RB No. L5A03

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
January 1945 as
Restricted Bulletin L5A03

XC-35 GUST RESEARCH PROJECT

CHARACTERISTICS OF VERTICAL DRAFTS AND ASSOCIATED VERTICAL-GUST VELOCITIES WITHIN CONVECTIVE-TYPE CLOUDS

By A. I. Moskovitz

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESTRICTED BULLETIN

XC-35 GUST RESEARCH PROJECT

CHARACTERISTICS OF VERTICAL DRAFTS AND ASSOCIATED VERTICAL-GUST VELOCITIES WITHIN CONVECTIVE-TYPE CLOUDS

By A. I. Moskovitz

SUMMARY

Records obtained in flight were evaluated to determine the relation between the velocities of vertical drafts and associated gusts within convective-type clouds. The velocity of the vertical drafts was evaluated from the variation of altitude with time recorded by a barograph and by motion pictures of the pilot's instrument panel. The draft velocities thus obtained were compared with the maximum true gust velocities in the draft region evaluated from airspeed and acceleration data.

Evaluation of the data showed that the vertical-draft velocity and the maximum vertical true gust velocity encountered within the draft region were essentially equal. A single draft was found to occupy from 3 to 42 percent of the width of a cloud and several drafts encountered at the same altitude within one cloud were found to occupy from 6 to 63 percent of the cloud width.

INTRODUCTION

The prediction of the intensity and distribution of atmospheric gusts within convective-type clouds from meteorological conditions is desirable for the safe operation of aircraft. Although much work has been done in connection with this problem, no quantitative solution has been found up to the present time because of its complexity. Meteorological processes indicate that the energy within convective-type clouds becomes evident in the form of vertical currents or drafts of considerable size and intensity, which are noticeable to the pilot by marked changes in flight altitude. The drafts are partly dissipated by shearing action between the draft and the relatively still air, which produces turbulence or gusts of varying sizes and intensities that are evident to the pilot from bumpy and irregular flight. It would be of considerable value as a basic step toward the prediction of the intensity of atmospheric gusts from meteorological conditions to show that the velocities of drafts and associated gusts are related.

Data on the intensity and size of drafts and vertical gusts were obtained from flights with the XC-35 airplane during 1941 and 1942 under a variety of weather conditions. (See reference 1.) Flights were made in the vicinity of Langley Field, Va. on days when meteorological information indicated that conditions were conducive to the development of convective-type clouds. The data obtained have been utilized to determine whether any definite relation exists between the vertical component of the draft velocity and the maximum gust velocity associated with the draft. The vertical components of the draft velocities were evaluated from records of variation of time with altitude obtained from motion pictures of altimeter and clock and from a barograph, and the gust velocities were evaluated from airspeed and acceleration records.

APPARATUS

The XC-35 airplane (fig. 1), which was used for the flights to obtain draft and gust data, is described in detail in reference 1. The airplane was equipped with governed (constant-speed) propellers and automatic manifold pressure controls, which delivered essentially constant thrust horsepower for fixed control settings during reasonable changes in altitude or operating speed.

The following instruments were used in the airplane to obtain the desired data:

(1) NACA air-damped recording accelerometer

(2) NACA airspeed recorder

(3) NACA timer (1-sec interval)

(4) Ciné-Kodak Special 16-millimeter motion-picture camera

(5) Airplane sensitive altimeter

(6) Airplane clock with sweep second hand

(7) Friez barograph

The accelerometer and airspeed recorder were fitted with magazine film drums containing sufficient film for 30 minutes of record at a film speed of 1/8 inch per second. The motion-picture camera, which was used to photograph the altimeter and the clock, was fitted with a magazine containing film for 8 minutes of motion pictures at a film speed of 8 frames per second. The barograph was a standard Friez instrument that recorded the barometric pressure on recorder paper at a rate of 0.07 inch of record per minute.

TESTS AND METHODS

The tests consisted of making traverses of the clouds at various altitudes up to 30,600 feet. The airplane was trimmed for steady level flight prior to entry into a cloud. During the traverse the pilot attempted to maintain a reasonably constant airspeed and disregarded the changes in the altitude of the airplane. The throttle setting during the traverses was not changed and the elevator control was used to adjust for any changes in airspeed of the airplane.

The barograph was in continuous operation throughout the flight, whereas all other recording instruments were operated only during cloud surveys and were turned on simultaneously and off simultaneously.

EVALUATION OF RECORDS

The variation of pressure altitude with time obtained from motion pictures and from barograph traces was evaluated to obtain the draft velocity U_d. Only outstanding changes in pressure altitude were evaluated because of the small time scale of the barograph record and the vibration of the altimeter needle in rough air. The minimum altitude change considered suitable for evaluation was approximately ±200 feet and the minimum time to traverse the draft was approximately 10 seconds. Since the rate of change of altitude was not constant throughout the horizontal extent of the draft, the velocity obtained from the following expression is an average:

$$U_d = \frac{\Delta h}{\Delta t} \tag{1}$$

where

U_d draft velocity, feet per second

Δh change in pressure altitude (standard atmosphere), feet

Δt increment of time for change in altitude, seconds

The determination of U_d is based on the assumption that

(1) The vertical motion of the airplane is the vertical motion of the air

(2) The pressure field within the cloud is constant

(3) The change in true altitude is equal to the change in pressure altitude

(4) A negligible change in airspeed and power occurs during traverses of the drafts

The maximum value of the true gust velocity U_t encountered within each draft was obtained from airspeed and acceleration data. Since the acceleration peaks corresponding to the maximum gust velocity might not have satisfied the conditions for evaluation of U_t given in reference 2, the effective gust velocity U_e was first computed from the basic data by the sharp-edge-gust formula (reference 3). The corresponding value of U_t was then computed from U_e by the relation given in reference 3 on the assumption that all the gusts were of the same shape and size. A reasonable value of gust size for the XC-35 airplane is 9 chord lengths. This value is obtained by averaging all values of gust-gradient distance H shown in figure 3 of reference 1. On the basis of the assumed gust size, the acceleration ratio for relating U_t and U_e

was found from equation 4 of reference 3 to be 0.67. The final relation therefore is

$$U_t = \frac{U_e\sqrt{\rho_o/\rho}}{0.67} \qquad (2)$$

where

U_t true gust velocity, feet per second

U_e effective gust velocity (see reference 3), feet per second

ρ_o mass density of air at sea level

ρ mass density of air at altitude

This procedure probably yields the best estimate of the maximum true gust velocity that can be made at the present time.

The horizontal extent of the draft d_d and of the cloud d_c was determined from the following relations:

$$d_d = V\,\Delta t_d$$

and

$$d_c = V\,\Delta t_c$$

where

V average true forward airspeed of airplane, feet per second

Δt_d increment of time to traverse draft, seconds

Δt_c increment of time to traverse cloud, seconds

The draft velocity evaluated from both the motion-picture and barograph records is shown plotted against the maximum true gust velocity associated with the draft in figure 2. These data, together with other pertinent characteristics of the draft and of the cloud in which the draft was encountered, are summarized in table I. The number of drafts evaluated herein represent only a small percentage of the total number encountered in the flights because of the very small time scale barograph records and the limited supply of motion-picture film. In several instances more than one draft was encountered on a traverse through a cloud; the draft velocity was therefore compared with the most intense gust within each draft region. The occurrence of more than one draft at any one altitude within a cloud is indicated by the equal altitude levels in table I.

PRECISION

The precision in the determination of the vertical-draft velocity U_d depends upon reading errors, deviations of the motion of the airplane from the motion of the air, and change in the pressure field within the clouds. The values of U_d evaluated from the motion-picture and the barograph records are estimated to be accurate within ±5 percent and ±15 percent, respectively, as a result of reading errors. The pilot was quite successful in maintaining a constant airspeed and, since power was not changed during a traverse, the airplane is believed to have followed the general vertical motions of the air within the draft. There is a possibility of a nonuniform pressure field within convective-type clouds and the effect on the recorded draft velocity of traversing such a field has been computed for conditions that are believed to be extreme. On the assumptions that the barometric pressure decreased linearly by 10 millibars over a distance of 5 miles and that the airplane was flying at a true airspeed of 150 miles per hour, the apparent rate of change of altitude would be 4 feet per second at 20,000 feet. From the considerations noted, the draft velocities are believed to have a probable maximum error of ±20 percent as determined from the barograph records and of ±10 percent as determined from the motion-picture records.

The precision in the determination of the true gust velocity U_t depends upon errors in the evaluation of the effective gust velocity U_e and upon errors arising from the assumption that all the gusts had a gradient distance of 9 chord lengths. The discussion of precision in reference 1 indicates that the values of U_e are accurate within ±10 percent. The data of reference 1 showed that in 85 percent of the cases the measured gradient distances would yield an acceleration ratio within ±5 percent of 0.67. Consideration of these sources of error indicates that the error in the value of U_t would be ±15 percent.

DISCUSSION

The results presented in figure 2 and table I show that the maximum true gust velocities in convective-type clouds are, on the average, equal to the velocities of the vertical drafts. The coefficient of correlation (see reference 4) of gust velocity with draft velocity determined from barograph records was 0.95 and of gust velocity with draft velocity determined from motion-picture records was 0.99.

Table I indicates that the direction of the maximum gust is the same as that of the draft. The significance of this result is difficult to determine, since in most cases the difference between the maximum positive and negative true gust velocities is small.

It is of interest to note in table I that within a single cloud updrafts, downdrafts, or any number of both may be encountered. A single draft occupied from 3 to 42 percent of the cloud width and several drafts encountered within a cloud at the same altitude occupied from 6 to 63 percent of the cloud width. It is highly probable, moreover, that drafts other than those encountered existed in other portions of the clouds surveyed.

CONCLUSION

Evaluation of data obtained in flight to determine the relation between the velocities of vertical drafts and associated gusts within convective-type clouds indicated that the maximum true gust velocities are, on the average, equal to the velocities of the vertical drafts.

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

REFERENCES

1. Moskovitz, A. I.: XC-35 Gust Research Project - Analysis of Gust Measurements. NACA RB No. L4D22, 1944.

2. Donely, Philip: Effective Gust Structure at Low Altitudes as Determined from the Reactions of an Airplane. NACA Rep. No. 692, 1940.

3. Rhode, Richard V.: Gust Loads on Airplanes. SAE Jour., vol. 40, no. 3, March 1937, pp. 81-88.

4. Rietz, H. L., and Crathorne, A. R.: Simple Correlation. Ch. VIII of Handbook of Mathematical Statistics, H. L. Rietz, ed., Houghton Mifflin Co., 1924, pp. 120-138.

TABLE I. - CHARACTERISTICS OF DRAFTS AND ASSOCIATED GUSTS

Type of cloud	Altitude (ft)	Draft velocity, U_d (fps)		Maximum true gust velocity, U_t (fps)	Horizontal extent of cloud, d_c (ft)	Horizontal extent of draft, d_d (ft)	d_d/d_c
		Motion-picture record	Barograph record				
Cumulus congestus	14,300	31.8	32.4	32.4	14,500	2,500	0.17
	12,300	-25.6	-21.5	-29.5	13,000	5,500	.42
Do----	21,000	49.1	52.9	52.1	36,500	8,000	.22
	19,000	-------	28.0	51.7	71,000	16,500	.23
	18,000	-------	37.2	36.4	44,000	13,000	.29
Do----	20,000	23.6	28.5	32.5	25,000	4,000	.16
	16,000	26.1	26.7	26.5	47,000	3,500	.08
Cumulo nimbus	21,000	21.1	34.6	23.1	105,500	13,000	.12
	19,000	-------	42.3	39.1	128,000	9,000	.07
	19,000	-------	35.4	27.7	128,000	6,000	.05
	17,000	-------	19.6	30.3	74,000	16,500	.22
Do----	29,000	-36.6	---------	-34.3	58,500	5,500	.09
	29,000	-46.6	-39.5	-47.6	58,500	11,000	.19
	29,000	22.4	---------	19.5	58,500	4,000	.07
	29,000	32.1	---------	37.2	58,500	16,500	.28
Do----	30,600	44.4	46.0	40.6	104,000	17,000	.16
Do----	28,000	25.2	---------	27.6	107,000	3,000	.03
	28,000	-29.3	---------	-25.2	107,000	3,500	.03

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

L-554

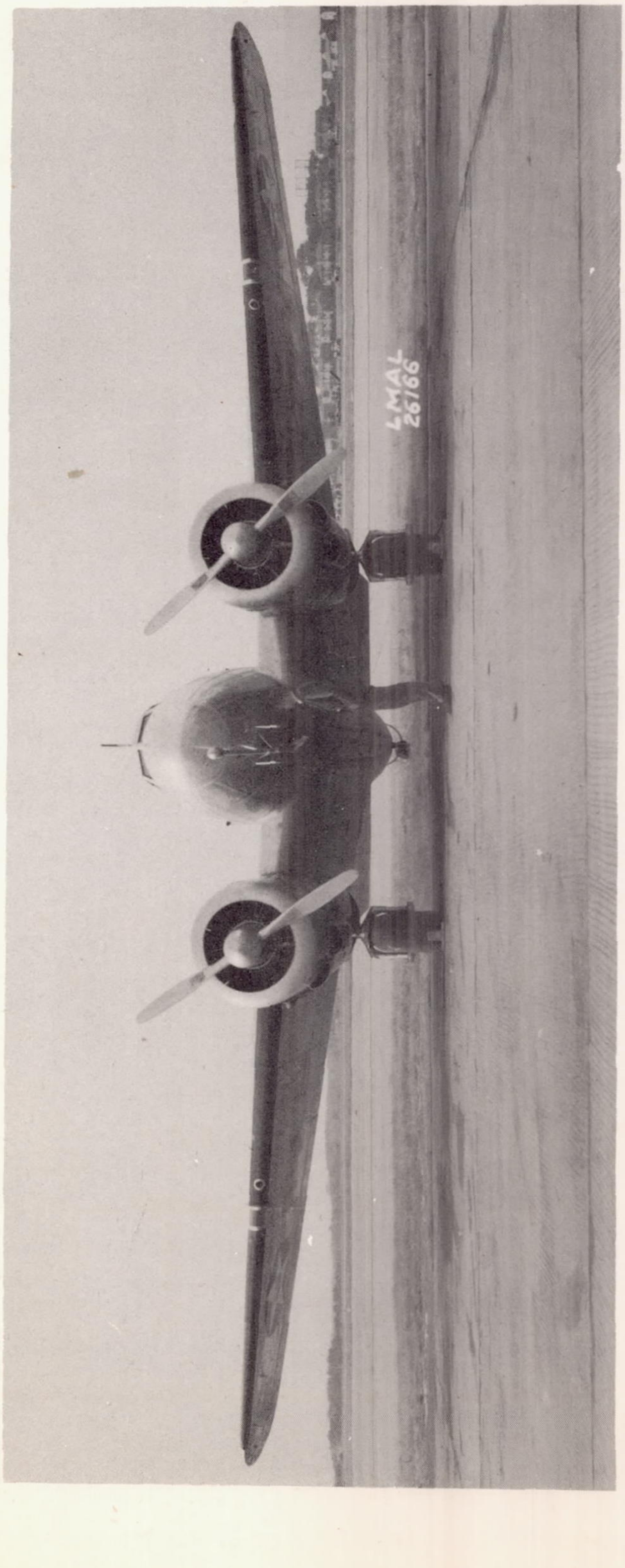

Figure 1.- Front view of XC-35 airplane.

L-554

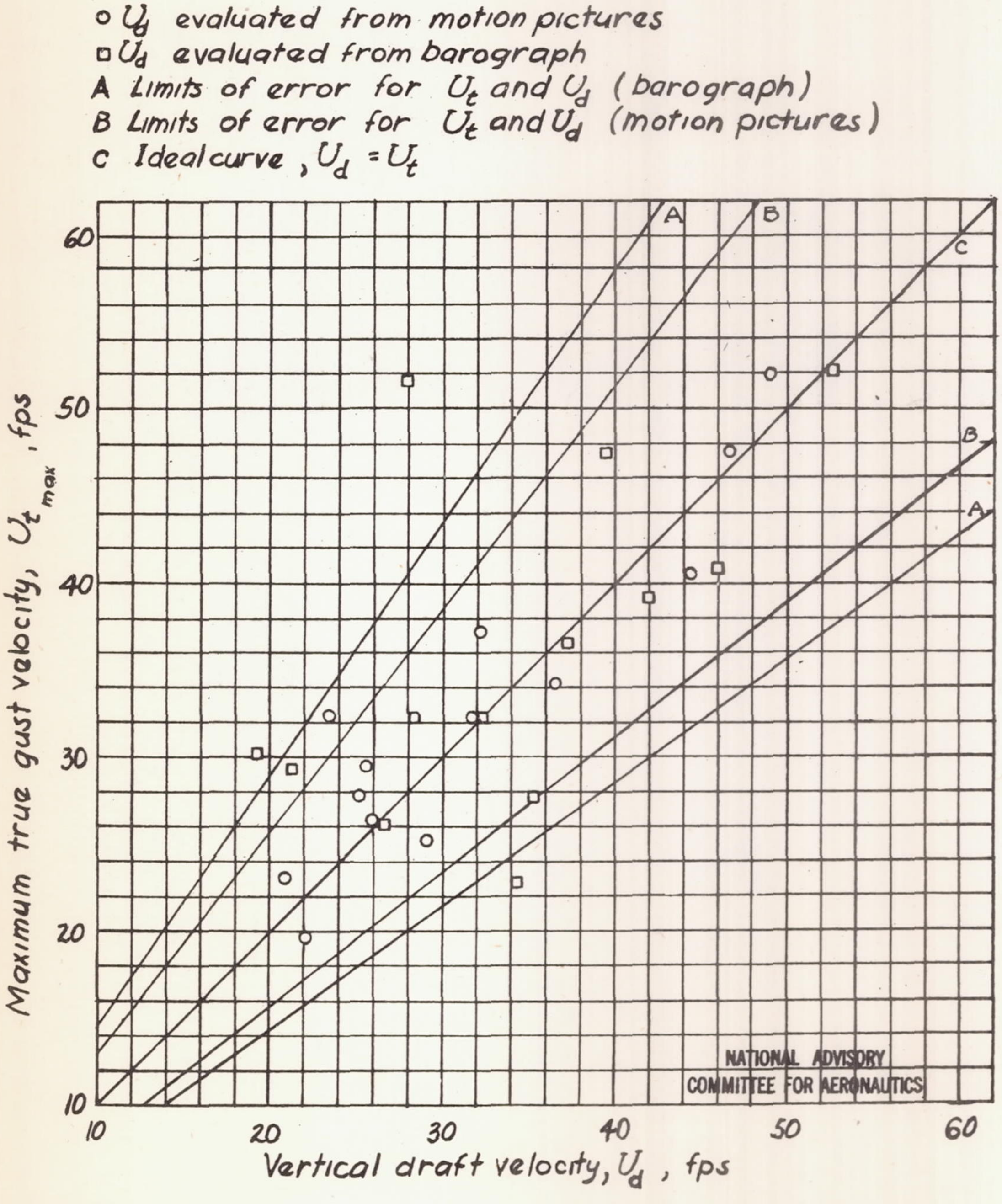

Figure 2.- Comparison of the maximum true gust velocity encountered within the vertical draft with the velocity of the draft.