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The Tornado-Research Airplane Project, 1958–1959

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ABSTRACT

This paper is a description of the Tornado Research Airplane Project during 1958 and 1959. The instrumentation of the aircraft, as well as the organization of the project, is described. A section on instrument calibration and a description of data reduction and processing are included. The results of a radiosonde comparison test made in 1959 are given, and these results are compared with the results of radiosonde comparison tests made during 1958. A sample of the graphical presentation that is available for each of the flights is shown. For the information of anyone interested in these data, a listing of all operational flights for both 1958 and 1959 is given.

1. History

The Tornado Research Airplane Project (TRAP) was originally organized to evaluate the feasibility of the use of aircraft as mobile platforms for meteorological instruments in the measurements of meteorological parameters associated with squall-line development. The project also included, as objectives, measurements of air-mass modifiction and conditions attendant to tornado activity. The project became operational in 1956. A P-51 aircraft was instrumented with National Research Laboratory axial-flow vortex thermometer, infra-red-absorption hygrometer, recording Kollsman pressure altimeter, National Advisory Committee for Aeronautics velocity-gust-height (VGH) meter, electric field meter, tape recorder and several cameras. Both the aircraft and instruments were untested quantities in this type of endeavor. 1957 saw the inclusion of the reverse flow, platinum resistance-type thermometer, dual omni-range indicator, photo panel and recording camera, and an improved method of time synchronization. In 1958, a P-38 replaced the P-51, bringing twin-engine safety to the aircraft operation. Radio communication between the aircraft and the Weather Bureau control station was established in 1959. A new improved infrared hygrometer was also installed. Thus, the

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project has been in a slow evolution, with progress made in the reliability of the operational probe, the instrumentation, and the utilization of the aircraft.

The project was directed by Mr. C. F. Van Thullenar, Chief District Meteorologist, District Meteorologist Office, U. S. Weather Bureau, Kansas City, Missouri. The aircraft were owned and operated under contract with the U. S. Weather Bureau by Mr. James Cook of Jacksboro, Texas. In 1958, the flight period was 1 February through 30 June, and in 1959 it was from 1 February through 31 May.

Flight planning, flight control and data processing were conducted by the Research Unit, District Meteorological Office, Kansas City, Missouri.

2. The aircraft

The aircraft was a modified P-38 with a cruising speed of around 200 kn. The maximum range of the aircraft, with auxiliary gasoline drop tanks, is over 1000 mi; however, a 3-½ or 4-hr flight (800 mi) was found to be the practical operational limit. The ceiling of the P-38 was over 25,000 ft; however, little flying was done above 500 mb. Although the aircraft is capable of ascent at a rate in excess of 2000 ft per min, a rate of 1000 ft per min was adopted as an operational standard. The purpose for such standardization was to simplify instrumental lag corrections.

3. Instrumentation of aircraft

Besides the normal instrumentation of an aircraft, the P-38 was equipped with various meteorological and recording equipment.

Two temperature-measuring devices were in operation on the aircraft. A National Research Laboratory axial-flow thermometer and a reverse-flow resistance-type thermometer were used in the flight evaluation because of its superior response-rate characteristics.

Measurements of the moisture content of the air were made by the use of the infra-red hygrometer.

The pressure height was sensed by a Kollsman altimeter equipped with a Kollsman synchrotel electric transducer and was recorded as a linear function on a Brown recorder.

Brown recorders were used to record the output of the reverse-flow resistance-type thermometer, vortex thermometer, infra-red hygrometer and, as mentioned above, the pressure height.

In the forward section of the aircraft, a modified instrument panel (photo panel) was photographed every 15 sec by a 35-mm camera. This photo panel contained an auxiliary altimeter, a gyro-horizon, a combination dual omni-range ADF magnetic compass heading indicator, a Veeder-Root counter number indicator, and clock. An electric field meter was also a part of the photo panel display.

Time synchronization was accomplished through an electrical hook-up with a Veeder-Root counter, such that the Veeder-Root clock automatically activated an advance in the counter number every 15 sec, and at the same time produced a deviation in the marking pen on each of the Brown recorders and triggered a picture of the photo panel. In this way, the two chart rolls and the photo panel were synchronized.

For special remarks on checking of synchronization, the pilot could manually trigger the taking of additional pictures of the photo panel, and, at the same time, hack marks were placed on the Veeder-Root traces of the Brown recorder.

For remarks, and as an additional post-navigational aid, a tape recorder was in use. All remarks made by the pilot as to position reports, entering clouds, encountering turbulence, sighting of tornadoes, *etc.* were recorded.

Vertical accelerations were measured by a VGH meter recorder designed and built by the National Aeronautics and Space Administration. This recorder was under separate control of the pilot and was turned on whenever the pilot thought the possibility of encountering turbulence existed. The completed records were evaluated by the National Aeronautics and Space Administration.

4. Objective

The objective of the probe flights was to learn as much as possible of the relation of meteorological variables to severe-weather phenomena, such as severe thunderstorms or tornadoes. Particular emphasis was placed on attempts to measure the time rate of change of the meteorological variables. In part, this resolved itself into sampling squall lines at various elevations and in various stages of development. It was not the objective of the project to have the aircraft actually penetrate tornado funnels or severe thunderstorms. Flight planning was accomplished through close coordination with analyses and forecasts made by the Severe Local Storms Forecast Unit (SELS).

The 1959 operation illustrated the fact that, even though this was a year of relatively few

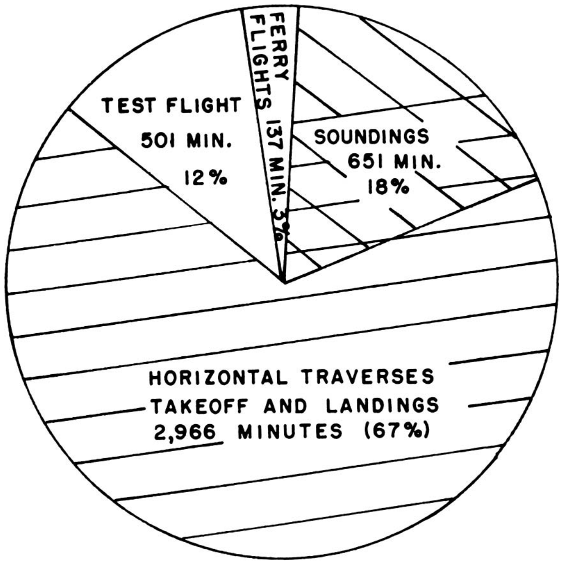

FIG. 2. Classification of flying time (total flying time—4255 min).

FIG. 1. Comparison of severe-weather days and operational flying during spring of 1959.

severe-weather outbreaks, the aircraft could be airborne and in a sampling position for most of these occurrences. Figs. 1A and 1B indicate the percentage of severe-weather days during the period and the percentage of these days the aircraft was able to sample.

5. Flight planning

Numerous types of flight missions were planned. Since flights in 1956 and 1957 were mainly at 700 mb, flights in 1958 and 1959 were planned largely for horizontal sampling at 850 and 500 mb so that a more complete model for the various stages of storm development could be developed.

Determining the time rate of change of the various meteorological parameters measured by the aircraft was accomplished in several ways. In a number of the flights, the suspected area of activity was crossed prior to the formation of clouds during the early formation and again when the line of clouds and associated weather were fully developed. In other flights, vertical air-mass soundings were made over a raob station near 1500GCT or 2100GCT (3 hr before or after the regular observations) or the soundings were made midway between raob stations at the time of scheduled observations. In several flights, soundings were made in advance of a moving squall line and to the rear of the squall line, within 25 mi and 2 hr of reported tornado occurrences. Other flights were just in advance or just behind a tornado-producing squall line. Subsynoptic-scale low centers and several meso-highs were sampled. At least two penetrations were made of pressure surge lines which produced severe turbulence in the clear air. Flight paths were in close proximity to several large-hail (1- to 2-inch diam) situations. One flight was made in the vicinity of the severe thunderstorms, with tornadoes visible and frequent, vivid, cloud-to-ground lightning occurring. Coordination with the Sferics Unit of the U. S. Air Force Weather Service resulted in the establishment of the fact that no noticeable atmospheric discharges were recorded on their 10-kc receivers from these lightning bursts. This means the atmospheric discharges must have been at a different frequency. Table 1 lists the operational aircraft flights for 1958 and 1959, with a brief resume of the flight. Fig. 2 indicates the proportion of flight time spent in soundings, horizontal traverses, ferry flights and test flights during 1959.

TABLE 1. Listing of tornado research airplane operational flights.

Flight	Date	Time CST	Route	Remarks
			1958	
20	Mar 23	1308–1430	DAL-UIM-DAL	To rear and in vicinity of a squall line
23	Mar 28	1155–1340	DAL-MAF	In preparation for Flight 24
24	Mar 28	1430–1820	MAF-LBB-HOB-DAL	Active squall line
25	Apr 2	0916–1058	DAL-AMA	In preparation for Flight 26
26	Apr 2	1207–1429	AMA-TCC-AMA	Active squall lines
27	Apr 2	1544–1817	AMA-DAL	Active squall lines
28	Apr 4	1321–1650	DAL-ABI-DAL	Line structure
31	Apr 17	1207–1443	ABI-BGS-MWL-DAL	Weak squall line
32	Apr 21	0941–1120	DAL-SPS-AMA	Encountered thunderstorm area
33	Apr 21	1212–1505	AMA-SPS-PNX-DAL	Active squall line
34	Apr 23	0956–1053	DAL-OKC	In preparation for Flight 35
35	Apr 23	1237–1548	OKC-SYO-OKC-SYO-DAL	Several traverses at low level across a dry front
39	May 3	1107–1425	DAL-SPS-MLC-DAL	Preactivity sample
40	May 7	0955–1253	DAL-HBR-DDC	Detailed an extreme gradient of temperature in vicinity of HBR
41	May 7	1436–1750	DDC-COLBY-AKO-SLN	Lee of mountain trough
42	May 7	1821–1851	SLN-TOP	Return from Flight 41
44	May 8	1430–1630	TUL-MLC-ADM-SPS-DAL	Low-level traverses of several lines
46	May 11	1342–1543	DAL-LBB	Activity sample, particularly electric field
47	May 11	1652–1918	LBB-DAL	Activity sample, particularly electric field
52A	May 23	1120–1347	DAL-PNC-OKC	Low-level traverses of cold front
53	May 27	1157–1510	DAL-ELD-FSM-TUL	Active squall line
54	May 27	1557–1757	TUL-DAL	Weak squall line
56	May 31	1018–1450	DAL-TOP-STJ-BIE-MKC	Severe squall line
57	May 31	1623–1941	MKC-STJ-BIE-SCT	Severe squall line
59	June 12	1009–1209	DAL-MKC	Marked temperature inversion in vicinity of TUL
60	June 12	1337–1750	MKC-HLC-TOP-OMA	Severe squall line and funnel. Case supplemented by serial rawinsonde observations from TOP and OMA
61	June 13	1216–1516	OMA-MKC-CNK-TOP	Weak squall line
65	June 18	1303–1544	MKC-TUL-DAL	Ferried to install new infra-red hygrometer. Encountered active squall line with funnel vicinity of TUL
70	June 27	0440–0744	MKC-DEN	To measure diurnal temperature changes in the lee of the mountains under conditions of southerly flow and lee of mountain trough
71	June 28	1510–1708	DEN-AMA	Preactivity sample of an incipient line
			1959	
8	Mar 4	1349–1635	DAL-ABI-CDS-SPS-DAL	Squall line and a meso-low development
9	Mar 25	1159–1357	DAL-BPR-GTH-ABI-SPS-DAL	Squall line development
10	Mar 25	1448–1601	SPS-BPR-DAL	Active squall line
11	Mar 31	1109–1300	DAL-ADM-OKC-TUL-OKC	Before squall line development
12	Mar 31	1456–1659	OKC-TUL-OKC-DAL	Active squall line
13	Apr 7	1119–1449	DAL-SPS-MAF-LBB-ABI	Area of thunderstorm activity
14	Apr 7	1624–1729	ABI-BPR-DAL	Ahead of squall line
15	Apr 16	1142–1501	DAL-OKC-GAG-DDC-HUT-DDC	Squall line development
16	Apr 16	1624–1821	DAL-ADM-GAG-DDC	Active squall line
17	Apr 17	1329–1426	DAL-MWL-ABI	Area of expected severe weather which did not develop
18	Apr 17	1525–1622	ABI-BPR-DAL	Area of expected severe weather which did not develop
19	Apr 18	1136–1410	DAL-HBR-CDS-DAL	Active squall line
20	Apr 19	1139–1509	DAL-BYT-TYR-GGG-DAL	Active squall line
21	Apr 27	1122–1322	DAL-OKC-SGF	Before squall line activity
22	Apr 27	1429–1705	SGF-CNU-BUM-MKC-CNU-BVO	Active squall line

TABLE 1. (*Continued*).

Flight	Date	Time CST	Route	Remarks
			1959	
24	May 4	1047–1220	DAL-OKC-PNC-ICT	Area ahead of squall line
25	May 4	1342–1732	ICT-HUT-CDS-DAL	Active squall line
28	May 18	1414–1730	OKC-HUT-HLC-HUT-OKC	Front and meso-high
29	May 19	1716–1902	OKC-HBR-OKC	Active squall line
30	May 19	2220–2310	OKC-DAL	Area ahead of strong squall line
31	May 20	1106–1153	DAL-OKC	Ahead of dissipating squall line
32	May 20	1428–1655	OKC-DDC-OKC	Active squall line
33	May 21	1111–1251	OKC-HBR-BPR-DAL	Near and in advance of front
34	May 22	1252–1600	DAL-ABI-GTH-ABI	Active squall line with a meso-high
35	May 22	1806–1856	ABI-DAL	Active squall line (pressure-jump line)
36	May 26	1117–1310	DAL-LAW-DAL	Active squall line
37	May 26	1424–1630	DAL-GRAHAM-DAL	Dry front
38	May 28	1359–1524	DAL-AMA	Before squall line formation and ahead of dry front
39	May 28	1654–1842	AMA-DAL	Dry front and squall line

6. Instrument calibration

The calibration and testing of the instruments cannot be considered fully satisfactory. Calculations based on the manufacturer's specifications indicate a lag of about 5 sec in the sensing-recording train, or approximately a 3-mb pressure lag at a 1,000-ft-per-min ascent or descent. This is in good agreement with the observation made on the radiosonde compatibility ascent.

The lag in the beginning of response to sharp changes for both the reverse-flow resistance-type thermometer and the infra-red hygrometer is estimated at less than 2 sec as determined by the blips placed on the record by the pilot as the plane entered a cloud.

In 1958 and 1959, comparison flights were made in conjunction with radiosonde flights. On 19 May 1959, the tornado-research aircraft made such a flight circling around the balloon as it ascended. Comparisons were made of the airborne reverse-flow resistance-type thermometer and the new infra-red hygrometer with the radiosonde instrument. At four points in the spiral ascent, the aircraft and raob pressures were compared. The average pressure difference (aircraft pressure minus raob pressure) was found to be −3.5 mb. In plotting the temperature and mixing-ratio curves (figs. 3 through 5), a 3.5-mb correction for altimeter error was added to the aircraft pressure in order to correct for this difference.

Fig. 3 is a comparison of the reverse-flow resistance-type thermometer and the infra-red hygrometer of the aircraft with the radiosonde data. Fig. 4 is a comparison of the aircraft's ascent and descent. The temperature curve for the descent was warmer than the curve for the ascent at nearly all points. It is believed that the pressure lag being greater than the temperature lag caused the descending curve to appear warmer and the ascending curve to appear colder than the true lapse rate. This condition was not present during the 1958 tests when an apparent greater temperature lag caused the descending curves to appear colder than the ascending curves. The reason for this difference between the two seasons is not known. A lag of about 1.9 mb appears present in the pressure measurement during the standard rate of ascent or descent, and so this correction was applied.

In the column of air near 700 mb, four soundings were taken (fig. 5) within half an hour. These were spiral ascents and descents at 1,000 ft per min.

The results of the 1959 reverse-flow resistance-type thermometer tests compare rather closely with the 1958 tests (table 2). Root mean square differences for the 1958 tests were somewhat smaller, while the range of differences was larger.

TABLE 2.

RMS difference Range of difference	1958	1959
Ascent	0.56C	0.77C
Descent	0.98C	1.24C
Ascent	−1.4 to 2.2C	−0.6 to 1.4C
Descent	−2.5 to 3.3C	0.0 to 1.6C

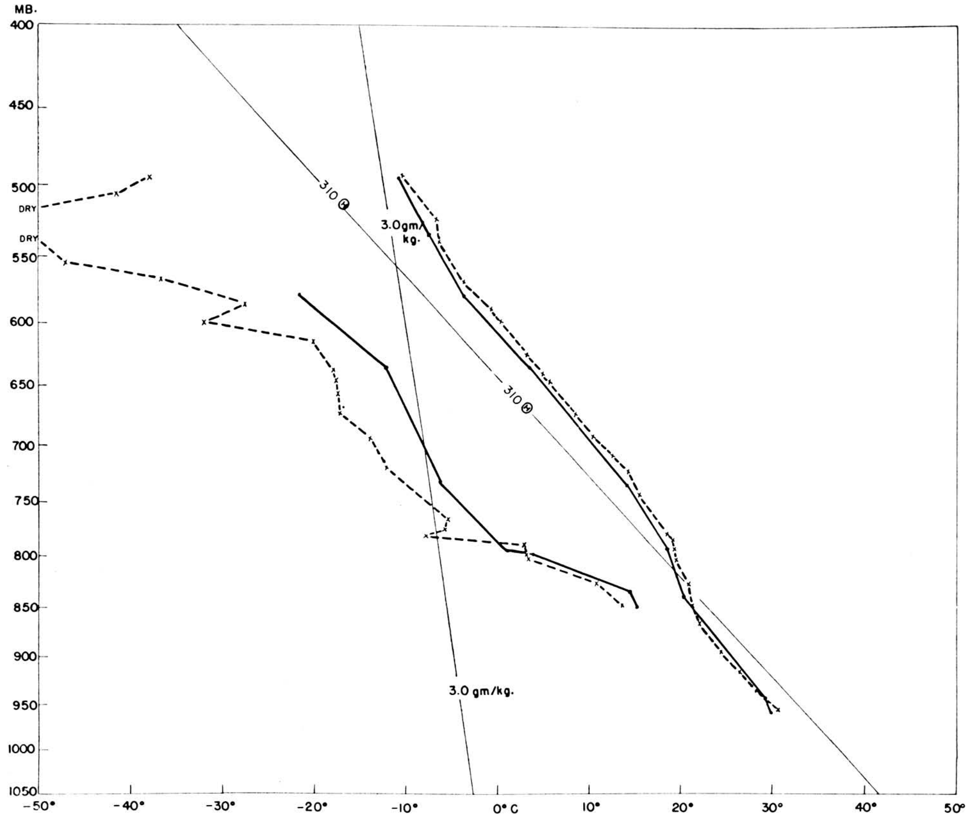

FIG. 3. Comparison of aircraft ascent (dashed line) and radiosonde (solid line). Temperature and mixing-ratio value curves indicated. 19 May 1959.

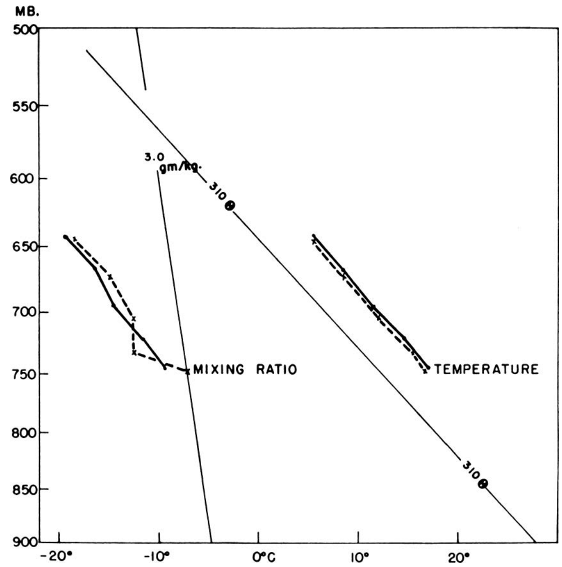

FIG. 4. Comparison of aircraft ascent (dashed line) and descent (solid line) made at rate of 1000 ft per min. Temperature and mixing-ratio curves indicated. 19 May 1959.

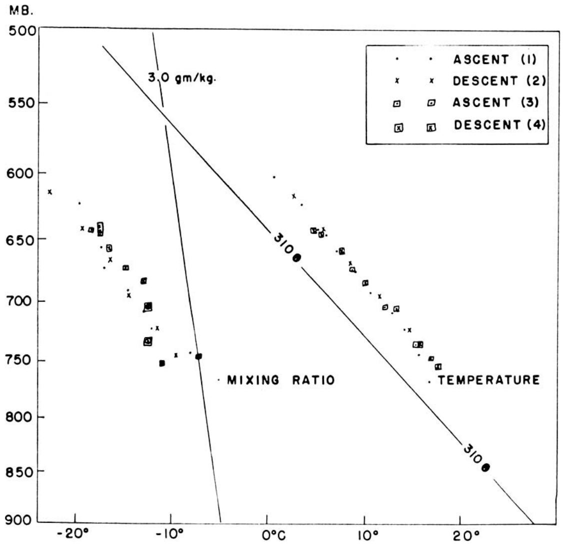

FIG. 5. Comparison of four aircraft soundings made at a rate of 1000 ft per min. 19 May 1959.

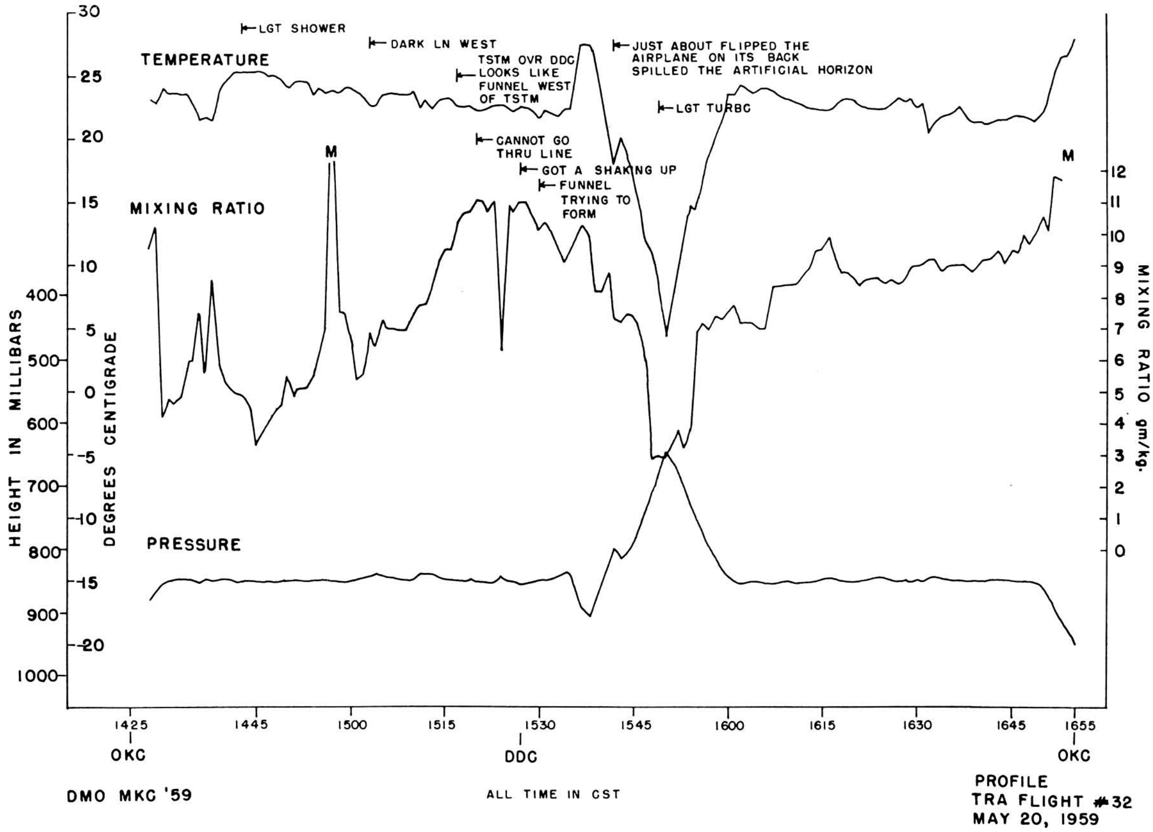

Fig. 6. Temperature, pressure and mixing ratio profiles of aircraft flight made 20 May 1959.

It is believed that the infra-red hygrometer in the aircraft is more sensitive than the radiosonde hygrometer. This is suggested by the fact that the aircraft hygrometer measured the moisture at some points when the radiosonde hygrometer was motorboating. This is also strongly supported by the consistency among the four repeated soundings taken at short-time intervals through the column of air near 700 mb. The one limitation on the infra-red hygrometer now in use is the fact that a mixing ratio of more than 12 gm kg^{-1} is difficult to evaluate because of the slope of the calibration curve.

7. Data reduction and processing

Initial phases of data reduction were accomplished as in the previous years with chart rolls and photo panel readings. Recorder records were transcribed every minute and at each significant point. Erratic fluctuations of recorder pens were not tabulated. Data necessary for the computation of true air speed, corrected temperature, pressure and humidity values were put on punched cards and processed on the IBM 650 electronic computer. The use of the IBM 650 computer during the 1959 season reduced by at least 50 per cent the number of man-hours previously required for data reduction.

Two general types of graphical presentation have been prepared from the research aircraft data. The flight path charts show the "plan position" of the aircraft at 2-min time intervals of the flight. The path was constructed by means of visual fixes, omni and ADF fixes, compass headings and true air-speed values.

Flight profiles (fig. 6) show the temperature, humidity and flight pressure plotted against time. Pertinent remarks by the pilot are plotted at the appropriate position. The completed flight-data presentation for each flight consists of (1) a brief description of the flight, the objective and results, (2) an edited transcript of the pilot's remarks, (3) navigated flight path and (4) flight profile (fig. 6). In addition, there are available the constant-pressure charts, surface charts, radar observations, and radiosonde observations pertinent to the flight. The preceding flight data can be made available upon request.

8. Operational summary

In 1958, there were 73 flights. Of these, 24 were operational flights. In 1959, there was a total of 39 flights. Twenty-nine were operational flights, 2 were ferry flights, and 8 were test flights. The average length of an operational flight was 2 hr and 24 min, although the time ranged from 48 min to 4 hr and 30 min. On some days two or more flights were made. The maximum airborne time for one day was 7 hr and 50 min.

The 1958 and 1959 flights produced 71 traverses of squall lines. These data are now being studied, and results will be published as soon as available.

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NEWS AND NOTES

The Cooperative Weather Observer

The U. S. Weather Bureau has recently issued a publication, *The Cooperative Weather Observer.* The booklet recognizes and honors the voluntary services of the more than 12000 cooperative weather observers all over the United States, many of whom have served 50 or more years.

Biographical sketches of observers with long service records, a short history of the cooperative program, and recognition of the many institutions and organizations with long service as weather observers are included in the volume. It also contains a fund of anecdotes on the experiences of the observers.

In a letter to the voluntary observers, Dr. F. W. Reichelderfer, chief of the Bureau, commended their unselfish devotion throughout the years. "In contrast to the many quickly perishable things in our lives, weather data gain in value with every observation that is added to the record. A long series of them determines the climate. Without the efforts of the cooperative observers our knowledge of the many climates of the United States would be very incomplete indeed," Dr. Reichelderfer said.

The Cooperative Weather Observer is for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at 65 cents per copy.

New York Weather Bureau Office Has Left the Battery

After fifty years at the Battery and ninety years in lower Manhattan, at the year's end the New York Weather Bureau Office moved uptown to Rockefeller Center.

A new weather radar requiring the tallest flat-topped building in the city was the principal reason for the move. The RCA Building answered the requirement, and once the instrument was installed the Weather Bureau Office had to follow. The scanner of the powerful new radar, capable of sweeping the sky to a distance of 250 to 300 miles, was expected to be in operation early in February.

The new official temperature readings are now made in a standard instrument shelter in Central Park. Comparisons for record extremes of heat, cold, rain and snow fall are now based on the data of weather observations taken in Central Park since 28 December 1868, two years before the first Federal station was set up in lower Manhattan under the Signal Corps. Ernest J. Christie, meteorologist in charge of the 32-man New York office at the time of the move, said that the Bureau had received many complaints about the temperature readings made on the roof of 17 Battery Place, 454 ft high. Charles Knudsen, supervising forecaster, was insisting on hourly street observations made from Rockefeller Plaza, and also hoped to have a raingage somewhere in the Plaza to check on the Central Park readings.

Underwater Waves in Lakes

Professors Reid Bryson and Robert Ragotzkie of the University of Wisconsin's meteorology department have gathered evidence that underwater waves may be as important as surface waves in the annual cycle of warming and cooling in a lake. During temperature studies of Lakes Mendota and Trout they discovered that underwater waves have many of the characteristics of surface waves; they travel at considerable speed, some were measured as high as 10 ft, and they often curl and break like the familiar whitecaps on the surface.

Using a string of thermopiles—electrical temperature-measuring devices—the scientists found, as expected, that during summer the lake is divided into two layers, an upper warm layer and a lower cold layer, with a thermocline existing at the junction of the two. They also found that a thermopile located right at the point of contact between the layers showed rhythmic variations in temperature. This, they reasoned, could only mean that waves stream along the top of the cold layer much like

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