The ESSA Research Flight Facility's Support of Environmental Research in 1969

HOWARD A. FRIEDMAN AND WILLIAM S. CALLAHAN,
Research Flight Facility, Miami, Florida

EFFORTS of the Department of Commerce to obtain environmental data with specially instrumented airplanes had its beginning in 1956 under the National Hurricane Research Project (NHRP), presently designated the National Hurricane Research Laboratory (NHRL), which is part of the ESSA Research Laboratories, Atlantic Oceanographic and Meteorological Laboratory (AOML), Miami, Florida. Initially, airborne hurricane research was supported by the United States Air Force with two WB-50 and one WB-47 aircraft which were instrumented and operated under the direction of the United States Weather Bureau through the 1956 to 1958 hurricane seasons.

During this three-year program considerable strides were made in melding together a viable complex of sensors and supporting instrumentation to yield meterological data in digital form. This program, combined with the cumulative experience gained in the processing and analyses of data, provided the foundation upon which the present Research Flight Facility (RFF) program has been built.

In 1959, when the Weather Bureau decided to continue the hurricane research program with its own aircraft and improved instrumentation, two DC-6 A/B aircraft were obtained from Trans-Caribbean Airlines; and, the Air Force transferred the title of a B-57A aircraft to the Department of Commerce. One of the DC-6 A/B aircraft was put into service in the spring of 1960, and the other aircraft were activated during the 1960 hurricane season.

In 1961 the Flight Operations Group of the NHRP was established as the Research Flight Facility. By that time it had become evident that the instrumented platforms and capabilities of this group were well suited to serve a wide variety of environmental research programs.

During its history, the RFF has also used a WB-26C, F-11A, and drone aircraft to support environmental research; and, in 1965 a C-54 (DC-4) aircraft was obtained from the Air Force. In addition to augmenting the fleet-in-being, the C-54 aircraft provided additional low-level measurement, test-bed, and logistical support capabilities.

Born of the need to investigate one of the most spectacular tropical weather phenomenon of all—the hurricane, the RFF has for over a decade supported major environmental research efforts aimed at providing scientists with a more fundamental understanding and complete description of convective, meso, and synoptic scale processes in the atmosphere.

RFF's major responsibility is to meet the requirements of the ESSA Research Laboratories and other government-supported activities for obtaining environmental measurements with specially instrumented aircraft. Within this frame of reference, the RFF has supported: major world-wide experiments, including the International Indian Ocean Expedition and the Barbados Oceanographic Experiment, major universities, and the scientific community at large.

The reader is directed to the publications listed in the "General Bibliography" for further details on the history, data processing, instrumentation, data validation procedures, and projects supported by the RFF.

Support of Environmental Research—1969

This past year (1969) was one of the most active in the ten-year history of the RFF. The facility accomplished 236 missions (approximately 1,540 hours of research and operational flying) in support of: the Atmospheric Physics and Chemistry Laboratory, ESSA-APCL; the Barbados Oceanographic

Fig. 1. Research Flight Facility prepares for a research mission during the Lake-Effect Snow Project. Photo by B. Patten, RFF.

and Meteorological Experiment, BOMEX; the ESSA-Weather Bureau, National Hurricane Center, ESSA/WB-NHC—including investigative flights into hurricane Camille and waterspout research; the National Hurricane Research Laboratory, ESSA-NHRL—including Project Stormfury (hurricane modification experiments), hurricane and tropical storm research, tropical cloud-line investigations, and special cloud physics instrumentation testing; RFF's own in-house programs for instrumentation testing, data validation, and air-crew proficiency; and, other operations that are described briefly below. The projects supported by the RFF, number and type of aircraft utilized, missions and flight times for each activity accomplished during 1969 are given in table 1.

TABLE 1

RESEARCH FLIGHT FACILITY SUPPORTED ACTIVITIES—1969

Activity	Aircraft	Missions	Flight times
Atmospheric Physics and Chemistry Laboratory	(1) DC-6 A/B	14	61 hr 18 min
Barbados Oceanographic and Meteorological Experiment	(2) DC-6 A/B (1) C-54 (DC-4)	141	1096 hr 12 min
National Hurricane Center	(2) DC-6 A/B	4	25 hr 57 min
National Hurricane Research Laboratory (including Project Stormfury)	(2) DC-6 A/B (1) C-54 (DC-4)	46	287 hr 46 min
Research Flight Facility (in-house testing of instrumentation, data validation and aircrew proficiency)	(2) DC-6 A/B (1) C-54 (DC-4) (1) B-57A	31	69 hr 15 min
Totals for 1969:		236	1540 hr 28 min

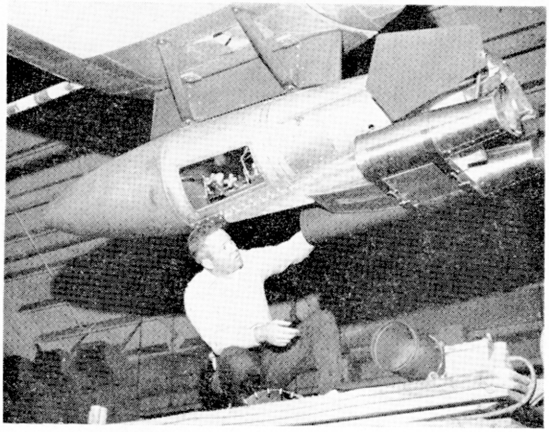

Fig. 2. RFF developed steady-state flame type generator being readied for a cloud seeding mission. Photo by B. Patten.

Atmospheric Physics and Chemistry Laboratory: Lake-Effect Snow Project

One RFF DC-6 A/B aircraft (N6539C) participated in the Lake-Effect Snow Project from 7 November through 14 December 1969. Special equipment, including silver iodide (AgI) steady-state flame type generators, dry ice dispenser, infra-red radiation detection, and cloud/ice nuclei instruments were installed on the aircraft. These instruments or devices provided additional measurement and/

Fig. 3. Steady-state flame type generator in operation during the Lake-Effect Snow Project. Photo by B. Patten.

or cloud seeding capabilities during the field program. Flight patterns were conducted over much of Lake Erie and in the vicinity of Dunkirk, N. Y., where snowfall is heavy due to the combined effects of the moisture uptake from the lake and local orography.

The purpose of this field experiment was to enable the researcher to obtain a more complete understanding of severe lake-effect storms by further investigation of the conditions under which these storms form. Scientists concentrated on obtaining measurements that would enable them to study and document: (a) the vertical and horizontal dimensions of these storms; (b) the physics of cloud and precipitation mechanisms involved; (c) the dynamics which lead to the generation of lake-effect storms and their persistence over relatively limited areas; (d) numerical modeling of lake-effect storms; (e) circulation patterns in the storms and heat-transfer energy budget evaluations; and, (f) the conduct of cloud seeding experiments in order to determine its possible effects on the storm structure.

The primary objective of the cloud seeding experiment was to redistribute the snowfall over a wider area, thereby lessening the effects of heavy amounts in more densely populated areas; and, to assess the feasibility of proposed large-scale, lake-effect storm modification operations.

Data for the measurement or determination of divergence, inflow, and storm intensity was provided with RFF's mesometeorological instrumentation systems (1, 2). In addition, special cloud physics measurements of cloud particles and ice nuclei (size, concentration and distribution) were obtained during the numerous cloud seeding and weather reconnaissance missions flown (figs. 1 thru 5). The DC-6 A/B aircraft also served as the control plane when multiple aircraft flight patterns were required.

Another project supported by the RFF during this field program involved the comparison of three techniques for cloud seeding, namely: AgI pyrotechnic flares; AgI steady-state flame type generator; and, dry-ice methods.

The Lake-Effect Snow Project is a continuing research activity which the RFF expects to support in the future.

The Barbados Oceanographic and Meteorological Experiment

The Research Flight Facility's major effort of the year was in support of the Barbados Oceanographic and Meteorological Experiment (BOMEX). Three of RFF's aircraft—(2) DC-6 A/B and (1) C-54 (DC-4)—were used extensively in support of this field program during the three-month period May through July 1969. Additional flights were performed prior to the field experiment in order to develop operational patterns and to test, calibrate, validate and compare aircraft sensor derived data (7).

The aircraft flew a total of 146 missions totaling over 1000 hours (including the pre-BOMEX missions), and obtained the following information: approximately three million digitally recorded meteorological observations; numerous sea-surface temperature and water vapor flux measurements; two million cloud and radar photographs; measurements of incoming and reflected solar radiation; dust concentrations; and, Aitken nuclei counts.

BOMEX was a bilateral program conducted by the governments of the United States and Barbados. United States participation was conducted on an interagency basis, with ESSA as the lead agency.

The program—a major scientific effort designed to study extensively the joint behavior and interaction of the atmosphere-ocean system in subtropical and tropical areas, from the sub-surface to the troposphere, including the synoptic, meso, and convective modes—was conducted from the island of Barbados (9).

One of the major observational experiments of BOMEX was the water vapor flux (WVF) measurement program. The WVF and other experiments are described in recent publications (7, 9).

RFF aircraft provided approximately 1100 flight hours for the collection of meteorological and other research data. Standard preliminary data processing procedures were employed to provide "first-look" data during the field program (5, 7). The RFF is continuing to support BOMEX, now designated as the Barbados Oceanographic and Meteorological Analysis Project-BOMAP, with a four-point program associated with the processing of the aircraft data, and aimed at determining er-

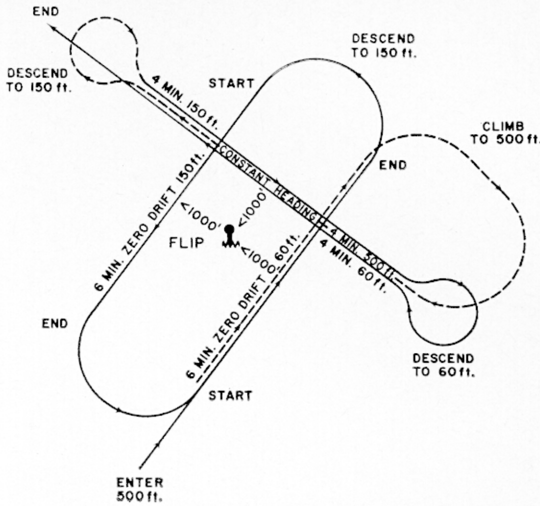

Fig. 4. Pattern flown in support of the water vapor flux measurement program of BOMEX.

rors to establish corrections for the meteorological and navigational parameters.

National Hurricane Center—NHC, Miami, Florida

In addition to supplying reconnaissance data to NHC on all hurricane and tropical storm research missions (normally, flown in support of the National Hurricane Research Laboratory, see below), RFF supported additional reconnaissance in hurricane Camille; and, provided multilevel research data in the vicinity of waterspouts near the Florida Keys.

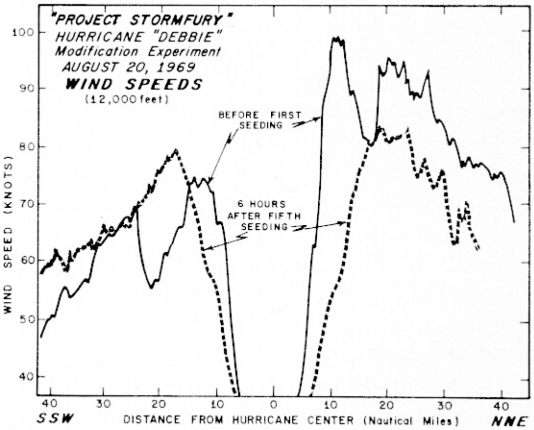

Fig. 5. Wind speed profiles before and after seeding hurricane Debbie, 20 August 1969. Courtesy of R. C. Gentry.

altitudes. The flare drops were monitored by trained observers from RFF and EML who were located on the beach of the State Park. A portable transmitter/receiver system was used for ground-to-air VHF communications between the observers on the ground and the B-57A aircraft. Time exposure photographs were taken of all flare releases, subsequently providing information on the flare reliability, burn time and trajectories (15, 16).

RFF also accomplished a "mercy" mission in support of the Atlantic Tradewind Experiment (ATEX). When an essential weather radar on board the U. S. Coast and Geodetic Survey ship DISCOVERER failed enroute to a rendezvous with two West German and one British research ships off the African coast, the RFF flew a critical radar part and made an "on target" drop of the part to the ship.

At the time of the drop, the DISCOVERER was being buffeted by 25 kt winds and heavy seas about 700 nautical miles from Miami in the Atlantic.

The new radar equipment was packaged in a dropsonde unit with special flotation gear and dye markers for identification. It was dropped to the ship and a successful recovery effected, permitting the ship to continue its ATEX mission without costly delay.

Computer Program Development and Implementation

RFF's standard data processing procedures have been described in detail in a recent publication (5). The so-called standard or basic data processing performed for all scientific users includes an original tape listing of collected data (OTL Program), and a quality-control analysis of the flight tape data (RFF01 Program).

Digital data acquisition system modification, and the development of a new prototype system (presently used on the C-54 aircraft), have required RFF's basic programs to be somewhat redesigned.

Other data processing programs which are designed to yield data in "final" form—ready for research application—have also been redesigned to meet new computer system specifications.

Programs have also been developed to handle frequency modulated (FM) analog data collected with the specially instrumented RFF DC-6 A/B aircraft. This data is relevant to RFF's turbulence measuring system, probe-sensors, inertial platform, and other fast response time sensors.

The development of this system includes the acceptance of the FM analog magnetic tape signals that represent parameters necessary for the determination of the water vapor flux. Twelve of the fourteen recorded channels are FM extended mode signals (bandwidth 3375 Hz $\pm$ 40%). One channel is reserved for phase-locking and is a direct recorded signal at 6250 Hz. The remaining channel is an "IRIG C" time-code generator signal. Processing is accomplished with a hybrid computer.

Analog tapes are run initially in a calibrate mode, at 30 ips, to obtain full scale values of the parameters. Then, in a run mode, selected channels are read and referenced to the full-scale values obtained during the calibration phase (or mode).

Scaled values are then low pass filtered through circuits which simulate a sixth-order Butterworth type filter. The time-code signal is read and decoded; and, all channels are then sampled and digitized at the rate of 40 frames per recording second. Digital tape records are written in a binary-coded decimal (BCD) form every 300 frames. Each frame contains 12 words of data (9 channels sampled at 20 sps, 1 channel sampled twice at 40 sps, and the time channel sampled each minute). The other main output of this program is a strip chart recording of all of the analog information.

A time series analysis subsystem has also been developed to process the water vapor flux data. The system accepts as its basic input, the digital tape output of the analog-to-digital conversion operation described above. A specially designed FORTRAN computer program, appropriate calibration, data search, and processing parameters are used with the input data on an IBM 360/75 data processing system.

Although many options are available, the principal analysis mode employed for the computation of the water vapor flux is as follows: (a) a particular data run is located; (b) this data run is processed, first to obtain linear trends of each component data channel; (c) the same data run is processed again to remove the linear trends, forming and storing the two main time series (W—vertical gust velocity, and H—absolute humidity); (d) the first four moments are computed for both W and H; (e) each time series is then band-pass filtered; (f) each time series is autocorrelated and cross correlated; (g) lag windows are applied; (h) power spectral densities are computed for each time series; (i) quadrature, copower, coherency and phase are computed; and finally, (j) all summary data is printed in both tabular and graphical form.

RFF's Plans and Goals for 1970

A multi-phase program has been established by the RFF for 1970. These phases include: (1) improvement and acquisition of new cloud physics instrumentation (including a Lyman-Alpha total water content system; modified instrumentation systems to measure ice and cloud particle sizes, concentrations, and distributions); (2) the definition and description of a complete integrated airborne sensor and data acquisition system for environmental research—reflecting the state of the art for such systems; (3) RFF expects to supply specifications, based on this study, for the acquisition and instrumentation of basic sensors and recording systems in a WC-130B aircraft, which will be delivered late in 1970, along with an evaluation of and recommendations for the retention of instrumentation presently installed on the RFF C-54 aircraft. This overall program is directed toward the acquisition of one or more new aircraft and/or the updating of the present RFF aircraft complex and instrumentation systems; (4) improvements in the accuracy and reliability of RFF's integrated data collection complex continue.

Additional activities include continued support of the East Coast Cyclogenesis Study (Snow Project), January through March of 1970; the Colorado Lee-Wave Project, January through March of 1970; Florida Cumulus Project, April 15 through May 1970; the Hail Suppression Project, July 1970; the National Hurricane Center and National Hurricane Research Laboratory, including Project Stormfury, July through October 1970; Lake-Effect Snow Project, December 1970. Other requests are being evaluated.

Acknowledgments

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(*Continued on page 185*)

larger earth's vorticity. Similarly, if the column is compressed, Δp becomes smaller and so must the absolute vorticity.

Thus the general result is that if air columns are stretched but not allowed to change latitude, they must spin faster. Of if they are made to spin faster, they must stretch out in the vertical. This reminds us of the twirling skater, who increases her speed of rotation by bringing her arms closer to her body and thus nearer to the axis of rotation. Both cases are examples of the fundamental fact that angular momentum must be conserved.

In atmospheric motion this means that the vertical stretching and rate of spin on the air columns are ultimately related, and so by studying potential vorticity we obtain valuable clues to the processes at work in the atmosphere.

We have seen that the tagging of air parcels with conservative properties is a powerful technique for meteorological analysis and prediction. There are, however, serious problems. There is no property of air, except perhaps its mass, that is completely conservative. Sooner or later, something happens to change it. Even more serious is the fact that the air parcels themselves lose their identity as time goes on. Given enough time, a parcel will mix with and become blended with the whole atmosphere of the earth.

When Cleopatra glided up the Nile in her papyrus boat she left behind her a long string of exhaled air parcels. If she smoked, these might have been visible for a time, but in any event they were marked by their high mixing ratio, high carbon dioxide concentration, and perhaps by higher potential temperature and by perfumes of various kinds. Where are those parcels today? They have been mixed thoroughly and carried to every part of the world, so that one can now confidently predict that in every breath you take, you inhale at least 200 million air molecules that were once inside the lungs of that fabulous Egyptian!

Footnote

The details of the calculation by which this estimate was reached may be of interest to some readers. Human tidal air averages about 400 cm^3 per respiration. This is about 0.5 gram of air, consisting of 1.0×10^{22} molecules. If this amount of air is mixed uniformly with the entire atmosphere (5×10^{21} grams) the resulting mixing ratio is 1.0×10^{-22} grams per gram. So, of the 1.0×10^{22} molecules that are in each breath, on the average one was contributed by each breath of Cleopatra. She is known to have lived to the age of 38 years, and can be presumed to have made about 3×10^{8} respirations. Even if we make a generous allowance of one-third off for air breathed more than once or exchanged with plants and ocean, we find you inhaling in each of your breaths no less than 2×10^{8} or 200 million molecules that were breathed by Cleopatra at some time during her life.

Flight Facility (*Continued from page 181*)

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