NACA

RESEARCH MEMORANDUM

for the

Navy Department, Bureau of Ships

MEASUREMENTS OF ATMOSPHERIC TURBULENCE ON SEATTLE-ALASKA AIRWAYS

By

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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INTRODUCTION

For about the past year, American Airlines has been engaged in obtaining data on various uses of air-borne radar under routine operating conditions. This work is under contract to the Navy Department, Bureau of Ships, and includes the investigation of radar as a navigational aid and terrain collision warning device and its use in icing and turbulence detection. In view of the work of the National Advisory Committee for Aeronautics on atmospheric turbulence, the NACA was requested to participate in the tests to the extent of obtaining and evaluating the turbulence data for use in the turbulence-detection phase of the work.

Gust measurements and air-borne radar observations were consequently obtained in February and March 1947 during routine flights of an American Airlines airplane on the Seattle-Alaska airways. Unfortunately, the weather conditions encountered during the flights gave no well-defined radar echoes and no comparison between radar indications and turbulence could be made. The gust data for the route, however, are of interest from an operational standpoint and are presented herein for the information of the Navy Department in accordance with previous arrangements.

APPARATUS

The airplane used in the investigation was a cargo-type DC-4. The characteristics of the airplane as flown are given in table I.

The instruments installed in the airplane to determine the gust velocities were:

(1) NACA air-damped recording accelerometer

(2) NACA airspeed-altitude recorder

(3) NACA synchronous timer (1-min interval)

The instruments were photographically recording and, due to cargo space requirements, were installed in a group within the cabin of the airplane about 18 feet forward of the center of gravity.

The accelerometer, which was used to measure the normal acceleration increments of the airplane, was about 0.7 critically damped and had a vane frequency of 12.7 cycles per second. The pitot-static lines of the airspeed-altitude recorder were connected to the corresponding lines on the copilot's instrument panel. The instruments were adjusted to give a film speed of 2.6 inches per minute on the accelerometer and 1.3 inches per minute on the airspeed-altitude recorder. The film speeds were selected to give time scales sufficiently open to permit detailed evaluation of the records. The instruments were supplied with film magazines for 6 hours of records on each flight. Time synchronization between the two sets of records was obtained by means of the 1-minute timer, and reference marks to denote events such as cloud entry or exit were impressed upon the records by means of a switch operated by a flight observer.

SCOPE OF OPERATIONS AND RESULTS

Gust-velocity measurements were made during 11 flights of this airplane involving various operating conditions on the Seattle-Anchorage-Fairbanks route (fig. 1) during February and March 1947. Nonschedule flights were made both day and night at a nominal altitude of 9000 feet although flight was occasionally conducted at altitudes up to 14,000 feet to avoid icing. Approximately 40 percent of the flight time was on instruments in stratus-type clouds and icing conditions were frequently encountered, especially in the vicinity of fronts which extended across the route. A summary of the operations is given in table II.

In general, it was intended to take continuous airspeed-altitude and acceleration records on each flight from take-off to landing. In two instances, however, unsatisfactory instrument operations interfered with this procedure, and in several other instances, the instruments were turned off by the operator when no turbulent air was being encountered. In all, 57.6 hours of records were taken during 69.7 hours of flight.

The records of airspeed, altitude, and acceleration were evaluated to obtain the effective gust velocity U_e for each acceleration peak corresponding to an effective gust velocity of about 4.0 feet per second or greater by use of the following formula (reference 1):

$$U_e = \frac{2\Delta n W}{\rho_o a V_e S K}$$

in which

U_e effective gust velocity, feet per second

Δn acceleration increment, g

W weight of airplane at time acceleration increment was experienced, pounds

ρ_o air density at sea level, slugs per cubic foot

a slope of lift curve, per radian

V_e equivalent airspeed, feet per second

S wing area, square feet

K relative alleviation factor (taken from fig. 1 of reference 1)

The effective gust velocities so obtained for each flight were grouped according to clear air or clouds, and the results are shown in table III as frequency distributions for gust-velocity intervals of 2 feet per second.

In an attempt to make the distributions comparable to other work of this nature (reference 1), a separate total count of all acceleration peaks to the smallest observable increment was made. The threshold used in this count was 0.08g which corresponds to an effective gust velocity of about 2.0 feet per second for the test airplane. These results are also shown in table III. The relative-frequency curves of figure 2 were obtained from a summation of the frequency counts in table III and indicate the proportion of gusts greater than a given gust velocity.

PRECISION

Inaccuracies in the acceleration measurements due to instrument errors are estimated to be within ±0.05g. This estimate is based on dynamic calibrations of the accelerometer under conditions simulating the flight conditions. Since it was necessary to locate the accelerometer

18 feet forward of the center of gravity of the airplane, however, angular accelerations due to pitching motions of the airplane under the action of gusts were recorded by the instrument in addition to the normal accelerations. Although no data are available to the NACA on the angular accelerations of the test airplane, data from an airplane of similar configuration indicate that, on the average, pitching motions may cause the normal acceleration measurements to be in error by about 20 percent for the present installation.

The value of airspeed used in the effective gust-velocity formula was the computed equivalent airspeed without a correction for installation error. Neglecting the installation error is felt to introduce errors into the gust-velocity computations of not over 2 percent.

The weight of the airplane for consecutive 30-minute intervals of the records was determined from gross weight at take-off and fuel-consumption data. Variations in weight with time do not, therefore, introduce error into the gust-velocity computations.

CONCLUDING REMARKS

Figure 2 indicates that for the present flights the probability of encountering a given gust velocity is practically equal for either stratus-type clouds or clear air. It is interesting to note that, although other type clouds were not encountered on the flights, effective gust velocities up to 22 feet per second, or about two-thirds the present design gust velocity for airplane structures, were recorded. While the present data are insufficient to evaluate the uses of radar in turbulence detection, it is obvious from the results obtained that in many cases turbulent air may be encountered with no radar indications.

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REFERENCE

1. Rhode, Richard V., and Donely, Philip: Frequency of Occurrence of Atmospheric Gusts and of Related Loads on Airplane Structures. NACA ARR No. L4I21, 1944.

TABLE I

CHARACTERISTICS OF TEST AIRPLANE

Gross weight at take-off, lb	73,000
Wing area, sq ft	1460
Wing loading at take-off, lb/sq ft	50.0
Span, ft	117.5
Mean aerodynamic chord, ft	13.6
Center-of-gravity location, percent M.A.C.	19.3 to 25.0
Slope of lift curve, per radian	4.5

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TABLE II

SUMMARY OF OPERATIONS OF DC-4 CARGO-LINER

ON SEATTLE-ANCHORAGE-FAIRBANKS ROUTE

Flight	Date	Route[1]	Record time (hrs)		Air miles flown	
			Clouds	Clear air	Clouds	Clear air
1	2-6-47	SA-HQ	0.9	4.8	190	1039
2	2-13-47	SA-FX	2.9	3.1	679	721
3	2-13-47	FX-HQ	.8	.4	189	91
4	2-13-47	HQ-SA	2.4	4.0	509	851
5	2-18-47	SA-HQ	2.7	4.4	592	948
6	2-19-47	HQ-SA	3.2	3.2	706	694
7	2-22-47	SA-HQ	2.3	4.2	485	895
8	2-23-47	HQ-FX	0	.9	0	210
9	2-23-47	FX-SA	1.8	4.7	461	1182
10	3-5-47	SA-HQ	2.1	2.1	878	462
11	3-6-47	HQ-SA	2.9	3.8	630	830
Totals			22.0	35.6	5319	7923
Totals for combined flights			57.6		13,242	

[1]Station identification symbols: SA-Seattle
HQ-Anchorage
FX-Fairbanks

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TABLE III

FREQUENCY DISTRIBUTIONS AND TOTAL COUNTS

OF EFFECTIVE GUST VELOCITIES

U_e (fps) \ Flight	1	2	3	4	5	6	7	8	9	10	11	Total
Clouds												
4.0-5.9	4	55	183	62	54	46	44		75	22	11	556
6.0-7.9	3	13	67	13	12		23		20	1	1	153
8.0-9.9		5	20		--		5		23	2	1	55
10.0-11.9		7	8		1		2		1	--		19
12.0-13.9		--	1				1			1		3
14.0-15.9		1	2									3
16.0-17.9												
Total count to threshold of 2.0 fps	1229	713	2466	2438	2445	3430	3427	--	3943	1446	1398	22,935
Clear air												
4.0-5.9	47	250	41	108	144	18	22		11	14	34	689
6.0-7.9	16	77	13	18	72	3	34		1	39	6	279
8.0-9.9	13	15	10	4	18		1		1	26	3	91
10.0-11.9		2		5	9		4			12		32
12.0-13.9		1			5		1			10		17
14.0-15.9										5		5
16.0-17.9										5		5
18.0-19.9										--		--
20.0-21.9										--		--
22.0-23.9										1		1
Total count to threshold of 2.0 fps	2897	2710	1100	2550	3114	2374	3133	580	1582	646	1970	22,656

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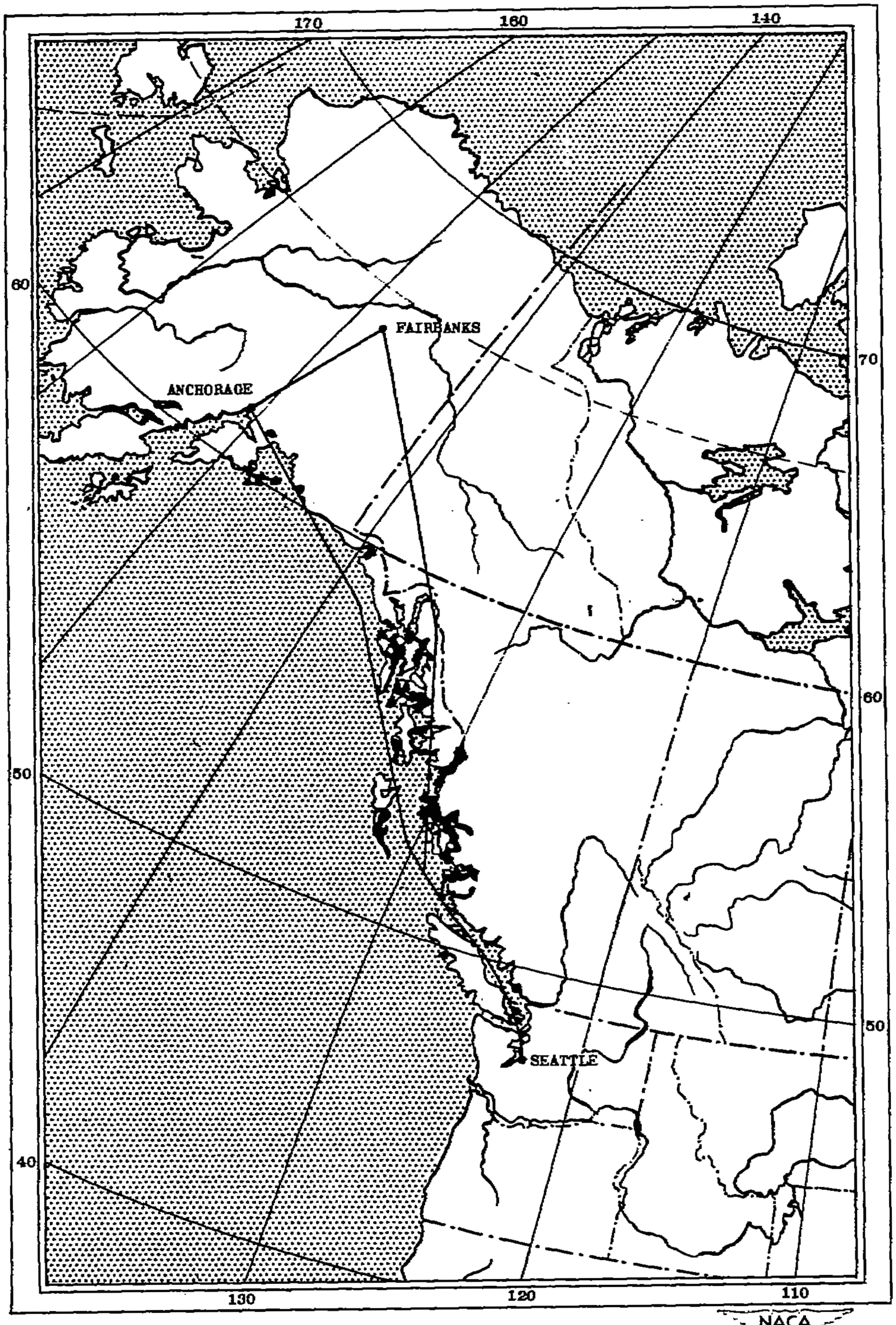

Figure 1.- Route of Operations.

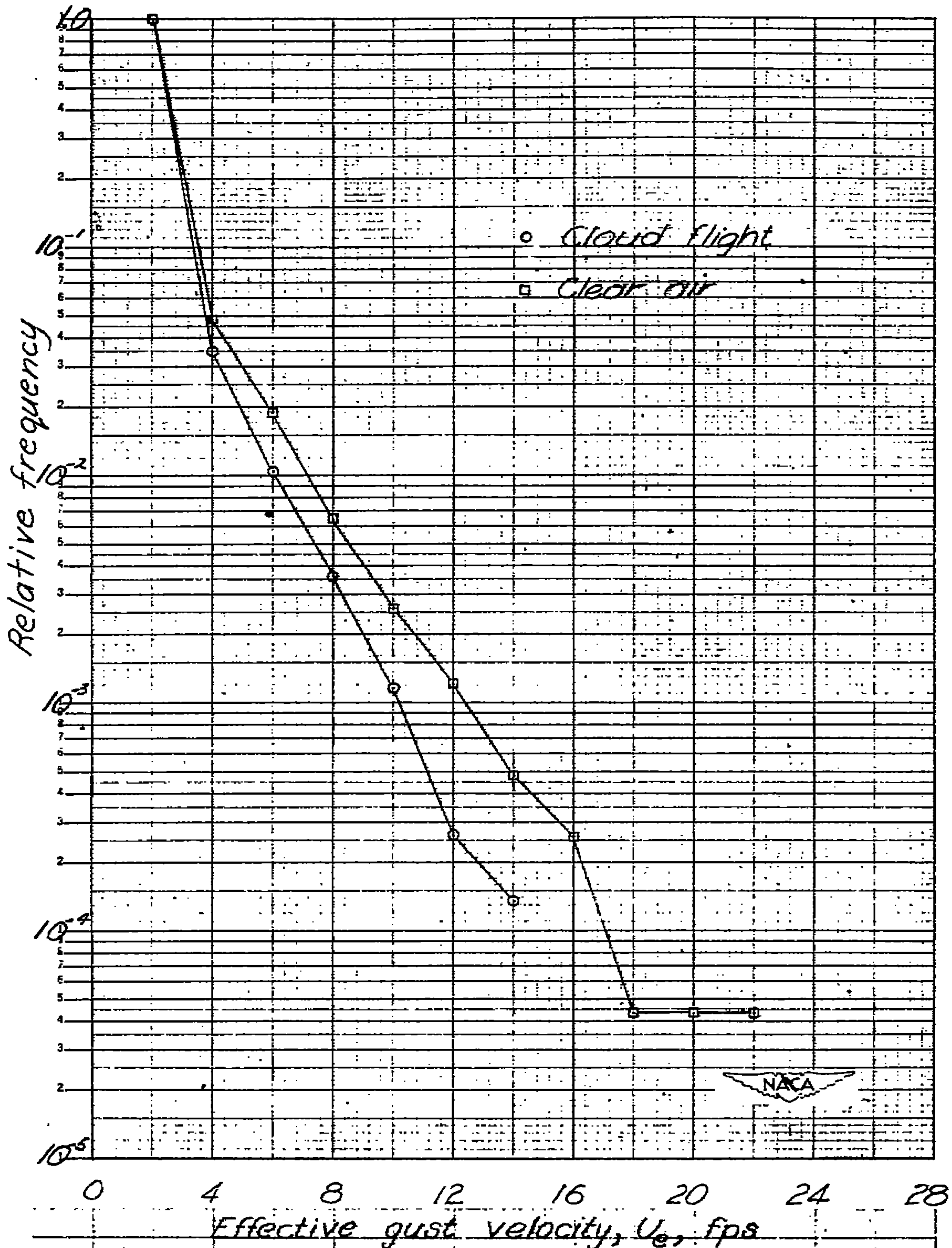

Figure 2 - Relative Frequency of exceeding a given gust velocity