Mesoscale Temperature Variability Below 60,000 Feet¹

PAUL F. NEE

Air Force Cambridge Research Laboratories, Bedford, Mass.

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ABSTRACT

Temperature measurements within 200 mi of the airport, and for altitudes up to 60,000 ft, will be necessary for calculating the fuel requirements of supersonic transports. In order to determine an adequate time and space separation for these measurements, a detailed knowledge of the mesoscale variability of temperatures in such regions is necessary. This paper, based on a series of approximately 300 radiosonde flights launched within 50 mi of Ft. Sill, Okla., during March and April 1958, presents the root mean square changes in temperature with time up to 6 hr and with distance up to 50 mi for every thousand feet from the surface to 60,000 ft. Temperature variability increases with time to a maximum of 3.5C at 6 hr at 37,000 ft. The variability increases with distance below 20,000 ft to a maximum of 3.0 C at 50 mi separation. Above 20,000 ft, temperature variability increases to a maximum of 2.5C at 40 mi and 45,000 ft, and then decreases.

1. Introduction

The results of a study on the effects of temperature variability on the performance of the supersonic transport (SST) were presented at the Fifth National Conference on Applied Meteorology at Atlantic City by Nelms (1964). He indicates that although high temperatures would increase the landing and take-off distances of the SST there should not be any new meteorological problems in this area. In addition, low power settings for descent would vitiate the significance of high temperature effects at flight destination.

The two most important factors that would be affected by temperature are the fuel consumption during the transonic acceleration and the fuel required during cruise.² The additional fuel for reserve is a minor consideration but could amount to 1 per cent of the standard requirement. The effect of temperature on the performance of the SST during the transonic acceleration, however, is a major consideration more than twice as important as during cruise. For operation at 20F above standard, the increase in fuel is 2.3 per cent of a standard day fuel requirement or 4350 lb. This portion of the flight, roughly 200 mi long, taking only 15–20 min requires two-thirds of the extra fuel that a transcontinental flight would need for a flight in which there was a uniform positive temperature anomaly.

Therefore, a detailed knowledge of the mesoscale time and space variability of temperatures in the transonic acceleration segment of the flight is necessary.

This paper presents the results of a study of this variability from GMD-1 radiosonde data and attempts to relate the observed variability to the effects on the SST.

2. Data

During March and April 1958, Project Metro Precision was conducted by the U. S. Army at Ft. Sill, Okla., Altus AFB, Okla., and Sheppard AFB, Tex. The purpose of the experiment was to determine observation representativeness of GMD-1 radiosonde equipment for use with artillery. There were six launch sites located at Ft. Sill as indicated in Fig. 1. Additional sites were located at Altus AFB about 50 mi west of Ft. Sill and Sheppard AFB about 50 mi south. The flight program of eight simultaneous launches at four times on a given day was repeated on eight days. The launches began at 0600, 0700 or 0800 CST and terminated at 1300, 1400 or 1500. At the end of the program the six observing teams at Ft. Sill set up their equipment at one location on 23 April and all tracked one balloon at 0900, 1100, 1300 and 1500 for a compatibility test.

The initial data reduction of these soundings was organized and conducted under the supervision of Mr. Robert W. Lenhard, Jr., of the Design Climatology Branch of the Air Force Cambridge Research Laboratories. The data were received on IBM cards and consisted of 1-min observations of azimuth and elevation angle, and significant level data. The data reduction was performed on a 7094 computer, which produced four tables of data for each sounding.

The reduced data were checked for misprints and obvious errors. The temperature profiles from the

¹ Presented at the AMS/AIAA Conference on Aerospace Meteorology, Los Angeles, Calif., 28–31 March 1966.

² Gringorten, I. I., 1966: The frequency distribution of route temperatures at SST levels. Presented at the Sixth National Conference on Applied Meteorology, Los Angeles, Calif.

FIG. 1. Geographical distribution of stations for Project Metro Precision.

significant-level data were plotted for all soundings and rechecked for errors and superadiabatic lapse rates. A number of erroneous soundings were discovered and corrected. A computer program was then written to produce for each sounding temperature, x, y position and time after launch for every 1000 ft. The output of this program was used to perform the variability analysis.

Time variability data were obtained by matching the station numbers of soundings with the same date. The difference in time including the time after launch to that altitude and the square of the difference temperature for all possible matched pairs was then computed for all levels and the square of temperature change was accumulated according to 15-min class intervals. In addition, the program was run for time intervals of 30, 45 and 60 min.

The spatial variability data was obtained by matching nominal launch times of soundings with the same date. The difference in distance, including the distance from launch site at that altitude, and the square of the difference in temperature were then computed every 1000 ft for all matched pairs. The square of the temperature difference was then stored by 5 n mi class intervals. The program was also run for separations of 10, 15 and 20 n mi.

It was necessary to use the 60-min class intervals for the time variability in order to get a reasonable number of cases in most of the intervals. For the spatial variability analysis the 10 n mi intervals yielded a sufficient distribution of sample sizes. The results of both the time and space variability were then averaged for every 5000 ft up to 60,000 ft and plotted. Isopleths of root mean square change in temperature were then drawn.

3. Accuracy

An Air Weather Service paper² gives the rms error in temperature obtained with the operational radiosonde system as 0.7°C. As a check on this sample, the multiple track soundings on 23 April were used to estimate the data reduction error in this sample. If we assume that each multiple track observation of temperature consists of some true value plus a zero mean, normally distributed, random error, then the standard deviation of the observed temperatures will be the rms error due to data reduction. The standard deviation of the multiple track temperature observations was computed for every 5000 ft up to 60,000 ft. The results did not show any trend with height and the average data reduction rms error was 0.6°C. Since we have an estimate of 0.6°C for the data reduction error in the sample and an estimate of 0.7°C for the total system error, we can estimate the rms sensor error. This yields an estimate of 0.3°C for the rms sensor error in this sample.

The computed rms differences for balloons separated less than 5 mi was as small as 1.1°C for 26 of the 40 levels with a sample size of at least 100. These figures indicate, that if there were no spatial variability, the rms system error in this sample would be 0.8°C. The spatial variability, however, is not zero and, therefore, the system error in this sample is certainly less than 0.8°C.

Both the estimate of the data reduction error of 0.5°C from the multiple track soundings on 23 April and the derived system error of less than 0.8°C from the computed rms differences in temperature for small separations, agree reasonably well with the Air Weather Service estimate of 0.7°C for system error. In addition, the estimate of data reduction error of 0.6°C is twice the estimate for sensor error. Hodge and Harmantas (1965) also found the data reduction error to be the major contributor to system error in the observed temperature from a GMD-1 radiosonde set.

4. Discussion

Meteorologists should note that this variability is at computed geopotential altitude and not for the mean height of constant pressure surfaces. Geometric and geopotential altitude differences are negligible at these levels. Pressure altitude, however, may differ by a few hundred feet.

Variability increases with time at all levels. Relative maxima in the vertical profile occur at the surface, 10,000 to 25,000 ft and again between 30,000 and 50,000 ft at lags of 2, 4 and 6 hr. In the 10,000 to 25,000 ft region and also in the 30,000-ft region the relative minima in the variability with time at lags of 3 and 5 hr is probably due to variations in the sample size and observational error. The levels of minimum varia-

² Johannessen, K. R., 1959: Accuracies of meteorological upper air data. Unpublished 4th Weather Group Letter.

FIG. 2. Root mean square temperature change with time over Fort Sill, Okla., during April 1958.

bility with time at 10,000 and 27,000 ft appear to be real. The maximum observed change was 3.5C at 37,000 ft for a lag of 6 hr. The results are shown in Fig. 2.

The spatial variability of temperature is presented in Fig. 3. The region below 30,000 ft shows an increase of rms change in temperature with distance at all levels. The lower altitudes demonstrate a slightly larger change with distance than the levels near 20,000 ft. Above 20,000 ft the variability increases with distance up to 30–40 mi at all levels and then decreases to the same variability at 50 mi as was ob-

FIG. 3. Root mean square temperature change with distance over Fort Sill, Okla., during April 1958.

served for about 15-mi separation. Vertical variations are almost nonexistent at separations of less than 25 mi but for separations between 25 and 45 mi the variability above 20,000 ft is larger than below. For separations beyond 45 mi the variability above 20,000 ft is less than that above. The decrease in variability at the higher levels for separations beyond 45 mi is probably real.

In Fig. 4, comparisons of the standard deviation of temperature about the monthly mean for Washington, D. C., during April from Cole and Nee (1965) with the 6-hr rms temperature changes from Fort Sill show that the 6-hr changes are about one-half the monthly standard deviation. Both the time variability and the sigma curves have levels of large variability at the surface, decreasing variability to 25,000–30,000 ft, increasing again to 35,000 or 40,000 ft and then decreasing. On the other hand, the spatial variability curve which is a plot of the rms changes for 45-mi separation, shows little, if any, variability with height.

Nelms (1964) gave estimates of the increase in fuel required for given temperature increases over various portions of the flight profile. The transonic acceleration, according to Nelms, is the most significant segment of the flight for sensitivity to temperature increases. This segment occurs between 25,000 and 40,000 ft within 200 mi of the airport.

In order to relate the effect of mesoscale time and space variability of temperature to the operation of the SST, it is necessary to have an initial temperature profile. An increase of t degrees of temperature can be of small or large importance depending upon the initial temperature. According to Kantor and Cole

FIG. 4. Comparison of mesoscale time and space changes of temperature over Fort Sill, Okla., during April 1958 with the monthly standard deviation over Washington, D. C., during April.

(1965), the mean temperature for April at 30N between 25,000 and 40,000 ft is about 6–9C above the standard. This increase in temperature would require an additional 4500 lb of fuel.

The maximum rms temperature change with time, 3.5C, observed for a 6-hr lag is in the transonic acceleration region. If we consider the model atmosphere to be an observed profile at the point of departure for the aircraft, then the addition of 3.5C for a 6-hr change, which has an 18 per cent probability, would require another 4000 lb of fuel.

The maximum rms temperature change with distance, 3.0C, observed for a separation of 55 mi is outside the transonic acceleration region. The 2.0C rms change observed between 20 and 45 mi, however, is in the transonic acceleration region. The probability of occurrence is 18 per cent and it would cause an increase of about 2000 lb above the 4500 lb over standard necessary for the assumed initial profile. In this sample, data exists for a maximum of 60 mi. The transonic acceleration region requires spatial variability studies out to 200 mi in order to reliably estimate fuel requirements based on an observation taken at the point of departure. For those distances the spatial variability may be more important than the time variability.

5. Conclusions

1) Root mean square changes in temperature increase with time out to six hours at all levels below 60,000 ft. Relative maxima in variability occur between 12,000 and 22,000 ft and also between 30,000 and 40,000 ft. Relative minima occur at 10,000 and 27,000 ft. The

absolute maximum rms change in temperature, 3.5C, occurs at 37,000 ft at a lag of six hours.

2) Root mean square changes in temperature increase with distance out to 60 mi below 20,000 ft and out to 40 mi above 20,000 ft. At levels above 20,000 ft, the rms temperature changes are less for separations between 45 and 60 mi than for those between 20 and 45 mi. Relative maxima and minima in the vertical profile of the variability are not as pronounced as were those for the time curves. The absolute maximum, 3.0C, occurs at 8000–20,000 ft at a separation of 55 mi. The maximum spatial variability in the transonic acceleration region is 2.0C and occurs at a separation of 20–45 mi.

3) Over Oklahoma, the rms 6-hr mesoscale changes in temperature in the transonic acceleration region may increase fuel requirements by as much as 4000 lb over that required for average April conditions.

4) Over Oklahoma, the 20–45 mi rms changes in temperature in the transonic acceleration region may increase fuel requirements by as much as 2000 lb over those required for April.

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