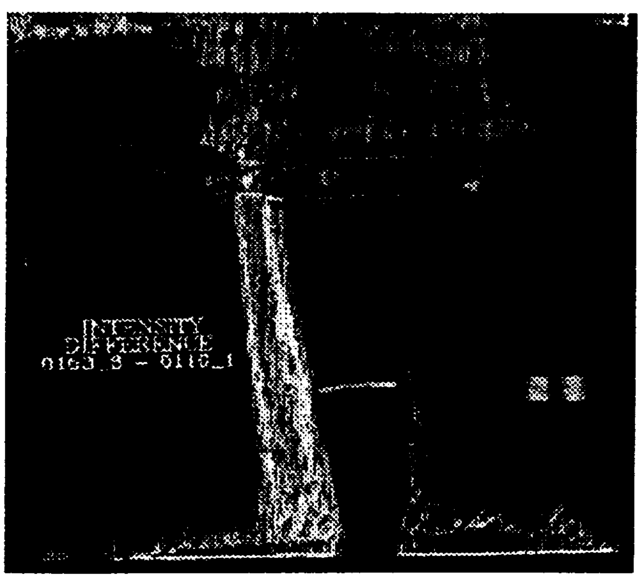


Figure 20. Difference of Plume Images

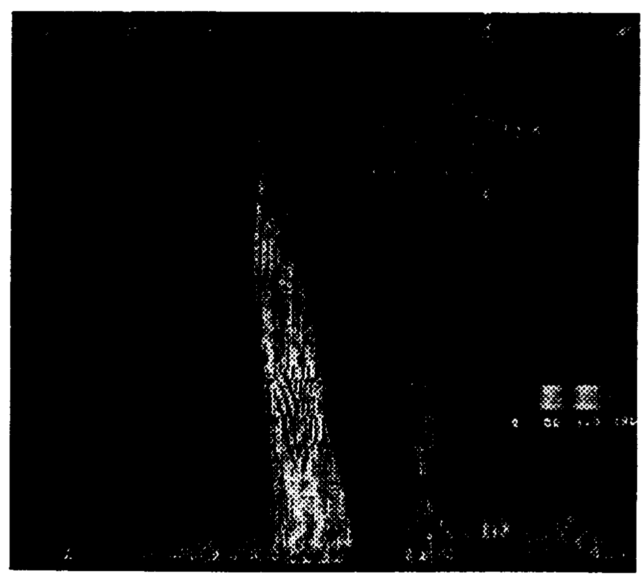


Figure 21. Difference of Two Sequential Images of Plume with Streak

Figure 20 is a pseudo-colored version of the differences between 0110-1 (Figure 19) and a plume image (not shown) with a streak. The first objective in producing this type of image was to determine the differences in a "clean" plume and one containing an anomalous event such as a streak. The second objective was to determine the differences in the clean plume and the plume as it appeared immediately before the presence of an anomaly. This second objective was important because such a difference would contribute to the ability to predict when anomalies were imminent.

After examining difference-pairs for all images and viewing them in a "movie loop" (rapid, repetitious displaying of difference-pairs), it was determined that there were no detectable indicators preceding an anomaly. The only detectable differences noted between a normal plume and an anomalous plume were the anomalies.

Figure 21 shows the difference between an image and the one preceding it. The only significant variation noted was the growth of the streak once detected.

## Electric Field Measurements of Plumes

One project initiated under the SSC Director's Discretionary Funding Program was a study of emission measurements as they relate to exhaust plumes. Because the plume is a cold plasma composed of high-temperature ionized gases, the radiation strength of an electric field (EF) is related to plasma electron density.

This activity is a continuation of previous effort and involves the evaluation of EF plume data collected in FY88, FY89, and FY90.

EF data were collected using a state-of-the-art Nanofast EFS-2 Electric Field Sensor (Figure 22), which measured the electric field directly as a function of time. The sensor has a frequency range of 350 Hz to 250 MHz and a full-scale setting of 100 V/m. The EFS-2 consists of a 4.5-inch-diameter, spherical dipole antenna with built-in fiber optic circuitry and associated receiver chassis connected by a duplex fiber optic cable. During operation, the voltage induced in one-half of the dipole antenna is sensed by the internal circuitry in the other dipole half, converted to optical form, and transmitted over the fiber optic cable to the receiver. Electric fields exist naturally as three-dimensional phenomena. The EFS-2 sensor is capable of measuring only one dimension at a time. In this application it was oriented to measure the plume's axial EF.

At the DTF the sensor was mounted six feet downstream from the nozzle exit and six feet from the plume centerline, in the plume's horizontal plane. Data from the EFS-2 receiver were converted into digital format and stored to disk on a Macintosh II computer using National Instruments analog-to-digital board and LabVIEW software. Data were collected at a rate of 7000 Hz.

At the A-1 Test Stand the EFS-2 sensor was held by a wooden mount ten feet from the SSME nozzle exit, five feet above the grating floor. Data from the receiver were transmitted to a Tektronix oscilloscope where the front panel trace was recorded on video tape.

Electric field sensor data were analyzed by a Macintosh II computer system using LabVIEW and AcqKnowledge software.

The first step in data analysis was to note general characteristics of the waveform, such as wave structure, frequency, and whether spiking occurred. Characteristics of waveforms at various dopant concentration levels were compared. Large spikes in the EF data were compared with video data for correlation with visible changes in the plume. No anomalies were observed in the video data.

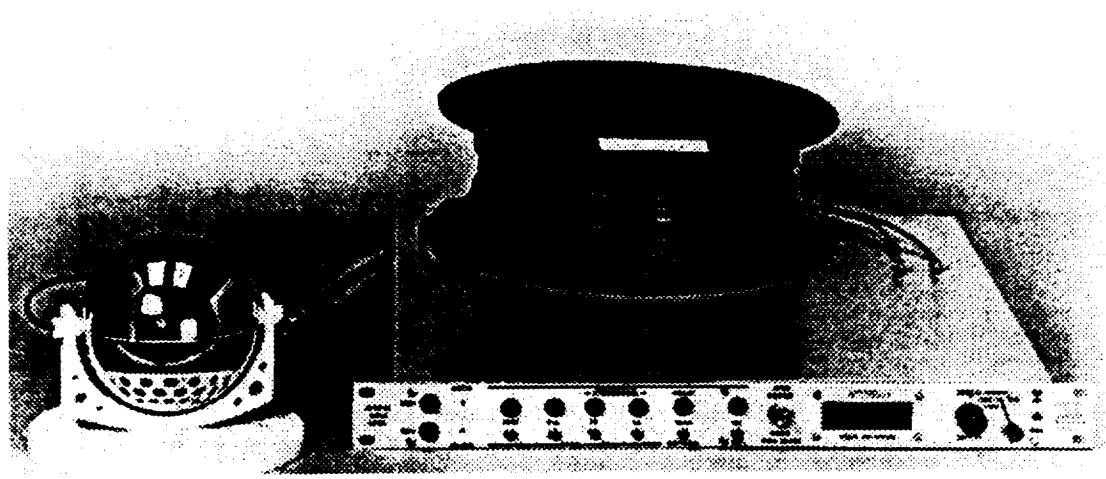


Figure 22. Nanofast EFS-2 Electric Field Sensor

The 60 Hz component was filtered out of selected waveforms using a finite impulse response (FIR) filter to perform digital filtering. A Kaiser-Bessel window was used in conjunction with a 1000 coefficient filter using a bandstop of 55 Hz to 65 Hz at -3 dB. The strength of this 60 Hz component was found to be insignificant when compared with the overall signal level and has been neglected in this analysis.

The respective baseline was subtracted from each firing and each waveform was windowed with the Kaiser-Bessel function. Then a Fourier transform was performed on all electric field data. The frequency spectra of all the waves were studied for overall characterization, attributes, and any generalizations.

### *DTF Electric Field Measurements*

Figure 23 is a graph of data collected immediately prior to a DTF test. The waveform has a time interval of 0.29 second. Large spikes possibly indicate cycling of the solenoid valves used for DTF operations. The cause for the smaller spikes has not yet been determined.

Figure 24 shows data taken during a DTF firing. The two very large spikes occurred approximately 0.1 second after ignition. These spikes are at least an order of magnitude above the average signal level of this test; however, the sensor saturated during this event, making it impossible to determine an exact signal level. The figure displays a time span of 56 milliseconds. According to DTF engineers, the engine ignitor burns in the plume's exhaust for the first 0.2 second of the firing. One possible explanation for the spikes is that a piece of metal wire used in the DTF ignitor passed through the combustion chamber and into the exhaust plume, creating a momentary fluctuation in the plume's electric field.

At the shutdown of every DTF test, the liquid oxygen (LOX) valve is closed 6.25 seconds after ignition. This is 1 second before the hydrogen valve is closed. Afterburning causes the plume to become a hydrogen-rich flare, which is believed to be responsible for the increase in the electric field signal pictured in Figure 25. This increased signal is two to three times the intensity of the steady-state burn signal.

Fourier transforms were performed on selected time domain data in an attempt to determine if the plume has a specific "signature" in the frequency domain. Figure 26 shows the frequency spectrum of a DTF test containing 10 ppm iron. The X-axis indicates

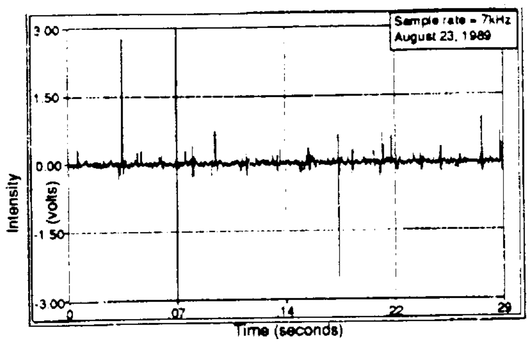



Figure 23. DTF Test, Ambient Data

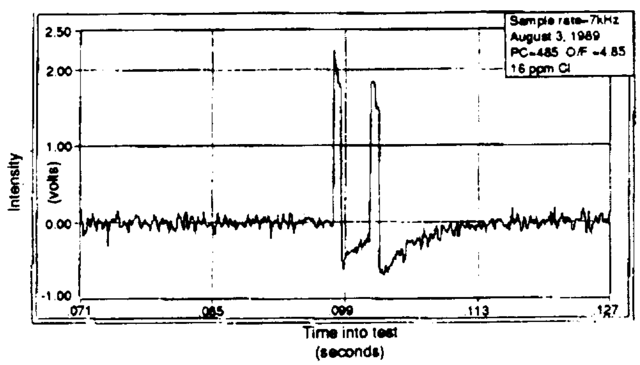



Figure 24. DTF Test, Large Spikes

the frequency and the Y-axis expresses signal intensity in volts. This transform represents the steady state portion of the firing and excludes startup and shutdown transients. Figure 27 depicts the frequency spectrum of a DTF test containing 10 ppm cobalt. The differences in these two firings are quite distinct; therefore, it may be possible to differentiate between dopants by their individual frequency signatures. However, it should be noted that the EF signal levels are so small that background noise must be reduced in order to detect the authentic dopant frequency signature.

### *SSME Electric Field Measurements*

Selected video images of the oscilloscope trace for SSME Test 901-606 on the A-1 Test Stand were digitized on a Macintosh II computer and hard copies were used for analysis. The "pretest" waveform, shown in Figure 28, Image A, was taken approximately 60 seconds before ignition, and a typical "during test" waveform, shown in Image B, was taken approximately 70 seconds after ignition. Comparing these two waveforms, it is evident that an electric field is being generated by the SSME plume. The signal intensity is 0.4v to 0.5v peak-to-peak, with a composite frequency of approximately 500 Hz.

## Signal Processing Techniques for Plume Diagnostics

The effort addressed here was approached from a controls engineering viewpoint with the goal of establishing methods for preprocessing optical spectral data acquired at the DTF and scaling the data to optical spectral data acquired from the SSME exhaust plume. In so doing, a well-established data technique was evaluated that shows promise for on-line element and material identification. This technique has the potential for application to ground test controls and flight-rated avionics and control systems. Preprocessing of optical emissions data using this technique could provide qualitative and quantitative information concerning SSME material wear and degradation.

The intent is to explore the identification process of an alloy dopant using the spectral database from DTFT testing, and to define spectral data requirements for future testing.

Several factors make identification of a particular alloy

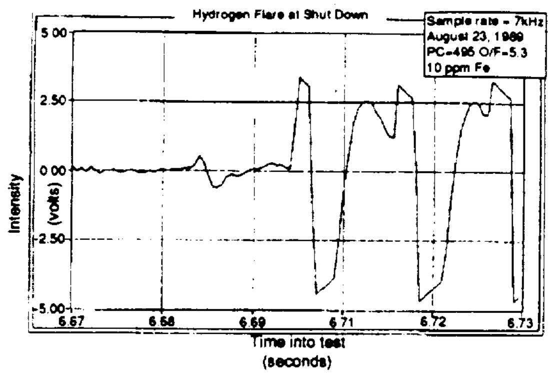



Figure 25. DTF Test, Hydrogen Flare at Shutdown

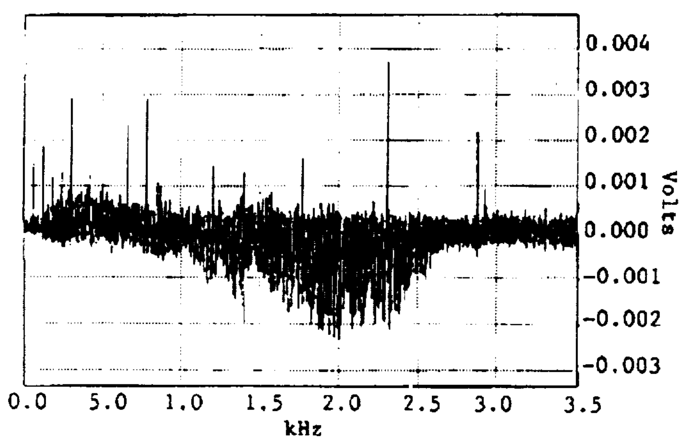



Figure 26. Frequency Spectrum DTF Test with Iron

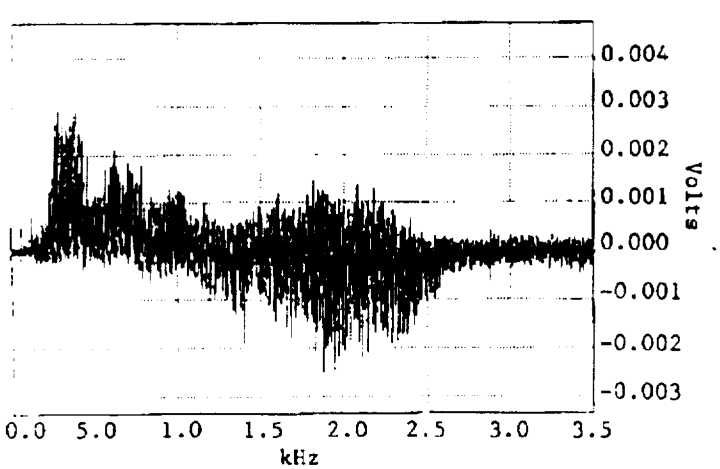



Figure 27. Frequency Spectrum DTF Test with Cobalt

injected in the DTFT difficult. One is removal of hydroxide, sodium, and potassium spectral regions from consideration due to their saturation of spectral sensors. Another is the unintentional injection of emitting trace elements with the dopant or fuel. A third is that all emitting elemental constituents of an alloy must be considered, or the incomplete data set will yield misleading results. Finally, the spectral data set must have sufficient resolution and limited background signals to provide a definite decision on plume content. Under study was the process of determining the constituent elemental spectra contained in the spectra of some unknown dopant, thus quantitatively determining the elemental makeup of that dopant.

The process is difficult when applied directly to the SSME plume, since the baseline spectra are changing due to gimbal position, swirling water vapor, thrust level, and atmospheric conditions. Such experimental evidence of the SSME plume is sparse and the few abnormal situations are not quantifiable. Also, dopant signatures in the SSME plume are not known. It is therefore desirable to translate knowledge acquired at the DTF as directly as possible to the SSME knowledge base.

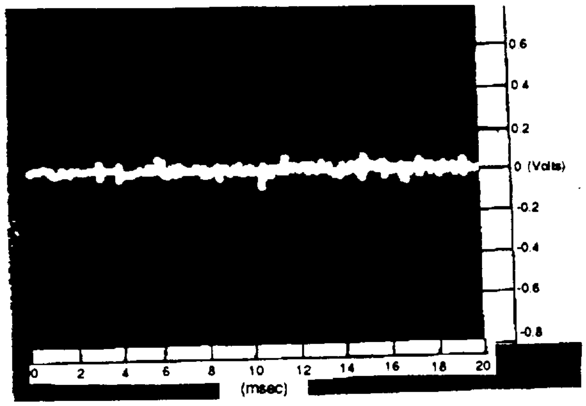
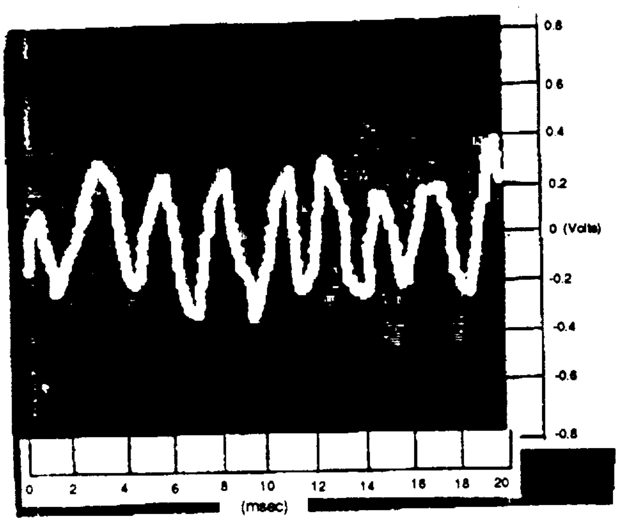



*Image A. Pretest*




*Imagè B. Durihg Test*

Figure 28. Oscilloscope Trace for SSME Test 901-606

A data preprocessing technique developed during the study is an important contribution of this research. This simple mathematical technique was found to eliminate broadband spectral components and enhance the desired signal peaks. An obvious application is in spectral research in which the baseline is time-varying (as with the SSME). In addition, the resulting preprocessed spectrum was found to be a zero-mean sequence. This is an advantage in the identification equations.

The project was accomplished under a 1990 NASA-ASEE summer appointment to SSC, with Professor Bert Nail of Mississippi State University's Electrical Engineering Department as the Principal Investigator. Results were presented at the Second Annual Health Monitoring Conference for Space Propulsion Systems in a paper entitled "Signal Processing of Spectroscopic Data for Engineering Diagnostic Applications" (Nail, et al., 1990).

## Diagnostics Testbed Facility

### Engine Diagnostics Console Development

The Engine Diagnostics Console (EDC) is a hardware and software package that permits near real-time monitoring of plume emissions during ground testing; the long-range goal is the development of an instrument to detect pending catastrophic engine degradation and respond appropriately to prevent further wear or damage.

The immediate goal for FY90 was to develop the ability to process spectral data from a plume and rapidly identify selected elements and materials automatically.

The ability to identify materials on-line and in near real-time is a significant step toward determining which specific engine component is degrading and thus predict (and prevent) catastrophic failures. In addition, material identification can improve maintenance and inspection methods of engine hardware components.

The development and testing of the EDC occurred at the DTF during the on-going plume seeding project. In FY90 the EDC was upgraded for real-time identification of the following eight elements: chromium, copper, calcium, nickel, iron, cobalt, manganese, and silver. The EDC also has the capability to identify the following six materials: Inconel 718, Haynes 188, MAR-M 246+Hf, Waspaloy X, AISI 440C, and NARloy-A. These elements and materials were chosen because they are prominent constituents in certain critical hardware components of the SSME and have top or intermediate priority for SSME status monitoring.

Another EDC improvement is the preservation of a near real-time response independent of engine test duration. The EDC identifies any combination of the eight elements and any one of the six materials within one second of their appearance in the plume. Figure 29 shows the front panel display of the EDC as it appeared during an actual test at the DTF. The display includes the following output indicators:

- Strip chart displays for four elements.
- Warning lights to indicate anomalies.
- Status window to show instrumentation status.
- Materials window to show elemental and material contaminants.
- X-Y display of the current spectral scan.

Other front panel indicators are the data acquisition trigger and input box for data acquisition duration.

The EDC displays information on the time history of elemental plume contaminants, overlimit status of each element and material, and the overall spectral content of the exhaust plume. The information is presented in a user-friendly format that requires minimal operator interaction, thus preserving the near real-time response.

EDC systems are being used to monitor all SSC SSME tests. The SSME systems do not yet include the material identification subroutines, although elemental emissions are monitored.

More work is needed to determine the similarity between the spectral signatures of material contaminants in the DTF and SSME plumes. Establishing threshold limits for plume contaminants in an SSME test is made difficult by the history of catastrophic failures; however, it is possible to identify "above normal" levels for SSME plume contaminants. When refined, the material identification routines will be incorporated into the SSME test systems.

## Plume Seeding and Materials Database

Over the past several years, there has been an on-going development of SSME exhaust plume status monitoring sensors at SSC. The sensors have been designed to monitor the spectral signature of a plume and to detect the presence of elements or materials that have been introduced into the plume due to engine anomalies such as component wear or failure.

These sensors have the potential for being integrated into ground-based, engine test, and flight hardware as an early warning engine anomaly detection system. To aid in accomplishing this task, a plume seeding test program has been established at the DTF. The DTF consists of a 1200-pound thrust hydrogen/liquid oxygen ($GH_2$/LOX) rocket engine that can be seeded with dopant solutions.

The primary goal of the seeding experiments is to obtain extensive sets of spectral data of SSME-related materials in $GH_2$/LOX propellant exhaust plumes. Spectral information on these elements and materials in rocket exhaust plumes or

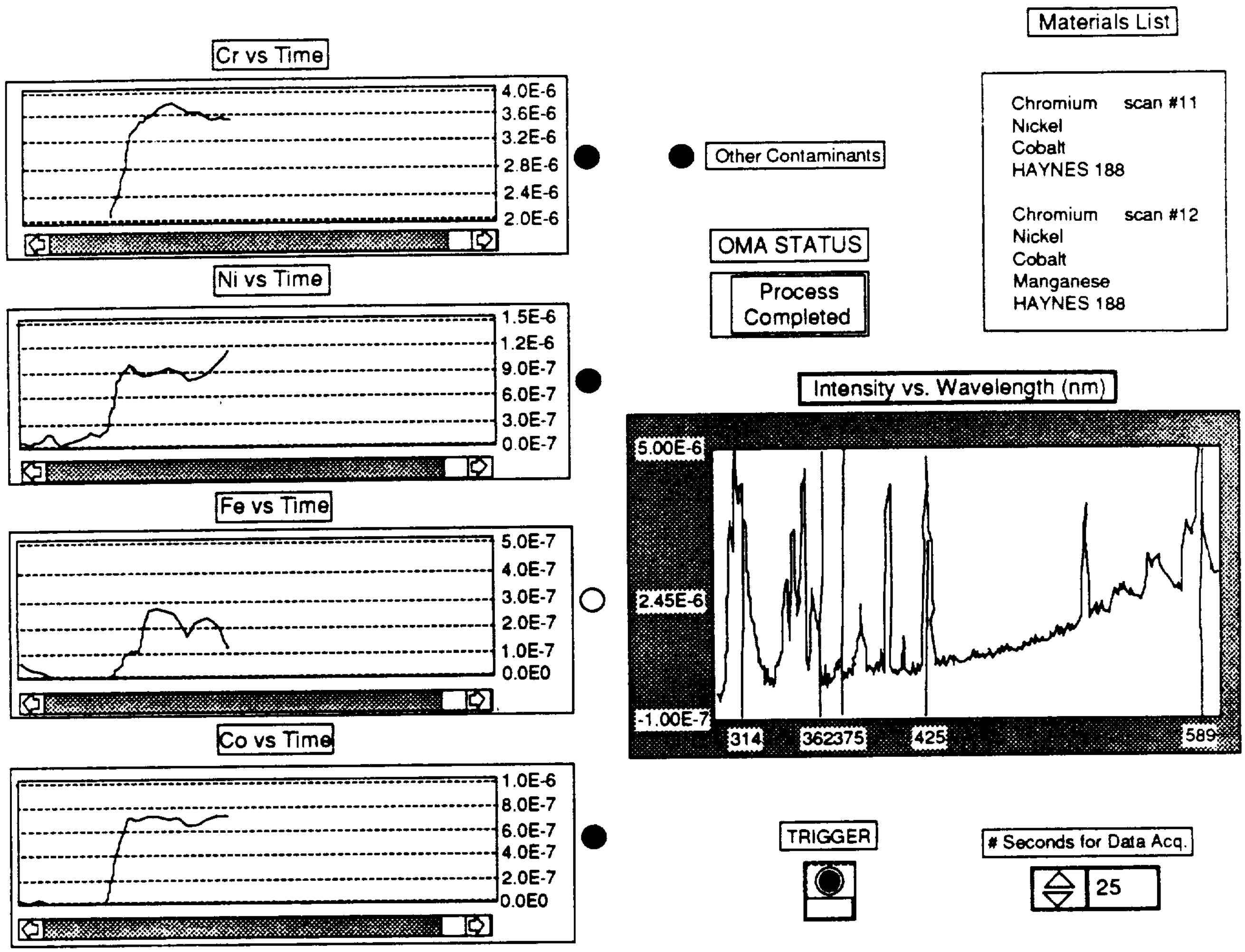



Figure 29. Engine Diagnostics Console Front Panel

equivalent conditions is nonexistent in current literature. The elements and materials tested during FY90 at the DTF are shown in Table 3. These elements and materials have been identified as constituents of SSME critical components which are subject to wear and/or failure.

The spectral data collected during FY90 were analyzed to determine the predominant spectral features of the tested dopant. These features were then incorporated into the Engine Diagnostics Console.

Considerable spectral data are being acquired during seeding tests at the DTF, and by data analysis, literature searches, and reporting. To make these data available in a very flexible and applicable form for SSC and other personnel involved in SSME plume diagnostics, an automated computer database was developed during FY90 using the software "Oracle for the Macintosh," Version 1.2. This database has been named "The Plume Emission and Materials Database," Version 1.0, and consists of the following information:

- DTF testing history.
- SSME critical component materials data.
- Elemental composition of critical component material.
- Predominant spectral lines for the SSME-related elements tested at the DTF.

Table 3. Dopants Tested at the DTF

| ELEMENTS | | MATERIALS | |
|---|---|---|---|
| Co | Si | Inconel 718 | K Monel |
| Cr | Sn | Haynes 188 | Ti-5Al-2.5Sn ELI |
| Cu | Ta | MAR-M246+Hf | Ti-6A1-6V-2Sn |
| Fe | Ti | Waspaloy X | Tens-50Aluminum |
| Mo | V | AISI 440C | 6061 Aluminum |
| Mn | Y | $MoS_2$ | Hastelloy B |
| Ni | Zr | NiCrAlY | Hastelloy B-2 |
| W | Cl | $ZrO_2 \cdot 8\% Y_2O_3$ | Hastelloy X |
| Al | Li | 347 CRES | Rene 41 |
| Ag | Pd | A286 CRES | Waspaloy |
| Au | Zn | Inconel 625 | NARloy-A |
| Hf | Sc | Inconel 600 | 304L CRES |
| Mg | Rb | Incoloy 903 | |
| Nb | La | Inconel X-750 | |
| Sr | Nd | Armco 21-6-9 | |

- Spectral plots of the SSME critical component materials and elements acquired at the DTF.

The spectral data contained in this database were collected at the DTF and are continually being updated as DTF testing continues. This database also has networking capabilities for remote accessing.

## Expert System Applications to Engine Monitoring

The current SSC approach to engine plume diagnostics is to spectroscopically monitor emissions from engine components that are subject to deterioration. Vast amounts of spectral plume data have resulted from the 100% test coverage of the SSME on the A-1 and B-1 Test Stands, as well as from the plume seeding experiments at the DTF.

Engineers spend extensive periods of time analyzing these data in an attempt to discern significant events and probable causes. A specialized expert computer system would significantly decrease the time engineers spend analyzing these data because an expert system could make inference judgments based on past and present data. An expert system that could recognize trends in data would be invaluable in the development of a consolidated engine maintenance and safety program.

An expert system prototype will be developed to analyze DTF spectral data. Significant benefits will be realized by providing a permanent record of experimental knowledge gained by engineers who have years of experience in analyzing spectral data. Additionally, a new resource will be available to neophyte engineers to aid them in learning the specifics of spectral data analysis without requiring extensive instruction by human experts.

During FY90, an overall blueprint for the expert system prototype was established. In

Phase One, the system will identify DTF plume elements; in Phase Two, the system will utilize customized peak-detection software to determine alloys in the plume. A planning document has been written that outlines the procedure for developing the expert system prototype. Preparations for this document required the identification of the problem domain, acquisition of a knowledge base, and the specification of appropriate expert system tools.

Project personnel attended a Mississippi State University Expert Systems class in preparation for designing the knowledge base. Additionally, spectroscopy and plume diagnostics experts were interviewed to incorporate their skills and expertise into the Long-Term Expert System Concept (see Figure 30).

Secondary goals of this project were to procure and learn the expert system software and to prepare a requirements document. The results of a market search concluded that the prototype would be developed using NEXPERT OBC expert system software on a Macintosh.

Training was acquired on-site and project personnel learned the essentials of NEXPERT OBC programming. Subsequently, the requirements document was written to establish detailed functional and system needs for the prototype. This document will be updated and revised as the expert system progresses.

## RADIO FREQUENCY DETECTORS

### Millimeter-Wave Radiometry

As part of the NASA-wide effort to enhance the operational safety of the Space Transportation System, a prototype ice detection system is being developed to detect the presence of moisture, frost, and ice on the surface of the space

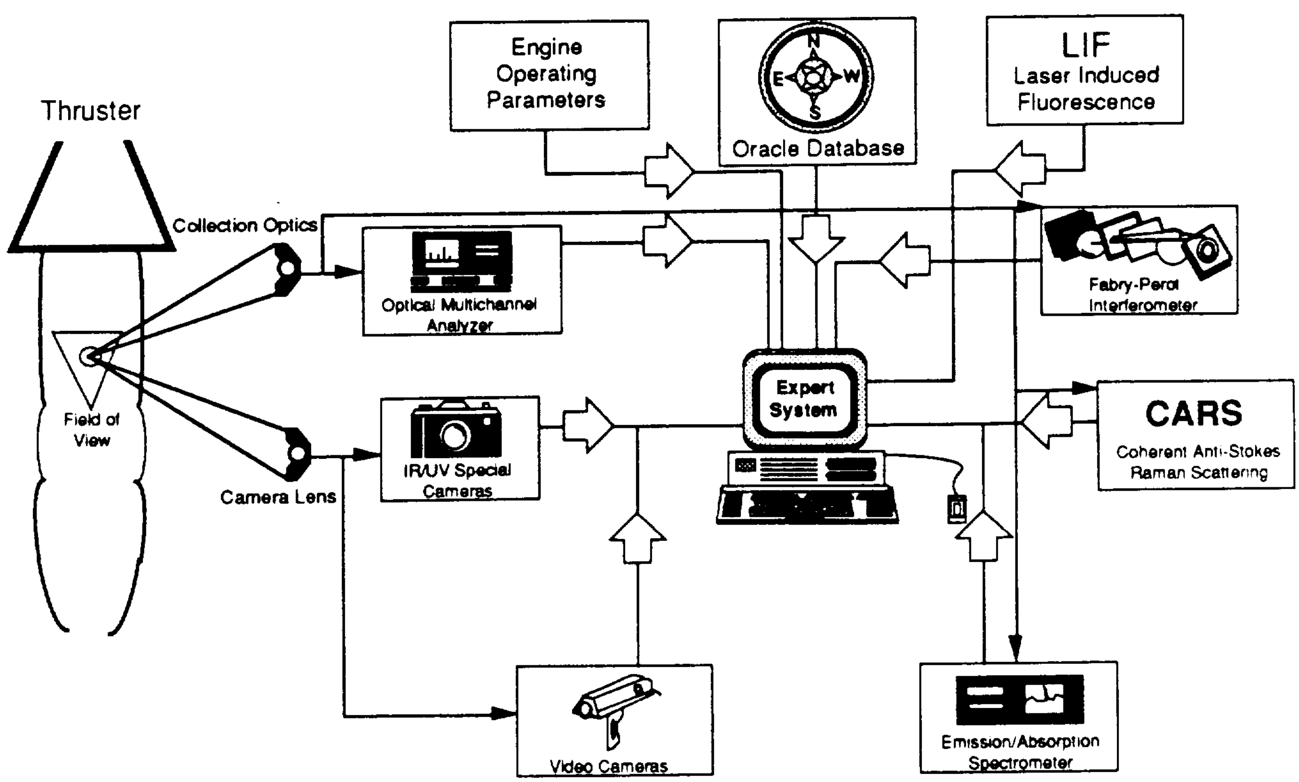



Figure 30. Long-Term Expert System Concept

shuttle external tank (ET) and fixtures. The ice detection system uses near and mid-IR spectra detectors. (See "Ice Detection Research and Development" earlier in this section.)

It is well known that multi-frequency microwave radiometers can detect the condition and thickness of ice over land surfaces; therefore, to detect and measure ice thicknesses on the ET surface, it is desirable to use microwave radiometer technology to enhance the lower spectra system's capability.

Through a university grant from SSC/STL, the University of Michigan's NASA Center for Space Terahertz Technology is conducting an experiment to model and characterize the microwave brightness temperature of ice on SOFI material.

The millimeter-wave radiometer center frequencies are 35, 94, and 140 GHz, with corresponding near-field distances of 2.7, 7.3, and 10.9 meters, respectively. The antenna diameter is 6 inches, with a minimum footprint of 0.023 square meter, and beam widths of 3.2, 1.4, and 0.94 degrees respective to the center frequencies.

The results of the investigation will be documented in a final report to be issued in early FY91. The study results have been published in a technical paper, "Design of Millimeter-Wave Radiometer for Measuring the Ice Thickness on the Surface of Space Shuttle External Tank." This paper will be presented at the 1991 International Geoscience and Remote Sensing Symposium (IGARSS'91), June 3-6, 1991, at the Helsinki University of Technology, Espoo, Finland.

## Synthetic Aperture Radar

As part of NASA's ongoing commitment to the observation of the planet and preserving resources, SSC/STL is applying multipolarized synthetic aperture radar (SAR) data to an assessment of mountainous Costa Rican tropical forest biophysical characteristics.

Because the airborne SAR data were acquired over a mountainous region with a large elevation gradient, it was necessary to digitize the elevation contour lines from a topographic map of the study area. These digital elevation data were used to correct the effect of elevation gradients that cause radar shadowing and to change angle of local incidence (ALI) of the target/scene as viewed by the SAR. A "rubber sheeting" computer program was used to georeference the SAR data set and the digital elevation data.

A computer program developed at SSC/STL was used to generate the terrain slope and aspect angle data from the terrain elevation data set. Another computer program, also developed at STL, was then used to compute ALI, using the slope and aspect data and radar look-angles. The computed ALI were used to delete shadowed data areas (those with ALI greater than 90 degrees) and to produce an unshadowed data set.

Two 1-km x1-km test sites were used, one at 1,000 meters above mean sea level (MSL) and the other at 1,900 meters above MSL. Each site contained 81 test plots 100 meters apart. Topographic and forest stand data were acquired for each test plot. The topographic data included map sheet number, elevation, life zone, slope, and aspect, while the forest stand data included principal species, canopy height, average diameter at breast height, and basal area.

The field-collected forest data and the unshadowed SAR data will be analyzed and the results reported in a paper, "Assessment of Tropical Forest Biophysical Characteristics with Multipolarization SAR Data Acquired over a Mountainous Region in Costa Rica."

It is believed that the results of the analysis will enable engineers and scientists to evaluate the use of a SAR system in the detection and assessment of forest structure occurring in tropical mountainous areas having persistent cloud cover.

## Polarimetric Synthetic Aperture Radar

Until recent years, the Rogers Lake Bed playa served the landing site needs of the U.S. aerospace program with only minor concern for the general playa condition; however, to compensate for strong cross winds during the landing of Discovery at Edwards Air Force Base in June 1985 (Mission 51-G), considerable differential brake pressure was required on the orbiter main landing gear. This resulted in ruts 9 to 10 inches deep in Runway 23's surface, especially during the last four feet of rollout.

The lake bed's ability to support the orbiter was again questioned in November 1985 (Mission 61-A), when during post-rollout towing of Challenger, the main wheels penetrated the hardened soil surface.

Because the hardened soil surface has substandard load-bearing strength in some areas where orbiter access is required, SSC is using remote sensors to map the surface and subsurface condition of the lake bed. These data will permit a rapid estimate of critical soil strength parameters.

Recent studies of polarimetric radar images indicate that P-band (440 MHz wavelength) VV polarization radar is capable of mapping submerged sediments in muddy water up to 3 meters deep. The surface penetrating and fast, large-area mapping capabilities of polarimetric radar are major factors in considering using radar for surface and subsurface condition surveys.

A request for a SAR data acquisition flight was submitted to NASA Ames Research Center (ARC) in early 1990, and the mission was flown over the Rogers Lake study area on June 29, 1990. The data sets are expected from Jet Propulsion Laboratory in late December 1990.

After receipt of data, the data set will be decompressed to form a three-frequency (P-, L-, and C-band), three-polarization (VV, VH, and HH) data set (V = vertical; H = horizontal).

Data analysis will be conducted using ELAS, an applications-oriented software package developed by STL. Analysis of SAR data, as well as the data acquired on the surface, will focus on the development of a predictive model to plot the vertical load-bearing strength profiles of the Rogers Lake Bed in particular, and other lake beds generally.

# COMMERCIAL PROGRAMS

- Commercial Earth Observations Program
  - Earth Observations Commercial Applications Program
    - Environmental Sensitivity Index Mapping
    - Forest Resource Management
    - Subsurface Gravel Detection
  - Commercial Satellite Initiative
  - Visiting Investigator Program
  - Small Business Innovation Research
- Environmental Monitoring for Rocket Engine Testing
  - SSC Geographic Information System
- National Technology Transfer Center

# COMMERCIAL PROGRAMS

## COMMERCIAL EARTH OBSERVATIONS PROGRAM

### Earth Observations Commercial Applications Program

NASA's Earth Observations Commercial Applications Program (EOCAP) supports the innovative and cost-effective transfer of technology from remote sensing R&D through applications development to the marketplace. As the designated Program Support Office for EOCAP, STL manages EOCAP's U.S. commercial remote sensing projects. In the summer of 1988, new applications research contracts were awarded to nine teams that were identified through a rigorous selection process. FY90 was the second year of these commercial development projects.

An annual review was completed for the projects on site in 1990. The review included a technical examination of the projects but focused mainly on the business development activities. All nine projects were recommended for third year funding. The projects and participating entities are listed in Table 4.

### Environmental Sensitivity Index Mapping

When the oil tanker Exxon Valdez struck a reef in Prince Williams Sound near Valdez, Alaska, in March 1989, it produced the largest oil spill in the history of the United States. The devastating impact of 11 million gallons of oil on the fragile coastal ecosystem and the economy of the surrounding fishing villages will be apparent for many years to come. Early attempts to contain the spill and mitigate its adverse effects were compromised, in part, by a lack of current, comprehensive information concerning biologically significant resources. At the time of the spill, no single geographic information system (GIS) had been developed for this portion of the Alaska coastline. Digitizing began the next day and eventually resulted in the development of three distinct databases used by four different agencies responsible for mitigation and treatment of spoiled shoreline.

During the past two years NASA has been working with Research Planning International (RPI) in the development of an improved Environmental Sensitivity Index (ESI) map product that will utilize NASA-developed technology. RPI has been producing ESI maps for several years. Working with scientists at the University of South Carolina, NASA intends to incorporate remote sensing and GIS technologies in the development of an improved ESI product that could offer more current and detailed information concerning shoreline sensitivity to oil spills than is now available in paper map products being used.

Remote sensing data involve the use of satellite images to show current land features and shoreline conditions. Knowing the condition of the shoreline is critical to decisions on where to place scarce oil spill response equipment. Since satellite images can be acquired as often as every two weeks, keeping track of changing natural conditions is much easier with remote sensing than by visiting these areas by boat or small aircraft.

While satellite images offer a unique look at remote environments, complete understanding of the biology of an area is not possible with remote sensing data alone. Other biological data, such as animal inventories for species diversity, range, and population, must be collected through traditional field survey tech-

Table 4. New Applications Research Contracts
(Each project has an industrial participant responsible
for commercial implementation of project results.)

| Contract Title | Company Affiliation | Institutions |
|---|---|---|
| Application of the Airborne Ocean Color Imager for Commercial Fishing | Daedalus Enterprises, Inc.; Zapata Haynie Corporation; Spectro Scan, Inc. | NASA/Ames Research Center; National Marine Fisheries Service |
| Commercial Development of an Ice Data and Forecasting System (IDFS) | Battelle's Space Systems; Weather Management Consultants; User Systems, Inc. | Ohio State University; Naval Postgraduate School, Dept. of Oceanography |
| Development of Practical, Cost Effective Methods Utilizing Satellite Data for Forest Resources Management | James W. Sewall Company | NASA/SSC/STL; University of Maine, College of Forest Resources |
| Algorithm Development for an Integrated Satellite APT and Ocean Color Scanner Receive/Process/Display System for Ocean Going Vessels | System West, Inc. | None |
| Commercial Environmental Sensitivity Index (ESI) Mapping Using Remote Sensing and GIS Technology | RPI International, Inc. | University of South Carolina; NASA/SSC/STL |
| Efficient Updates of Vector-Coded Geographic Information Systems Using Remotely Sensed Data | ERDAS, Inc. | San Diego State University |
| Using Landsat to Provide Potato Production Estimates to Columbia Basin Farmers and Processors | Cropix, Inc.; Eastern Oregon Farming Company | NASA/ARC; Oregon State University |
| An Evaluation of Current Uses and Recommendations for Future Uses of Remotely Sensed Data for Commercial Forest Inventory | Hammon, Jensen, Wallen and Associates, Inc.; Santa Fe Pacific Timber Company | University of California Berkley Space Sciences Laboratory |
| An Environmental and Archaeological Assessment of the Piedras Negras Region of Guatemala and Mexico | Geoinformation Services, Inc. | Mississippi State University; NASA/SSC/STL; National Geographic Society |

niques. These data are then entered into a computer database as digital maps. Analysis of these data and the satellite images is easily accomplished in a GIS. This technology allows the analyst to ask questions such as, "What animals are within the projected oil spill impact area?", or "Where are the most sensitive shoreline areas within 10 miles of the spill?" Through careful query of the database, scarce resources can be judiciously placed to protect fragile environments.

Oil spills are destructive events that leave impacts many years later. Through the use of NASA-derived technology, an improved ESI map will offer resource managers current, accurate data with which to make critical decisions. Also, the developed methods are applicable to other natural resource management issues, including toxic waste spills. Furthermore, resource managers using the developed technology would be able to generate a number of different scenarios for oil spills and develop the appropriate response procedures to minimize the environmental impact.

Work to date has focused on the development of a prototype ESI map product. A Product Evaluation Board, representing Government and private interests in oil spill response, reviewed this prototype and gave it an enthusiastic endorsement. The final phase of this project will deal with the development of appropriate map symbolism and display techniques.

## Forest Resource Management

Timely information about the distribution, condition, and extent of forest resources is important for resource planning and accurate wood fiber supply projections of industrial forest lands. Current methods of air photo acquisition, interpretation, detail transfer, and map digitization are labor intensive and costly to apply to the extensive forest lands owned by the nation's forest products companies. Given the cost of timely (annual) and reliable forest inventory data, and the great importance of a sustainable supply of spruce-fir fiber, industrial forest managers have become interested in the potential utility of satellite-aided forest inventory and assessment techniques. Computer processing of digital satellite data has been recognized as an attractive alternative to manual procedures now used most often by the forest industry for converting photo information into GIS formats.

A cooperative commercial development project among James W. Sewall Company of Old Town, Maine; the University of Maine, College of Forest Resources at Orono, Maine; and the NASA/SSC Science and Technology Laboratory was initiated in September 1988. The project seeks to integrate satellite remote sensing technology into a commercial package customized to support the specific forest management needs of large industrial forest landowners in the northeastern United States. During Phase I of the project (FY89), development of a resource analysis and database updating system was completed using satellite data. Phase II (FY90) of the project consisted of implementing an on-going test and evaluation of the inventory and assessment system. Phase III (FY91) will involve the integration of new services and products into Sewall's commercial offerings.

## Subsurface Gravel Detection

In an applications development project between NASA and the U.S. Forest Service (USFS), SSC/STL is exploring remote sensing technologies that would enable nonrenewable resource detection and subsequent inventories that could not be conducted otherwise. The Forest Service has an operational mandate to manage the nation's forest lands, which include extensive networks of roads that require perpetual upkeep. Gravel is a major component of these roads and represents an annual multimillion dollar cost in the USFS budget.

Gravel in U.S. forests is especially important not only because of the Forest Service's own demands for mineral aggregates, but also because outside interests want to exploit these reserves. This project is focusing on ten National Forests across the Gulf of Mexico coastal plains. Reserves in this region are sedimentary in character and depleted at the surface. The nearest rock resources suitable for crushing into aggregates are too distant to be economical. As a result, the unexploited National Forests are major targets of exploration. Exploration could be disastrous if economic and political pressures succeed in allowing unrestricted development. It is the intent of SSC/STL research to provide a means of surveying and mapping gravel occurrences so that such inventories can be used as a management tool for their orderly development.

This research project between SSC/STL and the USFS, Region Eight, Engineering Directorate, began in January 1989. It is the result of a NASA Office of Space Science and Applications research announcement for Remote Sensing Applications and Commercialization.

An experiment has been designed to measure the boundary heat flux parameters at a site that is known to have subsurface gravel and at a background site that does not. Basic thermal properties are being derived from each site. Implementation of this experiment over a two-year period will result in the diurnal and annual profiles of the target (gravel) and background (nongravel).

These profiles will be used to determine optimal periods of data acquisition with an airborne Thermal Infrared Multispectral Scanner (TIMS). Subsequent processing of the data will determine the utility of such an instrument as a gravel exploration tool.

In the first year, investigators located two excellent control sites. The instrumentation required to provide the ground measurements was identified, procured, and engineered into modified micrometeorological stations. Two pairs of these stations have been calibrated and installed, and are collecting data.

TIMS data covering the control sites have been acquired and processed. The same image processing methods were used in the computer environments of both STL and USFS to verify transferability of techniques. The following image processing activities were implemented to ensure compatibility:

- Verification of software algorithms.
- Georeference of image data sets.
- Registration to USFS base maps.

To optimize discrimination of the gravel bodies, *in situ* heat flux parameters are being measured at a continuous sampling rate. The data are monitored and analyzed for discrimination of large differential thermal responses between background and target materials to schedule test flights with the TIMS. Material samples from exact subsurface locations of sensor emplacement have been analyzed to determine mineral, physical, thermal, and chemical characteristics of each control site in order to understand the interrelationships between properties and their effects as a composite.

## Commercial Satellite Initiative

STL acts as the lead center for remote sensing activities within the Office of Commercial Programs. An STL initiative to promote commercial involvement in remote sensing technology has resulted in a Commercial Satellite Initiative (CSI) project. This project will develop and maintain a working knowledge in small spacecraft technology and opportunities concerning deployment of an orbital remote sensing system. One objective for CSI is working with the earth observations industry to facilitate a successful remote sensing venture.

CSI personnel have evaluated the technical and economic envelopes of a commercial remote sensing small satellite. The studies revealed that a small satellite system with a remote sensing payload could be deployed on a Small Expendable Launch Vehicle (SELV) for less than $30 million. FY90 activity focused on the systems design of launch vehicle, sensor, communications, attitude control, power, computational processing, and ground station capabilities for a case study. Case study design parameters are driven by available technology and market requirements for the sensor data. Part of the specifications of the proposed system include a very high spatial resolution (5 meters) panchromatic imaging system with a 60-kilometer swath width.

The NASA CSI project staff works closely with the remote sensing divisions of the Centers for Commercial Development of Space (CCDS), including the Mississippi Institute for Technology Development Space Remote Sensing Center and the Center for Mapping. Related technologies developed by Center for Space Power and the Center for the Commercial Development of Space Power and Advanced Electronics are also being investigated for incorporation into the CSI satellite system design.

## Visiting Investigator Program

The Visiting Investigator Program (VIP), implemented in FY88, provides an opportunity for industry to utilize the specialized resources located at STL and for various organizations and commercial entities to incorporate remote sensing technology into their operations.

The VIP is part of the Office of Commercial Programs mission to encourage the commercial development of space through the promotion of new space ventures and the development of new space technologies. Participants in the VIP are selected by evaluation of submitted proposals. SSC/STL may serve as a site for visiting scientists and engineers to conduct experiments as precursors to using other remote sensing facilities or establishing their own remote sensing capability.

The VIP operates under a nonproprietary agreement that lasts from 2-3 months. If promising remote sensing science and applications concepts are developed at STL, the potential exists for continued joint research efforts under other NASA Commercial Agreements.

STL supports the selected visiting investigators by providing access to sophisticated facilities capable of a full range of remote sensing activities. In this way visiting investigators are familiarized with remote sensing instrumentation and development, airborne data acquisition and decommutation, and data analysis using ELAS, ERDAS, ARCINFO, GRASS, and other GIS image processing software.

Participants in the program in FY90 included the following:

- BellSouth Services, Inc., located in Birmingham, Alabama, is the largest of the seven regional telephone holding companies that were divested from American Telephone and Telegraph Company (AT&T) in 1984. Their serving territory covers nine of the southeastern States containing 12 million residence and 2 million business customers covering 200,000 square miles. BellSouth participated in a VIP project to investigate the use of aerial and space images of the type used by NASA for providing certain components that will allow BellSouth to maintain its maps and database in a more current and complete level at lower costs.

- GeoSpectra Corporation, located in Ann Arbor, Michigan, is a consulting company with primary expertise in the fields of commercial image processing, multispectral imagery exploitation, algorithm development, and image analysis. GeoSpectra participated in a VIP project using a concept of eliminating the labor-intensive aspect of nonsystematic geometric correction of airborne scanner data, and relaxing the attitude control specifications of orbiting imaging sensor platforms. GeoSpectra used NASA Learjet, ER-2 aircraft, and Space Shuttle data to test the flexibility and space station mapping applicability of this concept. Results of this investigation could lead to reduced costs of airborne, space station, and free-flyer charge-coupled device (CCD) mapping systems and output products while providing the user with much more accurate marketable map products.

VIP plans in FY91 include greater promotion of the program through NASA Centers for the Commercial Development of Space, various symposia, and continued outreach activities.

## Small Business Innovation Research

SSC continued expanding its Small Business Innovation Research (SBIR) Program with seven Phase I awards and two anticipated Phase II awards. The objective of the SBIR Program is to stimulate technological innovation in the private sector, thereby meeting Federal objectives to increase commercialization of research results. Phase I awards are generally made for up to $50,000 and Phase II awards for up to $500,000. As required by law, NASA allocates 1.25% of its annual research and development budget for this program.

Subtopics were developed at SSC for the SBIR Program that will further NASA research and simultaneously stimulate commercialization. These subtopics cover areas of innovation for propulsion testing, remote sensing, and geographic information system research. Through the program, new innovative research will advance the use of science and technology for NASA and make the results more readily available to the private sector.

SSC is in the second year of a planned three-year NASA pilot project to develop methods for improving commercial outcomes of SBIR projects. This project, the Space Technology Small Business Initiative (STSBI), is an integral part of building a strong and active SBIR program at SSC. The project is confined to a five-State region (Arkansas, Mississippi, Louisiana, Tennessee, and Alabama) that is characterized by high unemployment and an under-developed high-technology small business industrial base.

Outreach efforts by Darkat, Inc., the subcontractor principally involved in assisting SSC with the implementation of STSBI, stimulated a marked improvement in the number of competitive proposals to SSC from within the targeted region (from 5 to 10). An 87% improvement in demonstrated interest for SSC's subtopic areas was reflected in the increased number of competitive proposals received (43 in

FY90 compared to 23 in FY89).

In addition to continuing aggressive outreach efforts, the subcontractor will attempt to stimulate commercialization planning and development parallel to technical progression of ongoing Phase I and Phase II projects that are under the technical supervision of SSC. One Phase II project for which SSC has technical monitoring responsibility was nearing completion by Odetics, Inc. By-products from the project have been introduced to commercial markets by Odetics.

The SBIR Program at SSC continues to make advances in the coordination of subtopic development, subtopic and proposal evaluation, target region outreach, and project commercialization support.

## ENVIRONMENTAL MONITORING FOR ROCKET ENGINE TESTING

### SSC Geographic Information System

Testing of the Advanced Solid Rocket Motor (ASRM) will begin at SSC in Spring 1994. With this test program comes the responsibility for monitoring the surrounding region for possible impacts from test operations. STL is involved in a project with SSC Center Operations and SSC Propulsion Test Operations to monitor environmental quality prior to and after ASRM test operations begin. Furthermore, STL is to establish a geographic information system for the storage and analysis of environmental information concerning test operations.

The SSC GIS is centered around information gathered by multispectral remote sensing instruments. The remotely sensed data will be analyzed with field-collected biological information to establish plant health in the Stennis Space Center region. This baseline information will be routinely updated throughout the expected ASRM program life and monitored for changes.

In addition to serving as a tool for the analysis of remotely sensed data, the SSC GIS will serve as the analytical arena for a wide range of data concerning the environment. The results of soil, air, and water samples and predictive models will be entered into the database for analysis with other data. Within the GIS, multivariate data that have a spatial component may be analyzed and the results displayed in a map format. This information will allow SSC managers to relate predictive models and field-collected data to SSC's facilities and to the surrounding region.

Significant progress was made in several critical areas of database development and monitoring activities. The initial acquisition of remotely sensed data over the SSC region was completed by the SSC Learjet 23 aircraft using the Calibrated Airborne Multispectral Scanner (CAMS). These data will be correlated with vegetation samples and used to build a database of health. The SSC Fee Area database was completed, including soils, land cover, transportation corridors, and environmental monitoring sampling sites. These data were then input into a workstation-based computer system dedicated to the ASRM project. This computer system also holds the Geographic Resources and Analysis Support System (GRASS) GIS software installed this year. FY90 also saw the initial optimization of the GRASS software to meet specific ASRM environmental program needs. Accomplishments to date include the ability to reformat data received from the NPUFF atmospheric dispersion model and overlay these data on other data in the SSC database. This capability will allow SSC program managers to review possible impacts of proposed test operations prior to firing.

## NATIONAL TECHNOLOGY TRANSFER CENTER

The National Technology Transfer Center (NTTC) mission is to enhance the ability of the United States to compete by facilitating the transfer of Federally sponsored R&D to the U.S. private sector. In fulfilling its mission, the NTTC will utilize and augment the nation's technology transfer and utilization activities and programs, including the Federal Laboratory Consortium, the NASA Technology Transfer System, and other Federal and State programs involving technology transfer and utilization. NASA has begun a phased (FY90-FY95) development program, now in its initial implementation phase, to fully establish the NTTC as a national focal point for accessing Federal technology transfer resources and networks; the center will be a leader in accelerating and expanding U.S. commercial sector utilization of Federal technologies. The NTTC focus on improving technology access is strengthened by supporting functions directed toward the use and enhancement of existing technology transfer resources nationwide. National outreach activities will stimulate U.S. private sector awareness of and demand for Federal technologies.

In FY90, drawing upon the extensive expertise of its Technology Utilization Program and a Congressionally directed preliminary NTTC definition/design study, NASA continued planning, research, and definition activities in preparation for initiating NTTC implementation in early FY91. The NTTC, following a regional demonstration of selected capabilities, will achieve initial nationwide operations in CY94. The final phase of the development program involves the incremental buildup of NTTC capabilities and activities, culminating in a fully operational NTTC in late CY95.

# TECHNOLOGY UTILIZATION PROGRAM

- State Technology Transfer Activities
  - Louisiana Activities
  - Mississippi Activities
  - General Office Activities
- Applications Engineering Projects
  - Digital Image Differencing of X-Ray Imagery
- Environmental Life Support
  - Indoor Air Pollution
  - Wastewater Purification by Artificial Wetlands
  - BioHome

# TECHNOLOGY UTILIZATION PROGRAM

SSC's Technology Utilization (TU) Program, funded primarily by the NASA Office of Commercial Programs, Technology Utilization Division, continued during FY90 to support national, regional, and State initiatives aimed at fostering and supporting the transfer of NASA and other Federally developed technology to the public and private sectors. The primary program elements are:

- Creation of an awareness of existing technologies and the procedures necessary to acquire information regarding them.

- Development and execution of applications engineering projects for spin-off applications of NASA technology.

## STATE TECHNOLOGY TRANSFER ACTIVITIES

FY90 was the initial year of two new technology transfer agreements between the Stennis Space Center, the Marshall Space Flight Center, and the States of Louisiana and Mississippi. These agreements allow for the joint conduct of technology transfer initiatives with State and local government and industry. Opportunities currently being pursued under this agreement umbrella are:

- Joint technology transfer projects with industry.

- Expanded infrastructure for industrial outreach.

- Coordination of State programs to support industries seeking to expand and to develop new products with Federal laboratory capabilities.

### Louisiana Activities

At the request of the Louisiana Department of Economic Development, a member of the SSC TU staff served on the Governor's Science and Industry Economic Advisory Board. This individual was later appointed leader of the Environmental Industry Group consisting of 14 members from the Louisiana industrial sector and the university system. After meeting on several occasions, this group submitted a report that described how Louisiana can better utilize various environmental issues as a catalyst for economic development.

Technology transfer workshops were conducted at the SSC for 80 members of the Louisiana Industrial Development Executives Association (LIDEA) and over 50 individuals representing the St. Tammany and Northwest Louisiana Technology Transfer Teams. In collaboration with the NASA Michoud Assembly Facility, other workshops were conducted in Shreveport and Monroe. Members of the TU Office also participated in technology transfer workshops in New Orleans and Lake Charles.

Also during FY90, the TU Office fielded and processed more than 100 inquiries from Louisiana industrial, academic, and private concerns. Action taken ranged from referrals to the NASA Industrial Applications Centers to complex and detailed investigations by members of the TU Office staff. These inquiries involved applications such as medicine, electronics, X-ray methods, non-destructive testing, environmental technologies, and several others.

### Mississippi Activities

Several activities were generated with entities from the State of Mississippi. Among these were the establishment of a Science and Technology Liaison Office by the Univer-

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sity of Mississippi, continuation of support for the Mississippi Technology Transfer Office (MTTO), establishment of a relationship between the SSC and the Mississippi Industrial Training Coordinator (ITC) Network, the execution of several technology transfer workshops, and the processing of inquiries generated from various industrial, academic, and private concerns.

The University of Mississippi Science and Technology Liaison Office was established at the SSC to provide a better interchange of talents and capabilities between the SSC and the University. Although a fledgling initiative, thus far the University has gained a better understanding of the space and ocean related SSC activities while allowing Center personnel to become more familiar with the research capabilities at the University.

During the past year, members of the TU Office accompanied MTTO personnel on several industrial visits. In addition, logistics and other support was rendered for the processing of several industrial inquiries, the execution of technology transfer workshops, and the generation of various products intended to attract opportunities to the State of Mississippi.

As a result of a technology transfer workshop attended by the Mississippi Industrial Training Coordinators, the leader of this group expressed a desire to work closely with NASA for the purpose of applying Federal technology and expertise to Mississippi industrial concerns. The Pearl River Community College (PRCC) ITC was designated as a point of contact for the entire State network. This initiative has led to a number of activities, such as development of an applications engineering project between the Michoud Assembly Facility and a gas tank manufacturing company in Cleveland, Mississippi. In addition, plans are currently underway to establish a geographic information system (GIS) capability at PRCC as a service for economic development officials in the six-county district served by the institution.

In collaboration with the MTTO, several technology transfer workshops were held at the SSC in continuance of the County Team initiative established during FY89. Over 120 individuals from Calhoun, Yalobusha, Jackson, Hancock, Pearl River, and other counties attended a day-long seminar at the SSC that introduced the participants to the benefits and access methods of Federal technology and other SSC programs. The workshop attendees represented State and local governments, economic development organizations, industry, banking concerns, and other entities. In addition, three members of the TU Office conducted seminars at a Northeast Mississippi Community College technology transfer workshop in Booneville.

A welding technology workshop, sponsored jointly by the SSC and Mississippi Power Company, was held in Gulfport. Attended by 60 individuals representing various welding trades, the workshop was designed particularly around applying NASA techniques and technologies to the special needs and concerns of local industry. Workshop sessions focused on NASA techniques utilized in arc welding of aluminum, nondestructive testing and evaluation, and training programs offered at Mississippi Gulf Coast Community College. Several inquiries have been fielded as a result of this initiative.

During FY90, more than 140 inquiries originating from Mississippi industrial, academic, and private concerns were received and processed. These originated from industries representing Mississippi catfish farmers and feed processors, eyeglass lens manufacturers, various high-technology companies, and others. Every case has resulted in a specific referral or a detailed investigation.

## General Office Activities

During the year, the SSC responded to 14 problem statements generated by Research Triangle Institute for Industry nationwide. In addition, the TU Office directly fielded and processed over 40 inquiries from companies nationwide. Several of these were handled with assistance from the Federal Laboratory Consortium.

The SSC TU Office also developed an operational Technology Utilization Reporting System (TUNS), which provides for the input, storage, and retrieval of new technology reports, inquiries, and other Center-related technology transfer activities. This system is currently being interfaced to a central node at NASA Headquarters, which will allow for the sharing of information among all NASA Centers.

# APPLICATIONS ENGINEERING PROJECTS

## Digital Image Differencing of X-Ray Imagery

Electronic transmission of radiological data (teleradiology) often saves crucial time in the analysis of a patient's condition and allows for the sharing of analytical expertise between hospitals and clinics. Expensive broadband systems are in use to transmit images; however, the high data volume rate of X-ray imagery causes the transmission process to be slow and the quality of the transmitted images is often deteriorated. Even with currently available compression algorithms used in these systems, rarely are compression ratios of 5:1 achieved. Storage of the imagery is also a problem. One uncompressed image requires approximately one megabyte of storage space, which means that memory requirements are substantial when it is necessary to maintain a library of digital images.

This project, which began in FY89 and continued through FY90, demonstrates a new technique of radiological image compression, useful for reducing both transmission time and storage requirements. The technique includes an image compression algorithm that makes use of the fact that X-ray images are inherently similar. It allows the subtraction of two X-ray images, one standard image and one diagnostically significant image. The image that remains after subtraction can be compressed far more efficiently than the primary image because it contains less contrast detail. It is this compressed differenced image that is transmitted and added to the standard image on file at the receiving station.

FY90 work demonstrated the feasibility of utilizing the technique on human X-ray imagery. Initial testing was undertaken on phantom images that had consistent body geometry, uniform absorption characteristics, and exposures at well defined and predetermined orientations. Under these ideal conditions, compression ratios of 100:1 were achieved. Additional testing on real clinical images was undertaken and achieved acceptable results with no loss of image fidelity. Under "live" conditions, compression ratios varied from 35:1 to 90:1, depending on the initial quality of the original image. Work will continue with the project industrial participant to reduce the amount of operator interface required to operate the system. A patent application for this work has been filed with the Office of Patents and Trademarks.

# ENVIRONMENTAL LIFE SUPPORT

NASA's Technology Utilization program supports several unique projects in the field of environmental research at Stennis Space Center. Efforts are addressing the purification of air and water by natural biological systems. This "bioregenerative" technology has the potential for applications in space and on earth.

## Indoor Air Pollution

The problems of indoor air pollution have been widely publicized. Chemicals such as benzene, formaldehyde, and trichloroethylene may frequently be found indoors. They stem from sources such as solvents, resins, and fabric dyes and have been linked to the development of numerous health complaints. Consequently, homes or office buildings with poor ventilation may pose a significant threat to occupants.

Preliminary studies at SSC have indicated that common houseplants may aid in decreasing this risk. Plants such as the golden pothos, peace lily, and spider plant have all been shown to significantly decrease ambient concentrations of volatile organic compounds. Current efforts are directed at determining the mechanisms involved in the breakdown process. Studies are evaluating the synergistic effect of chemicals as well as identification of saturation levels. Recent findings have revealed that the stomata, sites of gas exchange for plants, do not appear to close when exposed to chemical levels as high as 5 ppm.

Stable isotope studies are also underway in order to ascertain the primary site(s) of chemical deposition. It should also be noted that the breakdown process may involve microbiological activity as well. A preliminary microbial profile of the soil community revealed the presence of common soil bacteria including *Bacillus*, *Micrococcus*, and *Pseudomonas*. It is not surprising to consider the soil as a factor in the breakdown process. Soil has long been recognized as a sink for organics. Similarly, the microorganisms within the region (particularly bacteria) may have the capacity to degrade organic compounds. The next phase of this study will be to screen bacterial isolates for the presence of plasmids, extrachromosomal pieces of deoxyribonucleic acid (DNA) that encode the ability to degrade hydrocarbons.

## Wastewater Purification by Artificial Wetlands

SSC has also been actively developing wastewater purification schemes based on the combined functioning of plants and microorganisms. The low cost and high efficiency of these "artificial wetlands" have made them an attractive alternative to traditional methods. Numerous small communities have successfully utilized this technology as a means of treating municipal waste. This system also has the potential for application in the removal of organic pollutants. However, much more research is required for the systems to be used for salt and metal reduction.

Although the overall efficiency of such systems has been documented, there has not yet been a definitive study on pathogen reduction capabilities. This information is necessary not only for optimum use of the systems on earth, but also for possible inclusion in closed space systems since aspects of the technology may be a suitable complement to physical/chemical systems. Another critical consideration is the development of engineering design criteria. The transfer of this technology can be significantly enhanced by making this information available to the public. Plans call for development of a design manual based on data obtained from a pilot-scale system handling municipal waste.

## BioHome

Aspects of bioregenerative technology have been incorporated into the BioHome, a 650-square-foot habitat designed for closed system application studies. The BioHome includes living quarters for one individual as well as an indoor artificial wetland for purposes of wastewater treatment.

Numerous vegetable plants in the facility are grown on compost material obtained from plants within the wastewater system. Water vapor is obtained from ambient air via the process of evapotranspiration while oxygen is produced from photosynthesis. Consequently, the BioHome provides food, air, and water to the occupant, albeit on a limited scale.

At present, analyses are underway to characterize the possible risk of human infection within this facility. Recent findings indicate that the system can reduce numbers of bacterial pathogens such as *Salmonella* and *Shigella* as much as 98%. In addition, no viable enteric viruses have yet been recovered from the system. Plans are underway to expand the microbial profile of the wastewater treatment system to include heterotrophic as well as other pathogenic bacteria. This is a critical consideration since heterotrophs dictate, to a large extent, the presence or absence of bacterial pathogens.

Analyses of light levels within the BioHome have revealed that photosynthetic activity, and consequently food and water production, could be significantly enhanced by altering the light intensity and spectral distribution. Alternative lighting systems are being explored.

# INFORMATION SYSTEMS PROGRAM

- Information Systems Division
- STLnet
- ELAS
- SSC EOS Initiative
  - Scope of Participation
  - SSC EOS Science Working Group
- Chordic Input/Tactile Feedback
- U. S. Navy Programs
  - FNOC Satellite Processing Center Upgrade
  - NOO Satellite Processing System Upgrade
- Scanner Data Certification System

# INFORMATION SYSTEMS PROGRAM

## INFORMATION SYSTEMS DIVISION

It is the charter of the Information Systems Division to provide a science and engineering information systems core capability to process, analyze, archive, display, and communicate science and engineering data. The division plans, develops, manages, operates, and maintains information systems used in the areas of science, technology development, commercial programs, and propulsion test programs. The division also serves as SSC's interface with other NASA Centers, NASA Headquarters, and approved cost reimbursable projects. Specifically, the division supports the STL in the following functional areas: software development, hardware development, office automation and PC support, Data Analysis Laboratory operations, and data acquisition. The following paragraphs describe the more significant accomplishments of the division during FY90.

## STLNET

The Science and Technology Laboratory Network (STLnet) was established at STL to provide state-of-the-art communication links between the multiple array of heterogeneous computer systems at this laboratory. Currently STLnet supports the connection of 10 graphics workstations, 4 Concurrent computers, 1 Masscomp workstation, a number of PCs, and terminal servers, bridges, and multiconnect devices (Figure 31).

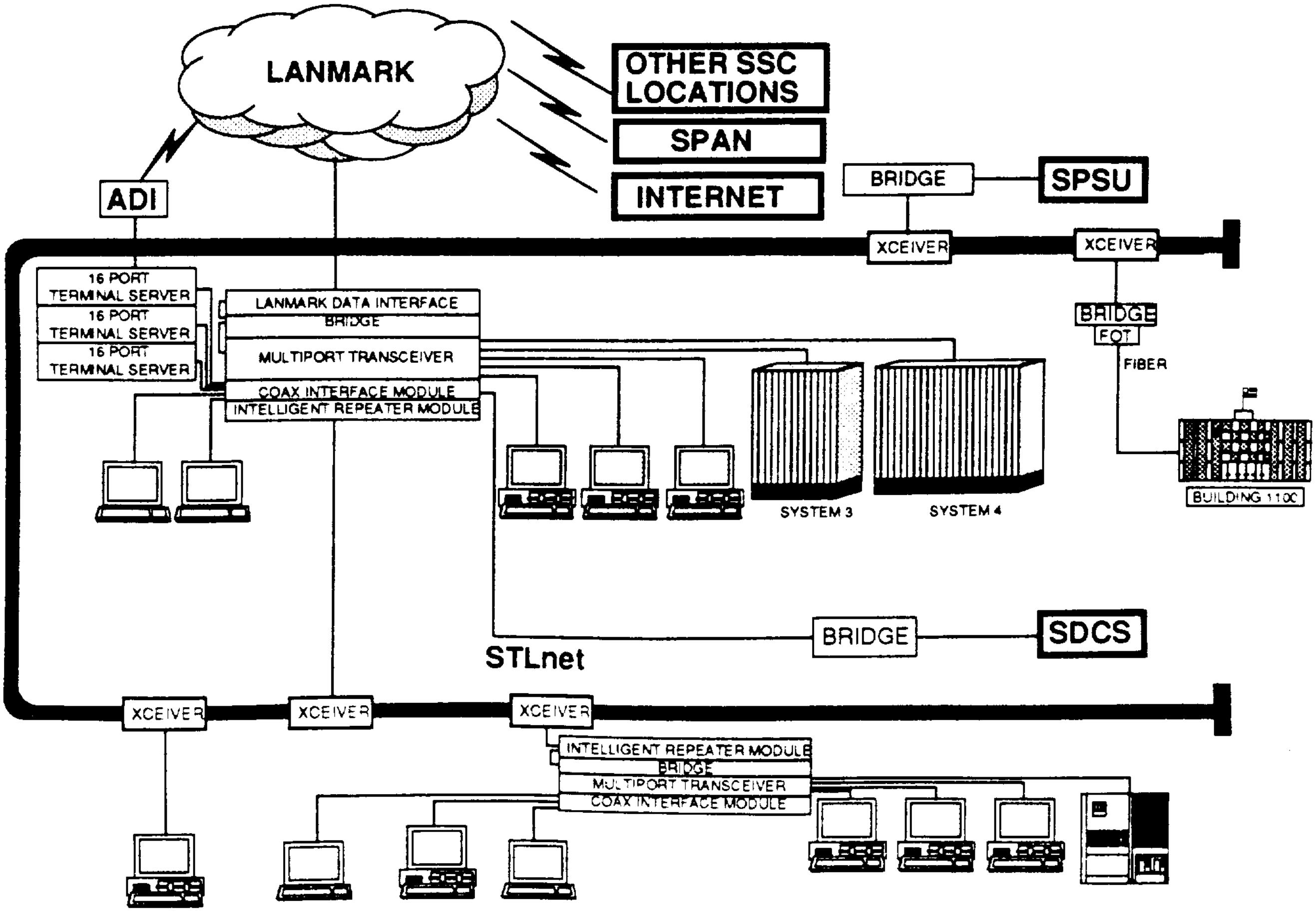


Figure 31. STL Scientific Communications Network (STLnet)

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STLnet consists of thick-wire cables, thin-wire cables, bridges, multiconnect units (both thick and thin wire), and terminal servers that give users connectivity through the use of the SSC central communication system.

The network is IEEE 802.3-compliant and supports all functionality of TCP/IP (Transmission Control Protocol/ Internet Protocol) including File Transfer Protocol (FTP), Network File System (NFS), Telnet Virtual Terminal User and Server, and Simple Mail Transfer Protocol (SMTP). STLnet, through the use of a Lanmark data interface and an internet router, has connectivity to any internet host throughout the world. This gives STLnet users the capability to connect to other NASA Centers, university computing centers, or corporate computers. The network has been extended to support STL scientists in Building 1100 by the use of a fiber ethernet link in order to maintain maximum ethernet throughput between Buildings 1100 and 1210. The capability exists to further expand the fiber to other locations at SSC.

This network uses the Simple Network Management Protocol (SNMP), which gives the network manager the capability to monitor and control network connectivity between devices, monitor the CPU or memory utilization of systems on the network, and monitor the availability of any system found on internet to be logged in. This network manager will also report and give alarms on systems or devices having network transmission errors.

## ELAS

ELAS applications software, which was developed at SSC in 1978, continues to be the mainstay for processing and analyzing data acquired from remote sensors as well as from other sources. ELAS contains approximately 240 separate executable programs that provide a variety of tools for processing and analyzing data for scientific research and/or operational applications.

Due to the acquisition of several scientific workstations within the Science and Technology Laboratory, the majority of the enhancements to ELAS in FY90 were made in the UNIX environment. ELAS had previously been implemented under UNIX on a Masscomp workstation. This implementation provided the foundation for porting the software to two new UNIX hosts--Sun and Silicon Graphics. Several modifications were made to the software to make use of certain characteristics of the UNIX environment. ELAS is now able to handle file names up to 64 characters long, facilitating use of the tree-structured directory system. The code is now relocatable, ensuring that the ELAS subdirectory can be placed anywhere on the system. Additionally, script files have been created to aid in the installation process.

Each of the new implementations is designed to support image display in a windowing environment. This enhancement permits the user to open more than one image window, allowing multiple-image display on the screen. The X11 standard was used for image display on the Sun. Host-specific windowing software was used on the Silicon Graphics.

Several capabilities were added to ELAS during FY90 that increased its flexibility and analytical power. These capabilities include the ability to compare two ELAS data files (including the file header information); to compute energy from Calibrated Airborne Multispectral Scanner data and to estimate temperature from the computed energy values; to generate a file in Calcomp plotter format from an ELAS data file; and to merge SeaMARC II side scan sonar data with its navigational log file. Module RFRIBS was

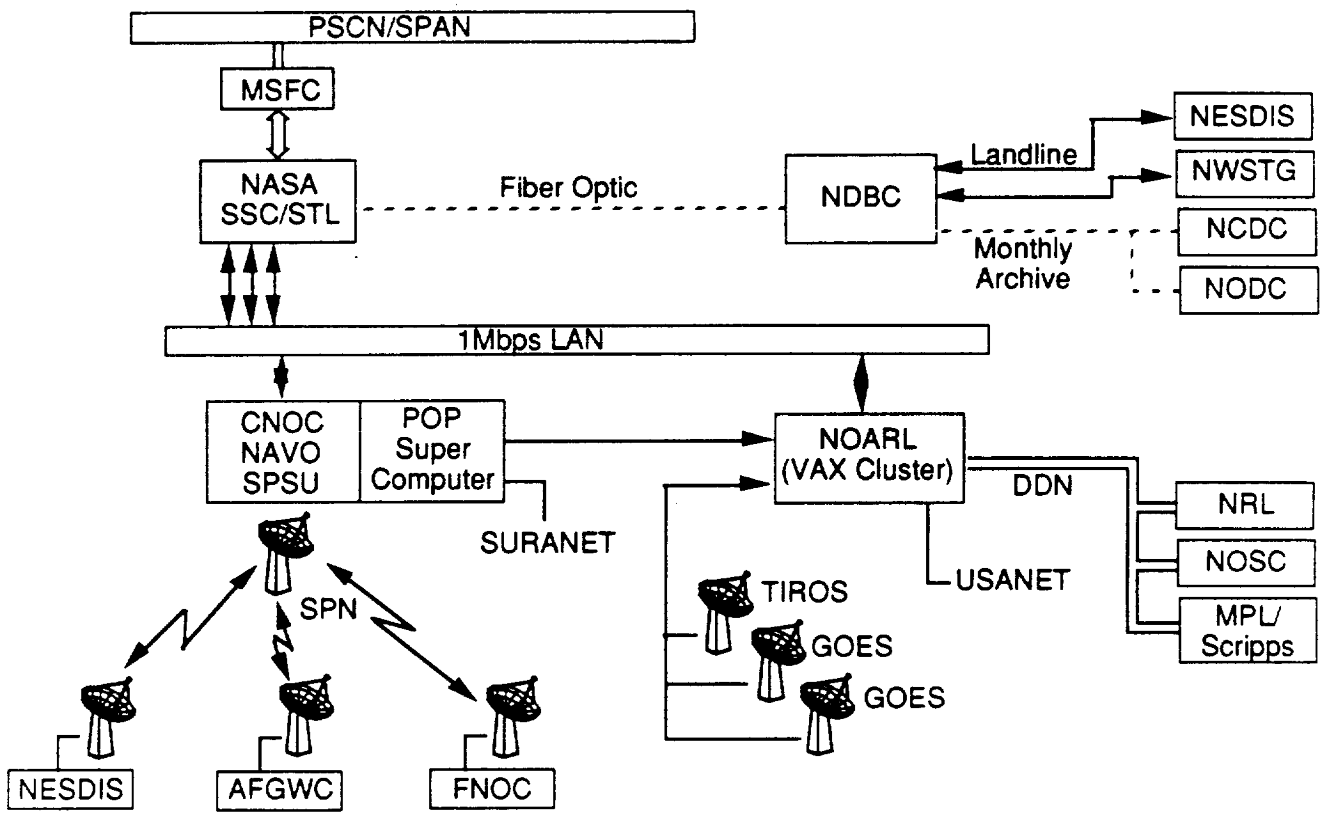



Figure 32. SSC Network Overview

modified to make it a general purpose reformatting routine. Additional modifications to the software resulted in the correction of 23 discrepancies reported in the software.

## SSC EOS INITIATIVE

### Scope of Participation

SSC's participation in the Earth Observing System (EOS) program may be categorized from both user and contributor standpoints. As an EOS user, SSC represents a very large and fully qualified cadre of scientists actively working in oceanographic, meteorological, and environmental sciences. Much of their involvement utilizes satellite remote sensing information, which they further enhance by quality checking against their array of *in situ* point measurements. Most agency representatives prefer Level 0-2, or raw sensor data.

The individual agency computing facilities and the existing interagency and site-wide network that connects them (see Figure 32) provide the tools for these scientists to generate products, and represent significant capability for exploiting mission-critical issues of the EOS program. With the installation of a planned SSC fiber optic (high-speed) network, along with the processing power of the Navy Class VII super-computer, the scientists' investigations will be limited by their imagination and/or budgets.

As a contributor to the EOS program, SSC has some very impressive capabilities in the primary areas of the EOS mission, goals, and objectives, which can provide significant early success for this very ambitious program. Contributions of active archives and databases are available to ground truth satellite sensor performance and provide boundary conditions for models. Some databases are directly usable for long-term global change analysis. Virtually all of the meteorological and oceanographic databases available at Naval Oceanographic and Atmospheric Research Laboratory (NOARL) and Commander, Naval Oceanography Command (CNOC) are unclassified and can be made available for civilian use.

SSC will also serve as a gateway to a support group of scientists from within the U.S. Navy's research community who are actively participating with the Naval Oceanographic Office (NOO) and NOARL on research efforts in global modeling and algorithm development. SSC/STL has for the last several years participated in the development of CNOC's most sophisticated environmental data acquisition and processing equipment. This unique association of NASA/STL and the U.S. Navy's environmental research and operations community will provide a conduit for transfer of available algorithms, data analysis results, and databases from this community to the EOS program.

The EOS program will be able to take immediate advantage of the experience compiled by SSC residents in quality checking environmental data for both on-line and off-line data distribution systems.

At SSC there is a broad base of environmental and earth sciences experience immediately available to the EOS program. This experience can be directly utilized to further the knowledge and subsequent development of such facilities as the EOS Distributed Active Archive Centers (DAACs). In combining the SSC information systems facilities, there exists at SSC a dynamic oceanographic, meteorologic, and environmental center of capability that can meet the requirements of most EOS Data Information System (EOSDIS) Version 0 (V0) implementation activities.

As a result of late FY90 meetings at NASA Headquarters and Goddard Space Flight Center (GSFC), SSC has been provided with an opportunity to develop "sea truth" data archives to support Moderate-Resolution Imaging Spectrometer-Nadir/Tilt (MODIS-N/T) and EOS science missions/ research.

## SSC EOS Science Working Group

Stennis has a multi-disciplinary research and operations environment consisting of resources, facilities, and a significant science research cadre in meteorology, oceanography, and atmospheric disciplines. An SSC-wide *ad hoc* working group was chartered in late FY90 to represent the SSC user community in matters related to EOS. Each member of this working group is interested in participating in EOS and, in most cases, requires data from the EOS program. Due primarily to the preponderance of meteorologic and oceanographic sciences represented, a scientific subgroup is presently working to demonstrate the synergism of SSC's members by jointly engaging in an EOS-related ocean science project. This, coupled with SSC's information systems capabilities and facilities, represents an "EOS-like" end-to-end systems capability.

## CHORDIC INPUT/ TACTILE FEEDBACK

The Chordic Input/Tactile Feedback project investigates methods of improving human/ computer interface technology, with a goal of providing such an interface for visually or physically handicapped individuals. The personal computer input device under study at SSC was originally developed by InfoGrip, Inc., under a small business contract with the Navy as a likely candidate for a "fire power" input device.

The InfoGrip hardware and software system is designed to replace or enhance the conventional keyboard. It utilizes fingertip keys to input data via chords. These keys can also be depressed by software, allowing the additional capability of an output device.

A prototype system has been built by InfoGrip and delivered to STL. The keyboard has been integrated into a host PC. STL personnel are currently developing training and testing software utilizing the InfoGrip system.

The Mississippi State University Rehabilitation Research and Training Center (RRTC) on Blindness and Low Vision has assisted in development of the training and testing software. RRTC received an initial version of the software for evaluation and has responded with recommended modifications and enhancements.

As a project participant, RRTC will perform training and testing of the InfoGrip system for the visually handicapped. InfoGrip has loaned a system to RRTC for evaluation.

Significant activities are planned in FY91 to evaluate productivity by non-handicapped users and visually and physically handicapped users, to evaluate the system as a learning tool with tactile feedback, and to determine promising applications.

## U.S. NAVY PROGRAMS

### FNOC Satellite Processing Center Upgrade

The SSC provides on-going data systems, computer technology, and systems/application software support to the Navy's Fleet Numerical Oceanography Center (FNOC), Monterey, California, in operational testing of their Satellite Processing Center Upgrade (SPCU). The SPCU support effort in FY90 was largely related to the integration of FNOC and third party software modules and minor redesign to simplify operational utilization.

The SPCU began operational readiness testing in May 1990 to meet an Initial Operating Capability (IOC) of June 1, 1990, and has become the primary operational system. The SPC in 1984 consisted of Control Data Computers (Cyber class), high-speed digital data communication system, and auxiliary hardware to receive and process, in real time, satellite sensor data for support of oceanographic research and fleet operations. Due to the age, inflexibility, and limited capabilities of the SPC, the SPC Upgrade was developed to provide state-of-the-art front-end and processing computers, computer-controlled PCM equipment systems, and computer-controlled interactive analysis workstations. The SPCU system design and state-of-the-art computer/hardware systems are projected to meet the FNOC satellite processing needs well into the 1990s. The system design, development, computer/hardware subsystem procurement, subsystem integration, and application software development and testing were provided by SSC/STL for FNOC.

### NOO Satellite Processing System Upgrade

NASA/SSC has been requested by the Navy to upgrade the Satellite Processing System (SPSU) at SSC for the Naval Oceanographic Office in a manner similar to the FNOC SPCU project described earlier. The SPSU will process real-time data from the TIROS satellites and provide derived products via the Shared Processing Network (SPN) to the USAF Global Weather Center, FNOC, and NOAA.

This system is based upon technology developed for the SPCU, with subsystems procured competitively and integrated by SSC with site-specific application software. The major subsystems are:

- PCM Subsystem for TIROS and SPN.
- Preprocessor Subsystem.
- Information Processing Subsystem.
- Interactive Image Analysis Subsystem.
- Communication Subsystem Interface to Other NOAA Systems.

An interim SPCU was delivered and tested to receive SPN data and generate Multichannel Sea Surface Temperatures (MCSST) during the first half of FY90. SPN transmit capability was to be added in October 1990 after installation of the Navy/NOAA-supplied transmitter. A Concurrent Computer Corporation (CCC) 3280 processor upgrade to the baseline SPS is the preprocessor subsystem and a CCC 3280E processing system has been procured as the information processing subsystem. The TIROS PCM Subsystem will be installed in early FY91. The SPSU integration is scheduled to be completed and the system moved to NOO by the end of the second quarter of FY91. User training and operating procedure development will complete the preparation for system operation by FY92.

## SCANNER DATA CERTIFICATION SYSTEM

SSC/STL completed the design, specifications, procurement, development, and factory acceptance of a Scanner Data Certification System (SDCS) for SSC/STL. The system will be housed in Building 1210 at SSC.

The SDCS was designed as a state-of-the-art replacement and upgrade for STL's pulse code modulated (PCM) decommutation system. It consists of a 14-channel software-controlled and fully programmable PCM subsystem, a high-performance UNIX-based workstation, two interactive graphics workstations, and communication capability with the STL network (Figure 33). When fully implemented, this system will support all current STL/airborne scanners and will include a robust data certification and validation program. The SDCS was designed to Government and industry standards and is readily expandable to meet future SSC requirements.

Overall system architecture design was completed in August 1989. The system design and project plan were approved in September 1989. The system was acquired through open competition and awarded in April 1990. The factory acceptance test was completed in September 1990, with installation at SSC scheduled for October 1990.

The system schedule calls for final acceptance testing and integration at SSC late in CY90, capability as a limited backup system in early CY91, and operational capability in June 1991.

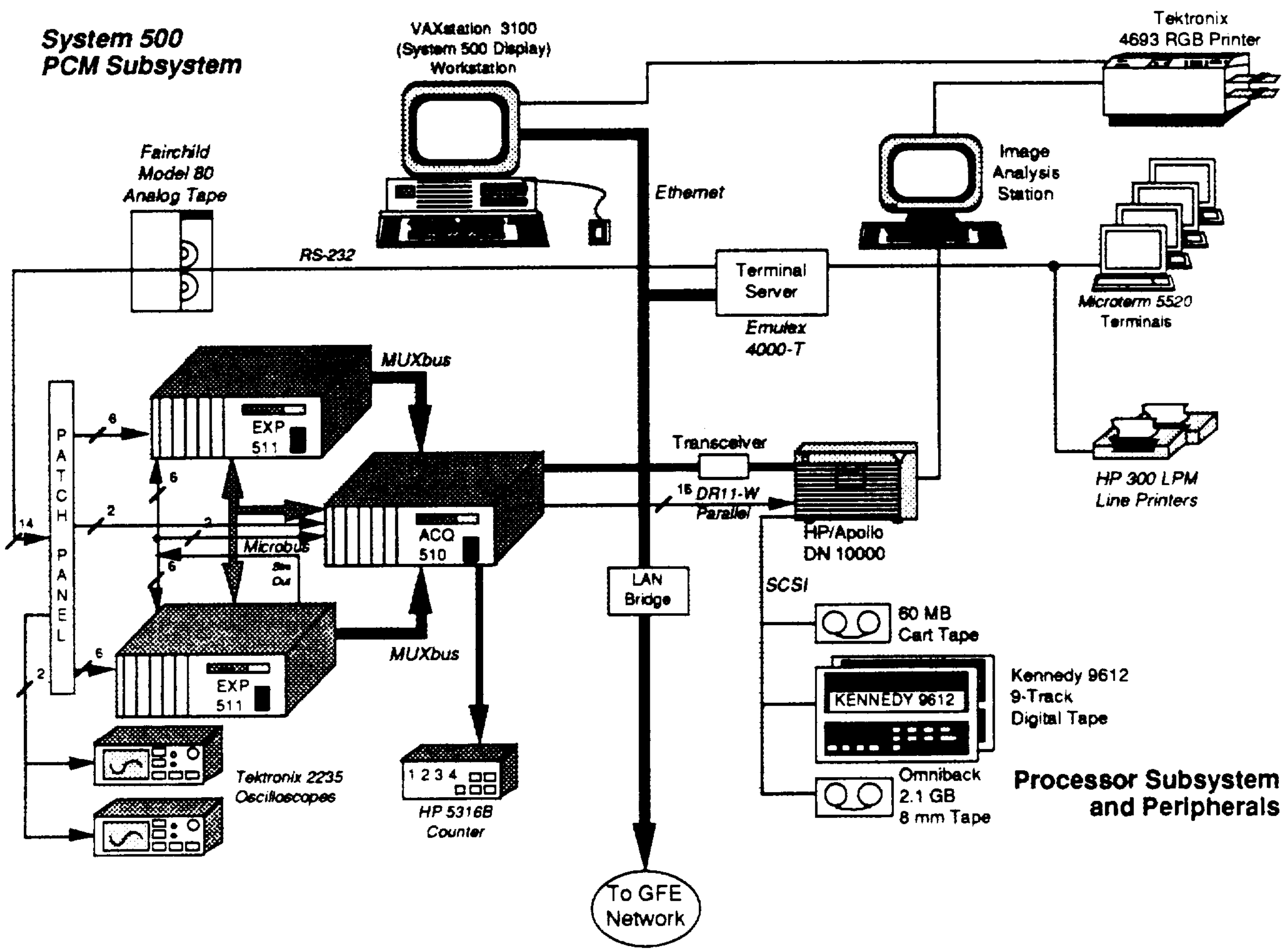
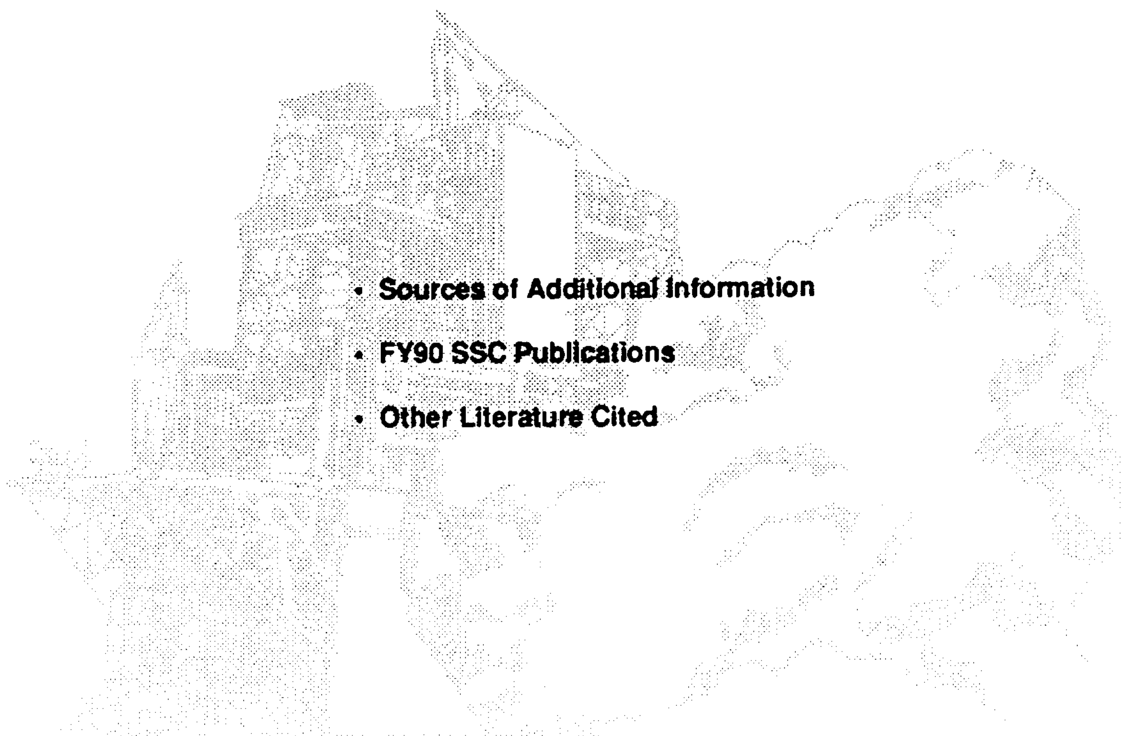



Figure 33. Scanner Data Certification System

# APPENDIX



- Sources of Additional Information
- FY90 SSC Publications
- Other Literature Cited

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# APPENDIX

## SOURCES OF ADDITIONAL INFORMATION

For additional copies of this report, contact:

P. G. Penton
Science & Technology Laboratory
NASA/SSC
John C. Stennis Space Center
Stennis Space Center, MS 39529
(601) 688-1932
FTS 494-1932

For additional information on the topics discussed, contact the principal authors listed below. (Note: Listed after each topic, in alphabetical order, are each project's primary sponsoring organizations if other than institutional support is provided.)

### Earth Sciences Research Program

- Forest Ecosystems Research
  - Forest Physiological Processes
    - Fundamental Influences on Spectral Reflectance of Leaves--G. A. Carter, 688-1918
    - Spectral Reflectance and Physiological Ecology--G. A. Carter, 688-1918
  - Forest Vegetation Thermal Studies--A. T. Joyce, 688-3830, Office of Space Science and Applications (OSSA)
  - Tropical Forest Inventory and Monitoring Techniques--A. T. Joyce, 688-3830, OSSA
    - Landsat Thematic Mapper--A. T. Joyce, 688-3830, OSSA
    - Synthetic Aperture Radar--A. T. Joyce, 688-3830, OSSA
    - Multisensor Data Sets--A. T. Joyce, 688-3830, OSSA
    - Guatemala Project--T. L. Sever, 688-1906, Office of Commercial Programs (OCP)
- Land-Sea Interface Research
  - Chlorophyll Pigment and Suspended Sediment Mapping--R. L. Miller, 688-1918
  - Coastal Ecosystems Study--R. L. Miller, 688-1918, Office of Equal Opportunity Programs
  - Sediment Transport and Land Loss Processes--R. L. Miller, 688-1918, OCP and OSSA
  - Wetlands Biogeochemical Flux--R. E. Pelletier, 688-1910, OSSA
    - Everglades Methane Flux Modeling--R. E. Pelletier, 688-1910, OSSA
    - Everglades Inundation Modeling--R. E. Pelletier, 688-1910, OSSA
    - Canadian Subarctic Methane Flux Modeling--R. E. Pelletier, 688-1910, OSSA
    - Hudson Bay Lowlands Peat Profiling--R. E. Pelletier, 688-1910, OSSA
    - Methanogenic Bacterial Population Studies--A. Johnson, 688-3155, OCP
  - Coastal Geomorphology--D. L. Rickman, 688-1920, OSSA

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- Development of Tools and Techniques
  - Jackson State University Project--D. A. Quattrochi, 688-1919, Office of Equal Opportunity Programs

### Technology Development Program

- Advanced Sensor Development Laboratory--P. J. Kelly, 688-1939
  - Sensor Development Support--P. J. Kelly, 688-1939
  - Sensor System Support--P. J. Kelly, 688-1939
    - Calibrated Airborne Multispectral Scanner--P. J. Kelly, 688-1939
    - Thermal Infrared Multispectral Scanner--P. J. Kelly, 688-1939
    - Ice Detection Research and Development--P. J. Kelly, 688-1939, Office of Space Flight (OSF)
- Thermal Imagery Activity
  - Preliminary Testing of EMU--J. E. Anderson, 688-1909, OSF
  - Thermal Imaging of Cereal Crops--C. C. Thurman, 688-1023, OSF
  - SRM Test Monitoring Using Thermal Imaging--C. C. Thurman, 688-1023, OSF
- SSC/STL Aircraft--P. J. Kelly, 688-1939
- SSF Payload Simulator Activities--W. T. Holladay, 688-1937, Office of Space Station (OSS)
- Gas Detectors
  - Hydrogen Gas Sensing Instrumentation--C. C. Thurman, 688-1023, OSF
  - Fugitive Gas Detection and Analysis--D. J. Chenevert, 688-3126, OSF
- Plume Analysis
  - SSME Exhaust Plume Diagnostics Project--D. J. Chenevert, 688-3126, OSF
  - Advanced Plume Diagnostics Capabilities
    - Flat-Flame Diffusion Burner--D. J. Chenevert, 688-3126, OSF
    - Spatial Imaging of Plume--D. J. Chenevert, 688-3126, OSF
    - Application of LIF and CARS Techniques--D. J. Chenevert, 688-3126, OSF
    - Video Imaging of SSME Plume--S. Wu, 688-1922, OSF
    - Electric Field Measurements of Plumes--S. Wu, 688-1922, OSF
    - Signal Processing Techniques for Plume Diagnostics--S. Wu, 688-1922, OSF
  - Diagnostics Testbed Facility
    - Engine Diagnostics Console Development--D. J. Chenevert, 688-3126, OSF
    - Plume Seeding and Materials Database--D. J. Chenevert, 688-3126, OSF
  - Expert System Application to Engine Monitoring--D. J. Chenevert, 688-3126, OSF
- Radio Frequency Detectors
  - Millimeter-Wave Radiometry--S. Wu, 688-1922, OSF

- Synthetic Aperture Radar--S. Wu, 688-1922, and A. T. Joyce, 688-3830, OSSA

- Polarimetric Synthetic Aperture Radar--S. Wu, 688-1922, and A. T. Joyce, 688-3830, OSF

## Commercial Programs

(Questions pertaining to this section should be directed to Mr. Robert Barlow, 688-2042)

- Commercial Earth Observations Program--OCP
  - Earth Observations Commercial Applications Program--OCP
    - Environmental Sensitivity Index Mapping--OCP
    - Forest Resource Management--OCP
    - Subsurface Gravel Detection--OCP and OSSA
  - Commercial Satellite Initiative--OCP
  - Visiting Investigator Program--OCP
  - Small Business Innovation Research--OCP
- Environmental Monitoring for Rocket Engine Testing
  - SSC Geographic Information System--OCP
  - National Technology Transfer Center--OCP

## Technology Utilization Program

- State Technology Transfer Activities
  - Louisiana Activities--R. A. Galle, 688-1929, OCP
  - Mississippi Activities--R. A. Galle, 688-1929, OCP
  - General Office Activities--R. A. Galle, 688-1929, OCP
- Applications Engineering Projects
  - Digital Image Differencing of X-Ray Imagery--R. A. Galle, 688-1929, OCP
- Environmental Life Support
  - Indoor Air Pollution--A. Johnson, 688-3155, OCP
  - Wastewater Purification by Artificial Wetlands--A. Johnson, 688-3155, OCP
  - BioHome--A. Johnson, 688-3155, OCP

## Information Systems Program

- Information Systems Division
- STLnet--B. G. Junkin, 688-1926
- ELAS--G. T. Irby, 688-1776
- SSC EOS Initiative
  - Scope of Participation--B. G. Junkin, 688-1926, OSSA
  - SSC EOS Science Working Group--B. G. Junkin, 688-1926, OSSA
- Chordic Input/Tactile Feedback--D. E. Walters, 688-1763

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- U.S. Navy Programs
  - FNOC Satellite Processing Center Upgrade --B. G. Junkin, 688-1926, Commander Naval Oceanography Command (CNOC) and Fleet Numerical Oceanography Center (FNOC)
  - NOO Satellite Processing System Upgrade --B. G. Junkin, 688-1926, CNOC and FNOC
- Scanner Data Certification System--J. E. Wakeland, 688-3464, OCP

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