NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1273

METEOROLOGICAL CONDITIONS ASSOCIATED WITH FLIGHT MEASUREMENTS OF ATMOSPHERIC TURBULENCE

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SUMMARY

The results obtained from a series of flight measurements of atmospheric turbulence within convective-type clouds and from meteorological soundings are presented together with descriptions of the flights and concurrent weather conditions. These results are presented to provide a background of experience for the forecaster and pilot by illustrating the turbulence conditions as indicated by effective gust velocities in convective-type clouds under spring and summer weather conditions along the eastern coast of the United States.

INTRODUCTION

Up to the present time, few detailed quantitative data have been available on meteorological observations made concurrently with measurements of atmospheric turbulence. This information is important to meteorologists and flight personnel in the planning of flight operations for which turbulence must be predicted on the basis of the usual synoptic meteorological reports.

An opportunity to obtain such data was afforded by a recent investigation of atmospheric turbulence conducted by the Langley Gust Loads Section of the NACA. Acceleration and airspeed records taken during flights of the XC-35 airplane through turbulent air in convective-type clouds permitted the determination of turbulence in terms of effective gust velocities, and radio soundings made at the time of each flight and concurrent synoptic weather reports provided the meteorological data.

In order to make the information available to meteorologists and flight personnel, the results obtained from the meteorological measurements and concurrent flight measurements of atmospheric turbulence for typical weather situations are presented herein. It is evident that this type of information obtained in a series of tests in one locality over a limited period of time is insufficient to establish general flight rules. The material presented is therefore intended only to provide a background of experience for the weather forecaster and pilot which would not be readily obtainable and which may be used as a guide for future estimates of atmospheric turbulence from other meteorological observations.

TURBULENCE MEASUREMENTS FROM AN AIRPLANE

A quantity extensively used in the measurement of atmospheric turbulence from an airplane in flight is the effective gust velocity U_e (reference 1) defined by

$$U_e = \frac{2\,\Delta nW}{\rho_o m V_e S K} \qquad (1)$$

in which

Δn acceleration increment normal to airplane, g (gravity) units

W weight of airplane, pounds

m slope of wing lift-coefficient curve, per radian

ρ_o mass density of air at sea level, slugs per cubic foot

S wing area, square feet

V_e equivalent airspeed, feet per second; obtained from

$$V_e = V\left(\frac{\rho}{\rho_o}\right)^{1/2}$$

V true airspeed, feet per second

ρ mass density of ambient air, slugs per cubic foot

K relative alleviation factor, a function of wing loading W/S, allowing for response characteristics of airplane and velocity gradient within gust

As indicated by equation (1), the effective gust velocity is determined from the acceleration response of the airplane to a gust and as such is a fictitious velocity assumed to act over the entire airplane and in a vertical direction since the usual gliding and climbing angles relative to the horizontal plane are small. The maximum effective gust velocity over a given path of rough air serves as a very useful parameter in the study of structural loads because of its relation to the maximum normal-acceleration increment of the airplane.

The relation between the effective gust velocity and the actual gust velocity, a basic meteorological quantity, depends upon the assumptions made in the derivation of equation (1). On the basis of data obtained in flights with the XC-35 airplane, it is shown in reference 2 that the maximum effective gust velocity is proportional to the maximum actual gust velocity as measured by indicated-airspeed fluctuations over a given flight path. Unpublished analyses made by the Langley Gust Loads Section have furthermore shown significant correlation between the maximum effective gust velocity and other meteorological quantities, which indicates the validity of the maximum effective gust velocity as a meteorological parameter. In view of the significance of the maximum effective gust velocity to structural loads on aircraft and to meteorological conditions, it is used in the present paper as the parameter specifying atmospheric gustiness.

APPARATUS

The XC-35 airplane used to obtain the flight data was a modification of the Lockheed 10-E incorporating a pressurized cabin and engines of greater power. It was designed for a service ceiling of 35,000 feet and had a wing loading W/S of 24.3 pounds per square foot. The K-factor used in computing the effective gust velocities was 1.08. (See fig.1 of reference 1.) Other characteristics and dimensions of the airplane are listed in reference 2.

The instruments used in the airplane to determine the gust intensities for the present study were:

(1) NACA air-damped recording accelerometer

(2) NACA airspeed recorder

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

The acceleration and airspeed recorders were standard NACA instruments and were fitted with magazines carrying sufficient photographic film for 30 minutes of record. The timer was used to synchronize the airspeed and acceleration measurements by impressing 1-second-interval timing marks on the records.

Photographs of cloud developments prevailing at the time of the flights and within which the measurements of turbulence were obtained were made from the airplane with a hand Agfa Speedex camera of $3\frac{1}{2}$-inch focal length.

Equipment for obtaining atmospheric soundings consisted of a Diamond-Hinman-Friez Raysonde, the development of which was sponsored by the Navy, incorporating an electric hygrometer and the cycloray type of ground recorder.

TEST PROCEDURE

Airplane flights and radiosonde ascents were made when weather conditions appeared conducive to turbulence at high altitudes. Morning synoptic reports and soundings provided information on which the turbulence forecast for the day was based, but flights were not begun until succeeding observations of cloud development verified the forecast.

The radiosonde program was arranged with the intention of obtaining three or four consecutive soundings spaced at intervals of about 2 to 4 hours throughout the days of the airplane flights. Because of instrumentation difficulties and forecasting limitations, however, the number of meteorological soundings and the time of soundings relative to the time of the airplane flights varied.

The usual procedure was to climb to service ceiling, to select a cloud formation for survey, and to make successive traverses through the cloud at various altitudes. Most of the traverses were made through cumulus-congestus and cumulo-nimbus clouds, but in several instances measurements of gust intensities were made in clear air when turbulence was encountered. The test instruments in the airplane were operated only at times when turbulent conditions prevailed, and measurements were made at altitudes varying from about 2000 to 34,000 feet.

SELECTION OF DATA

A total of 35 flights was made with the XC-35 airplane under a variety of spring and summer weather conditions. These flights were classified in accordance with the local weather conditions prevailing at the time; that is, measurements obtained under conditions in which thermal air-mass activity was predominant as the cause of cumulus cloud growth were separated from those which included other significant factors. The various categories are as follows:

(1) Tropical maritime air mass, very weak surface pressure gradient

(2) Tropical maritime air mass, advection from the south or southwest, cold front to the northwest

(3) Cold front passing, polar continental air replacing tropical maritime air

(4) Warm front approaching, polar maritime air at the surface, tropical maritime air aloft

(5) Stationary front to the south separating tropical maritime and polar maritime air

Flights were selected from each category on the basis of the completeness of the information available.

RESULTS

A total of 10 representative flights has been chosen for presentation herein. One figure is included for each flight: part (a) shows the surface synoptic weather chart for 1330 eastern standard time on the date of the flight, and part (b) shows the atmospheric sounding taken nearest to the time of the flight. Part (b) also includes one or two photographs of typical clouds traversed and a diagram to illustrate the vertical extent of the clouds traversed. In addition, the range of effective gust velocity experienced on each traverse of the flight is noted by horizontal bars superimposed on the cloud diagram. The end points of the bars represent maximum values with positive gust velocities directed upward and negative gust velocities directed downward. The symbols and nomenclature for the data included in the figures for each flight are given in table I.

In parts (b) of the figures, curves of constant potential temperature θ (dry adiabats) and constant equivalent potential temperature θ_e (moist adiabats) are drawn through the point which represents the height of the base of the clouds traversed. At each significant point represented by a circle, values are given for the mixing ratio in grams per kilogram and the relative humidity in percent. The observations for the upper winds at times closest to the time of flight are also shown. Each "half-length feather" on the wind arrow represents one number on the Beaufort scale. Examples representative of the various categories are given in the following sections.

Tropical Maritime Air Mass, Very Weak Surface Pressure Gradient

Flight of August 20, 1942.- The entire eastern part of the United States was covered by tropical maritime air circulating around the western side of the Bermuda high on August 20, 1942. As shown by the synoptic chart (fig. 1(a)) the surface pressure gradient was very weak at Langley Field, Va., which allowed a sea breeze to develop during the afternoon giving a moderate southeasterly wind. The possibility of frontolysis occurring near the Virginia - North Carolina border is indicated by the high clouds over Langley Field which were reported as a cirro-stratus overcast until 1430 EST and changed through broken alto-cumulus clouds to scattered clouds at 1600 EST. Scattered cumulus clouds with bases at 3000 feet also appeared during the morning and increased to broken cumulus-congestus clouds with tops up to 15,000 feet by 1600 EST. The radio sounding (fig. 1(b)) shows a conditionally unstable layer up to 13,000 feet topped by an isothermal layer from 13,000 to 15,000 feet. Winds aloft as shown in figure 1(b), were fairly light, veering from southwest at 4000 feet to west at about 20,000 feet.

The cloud selected for survey after take-off at 1435 EST was a cumulus-congestus cloud to the southwest of Langley Field with base and top estimated at 3000 and 15,000 feet, respectively. Between 1456 EST and 1518 EST, five traverses were made through the cloud which was apparently beginning to dissipate. Photographs of the cloud in two stages of development are given in figure 1(b).

Flight of September 9, 1942.- During the afternoon of September 9, 1942 cumuliform clouds, showers, and thunderstorms were prevalent over most of the southeastern states. The surface synoptic chart (fig. 2(a)) shows that surface temperatures ranged from 75° F on Cape Charles, Va., surrounded by water, to 94° F at South Hill, Va. A front, which probably did not affect the development of cumulus clouds on this day, is shown about 180 miles north of Langley Field.

Observations at Langley Field showed scattered cirrus clouds moving from the west and persisting all day. Cumulus clouds appeared at 1130 EST and developed to heights estimated to be 20,000 feet.

An analysis of the sounding (fig. 2(b)) does not indicate a great deal of energy available for convection but does indicate the possibility of cloud development at heights up to 28,000 feet. Other soundings made on the same day showed no significant differences other than in the lower layers influenced by diurnal heating.

A series of traverses was made through a developing cumulus-congestus cloud formation near Langley Field between 1331 EST and 1427 EST. The survey was made in steps of increasing altitude from 5000 to 15,000 feet, and during this time the cloud top increased in height from 10,000 to 20,000 feet. Up and down drafts were encountered in all traverses up to 14,000 feet and rain was observed above 9000 feet. Rain began to fall from the base of the cloud after the landing was made at 1446 EST and the cloud then dissipated rapidly.

Flight of September 19, 1942.- As shown in figure 3(a), Langley Field was between two high-pressure centers to the northeast and southwest and two low-pressure centers to the northwest and southeast on September 19, 1942. Classification of the air mass is accordingly somewhat difficult. The showers shown in figure 3(a) west of the Allegheny Mountains were probably associated with the cold front which was too far west to affect Langley Field weather. Cumulus-congestus and cumulo-nimbus clouds were reported over a wide region of the eastern United States during the afternoon and observations at Langley Field showed cumulus clouds beginning to form at 1030 EST with bases from 2500 to 3000 feet. These developed to heights estimated up to 25,000 feet and dissipated by 1630 EST. Temperatures in the state of Virginia varied from 84° F to 90° F at 1330 EST.

The radiosonde observation at 1255 EST (fig. 3(b)) revealed an inversion at 10,000 feet. Below the inversion the relative humidity was 60 percent or greater, and above the inversion the relative humidity was only 15 percent or less, which suggested subsidence. An appreciable amount of energy was available, however, for convection that would not be overcome by the inversion.

After the take-off at 1414 EST, four traverses between the levels of 8000 and 14,000 feet were made through a cumulus-congestus cloud located about 25 miles northwest of Langley Field. The first traverse was made at 1427 EST during the climb, and the last at 1447 EST. The cloud was then beginning to dissipate after having reached a maximum height estimated at 16,000 feet. Strong drafts were encountered at 12,000 feet and water collections were noted on the airplane during each traverse. A photograph of the cloud at its full stage of development is shown in figure 3(b).

A second cloud, about 30 miles south of Langley Field, with the top estimated at 25,000 feet, was surveyed between the altitudes of 21,000 and 16,000 feet from 1505 EST to 1536 EST. Light rain and hail were encountered by the airplane during all traverses, and drafts of sufficient intensity to carry the airplane upward about 1500 feet were encountered during the three highest traverses shown in figure 3(b).

Tropical Maritime Air Mass, Advection from the South

or Southwest, Cold Front to the Northwest

Flight of August 23, 1941.- A cold front was moving eastward on the afternoon of August 23, 1941 as shown in the synoptic chart (fig. 4(a)). The cold front was typical of summer fronts, poorly defined at the ground with tropical maritime air and polar continental air on the east and west sides of the front, respectively, and with cumulus clouds prevalent on both sides. The thunderstorm activity in the southeastern states might possibly have been associated with an ill-defined warm front noted on previous charts for this period but not apparent on the chart in figure 4(a).

The sounding at 1157 EST (fig. 4(b)) indicates moderately moist air at high altitudes as well as at lower altitudes and a sufficient amount of energy available for convection.

A cumulus-congestus cloud about 20 miles west of Langley Field was selected for survey. This cloud was part of a formation lying in an east-west direction with peaks estimated as high as 35,000 feet and with bases at 3000 feet. From 1500 EST to 1548 EST traverses were made through the cloud between the levels of 30,000 and 20,000 feet. Strong drafts were encountered at 30,000 feet which carried the plane up as high as 31,500 feet.

Flight of July 3, 1941.- The synoptic weather chart (fig. 5(a)) shows a quasi-stationary front with several waves to the north of Langley Field, with Langley Field situated in advance of the cold front section of one of these waves on July 3, 1941. The front was observed to pass Langley at 1945 EST when the wind, which had been south-southwest during the day, veered to the west-southwest.

The radiosonde observation (fig. 5(b)) shows high moisture content to about 3000 feet and moderate moisture up to 16,000 feet. Above this height the moisture content abruptly decreases. The lapse rate indicates that much energy is available for convective activity whether it is forced mechanically or thermally. The thin isothermal layer at 23,000 feet appears insufficient to stop cloud growth at this height.

A large cumulo-nimbus and cumulus-congestus formation about 30 miles north of Langley Field was selected for survey. The formation lay in a northeast-southwest line with bases at 3000 feet and tops estimated at 30,000 feet. A few lightning flashes were observed within the clouds at 11,500 feet during the climb. Traverses were started at 28,500 feet, just below the anvil of a cumulo-nimbus cloud at 1457 EST, and continued at successively decreasing altitudes to 1557 EST. One lightning flash was observed during the traverse at 26,500 feet. Light rain was encountered in the lower traverse (about 20,000 ft) and also in a neighboring cumulus-congestus cloud at 16,500 feet.

Flight of July 14, 1942.- The synoptic weather chart (fig. 6(a)) shows that a cold front was approaching the east coast on July 14, 1942. At the time of the flight, the front was about 300 miles northwest of Langley Field, although the upper westerly winds (fig. 6(b)) suggest a fast motion of the front. The trough in advance of the front moved eastward causing the wind at Langley Field to veer from southwest to west-southwest at 1600 EST. Observations at Langley Field showed broken cirrus clouds during the morning and afternoon changing to scattered clouds by 1600 EST and disappearing by 1700 EST. Cumulus clouds began to form at 1300 EST with bases estimated at 5000 feet and tops developing to about 18,000 feet.

The radio sounding (fig. 6(b)) shows the air to be conditionally unstable above the convection condensation level so that clouds could form through diurnal heating.

Seven traverses were made through a cumulus-congestus cloud about 25 miles northwest of Langley Field between 1411 EST and 1511 EST. The cloud top was estimated at 17,000 feet and the base at 5000 feet. Figure 6(b) includes a photograph of the cloud taken immediately before the first traverse.

Flight of September 5, 1941.- An examination of the synoptic chart (fig. 7(a)) reveals that Langley Field at the time of the flight on September 5, 1941 was situated at the southern end of a large warm sector, the air mass being tropical maritime. Surface temperatures were 90° F to 93° F in the vicinity. Observations at Langley Field showed scattered cirrus clouds to be prevalent all day. Cumulus clouds began to form at 1430 EST and developed to heights estimated at 31,000 feet. These clouds did not dissipate until 2000 EST.

The radio sounding (fig. 7(b)) reveals ample moisture and instability for cumulus clouds in the afternoon period.

A line of cumulus-congestus and cumulo-nimbus clouds lying in a northwest-southeast direction about 50 miles from Langley Field was approached after take-off at 1500 EST. Four traverses between the altitudes of 26,500 and 18,000 feet were made through a dissipating cumulo-nimbus cloud with base and top estimated at 4500 feet and 31,000 feet, respectively, from 1553 to 1608 EST. Two additional traverses at an altitude of about 16,000 feet were made through a neighboring cumulus-congestus cloud by 1617 EST.

Cold Front Passing, Polar Continental Air

Replacing Tropical Maritime Air

Flight of August 12, 1941.- The weather chart (fig. 8(a)) shows an active cold front moving toward Langley Field on August 12, 1941. At 1330 EST it was only about 70 miles to the northwest and passed the station about midnight. Broken alto-cumulus clouds were observed at Langley Field until 1300 EST, when cumulus and strato-cumulus clouds associated with cumulo-nimbus formations moved in from the northwest. The tops of the highest cumulo-nimbus clouds were estimated at 40,000 feet.

The radiosonde observation (fig. 8(b)) shows that the air mass over Langley Field was typically tropical maritime, which allowed a high afternoon temperature at the surface. The sounding also indicates a moderate amount of moisture aloft and ample energy for towering convection columns.

At 1414 EST one traverse was begun at 28,000 feet through a cumulo-nimbus cloud to the southeast of Langley Field. This cloud was part of a formation which lay in a northeast-southwest line and moved southeastward. The anvil top was estimated at 40,000 feet. The traverse lasted about 10 minutes and the airplane left the cloud at about 30,000 feet. Before entry, the cloud appeared very dark and turbulent, but with the exception that light rain and hail were encountered the traverse was without incident.

Immediately after the first cloud was traversed, a cumulus-congestus cloud, which was of the same formation but which appeared much less turbulent than the first cloud, was approached. The traverse was started at 1429 EST at an altitude of 30,000 feet. During the next 15 minutes the airplane was carried up to 34,000 feet, while gust velocities of about 30 feet per second were encountered. At this point a slight break in the clouds occurred and the descent was begun through closely packed cumulus-congestus formations. The descent was most difficult to accomplish because of the severity of the turbulence and about 20 minutes was required to reach 20,000 feet. Heavy rain and lesser quantities of sleet, hail, and ice were encountered during the entire period. Shortly after 1500 EST descent to 1000 feet had been reached, and landing was made at Richmond, Va. shortly thereafter.

Warm Front Approaching, Polar Maritime Air at the Surface, Tropical Maritime Air Aloft

Flight of April 4, 1941.- Figure 9(a) shows a large-wave cyclone affecting most of the eastern half of the United States on April 4, 1941. Low ceilings and visibilities with light steady drizzle, typical of the conditions in advance of a shallow warm front, were present. Morning observations at Langley Field showed a solid alto-cumulus overcast with the ceiling at 7000 feet and cloud tops at 12,000 feet. The clouds changed during the afternoon to broken strato-cumulus clouds with ceiling and cloud tops at 4000 and 9000 feet, respectively.

The radiosonde observation (fig. 9(b)) shows stable conditions aloft, the lapse rate not exceeding the moist adiabatic above 2000 feet.

Records of gust velocities were taken during traverses of cirro-stratus clouds and also in clear air at altitudes above 20,000 feet at approximately 1545 EST. Traverses were also made through lower strato-cumulus clouds with precipitation being encountered at 8000 feet, at approximately 1600 EST.

Stationary Front to the South Separating Tropical Maritime and Polar Maritime Air

Flight of October 2, 1941.- A poorly defined quasi-stationary front extended in an east-west direction south of Langley Field on

October 2, 1941 as shown in figure 10(a). Precipitation did not occur generally over the coastal states but did occur west of the mountains. The presence of the front south of Langley Field is borne out by the northeasterly surface wind observed during the afternoon accompanied by cumulus-cloud movement from the southwest and alto-stratus from the west. The alto-stratus cover was broken during the day and the cumulus clouds began to form at 1400 EST. The maximum development of the cumulus clouds was reached with tops extending up to about 11,000 feet at 1500 EST. All cumulus formations dissipated by 1630 EST.

The radio sounding and winds aloft are given in figure 10(b). From the sounding it appears that convection could take place because of surface heating but might be limited to a height of about 10,000 feet by the isothermal layer at that altitude.

Surveys were made through four separate small cumulus-congestus clouds between 1533 EST and 1541 EST. The cumulus-congestus clouds were observed to be small laterally and reached altitudes of about 11,000 feet.

CONCLUDING REMARKS

Although the preceding gust-velocity measurements were taken only within the vicinity of Langley Field, Va., similar conditions would reasonably be expected at other points along the eastern coast of the United States in similar meteorological situations. Gust velocities more severe than those measured within any cloud traversed, however, could be encountered because it obviously is not possible to conduct a complete survey of turbulence on each occasion with the equipment used.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., October 29, 1946

REFERENCES

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.

2. Tolefson, H. B.: Airspeed Fluctuations as a Measure of Atmospheric Turbulence. NACA ARR No. L5F27, 1945.

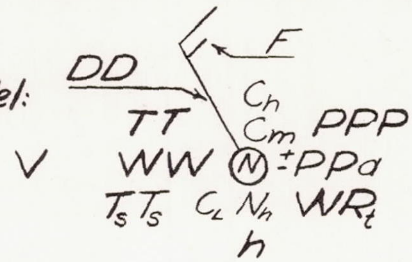
3. Anon.: Preparation of Weather Maps. S.R. & F./NRH, U.S. Dept. Commerce, Weather Bur., July 1, 1942.

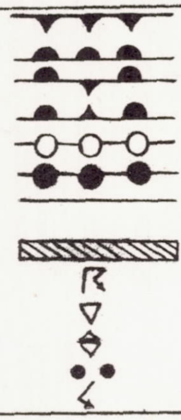
4. Willett, H. C.: Descriptive Meteorology. Academic Press, Inc. (New York), 1944.

TABLE I.- SYMBOLS AND NOMENCLATURE USED IN FIGURES

[All symbols and codes used for the plotting of station data are described in reference 3]

Station model:



Symbols	Definitions
Analysis	
	Surface cold front
	Surface warm front
	Surface stationary front
	Surface occluded front
	Weak surface cold front
	Weak surface warm front
	Isobars drawn for every 3 millibars
	Precipitation
	Thunderstorms
	Showers
	Hail
	Rain
	Lightning
Air mass (in accordance with reference 4)	
mP	Polar maritime
mT	Tropical maritime
cP	Polar continental
W	Air warmer than underlying surface
K	Air colder than underlying surface
Temperature	
θ	Potential temperature, degrees centigrade absolute
θ_e	Equivalent potential temperature, degrees centigrade absolute

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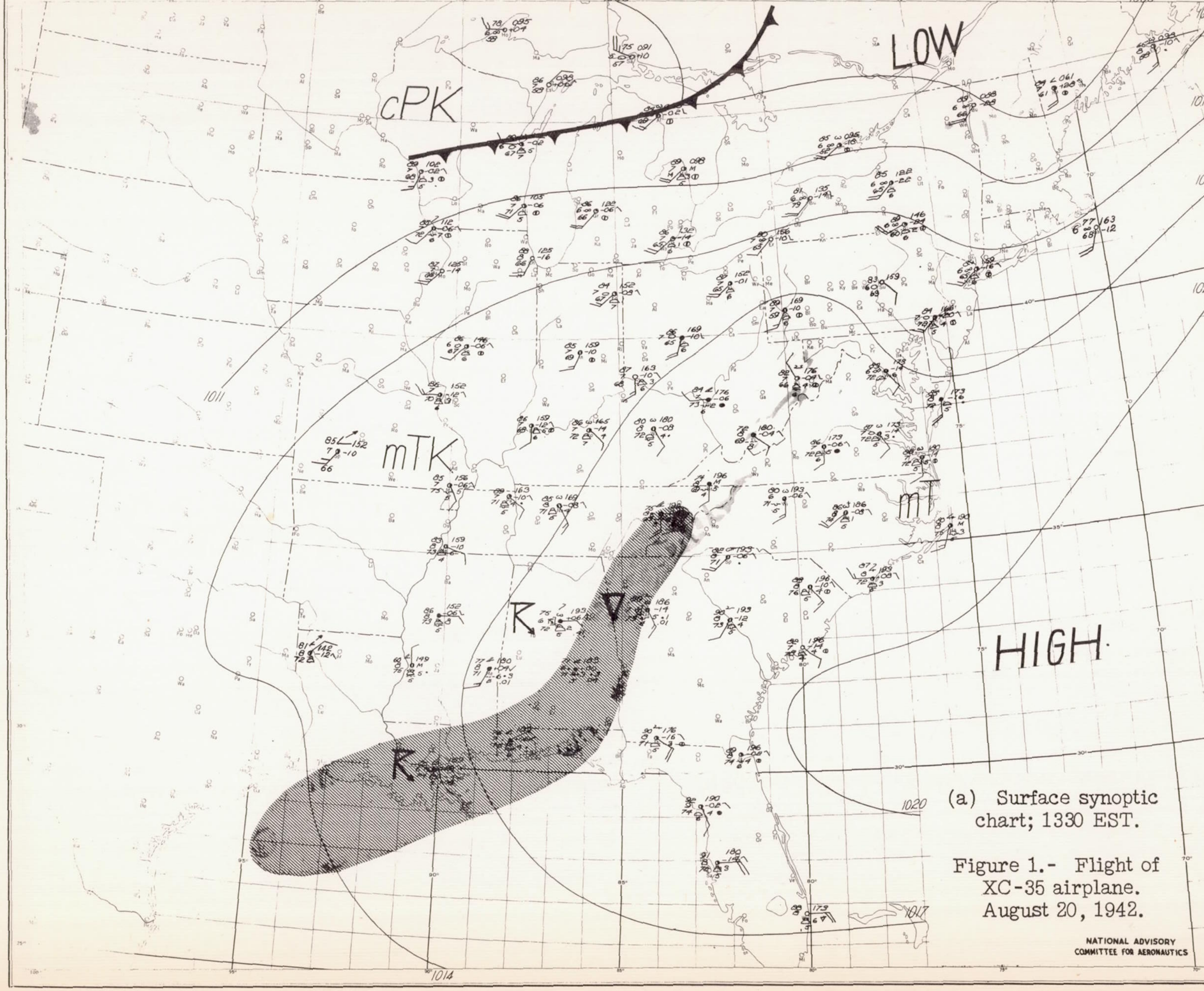

(a) Surface synoptic chart; 1330 EST.

Figure 1.- Flight of XC-35 airplane. August 20, 1942.

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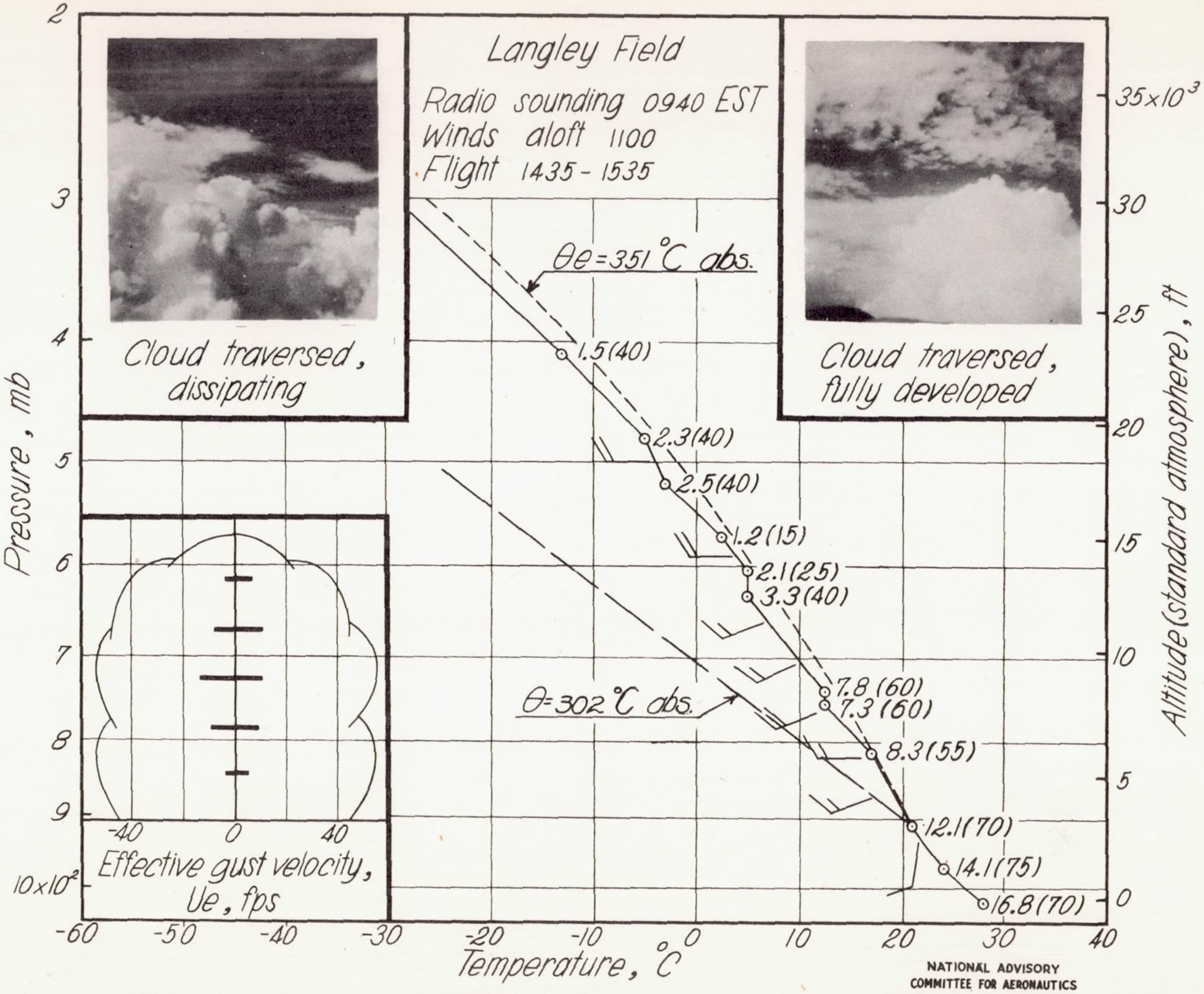
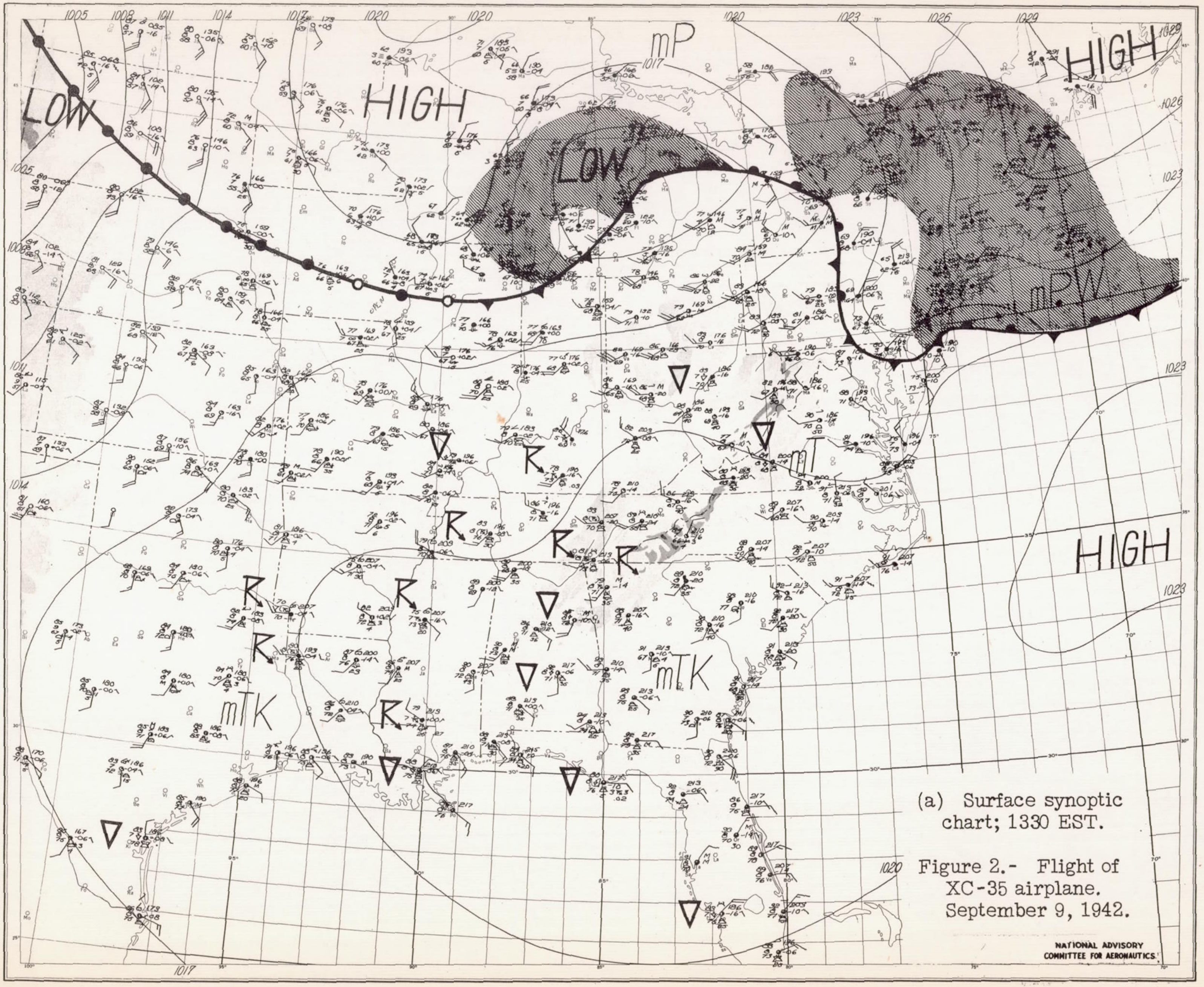


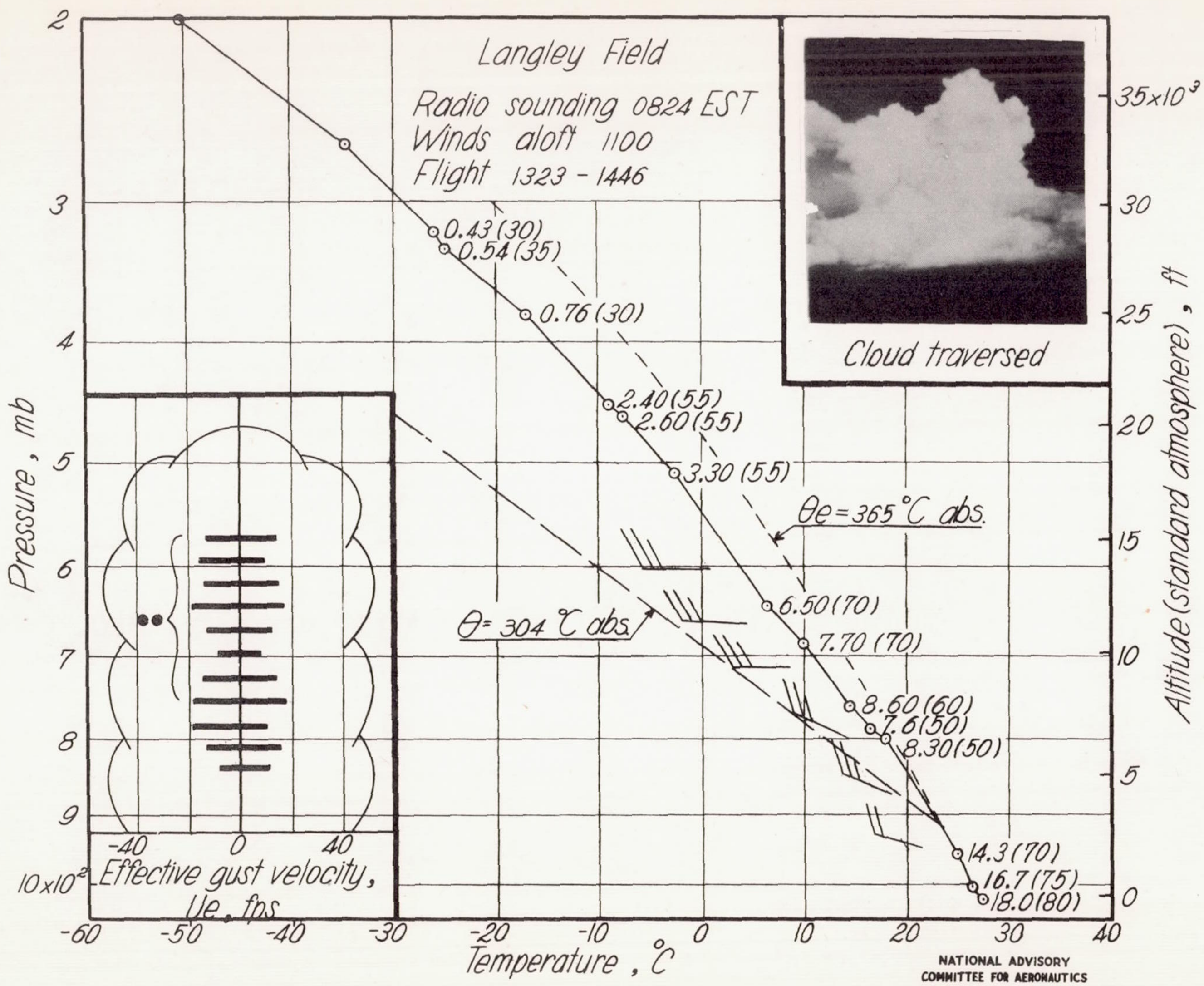
(b) Atmospheric sounding and turbulence measurements.

Figure 1.- Concluded.



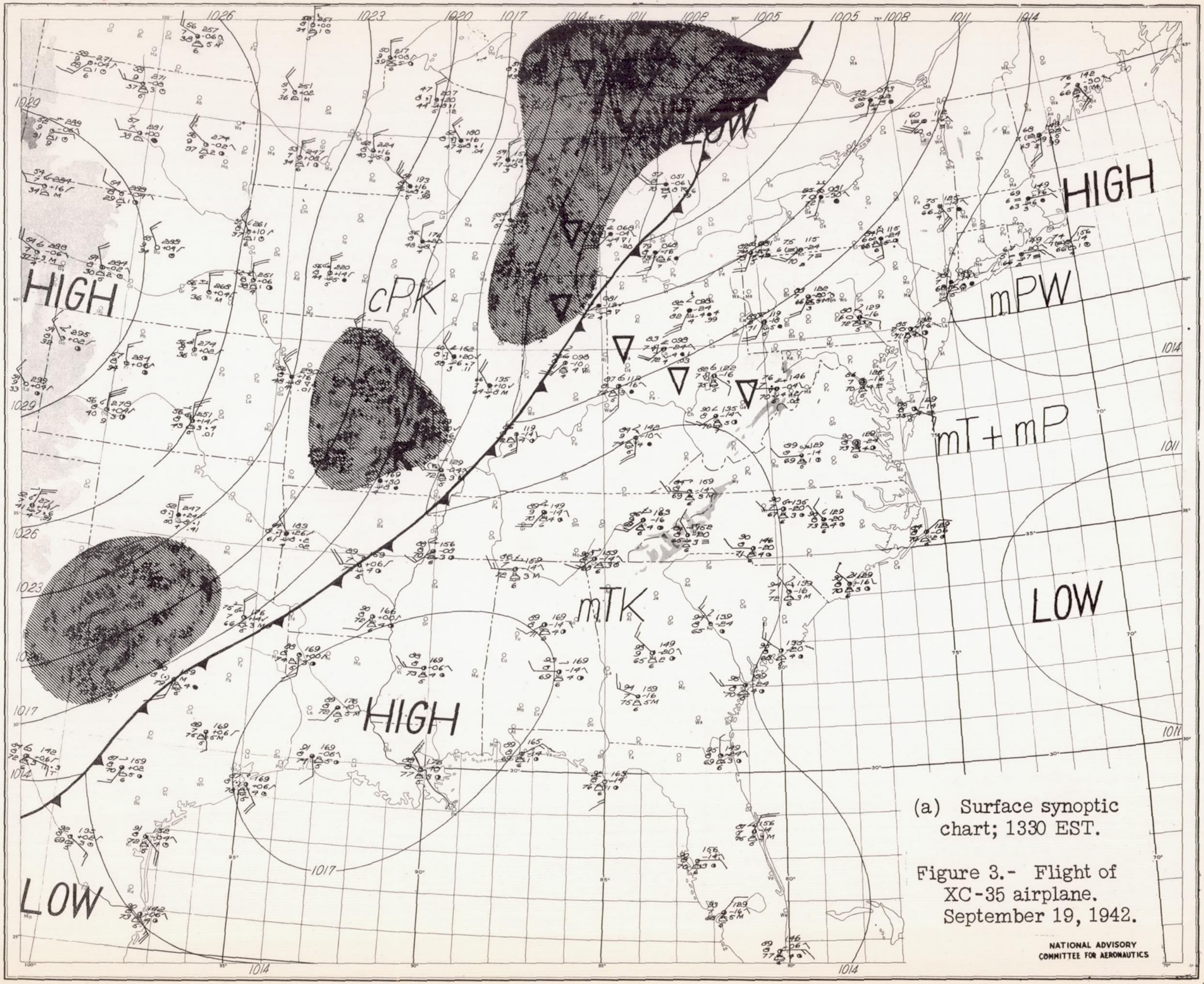
(a) Surface synoptic chart; 1330 EST.

Figure 2.- Flight of XC-35 airplane. September 9, 1942.



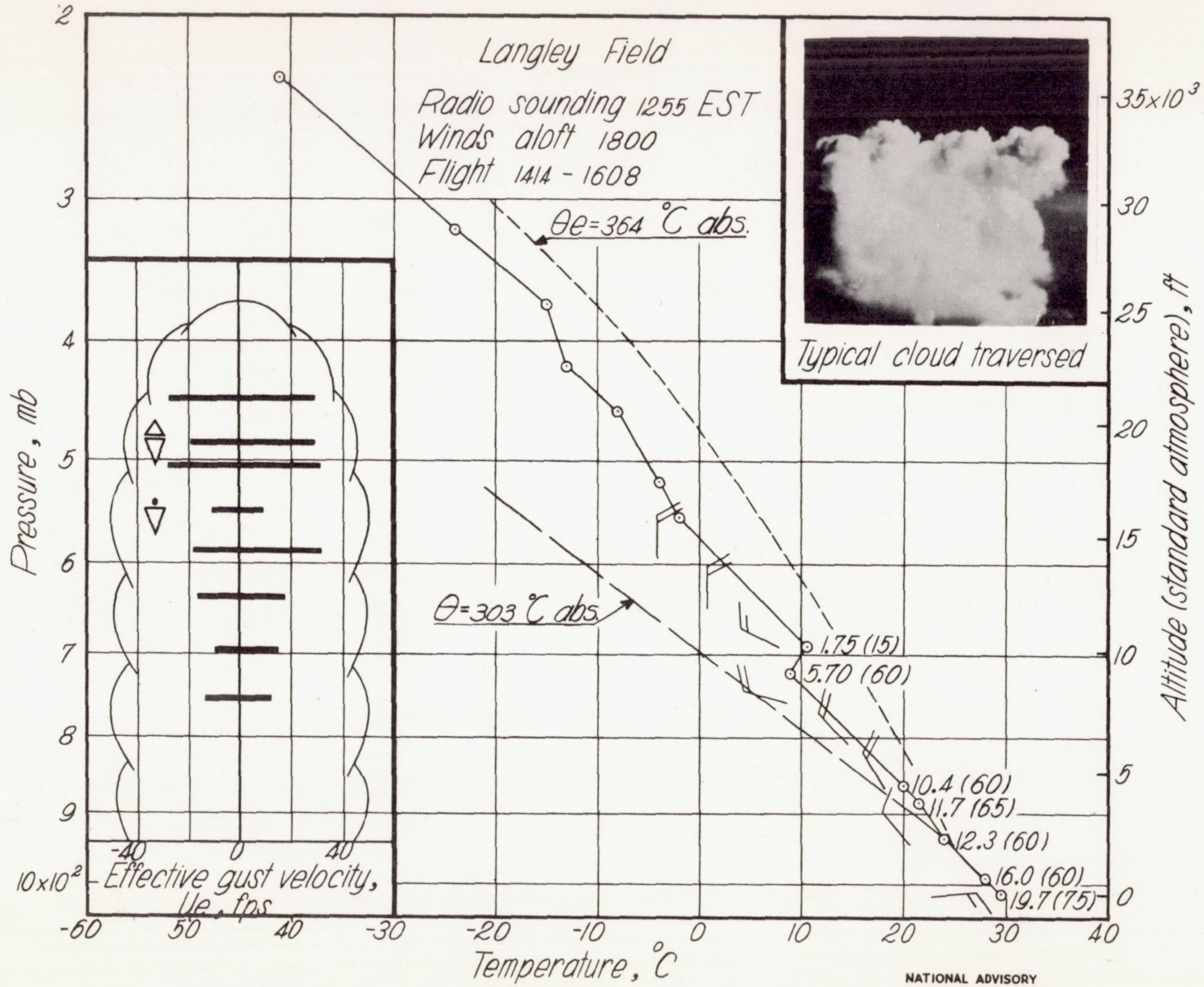
(b) Atmospheric sounding and turbulence measurements.

Figure 2.- Concluded.



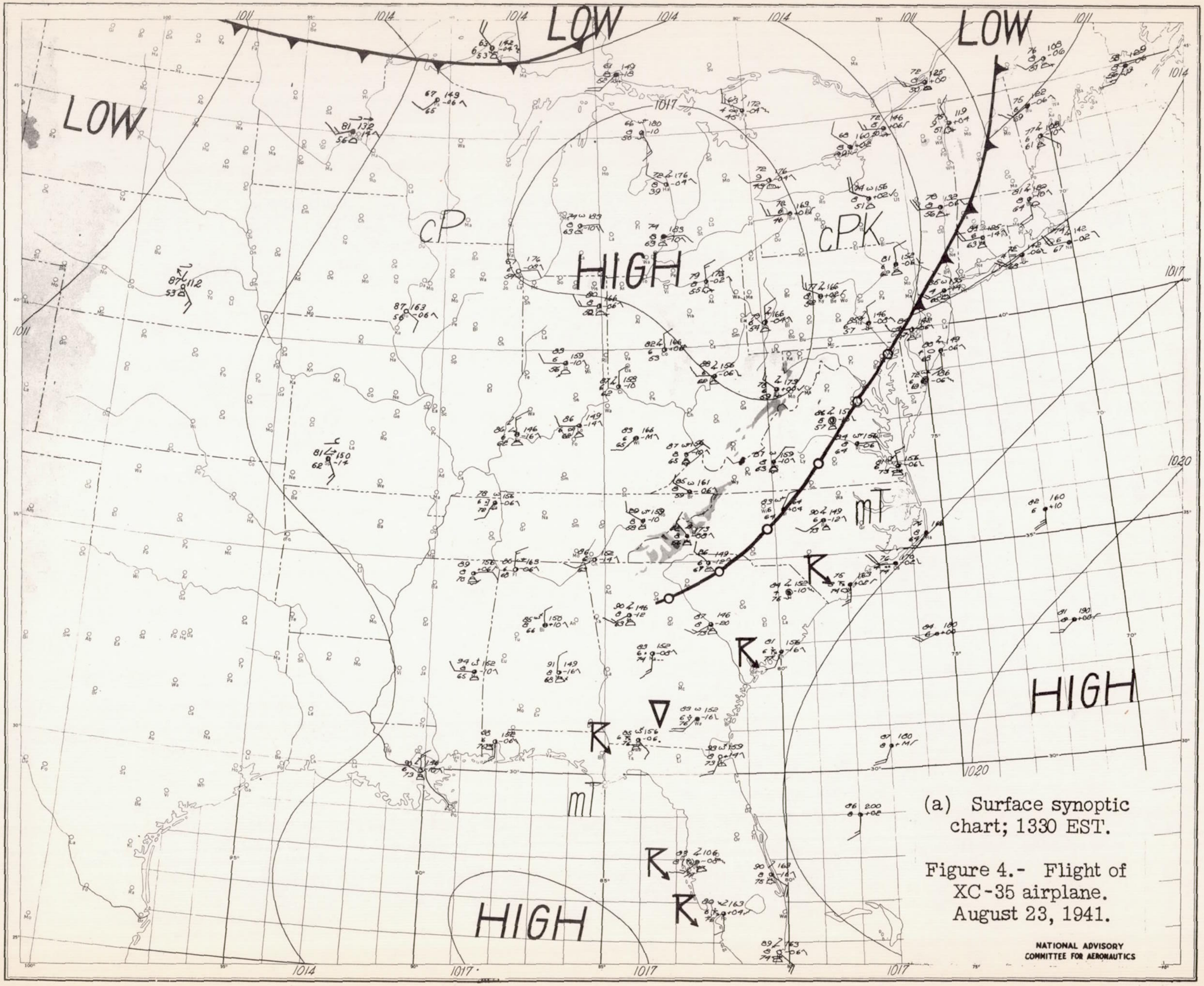
(a) Surface synoptic chart; 1330 EST.

Figure 3.- Flight of XC-35 airplane. September 19, 1942.



(b) Atmospheric sounding and turbulence measurements.

Figure 3.- Concluded.



(a) Surface synoptic chart; 1330 EST.

Figure 4.- Flight of XC-35 airplane. August 23, 1941.

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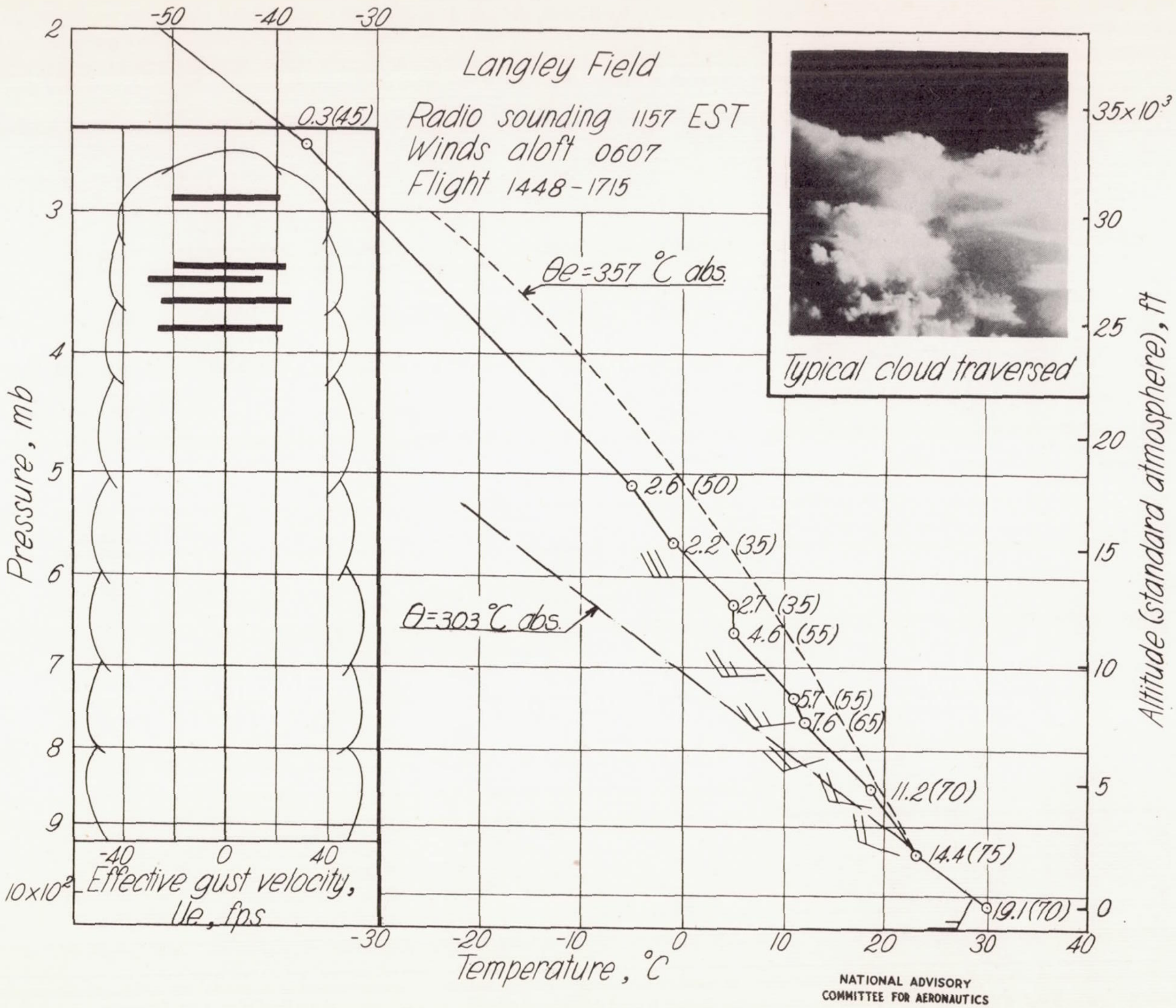
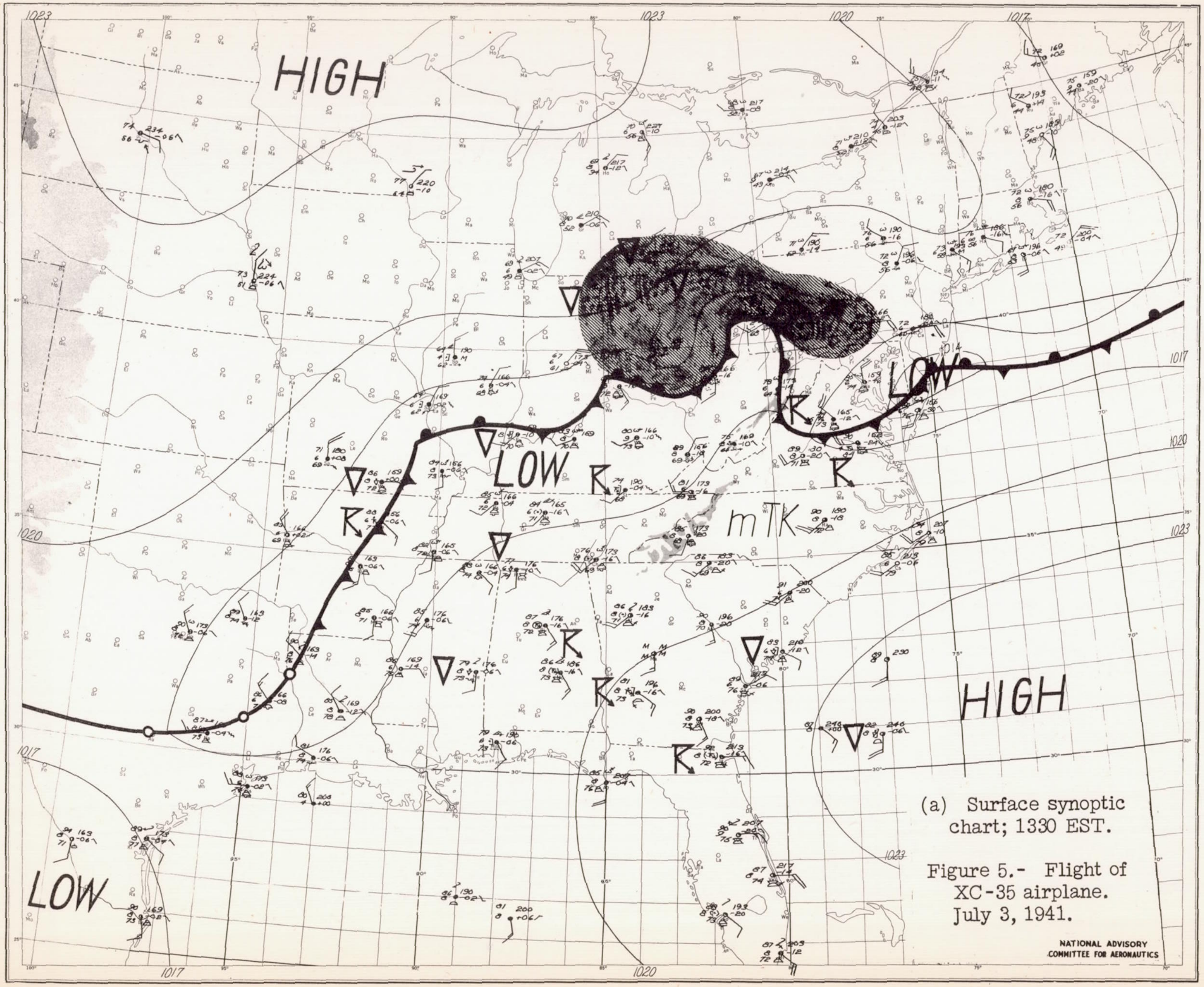


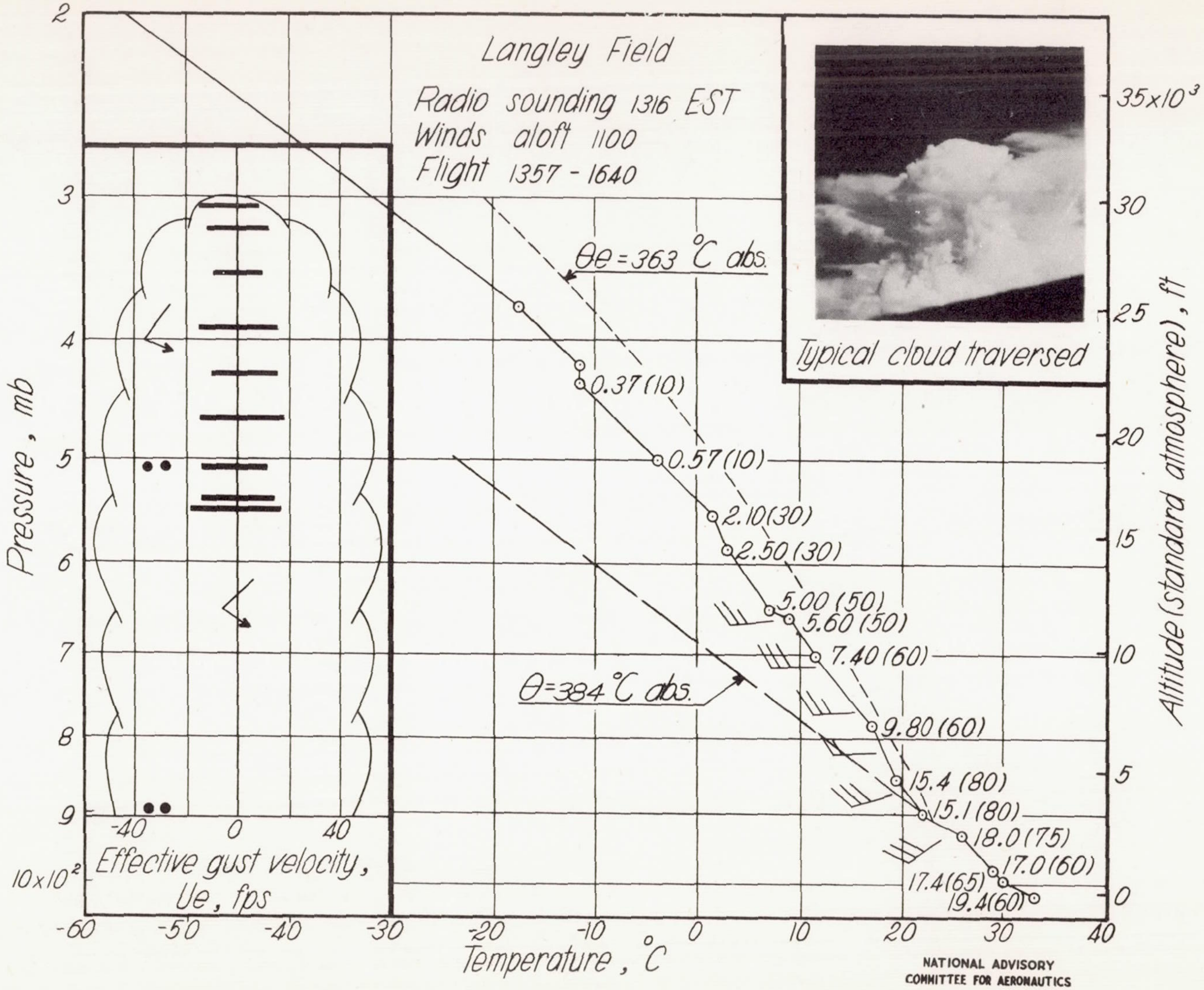
(b) Atmospheric sounding and turbulence measurements.

Figure 4.- Concluded.



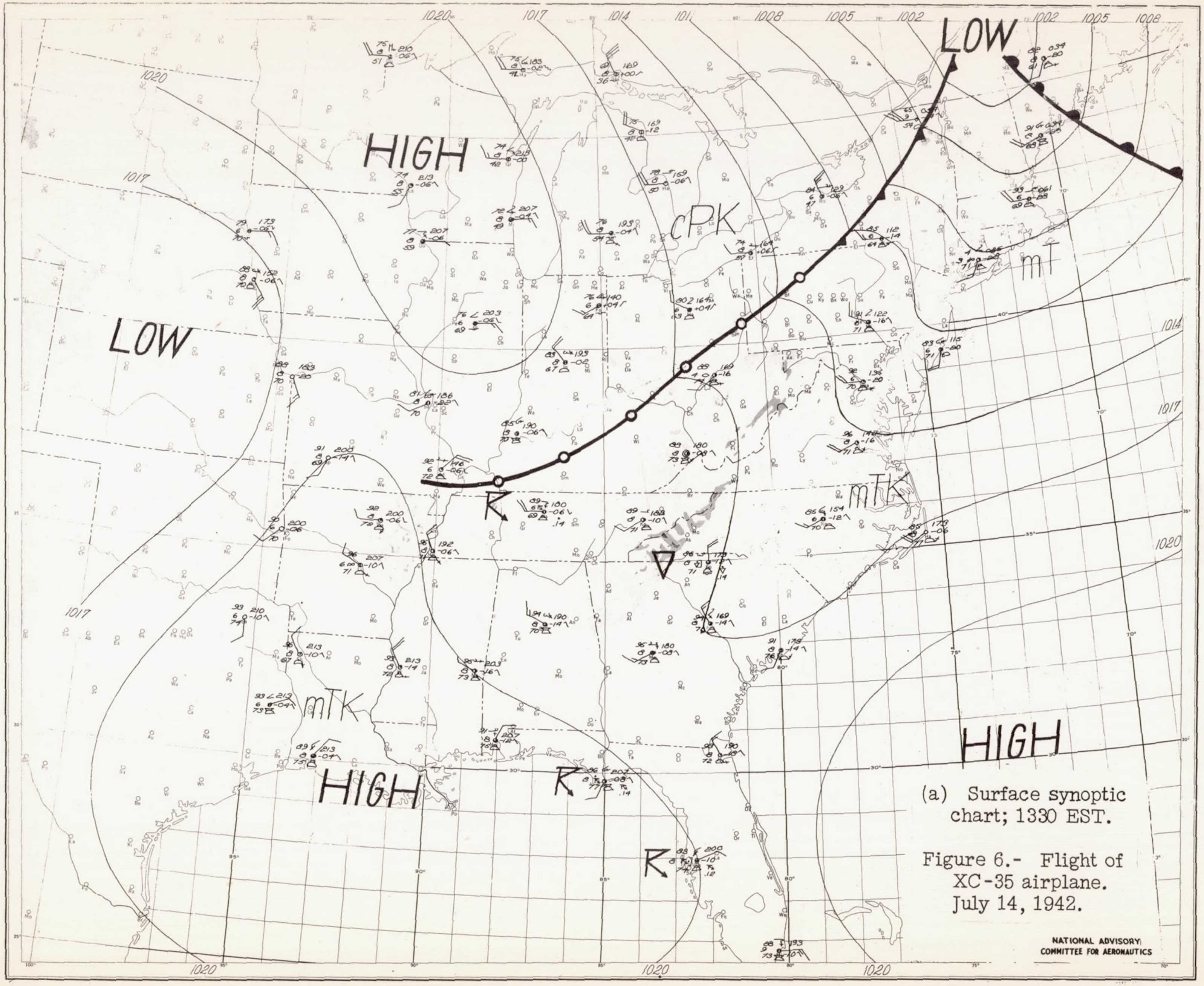
(a) Surface synoptic chart; 1330 EST.

Figure 5.- Flight of XC-35 airplane. July 3, 1941.



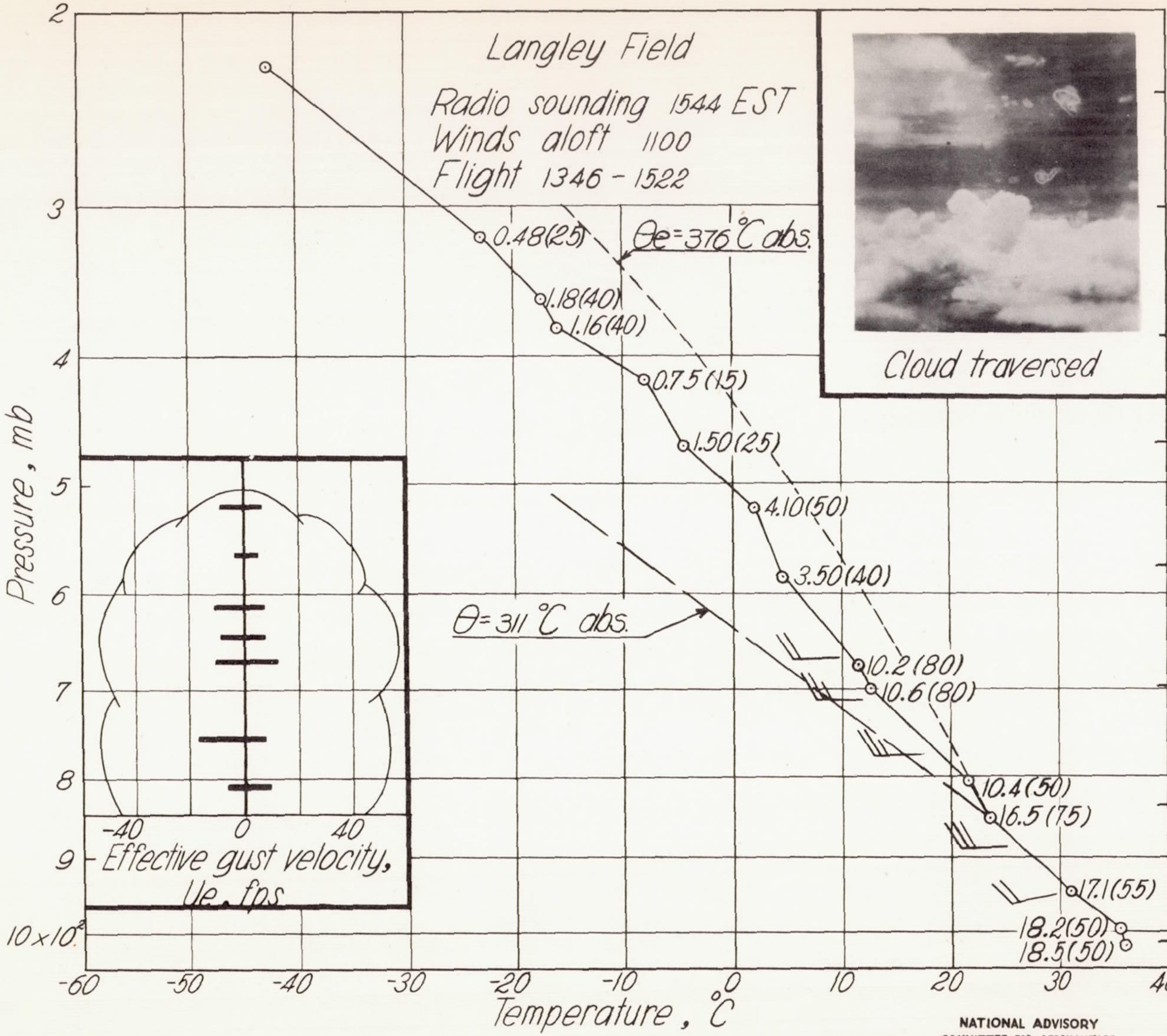
(b) Atmospheric sounding and turbulence measurements.

Figure 5.- Concluded.



(a) Surface synoptic chart; 1330 EST.

Figure 6.- Flight of XC-35 airplane. July 14, 1942.



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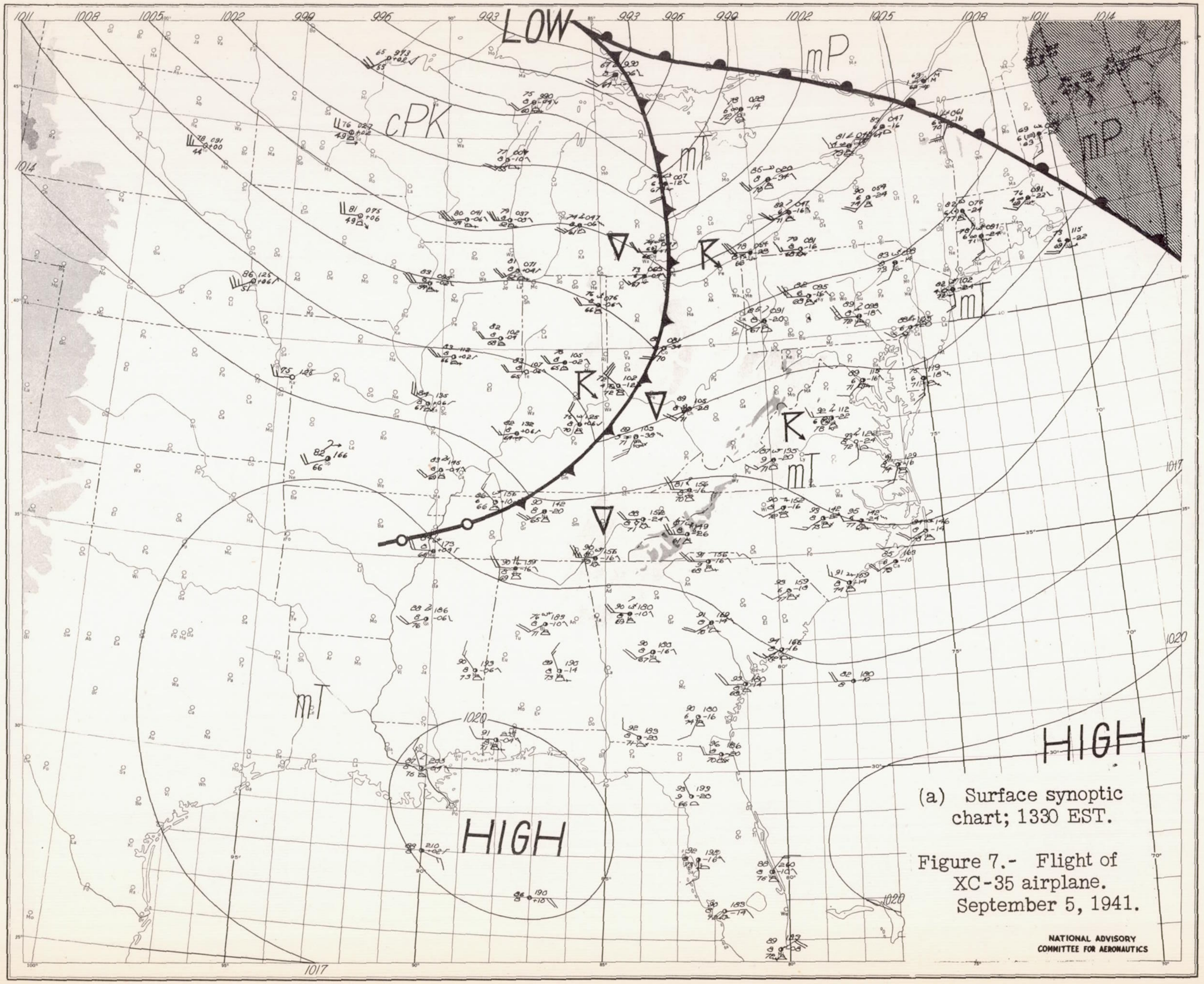
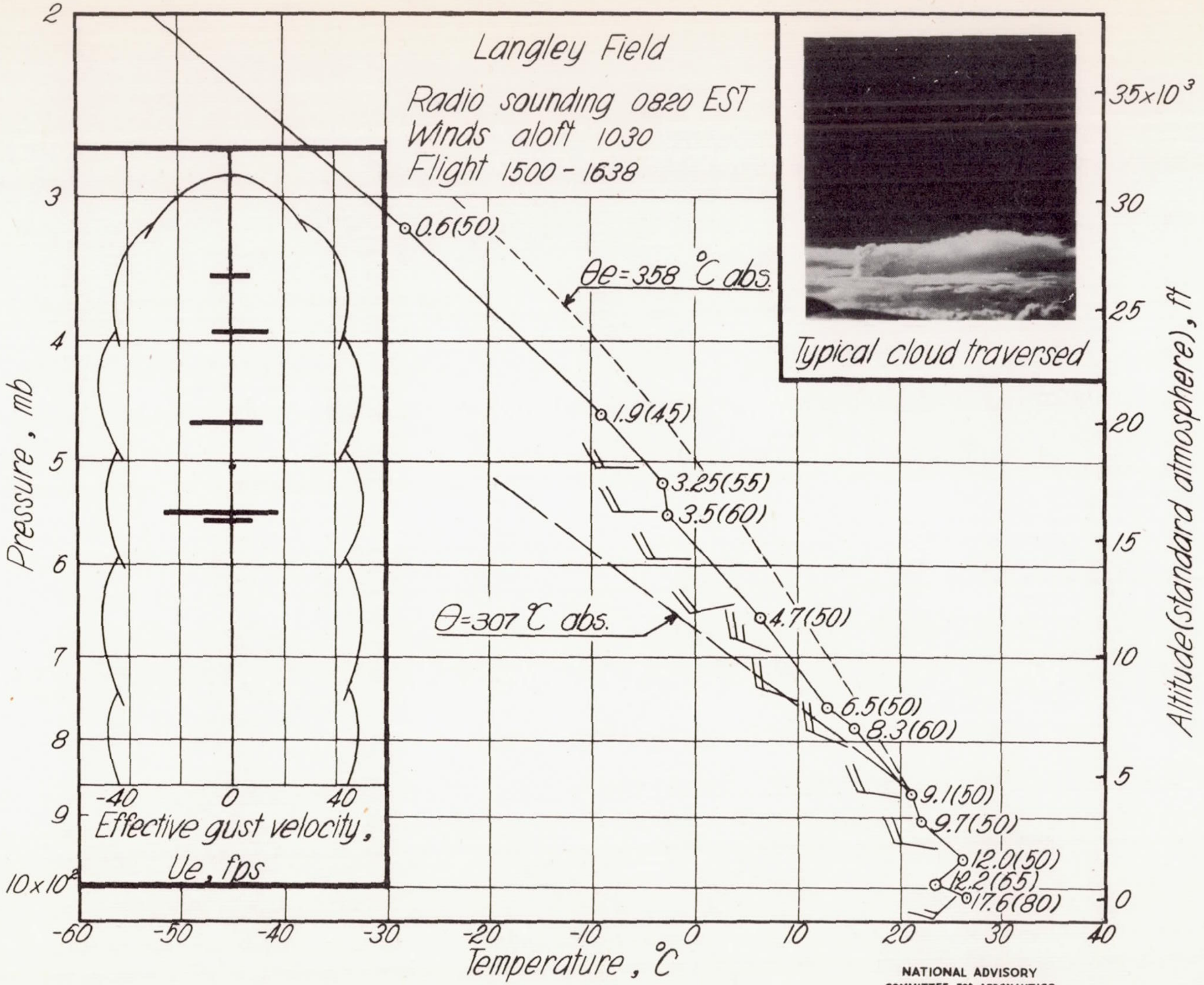
(b) Atmospheric sounding and turbulence measurements.

Figure 6.- Concluded.



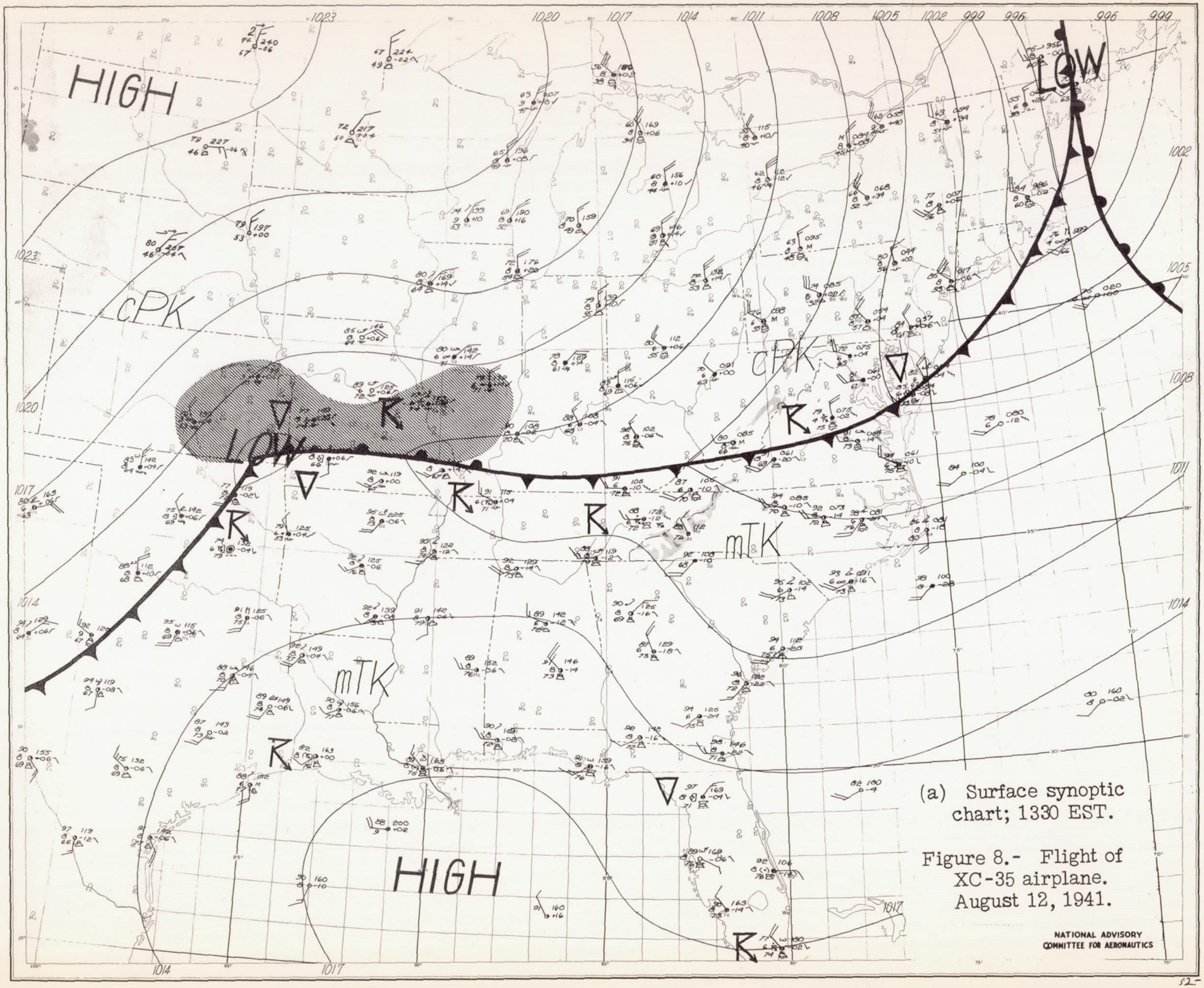
(a) Surface synoptic chart; 1330 EST.

Figure 7.- Flight of XC-35 airplane. September 5, 1941.



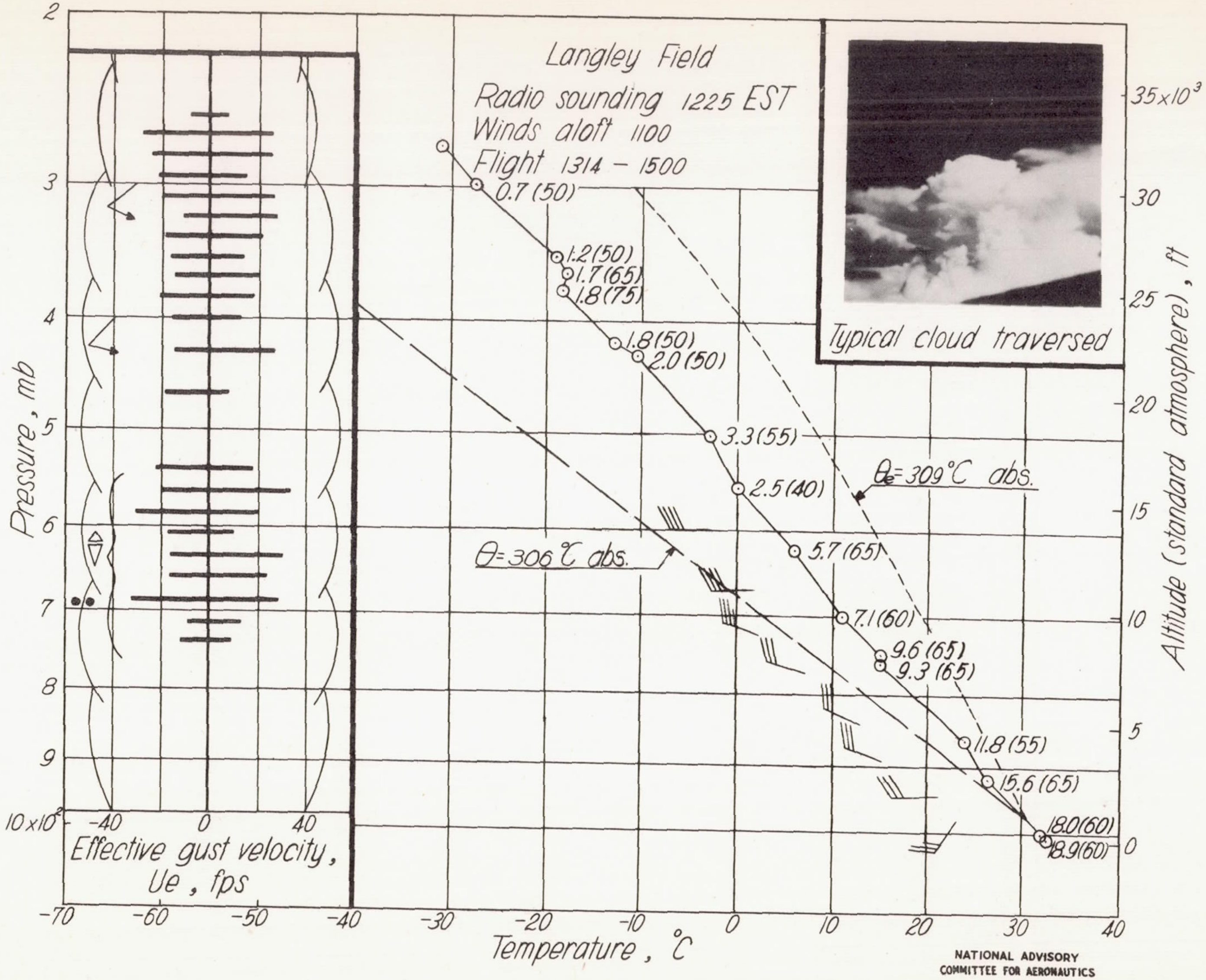
(b) Atmospheric sounding and turbulence measurements.

Figure 7.- Concluded.



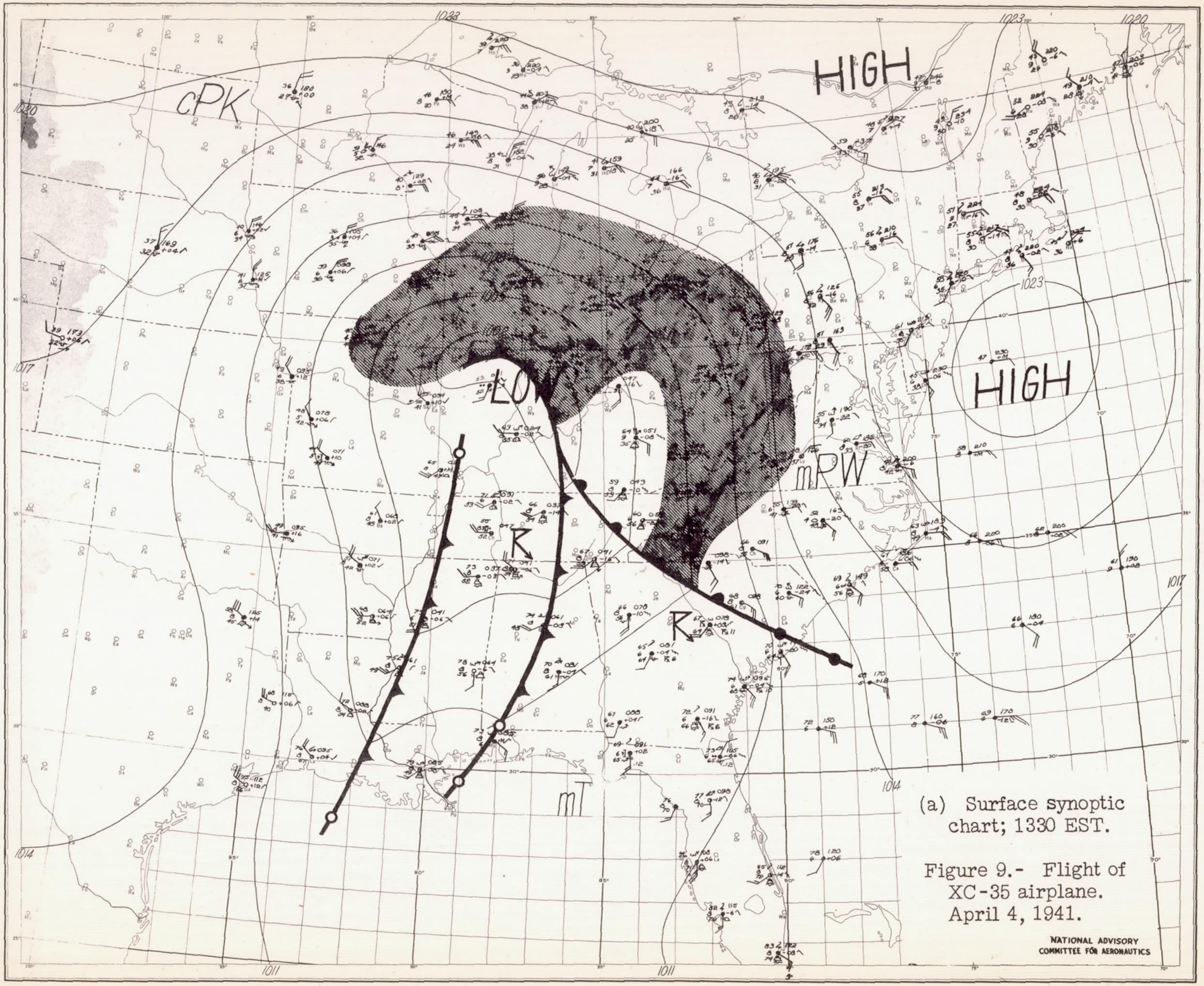
(a) Surface synoptic chart; 1330 EST.

Figure 8.- Flight of XC-35 airplane. August 12, 1941.



(b) Atmospheric sounding and turbulence measurements.

Figure 8.- Concluded.



(a) Surface synoptic chart; 1330 EST.

Figure 9.- Flight of XC-35 airplane. April 4, 1941.

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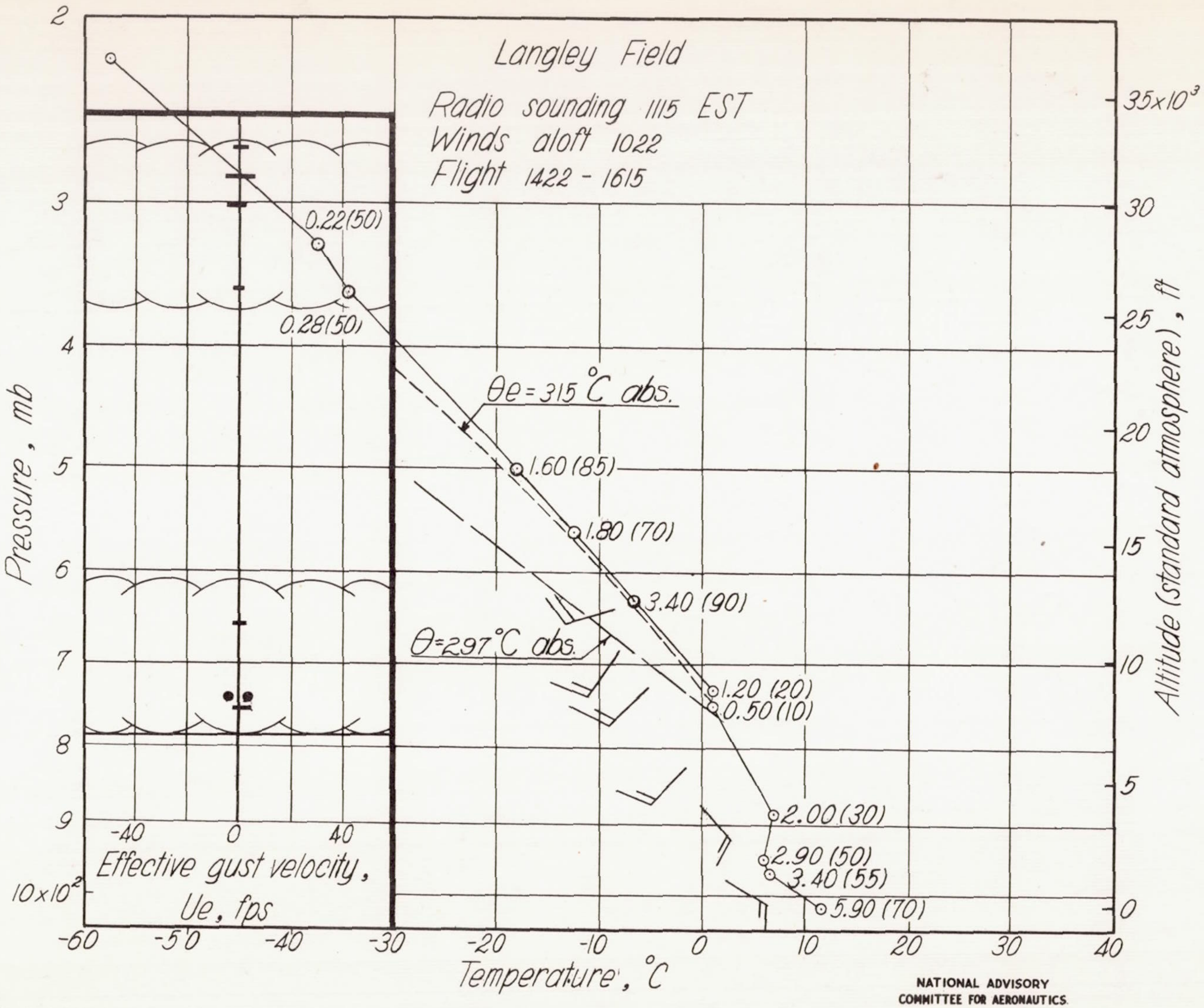
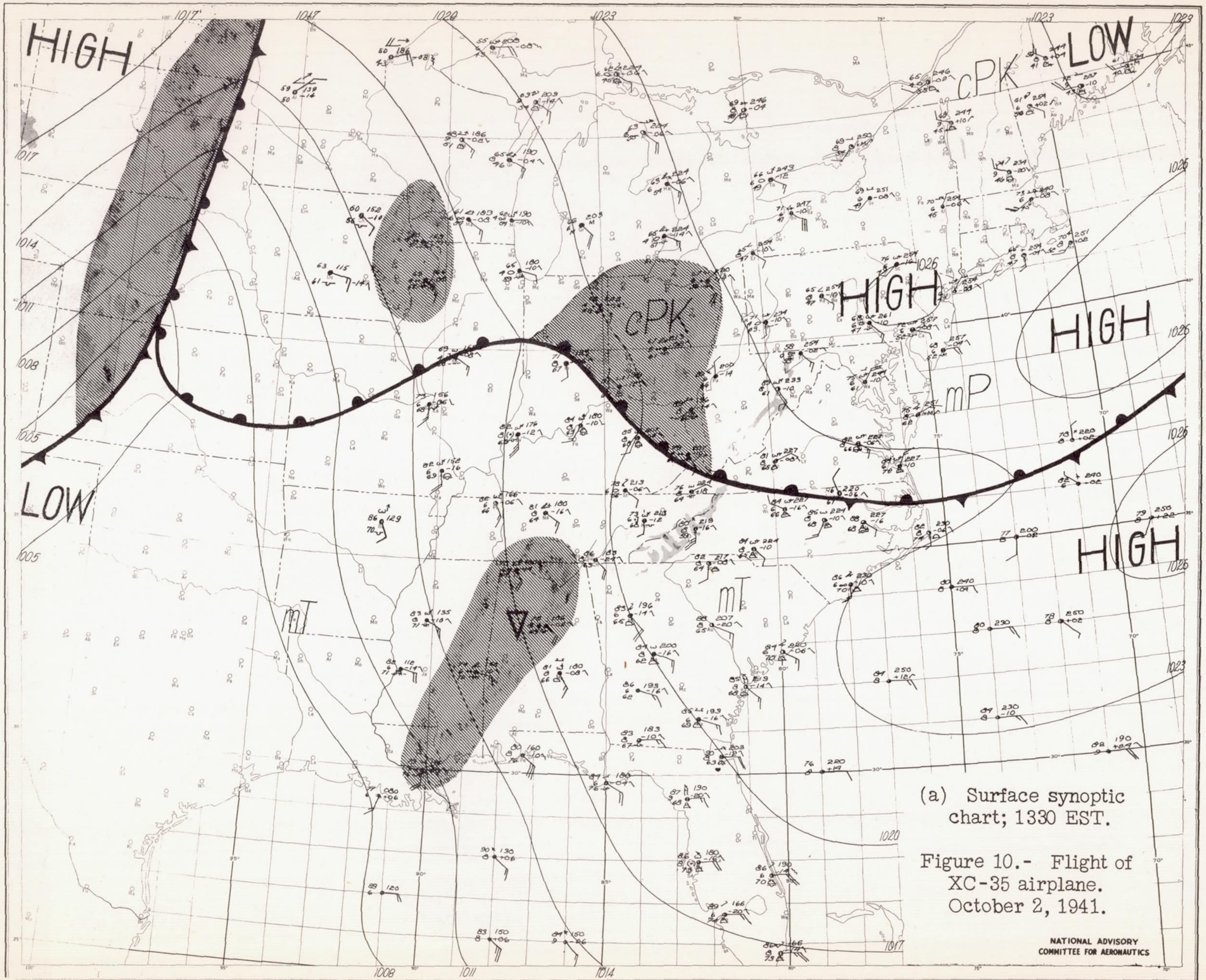


(b) Atmospheric sounding and turbulence measurements.

Figure 9.- Concluded.



(a) Surface synoptic chart; 1330 EST.

Figure 10.- Flight of XC-35 airplane. October 2, 1941.

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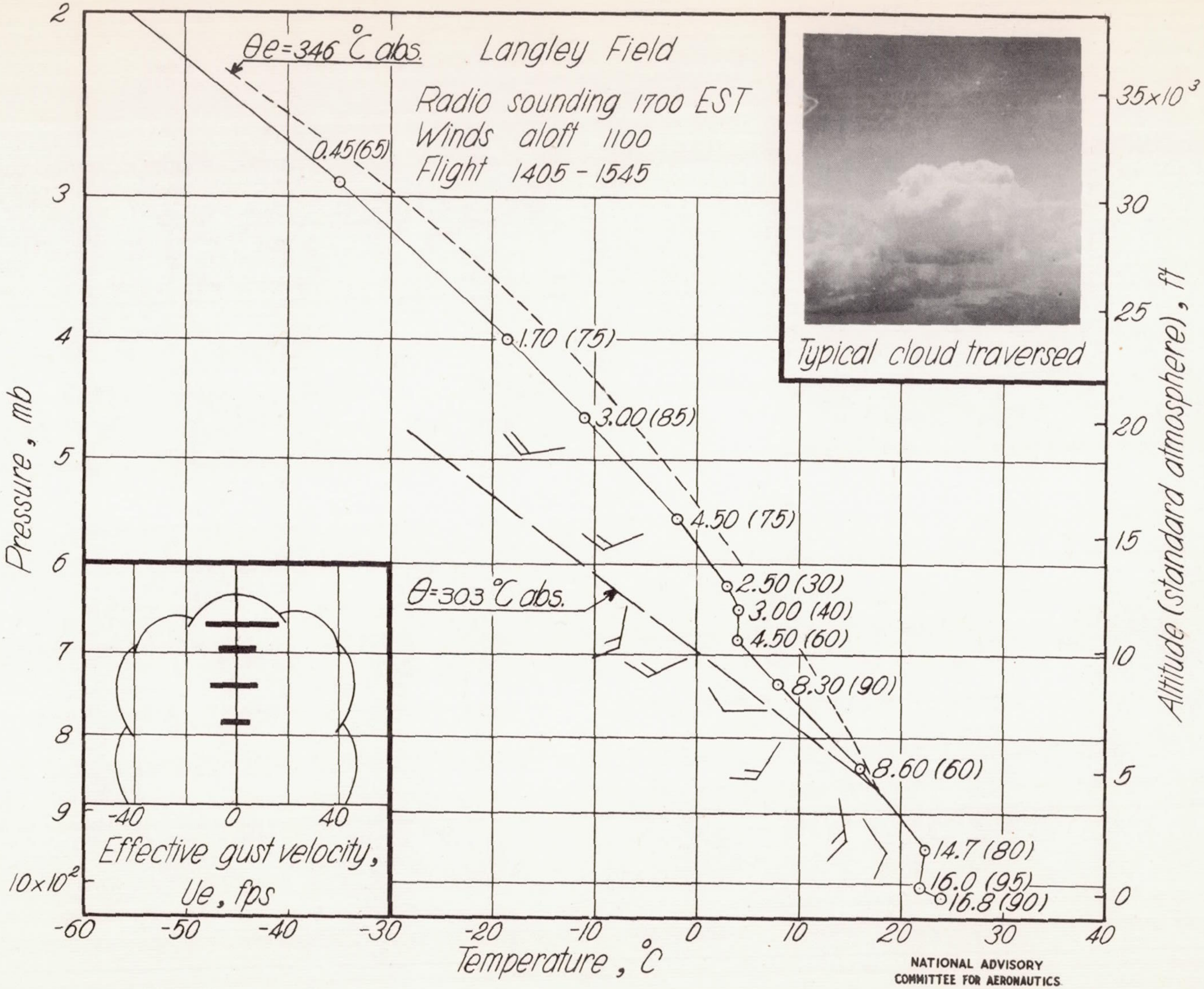

(b) Atmospheric sounding and turbulence measurements.

Figure 10.- Concluded.