NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 1960

AN EVALUATION OF THE USE OF GROUND RADAR FOR AVOIDING SEVERE TURBULENCE ASSOCIATED WITH THUNDERSTORMS

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SUMMARY

An analysis of data obtained from the 1947 Ohio operations of the U.S. Weather Bureau thunderstorm project indicates that the magnitude and intensity of gusts encountered in air-mass and frontal thunderstorms may be considerably reduced by avoiding storm areas as indicated by ground radar of a 10-centimeter wavelength. The analysis extends the use of ground radar for avoiding regions of severe thunderstorm turbulence in subtropical regions to include thunderstorms in temperate regions. The data also indicate that for turbulence avoidance the ground radar used becomes more effective with increasing altitude up to 25,000 feet and is least effective at 6,000 feet.

INTRODUCTION

The feasibility of utilizing ground radar as a means of avoiding regions of turbulence in Florida thunderstorms was investigated in reference 1. This investigation indicated that turbulence encountered in air-mass thunderstorms in Florida may be greatly reduced by avoiding regions of radar echo indicated by AN/CPS-1 ground-radar equipment.

Operation of the 1947 thunderstorm project at Clinton County Air Force Base, Wilmington, Ohio, offered an opportunity for extending this investigation to other regions and to other weather situations. Ground-radar observations of air-mass and frontal thunderstorms in Ohio, together with time histories of the turbulence within the thunderstorms as indicated by effective gust-velocity measurements (reference 2), were analyzed to determine the variation of turbulence with respect to areas of radar echo and surrounding air. This investigation was also extended to determine the variation of turbulence within these areas at different altitudes.

APPARATUS AND TESTS

The ground radar used for storm detection and airplane control was an AN/CPS-6 which had a peak power output of 1 megawatt and a maximum range of 260 miles. The identity and location of the airplanes within the area of radar echo were determined by an AN/APN-19 radar beacon installed in each airplane. These units transmitted to the ground radar a coded signal which could be differentiated from the storm echo.

Instruments installed in the test airplanes for recording data to determine the effective gust velocities were:

(1) NACA air-damped accelerometer
(2) NACA airspeed-altitude recorder
(3) NACA synchronous timer (1-sec interval)

The recording instruments were supplied with film drums holding 50 feet of film so that a minimum record time of 1 hour at a film speed of 1/8 inch per second was available.

The tests consisted of flight surveys of storms detected by the ground-radar equipment. For each flight, the plan was to fly five airplanes through the storm at the selected altitudes of 6,000, 10,000, 15,000, 20,000, and 25,000 feet. Because of mechanical difficulties with the airplanes, however, the survey at all five altitudes was not always possible. The airplanes were directed through the storm and the recording instruments turned on by members of the flight crew at the discretion of the ground-radar controller.

SCOPE OF DATA

Radar indications of thunderstorm areas and the flight path of the airplanes with respect to areas of radar echo for each cloud penetration were made available by the U.S. Weather Bureau thunderstorm project. These data were available for eight flights made in Ohio. Two hundred and five cloud penetrations at the altitudes of 6,000, 10,000, 15,000, 20,000, and 25,000 feet gave a total of 3149 miles of flight in and near thunderstorms. A summary of miles of flight according to altitude is shown in table I.

The eight flights investigated were made during July and August into afternoon storms of both air-mass and frontal types. The storms were associated with the flow of unstable maritime tropical air into temperate regions and are representative of similar thunderstorm conditions in other temperate locations.

Inasmuch as the cloud traverses were, in general, of only a few minutes duration, the assumption was made, as in reference 1, that the thunderstorm patterns would remain essentially constant during the traverse and that the photograph of the radar scope taken at a time corresponding to the midpoint of the traverse would be representative of the radar echo.

METHOD OF ANALYSIS AND RESULTS

The method of analysis used in this investigation was essentially the same as that used in reference 1, in which the differences between the effective gust velocity distributions for zones of radar echoes and surrounding air were analyzed. A zone of 0 to 2 miles from the echo was selected and used in reference 1 and in this investigation to act as a buffer zone. This buffer zone was intended to separate the effective gust velocities that, because of errors in determining the edge of the radar echo, might otherwise be assigned to the wrong zone.

The frequency distribution of the effective gust velocities U_e above a threshold value of 4 feet per second for each zone at different levels of altitude is given in table II. A summary of the pertinent statistical characteristics of the distributions is given in table III.

Pearson type III probability curves (reference 3) were fitted to the gust frequency distributions for each zone to provide a basis for extrapolation. The computed probability curves were then used to obtain the average number of miles required to exceed given gust velocities in the following manner: If P is the probability that the effective velocity of a gust selected at random will exceed a given value, that value will, on the average, be exceeded once in 1/P gusts. The average number of miles of flight necessary to equal or exceed that gust velocity may be given simply by the expression $\frac{1}{P}A$ where A is the average spacing in miles between gusts. The results together with the original test points are shown in figure 1.

In order to illustrate the variation with altitude of turbulence within each zone, figure 2 was obtained by cross-plotting from various plots of miles to exceed a given gust velocity for the different altitudes and zones. This figure shows the maximum effective gust velocity that would be encountered on the average in both 3 and 50 miles of flight for each zone and at the different altitudes.

DISCUSSION

Consideration of the curves shown in figure 1 indicates that appreciably smaller distances are required to exceed given values of gust velocity for flight within the area of radar echo than for flight more than 2 miles from the echo. The average distance necessary to exceed a gust velocity of 10 feet per second is increased from 1.36 to 5.35 miles, a ratio of 1:4, when the flight path is changed from area of radar echo to more than 2 miles from the echo. For gust velocities of 30 feet per second, these distances become 300 miles and 1750 miles, respectively, with a corresponding ratio of 1:6. Consideration of table III gives further evidence of the difference in intensity of turbulence between these two zones. The average number of gusts per mile for flight within the area of radar echo is 3.303; whereas the gusts per mile for flight more than 2 miles from the echo is 0.910. Because the mean gust velocities for the two zones are about the same, this difference in the number of gusts per mile would indicate that the zone of radar echo is clearly more turbulent than the zone more than 2 miles from the area of radar echo.

Comparison of these values with those obtained for the same zones in the Florida investigation of reference 1 indicates that, in both samples of data, flights within the zone of radar echo were significantly more turbulent than the flights more than 2 miles from the echo. In view of this general agreement between data obtained in different thunderstorm conditions, the ground-radar equipment used appears to be an effective means of locating and avoiding regions of severest turbulence within thunderstorms.

Consideration of figure 2 indicates that the relative turbulence intensities remain greater for flights within areas of radar echo when the data are analyzed with respect to altitude. Further consideration indicates that for purposes of avoiding regions of severest turbulence within thunderstorms, the ground-radar equipment used becomes more effective as the altitude is increased up to 25,000 feet. Figure 2 indicates little difference in the turbulence encountered at 6,000 feet in the various zones.

The use of ground radar for the reduction of turbulence encountered on flights through areas of thunderstorm activity does not include consideration of the vertical extent or slope of the visual cloud. It should be emphasized that the variation of turbulence with altitude shown in figure 2 is a direct result of the nature of the two-dimensional interpretation by the ground radar of the three-dimensional storm. The ground radar used cannot discriminate between flights in the clear which are either above or below the visible storm. Data collected concerning the actual times of cloud entry and exit indicate that airplanes flying in zones of radar echo were sometimes in the clear.

CONCLUSIONS

From an analysis of turbulence data taken within air-mass and frontal thunderstorms in Ohio and a comparison of the results with similar data obtained under widely different conditions in Florida, it is concluded that the turbulence experienced in flight may be greatly reduced by avoiding regions of thunderstorm area as indicated by AN/CPS-1 and AN/CPS-6 ground radar.

Because of the limitations of the ground-radar storm presentation, the results also indicate that the ground-radar equipment used becomes more effective with increasing altitude up to 25,000 feet and is least effective at 6,000 feet.

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National Advisory Committee for Aeronautics
Langley Air Force Base, Va., August 8, 1949

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TABLE I

MILES OF FLIGHT IN EACH ALTITUDE AND ZONE

Altitude (ft)	More than 2 miles from area of radar echo	0 to 2 miles from area of radar echo	In area of radar echo	Total
25,000	143.6	105.7	85.6	334.9
20,000	255.5	175.2	209.5	640.2
15,000	320.1	289.8	327.4	937.3
10,000	328.8	236.4	254.9	820.1
6,000	202.1	95.4	119.1	416.6
Total	1250.1	902.5	996.5	3149.1

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TABLE II

FREQUENCY DISTRIBUTIONS OF EFFECTIVE GUST VELOCITY

BY FLIGHT ZONE AND ALTITUDE

U_e (ft/sec) \ Altitude (ft)	6,000	10,000	15,000	20,000	25,000	Total
Area of radar echo						
4 to 5.9	149	467	357	287	58	1318
6 to 7.9	79	285	220	176	31	791
8 to 9.9	39	152	139	122	25	477
10 to 11.9	20	98	92	61	14	285
12 to 13.9	10	43	65	37	16	171
14 to 15.9	7	25	35	20	7	94
16 to 17.9	1	16	29	6	3	55
18 to 19.9	0	11	31	9	4	55
20 to 21.9	3	4	12	4	0	23
22 to 23.9	0	3	3	2	2	10
24 to 25.9	0		2	2	0	4
26 to 27.9	1		3	0	2	6
28 to 29.9			0	0		0
30 to 31.9			1	0		1
32 to 33.9			0	0		0
34 to 35.9			0	0		0
36 to 37.9			1	1		2
Total	309	1104	990	727	162	3292
0 to 2 miles from echo						
4 to 5.9	53	121	95	97	68	434
6 to 7.9	39	69	85	35	22	250
8 to 9.9	15	48	42	13	15	133
10 to 11.9	8	36	30	14	5	93
12 to 13.9	4	22	20	9	3	58
14 to 15.9	4	23	9	5	3	44
16 to 17.9	1	9	12	2	0	24
18 to 19.9	0	11	12	0	1	24
20 to 21.9	0	5	5	1	1	12
22 to 23.9	1	1		1		3
24 to 25.9		1		1		2
26 to 27.9		1				1
28 to 29.9		0				0
30 to 31.9		1				1
32 to 33.9		0				0
34 to 35.9		1				1
36 to 37.9						
Total	125	349	310	178	118	1080
More than 2 miles from echo						
4 to 5.9	118	163	151	24	27	483
6 to 7.9	82	85	72	21	13	273
8 to 9.9	29	48	44	19	10	150
10 to 11.9	22	26	40	7	1	96
12 to 13.9	12	18	9	11	2	52
14 to 15.9	5	11	6	8	2	32
16 to 17.9	3	10	5	1	2	21
18 to 19.9	1	6	5	0	1	13
20 to 21.9	2	2	5	2		11
22 to 23.9		3	2			5
24 to 25.9		0	1			1
26 to 27.9		1				1
28 to 29.9						
30 to 31.9						
32 to 33.9						
34 to 35.9						
36 to 37.9						
Total	274	373	340	93	58	1138

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TABLE III

SUMMARY OF GUST DATA BY FLIGHT ZONES

Zone	Miles flown	Number of gusts	Average number of gusts per mile	Mean gust velocity
Area of radar echo	996.5	3292	3.303	7.973
0 to 2 miles from echo	902.5	1080	1.197	8.224
More than 2 miles from echo	1250.1	1138	.910	7.818

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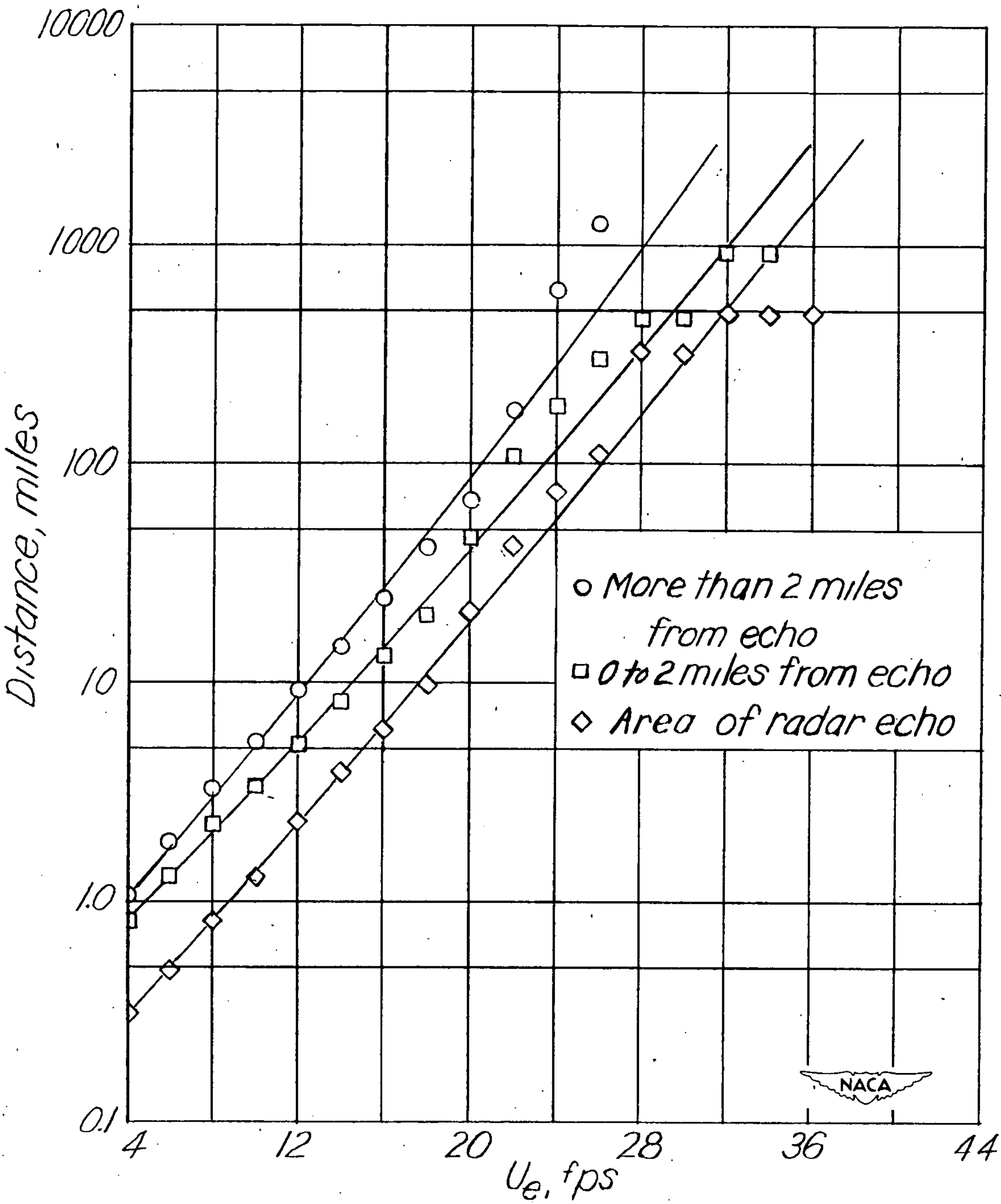

Figure 1.- Average number of miles required to exceed a given gust velocity.

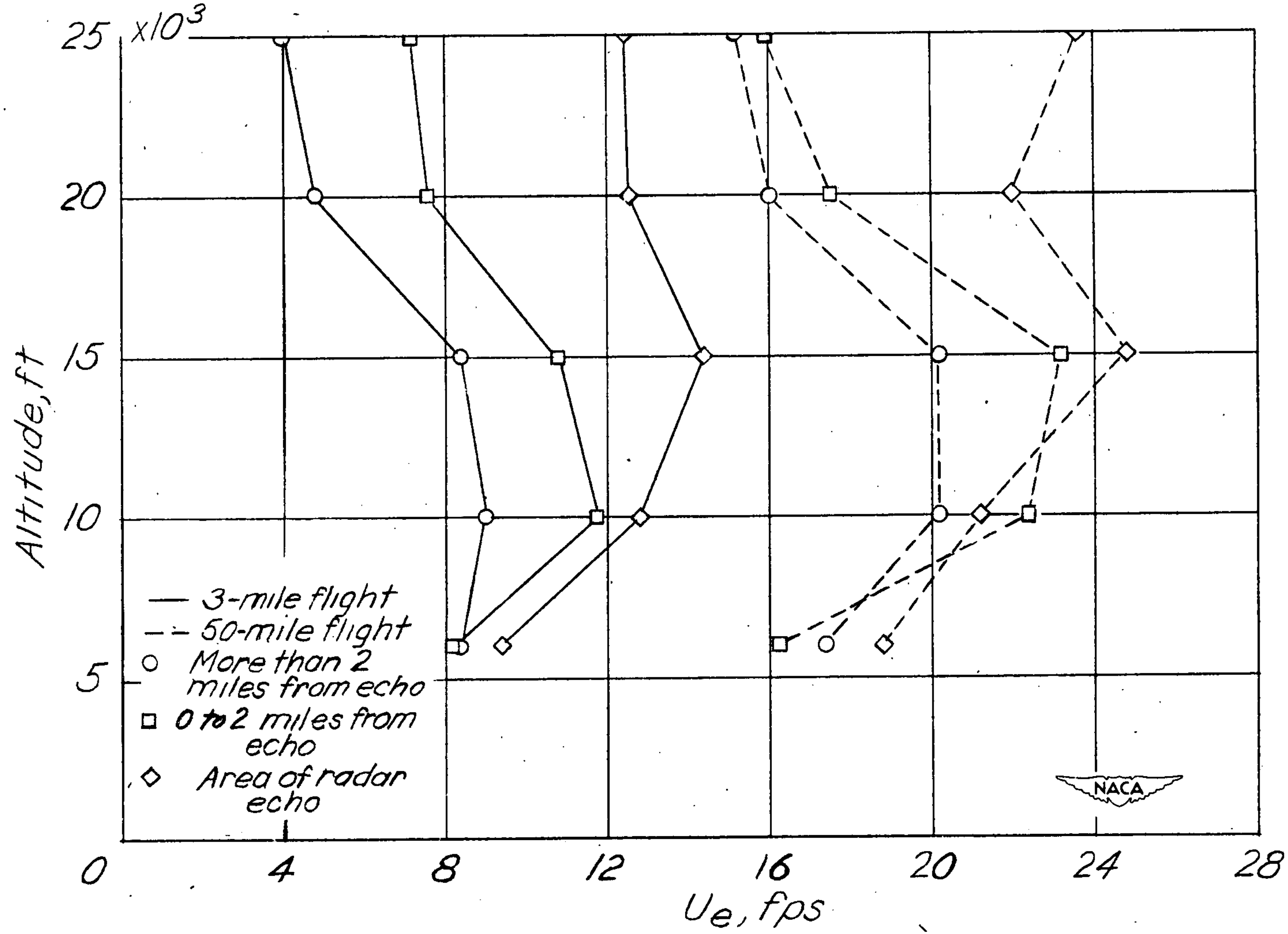

Figure 2.- Variation with altitude of maximum effective gust velocity encountered on the average for flights of 3 and 50 miles within each zone.