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Technical Memorandum

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SCTM 89-55

PROBABILITIES OF OCCURRENCE OF BARO-FUZE SYSTEM ERRORS MORE THAN 1000 FEET TOO LOW DUE TO IGNORING THE METEOROLOGICAL CORRECTION

REPORTS REFERENCE

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B. N. Charles - 5133

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ABSTRACT

Charts of the geographical distribution of the annual and seasonal D-values (pressure altitude minus true altitude) and their standard deviations at altitudes of 4500, 6000 and 7000 feet over Eurasia are derived. These are then used to estimate the frequency of occurrence of baro system errors more than 1000 feet too low due to ignoring the meteorological correction in the fuzing procedure. The effects of improved system design, and increased fuzing error allowances, are illustrated.

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TABLE OF CONTENTS

	Page
INTRODUCTION	4
STATEMENT OF THE PROBLEM	4
METHODS USED	4
Basic Meteorological Data	4
System Error Frequencies	5
RESULTS	7
REFERENCES	15

PROBABILITIES OF OCCURRENCE OF BARO-FUZE SYSTEM ERRORS MORE THAN 1000 FEET TOO LOW DUE TO IGNORING THE METEOROLOGICAL CORRECTION

INTRODUCTION

It has been indicated[1] that a single annual meteorological correction (D-value) might suffice in determining fuze settings for the TX-15, TX-17, and TX-21 baro-fuzing systems. If the degradation in burst-height accuracy which results from this procedure is acceptable, fuze-setting instructions and techniques can be simplified. This memorandum estimates the probability of occurrence of large baro-fuze system errors at several altitudes over Eurasia, if it is assumed that the US Standard Atmosphere will prevail over any target at any time of the year. This is equivalent to assuming that pressure altitude is identical with true altitude, i.e., that the D-value is zero.

STATEMENT OF THE PROBLEM

The specific question posed[2] is: How often will the fuzing system operate more than 1000 feet too low at elevations of 4500, 6000 and 7000 feet (above MSL) over Eurasia, if the meteorological correction is assumed to be zero?

METHODS USED

A problem of this type does not lend itself to exact solution. Rather, techniques of statistical approximation are used. The statistical distributions of the basic meteorological parameters and the fuzing system error parameters can be combined to yield a statistical estimate of the desired information.

Basic Meteorological Data

The basic data requirements include the mean daily D-value and its standard deviation* at each level, for the year, and for each season. Annual and seasonal D-values and standard deviations at sea-level are presented in Reference 4, which also includes the annual D-value and its estimated annual standard deviation at the 700-mb level (approximately 10,000 feet above MSL). Procedures were as follows:

1. Annual D-values and standard deviations were determined for 4500, 6000, and 7000 feet by graphical linear interpolation from the annual charts[4] for sea level and 700 mb.

2. Charts of the sea-level quantities $\left(D_{O_S} - D_{O_A}\right)$ and $\left(\sigma_{O_S} - \sigma_{O_A}\right)$ were then prepared, where D is the D-value, σ is its standard deviation, the subscript O refers to sea level, subscript A means annual, and subscript S is for a season.

---

* The frequency distribution of daily pressure during a season is essentially Gaussian Normal, and the mean and standard deviation may be assumed constant during the season.[3]

3. It was then assumed that at any level the difference between the seasonal and annual values of D or σ is equivalent to the difference at sea level. Therefore:

$$D_{h_S} = D_{h_A} + \left(D_{O_S} - D_{O_A}\right), \tag{1}$$

and

$$\sigma_{h_S} = \sigma_{h_A} + \left(\sigma_{O_S} - \sigma_{O_A}\right), \tag{2}$$

where the subscript h refers to an altitude.

Errors due to linear interpolation of D-values between sea level and 700 mb have been studied by Project AROWA.[5] It was concluded that maximum errors would occur near 5000 feet and would lie between +60 and -45 feet. Such errors are not prohibitive for the purposes of this study.

Data presented in Reference 4 show that the assumption of linear variation of σ with elevation between sea level and 700 mb results in overestimating the value of σ. The maximum error is about 50 feet near 3000 feet above sea level.

The errors due to the assumption in item 3 above are difficult to evaluate, because of the nonavailability of suitable data. It was found, however, that maximum standard deviations at 7000 feet in winter, as estimated by the above method, closely approximate maximum values at 700 mb in winter, as presented in a study by the Air Weather Service.[6] As shown in Reference 4, the standard deviation of pressure (or D-value) increases with elevation between sea level and 700 mb; therefore it appears that the effect of assumption 3 is to overestimate the standard deviation at intermediate altitudes in winter when the standard deviation is maximum.

It is believed, therefore, that the methods described above are conservative, in that they tend to make estimated values of D and σ larger than actual values at the altitudes considered.

System Error Frequencies

It is customary to consider the total error of the baro-fuzing system as having four components: The baro repeatability error, the pressure-sensing error, human error, and the error in meteorological prediction. The frequency distributions of the first three are considered to be Gaussian Normal, each having a mean value of zero. The last error is also Gaussian Normal, but the mean is the D-value, and is usually not zero but depends upon time and place. Each of the above-mentioned errors are independent of each other, and the total system error is the sum of the individual errors. Thus, an alement in the population of the variable $X_T = X_1 + X_2 + X_3 + X_4$ is derived by random choice of one element from each of the four elements. By the Addition Theorem for Normal Distributions,[7] the mean of the variable X_T is the sum of the means of the other variables, and the variance of X_T is the sum of the variances of the other variables. That is,

$$M_T = M_1 + M_2 + M_3 + M_4 = \sum_{i=1}^{4} M_i , \tag{3}$$

and

$$\sigma_T^2 = \sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \sigma_4^2 = \sum_{i=i}^{4} \sigma_i^2 , \tag{4}$$

where M is the mean, and σ_i is the standard deviation. For convenience, the first three variables, consisting of the baro repeatability error (X_1), the pressure-sensing error (X_2), and the human error (X_3), are lumped into a single distribution having the parameters M and σ. The baro-fuzing system error (X_T) will therefore be

$$X_T = X + X_4, \tag{5}$$

where

$$X = X_1 + X_2 + X_3,$$

and X_4 is the meteorological prediction error.

Similarly, the system mean error (M_T) and variance (σ_T^2) will be:

$$M_T = M + M_4 \tag{6}$$

and

$$\sigma_T^2 = \sigma^2 + \sigma_4^2 ,$$

where the subscript 4 refers to meteorological prediction. (7)

In Equation 6, M is equal to zero and M_4 is equal to the D-value. In Equation 7 the value of σ is taken to be 600 feet. Then the system mean error and its standard deviation can be computed at any point at which the D-value and its standard deviation are known.

The D-value is defined[4] as

$$D = PA - TA, \tag{8}$$

where PA = pressure altitude, and

TA = true altitude.

The pressure altitude can be thought of as the altitude the baro measures when it is actually at the geometric altitude TA. Thus, if PA > TA, D is positive and the baro

is actually at a lower elevation than its calibration indicates. Therefore, the baro will function too late, or below the desired altitude.

Consider the fuzing system error distribution shown in Figure 1.

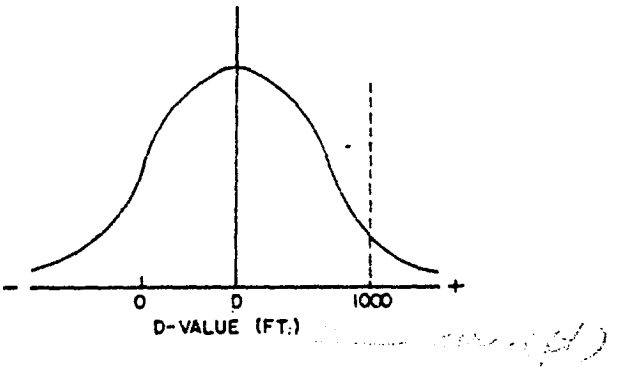

Fig. 1 -- Normal Distribution of Total System Error

The distribution is Gaussian Normal, with a mean equal to D, and a standard deviation determined from:

$$\sigma_T^2 = \overline{600}^2 + \sigma_D^2 \quad . \tag{9}$$

The normalized area under the curve to the right of the dashed vertical line (D = 1000 feet) is equal to the probability that any system error will be more than 1000 feet below the desired baro operating altitude. The quantity $\left(\frac{1000 - D}{\sigma_T}\right)$ can then be used with a table of areas of the normal curve (included in most statistics textbooks) to determine that probability. This computation was carried out at 63 points on the map of Eurasia, for each season and altitude. The resulting figures were then plotted on maps, and isopleths of equal probability were easily drawn. The results are shown in Figures 2-11 which depict the geographical distributions of the expected frequencies of baro operating altitudes more than 1000 feet too low at altitudes of 4500 feet and 7000 feet, if the meteorological correction is ignored in the fuze-setting procedures. (The results at 6000 feet were essentially the same as those at 7000 feet.)

RESULTS

The variations with altitude and season of the probabilities of occurrence of errors greater than 1000 feet are rather complex. At all altitudes considered, the probabilities are maximum in the northwest near Novaya Zemlya and Svalbard (Spitzbergen) in all seasons except summer, when the probabilities are maximum in the Yakutsk ASSR and the Anadyr Peninsula (northeast USSR). The maximum probabilities are about 25 percent, and occur at all altitudes near Svalbard, during winter. In winter, however, the probability south of the 60th parallel tends to be smaller at all the

altitudes considered than during the other seasons. In all seasons, the probability is five percent or more over much of Eurasia. In summer the probability is greater than five percent over most of Eurasia at all altitudes.

Figure 12 was prepared to show the effect of possible mechanical improvements in the baro-fuzing system. The probability of occurrence of errors more than 1000 feet too low was computed for the summer season at the altitude of 4500 feet, assuming that σ in Equation 7 is 350 feet, instead of 600 feet. (The season and altitude were selected on the basis of the southernmost location of the five percent isopleth; see Fig. 5.) Figure 12 shows that probabilities were generally reduced, but that the Yakutsk ASSR-Anadyr Peninsula region is still subject to probabilities greater than five percent.

Figure 13 was prepared to show the effect of increasing the allowable height error. In some applications of high-yield weapons, differences in effects cannot be correlated to burst-height increments of the order of 500 feet. For Figure 13, therefore, the probabilities of occurrence of errors more than 1500 feet too low were computed, again for the 4500-foot altitude in summer. In this computation, the currently attainable σ (in Equation 7) of 600 feet was used. It is seen that the isopleths have values smaller than five percent over the entire area. Sample calculations show that during the winter season at 7000 feet, the probabilities would be reduced to less than 10 percent in the Svalbard vicinity (from about 25 percent), using an allowable 1500-foot height error instead of 1000 feet. Over most of Eurasia, during all seasons at the altitudes considered, the probabilities of occurrence of errors more than 1500 feet too low would apparently be less than five percent.

B. N. CHARLES - 5133

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May 12, 1955

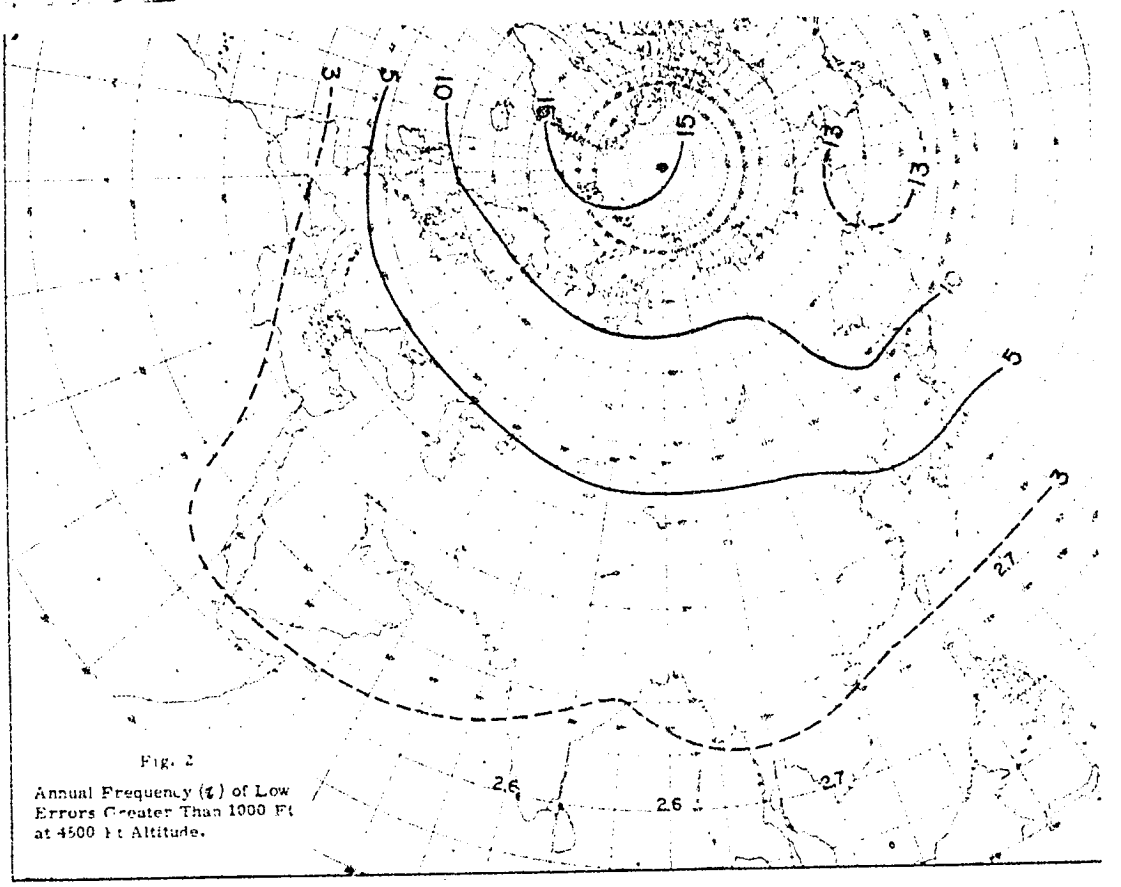

Fig. 2
Annual Frequency (%) of Low Errors Greater Than 1000 Ft at 4500 Ft Altitude.

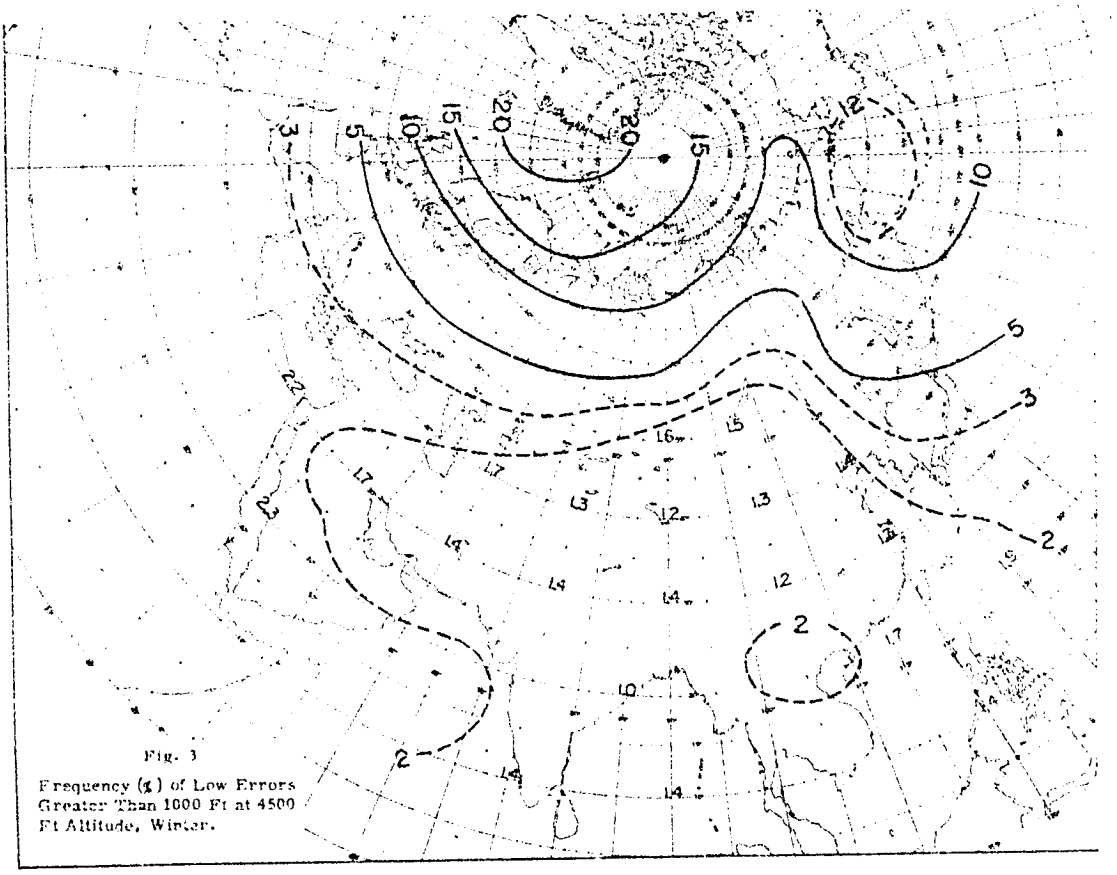

Fig. 3
Frequency (%) of Low Errors Greater Than 1000 Ft at 4500 Ft Altitude, Winter.

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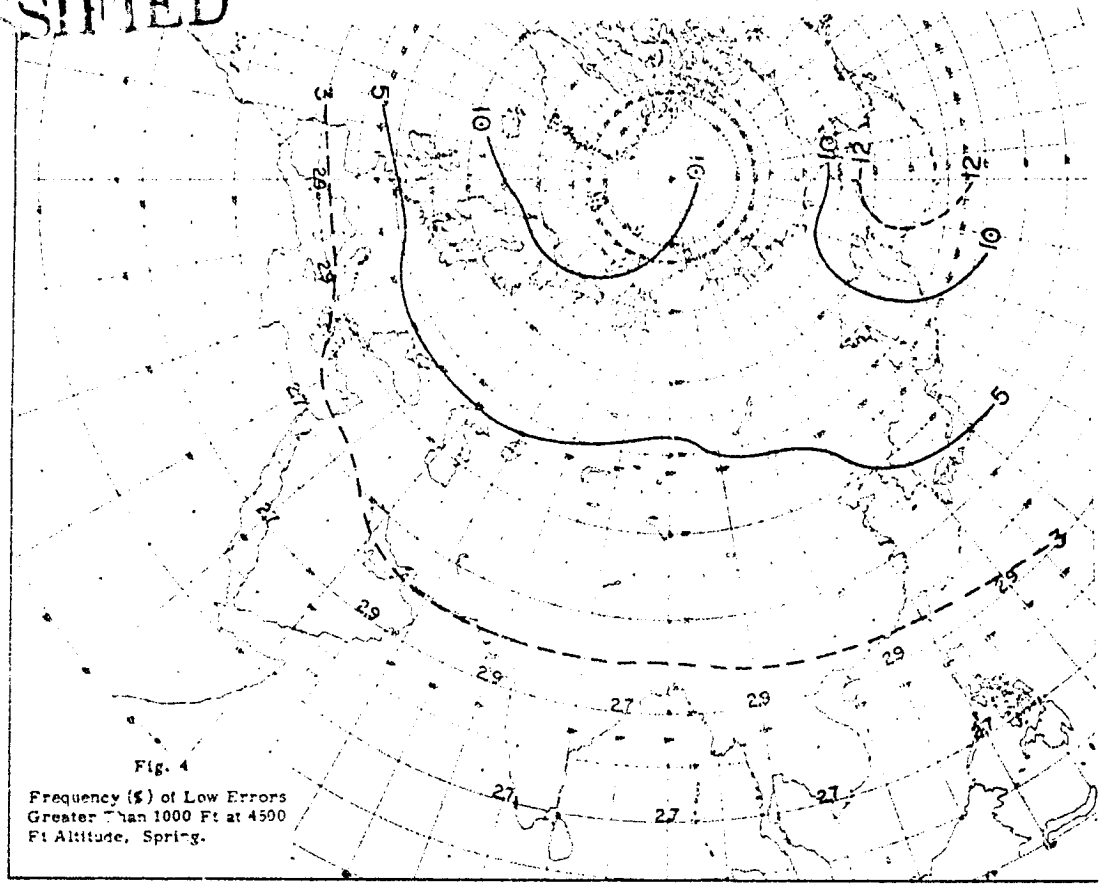

Fig. 4
Frequency (%) of Low Errors Greater Than 1000 Ft at 4500 Ft Altitude, Spring.

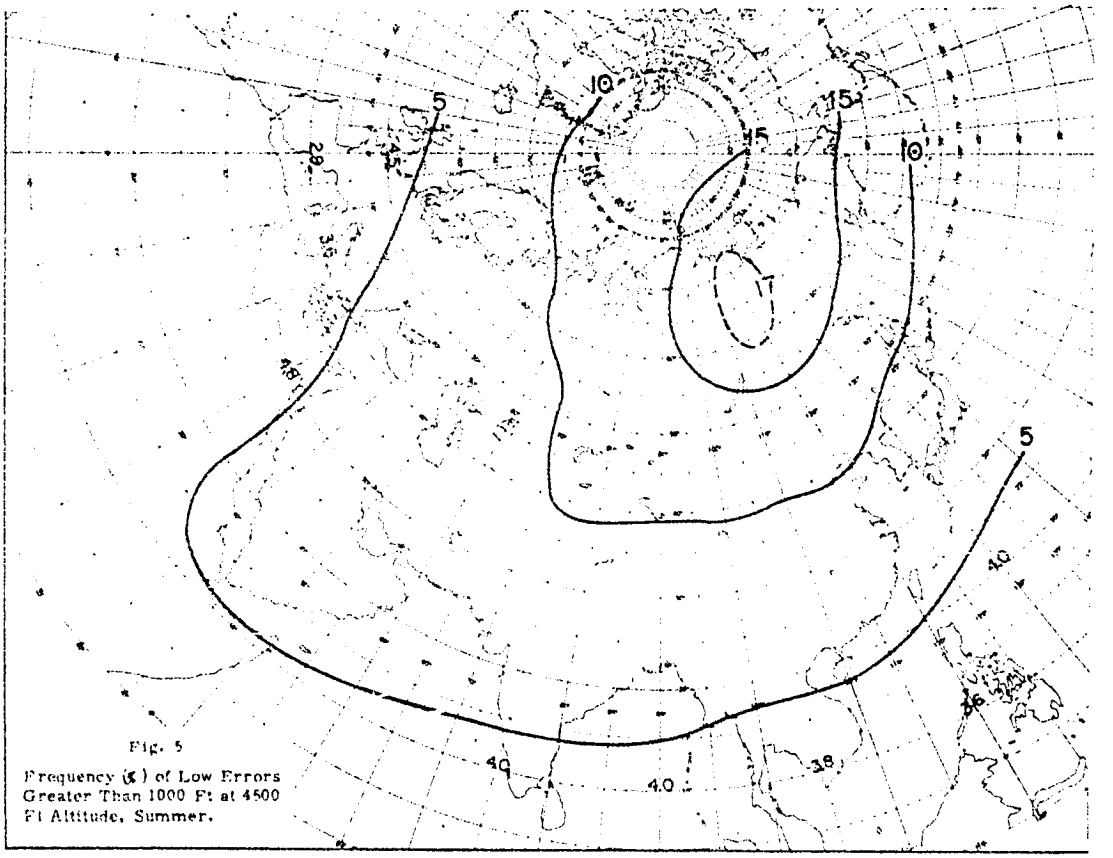

Fig. 5
Frequency (%) of Low Errors Greater Than 1000 Ft at 4500 Ft Altitude, Summer.

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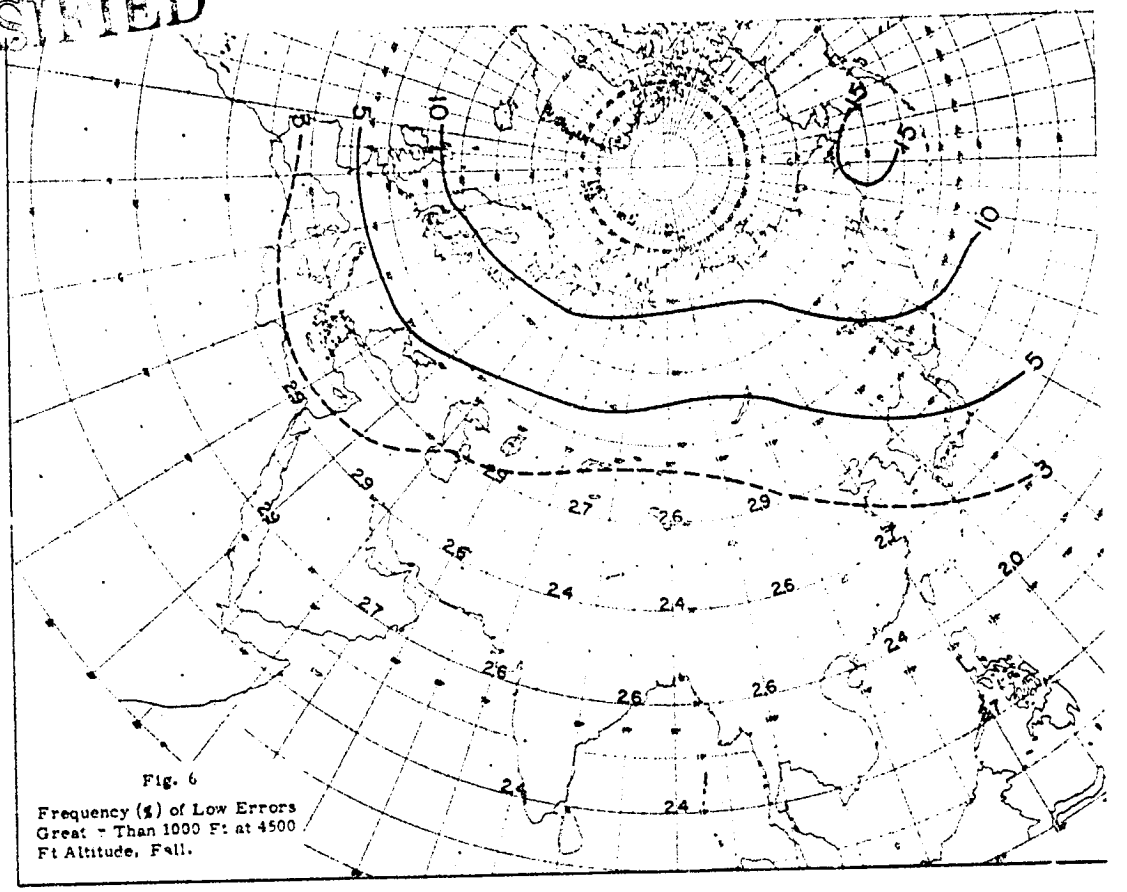

Fig. 6
Frequency (%) of Low Errors Great - Than 1000 Ft at 4500 Ft Altitude, Fall.

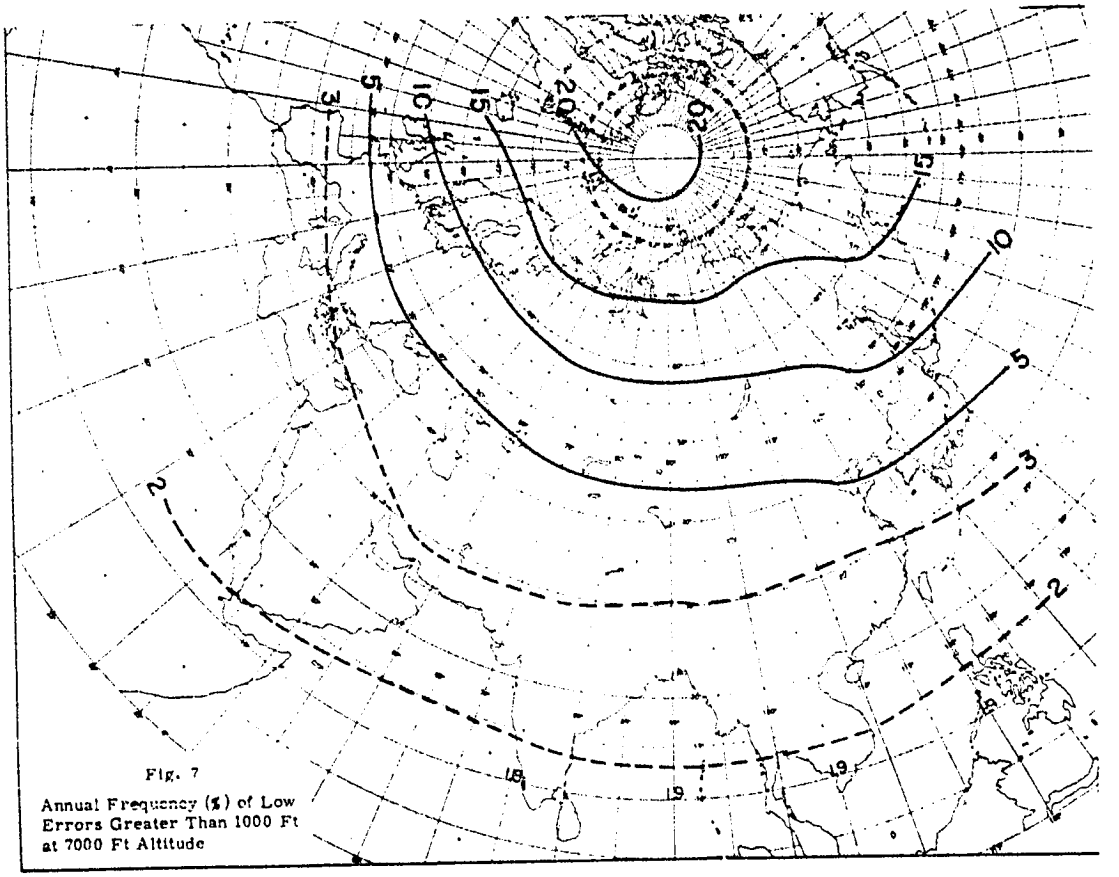

Fig. 7
Annual Frequency (%) of Low Errors Greater Than 1000 Ft at 7000 Ft Altitude

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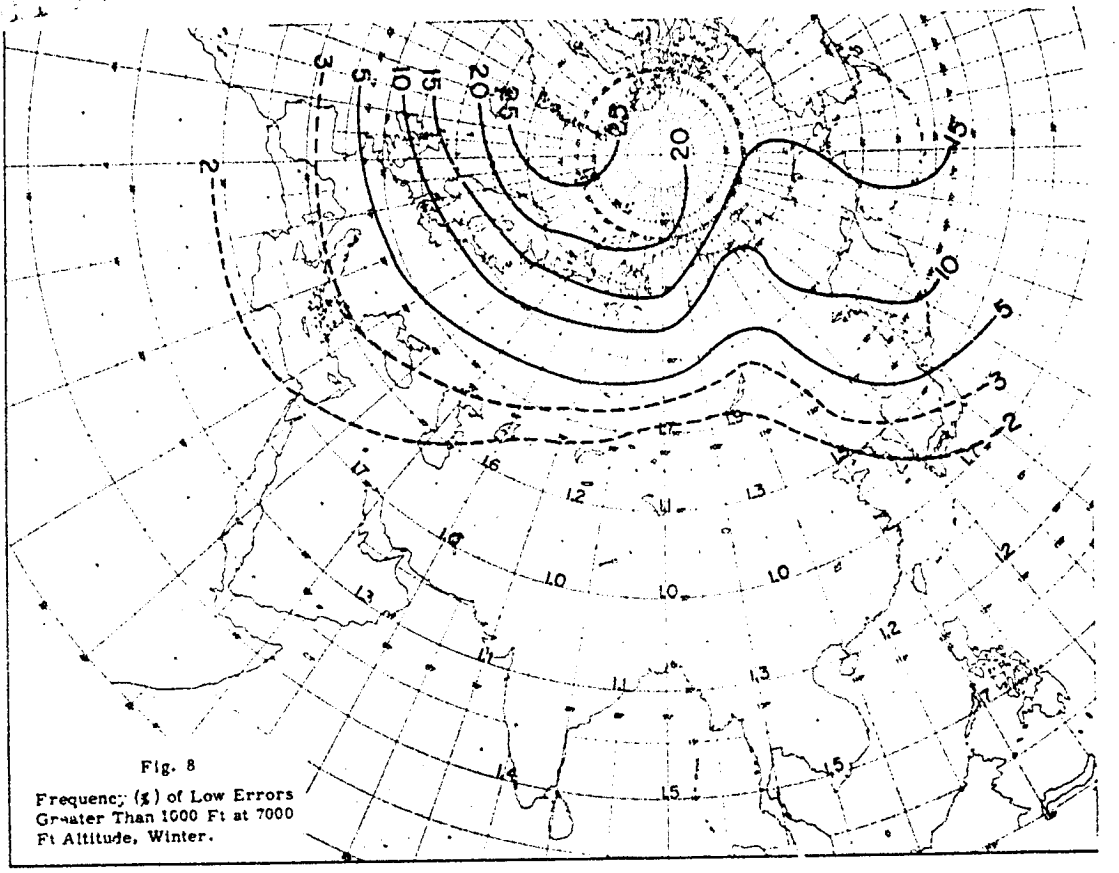

Fig. 8
Frequency (%) of Low Errors Greater Than 1000 Ft at 7000 Ft Altitude, Winter.

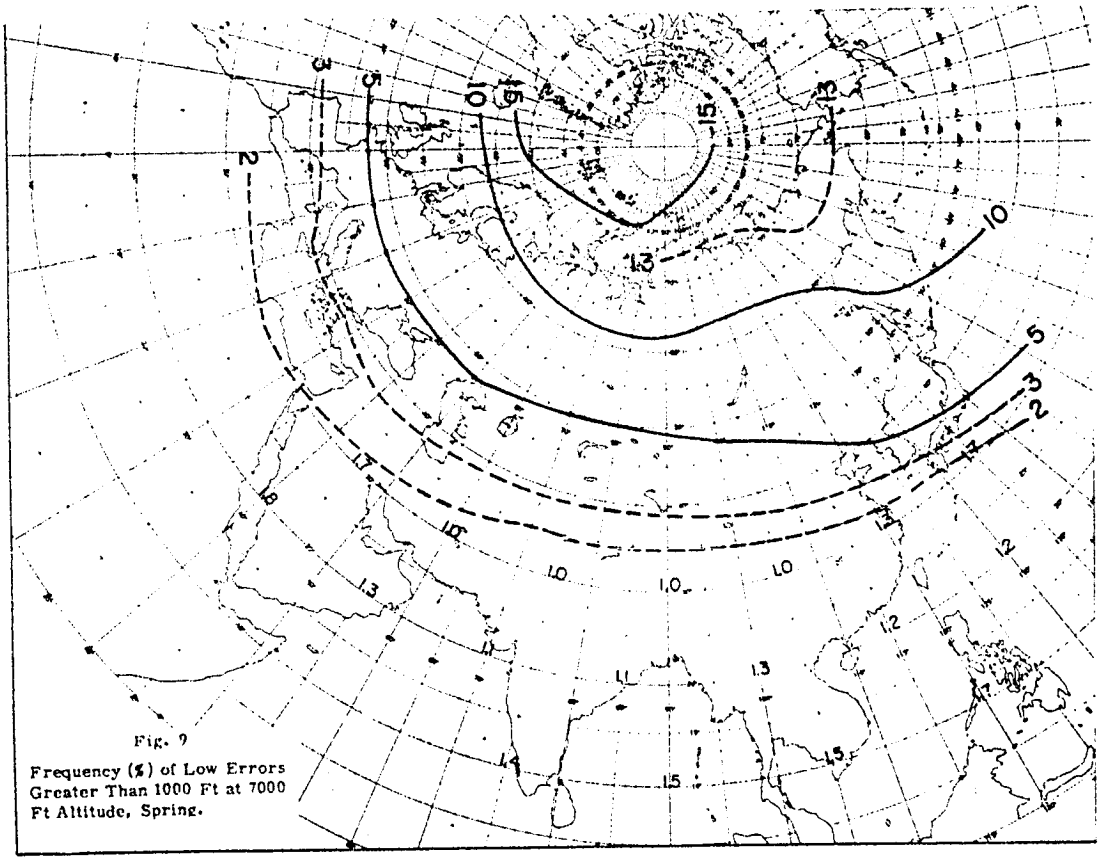

Fig. 9
Frequency (%) of Low Errors Greater Than 1000 Ft at 7000 Ft Altitude, Spring.

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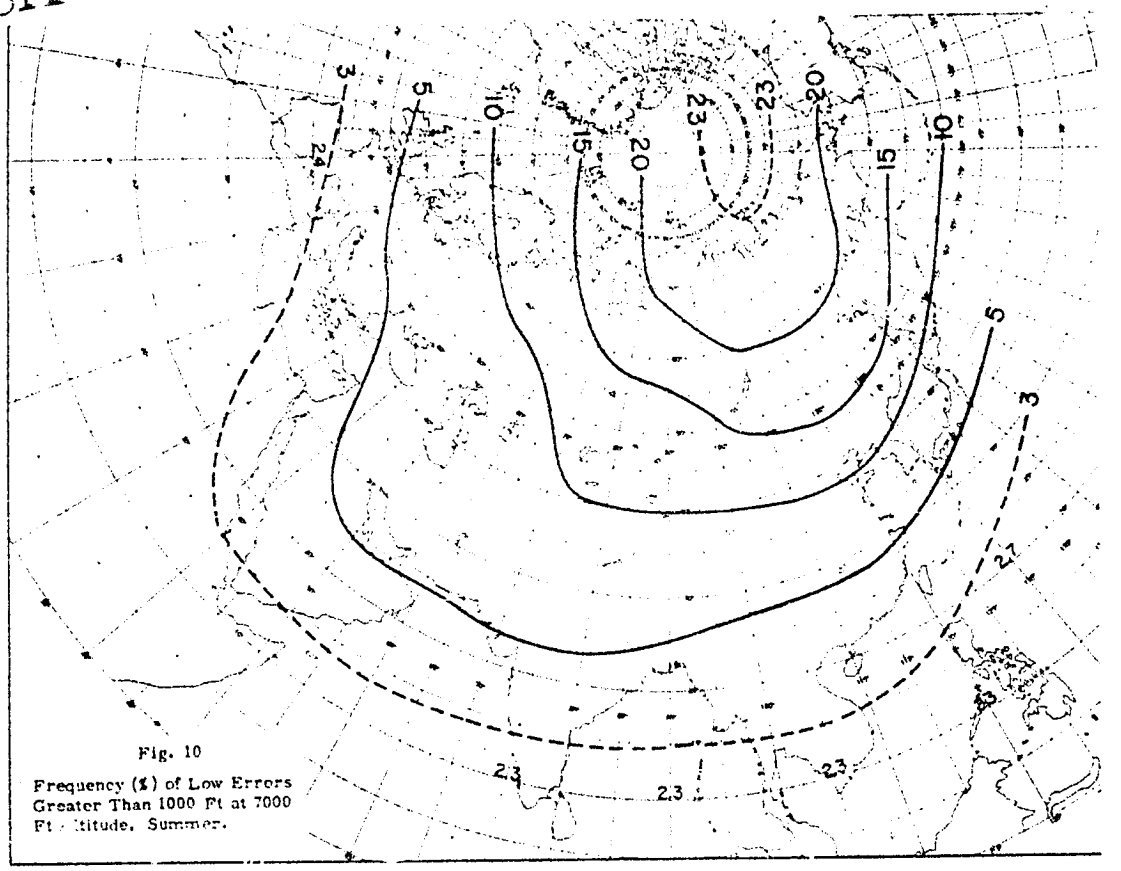

Fig. 10
Frequency (%) of Low Errors Greater Than 1000 Ft at 7000 Ft Altitude, Summer.

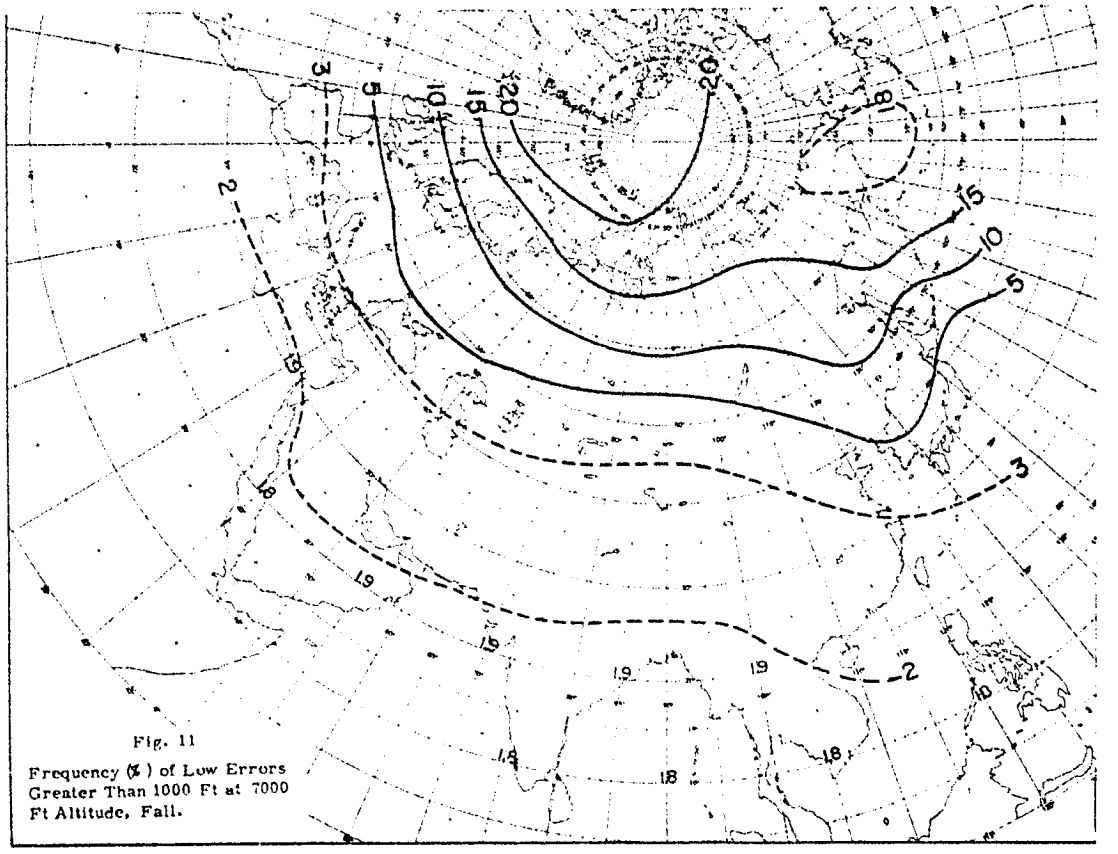

Fig. 11
Frequency (%) of Low Errors Greater Than 1000 Ft at 7000 Ft Altitude, Fall.

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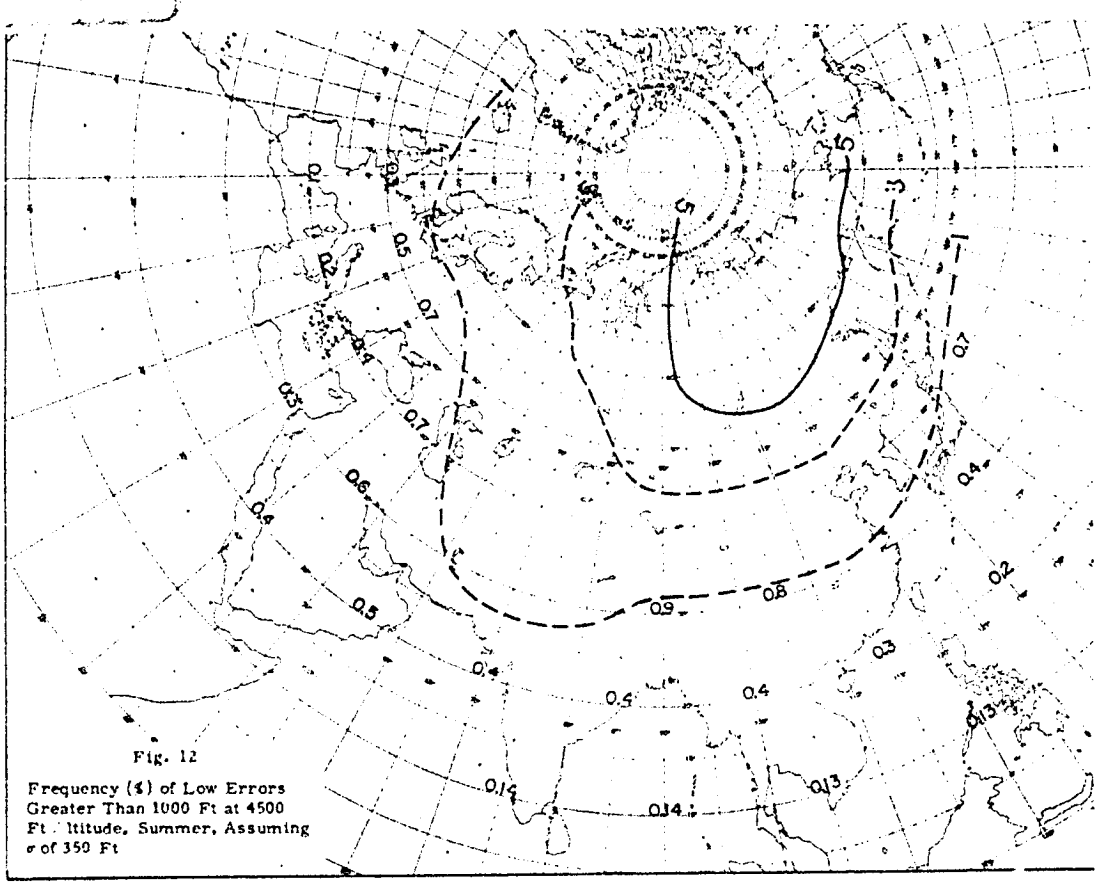

Fig. 12

Frequency (%) of Low Errors Greater Than 1000 Ft at 4500 Ft Altitude, Summer, Assuming σ of 350 Ft

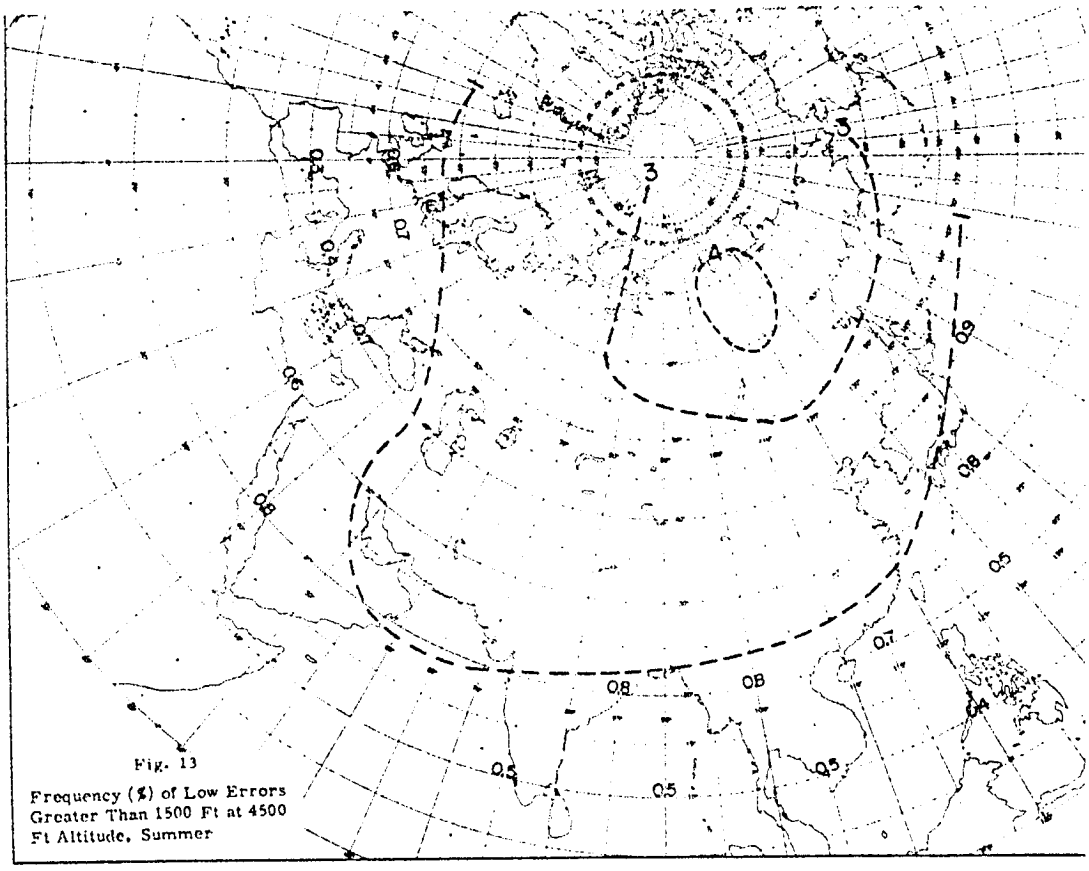

Fig. 13

Frequency (%) of Low Errors Greater Than 1500 Ft at 4500 Ft Altitude, Summer

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