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AN ANALYSIS OF THE RELATION BETWEEN HORIZONTAL TEMPERATURE VARIATIONS AND MAXIMUM EFFECTIVE GUST VELOCITIES IN THUNDERSTORMS

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SUMMARY

An analysis is presented of the relations between the horizontal temperature variations and the maximum observed effective gust velocities for the data obtained during operations of the United States Weather Bureau thunderstorm project in Florida and Ohio. The results indicate that the relation when extended to include frontal conditions appears useful for forecasting the intensity of turbulence for thunderstorms in temperate regions. The relation does not appear useful, however, for forecasting the intensity of turbulence in subtropical regions.

INTRODUCTION

The results of a recent investigation reported in reference 1 indicated that the horizontal temperature variations and height of convective activity appear to give a measure of the maximum effective gust velocities in clouds. The complete meteorological parameter M, which provided a measure of the maximum effective gust velocities, was given as

$$M = \sqrt{H_c \, \Delta T/T}$$

where

H_c vertical depth of convective activity for given air mass

$\Delta T/T$ relative horizontal temperature spread

As indicated in this reference, data available from the gust investigations with the XC-35 airplane substantiate these relationships for cumuliform clouds with correlation coefficients of the order of 0.70 between gust and meteorological variables. The simplified parameter defined by the maximum value, for a given sounding, of ΔT appeared to yield equally accurate estimates of the maximum effective gust velocities within the scope of the data presented. More recent gust and meteorological data obtained from the Florida and Ohio operations of the thunderstorm project provided an opportunity to verify further the indicated relation between ΔT and maximum effective gust velocities and to extend it to other weather conditions.

SYMBOLS

H_c	vertical depth of convective activity for given air mass, feet
M	gust parameter
T	observed temperature in absolute units at level from which T is taken, °C absolute
ΔT, ΔT^*	maximum horizontal temperature difference between warm rising air as indicated by moist adiabat from convective condensation level and cold air as indicated by wet-bulb temperature at each level (ΔT^* differs from ΔT in that observed instead of predicted surface temperatures are used in determining convective condensation level)
$U_{e_{max}}$	maximum effective gust velocity encountered during flight
$\overline{U}_e$	mean maximum effective gust velocity
S_{U_e}	standard error of estimate of effective gust velocity
σ_{U_e}	standard deviation of effective gust velocity

SCOPE OF DATA

Measurements of the maximum effective gust velocity $U_{e_{max}}$ from flights through thunderstorms and local early-morning radiosonde data were both available for 21 of the 38 flight days of the 1946 thunderstorm project. For the 1947 thunderstorm-project operations at Clinton County Army Air Field, Wilmington, Ohio, the number of available local early-morning radiosondes was insufficient for statistical analysis.

The radiosonde data from Nashville, Tennessee, were considered representative of the meteorological conditions over the flight area at storm time and consequently were used in the present analysis. Gust measurements and early-morning radiosonde data were available for 25 of the 29 flight days of the Ohio operations. No reliable data on the height of cloud tops were available for either year, thereby eliminating the use of this factor and the complete parameter as recommended in reference 1.

ANALYSIS AND RESULTS

The horizontal temperature differences as indicated by the parameters ΔT and $\Delta T/T$ were determined as described in reference 1. The expression ΔT is the maximum horizontal temperature difference between the warm rising air as indicated by the moist adiabat from the convective condensation level and the cold air as indicated by the wet-bulb temperature at each level. In the expression $\Delta T/T$, T is the observed temperature in absolute units at the level from which ΔT is taken. The values obtained for ΔT and $\Delta T/T$ and the value of $U_{e_{max}}$ for each flight day of the Florida and Ohio thunderstorm-project operations are shown in tables I and II, respectively.

The importance of the convective condensation level in determining the magnitude of these parameters led to the investigation of several alternate methods for its determination. The most noteworthy of these methods was one which utilized the actual maximum surface temperature observed in the thunderstorm-project network during the storm period. The convective condensation level was determined by the point on the pseudoadiabatic diagram at which the dry adiabat from the maximum observed surface temperature crosses the saturation mixing-ratio line for the mean mixing ratio of the lower one hundred millibars. The parameters obtained from this alternate method are denoted by the symbols ΔT^* and $\Delta T^*/T$ and are also shown in tables I and II.

The analysis of reference 1 was essentially based on air-mass storms and does not include any consideration of the influence of frontal conditions. Many of the Ohio flights were made, however, into storms that appeared definitely associated with frontal conditions. In these cases, frontal effects appeared to be important, inasmuch as the analysis of the radiosonde data revealed in some instances that surface heating alone was insufficient to lift the surface air to the level of free convection. In the present study, frontal action was assumed to provide the mechanical lift necessary to enable the potentially unstable air to reach the level of free convection.

The coefficients of correlation (reference 2) between $U_{e_{max}}$ and ΔT, $\Delta T/T$, ΔT^*, and $\Delta T^*/T$ are shown in table III for the Florida and Ohio data. The significance of each of these coefficients is also indicated on the basis of a probability level of 1 percent. For purposes of comparison, table IV presents a summary of some pertinent statistics from the investigation of reference 1 along with those from the Ohio and Florida thunderstorm project. Scatter diagrams for $U_{e_{max}}$ and ΔT for both the Florida and Ohio data are shown in figure 1. The lines of regression and limits of reliability as indicated by the standard errors of estimate (reference 2) are also shown.

DISCUSSION

The results shown in table III indicate that for the data obtained during the 1946 operations in Florida, the coefficients of correlation between $U_{e_{max}}$ and the meteorological parameters ΔT and $\Delta T/T$ were 0.32 and 0.25, respectively. On the basis of a 1-percent level of significance, a correlation coefficient of at least 0.56 is required for samples of this size. Obviously neither of these coefficients of correlation can be considered significant. Correlation coefficients between the $U_{e_{max}}$ values and the meteorological parameters ΔT^* and $\Delta T^*/T$ were 0.53 and 0.46, respectively. These values, although somewhat higher, are not clearly significant. The parameters used, therefore, apparently do not yield a significant measure of $U_{e_{max}}$ for the Florida data.

Table III also indicates that, for the 1947 operations in Ohio, the coefficients of correlation between the values of $U_{e_{max}}$ and the meteorological parameters ΔT, $\Delta T/T$, ΔT^* and $\Delta T^*/T$ are all of the order of 0.60. The 1-percent level of significance for samples of this size requires a correlation coefficient of at least 0.50. Although little difference in correlation exists between the several parameters, all correlation coefficients are clearly significant. The relations indicated in reference 1, therefore, apparently apply to the Ohio data. Although ΔT^* and $\Delta T^*/T$ yield somewhat higher correlation coefficients than ΔT or $\Delta T/T$, it is not possible to determine whether the differences are real.

The lack of significant correlation between gust and meteorological variables for the Florida data (table III) may, at first glance, be somewhat unexpected. Consideration of table IV indicates, however, that this discrepancy may be accounted for by the small variation in magnitude of the daily maximum gust velocities. The standard deviation of effective gust velocity σ_{U_e} for the Florida data is 5.7 feet per second as compared with 6.4 feet per second for the Ohio data and 7.5 feet per second for the XC-35 data. A measure of the random error, or error of estimation not accounted for by the relation to the temperature parameter, is given by the standard error of estimate S_{U_e}. It is of particular interest to note that this measure varies within narrow limits (5.1 to 5.4 ft/sec) for all three sets of data. It seems reasonable to expect that the random errors, including errors of measurement, and so forth, are roughly constant for each set of data. Inasmuch as the total variation given for the Florida data by σ_{U_e} of 5.7 feet per second is only slightly greater than the random errors given by S_{U_e} of 5.4 feet per second, the lack of correlation clearly results from the limited variation in the available maximum effective gust velocities. The Florida data are apparently too homogeneous to permit detection by use of the parameters discussed herein.

As indicated in figure 1, estimates of $U_{e_{max}}$ based on ΔT can be expected to be reliable within about ±5 feet per second of the true value 68 percent of the time and within about ±10 feet per second about 95 percent of the time. Consideration of the data of table IV indicates that the standard error of estimate S_{U_e} is in all cases a sizeable proportion of the total variation as measured by σ_{U_e}, varying from 95 percent for the Florida data to 69 percent for the XC-35 data. Considerable error apparently exists in the predictions made with present methods. Lack of cloud-top data has prevented the determination of the effectiveness of the complete parameter of reference 1. The use of cloud-top data or some other significant parameter could improve the accuracy of predictions.

In connection with the question of additional parameters, a recent report (reference 3) has suggested two parameters as a measure of the intensity of turbulence associated with frontal and squall conditions. The indications of these parameters would appear to be in good agreement with pilot reports of the intensity of turbulence. As a number of the Ohio flights were made into storms associated with fronts and squall lines, an effort was made to test the relation between these parameters and the values of $U_{e_{max}}$ available for these flights. The results, although they do not warrant report in detail, indicate that these parameters do not yield a significant measure of $U_{e_{max}}$ values encountered. It is felt therefore that though these two parameters may distinguish between pilot measures of degree of turbulence from light to severe as encountered in commercial operations, they are unable to discriminate between the values of $U_{e_{max}}$ obtained from the thunderstorm operations.

CONCLUDING REMARKS

The relations between the horizontal temperature variations and maximum effective gust velocity, as proposed in NACA TN No. 1569, when extended to include frontal thunderstorms, are apparently substantiated by the analysis of available data from the 1947 Ohio thunderstorm-project operations. Coefficients of correlation between gust and meteorological variables of about 0.6 were obtained. For samples of this size and scope, the values of maximum effective gust velocity may be predicted within 5 feet per second 68 percent of the time.

For the data from the 1946 operations of the thunderstorm project in Florida, the coefficients of correlation between the horizontal temperature variations and the values of maximum effective gust velocity are not significant. The lack of correlation appears to be the result of the limited day-to-day variations of gust and meteorological variables. On the basis of the available data, the horizontal temperature variations may be of little or no use in forecasting maximum values of effective gust velocities in subtropical regions.

Although the horizontal temperature variation provides a useful measure of the maximum gust velocity in thunderstorms, there remains the need for the determination of additional parameters in order to increase the accuracy of prediction.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va., February 16, 1949

REFERENCES

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2. Fisher, R. A.: Statistical Methods for Research Workers. G. E. Stechart & Co., 8th ed., 1941, pp. 168–202.

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TABLE I

SUMMARY OF GUST AND METEOROLOGICAL DATA FOR 1946 FLORIDA THUNDERSTORM OPERATIONS

Date	$U_{e_{max}}$ (fps)	ΔT ($^{\circ}$C)	$\Delta T/T$	ΔT^* ($^{\circ}$C)	$\Delta T^*/T$
7-19-46	31.0	9.2	0.034	10.5	0.039
7-20-46	23.5	6.0	.022	7.5	.027
7-23-46	16.9	6.8	.026	9.0	.034
8-6-46	22.1	8.7	.032	9.0	.033
8-7-46	21.3	6.5	.024	7.3	.027
8-13-46	24.8	7.7	.028	9.0	.033
8-14-46	38.2	11.7	.044	13.0	.049
8-15-46	24.3	8.2	.029	8.5	.030
8-19-46	27.3	5.5	.020	7.4	.027
8-21-46	24.2	8.0	.029	9.5	.035
8-22-46	35.5	7.8	.028	10.3	.037
8-23-46	31.5	6.0	.022	8.5	.030
8-26-46	27.8	8.5	.031	11.0	.040
8-27-46	17.5	5.1	.019	5.6	.021
9-5-46	20.3	11.6	.047	11.5	.046
9-6-46	17.9	7.1	.026	7.5	.028
9-11-46	20.1	8.0	.029	9.2	.033
9-12-46	21.6	7.0	.028	8.0	.032
9-16-46	25.2	5.7	.021	6.0	.022
9-17-46	19.7	6.8	.025	7.3	.027
9-18-46	30.3	7.0	.025	8.1	.030

TABLE II

SUMMARY OF GUST AND METEOROLOGICAL DATA FOR 1947 OHIO THUNDERSTORM OPERATIONS

Date	$U_{e_{max}}$ (fps)	ΔT ($^{\circ}$C)	$\Delta T/T$	ΔT^* ($^{\circ}$C)	$\Delta T^*/T$
5-13-47	16.5	10.0	0.040	6.0	0.024
5-27-47	27.6	9.0	.032	8.0	.028
5-29-47	15.7	5.8	.022	4.7	.017
6-2-47	18.9	7.0	.025	6.0	.021
6-6-47	29.0	11.0	.040	11.0	.040
6-11-47	23.9	11.0	.039	10.0	.035
6-13-47	28.0	8.0	.029	8.2	.030
6-27-47	25.1	10.8	.040	10.2	.038
7-11-47	24.3	5.7	.021	4.2	.015
7-14-47	23.0	12.2	.046	11.2	.042
7-18-47	23.8	6.2	.022	5.0	.017
7-31-47	33.0	12.0	.047	8.5	.029
8-5-47	43.0	11.8	.043	11.8	.043
8-6-47	35.2	12.8	.047	12.8	.047
8-7-47	18.3	5.7	.020	3.0	.011
8-12-47	23.3	5.8	.022	8.7	.033
8-13-47	25.6	9.5	.037	11.7	.046
8-14-47	29.2	11.0	.041	12.7	.047
8-15-47	26.2	8.5	.031	7.7	.028
8-20-47	22.8	9.7	.035	11.0	.040
8-21-47	37.2	10.0	.036	10.0	.036
8-25-47	36.4	12.0	.045	13.0	.048
9-5-47	31.7	11.8	.047	7.7	.030
9-10-47	29.2	9.7	.036	10.0	.037
9-15-47	25.3	12.0	.045	7.3	.027

TABLE III

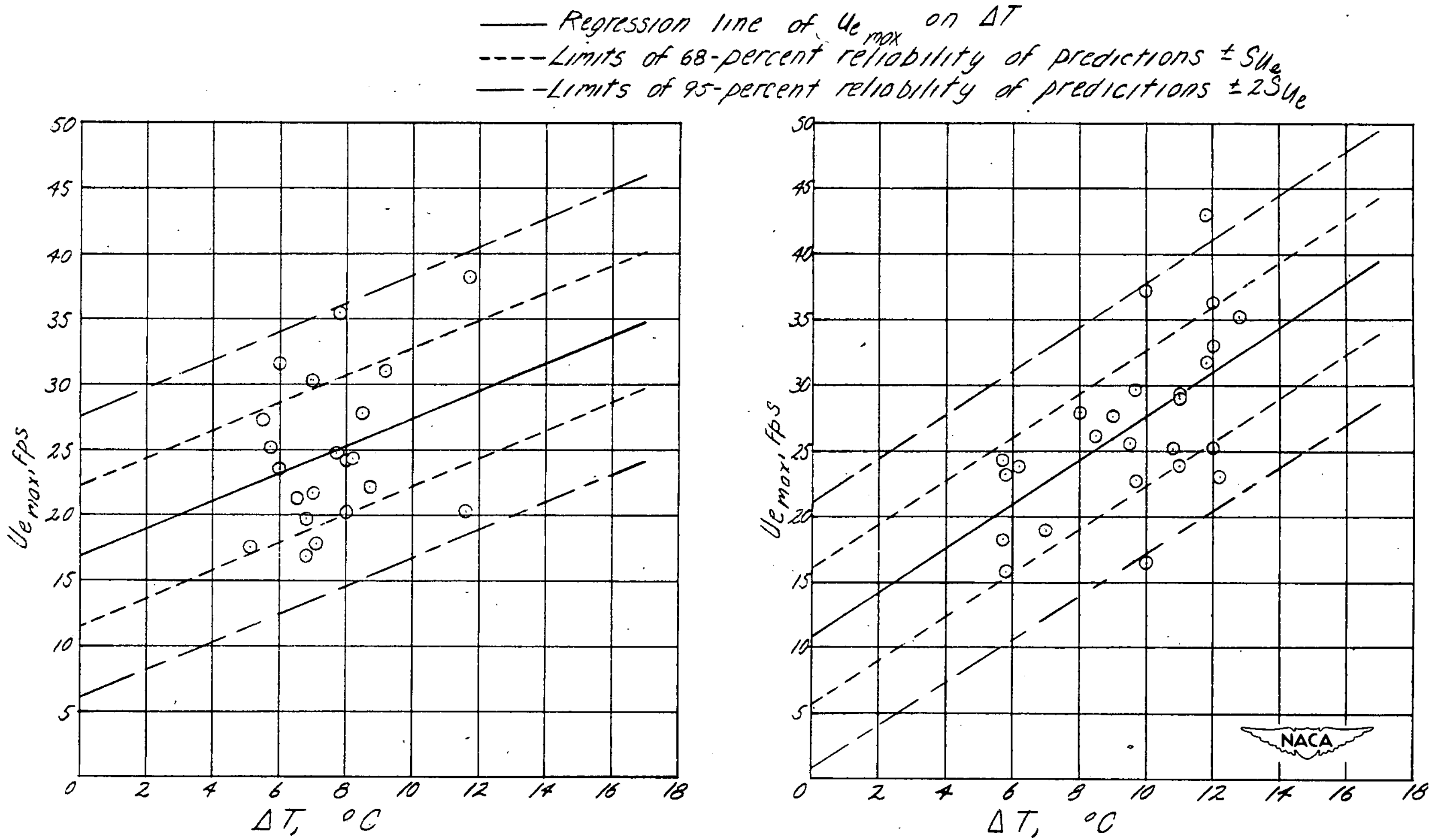
SUMMARY OF FLORIDA AND OHIO GUST-METEOROLOGICAL CORRELATIONS

Parameter	Number of days	Coefficient of correlation	One-percent level of significance	Remarks
Florida data				
$\Delta T/T$	21	0.25	0.56	Not significant
ΔT	21	.32	.56	Not significant
$\Delta T^*/T$	21	.46	.56	Not significant
ΔT^*	21	.53	.56	Not significant
Ohio data				
$\Delta T/T$	25	.56	.50	Significant
ΔT	25	.60	.50	Significant
$\Delta T^*/T$	25	.60	.50	Significant
ΔT^*	25	.64	.50	Significant

TABLE IV

COMPARATIVE SUMMARY OF PERTINENT STATISTICS FROM THUNDERSTORM INVESTIGATIONS

Statistic	XC-35	Ohio	Florida
Number of storm days	29	25	21
Mean $U_{e_{max}}$, $\overline{U}_e$	20.8	26.8	24.8
Standard deviation of $U_{e_{max}}$, σ_{U_e}	7.5	6.4	5.7
Correlation of $U_{e_{max}}$ with ΔT	0.72	0.60	0.32
Standard error of estimate of $U_{e_{max}}$, S_{U_e}	5.2	5.1	5.4



(a) Florida operations.

(b) Ohio operations.

Figure 1.- Scatter diagram of maximum effective gust velocity plotted against maximum horizontal temperature difference for each flight day.