NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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A PRELIMINARY EVALUATION OF THE USE OF GROUND RADAR FOR THE AVOIDANCE OF TURBULENT CLOUDS

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SUMMARY

A preliminary analysis of data obtained from the 1946 operations of the U. S. Weather Bureau thunderstorm project in Florida indicates that considerable differences exist between the magnitude and frequency of gusts encountered within areas of ground-radar echo and those encountered in surrounding areas. The results indicate that an appreciable reduction in gust experience can be achieved by circumavigation of areas of radar echo caused by air-mass convective storms. For the flight conditions studied, effective gust velocities greater than 30 feet per second may be expected once in every 120 miles of flight within areas of radar echo. For flights in a region more than 2 miles from areas of radar echo, it is estimated that effective gust velocities greater than 30 feet per second may be expected once in about 12,000 miles of flight.

INTRODUCTION

The use of radar, both ground and airborne, has been suggested as a possible means of detecting and avoiding regions of atmospheric turbulence. The effectiveness of this means in turbulence avoidance has been seriously questioned inasmuch as radar detects only those turbulent regions associated with areas of precipitation. The results of flight tests reported in reference 1 along with some unpublished data have indicated that moderate to severe turbulence is frequently encountered within areas of radar echo. Similar conditions may also be encountered, however, in areas not detectable by radar. For this reason there remains a need for information on the amount of reduction in the experience of turbulence that may be expected with the utilization of radar.

Recent data obtained from the 1946 operations of the U. S. Weather Bureau thunderstorm project (reference 2) provide an opportunity to obtain some information on the relation of turbulence to radar echo. In the course of this investigation, ground-radar observations of air-mass thunderstorms along with flight measurements of the effective gust velocities within the storms were obtained. These data have been analyzed to determine the relative intensity of turbulence within areas of radar echo and in the surrounding air. The results obtained are presented herein.

APPARATUS AND TESTS

For storm detection and control of aircraft in and around thunderstorms, two types of radar equipment were utilized by the thunderstorm project. Radar equipment AN/CPS-1 was used for storm detection and location. This is a fixed-station search set with a 10.5 centimeter wave length, a frequency of 2800 megacycles, a peak power of 750 kilowatts per transmitter, and a normal range of approximately 250 miles. To determine the location of the airplanes within the storms Mark V IFF equipment was used. Photographs were taken of the radar PPI scopes at 15-second intervals to provide a chronological record of both the storm echo and the airplane positions.

The instruments installed in each of the airplanes to determine the gust velocities were:

(1) NACA air-damped recording accelerometer

(2) NACA airspeed-altitude recorder

(3) NACA control-position recorder

(4) NACA synchronous timer

More detailed information on the instrumentation is given in reference 3.

The tests consisted of flight surveys of storms detected by the ground-radar equipment. For each flight it was intended that five airplanes would make successive traverses of the storm cloud at 5000-foot intervals from 6000 feet to 26,000 feet. It was not always possible, however, to operate five airplanes on every flight because of mechanical difficulties, and as a result many flights were made with fewer airplanes. The airplanes were directed through the radar echoes by a ground controller who also issued instructions regarding the times the instruments within the airplanes were to be operated.

SCOPE AND SELECTION OF DATA

The data utilized for the present analysis were obtained from 16 of the 38 flights of the 1946 operations of the thunderstorm project. These data, covering 134 traverses and roughly 1900 miles of flight, were believed a sufficient sample for a preliminary analysis. The operations of the project were conducted in the vicinity of Orlando, Florida, during the summer months. Flights were made during the height of afternoon convective activity and appear representative of thunderstorm conditions in a moist and unstable tropical air mass.

For each traverse, one photograph of the radar scope was selected as a representative echo. The scope photograph selected was the one corresponding to the time the airplane reached the midportion of the traverse. Inasmuch as the traverses were, in general, of only a few minutes duration, it seemed reasonable to assume that the thunderstorm pattern would remain essentially constant for the period of time covered by the traverse and that any change in the radar echo would be small.

The records of acceleration and airspeed used in the present analysis were in large part obtained within areas of radar echo. A sufficient amount of data for comparative purposes was obtained however in the area immediately outside of the echo. Records were obtained for 1168 miles of flight within areas of radar echo and 700 miles of flight within ten miles of areas of radar echo.

Inasmuch as the ground-radar echo is essentially a composite altitude picture of the rain core of the clouds, it cannot be used as an absolute indication of whether the airplane is within the visible cloud. The visible cloud nearly always extends beyond the radar echo. In addition, an airplane apparently within an echo may be in clear air either above or below the zone of precipitation. As no other accurate data were available on the cloud entry and exit times, no breakdown of the data by visible cloud was possible. Information available from project personnel indicates, however, that almost all the radar-echo data were obtained within visible clouds while a large part of the data taken outside of the echo was also taken within clouds.

METHOD OF ANALYSIS AND RESULTS

The method of analysis used in the present investigation was to divide each traverse, regardless of altitude, into zones representing areas of radar echo, areas more than 2 miles from the echo, and an intermediate area within 2 miles of the radar echo. The gust velocities measured within the zones were then examined for differences by the application of simple statistical methods.

A pictorial representation of the classification of a typical traverse into zones is given in figure 1. For the present purposes, the areas of intense and indefinite radar echo shown in figure 1, were combined, as only a small part of the echo area was considered indefinite. The intermediate zone is used as a buffer area intended to separate the gusts that, because of errors in timing and difficulties in determining the edge of the radar echo, might otherwise be assigned to the wrong zone.

The acceleration and airspeed data obtained in each of the three zones were evaluated for effective gust velocities U_e in accordance with the method described in reference 3. The effective gust velocities obtained for each of the three areas, to a threshold of 4 feet per second, were used to obtain the frequency distributions shown in table I. A summary of the statistical characteristics of these frequency distributions along with other pertinent information is given in table II.

Probability curves were fitted to the frequency distributions in order to smooth out the irregularities of the limited samples and to provide a basis for extrapolation of the data. Past experience has indicated that Pearson Type III probability curves (reference 4) frequently yield satisfactory results for data of this type. Curves of this type were consequently fitted to these data and the results along with the data points are shown in figure 2.

In order to obtain a simple measure of risk attending the three flight zones, the average flight distance in miles necessary to exceed given gust velocities was computed for each of these zones in the following manner: If P is the probability that the effective velocity of a gust selected at random will exceed a given value (determined from fig. 2), that value will, on the average, be exceeded once in 1/P gusts. The average number of miles of flight necessary to exceed that gust velocity may then be given simply by the expression $\frac{1}{P} \times A$ where A is the average spacing in miles between gusts. The results obtained, on this basis, are shown in figure 3 which indicates the average number of miles required to exceed given values of gust velocity for the three test areas.

DISCUSSION

Consideration of the results given in table II indicates that appreciable differences exist in the average magnitude and the average spacing of the gusts encountered in the three flight areas. The mean gust velocity for the gusts encountered within an area of radar echo is about 15 percent greater than the mean gust velocity for the area more than 2 miles from the radar echo. The average spacing between gusts varied from 0.204 miles within the areas of echo to 0.556 miles for the area more than 2 miles from the echo. The area of radar echo seems, therefore, to be appreciably more turbulent than the surrounding area.

A more detailed comparison of the relative gust intensity is possible from figure 2. This figure shows that the probability of exceeding the given values of gust velocity is appreciably greater for the area of radar echo than for the area more than 2 miles from the echo. As an example, figure 2 indicates that the number of gusts per thousand gusts that may be expected to exceed 20 feet per second varies from about 19 for the area of radar echo to 2 for the area more than 2 miles from the echo. Concerning the data for the area within the intermediate zone, the present results would appear to indicate that the immediate vicinity of the radar echo is a less turbulent region than the area of radar echo, but more turbulent than the surrounding area. This result is open to some question, however, because of the limitations previously noted for the data for this area.

For the comparison of risk, the curves of figure 3 indicate appreciably smaller distances required to exceed given values of gust velocity for the radar-echo zone than for the zone more than 2 miles from the echo. The average distances required to exceed gust velocities of 20 feet per second for these two zones are 11 miles and 200 miles respectively, or in a ratio of 1:19. When the data for the zone more than 2 miles from the radar echo are extrapolated, the average distances increase to 120 miles and 12,000 miles, respectively, at the design-effective-gust velocity of about 30 feet per second. The ratio of the average distances increases accordingly to about 1:100.

The foregoing results indicate that appreciable reduction in the risk of encountering large gust velocities can be achieved by circumavigation of areas of radar echo at least for the weather conditions represented in the present data. As an illustration of the actual reduction in gust experience that may be expected in a flight, the present results were utilized to predict the number and intensity of gusts for a hypothetical flight over Florida. On the assumption that the present data yield representative samples for the radar echo and the surrounding air, computations were made for two flight paths; one a straight-line flight through the echo area and the other a flight circumavigating the echo area. The flight paths along with the expected gust experiences are shown in figure 4. The results for this hypothetical flight indicate that despite the 10-percent increase in flight distance, it may be expected that the total number of gusts with an effective velocity greater than 4 feet per second may be reduced by approximately 35 percent and the maximum effective gust velocity may be reduced by approximately 25 percent.

The extension of the present results to other weather conditions is open to serious question. Although the present data indicate that turbulence is generally more severe within areas of radar echo than in the surrounding air, the intensity and spacing of gusts in other air-mass situations and within areas of frontal disturbance may be substantially different from those in the storms studied in Florida. The extension of the present results to other air-mass situations and to frontal weather conditions would, therefore, not appear warranted without further investigation.

CONCLUSIONS

Analysis of data taken within convective-type thunderstorms and in the immediate vicinity of the storms during the 1946 operations of the thunderstorm project indicates:

1. The magnitude and frequency of the gust velocities encountered may be reduced by avoiding regions of radar echo as indicated by ground-radar equipment.

2. For the conditions encountered in Florida, it may be expected that an effective gust velocity of 30 feet per second will be exceeded once in 120 miles of flight within areas of radar echo. For flights in a region more than 2 miles from areas of radar echo, it is estimated that gust velocities greater than 30 feet per second may be expected once in about 12,000 miles of flight.

3. The extension of the present results to other air-mass and to frontal situations does not appear warranted without further investigation.

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National Advisory Committee for Aeronautics
Langley Field, Va., April 12, 1948

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3. Tolefson, Harold B.: Preliminary Analysis of NACA Measurements of Atmospheric Turbulence within a Thunderstorm – U. S. Weather Bureau Thunderstorm Project. NACA TN No. 1233, 1947.

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TABLE I

FREQUENCY DISTRIBUTION OF EFFECTIVE GUST VELOCITY

BY FLIGHT ZONE

U_e (fps)	Area of radar echo	0 to 2 miles from echo	More than 2 miles from echo
4 – 6	2116	789	173
6 – 8	1495	473	89
8 – 10	835	241	43
10 – 12	531	112	21
12 – 14	268	70	9
14 – 16	194	19	8
16 – 18	105	10	5
18 – 20	69	7	1
20 – 22	39	9	----
22 – 24	33	1	----
24 – 26	11	1	----
26 – 28	10	----	----
28 – 30	10	1	----
30 – 32	2	----	----
32 – 34	2	----	----
34 – 36	3	----	----
36 – 38	----	----	----
38 – 40	1	----	----

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TABLE II

SUMMARY OF GUST DATA

BY FLIGHT ZONE

Item	Area of radar echo	0 to 2 miles from echo	More than 2 miles from echo
Miles flown	1168	506	194
Number of gusts	5724	1733	349
Mean gust velocity. . . .	8.137	7.167	7.011
Standard deviation. . . .	3.960	2.887	2.773
Coefficient of skewness .	2.096	2.102	1.741
Average number of gusts per mile, gusts. . . .	4.901	3.425	1.799
Average gust spacing, mile	0.204	0.292	0.556

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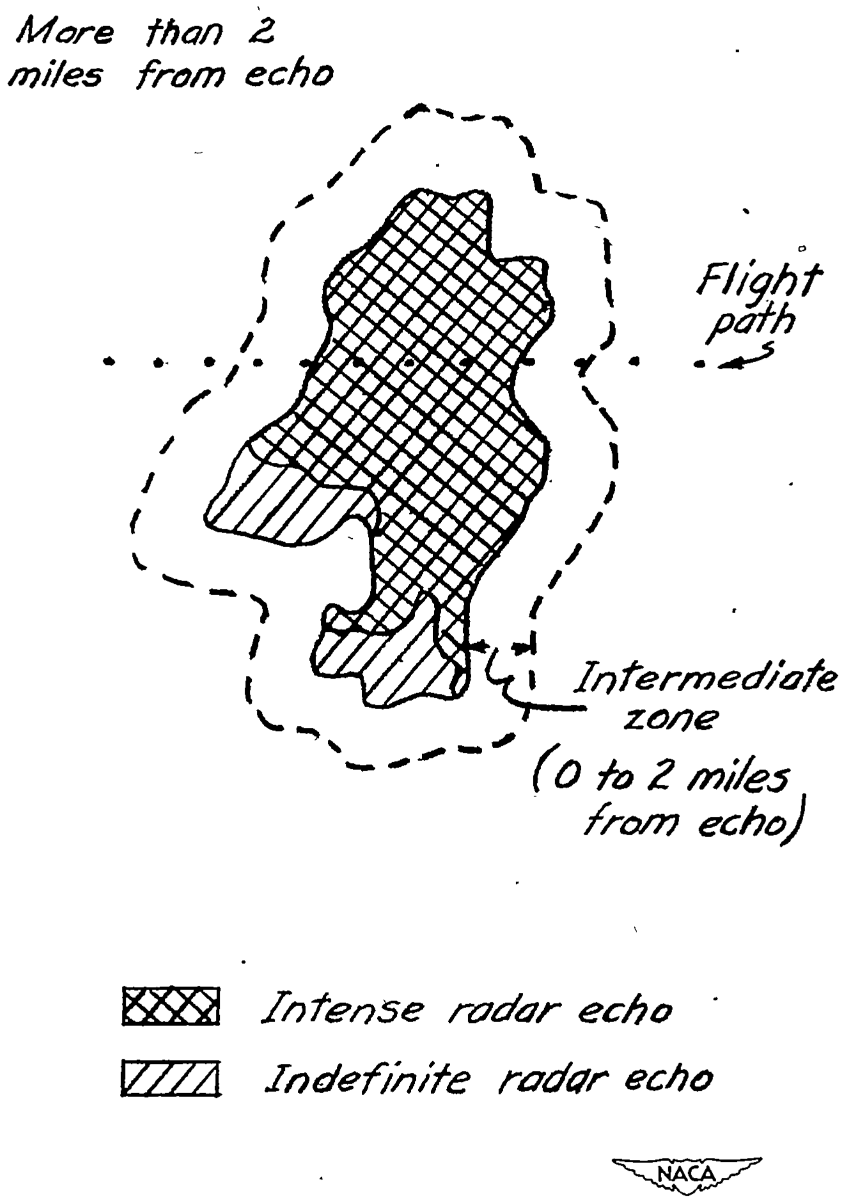


Figure 1. - Zonal classification of typical traverse through radar echo.

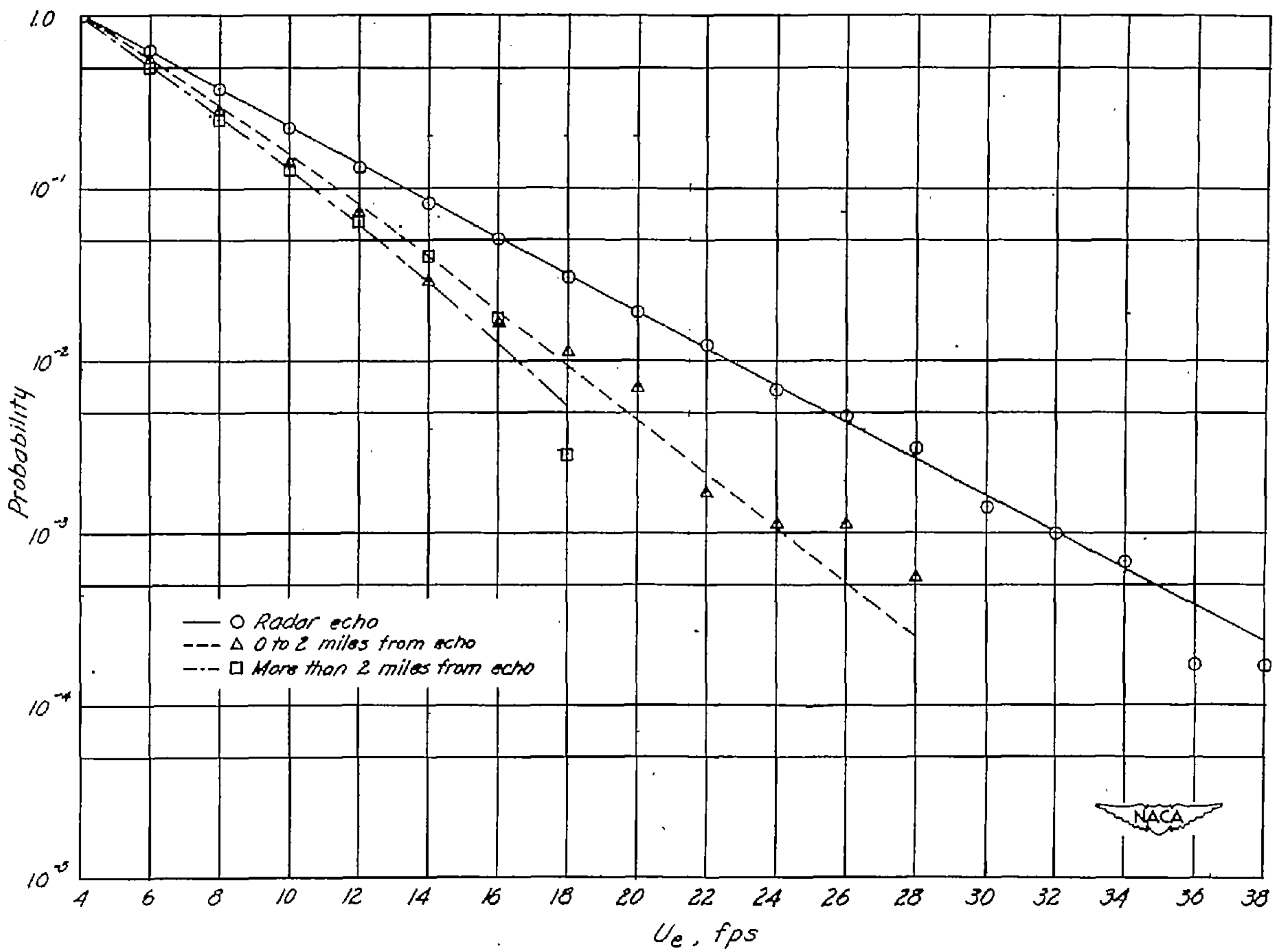


Figure 2. - Probability that a gust velocity will exceed a given value.

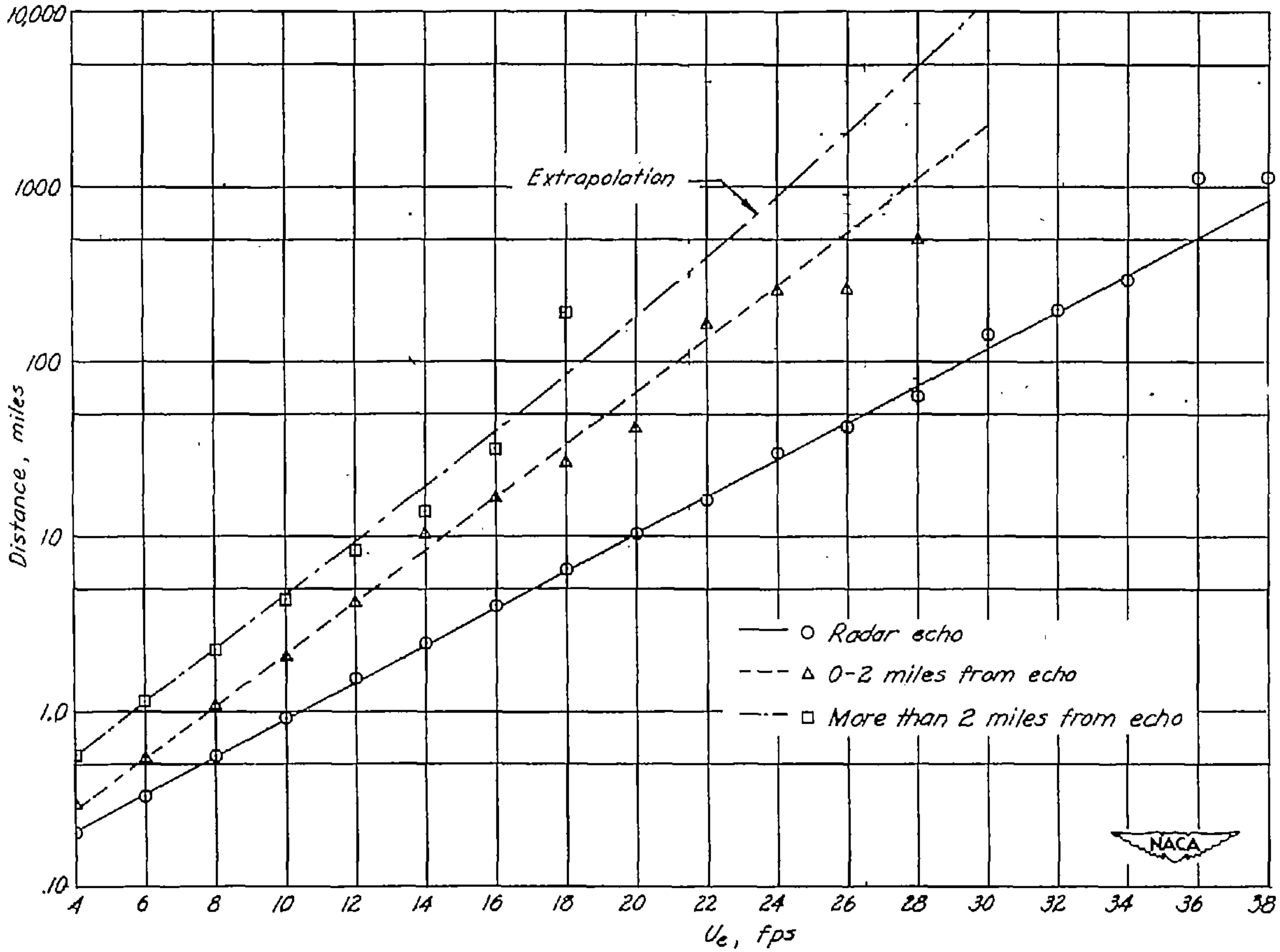
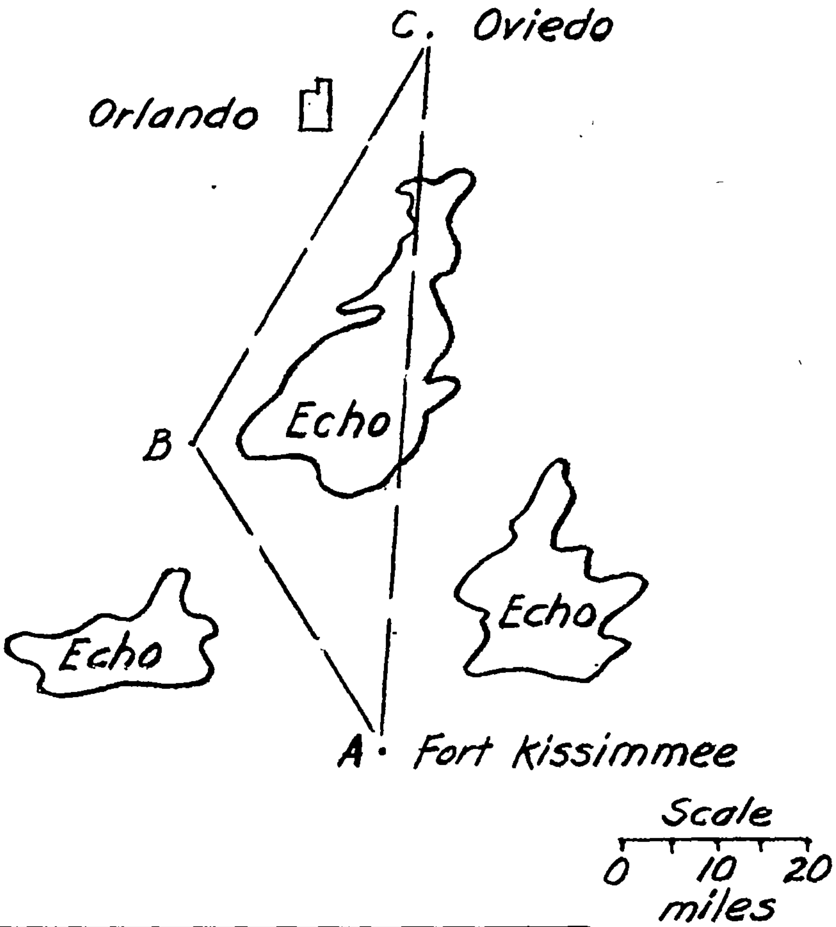


Figure 3.- Average number of miles required to exceed a given gust velocity.



Route	ABC	AC
Number of gusts	156	244
U_e max., fps	18	24
Distance, miles	87	78

Figure 4.- Hypothetical flight in Florida.