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Technology Transfer of NASA Microwave Remote Sensing System

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FINAL REPORT

TECHNOLOGY TRANSFER OF NASA MICROWAVE REMOTE SENSING SYSTEM

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Prepared for
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SECTION 1. PURPOSE

A study was conducted for the purpose of exploring viable techniques for effecting the transfer from NASA to a user agency of state-of-the-art airborne microwave remote sensing technology for oceangraphic applications. The study entailed a detailed analysis of potential users, their needs and priorities; platform options; airborne microwave instrument candidates; ancillary instrumentation; and other, less obvious factors that must be considered. From the analysis this report has derived some conclusions and recommendations for the development of an orderly and effective technology transfer of an airborne Microwave system that could meet the specific needs of the selected user agencies.

SECTION 2. BACKGROUND

NASA has been actively engaged in the development of microwave remote sensing instrumentation since the early 1970's. The primary objective of these projects was to obtain both active and passive spaceborne instruments for use on oceanographic applications on a global scale. However, during the development of this "instrument family" of microwave systems, NASA has flown prototype hardware on a large number of aircraft missions including participation in many national and international exercises. The results have proven the airborne instruments' usefulness for measuring significant sea surface parameters such as wind, wave height, temperature, etc.

Although the basic purpose of these flights has been to aid in the development of satellite instrumentation, the resultant data have proven to be of great value in areas of direct regional applications. These regional and local users have data requirements which will not be met by global systems due to spatial resolution, high-density data needs, time-span problems, targets of opportunity, or various other situations. Therefore, these users have needs to utilize microwave data derived from an airborne platform.

The NASA prototype instruments are one-of-a-kind items, with most having undergone continuing modifications over the developmental years. These instruments have evolved into very versatile and sophisticated systems with the capability to perform a variety of applications but have become too complex for most operational users to accept on a direct transfer of equipment.

Presently, the technical expertise to use and maintain these prototype instruments is resident within NASA but not the potential user community. Moreover, the cost of "duplicate builds" is prohibitive, and potential users would have to expend large amounts of resources to accept a transfer of these prototypes. Therefore, a technology transfer can only be effective if the instrument design complexity is restricted to a "necessary and sufficient" criterion which results in simpler, more reliable operational instruments that are based upon the present research instrument technology.

SECTION 3. STATE-OF-THE-ART MICROWAVE REMOTE SENSING CAPABILITIES

For purposes of technology transfer, state-of-the-art microwave sensing capability is defined as instruments whose performance parameters have been verified by laboratory testing, extensive calibration, and flight tests to understand platform compatibility and evaluate repeatability, reliability and stability. Furthermore, the science algorithms for data reduction to an oceanographic surface parameter must have been understood, developed and verified by laboratory and flight testing where adequate in-situ correlative measurements were present.

The candidate instruments which fulfil the above requirements are:

1. Synthetic Aperture Radars (SAR)
2. Radar Altimeters (RA)
3. Dual Frequency Scatterometer (DFS)
4. Step Frequency Microwave Radiometer (SFMR)

These are discussed in the remainder of this section. See Figure 3-1 for measurement capability matrix.

3.1 SYNTHETIC APERTURE RADAR (SAR)

The SAR consists of a pulsed transmitter, an antenna and a phase-coherent receiver. The antenna is mounted in the side of the aircraft and has a beam width of 5^{o} or more in the vertical direction and 1^{o} or less in the horizontal plane. The resultant footprint covers a long, narrow strip away from the aircraft. Aircraft velocity provides contiguous stripping to create an image of the surface.

Measurement of ocean surface wavelength and direction, ice coverage, and oil pollution detection have been verified for SAR. Currently, analysis is underway at NASA Langely Research Center in an effort to relate known turbidity observations to SAR data.

The primary developer of SAR technology has been the U.S. Air Force, which currently uses it operationally on a number of aircraft. Since the

Microwave Remote Sensing Capabilities

Parameter	Instrument Package
Surface Wind Speed	SFMR (5-7 GHz)
Surface Wind Direction	DFS (9-15 GHz)
Significant Wave Height	DFS
Sea Surface Temperature	SFMR + 18 GHz Rad
Salinity	SFMR + 18 GHz Rad + L-Band Rad
Rain Rate	SFMR
Dominant Wavelength and Direction	*Research
Wave Spectrum	*Research

*Instrument technology available, but correlation model not in operational state.

Figure 3-1. Microwave Remote Sensing Capabilities Matrix technology exists in state-of-the-art form outside of NASA and because the cost of an SAR is normally quite high, the transfer of in-house technology was precluded from further consideration.

3.2 RADAR ALTIMETER (RA)

The Radar Altimeter is basically a short-pulse nadir-looking radar which determines the time from pulse transmission to receipt of backscatter thus yielding a precise measurement of altitude. By also examining the slope of the return pulse leading edge the significant wave height is determined. However, the same information can be obtained using a Dual-Frequency Scatterometer, which additionally provides surface wind speed and direction. Therefore, this instrument was not considered further.

3.3 DUAL-FREQUENCY SCATTEROMETER (DFS)

The DFS is a non-imaging radar which transmits pulses at two discrete frequencies separated by a frequency of less than 40 MHz. The basic measurement is the amount of signal returned. This signal return is called backscatter and is the radar cross section (RCS) of the target used as the reflecting surface.

The measurement capabilities of the DFS instrument are:

1. Surface Wind Speed (SWS)
2. Surface Wind Direction (SWD)
3. Significant Wave Height (SWH)

Use of radar scatterometry to infer ocean surface characteristics was first initiated at NASA in the early 1970's as a part of the Advanced Applications Flight Experiments (AAFE) program. The 13.9 GHz RADSCAT was used to underfly the S-193 scatterometer on SKYLAB to develop both technology and science correlations for the instrument family of radiometers and scatterometers.

As part of the AAFE program, a series of flights were flown on the NASA JSC and NOAA RFC C-130's with the RADSCAT in an aft-scanning mode looking out of the rear cargo door. By banking the aircraft at a fixed angle and making 360^{0} turns an effective conical scan was achieved with the 3^{0} beam width antenna. It was in this manner that the sensitivity to measure sea surface wind speed and direction were first observed. This sensitivity results from the ocean's normalized radar cross section (NRCS) increasing with the friction velocity for incidence angle greater than 20^{0}. In turn, the friction velocity is related to the wind stress and the neutral stability wind. Also, the NRCS is anisotropic, and information on the wind direction can be obtained from scatterometer measurements having orthogonal azimuth angles. The NRCS is computed using the standard radar range equation.

The scatterometer geophysical algorithm which converts NRCS measurements to the friction velocity vector requires a comprehensive set of radar/anemometer data. The data for this algorithm were obtained from a variety of aircraft missions in which the aircraft flew an assortment of straight lines and circles (as in figure 3-2). A data base of the NRCS measurements was collected as a function of incidence angle and/or azimuth angle relative to the wind direction (figure 3-3). The measurements were obtained under a variety of conditions ranging from light winds and calm seas to gales. For each flight, the local wind vector and the atmospheric stability (air/sea temperature difference) were measured by either in-situ or airborne sensors.

The significant wave height measurement is obtained by correlating the phase shift differentials at the two offset frequencies. This differential is a function of the return time from a surface which is perpendicular with respect to the radar beam. The analytical basis for this technique is an application of the physical optics approximation to the Kirchhoff-Huygens integral.

The dual frequency technique is basically analogous to the impulse radar in that it measures the spread in ranges of the incoherent, randomly distributed targets that are illuminated. But unlike the impulse radar, which measures this range spread by observing the width of the time response, the dual frequency radar senses the average phase difference among the targets at two separated frequencies.

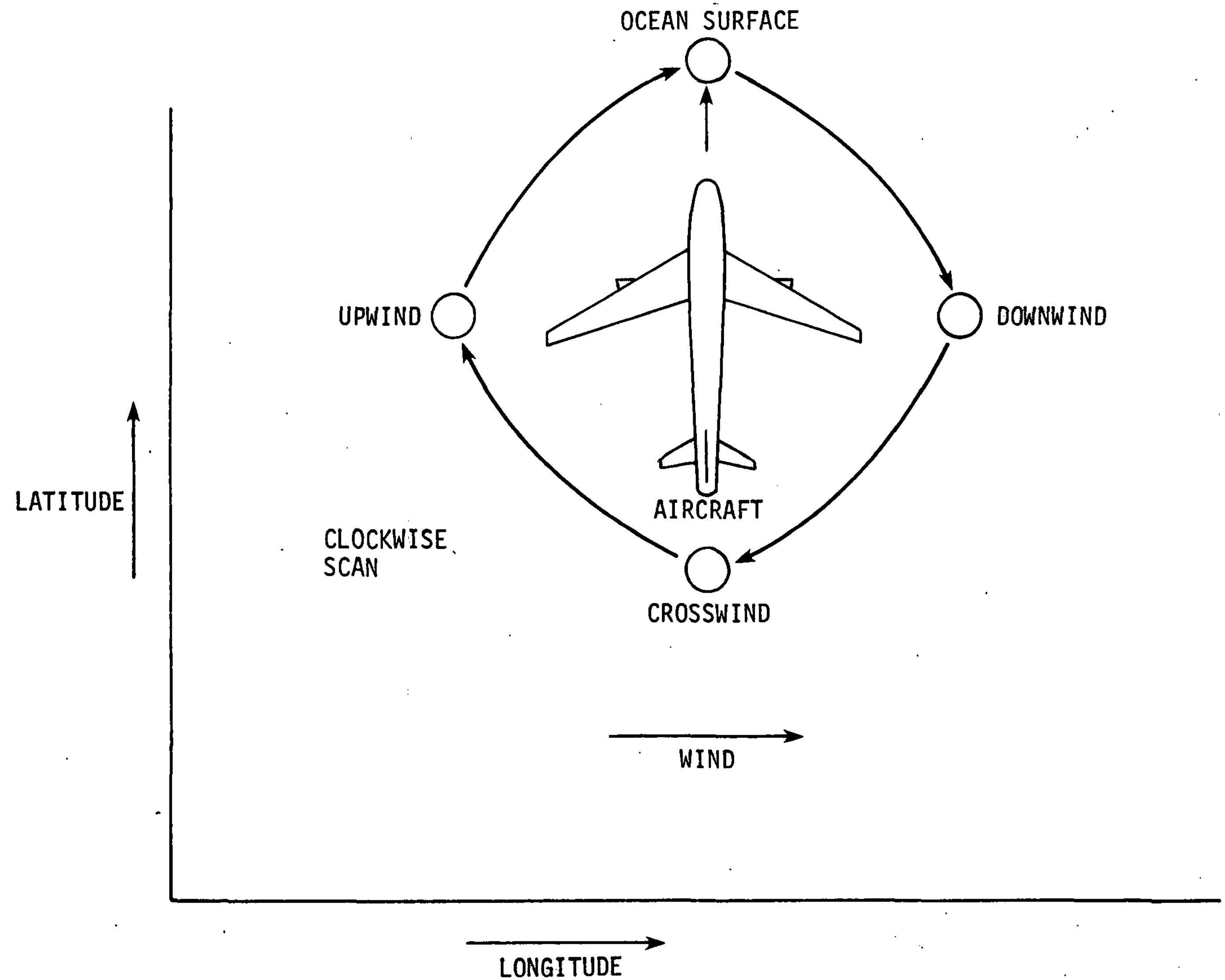

Figure 3-2. Typical Scatterometer Conical Scan

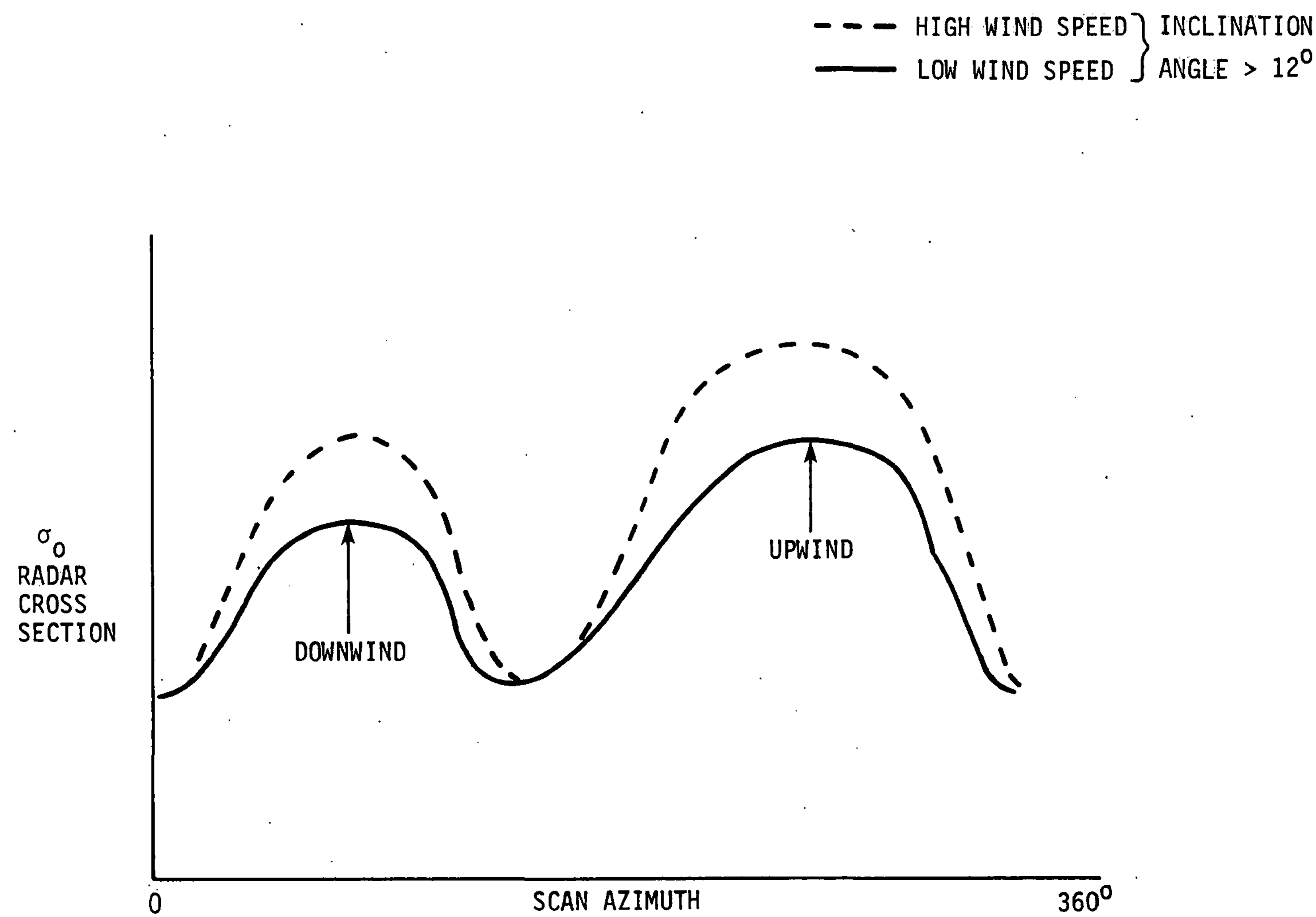

Figure 3-3. DFS Wind Speed and Direction Effects

To obtain all three measurements of wind speed, direction and wave height the DFS would require either a gimballed scanning antenna or a set of fixed antennas. The ambiguity of direction can only be removed by having orthogonal scans.

3.4 STEP-FREQUENCY MICROWAVE RADIOMETER (SFMR)

The SFMR is a passive instrument operating in 4.5 - 7.2 GHz frequency range. The SFMR utilizes a noise-injection feedback loop to obtain a highly stable and extremely sensitive measurement of surface radiometric brightness temprature as a function of polarization and frequency.

This broad band microwave system was developed, fabricated, and flight-tested by NASA Langley Research Center. It can operate in several different preprogrammed modes or from front panel controls. The digital subsystem provides both radiometer control functions and real-time data processing for real-time display of brightness temperature to the operator.

The radiometer operates at frequencies between 4.5 gigaHertz and 7.2 gigaHertz at bandwidths of 10, 50, 250 or 1000 megaHertz with integration times from 0.2 to 20 seconds. The frequency can be varied in incremental steps from approximately 0.2 to 5 times the bandwidth per integration time.

This capability provides the radiometer with many remote sensing applications. The frequency stepping program can be preplanned for different scientific measurements, then altered in flight to avoid RFI problems. The variable bandwidth and integration time provides the capability to trade spatial resolution on the surface for temperature resolution of the radiometric measurement during an experiment. This enables the experimenter to select one temperature resolution for an ice mission, typically 3^{o} Kelvin, and another for an oceanographic mission, typically 0.3^{o} Kelvin. The temperature resolution of the stepped frequency radiometer can be varied from 0.1^{o} to 3^{o} Kelvin. Also, dispersive geophysical media such as layered fresh water ice can be measured using the frequency stepping capability of the radiometer.

As with the Dual Frequency Scatterometer and Radar Altimeter, the SFMR is an evolutionary outgrowth of the AAFE program. Flight testing to date has verified the following measurement capabilities:

1. Sea Surface Wind Speed
2. Sea Surface Temperature
3. Rain Rate

Empirical results have verified that the surface emissivity of water is affected by thermal, chemical and roughness changes. For the SFMR to measure sea surface temperatures it must have an absolute calibration input such as that from a PRT 5 radiometer ($\pm 0.5^{o}C$), which measures surface temperature from an aircraft, or data from ships or buoys. The SFMR can then detect emission changes with a high degree of accuracy.

Sea surface wind speed is inferred by relating to two characteristics, namely surface roughness and foam coverage. The foam becomes a factor at wind speeds of about 7 m/sec. Emissivity effects of a rough surface are well understood, namely that brightness temprature increases with wind speed. Thus the no-foam flight results were excellent. However, foam coverage effects had to be empirically extracted from the data by cross-correlation with scatterometer data and in-situ measurements. The technique is now state-of-the-art.

The effect of water content between the radiometer and the surface are such that the various frequencies are attenuated at different rates. By using algorithms which relate these differentials, the rain rate within the beam can be inferred. Other atmospheric attenuation effects fall out because they are the same for the frequency range of interest. Figure 3-4 indicates the different effects noted in radiometer data.

Chemical changes, such as pollutants or salinity alter the basic emissivity of the water over discrete frequency ranges. For example, salinity effects are noted at L-Band frequencies (1-2 GHz) but are unseen at higher frequencies. A comparison between L-Band and SFMR data taken coincidentally can yield salinity measurements from an aircraft. NASA Langley Research Center personnel have used the L-band system to chart a

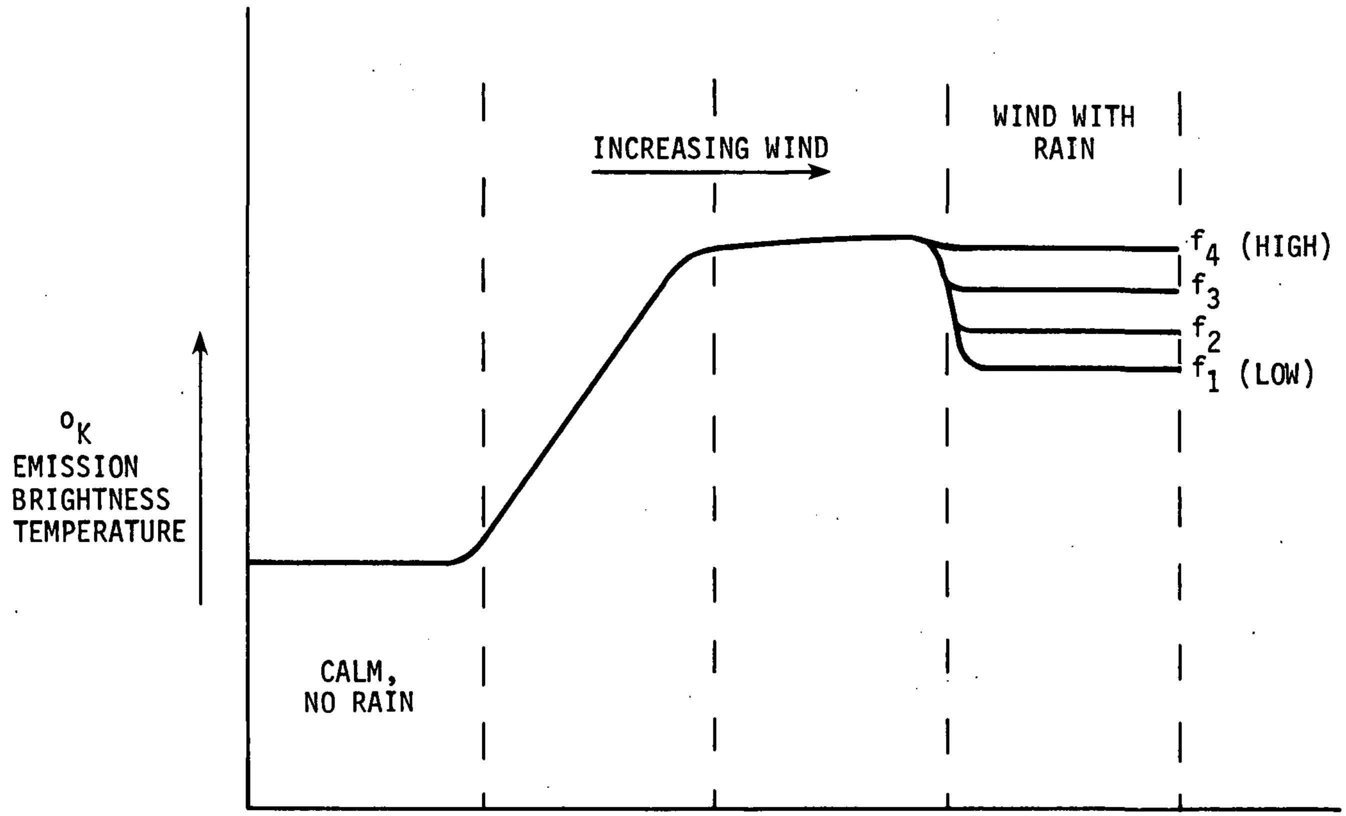

Figure 3-4. SFMR Radiometric Brightness Effects

large segment of the lower Chesapeake Bay region in as little as three hours, which has heretofore been a virtual impossibility without the use of a large number of ships and/or buoys.

SECTION 4. USER REQUIREMENTS

This section examines the variety of potential users of microwave remote sensing technology to select those which meet the criteria established for this study, and are most likely to result in successful technology transfer activities. The most significant requirements of these potential users, presented as applications of microwave remote sensing techniques, are also discussed in terms of their suitability in technology transfer activities.

4.1 USER COMMUNITY

The user community for applications of microwave remote sensing is overwhelmingly large, centered around government agencies and extending into the private and academic sectors. The applications for the technology are likewise varied, serving both research and operational programs. For this study it is assumed that the transfer of NASA microwave remote sensing technology will be directed toward other government agencies having either operational, research, or data distribution requirements as a prime mission within their charter. In addition, it is assumed that global or large area microwave data requirements will be satisfied by operational satellites. Therefore, the potential users are limited to those which have applications concerning targets of opportunity (e.g., severe storms, pollutant dumps or warm core rings) or localized high-density, high-spatial resolution obervations (e.g., salinity mapping of an estuarine region during a tidal change, or routine pollutant monitoring).

Based upon these assumptions, the primary targets for the transfer of microwave remote sensing technology are the following agencies:

1. Department of Defense (DOD)
2. Department of Commerce (DOC)
3. Environmental Protection Agency (EPA)

There are, in addition, a number of agencies, administrations and commissions which are dependent upon these prime agencies for microwave data in a timely manner. This diverse group represents regional, state, local and commercial users.

Having identified these agencies, a variety of specific groups within them were contacted to discuss their requirements in terms of microwave remote sensing applications. Discussions were held with representatives from a number of agency groups including those listed in Table 4-1. The applications which best served the requirements of these groups are presented in subsection 4.2.

4.2 MICROWAVE REMOTE SENSING APPLICATIONS WHICH MEET USER REQUIREMENTS

The discussions with the potential users mentioned previously identified two major areas in which microwave remote sensing techniques meet user requirements: Severe Storm Monitoring and Forecasting, and Near-Coastal and Estuarian Region Monitoring. The requirements and techniques which apply to these areas are discussed below.

4.2.1 SEVERE STORM MONITORING AND FORECASTING

Prime responsibility for severe storm monitoring and forecasting activities rests with the National Oceanic and Atmospheric Administration (NOAA) of DOC. A Federal Coordinator for Meteorological Services and Supporting Research has been established within NOAA to coordinate all government activities related to severe storm conditions in the Atlantic, Caribbean, Gulf of Mexico, Eastern Pacific and Central Pacific regions. An Interdepartmental Hurricane Warning Conference is held annually to focus the efforts of the Interdepartmental Committee for Meteorological Services and Supporting Research. The 35th such Annual Conference was held at Homestead AFB in Miami, Florida on January 26-30, 1981 and was attended by nearly one hundred representatives from numerous military, government, and private concerns. The number and diversity of the attendees at these conferences demonstrate the wide-ranging concern for storm monitoring and forecasting. The continued growth in population density and commercial and industrial development in low-lying coastal areas of the U.S. and the Caribbean and Pacific Islands necessitate pursuit of these activities.

Table 4-1. Potential User Agency Groups Contacted for Requirements

Department of Defense

Department of the Navy

Naval Eastern Oceanography Center
Norfolk, Virginia

Central Pacific Hurricane Center (CPHC)
Hawaii and Guam

Atlantic Fleet Operations
Norfolk, Virginia

Department of the Air Force

920 Weather Reconnaissance Group
Keesler AFB, Mississippi

Pacific Air Force
Guam

Department of Commerce

National Oceanic and Atmospheric Administration

Environmental Research Laboratories
Boulder, Colorado

Research Facilities Center
Miami, Florida

Atlantic Oceanographic and Meteorological Laboratories
Miami, Florida

National Hurricane Research Laboratory
Coral Gables, Florida

National Weather Service

National Hurricane Center
Miami, Florida

National Marine Fisheries Service
Rockville, Maryland

Environmental Protection Agency

Environmental Monitoring Systems Laboratory
Las Vegas, Nevada

In severe storm monitoring the parameters of interest are: surface wind speed, surface wind direction, wave height and rain rate. All four of these are of obvious interest in a severe storm situation because of the potential problems imposed to land masses and/or ships at sea. In priority ranking the most important information would be wind speed, followed by wave height, rain rate and wind direction. The reasoning for this order is straight forward. First, wind speeds have major impact on property damage as a force function and along with wave height and tidal conditions determine the storm surge effects on land fall. Rain presents a potentially disastrous flooding problem to inland as well as coastal areas. Knowledge of the precise wind direction on the surface of a severe storm is somewhat academic in as much as storm winds rotate in either a clockwise or counterclockwise direction depending on hemispherical location.

The accuracy required in measuring these parameters for severe storm monitoring is based upon a concensus of the meteorological community. The accuracies commonly cited are listed below:

Information Requirements for Severe Storm Monitoring

Surface Wind Speed	± 2 m/s or 5%, whichever greater
Wave Height	$\pm .25$ m
Rain Rate	Best Available
Surface Wind Direction	$\pm 10^{0}$

The measurement of these parameters at these accuracies is currently within the state-of-the-art capability of microwave systems flown by NASA.

In addition to the monitoring of severe storms, the need for advanced forecasting of storm intensity and velocity vector is also immediate and imperative. These modeling procedures utilize a variety of parameters as input such as surface pressure, wind speed and direction, significant wave height, surface water temprature, and precipitation. The frequency of coverage (less than 24 hours) and resolution (nominally 10 km) required for the models precludes current satellite systems. These data must be obtained by ships, stations of opportunity, and/or aircraft utilizing remote sensors and relaying the data on a near-real time basis. As stated previously, the measurement of some of these critical parameters, such as wind speed and direction, wave height, and rain rate is within the capability of airborne microwave systems at the accuracies required.

4.2.2 NEAR-COASTAL AND ESTUARIAN REGION APPLICATIONS

The applications of microwave remote sensing in the near-coastal and estuarian regions are of a much more diverse nature than in the severe storm case. EPA, NOAA, DOD, DOT, DOE, DOI and numerous other federal, regional, state and local users are involved in these areas. Some of the applications which pertain to this area are oil spill monitoring, fate modelling, special studies, and estuarian investigations. Each of these applications is discussed below.

A prime application of microwave remote sensing in the near-coastal region is the surveillance, detection, assessment, and control of oil spills. This topic has been examined in detail in a study entitled "Assessment of the Use of Space Technology in the Monitoring of Oil Spills and Ocean Pollution" to which the reader is referred for an in-depth discussion (see bibliography). The potentially serious impact of these spills has led to significant research efforts in this application as well as an operational program sponsored by the U.S. Coast Guard. In this program the Airborne Remote Identification System is being developed which includes an SAR, an ultraviolet/infrared scanner, a TV camera, an aerial mapping camera and an annotated data system. This system is scheduled to provide surveillance to 200 miles in all US coastal waters beginning in the 1984-1986 time frame and will be used to support monitoring of oil and other pollutant spills. Because the design and planning for this system are already underway outside of NASA, it is assumed that technology transfer efforts need not be undertaken in this area.

Another area of interest for microwave remote sensing is fate modelling, or prediction of the trajectory and spreading characteristics of a dump, spill, or effluent. Much of the fate modelling is dependent on underwater currents, imposing information requirements for the bathymetric layer. Microwaves do not penetrate the top layer to provide this information so in-situ measurements are required and ships are used in these missions. Nevertheless, various groups are investigating how surface parameters measurable by microwave play a role in these models. These models normally require synoptic data over a short time span and on a very localized basis. Moreover, fate modelling activities are basically research efforts which do not require data on a continuous and operational basis. Although agencies like NOAA, EPA, USCG, DOI and AEC have significant needs for this research, budget austerity has necessitated that priority be given to their on-going, operational programs. For this reason it is premature to pursue technology transfer efforts to support fate modelling.

Other near-coastal experimental or research applications can utilize microwave remote sensing techniques, such as the warm core ring Nantucket Shoals Experiment in May 1981. However, funding for these efforts is uncertain and normally does not support the development of new systems. Technology transfer efforts are unlikely to be feasible in these experiments.

Research in the estuarian environment can be supported by microwave measurements of surface temperature. Mapping of this parameter provides inputs to modelling tidal flows, pollution dispersion, fresh water influences, turbulence, shelf circulation, and mixing.

SECTION 5. PLATFORMS AND ANCILLARY INSTRUMENTATION

5.1 INTRODUCTION

There are numerous platforms which will meet requirements for microwave remote sensing missions, ranging from lighter-than-air (LTA) to operational jet aircraft. The major criteria of interest in a technology transfer program are: availability, cost effectiveness, mission suitability, ancillary equipment and adaptability.

5.2 PLATFORMS

Lighter-than-air platforms can be summarily dismissed due to lack of availability. It should be noted that the U.S. Coast Guard is considering developing a fleet of surveillance blimps within the next five years. As such, they would make ideal platforms for coastal and estuarian region sensing missions.

Although helicopters are useful for the same missions as are LTA's, the size required to carry the microwave sensing package is not cost effective in operational considerations. Thus, airplanes were considered as the optimum platform for the operational microwave system. Therefore, an analysis was made of the available aircraft within the potential user agencies. This included EPA's Twin-Beechcraft CV680, NOAA and the U.S. Navy's Lockheed P-3s, and NOAA and USAF's Lockheed C130's.

The Environmental Protection Agency utilizes a twin-engine CV680 for its water quality monitoring programs. Even though the aircraft is economically viable, it is extremely limited in its payload capacity and even more restrictive in antenna placement sites. Major modifications would be required to adapt to needs.

The P-3 is used by both NOAA and the U.S. Navy. The NOAA aircraft is based at the Research Facilities Center (RFC) in Miami, Florida and has been used for microwave remote sensing research flights in the past. However, RFC personnel feel that in order to use this aircraft in a technology transfer program, major problems will be encountered with structural modifications to accommodate the antenna system.

The C-130 Hercules (Figure 5-1) is one of the most widely used all-purpose platforms available today. It is flown by both NOAA and the USAF Weather Reconnaisance Groups on normal severe storm missions. Designed as a cargo aircraft, the C-130 has a large cargo capacity, adequate floor space for antennas, power, is routinely flown on remote sensing missions of a nature satisfactory to meet user needs, and is already equipped to provide the ancillary measurements required by the DFS and SFMR.

5.3 ANCILLARY INSTRUMENTATION

Ancillary measurements required by both the DFS and SFMR are altitude, position, and aircraft attitude relative to the Earth. Position and attitude are routinely provided by an inertial navigation system. The altitude can be obtained by the DFS or by a standard radar altimeter.

For absolute measurement of temperature, the SFMR must calibrate with either an on-board PRT-5 radiometer or in-situ data provided by ship or buoy at some point in the flight.

The Environmental Research Laboratory of NOAA, in conjunction with DOD, is currently developing an aircraft instrument package called the Atmospheric Distributed Data System (ADDS). The ADDS will be placed on the Air Force C-130 and tested during the 1981 hurricane season. It provides real-time measurments of atmospheric parameters outside the aircraft and is a complementary package to the INS winds and lower altitude winds derived from DROPSONDE data.

The one piece of operational ancillary equipment that does not yet exist for a Microwave Remote Sensing Package is an on-board data processing subsystem. However, in parallel with this study, LaRC initiated design and procurement of long-lead time ADP equipment to fulfill this recognized need. The data acquisition and presentation technique currently utilized in the microwave remote sensing program does not yield real time, or near-real time, output of the ocean surface parameters observed. As a general

Figure 5-1. Weather Instrumented USAF C-130 Aircraft Flown for Hurricane Reconnaissance

rule, analog data are taped and reduced at a remote site after the flight programs are completed. This method, while satisfactory for the researcher whose need is normally not urgent, does not fulfill the requirements of operational users faced with decision making responsibilities.

The need for near-real time data may be most obvious in the severe storm application. Literally millions of dollars in operatonal money can be expended over a short time period in the preparation of storm landfall areas. Obviously, data must be gathered, processed and transmitted as quickly as possible. Thus, on-board data processing is considered to be a user requirement. The technology is state-of-the-art. NASA Langley has a program underway developing such a subsystem.

Lastly, all the owners of potential platforms agreed on one portion of design criteria. Namely, the instrument package should be modular (preferably palletized), utilize available interface capabilities wherever possible and minimize installation requirements in order to reduce impact on other aircraft missions.

SECTION 6. SUMMARY

The Microwave Remote Sensing Instrumentation available today is capable of providing a wealth of useful and pertinent information to both the research and the operational sectors of the user community.

The Synthetic Aperture Radar (SAR) was precluded from consideration in this study because the technology is already in use outside NASA. The Radar Altimeter (RA) was precluded because the Dual Frequency Scatterometer (DFS) will do virtually the same job while contributing wind speed and direction measurements.

The most reasonable choices of instruments for technology transfer are the DFS and the Step-Frequency Microwave Scatterometer (SFMR). These instruments have the capability of measuring surface wind speed and direction, significant wave height, sea surface temperature and rain rate.

The DFS-SFMR package provides data required for the monitoring of severe storms as well as fate modeling data for near-coastal and estuarian regions. Addition of the NASA L-Band radiometer to the SFMR yields surface salinity measurements.

The user community is comprised of government agencies and regional, state, and local operations as well as industrial, research, and institutional concerns. The prior include Department of Defense (DOD), Department of Commerce (DOC), Environmental Protection Agency (EPA), Department of Interior (DOI) and Department of Transportation (DOT). Interests can be divided into two categories; severe storm monitoring and forecasting, and near-coastal and estuarian observations.

Platforms available today for technology transfer are the C-130, P3, and CV-680 type aircraft. Ancillary equipment required to support the microwave instruments are an inertial navigation system, an on-board processor and in the case of surface temperature measurements a PRT-5 radiometer is needed.

A matrix of instrument capabilities and useage is given in Figure 6-1.

PHYSICAL PARAMETER	INSTRUMENT	PRIME USERS	SEVERE STORM USE	ESTUARIAN AND NEAR-COAST USE
Surface Temperature	SFMR	DOC, DOD, DOI	X	X
Surface Wind Speed	SFMR or DFS	All	X	X
Surface Wind Direction	DFS	All	X	X
Rain Rate	SFMR	DOC, DOD	X	
Significant Wave Height	DFS	DOC, DOD, DOT	X	
Surface Salinity	L-Band	DOC		X

Figure 6-1. Instrument-Usage Matrix

SECTION 7. CONCLUSION AND RECOMMENDED PLAN

This section contains the conculsions gleaned from the study and provides a recommended course of action.

7.1 CONCLUSIONS

It has become increasingly apparent that in the atmosphere of today's data needs coupled with today's resource availability, any transfer of existing microwave remote sensing technology will require implementation of a carefully laid out interdepartmental plan between NASA and the user agency. Agreements must be reached on resource commitments of manpower, funding and scheduling.

The obvious technology to be transferred is that possessed by NASA Langley in the Dual-Frequency Scatterometer (DFS) and the Step-Frequency Microwave Radiometer (SFMR). Both instruments are fully state-of-the-art with respect to the applications of interest. A prototype DFS and SFMR package needs to be designed, fabricated, calibrated, aircraft integrated and tested.

Design considerations must be based strictly on "necessary and sufficient" criteria and include aircraft integration requirements, modularity, component standardization, ease of installation, repairability, reliability and cost effectiveness.

A modular concept for a Microwave Ocean Remote Sensing System (MORSS) is shown in Figure 7-1. Included are a DFS and a SFMR which are supported by the INS and On-Board Processor. A PRT-5 is shown for use in sea surface temperature calibration.

The users with the most apparent needs are NOAA and DOD for purposes of monitoring and forecasting severe storms. The system could certainly be utilized for other purposes, but a national committee exists in this arena which could serve as a focal point for a technology transfer which would include NASA, NOAA and DOD. This, of course, is the Interdepartmental Committee of Meteorological Services and Supporting Research.

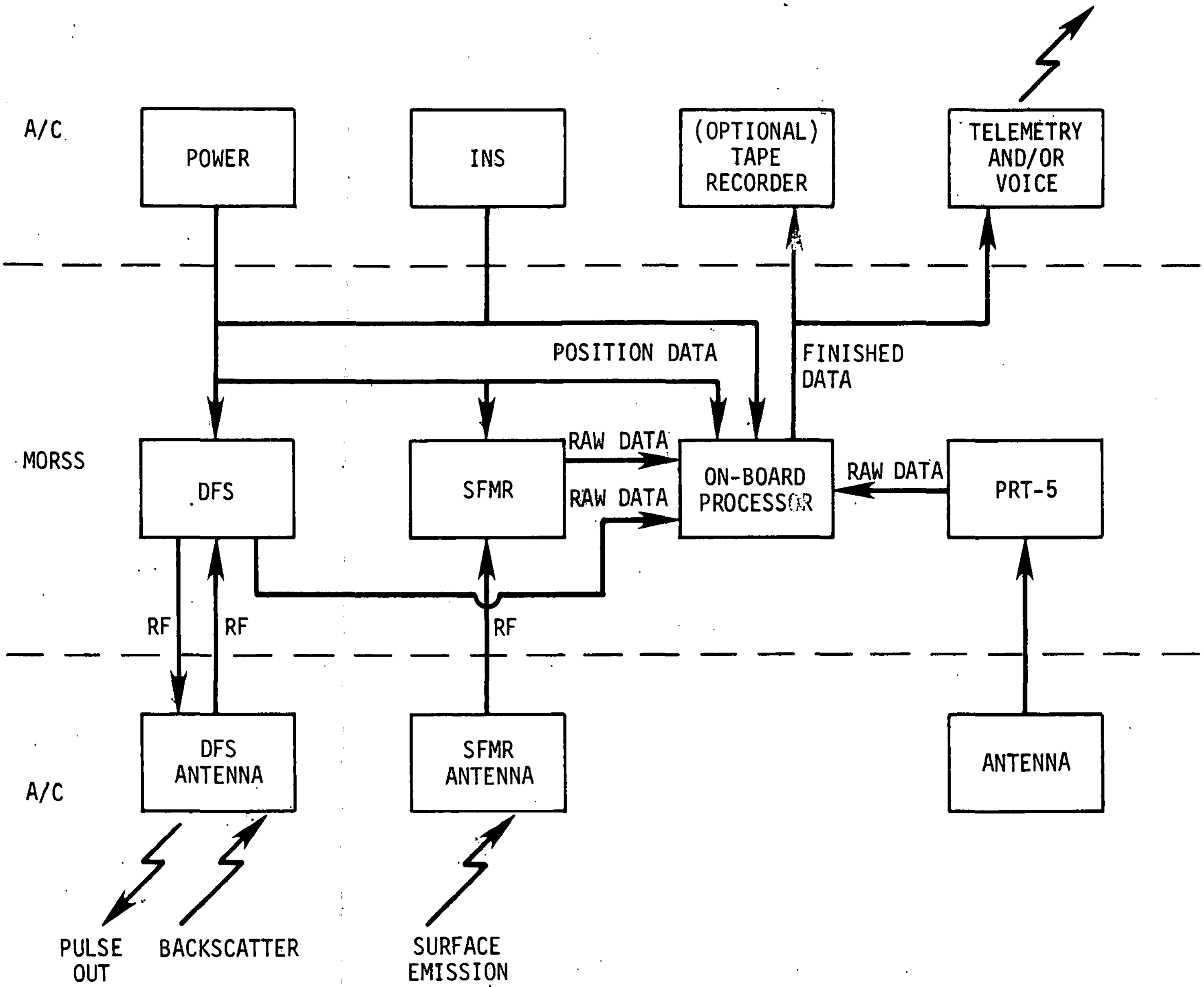

Figure 7-1. Microwave Ocean Remote Sensing System (MORSS)

The best suited aircraft for the transfer is the C-130. Either the NOAA Miami aircraft or the weather Reconnaisance Group (WRG) C-130's based at Keesler AFB are suggested. The NOAA personnel already have experience flying these instruments while the WRG is routinely involved in flying hurricanes missions and is currently working with the ADDS system.

A three phase plan for effecting this transfer is outlined in Section 7.2.

7.2 RECOMMENDED PLAN

The most viable plan for the effective transfer of Microwave Remote Sensing Technology is a three-phase program. The phases should be:

Phase I	Preliminary Design (6 months)
Phase II	Final Design, Fabrication and Calibration (16 months)
Phase III	Integration and Flight Test (6 months)

The program should include the following elements:

Participants	NASA DOC (NOAA) DOD Interdepartmental Committee for Meteorological Services and Supporting Research
Measurements	Surface Wind Speed Surface Wind Direction Significant Wave Height Rain Rate
Objective	Monitoring of severe storms for both operational and research purposes
Instrumentation	Dual-Frequency Scatterometer (DFS) Step-Frequency Microwave Radiometer (SFMR)
Platform	C-130 aircraft (NOAA or DOD)

Design Considerations	Aircraft interface requirements Palletized or modular system Off-the-shelf components On-board data processing Cost Options (e.g. fixed horn antenna versus scanning parabolic)
Resource Requirements	Funding levels would be defined in Phase I as a design function. It is reasonable to assume that Phase I would cost between \$100K-\$125K. Funding of Phase I should probably be a tri-party arangement, with Phase II and III costs being borne by DOD and NOAA. Manpower would be supplied by all agencies, with NASA's involvement being phased out as DOD/NOAA comes up to speed on the instruments.
Option 1	As a cost saving item, it may be desirable to transfer only the SFMR instrument. This would negate the measurements of wind direction and significant wave height, but should save about one third of total program costs.
Option 2	For the same reasons, a DFS could be transferred as a single instrument. This would negate the measurement of sea surface temperature and rain rate. Cost savings would probably be of the same order of magnitude as Option 1.

A suggested Statement of Work for Phase I follows.

7.3 SUGGESTED STATEMENT OF WORK

Preliminary Design of a Prototype Microwave Technology Transfer system consisting of a Dual-Frequency Scatterometer (DFS) and a Step-Frequency Radiometer (SFR).

Background. Results of Contract NAS1-16380, "Technology Transfer of NASA Microwave Remote Sensing Systems" have shown that a very urgent need exists for airborne instrumentation to determine severe storm parameters over oceans on a near real-time basis. The measurements of interest are:

1. Surface wind speed
2. Surface wind direction
3. Wave height
4. Rain rate

Current capabilities of measuring these parameters are archaic in comparison to those now available by means of this technology transfer. The most obvious civilian interest lies in the sector of those who are responsible for protecting life and property in the potential impact areas of hurricanes and typhoons. Major and costly decisions of vital importance are affected by the reliability of these data.

Technology developed and tested at NASA LaRC and verified by NOAA has yielded research instruments capable of performing these measurements. However, these instruments, the DFS and SFR, are research tools and are of a much more complex nature than is required for current operational needs.

The purpose of this effort is to do the preliminary design of a prototype operational DFS and SFR modular package.

Task 1. NASA, NOAA and DOD personnel shall define the electrical, mechanical, and aircraft interface specifications for a prototype operational microwave system composed of (a) a Dual-Frequency Scatterometer (DFS) and, (b) a Step-Frequency Radiometer (SFR). Consideration shall be given to installations on the NOAA Research Flight Center (RFC) C-130 and P-3 aircraft based in Miami, Florida and the Air Force C-130's used for hurricane reconnaisance based at Keesler AFB, Mississippi.

Task 2. Based on the results of Task 1, utilizing drawings and hardware existing at NASA, and in conjunction with NASA personnel, effect a preliminary design of the DFS and SFR instruments. Considerations in the design shall include, but not be limited to, cost effectiveness, size, weight, operational ease, reliability, repairability, and safety of flight. Output data stream specifications will be provided by NASA, NOAA and DOD.

Task 3. Conduct a preliminary design review, approximately four months after contract award. The review shall include discussion of "first-cut" build schedules, long-lead procurement requirements, and potential problem areas.

Task 4. Following Task 3, modify the preliminary design as required and provide a detailed plan of schedule and resources for final design and building of the DFS and SFR instruments. Also provide a preliminary plan for test, calibration, aircraft installation and flight testing of the system.

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16. Abstract

A study was conducted for the purpose of exploring viable techniques for effecting the transfer from NASA to a user agency of state-of-the-art airborne microwave remote sensing technology for oceangraphic applications. The study entailed a detailed analysis of potential users, their needs and priorities; platform options; airborne microwave instrument candidates; ancillary instrumentation; and other, less obvious factors that must be considered. From the analysis this report has derived some conclusions and recommendations for the development of an orderly and effective technology transfer of an airborne Microwave system that could meet the specific needs of the selected user agencies.

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