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U.S. DEPARTMENT OF COMMERCE/Environmental Science Services Administration

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RFF 1

Technical Report

RESEARCH LABORATORIES

ERL 126-RFF 1

The ESSA Research Flight Facility: Facilities for Airborne Atmospheric Research

HOWARD A. FRIEDMAN

FRANK S. CICIRELLI

WILLIAM J. FREEDMAN

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Atlantic Oceanographic and Meteorological Laboratories and Pacific Oceanographic Laboratories: Oceanography, with emphasis on ocean basins and borders, and oceanic processes; sea-air interactions; and land-sea interactions. (Miami, Florida)

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ESSA TECHNICAL REPORT ERL 126-RFF 1

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RESEARCH FLIGHT FACILITY
MIAMI, FLORIDA
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DEDICATION

This series of RFF technical reports is dedicated to Dr. Robert H. Simpson, Director, National Hurricane Center, ESSA/Weather Bureau, Miami, Florida.

Persons familiar with the formation and development of the Research Flight Facility know that Dr. Simpson was the leading pioneer in establishing an airborne platform for meteorological research. The instrumentation he originally proposed remains the backbone of this facility and is the definition of the next generation of airborne data acquisition systems.

His continuing support and encouragement of RFF's activities serve to inspire and encourage devotion to the accomplishment of all assigned missions.

Howard J. Mason Jr.

Howard J. Mason, Jr., Chief
Research Flight Facility

FOREWORD

In presenting this series of technical reports, the Research Flight Facility (RFF) is attempting to provide a basic understanding and textual reference for its approach to airborne meteorological data collection and processing.

This first volume of the series introduces the reader to the history of the facility, its aircraft, logistical support requirements, navigational and operational practices, and radio communication capabilities. In addition, the reader is presented with illustrations of the way in which research scientists have used the RFF for research and operational missions.

In later reports, information concerning meteorological and related systems and subsystems, data processing, and current and future systems development will be presented. Any dynamic changes in instrumentation, data processing and/or quality control procedures, which affect the collected data, will be reported in future publications of this series.

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ABSTRACT

This is the first of a series of reports de--scribing the services of the ESSA Research Flight Facility (RFF), an airborne research organization that provides worldwide services to the scientific community. The first volume gives a brief history of the RFF and describes the RFF aircraft, logistical support requirements, navigational and operational practices, and communications capabilities. Typical flight patterns and aircraft capabilities are also described as an aid to researchers in planning particular experiments or data collection programs.

THE ESSA RESEARCH FLIGHT FACILITY: FACILITIES FOR AIRBORNE ATMOSPHERIC RESEARCH

Howard A. Friedman, Frank S. Cicirelli, and William J. Freedman

1. INTRODUCTION

The primary mission of the Research Flight Facility (RFF), under current U.S. Department of Commerce, Environmental Science Services Administration (ESSA) authority, is to provide airborne measurements in support of meteorological research programs within ESSA and the scientific community. These programs include research activities conducted by other U.S. Government agencies, universities, or research institutions, the National Science Foundation (NSF), and World Meteorological Organization (WMO) sponsored international programs, such as the International Indian Ocean Expedition (IIOE), Equatorial Atlantic Research (EQUILANT), Barbados Oceanographic and Meteorological Experiment (BOMEX), Project Stormfury, and others.

To effectively perform its overall mission, the RFF maintains a close and continuing working relationship with leaders of the scientific community. Scientific research objectives and operational capabilities are melded together. With this goal in mind, the RFF staff members meet with prospective researchers to jointly develop meaningful data collection and processing programs and to discuss current and future instrumentation capabilities.

The RFF staff provides coordination with other government agencies (e.g., Federal Aviation Agency, Federal Communication Commission, etc.) to help translate the researchers scientific requirements into a meaningful, operationally practical program.

RFF efforts to satisfy the needs of the researcher go beyond the collection of data and the coordination of programs. Information concerning the validity, calibration and other aspects of collected data are also provided. Assistance in data processing and interpretation is normally accomplished on an individual basis, as required.

1.1 Purpose

This report provides the meteorological and related scientific communities with a history and guide to the services and systems offered by the ESSA Research Flight Facility. The existence of the RFF is not solely justified by its data collection program alone. We believe that information, when provided as a ready reference for the researcher, can help to establish a level of confidence in the validity of the data supplied. We inform researchers of the following: services provided by the RFF, operational information serving as a guide to planning a data collection program with the RFF aircraft and instrumentation systems, types of data collected, quality-control and data reduction procedures, manufacturers' and field test information on the sensing systems, and calibration procedures and standardization.

In another report of this series, the researcher will be acquainted with the accuracy that may be expected in each parameter. A brief description of the theory of operation of each sensing system will be presented and an integrated picture developed following the sensor-derived information to the appropriate recording systems.

RFF data-processing requirements vary from customer to customer. There is, however, a certain minimum amount of data reduction necessary for data quality-control analysis and the conversion of the recorded data into meaningful "engineering" units. In general, the RFF provides this type of service for all customers. Data quality-control processing is performed for all collected data, to provide the researcher

and the RFF with complete information on each individual mission and data collection program. The researcher is then given a final "data-packet" that includes the original and processed data, and all of the information necessary to interpret the data from a systems standpoint. Data- processing and quality-control procedures are discussed in a subsequent report.

1.2 Objectives of the Research Flight Facility

The objectives of the Research Flight Facility are to meet the requirements of the Research Laboratories in ESSA and other government laboratories and government-supported research to the extent possible for atmospheric measurements from aircraft.

To accomplish its objectives, the RFF, with specially instrumented research aircraft, works closely with the meteorological community in developing and conducting flight programs to meet the needs for obtaining measurements from aircraft.

The RFF has three major branches - Instrument Development Branch, Operations Branch, and Systems Maintenance Branch.

1.2.1 Instrument Development Branch

The primary function of the Instrument Development Branch is to provide improved instrumentation for airborne meteorological measurements. It is engaged in the design, development, and evaluation of such instrumentation. The Instrument Development Branch maintains liaison with groups who have requirements for meteorological measurements from aircraft and are engaged in the development of airborne meteorological probes and sensing systems or both.

1.2.2 Operations Branch

The Operations Branch obtains meteorological and related measurements for research projects with the specially instrumented aircraft of the RFF. It is comprised of the Flight Data Acquisition Section and the Aircraft Operations Section.

The Flight Data Acquisition Section obtains and validates the meteorological data collected on research and other missions. The Aircraft Operations Section schedules flights and is responsible for air crew training. All RFF flight crew members participate in training programs supervised by the chief pilot and/or the chief navigator and approved by the chief of RFF.

1.2.3 Systems Maintenance Branch

The Systems Maintenance Branch provides aircraft and meteorological systems to meet the objectives of the Operations Branch. It is also responsible for the operation of home base of the RFF. Specifically, it organizes and directs the systems maintenance and modification programs for two major sub systems: (a) aircraft, and (b) meteorological instrumentation. The overall function also includes the organization and direction of the support services and administrative programs. The aircraft program includes maintenance and modification to aircraft and related systems. The meteorological systems maintenance, installation, and operation are supervised by the Instrument Engineering Section, a division of the Systems Maintenance Branch.

1.3 Future Goals

The RFF has set as its goal for the next several years a continuing program for the improvement of existing sensors and the development of new sensors and associated recording systems. In particular, it is directing its attention toward increasing the accuracy and reliability of all sensing and recording systems and better establishing the validity of data and calibrations through new instrumentation systems, including the following, which have been installed on one or more of the RFF aircraft: (a) stable (inertial) platform - used in conjunction with the (b) gust probe (integrated verticle acceleration system; (c) low-level Doppler measuring devices - used to obtain ground speed and drift angle measurements down to within

approximately 70 ft of the earth's surface (information used to compute the low-level wind); (d) digital recording system capability for the C-54 (DC-4) aircraft; (e) vapor flux measuring system, combining systems (a) and (b); and (f) increased facilities for cloud seeding. These are but a few of the "in-house" projects that are receiving attention at RFF.

Because dynamic and permanent changes in aircraft, instrumentation, or procedures can be expected from time to time, periodic reports will be published to reflect changes that affect the interpretation, validity, or accuracy of the data. In this manner, the researcher will be able to obtain information on the particular systems configuration applicable to his program.

2. HISTORY

For the Department of Commerce, the effort to collect meteorological data with instrumented airplanes had its beginning in 1956 under the National Hurricane Research Project (NHRP), now the National Hurricane Research Laboratory (NHRL). As a result of a series of devastating hurricanes that struck the east coast of the United States, Congress in 1955 gave the United States Weather Bureau responsibility for taking immediate action to set up a major research effort on hurricanes.

The Weather Bureau first used instrumented airplanes for hurricane research in 1956. Three aircraft (two WB-50 and one WB-47 aircraft) were furnished and operated by the U.S. Air Force, Air Weather Service. Meteorological equipment was installed and operated under the direction of the Weather Bureau. These aircraft were used during the 1956, 1957, and 1958 hurricane seasons; sensors employed were mostly of the type having some previous service history in other activities. During the 3-year program, considerable strides were made in melding together a variety of sensors and supporting instrumentation to yield meteorological data in digital form. This program, combined with the cumulative experience in the processing of aircraft data, provided a valuable foundation upon which the present RFF program has been built. (Hilleary and Christensen, 1957; Hawkins et al., 1962; Reber and Friedman, 1964). As collected data were analyzed, it became evident that additional investigative work was necessary to provide scientists with a more complete description of the hurricane. It was decided to continue the project with Weather Bureau aircraft and improved instrumentation.

Accordingly, two DC-6A/B airplanes were obtained in 1959 from Trans-Caribbean Airlines, and the U. S. Air Force transferred title of a B-57A aircraft to the Department of Commerce.

The three aircraft were put into service during the 1960 hurricane season.

On January 1, 1961, the Flight Group of the National Hurricane Research Project became the Research Flight Facility and directly responsible to the Office of Meterological Research of the Weather Bureau. By that time, it had become evident that the instrumented aircraft and capabilities of this group were suited to serve other meteorological research efforts, in addition to maintaining its support of the hurricane effort.

During the spring seasons of 1960 through 1963 and 1965 through 1967, RFF research aircraft were deployed to Oklahome City, Oklahoma, to serve the needs of the National Severe Storms Project (NSSP), now the National Severe Storms Laboratory (NSSL). Other projects were assigned to the RFF and further experience was gained (see table 1). As a result, the ability of the organization to serve a rather wide range of meteorological and other research efforts was established.

In 1961, the original group of three airplanes was augmented by the acquisition of a Douglas B-26C. The aircraft, equipped with analog and photopanel recording systems, was originally instrumented to serve the severe local storms research effort of NSSP. The B-26C was operated by the RFF from 1961 to 1963 and then was retired from service.

In 1962 an experimental drone program was conducted in collaboration with the U.S. Navy, whose purpose was to fly drone airplanes into thunderstorms by radio direction from the RFF DC-6A/B aircraft telemetering data back to the "mother ship" (Ruskin, 1963).

In 1963, an F-11A (Tiger) jet-fighter airplane was obtained on a temporary loan from the U.S. Navy to meet the needs for an airplane that could obtain turbulence data and other measurements under thunderstorm conditions. The F-11A aircraft was

Table 1. Activities Supported by Research Flight Facility, 1960-1969

Activity	Investigators	Aircraft
Air Resources Laboratory	Dr. L. Machta	DC-6A/B, C-54(DC-4)
Argonne National Laboratory	Dr. J. Kastner	DC-6A/B
Army Signal Corps		B-57A
Atmospheric Physics and Chemistry Laboratory	Dr. H. Weickmann	DC-6A/B
U.S. Atomic Energy Commission	Mr. P. Raft Dr. T. Crawford	DC-6A/B, C-54(DC-4)
BOMEX	Dr. B. Davidson Dr. J. Kuettner Dr. J. Holland Dr. J. Charney	DC-6A/B, C-54(DC-4)
CABRIOLET	Dr. T. Crawford	C-54(DC-4)
Cloud Physics Research	Dr. J. Simpson	DC-6A/B, B-57A
Cold Low Study	Mr. N. Frank	DC-6A/B, B-57A, C-54(DC-4)
Colorado State University	Dr. H. Riehl	DC-6A/B, B-26C
Bureau of Reclamation, U.S. Department of the Interior	Dr. A. Kahan	DC-6A/B, B-57A, C-54(DC-4)
Eastern Caribbean Cooperative Reconnaissance Organization	Dr. R. C. Gentry	DC-6A/B
EQUALANT	Dr. H. Johnson	DC-6A/B
Florida State University	Dr. C. Jordan	DC-6A/B, B-57A, C-54(DC-4)
International Indian Ocean Expedition	Dr. C. Ramage	DC-6A/B, B-57A, B-26C
Jet Stream Project	Dr. H. Riehl	DC-6A/B, B-57A
Lake Effect Snow Project	Dr. H. Weickmann	DC-6A/B
Mountain Wave Project	Dr. J. Kuettner	B-57A
National Hurricane Research Laboratory	Dr. R.C. Gentry	DC-6A/B, B-57A, C-54(DC-4)

Table 1. (Continued)

Activity	Investigators	Aircraft
National Severe Storms Laboratory	Dr. E. Kessler	DC-6A/B, B-57A, B-26C,F-11A
New York University	Dr. J. Spar	DC-6A/B, C-54(DC-4)
Operational (Synoptic) Missions (miscellaneous)	Dr. G. Dunn, Dr. R. H. Simpson, NHC, Mr. S. Simplicio, ERHQ/ESSA	DC-6A/B, B-57A, C-54(DC-4) B-26C
Project Mercury	Mr. J. Gulick	DC-6A/B
Project Stormfury	Dr. J. Simpson (thru 1967;) Dr. R. C. Gentry (1967 following)	DC-6A/B, B-57A, C-54(DC-4)
Research Flight Facility	Mr. H.J. Mason, Jr.	DC-6A/B, B-57A, C-54(DC-4) B-26C, F-11A, Drone
Sea Air Interaction Laboratory	Dr. J. McFadden	DC-6A/B, C-54(DC-4)
Sea Breeze	Mr. N. Frank	DC-6A/B
Sea Breeze (Part of IIOE)	Mr. J. Nicholson	DC-6A/B, B-57A, B-26
Snow Project (East Coast Cyclone Study)	Dr. J. Spar Mr. S. Simplicio	DC-6A/B, C-54(DC-4)
Storm Cloud	Dr. E.P.McClain	DC-6A/B, B-57A, B-26C
Sub-Cloud (mixing layer) Investigation	Dr. H. Riehl	DC-6A/B, B-26
U. S. Air Force (Research and Development)		B-57A
University of Chicago	Dr. T. Fujita	DC-6A/B
University of Miami	Dr. G. Ostlund	DC-6A/B, C-54(DC-4), B-57A
University of Stockholm	Dr. W. Bischof	DC-6A/B
University of Washington	Dr. R. Fleagle	DC-6A/B, B-57A, B-26C

operated in Oklahoma during the 1964 thunderstorm season in support of NSSL.

Recently, the organization has conducted research flights over the North and South Atlantic areas as far east as Africa in support of meteorological satellite data evaluation studies.

In 1963 the RFF undertook its first major overseas assignment. For approximately 3 months, research aircraft* and crews were temporarily based at Bombay, India, to support the meteorological program of the International Indian Ocean Expedition (wet monsoon period). Some 420 hours of research flying was spent over the Bay of Bengal, the Arabian Sea, and the equatorial belt extending from the east coast of Africa to Singapore. A similar operation was carried out in early 1964 when, during the winter monsoon period, the RFF deployed two DC-6A/B aircraft to Bombay, India.

In 1965, a C-54 (DC-4) aircraft was obtained from the U.S. Air Force to fill the gap left by retirement of the Douglas B-26C. The same year, as part of the Department of Commerce reorganization program, the RFF was transferred from the Office of Meteorological Research and became a part of the Environmental Research Laboratories, which is directly responsible to the Administrator, Environmental Science Services Administration (ESSA).

The RFF is currently engaged in a protracted program to remodel its aircraft to provide additional services to the scientific community at large. This program will also provide additional cloud-physics measurement capabilities.

A more detailed description of RFF supported research is given in the appendix.

---

*The RFF deployed the following four aircraft to Bombay, India, in support of the IIOE (wet monsoon period) program: two DC-6A/B, one B-57A, and one B-26C.

3. RFF AIRCRAFT

The RFF fleet is comprised of the following four aircraft:

Type	Registration No.
DC-6A/B	N6539C
DC-6A/B	N6540C
B-57A	N1005
C-54 (DC-4)	N91282

This section will acquaint the reader with the characteristics of each aircraft's design, its operation and capabilities, crew and flight equipment involved, and certain practical

Figure 1. RFF DC-6 A/B aircraft.

limitations of its use in research and operational data collection programs or both (see tables 2,3,4 at the end of section).

3.1 RFF DC-6A/B Aircraft

3.1.1 Design Characteristics

The RFF DC-6A/B aircraft (fig. 1) designed and manufactured by the Douglas Aircraft Company, is a long-range, four-engine (reciprocating type) land plane. It has hot air anti-iced wing and empennage (leading edges), a complete cabin control system consisting of two Douglas superchargers, a heater, and an air cycle refrigeration unit.

Engines are Pratt and Whitney R-2800 (piston displacement) CB-17 air cooled, 18 cylinder, incorporating a single-stage two-speed blower and three-bladed Hamilton standard propellers (No. 43E60, blade No. 6895-8). These engines develop 10,000 combined horsepower at takeoff with 108/135 octane fuel (brown). Because the 108/135 octane (brown) fuel is not readily available commercially, the RFF uses the next higher performance rated fuel, 115/145 octane, which is dyed purple for identification, along with a water injection system (ADI) to control combustion. The jet stack exhaust arrangement utilizes the engine exhaust velocities to augment the engine's propulsive thrust, yielding an additional 400 hp impetus (more effective at higher speeds).

Fuel capacity is 5512 gal; 115/145 octane grade fuel is used, and CB-17 ratings apply. ADI (anti-detonant injection), a water methyl-alcohol mixture, 50/50 by volume, is used with the 115/145 octane fuel to increase brake horsepower by controlling combustion. If 100/130 octane fuel is used, a restricted performance, CB-16, would apply. The maximum gross weight allowable would also be reduced from 107,000 to 103,800 lbs.

Oil is grade 1120. Either ashless dispersant or non-detergent type is used for all-weather operations (33 gal per engine).

Weights are

Maximum (takeoff) gross weight	107,000 lbs.
Maximum landing weight	88,200 lbs.
Maximum zero fuel weight	83,200 lbs.
Empty weight of aircraft	72,000 lbs.

Dimensions are

Wing span	117 ft 6 in.
Fuselage length	106 ft 6 in. (not including nose boom or tail radome).
Maximum height	29 ft 1 in.
Wing dihedral	7°.

3.1.2 Operational Limitations

Operational Crew. All flights (operational and/or research) require a minimum flight crew of pilot, copilot, and flight engineer; all over-water flights require a navigator to augment the minimum crew.

Scientific Support Crew. Research and/or synoptic missions must include a lead meteorologist, who serves as flight director, two or more electronics technicians, and a radio operator (see sec. 5). An assistant meteorologist is also part of the support crew whenever practicable. The user (research project) is encouraged to augment the support crew by providing one or more project scientists to accompany each flight (see sec. 5).

Air Speeds. The maximum cruising speed for flights from sea level up to 17,000 ft (pressure) altitude is 248 knots (true air speed). This figure is reduced by approximately 5 knots per 1000 ft for flights at altitudes greater than 17,000 ft.

Altitude. Maximum altitude for the RFF DC-6A/B is 25,000 ft (pressure altitude). This is exclusive of CAR (civilian air regulations) oxygen requirements. The maximum altitude

the aircraft can maintain a 10,000-ft cabin altitude is 23,000 ft (pressure altitude), with a cabin pressure differential of 4.16 psi.

Cross-Wind Component. The maximum cross-wind component in which this airplane has been tested for takeoff or landing is 26 knots (measured at 50 ft above the ground); consequently, in determining the effective takeoff and landing runway lengths, a cross-wind component greater than 26 knots may not be used.

Icing Conditions. The RFF DC-6A/B aircraft is limited to operation in light icing conditions.

Structural (Acceleration) Limits. A limit load factor of 2.5 g applies for flaps-up operation, while in a flaps-down configuration the limit load factor drops to 2.0 g.

Performance Requirements. The airplane's performance and the route it flies are closely related. The aircraft's maximum weights allowable for minimum safety standards and for any given use are clearly defined. Various emergency conditions have been considered in establishing these standards; the condition that is of primary concern and interest is engine failure.

Runway Requirements. Runway length must be sufficient to permit a takeoff to be either continued or aborted in the event of an engine failure during the takeoff sequence. It is mandatory that in the landing configuration the aircraft can be brought to a stop from a 50-ft height within 60 percent of the effective length of the landing area.

In the configuration corresponding to each important operating condition near the airport, enroute to destination, or during research mission, the maximum operating weights are defined by certain rates of climb (for emergencies with one engine inoperative). These minimum rates of climb vary, for the most part, as the stalling speed squared and, therefore,

tend to promote the retention of low stalling speeds or demand a rapid increase in performance as the stalling speed is increased.

The runway length required for takeoff is based on two speeds: V_1, the critical engine failure speed, and V_2, the minimum takeoff climb speed. The runway length must be the larger of either (a) the distance required to accelerate to V_1 and be able to stop on the runway, or (b) the distance required to accelerate to V_1 and then, with the most critical engine inoperative, accelerate from V_1 to V_2 and a height of 50 ft above the runway on a (meteorologically) standard day.

To determine the minimum runway length for a takeoff at maximum gross weight, the following items must be taken into consideration: (a) aircraft gross weight, (b) accelerate-stop distance, (c) temperature accountability, (d) humidity accountability, (e) runway slope corrections, (f) wind corrections, (g) field elevation, and (h) second segment climb. Items (a) through (g) are essentially self-explanatory. The second segment climb requirement, item (h), however, is designed to: (1) provide sufficient climb for maneuvering and returning to the field after takeoff, and (2) require greater performance from airplanes with high wing loadings.

In general, any runway less than 6500 ft at sea level is not practical for research/operational missions. If the field elevation is 5000 ft or higher, the second segment climb consideration becomes a limiting factor for the gross weight of the aircraft.

The landing distance requirements for the DC-6A/B is a function of both the air run distance from a 50-ft height to runway contact and the ground run distance from contact to stop.

In order to provide a margin of safety to account for

nonstandard atmospheric conditions and pilot technique, CAR requires that landing distance be less than or equal to 60 percent of the minimum effective landing runway length at regular, provisional, and refueling airports. At alternate airports, the requirement is that landing distance be less than or equal to 70 percent of the minimum effective landing runway length.

Cruise Control. Aircraft engine calibration, fuel flow, and operating limitations are provided for RFF by the Pratt and Whitney Company with specific instructions for the R-2800 CB16/17 engine. The revolutions per minute (RPM), brake mean effective pressure (BMEP),BMEP/Drop, and fuel flow settings are listed on cruise operating charts. This information then establishes the required brake horse power (BHP) for the weight-altitude bracket in accordance with engine limitations specified by the manufacturer.

Flight Planning (DC-6A/B). Based on various limitations of structural or performance weights, route variables, and type of cruise (power) settings, this section provides information necessary to determine appropriate flight time, fuel required, and available cabin load for any flight.

Fuel burn-off tables are used to determine the quantity of fuel required. A good rule of thumb, however, is to use 600 gal for the first hour of operation (this includes takeoff power, maximum except for takeoff power, METO, and normal climb power), and 400 gal for every hour thereafter at normal cruise power. (See table 2.)

Long-range cruise power settings enable the DC-6A/B to fly a maximum of 13 or 14 hours (with no reserve fuel). Maximum range under optimum conditions is approximately 2600 n mi; however, a more realistic figure would be closer to 2400 n mi. (no wind conditions).

The two DC-6A/B aircraft (N6539C and N6540C) are the primary work horses of the RFF. They have proven their reli-

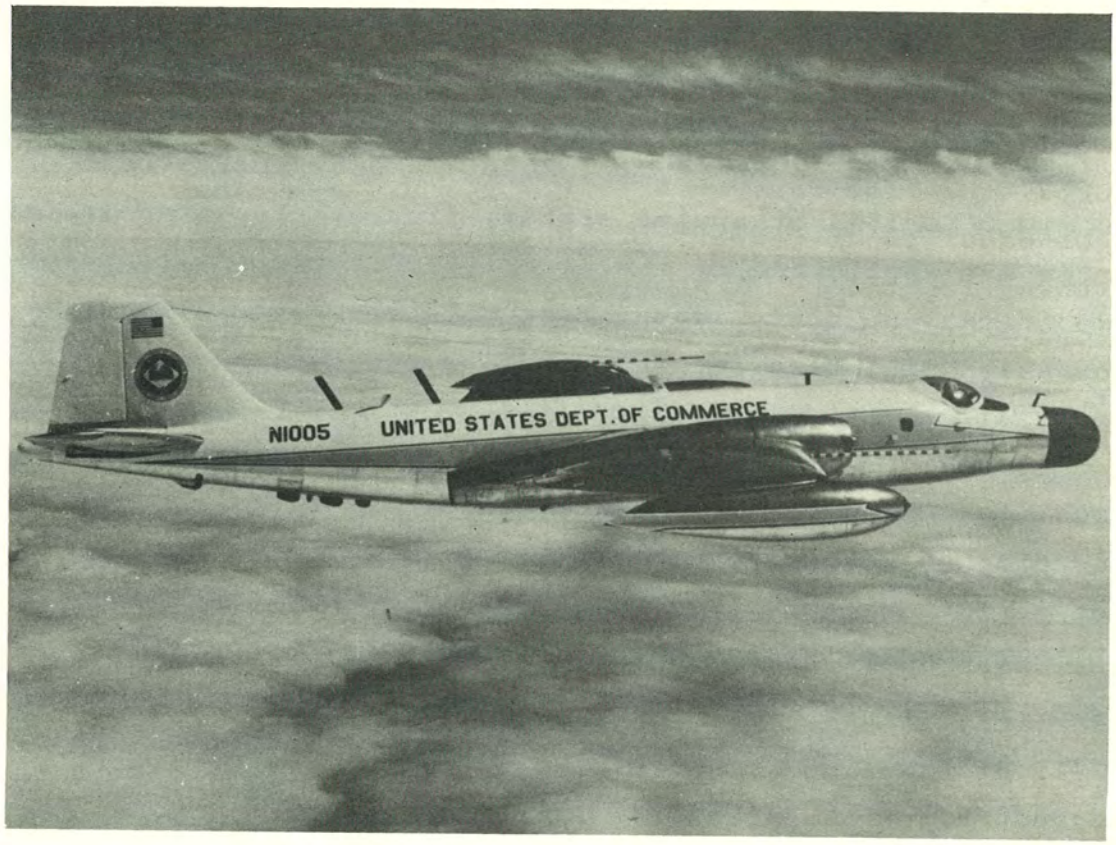

Figure 2. RFF B-57A aircraft.

ability by flying into virtually all types of meteorological conditions. (See table 3 for a summary of significant operational information.)

3.2 RFF B-57A Aircraft

3.2.1 Design Characteristics

The RFF B-57A (fig. 2), manufactured by the Martin Company, is primarily a high-altitude twin jet reconnaissance aircraft that is used by the RFF for collection of meteorological data at altitudes between 30,000 and 43,000 ft. The all-metal turbojet propelled monoplane has a rotary bomb door that houses much of the RFF electronic and meteorological equipment in its current configuration (prior to June 1969).

It is currently undergoing a modification that will extend its range capability. In the modified configuration

(expected completion June 1969), the electronics and meteorological equipment will be removed from the rotary bomb door and relocated. A fuel tank will be installed in the bomb-bay area. Range capability is expected to be increased to 1900 mi. (Unless otherwise stated, figures presented in this section are applicable to the aircraft characteristics prior to modification, since actual test data are not available. Information will be presented after some experience has been gained with the modified aircraft.)

The cabin, which may be pressurized at altitudes above 10,000 ft, houses the crew stations for pilot and navigator/meteorologist, who also serves as the flight director. The pilot's station contains all equipment and controls necessary to flight, while the navigator/meteorologist's position, located aft of the pilot, contains navigational equipment and meteorological instrumentation controls and read-outs (see sec. 5).

Pilot and navigator/meteorologist have ejection seats that are covered by a jettisonable transparent canopy and solid hatch, respectively, for emergency evacuation.

Main fuel tanks are located in the center section of the fuselage. The bomb door is located on the underside of the fuselage. In the unmodified configuration, the rotary bomb door contains approximately 80 percent of the meteorological electronic equipment. The door may be lowered or rotated to a semivertical position for easy access and ground maintenance. The aft section of the fuselage contains the remainder of the electronic support and meteorological equipment and a stowage area for miscellaneous B-57A ground handling equipment.

Wings of the aircraft are of the full-cantilever type containing the leading-edge fuel tanks, inboard and outboard split-type flaps, dive brakes, and provisions for wing tip tanks. The aircraft has no anti-icing equipment.

Engines used on the RFF B-57A aircraft are two Wright J-65-W-5B axial flow turbojets rated at 7220 lbs of static thrust (per engine) for a tail pipe temperature of 620°C. The engine consists of 13 compressor stages and 2 turbine stages. No after-burner or water injection is used to augment the rated engine thrust. Air is bled from the engine at the 13th compressor stage for the cabin conditioning system, fuel transfer from the wing-tip tanks, and for pressurization of the aircraft's main hydraulic reservoir. The engines do not have inlet screets or anti-icing equipment.

Fuel capacity is 2892 (usable) gal (unmodified) and 3440 (usable) gal (modified). Types of fuel that can be used and their limitations are: (1) JP-4 fuel whose freezing point is -76°F with altitude unrestricted (up to service ceiling); (2) JP-1 and Jet-A fuel that both have a freezing point of -40° F and maximum altitude restricted to approximately 30,000 ft; (3) Jet- A1 and Jet-B fuel, which have freezing points of -56°F and -57°F, respectively, and maximum altitude is restricted to approximately 35,000 ft. The amounts may vary somewhat depending upon power settings used and altitudes flown but the following shows rate of fuel consumption:

Time	Quantity
1st hour (taxi, run-up and climb)	6,000 lbs.
2nd hour (cruise)	4,000 lbs.
3rd hour (cruise)	4,000 lbs.

(plus 1/2 hour and 2,000 lbs for landing).

Oil for the B-57 is a synthetic base oil (Spec. No. MIL-7808-E or MIL-7808-C). Commercial types that conform to the above are also compatible (3 gal per engine).

Weights are

Maximum takeoff gross weight	48,000 lbs (unmodified), 52,000 lbs (approx. with modification).
Maximum landing gross weight	No restriction.

Dimensions are

Wing span	64 ft.
Length	65 ft, 6 in.
Height (to top of fin)	15 ft, 7 in.
Tail span	27 ft, 10 in.
Fuselage ground clearance (lowest point, at maximum gross weight)	19.2 in.
Tip tank to ground clearance (at maximum gross weight)	5 ft, 5 in.

3.2.2 Operational Limitations

Operational Crew. B-57A flights require a minimum flight crew of the pilot and navigator/meteorologist (for all over-water and research flights). A navigator may not be required in certain instances for ferry and test flights.

Scientific Support Crew. The navigator/meteorologist serves as the flight director and performs the functions of the support crew. No space is provided for technicians or other support crew members.

Air Speed. The maximum cruising speed for flights at any operational altitude is 350 knots (indicated air speed).

Altitude. The maximum operating altitude for the RFF B-57A is 43,000 ft (pressure altitude). The pilot and B-57A is navigator/meteorologist use oxygen at all flight levels.

Cross-Wind Component. The maximum cross-wind component for takeoff or landing is 25 knots.

Icing Conditions. No anti-icing equipment is available on the RFF B-57A aircraft; therefore, no attempt should be made to fly at any level when moderate or heavy icing conditions are forecast. Ice can build up on the engine's inlet guide vanes when the aircraft is flown through weather where icing conditions prevail. Ice buildup may take place even when there is no visible evidence of ice on the aircraft.

Such icing restricts the flow of inlet air, thereby causing a loss of thrust and an accompanying rapid rise in exhaust gas temperatures. Attempts to control the loss of RPM by delivering more fuel to the engine will only aggravate the condition. Under severe icing conditions, engine failure can occur in less than 4 min. Icing conditions should be avoided when planning flight patterns with the RFF B-57A aircraft.

Structural (Acceleration) Limits. The B-57A has a relatively light wing-loading and high load factor strength and, as a result, is extremely maneuverable. In the unmodified configuration, the aircraft has a maximum load factor of 5 g (without wing-tip tanks) at a gross weight of 37,600 lbs. At higher weights, this load factor is reduced linearly and is equal to 4 g at 44,000 lbs with full wing-tip tanks. The maximum acceleration is 4 g at 53,077 lbs (war time maximum gross weight). With empty wing-tip tanks, these limits are reduced to 4 g at 48,000 lbs. Indicated airspeed is also a factor that must be taken into consideration when computing the allowable factor. These figures are not expected to change radically after the modification. (For more detailed information see Flight Manual, USAF Series RB-57A Aircraft, T.O. 1B-57(R)A-1.)

Performance Requirements. When the air is turbulent, even moderately so, speeds in excess of 250 knots (indicated air speed) at low levels can subject the airplane to loads that will rapidly approach the maximum allowable limits. When such conditions are encountered during research/operational missions, the indicated air speed is normally reduced below 250 knots.

Runway Requirements. At maximum gross weight on a standard meteorological day, the minimum runway length is 6,500 ft.

Field elevation and nonstandard meteorological conditions are also factors for computing the runway requirements. Figures for the modified aircraft are not currently available; however, those given above are not expected to change materially.

Cruise Control. The RFF B-57A aircraft is flown in accordance with specifications supplied by the manufacturer. Fuel consumption rates are given above.

Flight Planning. Fuel consumption and type used, flight altitude and range combine to determine flight duration. These items have been previously discussed in this section. Planning for jet aircraft operations is more critical than for other aircraft, due primarily to the low fuel reserve maintained for maximum duration missions and the need for additional reserves to alternate airports in the event of poor terminal weather conditions. The expected range of the RFF B-57A with modifications is approximately 1900 n mi with landing reserve fuel of about 40 min. For planning purposes, a 4-hour, 50-min mission with 950-n mi radius of action can be expected. (See table 3 for a summary of significant operational information.)

3.3 RFF C-54 (DC-4) Aircraft

3.3.1 Design Characteristics

The RFF C-54 (DC-4) (fig. 3) manufactured by the Douglas Aircraft Company is a long-range, four-engine (reciprocating type) land plane. It was originally designed for long-range cargo, troop, or personnel transport. In its current configuration, the aircraft is used for research/operational missions and as a test-bed for developmental instrument and recording systems.

The economy of operating the C-54(DC-4) makes it desirable for limited-budget data collection programs that do not require a high performance airplane.

Figure 3. RFF C-54(DC-4) aircraft.

The operating altitude and range of the C-54(DC-4) are essentially similar to those of the DC-6A/B; differences are (a) slower speed, (b) unpressurized cabin, and (c) type of de-icing equipment.

If the maximum cargo load is restricted to 18,000 lbs (regardless of how much fuel is carried), the structural stability of the aircraft will be maintained and there will be virtually no restrictions or cruise speeds.

Engines are four 14-cylinder, twin-row, air cooled, Pratt and Whitney (R-2000-4). Each engine incorporates an integral single-stage, two-speed supercharger and develops 1450 BHP (each) takeoff power at sea level.

Fuel capacity is 3540 (usable) gal. The following fuels may be used on the C-54(DC-4) without any restrictions: (a) 100/130 octane grade (green) fuel, (b) 108/135 octane grade (brown) fuel, and (c) 115/145 octane grade (purple) fuel.

Oil is grade 1120. Either ashless dispersant or non-detergent type is used for all-weather operations (25 gal per engine).

Weights are

Maximum take-off gross weight	73,000 lbs.
Maximum landing weight	63,500 lbs.

Dimensions are

Wing span	117 ft 6 in.
Length	93 ft 10 in.
Length (including radome nose)	94 ft 6.75 in.
Height	27 ft 6.3 in.
Stabilizer span	39 ft 6 in.

3.3.2 Operational Limitations

Operational Crew. Accommodations are provided for a regular crew of five members: pilot, copilot, flight engineer, radio operator, and navigator.

Scientific Support Crew. On normal research operational flights, stations are also provided for a lead meteorologist and an assistant, electronic technicians, and visiting scientists. Transport seats are available to carry 20 additional persons.

Air Speeds. The maximum cruising speed for flights from sea level up to the service ceiling is 217 knots (indicated air speed).

Altitude. Maximum operating altitude for the RFF C-54 (DC-4) is 24,000 ft (pressure altitude). The aircraft is not pressurized and oxygen is required for all crew and passengers when sustained flights above 10,000 ft are made.

Cross-Wind Component. The maximum cross-wind component for takeoff or landing is 26 knots.

Icing Conditions. The RFF C-54 (DC-4) aircraft is limited to operation in light icing conditions.

Structural Limits. A limit-load factor of 2.5 g applies for flaps-up operation, while in a flaps-down configuration, the limit-load factor drops to 2.0 g.

Performance Requirements. The airplane's performance requirements are essentially the same as those given for the RFF DC-6A/B aircraft (see sec. 3.1.2).

Cruise Control. Aircraft engine calibration, fuel flow, and operating limitations are provided by the Pratt and Whitney Company, with specific instructions for the R-2000-4 engine. The RPM, manifold pressure, and fuel flow settings are listed on cruise operating charts. This information establishes the required BHP for the weight-altitude bracket, in accordance with engine limitations specified by the manufacturer.

Flight Planning. Information for C-54 (DC-4) flight planning is essentially similar to that given for the DC-6A/B aircraft (see sec. 3.1.2) with the following exceptions: 350 gal of fuel are used for the first hour of operation (this includes takeoff power, METO power, and normal climb power). Between the first and eighth hour of flight, 220 gal of fuel are used per hour; after 8 hours of flight, the consumption rate drops to 200 gal per hour (see table 2). Use of long range cruise power settings enables the C-54 (DC-4) to fly for up to 17 hours. Maximum range under optimum conditions is approximately 2900 n mi; however, a more realistic figure would be close to 2700 n mi. (See table 3 for a summary of significant operational information.)

Table 2. RFF Aircraft Fuel and Oil Requirements

Aircraft and Registration Number	Oil Type	Oil Capacity	Fuel Type	Maximum Usable Fuel Capacity
DC-6A/B N6539C	1120 grade[1]	33 gal per engine	115/145 octane[2] with ADI[3]	5512 gal
DC-6A/B N6540C	1120 grade[1]	33 gal per engine	115/145 octane[2] with ADI[3]	5512 gal
C-54(DC-4) N91282	1120 grade[1]	25 gal per engine	100/130 octane (green) 108/135 octane (brown) 115/145 octane (purple)	3540 gal
B057A N1005	Synthetic Base (Mil-7808-E[5] or Mil-7808-C)	3 gal per engine	JP-4 JP-1 and Jet-A Jet-A1 and Jet-B[4]	2892 gal 3440 gal[6]

[1] Either ashless dispersant or nondetergent type is used for all weather operations.

[2] CB-17 ratings apply. If 100/130 octane fuel is used CB-16 (restricted performance) ratings would apply. The maximum gross weight allowable would also be reduced from 107,000 lbs to 103,800 lbs (see table 4).

[3] A.D.I. antidetonation-injection is a water/methanol mixture, 50/50 by volume to increase brake horsepower by controlling combustion.

[4] JP-4 fuel has a freezing point of -76°F; altitude is unrestricted (up to service ceiling).
JP-1 and Jet-A fuel have a freezing point of -40°F; maximum altitude is restricted to approximately 30,000 ft.
Jet-A1 and Jet-B fuel have freezing points of -56°F and -57°F, respectively; maximum altitude is restricted to approximately 35,000 ft.

[5] Commercial types that conform to these specifications are also compatible.

[6] After modification.

Table 3. Use of RFF Aircraft With Operating Limitations

Type of Aircraft	DC-6A/B	DC-6A/B	C-54(DC-4)	B-57A[9]
Registration Number	N6539C	N6540C	N91282	N1005
T/O runway length required at maximum gross weight	6000 ft	6000 ft	4300 ft	6500 ft
Landing distance over a 50 ft obstacle at landing gross weight	3200 ft	3200 ft	2800 ft	6500 ft
Maximum cruise speed at optimum altitude and weight	248 kt[1]	248 kt[1]	217 kt[2]	350 kt[2]
Long range endurance at optimum altitude with reserve	12 hrs	12 hrs	17 hrs	4 hr 50 min
Service ceiling	23,000 ft[3]	23,000 ft[3]	20,000 ft[4]	43,000 ft
Maximum mission radius with no time on station	1300 n mi	1300 n mi	1350 n mi	950 n mi
Mission radius with time on station[5]	1100 n mi	1100 n mi	1190 n mi	535 n mi
Maximum range with reserve[6]	2600 n mi	2600 n mi	2700 n mi	1900 n mi
Rate of climb at sea level	600 ft/min	600 ft/min	500-700 ft/min	1500 ft/min
Climb time	45 min[7]	45 min[7]	45 min[7]	30 min[8]

[1] True air speed.
[2] Indicated air speed.
[3] 1800 ft is normally considered to be the highest functional altitude.
[4] The C-54(DC-4) is unpressurized. Oxygen is required for crew and passengers above 10,000 ft.
[5] 2 hrs on station time.
[6] At altitude.
[7] Sea level to 18,000 ft (not at maximum gross weight).
[8] Sea level to 40,000 ft.
[9] In the modified configuration.

Table 4. RFF Aircraft Weights and Dimensions

Type of Aircraft	DC-6A/B	DC-6A/B	C-54(DC-4)	B-57A
Registration Number	N6539 C	N6540 C	N91282	N1005
Maximum takeoff gross weight	107,000 lbs[1]	107,000 lbs[1]	73,000 lbs	48,000 lbs[2]
Maximum landing gross weight	88,200 lbs	88,200 lbs	63,500 lbs	no restriction
Maximum zero fuel weight	83,200 lbs	83,200 lbs	58,000 lbs	not applicable
Empty weight of aircraft	72,000 lbs	72,000 lbs	46,775 lbs	29,024 lbs
Maximum length	106' 6"[3]	106' 6"[3]	93' 10"[4]	65' 6"
Maximum height	29' 1"	29' 1"	27' 6.3"	15' 7"
Wing span	117' 6"	117' 6"	117' 6"	64'
Stabilizer span	46' 6"	46' 6"	39' 6"	27' 10"

[1] 103,800 lbs is maximum takeoff gross weight, if 100/130 octane fuel is used (see table 2).

[2] 2,000 lbs approximately with new modification.

[3] Does not include boom and tail radome.

[4] Including radome nose 94' 7".

4. LOGISTICAL SUPPORT REQUIREMENTS FOR LIMITED STAGING OPERATIONS

Quite often, the RFF is called to perform successive research/operational missions from advanced field or staging locations. The amount of preplanning for logistical support of the aircraft during these operations varies with the nature and duration of the field operation and the type of facilities available at the field site or base. Obviously, requirements for the International Indian Ocean Expedition (IIOE), which called for the RFF aircraft to stage out of Bombay, India, for approximately 3 months, would be more rigorous than those for the SNOW Project, in which only one aircraft was to be based in New York (LGA) with normal aircraft support services commercially available.

The logistical support requirements presented here are not meant to be typical of a protracted operation in a relatively difficult area - such as IIOE, nor of an operation from a large commercial airport where most normal support services can be expected to be available - such as New York. They are, however, typical of the support necessary for the RFF whether provided by a military installation or provided for themselves in the form of "fly-away kits."

4.1 Food and Lodging

Suitable accommodations and eating facilities are proposed for approximately 34 civilians.

4.2 Ground Support Equipment

Ground support equipment provided consists of (1) three power units, type MD-3(28 VDC, 400 Hz, 3-phase 115V), and (2) routine aircraft support.

4.3 Fuel/Oil

Fuel and oil are required as follows:

(1) DC-6

(a) AVGAS 115/145; 100,000 gal.

(b) Oil AD-1120 grade; 960 gal.
(Other grades may be acceptable but will limit altitude capabilities of the aircraft; see sec. 3.2.1.)

(3) C-54(DC-4)

(a) AVGAS 100/130; 26,000 gal.

(b) Oil AD-1120; 480 gal.

4.4 Transportation

Transportation normally required consists of (1) a one-half-ton pickup truck (or suitable substitute), (2) one stationwagon (or suitable substitute), (3) necessary crew (approximately 34) transportation.

4.5 RFF Instrument and Aircraft Spares

RFF will determine the requirements for instrument and aircraft spares. Normally, these requirements are functions of the nature and duration of the mission, the location and availability of required spare parts (locally), or the associated logistical support connections with the main base of operations and supply (usually Miami) or both.

5. RFF AIRCRAFT NAVIGATIONAL AND OPERATIONAL PRACTICES

5.1 General Introduction

From an operational point of view, research missions involving the RFF aircraft are quite complex. After a data collection experiment has been designed to accomplish the researcher's scientific goals, the RFF must translate these objectives into a workable operational program.

Coordination with the Federal Aviation Agency (FAA) for special handling requirements, such as control, permission to release dropsondes, and obtain area or sector reserved air space, is of paramount importance to the overall success in the operational performance of the mission.

This chapter briefly discusses navigational and operational practices of the RFF aircraft. Logistical support for the aircraft on staging operations, another important factor in the overall planning stages of a research mission, was covered in section 4.

5.2 Navigational Practices

Routine navigational problems encountered by the RFF during mission planning and operations stages are treated in accordance with standard USAF procedures and are defined under existing regulations (FAA, ICAO).

On all research or operational missions, at least one qualified USAF and/or FAA certified chief navigator is an integral part of the flight crew. In addition to providing position and other information required by the pilot, the navigator aids the flight director (lead meteorologist on the aircraft) in successfully carrying out the scientific mission requirements. Research flights often involve complicated deviations from preselected patterns. The navigator's services are indispensible in helping to provide the researcher

with an extra margin of fleixibility in the preselection of patterns, when such flexibility is necessary. Navigators on the RFF aircraft are often called to coordinate the movements of other participating aircraft during multiple (agency) aircraft research missions.

Instrumentation and navigational techniques available to the navigator on the RFF aircraft are given in table 5. Information concerning techniques of using these instruments and/or about the instruments themselves is beyond the scope of this publication; such data may be found in standard references concerning air navigation. The navigator's station on RFF DC-6A/B, and C-54 (DC-4) aircraft is shown in figures 4 and 5a and b, respectively. The navigator/meteorologist position on the B-57A is shown in figures 6a and b.

Since its inception, special navigation-oriented problems have been encountered by the RFF. Many of these were solved by trial and error methods, and empirically developed techniques have resulted; these techniques are now put into practice during RFF-supported missions.

In general, hurricane research and reconnaissance patterns provide the greatest challenge for the navigator. Operating over remote oceanic areas, often in areas of unreliable or unavailable LORAN reception, and unable to use celestial or pressure pattern techniques, the navigator is hard pressed to determine his position accurately (for research purposes, position must be accurately known).

Most hurricane research missions also require the navigator to determine his track with respect to the storm center. When radar coverage of a storm is feasible, the navigator is able to use radar effectively to position his track correctly with respect to the moving storm center. The radar operator's

Table 5. RFF Aircraft Navigational Equipment and Techniques

	Aircraft*		
	DC-6A/B	B-57A	C-54(DC-4)
Instrument System:			
Doppler navigator (AN/APN-82)	x	x	x
Doppler system (AN/APN-153)	x	x	x
True airspeed indicator	x	x	x
X-Y position plotter[1]	x		x
Accurate time (GMT reference)	x	x	x
Absolute (radar) altitude	x	x	x
Sensitive pressure altimeter	x	x	x
Standard aircraft magnetic compass	x	x	x
J-1 flux-gate compass system			x
C-1 flux-gate compass system	x	x	
N-1 compass system (primary)	x	x	x
Directional gyro	x	x	x
Drift (sight) meter	x		x
LORAN	x		x
ADF	x	x	x
VHF	x	x	x
UHF	x	x	x
HF	x	x	x
LF	x	x	x
Celestial	x		x
Radar	x	x	x
DME	x	x	x
VOR	x	x	x
TACAN			x
Navigational Techniques:			
Pressure pattern navigation	x	x	x
CONSOLAN	x	x	x
DR	x	x	x
Pilotage	x	x	x

* "X" indicates that aircraft is equipped with system.

[1] Optional use only. Information is provided by Doppler system (AN/APN-82).

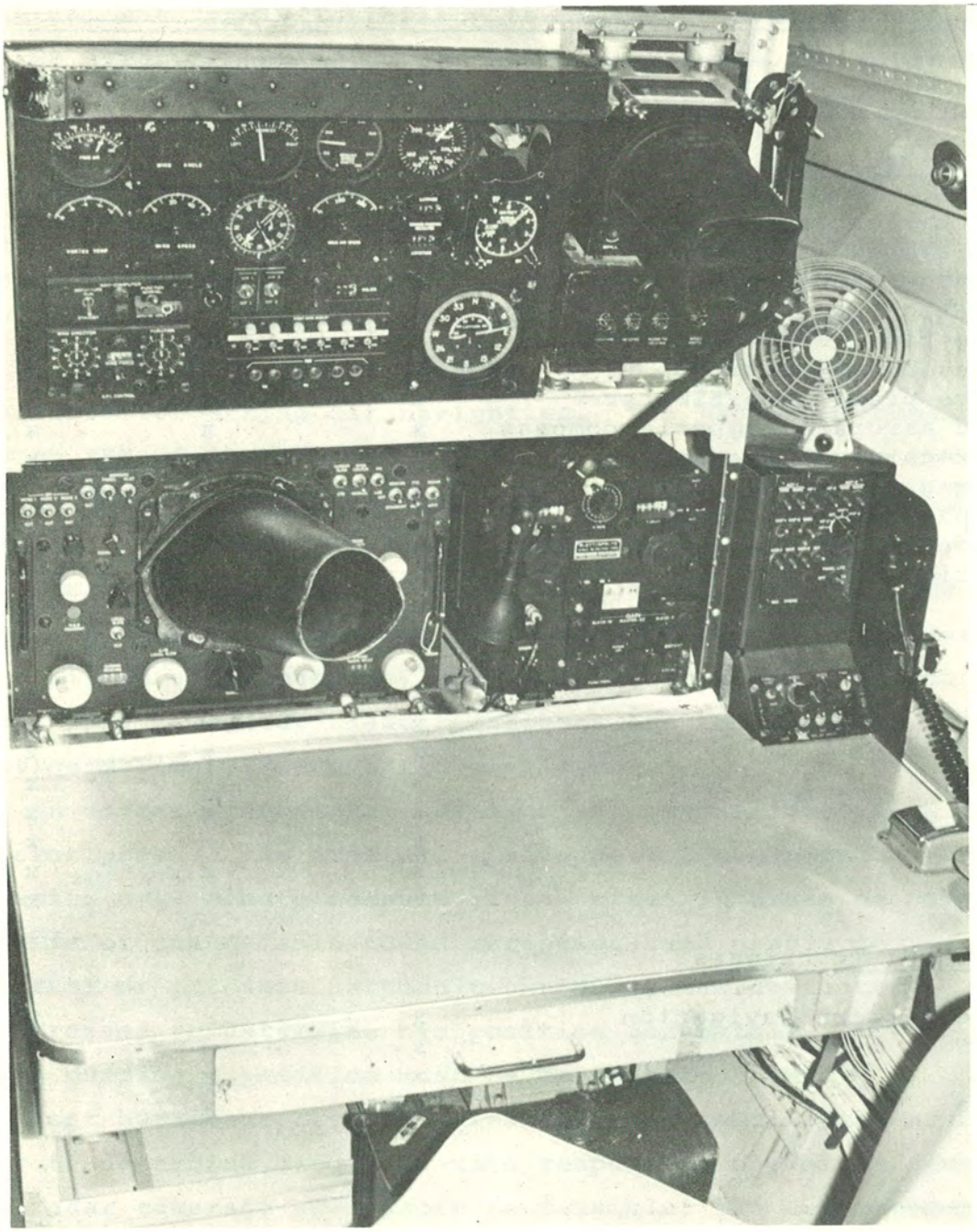

Figure 4. Navigator's position, RFF DC-6 A/B aircraft.

station on RFF DC-6A/B aircraft is shown in figure 7. To maintain a prespecified track or accomplish a given pattern involving both circumnavigations and radial penetrations of a storm at several levels, the navigator, working closely with the flight director, must anticipate the ever-changing wind field. Since the horizontal wind shear in hurricanes is relatively pronounced, it becomes difficult to "keep ahead" of the aircraft.

The changing pressure field (slope of the pressure surfaces) in a hurricane also causes problems in maintaining a given altitude. Since the constant pressure surfaces slope down toward the eye and the pressure altimeter follows these sloping surfaces, it becomes necessary to keep the pilot informed of the altitude corrections required to remain at an approximately constant true flight level. This is especially critical in low-level flights because of the safety factors involved and is important for successfully completing the required mission profiles at all desired levels.

Operational requirements placed on the RFF by the National Hurricane Center make it necessary for the navigator to obtain a position or "fix" at 15-min intervals. In this way, he is able to update corrections to the automatic navigation (Doppler, APN-82) equipment installed on the aircraft. The corrections and the navigator's approximate 15-min fixes are useful in reducing and analyzing the recorded flight level data.

Because of the limited range and faster speed of the B-57A aircraft, additional navigational preplanning is necessary for its flights. The radius of action limitations and the restrictions on accepting in-flight pattern changes that would require major reprogramming essentially put the burden of successfully achieving the research mission requirements on the navigator/meteorologist of the B-57A aircraft. The navigator and meteorologist on the DC-6A/B or C-54(DC-4) aircraft

Figure 5a. Navigator's position (left side), RFF C-54(DC-4) aircraft.

Figure 5b. Navigator's position (right side), RFF C-54(DC-4) aircraft.

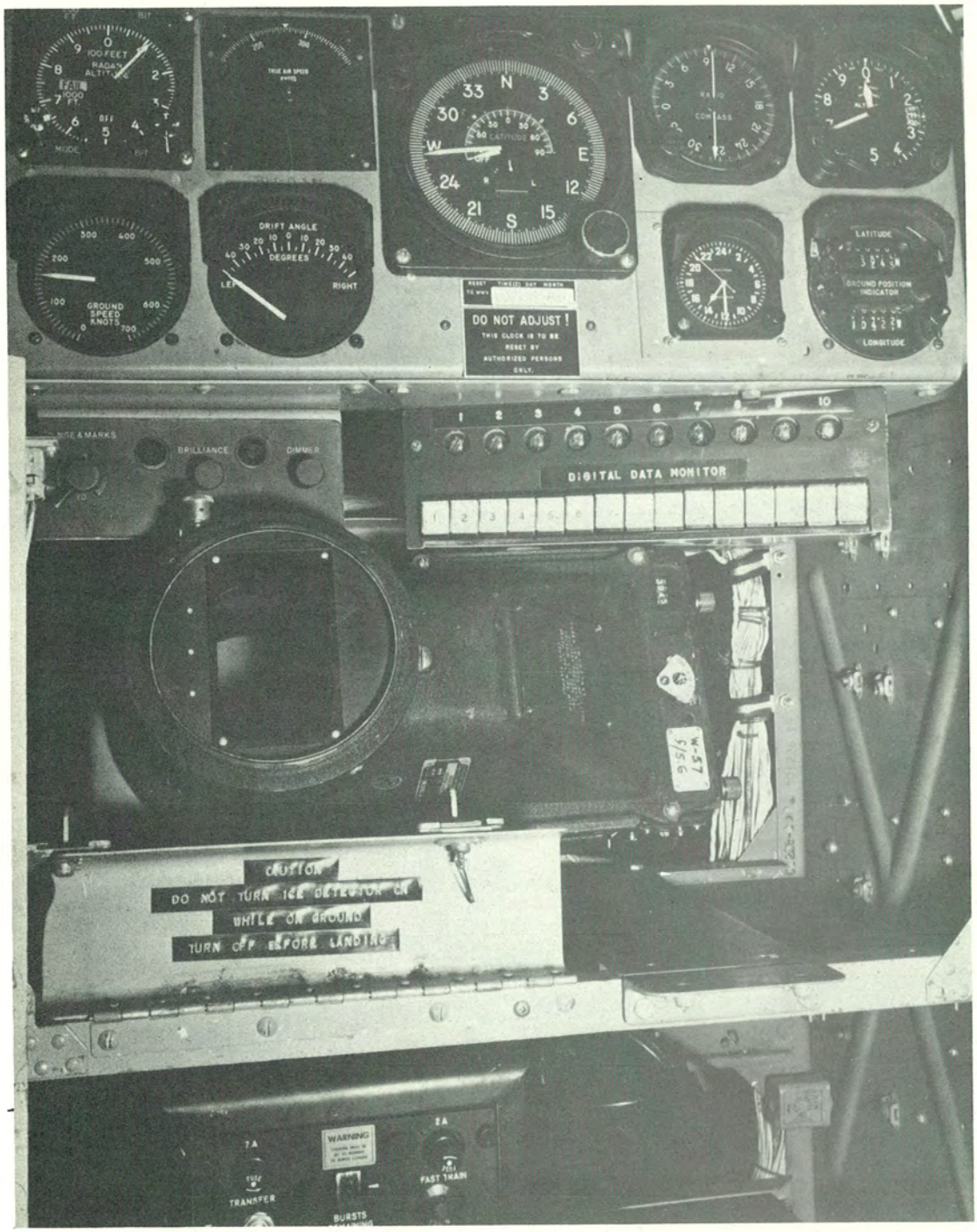

Figure 6a. Navigator/meteorologist's position (front view), RFF B-57A aircraft.

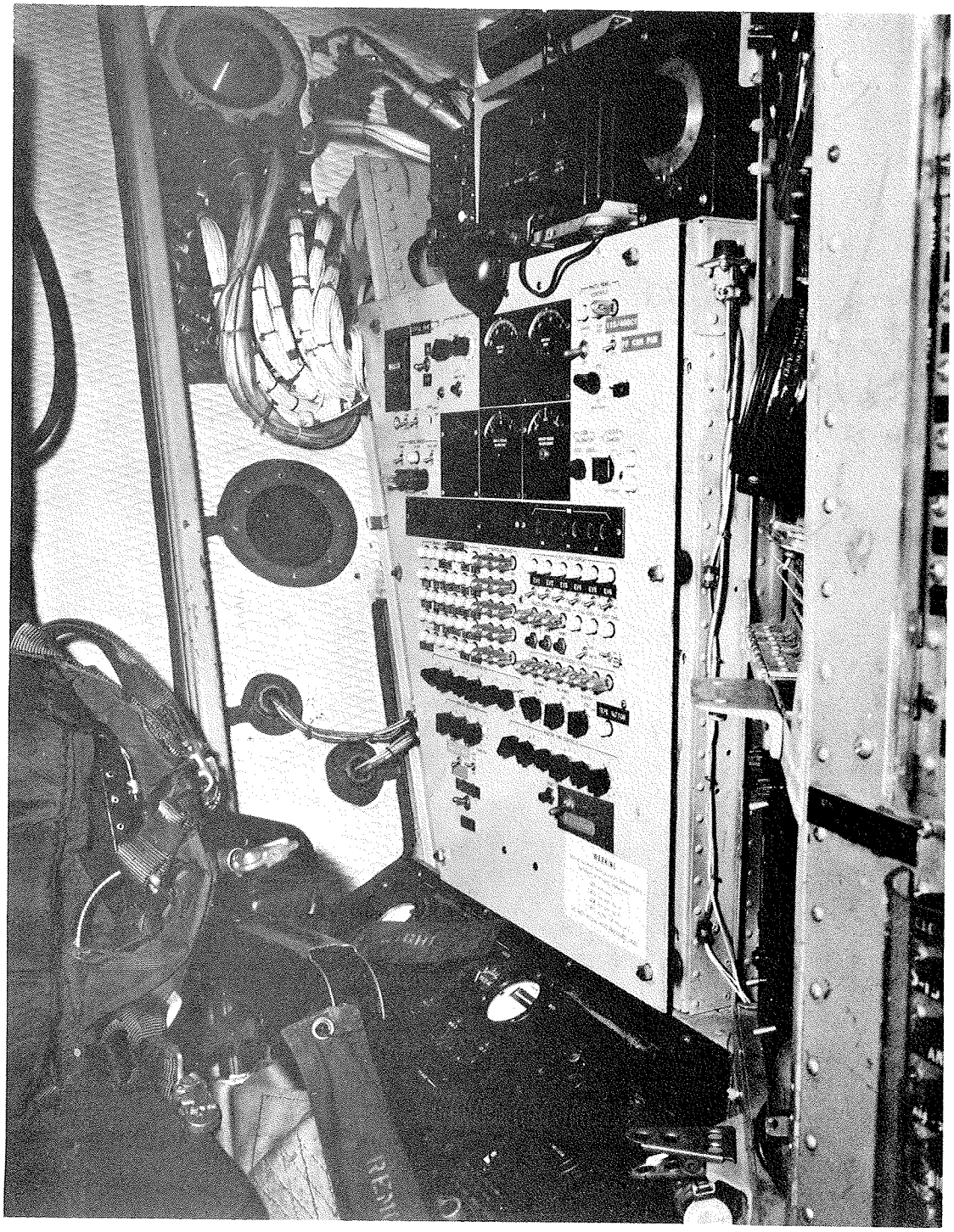

Figure 6b. Navigator/meteorologist's position (side view), RFF B-57A aircraft.

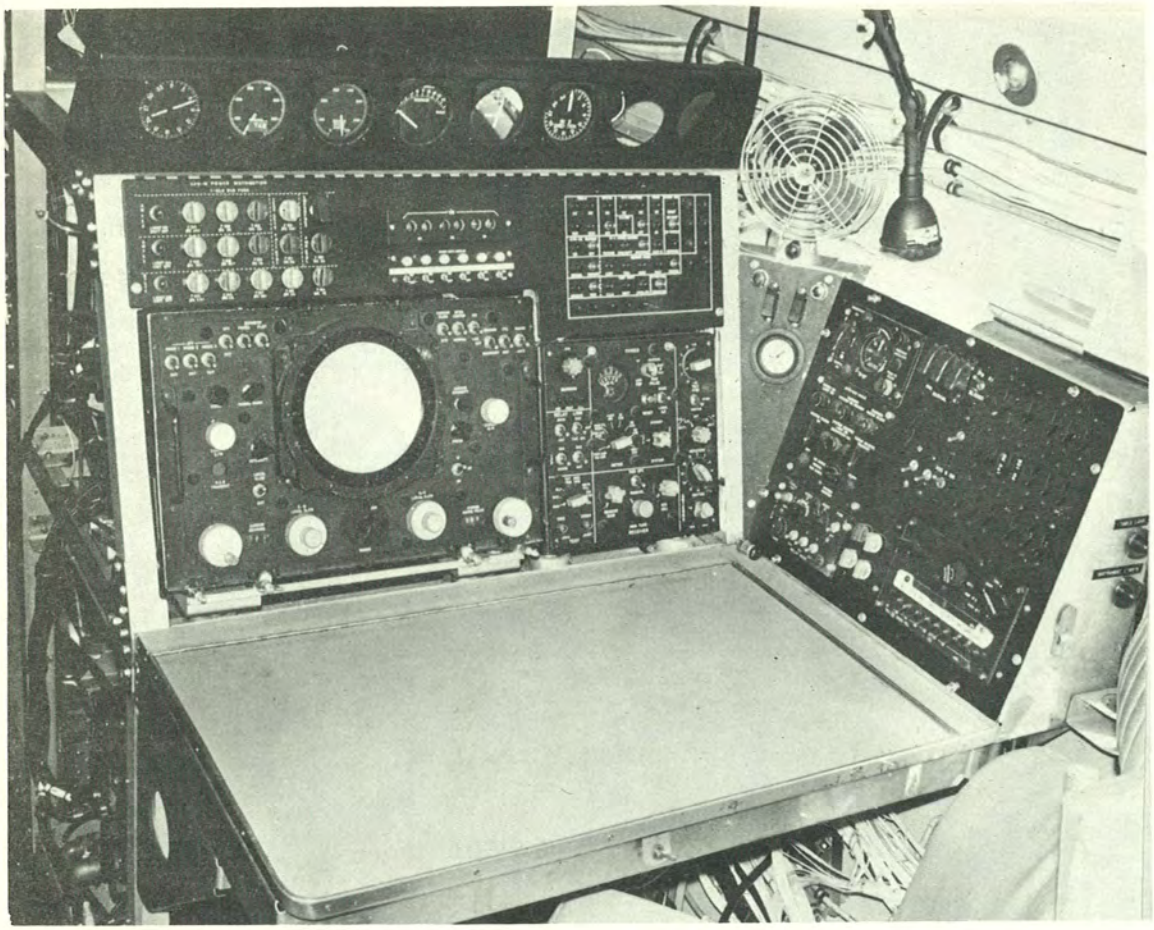

Figure 7. Radar operator's position, RFF DC-6 A/B aircraft.

have more flexibility and are usually in a better position to accept pattern modification requests in flight.

Flight patterns, conducted within range of reliable standard aids to navigation, are normally completed with less difficulty from a navigation standpoint; however, these flights are often over or within high density air-traffic areas and are under adverse weather conditions; major modifications to preplanned routes imposed by Air Route Traffic Control centers are the rule rather than the exception.

5.3 Operating Practices

Operational or mission practices of the RFF concerning its mission objectives, in-flight responsibilities, pre-planning and coordination are discussed in this section. RFF aircraft are operated in accordance with appropriate CAR and FAA regulations and with approved safety of flight procedures. This body of rules serves as the foundation for RFF SOP (standard operating procedures). The RFF SOP prescribes the minimum amount of crew rest necessary between flights, the amount of usable fuel required for reserve or alternate airport requirements or both, the nature and frequency of periodic scheduled inspections and replacements, crew proficiency and training, and safety of flight equipment. In unusual circumstances where no SOP have been established, the chief of the RFF or his designated alternate, usually the chief pilot or operations officer, provides guidance.

5.4 In-Flight Responsibilities

The flight director (RFF senior flight meteorologist) on each aircraft is responsible to see that all necessary action, with regard to flight patterns and equipment operation and schedule for his aircraft, is taken to accomplish a researcher's mission requirements. Figures 8 and 9 show the flight director's position on RFF DC-6A/B and C-54(DC-4) aircraft, respectively. The RFF encourages users of their aircraft to have a representative of the scientific project on each flight when practicable. In this manner, each project has an on-site representative working closely with the flight director.

The flight director is responsible for carrying out the primary mission objectives. Any and all changes in flight must be coordinated with him. It is the responsibility of the flight director to keep the project or visiting scientist informed on mission progress, to anticipate difficulties that might require alternate action, and to be responsive, as

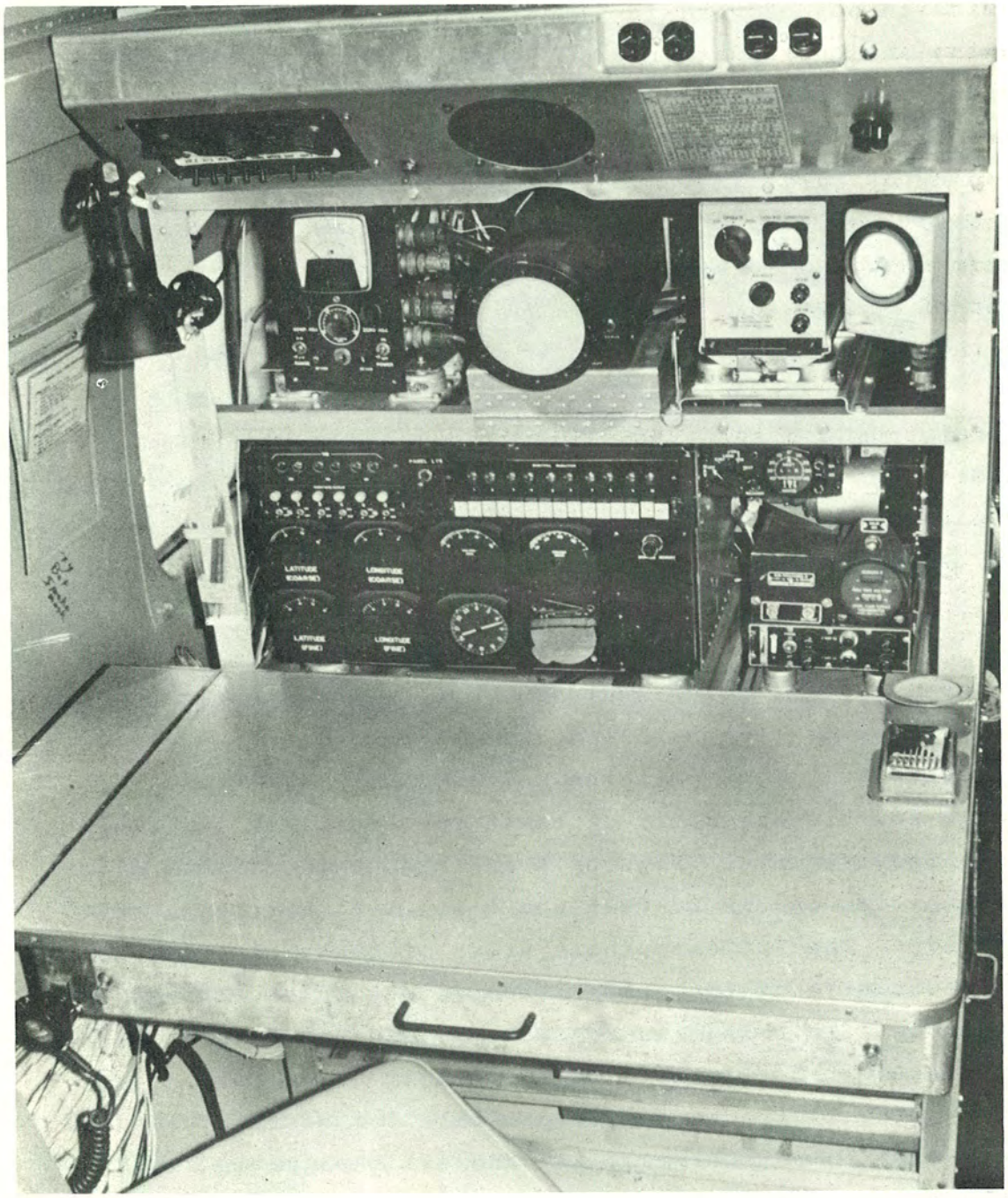

Figure 8. Flight director's position, RFF DC-6 A/B aircraft.

far as practicable, to the desires of the project scientist to the fullest extent that instrumentation, aircraft capabilities and safe operational practices will permit. The visiting scientist's position on RFF DC-6A/B is shown in figure 10. The flight director coordinates any requests for changes in flight track, altitude, mission duration, or other changes that concern flight operations. Final responsibility for the safety of the aircraft remains, naturally, with the aircraft commander.

The in-flight senior electronics technician has direct supervision over the function and operation of the meteoro-

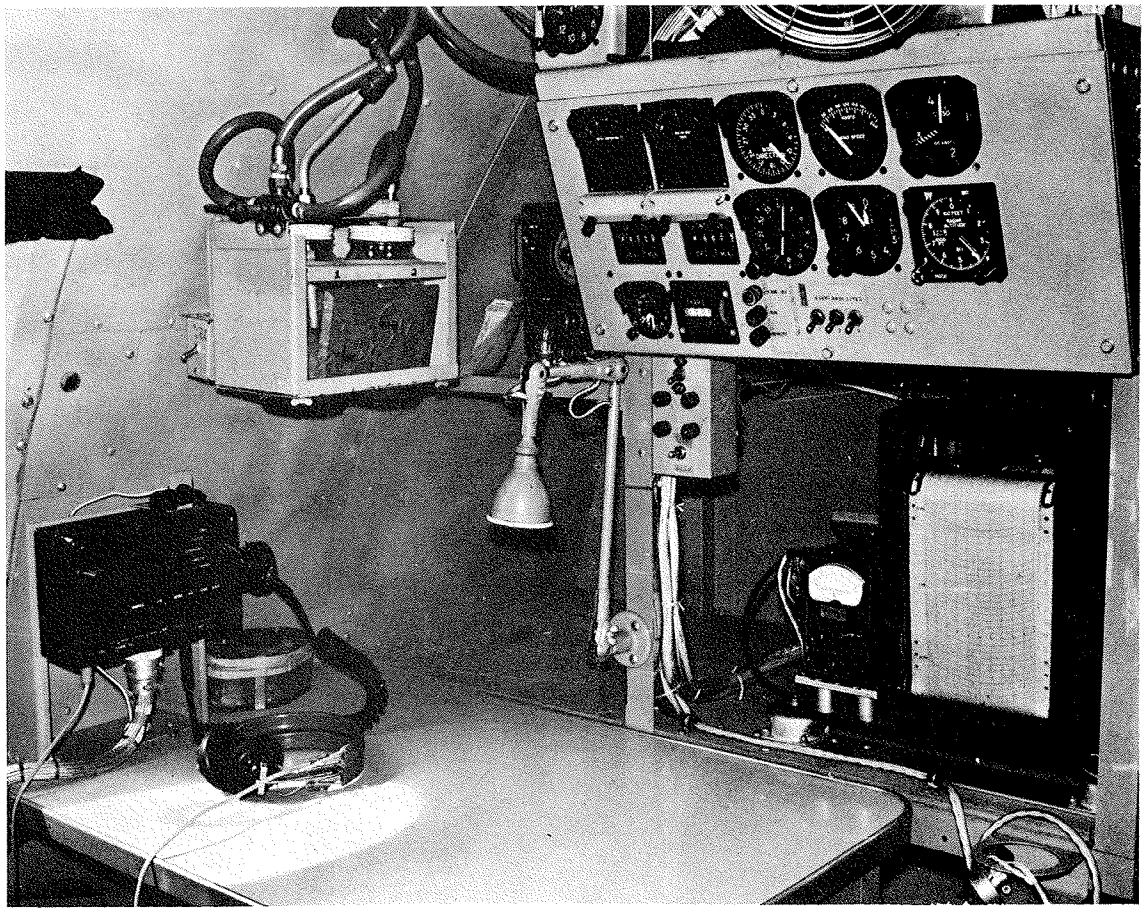

Figure 9. Flight director's position, RFF C-54 (DC-4) aircraft.

logical instrumentation and related systems. He directs the activities of other electronic technicians in flight. He is responsible to the flight director.

Whenever possible, an assistant meteorologist serves as the flight radar meteorologist and assists the flight director in RECCO observation coding, dropsonde equipment operation, etc., except in the case of B-57A operations - which only provides for a crew of two, the pilot and the navigator/meteorologist. In-flight repair of systems are not practicable. Radar equipment installed on the C-54(DC-4) aircraft is operated by the navigator.

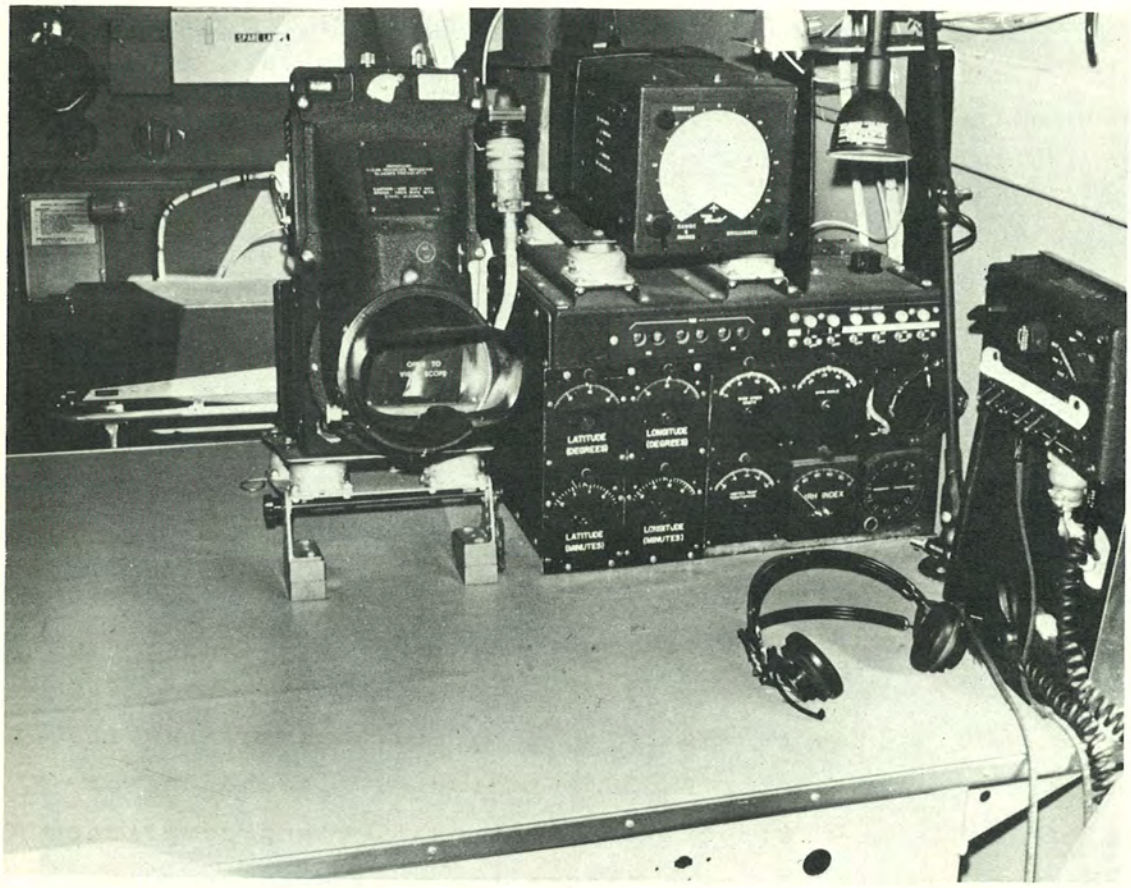

Figure 10. Visiting scientist's position, RFF DC-6 A/B aircraft.

5.5 Mission Briefing/Debriefing

To insure complete understanding of the researcher's mission objectives, project scientists using RFF aircraft are encouraged to provide advanced briefings that delineate mission goals, requirements, possible alternate plans, and intended use of the data. These serve as the basis for the final flight plan. Following a mission, crew debriefings held by the RFF or the researcher or both are often helpful for providing the researcher with information concerning aircraft and meteorological systems "ready-status", especially when a project involves a series of consecutive flights.

With the exception of the B-57A, where no space is available, the RFF provides space on all of its missions for a visiting scientist, who is encouraged to participate actively on each flight; analog readouts of various meteorological parameters of interest are readily available at his position. The visiting scientist's position is also equipped with an intra-aircraft communications system linking him with the flight director and flight crew members. The use of this system is encouraged to minimize unnecessary movement in the aircraft cabin during the flight.

It must be stressed that any changes in pattern or requirements desired by the researcher must be coordinated with the flight director (senior flight meteorologist); the researcher must not communicate his requests for changes directly to the pilot. Upon the request of the researcher, the flight director will coordinate all changes with the navigator, who will then work up the necessary changes and pass the new information to the pilot for implementation. This channel of communication is most effective operationally, and compliance with this policy will help to insure the successful completion of the researcher's mission.

6. RADIO COMMUNICATIONS

6.1 Introduction

A modern and relatively flexible radio communications capability is maintained on all ESSA/RFF aircraft. Conventional VHF, UHF, and HF (voice) communications systems are provided for direct use of the air crew and/or radio operator to handle air-traffic communications and for use in aircraft-to-aircraft coordination. RFF DC-6A/B and C-54(DC-4) aircraft have radio-operator (R/O) positions, which are used extensively on all research/operational missions.

The R/O or communications stations on the DC-6A/B and C-54(DC-4) aircraft (figs. 11 and 12) are used mainly to handle the transmissions of weather and/or reconnaissance messages and/or to relay aircraft and equipment status information to the base of operations (field location) and Miami. These stations have the capability for single-sideband (SSB), AM and CW communications. The RFF B-57AS communications complex is shown in figure 13. A communications plan, which was devised for the support of hurricane research operations, is included as an illustration in section 6.3.

For advanced staging operations, the RFF also maintains the capability for installing and operating, under the appropriate authority, a portable ground-based radio station. The facility is operated with a minimum of ground support; however, several weeks' lead-time may be required to obtain the appropriate authority for use of the station on approved frequencies.

Experience gained by operation of the aircraft radio communications facilities shows that this capability can be used effectively for the real-time transmission of significant meteorological information (hurricane RECCO data, etc.) and for ground-based flight direction (by project scientist, radar-control operations, etc.).

Figure 11. Radio operator's position, RFF DC-6 A/B aircraft.

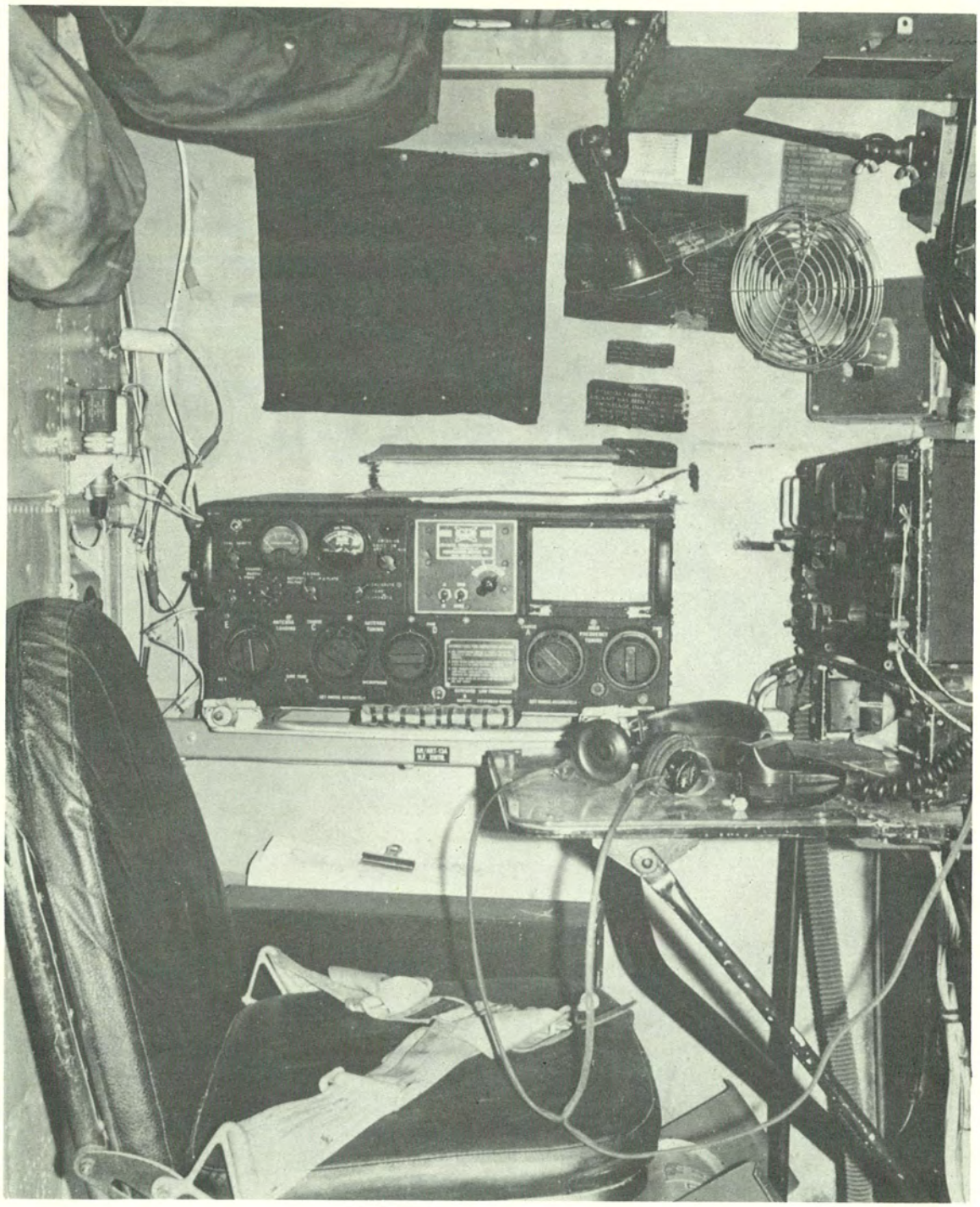

Figure 12. Radio operator's position, RFF C-54(DC-4) aircraft.

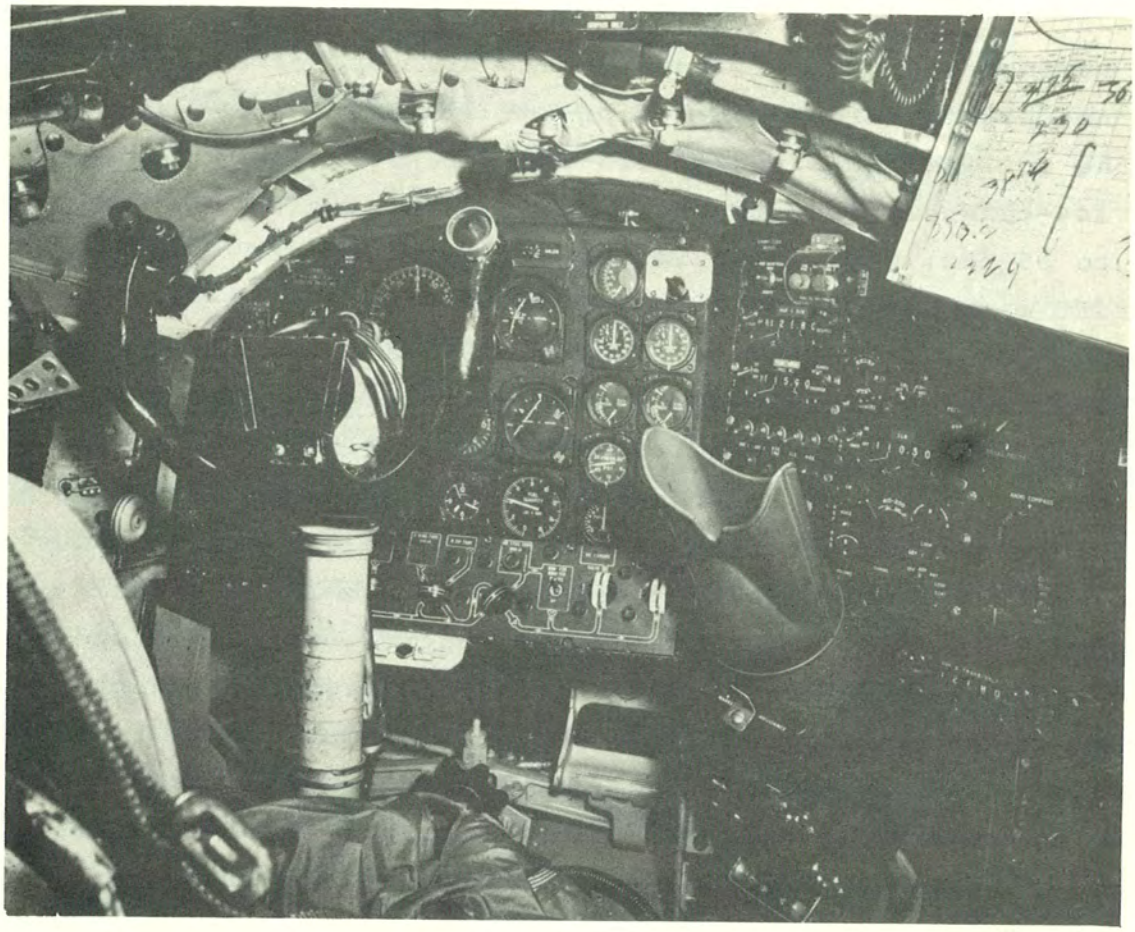

Figure 13. Communication systems (in aircraft cockpit), RFF B-57A aircraft.

6.2 Communications Capabilities

RFF aircraft are equipped with both VHF and UHF transceivers for short-range communications, normally used for airport ground control, flight clearance, tower-approach control, radar surveillance, direct communication with Air Route Traffic Control (ARTC) Centers, and inter-plane communication. The DC-6A/B airplanes each have two VHF systems and one UHF system,while the C-54(DC-4) and B-57A each have one VHF and one UHF system. VHF systems operate between 118.0 and 135.9 MHz (in 50-kHz increments), and the UHF systems each have 1700 channels.

During over-water flights, where distance or altitude does not permit direct control on VHF or UHF, the RFF aircraft use the Collins 618-S and/or 618-T HF transceivers. The 618-S is a 144-channel fixed crystal auto-tune system in the range of 2 to 25 MHz, with approximately 100w RF output. The DC-6A/B aircraft each have two 618-S (AM/CW) systems; the C-54(DC-4) has one 618-S (AM/CW) system; and the B-57A is equipped with one 618-S (AM) system. The DC-6A/B aircraft also have the additional capability of using the 618-T, which is a compact HF single sideband (SSB) transceiver for voice, CW data,or compatible AM communication in the 2.0- to 29.999-MHz frequency range. It is automatically tuned in 28,000 - 1-kHz channel increments by means of an operator's control unit. The operating frequency is indicated directly in a digital presentation. Nominal transmitted power is 400-W peak envelope power in SSB or 100 W in compatible AM. Nominal channel change time is 30 sec by use of the 180L-3A antenna coupler, which is currently in use with the KWM-2 transceiver and compatible with the 618-T.

The KWM-2 system, manufactured by Collins and installed on the RFF DC-6A/B aircraft, is a crystal-controlled transceiver with variable BFO, auto-tune, and 100-W output in the SSB and CW modes. This system is used as a backup for the Collins 618-T and 618-S models in the DC-6A/B aircraft.

A modified Collins 618-S system is installed in the RFF C-54 (DC-4) aircraft to provide for an SSB capability. Communications beyond the range of VHF or UHF are normally conducted with the FAA/IFSS (Federal Aviation Agency, International Flight Service Stations). When congestion of frequencies or atmospheric conditions are such that the IFSS facilities are unusable, the services of Aeronautical Radio Incorporated (AIRINC) with its greater frequency availability are employed. In addition, AIRINC provides a phone-patch

capability that may be used for the transmission of high priority "traffic." The services of the U.S. Air Force Airways Stations is also used for traffic control purposes.

During hurricane or other weather research/reconnaissance missions in the Atlantic, Caribbean Sea, Gulf of Mexico, or combination of these communications are normally conducted through the U.S. Navy Fleet Weather Facility SSB net that consists of "JAX HURRECO CONTROL," "ROOS ROADS WEATHER," and "FLEET WEATHER SUITLAND." To use this net, the RFF DC-6A/B aircraft uses the Collins 618-T transceiver as the primary system, and the KWM-2 communication systems as back-up. As previously mentioned, the RFF C-54 (DC-4) uses a modified 618-S system to give it SSB capability.

The RFF also maintains a complete lightweight portable ground (SSB and CW) communication station. The system used is a 100-W Collins 32-S transmitter and 75-S receiver. It includes a power supply and station control speaker. Power required to operate this system is normally readily available ("house" current 60 Hz/115v). Space is also needed for the erection of a 66-ft half-wave doublet antenna to operate on the "authorized Weather Bureau frequency (6977.5 kHz)." Approximately 4 to 6 weeks lead-time is required to secure agency approval for station operation at a proposed location.

Other communications capabilities include the use of ship-to-shore telephone service provided by the American Telephone and Telegraph High Seas Radio Telephone Stations, WOM at Fort Lauderdale, Florida and WOO at New York, New York. The ATT service is conducted through paired frequencies. The RCA Marine Coast Stations are also used for sending or receiving radio telegrams via CW means.

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6.3 RFF Hurricane Research/ Reconnaissance Communications Plan

The communications plan shown in this section is typical of the type used for hurricane research/reconnaissance flights by the RFF aircraft.

6.3.1 Fleet Weather Facility (FWF) Jacksonville Communications

RFF communications will be conducted in accordance with the current interdepartmental Atlantic Hurricane Plan when possible in support of NHRL operations. The primary means of communication will be the FWF (JAX), ROOS ROADS, FWC (SUITLAND RECCO Circuit-SSB).

This circuit is used for RECCO, administrative and operational messages, and relay of air traffic information to appropriate ARTC locations that can be reached via SSB when other means or contact cannot be established. FWF (JAX) will use the voice call sign, "JACKSONVILLE HURRECO CONTROL"; Roosevelt Roads will use the voice call sign, "ROOSEVELT ROADS WEATHER", and Suitland will use the voice call sign, "FLEET WEATHER SUITLAND", for all communications on this circuit. Voice procedures and circuit logs will be as outllined in ACP 125(B) (Atlantic Communications Plan).

All hurricane reconnaissance reports received by the Fleet Weather Facility, Jacksonville (FLEWEAFAC), are distributed through one or more of the following systems: (a) Automatic Digital Network (AUTODIN), which is an on-line encrypted duplex teletype circuit used to distribute warnings, intermediate storm position estimates, and tropical weather summaries to military addressees and to NAVCOMSTAS for transmission on the Atlantic Fleet broadcasts· (b) Circuit 30GT2352, Direct Line Teletype, which consists of IFSS, MIAMI, NHC MIAMI, WEARECONRON FOUR, FWF JACKSONVILLE and ESSA/RFF. The reconnaissance aircraft PLAN OF THE DAY is also transmitted on

this circuit by the military coordinator at NHC MIAMI. All reconnaissance reports received at FWF JACKSONVILLE via SSB will be placed on this circuit as soon as received and monitored. NHC MIAMI is responsible for entering these reports on the Hurricane Circuit 23421. FWF JACKSONVILLE acts as back-up for this responsibility in the event of any major problems at NHC MIAMI. (c) Circuit 30GP2901, Direct Line Telephone, which connects FWF JACKSONVILLE and NHC MIAMI. This line is also used to coordinate the PLAN OF THE DAY with CARCAH at NHC, MIAMI and for discussing hurricane data with NHC, MIAMI and for discussing hurricane data with NHC MIAMI. (d) COMET II Circuit, which is used for all reconnaissance reports received at FWF JAX via SSB. (e) FWF JACKSONVILLE-ROOSEVELT ROADS - FWF SUITLANT RECONNAISSANCE CIRCUIT (SSB), which is used for operational messages to and from WEARECONRON FOUR at ROOSEVELT ROADS and for communications with the hurricane reconnaissance aircraft. FWF JACKSONVILLE uses the voice call sign "JACKSONVILLE HURRECO CONTROL" for communications on this circuit.

For hurricane messages the following precedences will be used:

Message Type	Precedence
Warning	Immediate (O)
Position Estimates	Immediate (O)
Tropical Weather Summary	Routine (R)

6.3.2 Aircraft Reconnaissance Communications

FWF JACKSONVILLE-ROOSEVELT ROADS-FWF SUITLAND Reconnaissance Circuit (SSB)

(A) This circuit will operate as a FREE NET unless otherwise directed by NET CONTROL (FLEWEAFAC JACKSONVILLE) and will be the primary circuit for passing reconnaissance data.

(B) Except in case of emergency, the aircraft will notify NET CONTROL prior to leaving the circuit.

(C) Use of frequencies - as assigned in accordance with JANAP 195 will be as follows.

(1) FWF JACKSONVILLE will guard circuits as follows:

a. Primary: Circuit CHARLIE (13221 kHz).

b. Secondary: Circuit DELTA (15081 kHz).

(2) ROOSEVELT ROADS will guard backup circuits as follows:

a. Primary: Circuit CHARLIE (13221 kHz).

b. Secondary: Circuit DELTA ((15081 kHz).

(3) FWF SUITLAND will guard back-up circuit CHARLIE (13221 kHz).

(4) Circuits ALFA (4700 kHz) and BRAVO (9010 kHz) may also be used, if required.

(5) When two or more reconnaissance aircraft are operating in a storm area, voice communications between the aircraft will be established and conducted on UHF frequency 304.8 MHz. If initial contact fails on 304.8 MHz, UHF Guard Frequency 243.0 MHz will be used.

6.3.3 Air-Ground Voice Air Force Circuit (SSB)

If communications cannot be established and maintained on the primary circuit (SSB JACKSONVILLE-ROOSEVELT ROADS - FWF SUITLAND) the Air-Ground Voice Air Force circuit, as outlined in the U.S. Air Force Communications Plan of the current National Hurricane Operations Plan, will be used. If communications are established with the Air Force SSB station at McDill AFB, AUTOVON Number 431-1660 should be requested.

Aeronautical stations at McDill, Andrews, and Albrook AFB's, will be called upon in the order they are listed. The HF and SSB frequencies are listed in the appropriate USAF/USN

flight information publications enroute supplements. When circuit conditions permit, a direct phone patch between the aircraft and FWF JACKSONVILLE (via AUTOVON Number 431-1660) will be arranged by the ground station (as above). When circuit conditions warrant, phone patches can be made to any AUTOVON and most commercial telephones. USAF has authorized the use of "Immediate" priority for transmission of Hurricane Reconnaissance Reports. Whenever conditons are not of phone-patch quality, the aircraft requests ground station to relay via AUTOVON, teletype, commercial long distance phone, or whatever means is most expeditious.

6.3.4 Navy Universal Air-Ground (CW) Circuit

If communications cannot be established and maintained on circuits as outlined, the Navy Universal Air-Ground (CW) Circuit will be used. "TANGO" instructions will be included on messages passed on this circuit.

The following frequencies have been assigned for emergency and stress:

Frequency	Emission	Use
500.0 kHz	CW	International distress and calling frequency
2182.0 kHz	V	International distress and calling frequency
2678.0 kHz	V	Coast Guard calling and working frequency
5680.0 kHz	V	Search and rescue control (Coast Guard)
5695.5 kHz	V/CW	Rescue rescue control (Navy)
8364.0 kHz	CW	International lifeboat, liferaft and survival craft frequency
121.5 MHz	V	Emergency and distress for aircraft and ships SAR and VHF/DF primary
243.0 MHz	V	Military common emergency frequency, UHF

Reports via SSB or CW channels from RFF aircraft and reconnaissance flights addressed to Fleet Weather Facility, Jacksonville, or its alternate, Fleet Weather Central, Suitland, will be preceded by "UH" or "UR" unit identification and message number, with "one" assigned to the departure report. The sequence will be continuous for all messages on each particular flight, regardless of whether messages are transmitted in RECCO code, plain language text, or a combination of the two.

At the end of each RECCO message, the coded longitude and latitude groups and the flight level and surface wind groups will be repeated for the purpose of confirmation.

An example of a hurricane RECCO message (second message from the first RFF mission on hurricane "ELLA") follows:

0 181902 Z: (Preamble-priority, date-time group).
FM N6539C : (Originator).
TO HGXP Miami (National Hurricane Center): (Address).
(GR 29) BT : (Prefix)
<u>UHN 6539C</u> ESSA ONE ELLA TWO 97779 etc.: (Text).

Named storm numbers will be consecutive and end when specific named storm is terminated.

ESSA numbers on investigative or unnamed storm flights will be consecutive throughout the hurricane season.

6.3.5 Air Traffic Control Communications

ATC A/G communications by RFF aircraft operating within U.S. FIR areas of responsibility will be conducted in accordance with the following priorities:

1. 6567 (FAA)
2. AIRINC
3. USN SSB
4. USAF AIRWAYS STATIONS

6.3.6 Air-Ground Communications with FAA and AIRINC Facilities

If the primary and alternate air-ground communications fail, reconnaissance aircraft may transmit their hurricane data in plain language by voice to Miami, New York, or San Juan in that order of priority. FAA IFSS will be used initially on 6567 kHz, and, if that fails, AIRINC with its greater frequency availability will be brought into use. In addition, AIRINC provides direct phone patch on VHF or any AIRINC HF frequency in any high priority situation, whenever other phone patch means is not available.

6.3.7 American Telephone and Telegraph High Seas Radio Telephone

RFF aircraft have the capability of ship-to-shore telephone service provided by ATT high seas radio telephone station WOM, located at Fort Lauderdale, Florida. This facility can be brought into use while operating in the Caribbean or Gulf of Mexico area when other phone patch means are not available. ATT service is conducted at a nominal charge and on a duplex basis through paired frequencies in the following manner.

WOM (Transmitting Frequency)	Aircraft (Transmitting Frequency)
4428.6 kHz	4123.6 kHz
8792.8 kHz	8242.8 kHz
13154.5 kHz	12354.5 kHz

SSB frequencies are also available in accordance with the ATT brochure.

6.3.8 Radio Telegrams

RFF aircraft have the capability of sending and receiving radio telegrams via CW through the facilities of RCA Marine Coast Stations at locations on frequencies published in the RCA brochure.

7. ACKNOWLEDGMENTS

The authors would like to acknowledge the contribution to this publication by Mr. J. Michie, who prepared much of the tabulated data presented throughout the report; Mr. F. Werley, Chief Pilot, and Mr. J. Lubin, Chief Navigator, who assisted with materials presented in sections 3 and 5; Mr. R. D. Decker, Photo-Optical Branch, who provided photographs used in this publication; and Mr. C. True, National Hurricane Research Laboratory, who made figure 2 available to us.

We also wish to thank Messrs. H. J. Mason, Jr., Chief, RFF, H. W. Davis, Chief, Data Acquisition Section, and Dr. G. Conrad, Chief, Instrument Development Branch, for their thoughtful comments, many suggestions, and encouragement during the preparation of this report.

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APPENDIX
RFF-SUPPORTED RESEARCH

Since 1960, researchers have employed the RFF for data collection, processing, and related services.

The summaries of operations presented in this appendix are taken from publications of the research organizations, which are referenced, or from personal communications.

A.1 National Severe Storms Laboratory*, ESSA

Principal Investigator: Dr. Tetsuya Fujita, University of Chicago

During a 7-year period beginning in 1961, Dr. T. Fujita and his associates at the University of Chicago, working closely with the NSSL staff, participated in severe storms research programs with RFF aircraft. Dr. Fujita, under contract, served as a consultant to NSSL for the design of the aircraft program and the analysis of collected data. In order to fulfill the objectives of the severe storms investigations, he emphasized using RFF aircraft to provide wind-field data around isolated and line (severe) storms. He found that Doppler winds are extremely useful for the mapping of flow patterns at approximately constant pressure levels.

The following is a brief history of the operational, research and calibration flights made by the RFF for NSSL from 1961 to 1967.

<u>1961</u>: During the spring operation in Oklahoma, Dr. Fujita, working with Dr. C. Newton who was then associated with NSSL, used the RFF aircraft to make measurements of meteorological parameters around isolated thunderstorms at the 850-, 500-, and 200-mb pressure levels.

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*Formerly designated National Severe Storm Project (NSSP).

Low- and middle-level winds were calibrated and corrected several times in later years in an attempt to determine the mesoscale wind field beneath and around active thunderstorms. A thunderstorm case of April 21 was analyzed in detail and evidence of thunderstorm rotation resulted.

1962: A series of flights over the Midwest were made in an attempt to explore the possibilities of investigating the mesoscale structure of the atmosphere that gives rise to the development of squall lines and isolated thunderstorms. Besides the studies of wind and cloud patterns, basic problems of the error in the Doppler fixes were studied by Dr. Fujita. While participating in several flights, he made a large number of visual fixes for the purpose of determining absolute errors in Doppler fixes. It was found that the time derivatives of the error vector were large enough to cause Doppler winds to be affected. This finding initiated a comprehensive study of the ASN-6 winds, which were computed on the aircraft. The ASN-6 is part of the AN/APN-82 system. After this study was accomplished, it was found that the influence of the time derivative of the position error vector on the output values of the Doppler wind was actually quite small.

1963 and 1964: Two calibration flights were made to establish methods of accurately calibrating Doppler winds measured by the RFF DC-6A/B and B-57A aircraft. Because of difficulties involving wind measurements under the influence of falling raindrops, calibration flights were made over Florida and Oklahoma on relatively cloud-free days. A loop-flight technique was established by Dr. Fujita, who indicated that in-flight calibrations could be made by simply flying a loop pattern while maintaining a constant pressure altitude. After applying the results of this calibration technique, the expected errors were no more than 2 to 3 knots in the

vector winds; wind direction could be in error when wind speeds are lower than about 10 knots. This loop-flight calibration technique has been used in later years by Dr. Fujita to improve the accuracy of wind data. The RFF F-11A on loan from the U.S. Navy was also used for thunderstorm penetrations during this period.

1965: Extensive test and calibration flights with two RFF DC-6 A/B's were made over Oklahoma and Kansas for the purpose of establishing reasonable procedures of smoothing the Doppler winds that are "measured" by the aircrafts' APN-82 system. Fujita found that the winds computed by averaging ten 1-sec interval winds are more meaningful than weighted winds involving an exponential function for each wind speed and direction computation.

Four flight programs were designed and accomplished during the 1965 field program:

(1) Flights over the NSSL Beta network stations were made in order to compare winds with Doppler winds, both measured at the (approximate) 2500-, 3500-, and 4500-ft levels over these stations. The poorest correlation between the surface wind and the Doppler wind occurred during the early morning hours when the low level atmosphere was extremely stable. It was found that the Doppler winds are very close when measured by two DC-6 A/B's flying side by side with a separation of less than 1 mi.

(2) The vertical wind shear was determined using the Doppler winds that were measured while the two DC-6 A/B aircraft were flying with a vertical separation. This technique was useful for the estimation of the mesoscale thermal wind field existing prior to the development of severe storms.

(3) Flights were accomplished to evaluate the changes that took place while the aircraft were flying across the coastlines at various crossing angles. The results of this

program showed that there were no noticeable changes, probably due to the fact that the coastal current southeast of Houston where the flight was made was too weak to influence the wind measurements. Dr. Fujita speculated, however, that a significant variation in the Doppler winds could take place while crossing shore lines under the influence of hurricane winds or a very strong oceanic current such as the Gulf Stream or both.

(4) Mesoscale wind fields of isolated thunderstorms were measured by two RFF DC-6 A/B's flying beneath these storms and at midlevel around them. Dropsondes were also used in order to determine the vertical distribution of temperature and humidity of the storms' environment. It was found that Doppler winds are accurate enough to compute the subcloud convergence and the vorticity around storms with an accuracy of 10^{-4} sec^{-1}. If values are much smaller than 10^{-4}, it is difficult to tell whether measured values are real; nevertheless, these measurements proved to be useful in the study of severe storm dynamics, since the order of magnitude of divergence or convergence associated with severe storms are at least one order of magnitude larger than those associated with so-called synoptic systems.

1966: The RFF aircraft were employed in Oklahoma during May to sample meteorological parameters of interest while the aircraft were flying over the NSSL "Beta" network, which was additionally covered (sampled) by radar and upper-air sounding observations. Attempts were made to determine the mesoscale wind field around convective clouds that formed and developed over the network. Despite the fact that nature did not produce any large storms during the operational period, two situations over the network and adjacent areas were studied.

Mesoscale wind data obtained have been used in a study of a situation that did not give rise to the development of

a squall line over the network, and one with very weak westerlies in which a storm developed and moved northward.

1967: The basic objective of the NSSL program for 1967 was to gain understanding of the kinematic and dynamical properties of severe storms by measuring meteorological parameters in such detail that the energy and water budgets of a few thunderstorm situations and the shapes of the associated air circulations would be well defined by careful analyses. This operation was designated "Project Rough Rider."

From the preceding history of Dr. Fujita's and NSSL's use of the aircraft and services of the RFF, it is evident that earlier experiences served both the researcher and the RFF in the evaluation and development of subsequent research objectives and flight programs.

A.2 Project Stormfury

Principal Investigators: Dr. Joanne Simpson, Chief, Experimental Meteorology Branch, Atmospheric Physics and Chemistry Laboratory, ESSA and Dr. R.C. Gentry, Director, National Hurricane Research Laboratory, ESSA.*

Stormfury is a cooperative joint project of the Department of Commerce (ESSA) and the Department of Defense (Navy and Air Force). It is a major data-gathering and research program in ESSA supported by the RFF.

The major objectives of Stormfury are to (1) gather data to determine the mechanism of tropical clouds, storms and hurricanes; (2) gather data to determine the natural fluctuations in tropical storms and hurricanes; and (3) monitor tropical hurricanes and cumulus clouds, before and after seeding with silver iodide pyrotechnics to determine if seeding caused measurable changes in the storm or cloud mechanisms.

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*Dr. Simpson served as director of Project Stormfury through 1967; Dr. Gentry then took over as director of the project.

The RFF aircraft have accomplished a variety of flight patterns* from low-level inflow monitoring near the cloud or hurricane bases to high-level outflow data monitoring, including several of the intermediate levels. RFF DC-6A/B and C-54(DC-4) aircraft have been used from about 1000 ft to 20,000 ft, while the B-57A has flown at levels between 23,000 and 43,000 ft. Specific flight patterns have depended primarily on the nature of the specific data collection requirements and have included traverses and circumnavigations of the tropical storms and hurricanes at many different monitoring levels.

Data have been used by project research meteorologists to verify the hypothesis on which the research was based. The Project Stormfury physical hypothesis is essentially this: By sowing the supercooled strata of a tropical hurricane with silver iodide, the latent heat of fusion, released due to change from the liquid-water to the ice phase, will be sufficient to alter the energy exchange mechanism, resulting in lower maximum wind speeds or changing the energy distribution within the circulation or both.

Virtually all data made available by RFF aircraft are used in the research. Especially valuable are pressure (D-values), temperature, humidity, cloud particle size and distribution, wind direction and speed, vertical soundings (dropsondes), radarscope photographs, both PPI and RHI, and cloud photography. Accurate times and positions in space of all observations are vital to the value and usefulness of all observed data. Accurate time is generated by a highly stable 24-kHz crystal-controlled oscillator and is recorded on magnetic tape, thus fixing each piece of recorded data with an accurate common time reference. Position information is provided by the Doppler (APN-82) system, radar, celestial,

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*See Project Stormfury Annual Reports for 1963 through 1968.

LORAN, DME, and other standard aids to navigation on the aircraft. Stormfury is a continuing research program. The RFF will also continue its support of the field-data collection program in the future.

A.3 Cumulus Cloud Research

Principal Investigator: Dr. Joanne Simpson,
Chief, Experimental Meteorology Branch, APCL, ESSA.

Cloud physics research with RFF aircraft began while Dr. Simpson was in charge of Project Stormfury. Investigations of the cumulus scale in the tropics seemed quite natural as both an adjunct to the Stormfury program and a separate area of research. Dr. Simpson believed that a better understanding of cloud physics on the hurricane scale could be obtained obtained from studies of individual cumulus clouds. To this end, the cumulus research was essentially combined with the larger scale studies.

In 1967, when Dr. Gentry became director of Project Stormfury, the Experimental Meteorology Branch, now under the leadership of Dr. J. Simpson, concentrated its major efforts on problems connected with cumulus scale convection. Several field experiments (Puerto Rico 1965, 1967; Florida, 1968) to collect cumulus cloud data on seeded and nonseeded clouds were supported by the RFF.

Several cloud-physics instruments on the RFF aircraft were designed or installed or both to provide for the specialized data requirements of the Experimental Meteorology Branch.

A specific flight pattern depends on the nature of data requirements for a given set of conditions, but, in general, it normally consists of monitoring runs before and after "seeding." Control clouds are selected to provide a statistical comparison of the results of seeding tropical cumulus clouds. To date, analyses indicate that seeded clouds will

grow measurably when compared with nonseeded control clouds (if seeded under appropriate conditions).

During the operations conducted in Florida in 1968, the RFF B-57A aircraft was used to dispense the pyrotechnics (AgI) flares into selected clouds, providing an additional cacpability for cloud physics research missions. Further detailed information on this program has been published by Simpson et al. (1967), Woodley and Partagas (1969), and Simpson et al.(1969).

A.4 University of Stockholm

Principal Investigator: Mr. Walter Bischof

In cooperation with Dr. Lester Machta (ESSA), and Dr. Gote Ostlund (Institute of Marine Science, University of Miami), air samples were collected for subsequent analyses of the CO_2 content to study large-scale mass exchange in the atmosphere. These samples were collected by the RFF aircraft with a collection system devised by Dr. Ostlund. In general, the samples have been analyzed by Mr. Bischof in Stockholm; however, during March and April 1965, while he was in residence at RFF, the samples were analyzed here with special equipment brought from Stockholm for the purpose. Approximately 200 samples were collected and analyzed in the 1965-1966 period. Flight programs are shown in tabular form in table A.1.

Table A.1 Flight Programs

Date	Area	Purpose
3/14/65	Miami-Aruba-Miami	To investigate the CO_2 distribution in sub-tropical high areas
3/19/65	Miami-U.S. East Coast-Miami	Air mass modification experiment (Dr. L. Machta, principal investigator)
4/1/65	Miami-Miami	To investigate the CO_2 distribution over the sea
3/5-6/66	U.S. East Coast	Air mass modification experiment (Dr. Machta)
4/27-29/66	Miami-Panama-Equator-Miami	To investigate the CO_2 distribution over ITC areas

A.5 International Indian Ocean Expedition

Principal Investigator: Dr. Colin S. Ramage
Meteorological Director, (IIOE).

1963: May 11 through July 10.

Several flights were made across the Bay of Bengal from Madras, India, to Bangkok, Thailand, to obtain information about meteorological conditions during the early part of the summer (wet) monsoon.

Two penetrations of a cyclonic storm of hurricane intensity, which occurred in the Arabian Sea, were made.

A mission to observe summer monsoon circulation conditions in the western Arabian Sea was made by following streamlines in the surface wind flow from Bombay to Aden and Nairobi (East Africa) and returning along the same route.

An investigation of equatorial conditions was made flying the aircraft from Bombay to Gan Island, Maldive Islands, then to Singapore,with return along the same route.

A number of sorties were made over the eastern Arabian Sea to observe summer monsoon conditions. Generally, a triangular track was followed during these sorties.

Two RFF DC-6A/B's participated in these flights. The RFF B-57A participated in most of them, while a RFF B-26C flew shorter flights supporting, but not duplicating, the missions flown by the other aircraft. The B-26C also participated in collecting data for documentation of the sea-breeze phenomena on the west Indian coast.

1964: January 28 through March 10

The longest expedition was made to investigate the winter (dry) monsoon conditions in the eastern Arabian Sea, the equatorial circulation, and the southern hemisphere summer activity in the equatorial low pressure trough. The two participating RFF DC-6A/B aircraft flew tracks from Bombay (India), to Gan Island (Maldive Islands), and to Mauritius, then returned to Gan Island, Cocos Island, Darwin (Australia), and Singapore, and returned to Bombay via Gan Island.

Many sorties were flown in the northeastern portion of the Arabian Sea to obtain data for air-sea interaction studies, as well as studies of the sea breeze of India. In general, the two RFF DC-6A/B aircraft flew horizontal square patterns centered on an especially instrumented (University of Washington) buoy designed to gather at and immediately above the sea surface. These squares were flown at several different levels. For study of the sea breeze, excursions were made off the square or through its center to obtain data in cross section. Two RFF DC-6 A/B's participated in these flights and the data have been put to use for the study of: (1) air-sea interaction conditions over the Arabian Sea; (2) the circulation of a mid-tropospheric cyclone, which occurred over and near

the Bombay region of the west coast of India during the summer monsoon of 1963; (3) the sea breeze circulation in the vicinity of Bombay, India, and (4) cloud distributions over the Indian Ocean.

The penetrations of this cyclonic storm resulted in an immediate benefit; the accurate location of this storm enabled forecasters to issue timely warnings to commercial ship operators and others concerned.

A.6 National Hurricane Research Laboratory*; ESSA

Principal Investigators: Dr. R.C. Gentry, Director; Mr. H.H. Hawkins

The National Hurricane Research Laboratory makes extensive use of the aircraft of the Research Flight Facility for research reconnaissance into all types of tropical circulations. For example, the aircraft are used for study of hurricane genesis situations and for study of mature hurricanes. They are also used to measure the steadiness or variability of various tropical wind fields and to obtain data that will permit deductions concerning the energy transformations in disturbed areas.

"Most of the investigative flight plans call for each aircraft to remain at either one or two levels throughout the flight. Rarely are efforts made to use the airplane at three levels because this would not permit efficient use of flight time for most types of investigations used in tropical meteorological research on the meso- or synoptic scales.

"The RFF aircraft are usually scheduled to fly at the same time in order to obtain data concurrently at three or four different levels for hurricane investigations.

"If the hurricane is close to the operating base, the two DC-6 A/B's occasionally try to obtain data at two levels

*Formerly designated National Hurricane Research Project.

each, and the B-57A makes two flights the same day in order to obtain data at two levels from the aircraft within the same 8- to 10-hour period. This permits defining the 3-dimensional structure of the hurricane or tropical disturbance.

"Many examples of flight plans used (too numerous to describe here) are outlined in Hawkins et al. (1962). A favorite flight plan used for investigation of hurricanes is described in the report on Hurricane Cleo (1958) by Dr. N.E. LaSeur and H.F. Hawkins (1963).

"In investigating potential genesis situations, where the disturbance is not yet well defined and many of the major circulation features are not concentrated in a relatively small area, the flight patterns differ markedly from those used in hurricanes. In such a case it is planned for each DC-6 A/B to fly long flight legs that intersect each other. Such a complete flight pattern will include several enclosed areas for which line integrals can be computed.

"The Research Flight Facility has also been used in special experiments, such as Project Stormfury and Project ECCRO. In Project Stormfury, the aircraft are used to obtain data before and after the seeding experiment to measure the change as a function of time of the meteorological parameters. In Project ECCRO, the Research Flight Facility, along with aircraft of the U.S. Navy and U.S. Air Force, were used to obtain data at five different levels over the eastern Caribbean Sea to make possible a very meticulous analysis of synoptic situations against which other types of analysis might be compared. These data are also being used to determine the quantity of data and the degree of data accuracy required for different types of analyses in the tropics" (Dr. R.C. Gentry, 1967, personal communication).

A.7 Radiation Branch, ESSA

Principal Investigator: Dr. H. F. Mueller, Chief

RFF aircraft were requested to participate in three activities during 1966 concerning nuclear reactor experiments conducted by the Westinghouse Astronuclear Laboratory and the Space Nuclear Propulsion Office at the Nuclear Rocket Development Station, Jackass Flats, Nevada. These experiments were designated NRX/EST, EP IV, 3/16/66; NRX/EST, EP IV, 3/25/66; and NRX-A5, EP IV, 6/23/66.

"Nuclear rocket experiments produce a radioactive effluent which is released to the atmosphere and transported for great distances by the prevailing winds. The effluent becomes mixed in a layer from the earth's surface to heights like 15,000' MSL. It is the responsibility of ESSA, ARFRO to predict the trajectory and transport speed of this effluent and to make estimates of downwind air concentrations of the radioactive fission products released.

"The scale of this problem and the paucity of meteorological observations in the western United States makes the problem of predicting trajectories and concentrations and of evaluating the observed radiological data a difficult one. Meteorological information, wind, and temperature sounding obtained by aircraft are very desirable operationally, if they are available in real time. Diagnostically, they are useful in establishing post-facto trajectories of the effluent cloud. Radiological data from ground monitoring activities, in general, are quite sparse, and it is very important to be able to determine the representativeness of each piece of information in order to evaluate downwind concentration prediction capability. Aircraft data, both radiological and meteorological, assist immeasurably in accomplishing this evaluation by establishing the aerial extent of the cloud, the vertical and horizontal distribution of the radioactivity, and the winds and temperature structure affecting the cloud.

"To date the data obtained by the RFF aircraft missions have been used only in preliminary evaluations. The radiological sampling has been most useful in establishing vertical profiles of the radioactivity concentrations as a function of downwind distance. Measurements of peak concentrations of activity have been combined with activity measurements made by other participating organizations and have been of benefit in establishing long range dillution rates. The prediction of dillution rates for great distances is of vital importance to the testing program at the NRDS as well as the NTS.

"Both the meteorological and radiological data obtained by the RFF aircraft will be examined in greater detail as time permits. A study is currently in progress to establish the effect of mountain waves on the distribution of radioactivity as it crosses mountain barriers" (Dr. H.F. Mueller, 1967, personal communication).

A.8 Sea-Air Interaction Laboratory (SAIL), ESSA
Principal Investigator: Dr. James D. McFadden*

Project 1. Sea-Surface Temperature in the Wake of Hurricane Betsy (1965)

Two flights were made at night over the Gulf of Mexico: the first prior to the hurricane passage and the second 5 days after the passage of Hurricane Betsy. The purpose of the flights was to detect sea surface temperatures with the Barnes IT-2 radiometer in an effort to determine the effects of the hurricane on the thermal pattern of the sea surface. The data were used, first, to locate the position and size of a cold water zone, presumably produced by upwelling, and second, to show that the thermal pattern was considerably altered by surface currents over the relatively short period between

* Dr. McFadden is currently affiliated with the RFF.

flights, thus supporting the argument that an aircraft is more suitable than a ship for obtaining this type of information.

Project 2. Instrument Comparison Test.

Before embarking on any project where data of the same type but collected by different instruments carried on various platforms are to be compared, it is essential that all sensors measuring the same parameter be compatible. With this in mind, SAIL, with RFF and the Naval Oceanographic Office ASWEPS group, organized a test to determine the comparability of data obtained from two aircraft, radiosondes and shipborne equipment.

Project 3. Hurricane Intensity and Movements - Sea-Surface Temperature Relationship.

A flight was made on October 6, 1966, in the area ahead of Hurricane Inez to obtain sea-surface temperatures in an effort to determine the relationship between the temperature pattern obtained and the intensity and direction of movement of the hurricane as it passed through that area. Subsequent flights by the RFF aircraft to obtain sea-surface temperatures (Gladys, 1968) following hurricane passage over the sea have also been accomplished. These data have been published (Kuhn and McFadden, 1967; McFadden and Wilkerson, 1967; McFadden, 1968a,b; McFadden and Kuhn, 1969).

A.9 Comments by Dr. R. H. Simpson

Director, National Hurricane Center, ESSA/WB, Miami, Fla.

"Any summary which I would supply you would for the most part overlap the more definitive information which you should obtain from NHRL and NSSL and the special users of the RFF systems. My role has been that of attempting to develop the instruments, in some instances exotic and specialized instruments for special purposes, not all of which accomplished their purposes, but indeed all of which have stimulated fresh ideas on the use of aircraft in meteorological research.

"The several instrumental components which should not be overlooked in your summary are the Giannini gust probe system which was intended for use in measuring turbulent exchanges in the boundary layer, including the vertical flux of heat and momentum.

"The design of the experiment, which was never completed due to the fact that we were never able to make the instruments operate as intended, was described by me at the Pacific Typhoon Conference at Baguio in February 1963. As you know, we conducted a number of experiments using this probe during the first trip to the Indian Ocean.

"The second item which should not be overlooked is the work done in the air-to-air tracking and control of meteorological drones experiment, which was carried out in western Oklahoma in April and May 1962. Here, the feasibility of air-to-air control was demonstrated, although the performance of the drone in convective storms indicated that further development of the basic aircraft controls would be needed before effective research could be accomplished by this means. The principal report on this activity is by Mr. Robert Ruskin of the Naval Research Laboratory (Ruskin, 1963). This appeared in NRL Report 5923 of June 14, 1963. You will of course obtain a detailed summary from Dr. Joanne Simpson concerning instrumentation used in support of Stormfury and I will not attempt to speak of these here.

"I consider the greatest strength in the overall system the high performance of the Doppler wind system and of the digital systems which permit rapid data recording and processing. I consider that the application of the RDR radar has been unique and one of the most powerful tools of analysis available through airborne reconnaissance.

"These comments are general and may not provide much grist for your report. However, I am counting on what should be the contributions to come from those who have spent the larger portion of the time in research on the data you acquired with the aircraft" (Dr. R. H. Simpson, 1967, personal communication).

A. 10 Institute of Marine Science
University of Miami: Hurricane Tritium Project (1965-1967)
Principal Investigator: Dr. G. Ostlund

(1) Mission Objectives. The primary mission objectives for the tritium project are the sampling of liquid-water (precipitation) and atmospheric water vapor. These samples are analyzed for tritium in order to:

(a) Study the air/sea exchange of water in hurricanes.

(b) Investigate the possible occurrence of stratospheric subsidence into the hurricane eye.

(c) Examine the natural modification of a continental air mass over water (a study made in collaboration with Dr. Machta of ESSA's Air Resources Laboratory).

(d) Study the vertical distribution of tritium in tropical atmosphere.

(2) Projects and Associated Flight Patterns. Many different flight patterns have been used in conjunction with the projects listed below; however, only the most effective patterns used to date are mentioned.

(a) Air/Sea Exchange of Water in Hurricanes:
"The best flights thus far have been long diametral crossings through the storm center (eye), starting well outside the storm envelope on one side and ending well outside the storm envelope on the opposite side. If two diametral crossings were used, they were at right angles to each other

(usually north/south or east/west). These tracks were effectively employed in hurricanes CELIA, FAITH, and INEZ during the 1966 hurricane season and on two storms in one flight during the 1967 hurricane season, a first for the RFF (CHLOE and DORIA).

(b) Possible Stratospheric Subsidence in the Hurricane Eye: "The flight pattern employed here is very simple-orbits in the eye, well away from the inside eye wall. This was usually done in conjunction with other flight patterns utilized by both the National Hurricane Research Laboratory and the Institute of Marine Science.

(c) Modification of a Continental Air Mass Over Water: "The pattern for this mission was requested by Dr. L. Machta, Director, ESSA, Air Resources Laboratory, and the actual sampling was accomplished by the Institute of Marine Science and the RFF aircraft. It consisted of a series of box patterns at altitudes ranging from 200 to 6000 ft, oriented along a line perpendicular to and behind a cold front. These flights were made during March 1965 and 1966.

(d) Vertical Distribution of Natural Tritium in the Undisturbed Tropical Atmosphere: "Two aircraft were used for this pattern (October 1965, August and September 1966). The RFF DC-6A/B sampled at levels from 200 to 20,000 ft, while the RFF B-57A sampled the 31,000 ft and 41,000 ft levels. Each level was located over the same geographical area " (Dr. G. Ostlund, 1967, personal communication).

(3) Special Instrumentation on the RFF Aircraft.

(a) Liquid-Water Sampling System: A 100-cm^2 forward-facing scoop has been mounted on the fuselage (ahead of the propeller line) of each RFF DC-6A/B and the C-54(DC-4) aircraft. Liquid water is collected on the aircraft in 1-quart containers inside the aircraft. The containers are easily changed during flight, even under turbulent conditions. The control valves and containers for this system are located at the visiting scientist and meteorologist positions on each of these aircraft respectively.

(b) Water Vapor Sampling System: An air flow system with a flow rate of 300 to 400 liters/min through a 10-mm (minimum) diameter line is located at the visicorder station (rear starboard with a dual outlet at the visiting scientists position) on both RFF DC-6A/B aircraft. These systems derive their air pressure from aftercooler stage of the aircraft cabin pressurization system. The C-54(DC-4), having no cabin pressurization system, must use a 70 liter/min dry air pump with an air intake that is an aft-facing tube mounted on the top of the liquid-water probe scoop. Water vapor samples are obtained from these systems by passing the air through a water absorbant material, Linde Molecular Sieve 4A. The air flow for water vapor sampling on the RFF B-57A aircraft is obtained from a 2-inch diameter forward-facing scoop. The flow rate from ram-air pressure is approximately 300 liter/min through a 10-mm diameter line at 41,000 ft.

(4) How the Data Are Used. Liquid-water vapor samples are processed at the Institute of Marine Science Hurricane Laboratory for tritium measurements. These measurements are used in conjunction with meteorological and navigational data supplied by the RFF to obtain correlations pertaining to the project objectives. These data, especially those obtained from the molecular sieve, can also be used as an independent check (or comparison) for the RFF infra-red hygrometer (vapor density) measurements.

A. 11 Colorado State University

Principal Investigators: Dr. H. Riehl, Dr. W. Gray

"I have participated in planning execution and analysis of RFF missions from the inception of hurricane research flights, and I have greatly enjoyed my relations with RFF. Much of the progress in knowledge on hurricanes and their forecasting in the last decade has come from the results of these missions.

"Research objectives, towards which flights have been directed with my assistance, have been in part: (1) determination of the mechanics and energetics of the mature hurricane, and (2) determination of factors favoring or impeding hurricane formation from waves in the easterlies.

"Results of these studies have been published in various journals. I should mention that of the more recent flights, those of August 1964 have been and still are of particular interest inasmuch as they have pointed to an important mechanism in establishing the structure of waves in the easterlies and the deepening of such waves. Research on this very important subject is continuing.

"In spite of the great achievements and excellent flight record of the RFF, much remains to be done with research flights before the hurricane problems can be considered to be really solved. In particular, flights below cloud base and around 40,000 ft altitude are needed, and this should be taken into account in acquisition of aircraft and future instrumentation. Further, the resources of RFF have been marginally low for exploring many research purposes, both as to number and speed of aircraft. It would be highly desirable to add two 400-knot aircraft with long range capability to the present fleet, as well as subsonic jet aircraft for thorough exploration of the upper troposphere.

"In addition to hurricane associated missions, the RFF has supported research on the documentation of the sub-cloud (mixed) layer. Flights were made with the RFF B-26C aircraft in October 1961 and August-September 1962. An RFF DC-6A/B aircraft also supported the sub-cloud missions in September 1964" (H. Riehl, 1967, personal communication).

A.12 Air Resources Laboratory, ESSA

Principal Investigator: Dr. L. Machta, Director

(1) Air Mass Modification Project

Conducted in March 1965 and 1966; supported by USAEC transfer funds.

(a) Objective: To measure gradients of artificial and natural radioactivity, temperature, moisture, wind, carbon dioxide, tritium, deuterium and ozone as an air mass moves from land to sea. The prime objective was to see if changes in the gradient of atmospheric particulate radioactivity could shed light on special oceanic uptake of the radioactivity.

(b) Pattern : Vertical profiles obtained aircraft remaining at a given altitude to perform sampling from 15 to 30 min. Profiles were obtained over land and at several downwind locations over sea. Altitudes normally confined to 3000 ft and below. Replicate samples were obtained by having two aircraft fly about the same patterns.

(c) Uses for Data: The synoptic situation in 1965 was known to be marginal and the rapid movement from land to sea failed to occur. Patterns of profile changes made little sense. 1966 results promise to be better but full analyses and interpretation is incomplete. If successful, publication is planned.

(2) Carbon Dioxide Measurements in the Equatorial Zone Project.

Requested by Mr. Walter Bischof, University of Stockholm; supported by USAEC transfer funds, conducted in April 1966 (see A.4).

(a) Objective: To explore, for the first time, the spatial distribution of carbon dioxide in the lower equatorial troposphere. Mr. Bischof followed up this work by using commercial aircraft for upper tropospheric CO_2 sampling. Ozone and natural radioactivity measurements were also obtained for the first time. An AEC gamma sensing instrument was tested by the RFF.

(b) Pattern: A ferrying operation to Panama was followed by flights through the Inter-Tropical Convergence Zone, generally below 10,000 ft.

(c) Uses: Results of CO_2 and natural radioactivity study to be published. It was shown that the

gamma sensing instrument could not be used aboard the aircraft because of high background noise from the aircraft and its instruments" (Dr. L. Machta, 1967, personal communication).

A.13 Atmospheric Physics and Chemistry Laboratory, ESSA
Principal Investigator: Dr. Helmut K. Weickmann, Director

In addition to the support given by the RFF to the projects of the Experimental Meteorology Branch of the Atmospheric Physics and Chemistry Laboratory (see A.3), the RFF supported APCL research described below.

(1) Project Hailsworth

RFF aircraft were used to support data collection program. The APCL participated for two reasons:

(a) To offer its research facilities to the scientific community; these facilities included a mobile cold chamber used for hail analysis, and the use of the RFF aircraft for storm surveillance.

(b) To test various proposed hypotheses and concepts connected with the mesometeorological characteristics of hailstorms.

Hailswath is considered by ESSA participants to be a proving ground for future hail suppression projects. Mobility is the byword in the study of such storms, due to the sporadic nature of their occurrence. The RFF DC-6 A/B aircraft were used to make the necessary in situ measurements of the storm and its ambient environment.

The aircraft enabled storm systems to be analyzed and studied on a subsynoptic scale. This is necessary since the hailstorm is generally considered to be a mesoscale phenomen.

A question was posed: Can an aircraft equipped with a digital data recording system such as the system in the RFF DC-6 A/B fulfill the mission of a mesometeorological station?

APCL believes "that the test of this concept was successful beyond expectations and that with several identically equipped aircraft the problem of a mesometeorological observation system can be solved" (Dr. H. Weickman, 1967, personal communication).

(2) Mesometeorological Storm Surveillance.

"Three flights were made by the RFF DC-6 A/B in June 1966. On two of the three days, there were thunderstorms; however, on June 17, the only major storm system was encountered. The aircraft's 5 cm (WP-101) radar was quite helpful in detecting and skirting the precipitation area of interest. During this time digital data was being recorded at one sample per second. Several interesting mesoscale features were delineated during this flight. Cross-section radar coverage from the 3 cm (RDR-1D) radar on the aircraft helps to pictorialize the three-dimensional structure of the storm. The results of this and other flights indicate that the aircraft's instrumentation system is most suitable to serve as a line of meso-meteorological stations along the flight path. The horizontal measurements (made by onboard sensors) coupled with the vertical measurements (dropsonde) and radar data (both PPI and RHI presentations) make the RFF aircraft highly valuable for studies of the nature described herein" (Dr. H. Weickman, 1967, personal communication).

In 1968, the RFF again supported APCL in a major field operation known as the Lake Effect Snow Project. The purpose of this project was to acquire a better understanding of severe lake-effect snow storms by further investigation of the conditions under which the storms form and to:

(a) Study the horizontal and vertical dimensions of the storm;

(b) Study the physics of the cloud and precipitation mechanisms involved;

(c) Study the dynamics that lead to the generation of storms and their persistence over relatively limited areas;

(d) Continue studies of numerical modeling of lake-effect storms;

(e) Study circulation patterns in the storms and the heat transfer energy budget evaluations; and

(f) Conduct cloud seeding to determine its effect on the storm structure with the objective of redistributing the snowfall over a less concentrated area and to assess the feasibility of future large-scale lake storm modification.

A.14 Meteorological Satellite Laboratory, Project Storm-Cloud

Principal Investigator: Dr. E. Paul McClain

(1) Introduction

Project Storm-Cloud was designed to make extensive use of the RFF meteorological research aircraft and operational satellites in case studies of "east coast" cyclones, that develop near the Atlantic coast of the United States. Nearly simultaneous satellite photographs, aircraft time-lapse cine film, and radar scope photography enables a synergistic approach to the synoptic-scale meteorological analysis performed on the Storm-Cloud data. The satellite pictures provided a broad-scale framework about which the other forms of data could be organized, while highly detailed data provided the RFF research aircraft enabled better interpretative use of the satellite pictures.

(2) Discussion

The investigation of a coastal cyclone is often hampered by the fact that much of the circulation is found over

the ocean, where detailed conventional meteorological data is almost nonexistent. The field program of Project Storm-Cloud was therefore designed to make extensive use of the RFF research aircraft for the collection of detailed meteorological observations in conjunction with satellite passages over the area.

A.15 East Coast Cyclone Development Study, Project Snow

Principal Investigators: Dr. Jerome Spar, Department of Meteorology and Oceanography, New York University, and Mr. Silvio G. Simplicio, Director, Eastern Region, ESSA/Weather Bureau

A major prediction problem facing the meteorologist is that of producing short-range forecasts approaching the mesoscale in time and space. This involves the ability to deduce mesoscale meteorological details through the interpretation of the synoptic-scale features.

Since the advent of numerical weather prediction, the role of the forecaster has undergone a revolutionary change. The emphasis has been placed on prediction of the weather elements for the shorter time intervals, in contrast to the previous role, which included the prediction of the fields of motion and moisture in addition to the resultant weather parameters. It is quite apparent that the meteorologist is not prepared for this new role and that the state of the art is lacking. The problem of meso-scale prediction is quite complex from both an observational and forecast point of view. In fact, the problem is so universal among all federal agencies concerned with meteorological practices that the Federal Coordinator for Meteorology has been assigned the task of finding a solution.

With the above in mind, a study is now in progress under the direction of Dr. Jerome Spar, New York University, and Mr. Silvio G. Simplicio, Director, Eastern Region, ESSA/

Weather Bureau, which is aimed at submitting east-coast winter storms to diagnostic analysis in order to: (a) determine a model relating the mesoscale features to those of the synoptic scale for this particular type of development; and (b) assess current and future needs and facilities for mesoscale forecasting.

The program includes the following three phases: (1) data collection of special observations on a mesoscale (time and space) for two developing situations, (2) diagnostic analysis of the three-dimensional field of motion, temperature, moisture and the derived field of vorticity at 3-hourly intervals during the evolution of the storm and (3) determination of the feasibility of the mesoscale prediction with the observational network (in time and space) available for the study and suitable recommendations made for precedures and on further observational requirements.

RFF aircraft supported the data collection program of the project on February 18 and March 7 of 1967. The aircraft data was supplemented by special, surface, upper-air, radar and satellite observations made for this study.

Patterns were primarily flown over the ocean off the east coast in an area for which data are lacking. The information collected by the RFF research aircraft included horizontal and vertical(dropsonde) distribution of wind, temperature, and moisture, as well as cloud weather information (visual and photographic) and radar photography on both PPI and RHI presentations.

"The RFF operated under adverse weather conditions and ARTC (Air Route Traffic Control) constraints and on extremely short notice. The complete operation involved detailed and painstaking work in preliminary planning with the Federal Aviation Agency (ARTC), since approximately five different control centers were involved in the flight program. This

advance planning made it possible for the RFF to accomplish the missions which involved complex height and route deviations around reserved air space during extremely busy air traffic periods and poor weather conditions.

"This is another first in a long list of achievements by the RFF which has my complete endorsement as an excellent operational and research facility."*

The ESSA/RFF also supported this research/operational program during the winter season of 1968 with two aircraft.** ESSA (N6540C) DC-6 A/B was staged out of New York (LGA), Miami, and Charleston (S.C.) for the period January 15th through March 13, 1968. Four research missions were flown (on three storm systems). Real-time transmission of reconnaissance (meteorological) data from the aircraft to the ESSA/Weather Bureau Eastern Region via SSB (and other methods) proved quite successful from an operational and research data dissimination point of view.

Research based on the RFF collected and processed data is now being performed at New York University by Dr. J. Spar and his associates. Some results have been published by Spar et al. (1968).

A.16 Barbados Oceanographic and Meteorological Experiment

Principal Investigators: Dr. J. Kuettner, Project Director; Dr. J. Holland, Scientific Director, Phase I, II, and III; Dr. J. Charney, Scientific Director, Phase IV.

The Barbados Oceanographic and Meteorological Experiment (BOMEX) is a bilateral program conducted by the government of the United States in cooperation with the government of Barbados. Participation of the United States is conducted on

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*From letter of commendation sent to Dr. G. Benton Director, ESSA/ERL.

**DC-6A/C (N6540C) flew the first three missions, and DC-4(C-54) (N91282) accomplished the fourth mission.

an interagency basis with ESSA as the lead agency. BOMEX is a scientific effort designed to study extensively the joint behavior and interaction of the atmosphere-ocean system in subtropical and tropical waters from the subsurface to the troposphere, including synoptic, meso, and convective modes of the system.

During the period of the BOMEX field operation, May 2 through July 29, 1969, the RFF aircraft provided approximately 1000 research flight hours. The RFF will continue to support the project now that the field program has been concluded by providing its services for data processing, reduction, and preliminary analyses.

The BOMEX data collection program was divided into four phases. The first three phases provided for a concentration of efforts for measuring and studying the continuous exchange of energy, momentum, gases, particulates, and electric charges at the air-sea interface and for ways in which energy and the other properties are transported from the experimental area by the atmosphere and the ocean.

The aircraft program is designed to compliment ship data provided by surface vessels of the other participating agencies. The collected data will be used for the study of (1) the vertical flux of momentum, sensible heat, latent heat, radioactivity, and other properties at the interface and horizontal transport of these properties through the lateral boundaries of the observational array, (2) the vertical and horizontal divergence of these fluxes within the interior of each fluid, and (3) the feasibility of parameterizing the area-wide integral of at least the surface fluxes from conventional observation at fixed corners of the array.

During the fourth phase accomplished in July 1969, the project concentrated on a study of tropical weather disturbances, with the specific objective of gaining information needed for improved mathematical models of the global atmosphere.

For this phase, the principal investigators hope to learn whether moderate disturbances are similar in structure to intense disturbances, such as hurricanes, and also how cumulus convection interacts with the frictional boundary layer and is coupled with large-scale circulation.

A.17 Concluding Remarks

The subsections and references contained in this appendix are, in general, representative of the overall versatility of the RFF to perform successfully for a wide variety of research programs. Information concerning other programs supported by the RFF since 1960 was not received in time for inclusion in this publication.

Researchers and/or projects served by the RFF, as well as prospective users are encouraged to provide comments for future publications of this nature. This type of "feedback" from the researcher can be helpful for the RFF in providing an improved comprehensive service to the entire scientific community.

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