NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1233

PRELIMINARY ANALYSIS OF NACA MEASUREMENTS OF ATMOSPHERIC TURBULENCE WITHIN A THUNDERSTORM - U. S. WEATHER BUREAU THUNDERSTORM PROJECT

By Harold B. Tolefson

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

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SUMMARY

A general description of the field operations of the U. S. Weather Bureau thunderstorm project conducted in the vicinity of Orlando, Fla., during the summer months of 1946 is given. The participation of the NACA in this project is described and measurements of atmospheric turbulence taken by the NACA are presented for one of the flights.

The results indicate that some regions of thunderstorms may present no great hazard to flight, while exceptionally severe conditions of atmospheric turbulence may occur in other regions, or even in the same region, at about the same time. The results also indicate that these severe conditions of turbulence might lead to loss of control with the possible loss of the airplane.

INTRODUCTION

Most routine flight operations require a certain amount of thunderstorm flying for the reason that it is not always possible or practical for the pilot to avoid all storm areas. Night operations, for instance, lead to difficulties in detecting individual thunderstorms or clear regions between thunderstorms. In other cases, it may not be considered an economical procedure to detour a line of thunderstorms. Pilots, on many such occasions, have flown through the thunderstorms without incident, while others have only rarely experienced severe turbulent conditions.

As contrasted to these experiences, others have been reported which show the violent characteristics of thunderstorms. Consideration of all such cases would indicate that hazardous conditions of atmospheric turbulence may at times occur in some regions of thunderstorms, while in other regions no great difficulty to flight will occur. To date, however, no quantitative data have been obtained to verify this point.

During the 1946 operations of the thunderstorm project near Orlando, Fla., data were obtained which relate to the foregoing question. The purpose of the present paper is to present these data together with a general description of the activities of the project.

ORGANIZATION AND FIELD OPERATIONS

OF THE THUNDERSTORM PROJECT

The thunderstorm project is under the direction and coordination of the U. S. Weather Bureau with the active participation of the Army Air Forces, the Navy, the University of Chicago, and the NACA. All field operations during the summer of 1946 were conducted within the vicinity of Orlando Army Air Base, Orlando, Fla. This site was chosen as the base of field operations for the project because it is located in the region of maximum frequency of occurrence of convective thunderstorms during the summer months and because Army facilities required for many of the operations were already installed at nearby bases.

The field operations of the thunderstorm project can be divided into four separate but closely related phases - flight surveys of thunderstorms to obtain data on various meteorological quantities and on the indications of airborne radar equipment within the storms, ground radar observations of thunderstorm echoes and of flight paths of the airplanes during cloud surveys, detailed surface measurements of meteorological conditions such as precipitation and pressure changes associated with the thunderstorms, and radiosonde and rawin measurements to determine upper air conditions preceding and during the time of the thunderstorm.

The flight surveys were made by five airplanes under the direction of a ground controller. On the basis of ground radar observations of the thunderstorms and of the position of the airplanes, directions as to flight altitudes and headings were issued to the pilots so that nearly simultaneous traverses at altitudes from 6000 to 26,000 feet and at approximate 5000-foot vertical intervals could be made. During the traverses, measurements were taken of atmospheric turbulence, and motion-picture records were taken of the indications of radar equipment installed in the airplanes. Following the flights, additional information was obtained from the flight crews concerning the intensity and location of regions of icing, various forms of precipitation, lightning discharges, and other factors affecting the handling of the airplane.

The ground radar indications of the thunderstorms and of the locations of the airplanes were photographed at 15-second intervals so that the actual paths of the airplanes could be plotted in relation to the storm echoes. These photographs together with measurements of the intensity of the thunderstorms provide data for studies relating to the use of radar as a means of detecting hazardous storm conditions.

Detailed surface measurements of meteorological conditions associated with the thunderstorms were taken from a network of 55 stations covering roughly a 7- by 15-mile area. The surface measurements taken at each station consisted of automatic recordings of temperature, pressure, relative humidity, rainfall, wind speed, and wind direction. These measurements were taken continuously throughout the duration of the project.

The upper air measurements were taken with radiosonde equipment installed at six stations and rawin equipment installed at ten stations. As a safety precaution, the upper-air measurements were taken only preceding and following the airplane flights.

APPARATUS AND METHOD FOR MEASURING

ATMOSPHERIC TURBULENCE

The airplanes used in the thunderstorm project were of the type shown in figure 1. The characteristics of the airplanes as flown are given in table I.

The instruments installed in each airplane 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 (1-sec interval)

The accelerometer, which was installed at the center of gravity of each airplane to measure the normal acceleration increments, was 0.7 critically damped and had a vane frequency of 12 to 13 cycles per second. The airspeed-altitude recorder was connected to a special airspeed head mounted on the underside of the nose section of the airplane. This installation was independent of the pilot's airspeed system. The control-position recorder was connected to the elevator cables to give a measure of control deflections so that a selection of accelerations resulting from gusts as contrasted with those resulting from control movements could be made. The instruments were adjusted to give a record speed of about 0.2 inch per second and were synchronized by the 1-second interval timer. Operation of the instruments was controlled by the pilot by means of an on-off switch.

The records of acceleration, airspeed, and altitude were evaluated to obtain the effective gust velocities U_e by use of the formula (reference 1):

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

in which

U_e effective gust velocity, feet per second

Δn acceleration increment, g units

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-coefficient curve corrected for Mach number effect, per radian

V_e equivalent airspeed of airplane, feet per second $(V\sigma^{1/2})$ (reference 2)

S wing area, square feet

K relative alleviation factor taken from figure 1 of reference 1 (K = 1.19 for wing loading of 45.7 lb/sq ft)

PRECISION

The accuracy of the NACA acceleration measurements was determined by dropping the accelerometers on calibrated springs to obtain one-half sine waves of impressed accelerations. These tests indicated that for the instruments used in the thunderstorm project the dynamic errors were less than 0.05g for frequencies up to 5 cycles per second. An inspection of the records obtained from the flights indicated that this range of frequencies corresponded to the range of impressed frequencies due to gusts. At times, however, additional acceleration increments of about 0.05g due to airplane vibration were recorded by the accelerometers. The acceleration increments when read from the records to ±0.01g are therefore felt to be accurate to within ±0.10g.

The NACA airspeed recording system was calibrated in accordance with the method described in reference 3 by flying one of the airplanes at various airspeeds past a reference point of known elevation. All recorded airspeeds were corrected by means of this calibration in obtaining the values of V_e used in the effective-gust-velocity formula. These values of V_e are believed to be accurate to within ±2 feet per second.

The maximum error in the effective gust velocities resulting from errors in the airspeed-acceleration measurements is ±2 feet per second. Weight changes of the airplanes due to fuel consumption are taken into account in computing the gust velocities.

FLIGHT INVESTIGATION OF A THUNDERSTORM

ON JULY 2, 1946

Four airplanes participated in the surveys on the afternoon of July 2, 1946. As directed by the ground control operator, each airplane made four or five traverses through the thunderclouds at its assigned altitude of 6,000, 11,000, 16,000, and 21,000 feet over the period 1415 to 1515 EST. All traverses were made at approximately 180 miles per hour indicated airspeed.

The reports of the flight crews indicated that the cloud initially extended from an altitude of 5,000 feet up to 28,000 feet and, as the traverses progressed, the tops gradually built up to about 33,000 feet. Light to heavy rain was encountered in the lower parts of the clouds with light to moderate hail, freezing rain, or snow being encountered in the upper parts. Occasional lightning within the clouds was reported by all flight crews. According to the estimates of the pilots, light to severe conditions of atmospheric turbulence were encountered at all altitudes within the storm. Only at 21,000 feet, however, were these conditions of such severity as to lead to difficulty in maintaining control of the airplane.

RESULTS

The maximum positive and negative effective gust velocities $U_{e_{max}}$ obtained for each traverse of the four airplanes are summarized with the corresponding maximum acceleration increment and the starting time and length of the traverses in table II. In order to give a better indication of the relative intensity of the turbulence encountered at the different times and altitudes, time histories of acceleration of the last traverse of the airplanes at 6,000, 11,000, and 16,000 feet and for the last two traverses of the airplane at 21,000 feet are shown in figure 2. The variation of the absolute maximum effective gust velocity $|U_e|_{max}$ with time for all traverses is shown in figure 3.

DISCUSSION

Table II indicates that with the exception of the last traverse, effective gust velocities less than 20 feet per second were encountered. The pilots indicated that on these traverses no marked difficulty of control was experienced and, in general, the intensity of the turbulence was classified as light to moderate. On the last traverse of the airplane flying at 21,000 feet, however, effective gust velocities slightly greater than 28 feet per second were encountered and the pilot indicated that the conditions were of such severity that at times the airplane was almost out of control.

The time histories of figure 2 indicate quite clearly that the airplane at 21,000 feet experienced much more severe conditions at 1505 EST than on a previous traverse through the cloud at the same altitude or than other airplanes at other altitudes. The large sustained negative acceleration increments experienced during the latter part of the traverse led the pilot and radar operator to believe that the airplane was inverted on two occasions. It may be observed from these time histories that extreme turbulence may occur in some regions of thunderstorms while other regions may not be exceptionally severe.

Figure 3 indicates that the turbulence at the different altitudes within the clouds followed a generally similar tendency to decrease and then increase with the passage of time. The rate of increase was more rapid, however, and the turbulence became more severe at 21,000 feet than at other altitudes. Thus, turbulence may not be extreme in all parts of a thunderstorm nor throughout its life cycle, but in some portion during the cycle exceptionally severe conditions may be encountered.

CONCLUDING REMARKS

Extreme conditions of atmospheric turbulence may not always be encountered when flying through thunderstorms; nevertheless, at some time and place within a storm, conditions may be exceptionally severe. Until extremely turbulent regions within thunderstorms can be accurately predicted or detected, all thunderstorm flying should be regarded as potentially hazardous. The results of this preliminary analysis show promise that analysis of additional data will contribute substantially to the safety of thunderstorm flying.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., January 29, 1947

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TABLE I

CHARACTERISTICS OF AIRPLANES USED

Gross weight at take-off, lb	30,300
Wing area, sq ft	662.4
Wing loading at take-off, lb/sq ft	45.7
Span, ft	66
Mean aerodynamic chord, ft	10.5
Center-of-gravity location, percent M.A.C.	25.2
Slope of lift curve, per radian	4.83
Length, ft	48.7

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TABLE II

SUMMARY OF ACCELERATION AND GUST VELOCITY

MEASUREMENTS WITHIN A THUNDERSTORM

ON JULY 2, 1946

Airplane flight altitude (ft)	Start of traverse (EST)	Length of traverse (ft)	Maximum acceleration increment, Δn_{max} (g)		Maximum effective gust velocity, $U_{e_{max}}$ (fps)	
6,000	1408	6,873	0.45	-0.35	10.3	-8.0
	1425	42,717	.40	-.47	11.5	-12.8
	1453	21,636	.40	-.35	10.9	-9.0
	1457	25,651	.84	-.62	19.8	-14.7
	1500	71,907	.69	-.56	14.7	-11.8
11,000	1411	46,263	.79	-.54	18.7	-13.0
	1428	24,000	.52	-.30	13.5	-7.9
	1451	35,571	.34	-.34	7.8	-8.4
	1513	75,725	.54	-.42	11.9	-10.1
16,000	1418	35,592	.67	-.59	15.9	-14.9
	1428	22,666	.59	-.39	16.7	-10.4
	1448	36,945	.52	-.54	14.3	-14.0
	1504	48,760	.79	-.54	18.5	-14.2
21,000	1418	48,183	.63	-.59	17.3	-15.4
	1441	27,703	.38	-.23	10.4	-6.9
	1453	47,671	.32	-.23	9.4	-6.9
	1505	79,020	1.16	-1.25	28.3	-28.6

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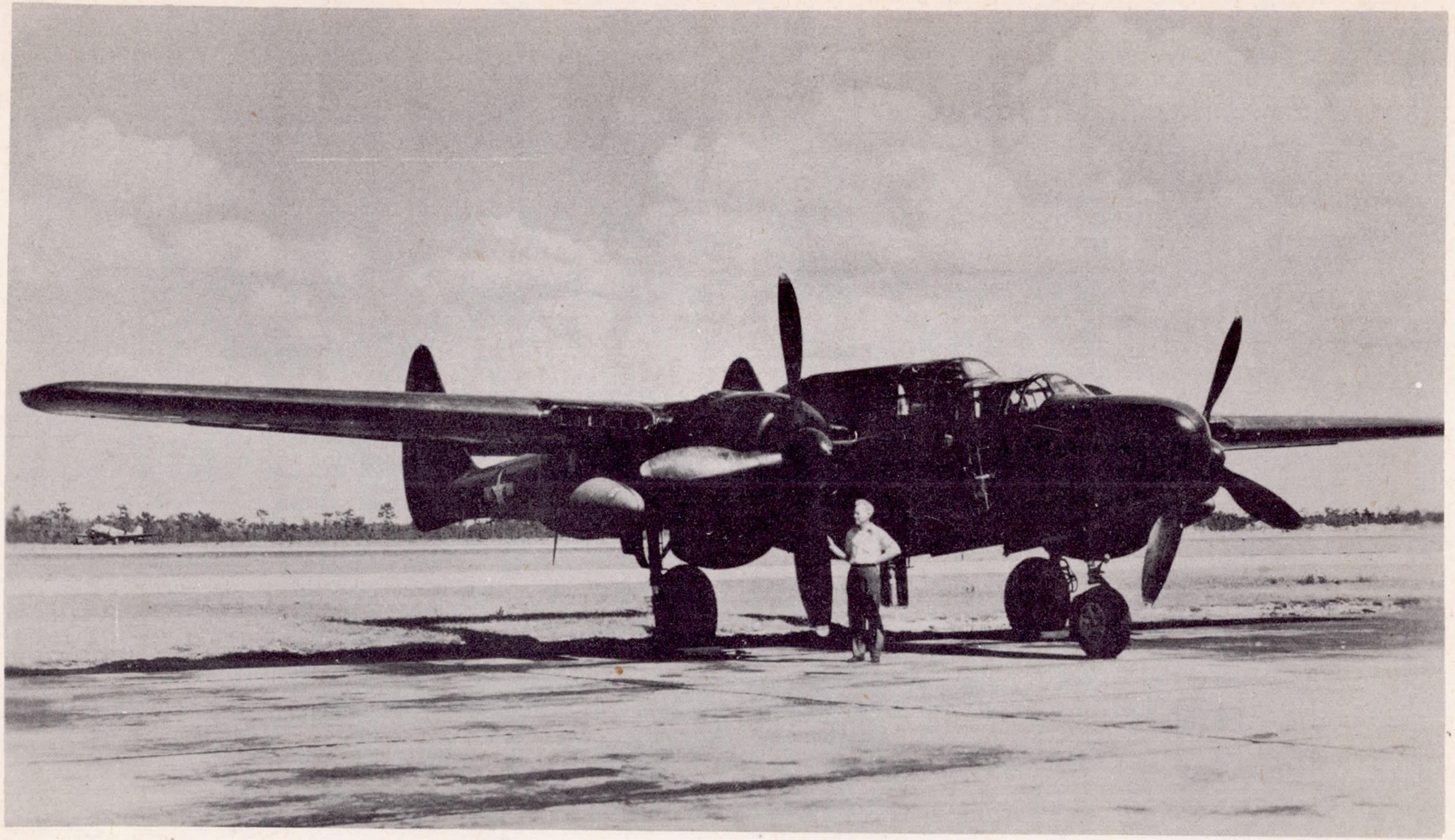

Figure 1.- Airplane used in thunderstorm project.

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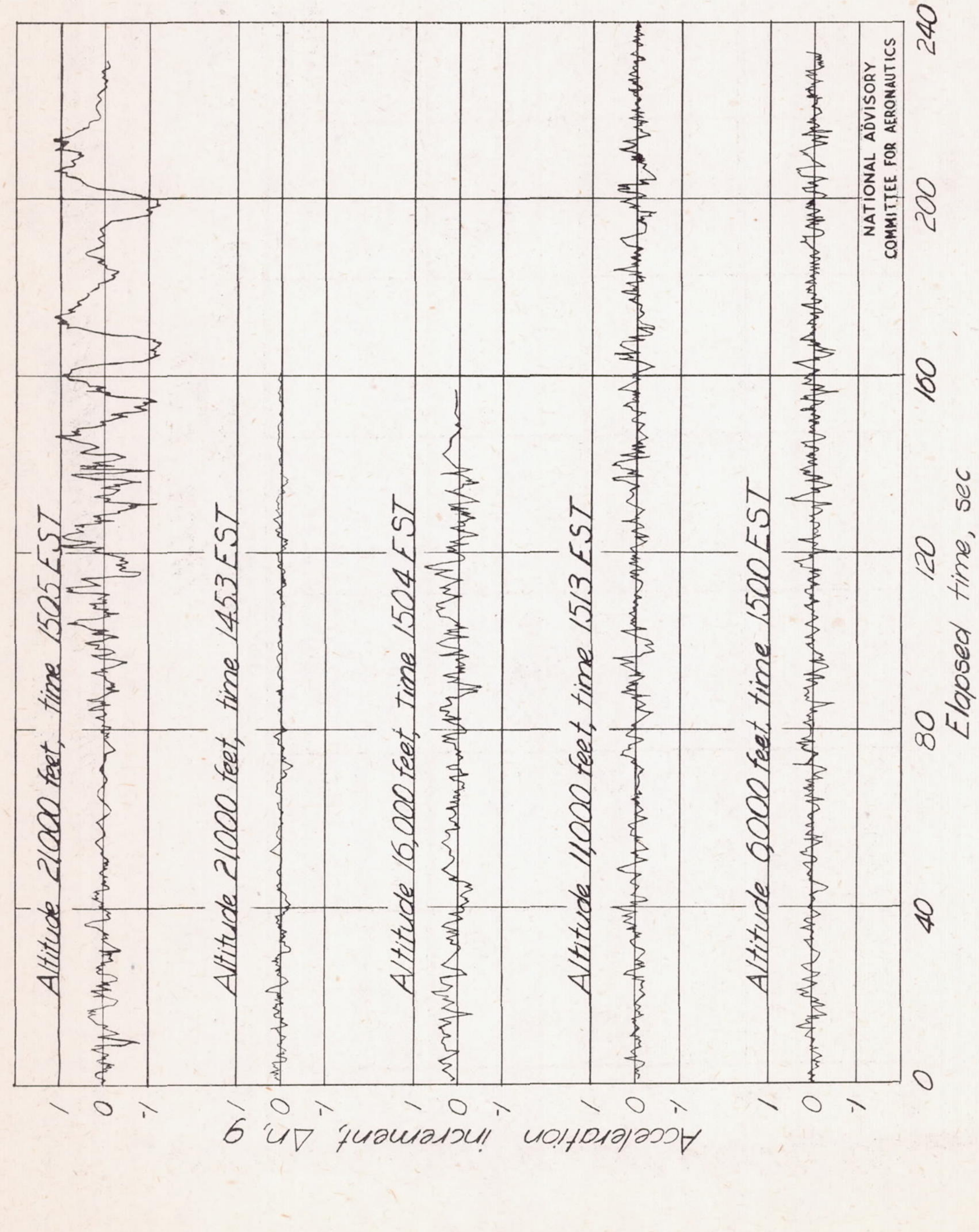

Figure 2.- Time histories of acceleration for traverses through a thundercloud on July 2, 1946.

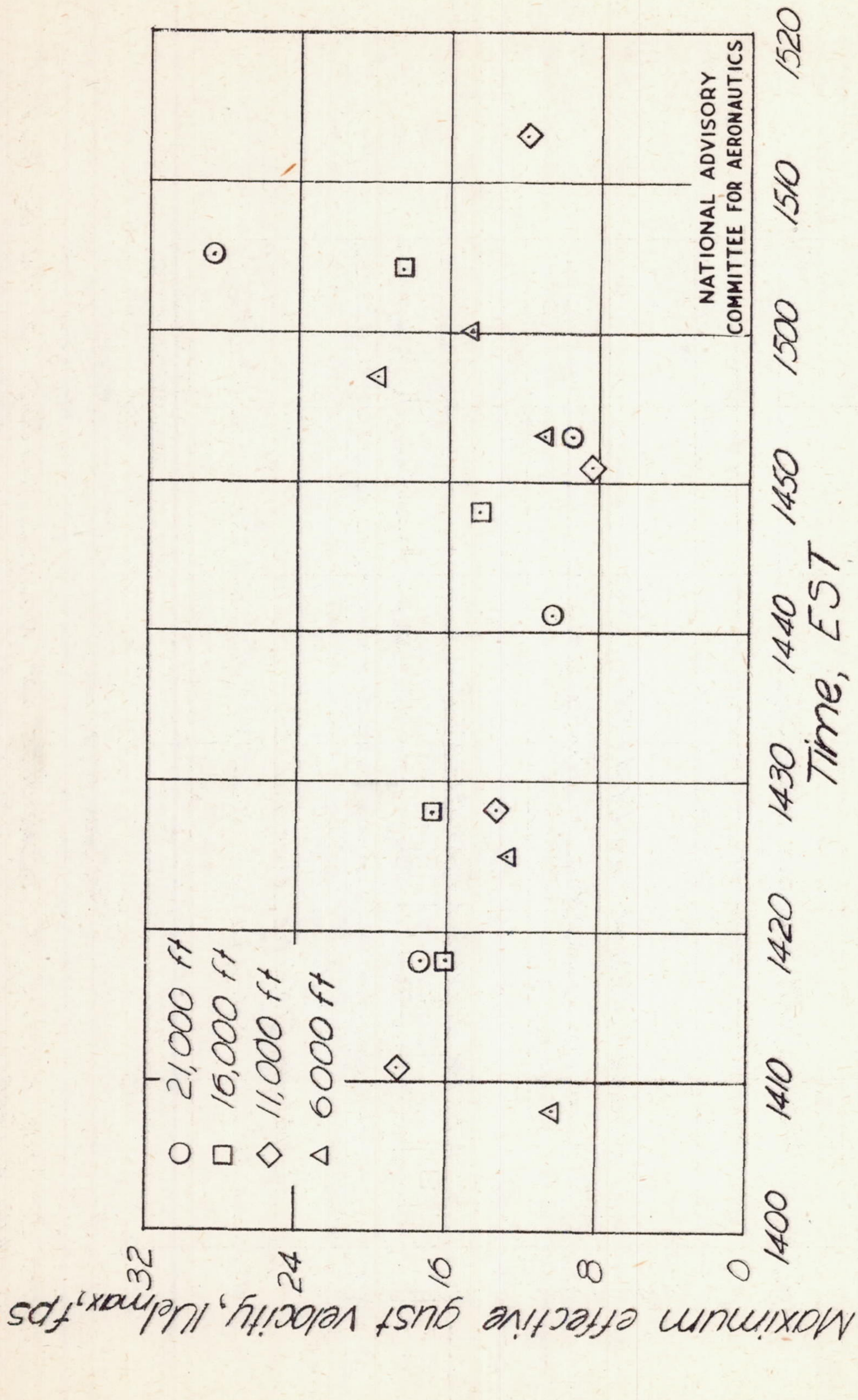

Figure 3.- Time variation of atmospheric turbulence measured within thunderclouds.