WIND AID FROM WIND ROSES

by

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1. Introduction

Wind either aids or retards an aircraft in flight. For this reason, over a prescribed ground course, the expected wind effect assumes a major role in operational flight planning. To take advantage of the aid and to minimize the hindrance, newer and better planning guides must be continually developed.

2. Purpose

It is the purpose of this paper to show that wind roses can be used to approximate the wind effect on an aircraft at specified points along a ground course. Information obtained in this manner can be applied to an entire route, though that aspect in not presented here. In this paper the wind effect is presented as positive and negative aid.

3. Source of Data

The data used are on file at the National Weather Records Center in Asheville, North Carolina. These consist of rawinsonde observations obtained for five-year periods during 1947-1953. Where actual data are missing, scaled data from upper air charts were inserted to provide a continuous record.

4. Previous Investigation

Many people have contributed to our present knowledge of surface and upper winds. The work of some, of course, more directly affects the development of this paper. Among these are the works of Robitszch[1], Gregg and Van Zandt[2, 3], Hazen[4], Hesselberg and Bjorkdal[5], Sawyer (Giblett, and Gold)[6], Bilham[7], Brooks, Durst, and Carruthers[8, 9, 10], and Mintz[11]. Here, also, the recent publication by the U. S. Navy on "Wind Aid and Retard"[12], should be mentioned.

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5. Vector Computation of Wind Aid

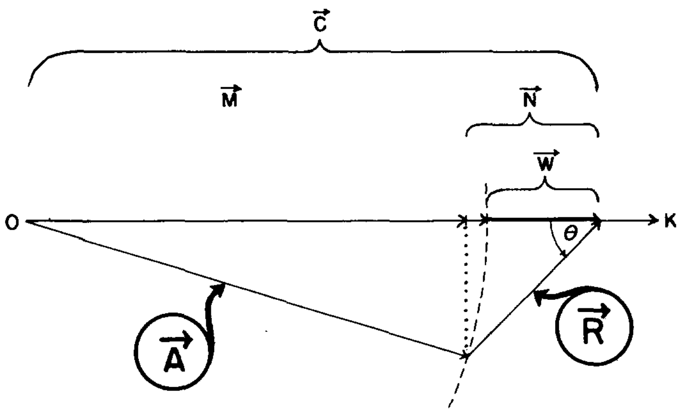


FIG. 1 Vector Representation of Wind Aid, $\vec{W}$

Where, O is the aircraft departure point at a pressure surface along the path OK,

$\vec{A}$ is the aircraft vector, heading and speed,

A is the magnitude of aircraft speed,

$\vec{R}$ is the wind vector, direction and speed,

R is the magnitude of the wind speed,

$\vec{C}$ is the path traveled by the plane, direction and speed,

C is the magnitude of the aircraft speed along the flight path,

θ is the angle between the flight path and wind direction.

Where, $\vec{M}$ is the projection of $\vec{A}$ on $\overrightarrow{OK}$ and

$\vec{N}$ is the projection of $\vec{R}$ on $\overrightarrow{OK}$.

Now, $\vec{C} = \vec{A} + \vec{R} = \vec{M} + \vec{N}$ (1)

and the magnitude of the wind aid,

$W = C - A = M + N - A.$ (2)

As $M = (A^2 - R^2 \sin^2\theta)^{1/2}; N = R\cos\theta$ (3)

$W = (A^2 - R^2 \sin^2\theta)^{1/2} + R\cos\theta - A$ (4)

Each individual wind observation can be reduced to a wind aid for any flight path and aircraft speed. These individual wind aids can then be grouped into class intervals, tabulated, and if desired, used to produce graphic presentations of the distributed wind aid.

6. Graphical Wind Aid Computation

A base chart of aircraft velocities may be prepared and the effect of a single wind vector be found for any aircraft flight path and aircraft speed. Such a chart, as illustrated in Figure 2, consists of concentric circles marked with aircraft speeds in any desired speed units. Here, a N-E course has been selected.

Now, the origin of any wind vector may be placed on the selected aircraft speed circle so that the head of the wind vector lies on the desired track. The aid is then read as the difference between the position of the speed circle and the head of the wind vector on the flight path.

Just as with equation (4), the effect of individual winds may be obtained. Either of these two procedures may be used in planning a single flight on a particular day if the wind has been forecast. However, it is the stated purpose of this paper to work from wind roses for long-term planning.

7. Wind Roses

Many types of Wind Roses can be used to obtain wind aid. Some of these are quite limited. For example, a wind rose displaying mean values will provide only average values of wind aid.

There are two wind roses which are relatively new in concept and which exhibit the greatest potential. These are:

i. The Contingency Wind Rose, and

ii. The Standard Vector Deviation Wind Rose

The first uses the observed distribution of the winds while the second uses statistical parameters derived from the wind distribution. Due to time limitation, only the second type will be used in this presentation and it will be referred to as an SVD Wind Rose.

A. Standard Vector Deviation (SVD) Wind Rose

Although the application of the circular normal distribution to winds is covered in the reference papers, a short resume is given in the addendum.

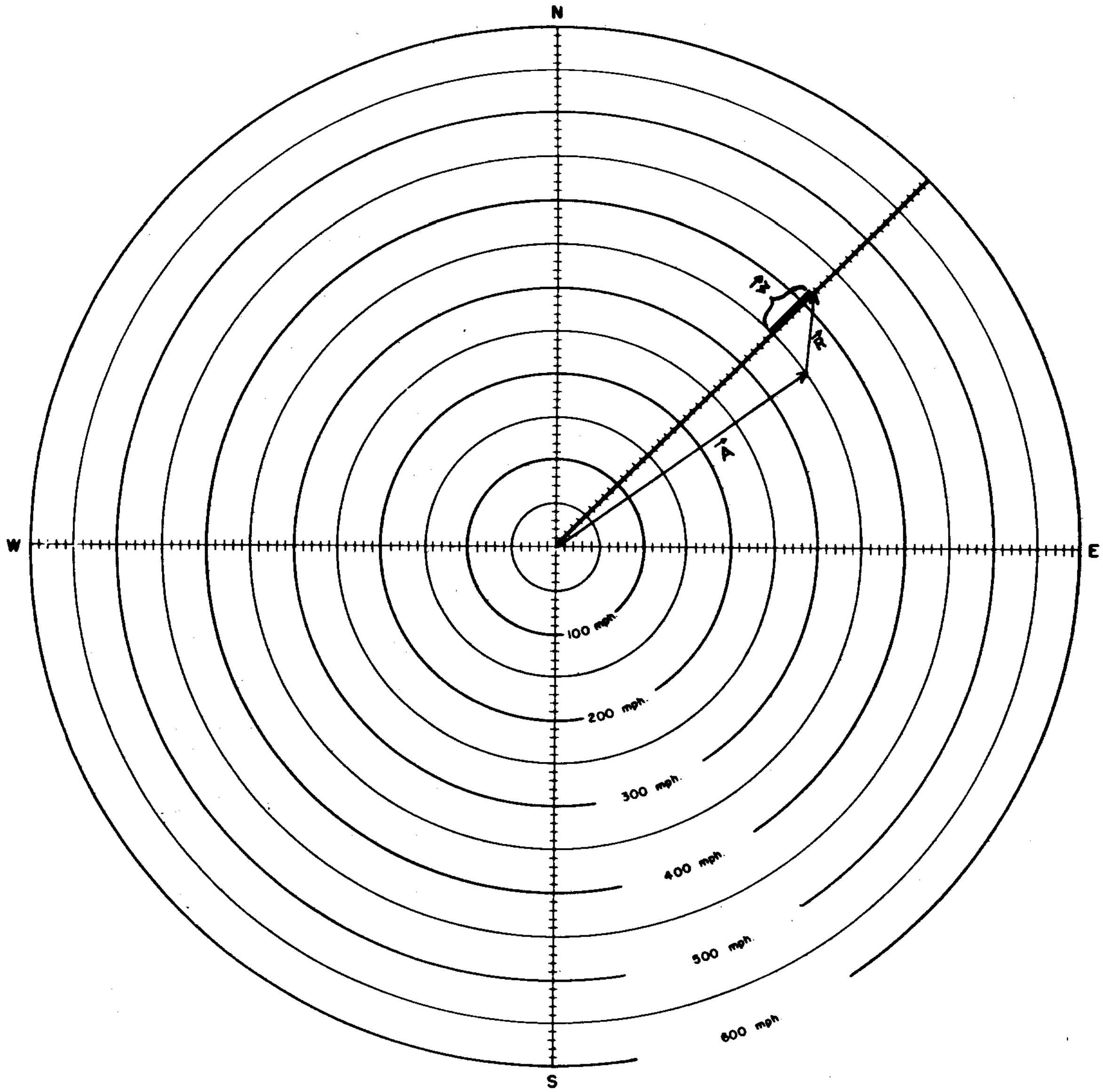


FIG. 2 BASE CHART OF AIRCRAFT VELOCITIES WITH ONE ILLUSTRATED CASE OF WIND AID.

$\vec{A}$ = AIRCRAFT HEADING AND SPEED.

$\vec{R}$ = WIND VELOCITY VECTOR.

$\vec{W}$ = AID (POSITIVE).

Construction of SVD Wind Rose

Two parameters are needed to construct this wind aid rose; the vector mean wind, $\vec{\bar{V}}$, and the Standard Vector Deviation, denoted here as $\sigma_{\vec{V}}$. The concept of $\sigma_{\vec{V}}$ is well known. The $\sigma_{\vec{V}}$ has magnitude only and may be defined as follows:

$$\sigma_{\vec{V}} = \sqrt{\frac{\Sigma V^2}{n} - |\vec{\bar{V}}|^2} \qquad (5)$$

which is analogous to

$$\sigma = \sqrt{\frac{\Sigma V^2}{n} - \bar{V}^2} \qquad (6)$$

where

$\sigma_{\vec{V}}$ is the standard vector deviation,

σ is the standard deviation of wind speeds,

n is the number of observations,

ΣV^2 is the sum of the squares of the speeds,

$|\vec{\bar{V}}|$ is the magnitude of the vector mean wind, and

$\bar{V}$ is the scalar mean wind.

To use the graphical method, the wind roses must be in transparent overlay form which will be placed over the base, previously described.

On a transparent overlay sheet inscribe two axes which are mutually perpendicular and mark them with the points of the compass, N, E, S, and W. To facilitate the extraction of wind aid data, the intersection of the axes is used as the origin of the wind vector, with the vector mean wind extending in the direction toward which the wind blows. The scale used on the overlay must be the same as the base. Circles centered at the head of this vector will intercept or cut off certain percentages of the wind aid distributed along any flight path. The wind aid is distributed in the linear, not circular, sense. Therefore, the radius of a circle which will intercept 68% of the wind aid will have a magnitude of 0.707 $\sigma_{\vec{V}}$.

Table 1a gives the radii of circles which cut off specified portions of the distributed wind aid.

Table 1a. RADII OF CIRCLES WHICH INTERCEPT SPECIFIED PORTIONS OF DISTRIBUTED WIND AID

	Percent of Observations					
	25	50	75	90	95	99
Radius of Circle	$0.23\,\sigma_{\vec{v}}$	$0.47\,\sigma_{\vec{v}}$	$0.81\,\sigma_{\vec{v}}$	$1.17\,\sigma_{\vec{v}}$	$1.39\,\sigma_{\vec{v}}$	$1.98\,\sigma_{\vec{v}}$

However, if the distributions are elliptical, then the standard deviations along the major and minor axes must be obtained or estimates of these must be made. Either axis may lie along the vector mean wind. Here, σ_a & σ_b are the standard deviations along the major and minor axes, respectively. If the major and minor axes are to be estimated from plotted distribution, then the relation of $\sigma_{\vec{v}}^2 = \sigma_a^2 + \sigma_b^2$, must hold.

Table 1b gives the magnitude of the vector radii of the ellipses which will cut off specified portions of the distributed wind aid.

Table 1b. VECTOR RADII OF ELLIPSES WHICH INTERCEPT SPECIFIED PORTIONS OF DISTRIBUTED WIND AID

	Percent of Observations					
	25	50	75	90	95	99
Major & Minor Vector Radii	$0.32\begin{cases}\sigma_a\\ \sigma_b\end{cases}$	$0.67\begin{cases}\sigma_a\\ \sigma_b\end{cases}$	$1.15\begin{cases}\sigma_a\\ \sigma_b\end{cases}$	$1.65\begin{cases}\sigma_a\\ \sigma_b\end{cases}$	$1.96\begin{cases}\sigma_a\\ \sigma_b\end{cases}$	$2.57\begin{cases}\sigma_a\\ \sigma_b\end{cases}$

Figure 3 shows a Standard Vector Deviation Wind Aid Rose. Here $\vec{\bar{V}}$ is 285° and 108 mph, while $\sigma_{\vec{v}}$ is 64 mph.

Figure 4 shows the placement of this rose on a base of aircraft velocities. The scales of rose and base are the same.

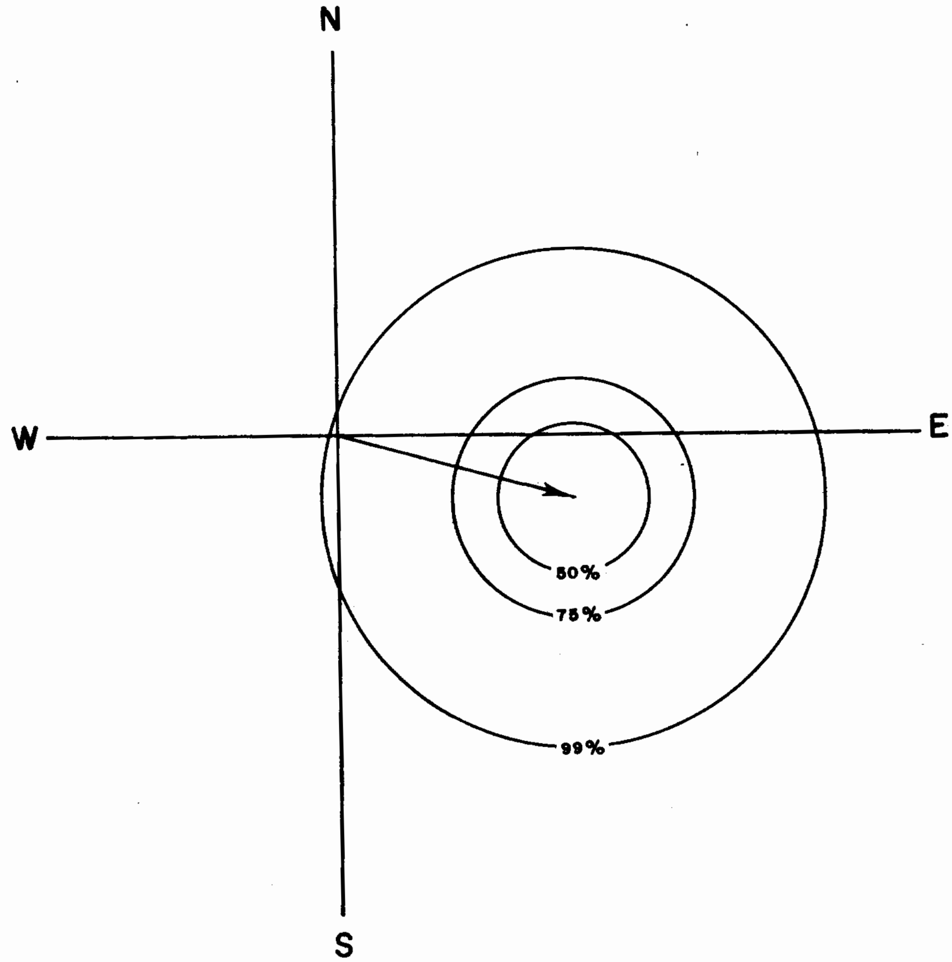


FIG. 3 STANDARD VECTOR DEVIATION WIND ROSE

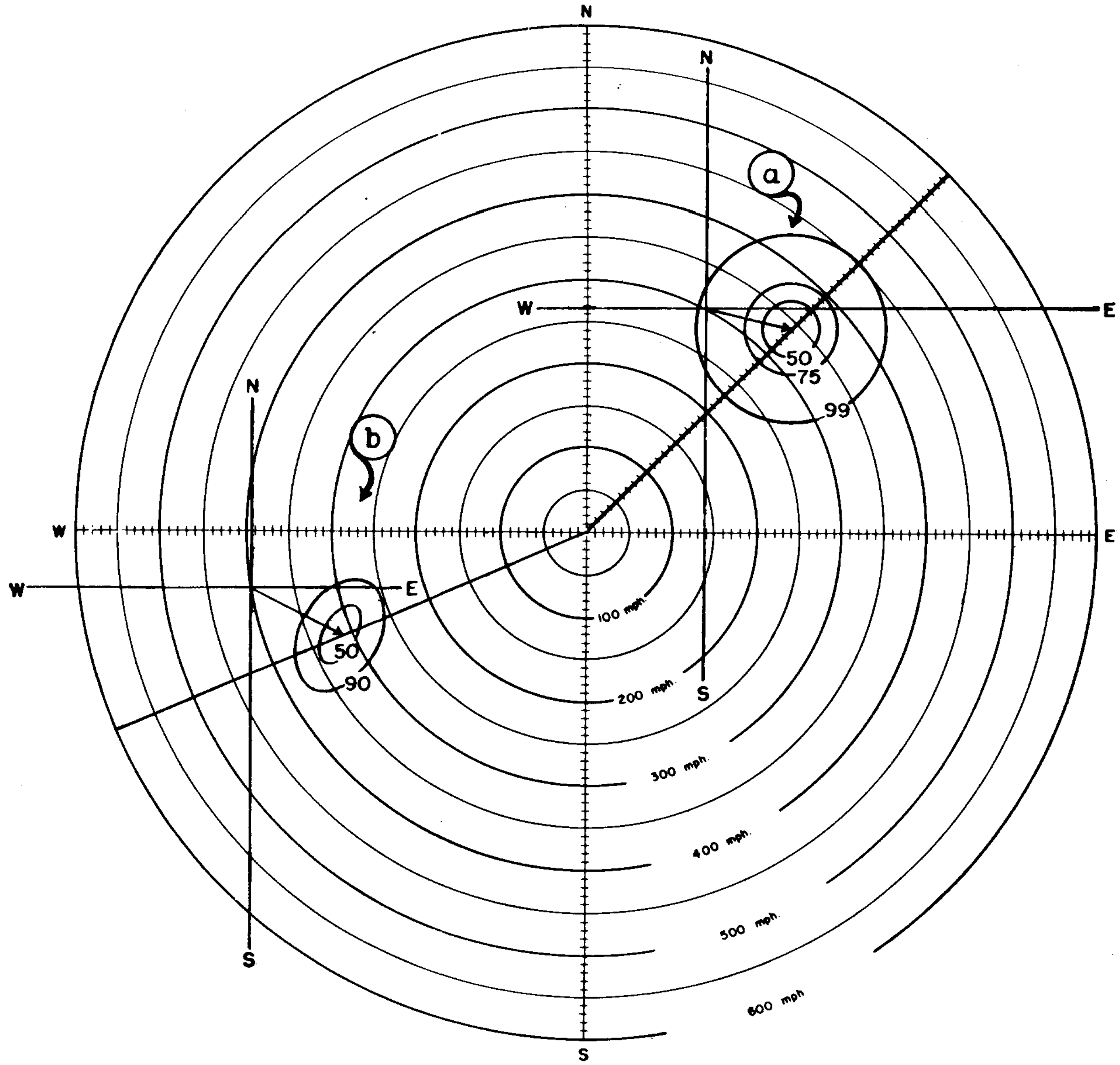


FIG. 4 Standard Vector Deviation Wind Roses

a. Illustrating Circular Distribution

b. Illustrating Elliptical Distribution

For the circular distribution shown, an aircraft speed of 300 mph and a flight path of 45° N-E was also selected. The overlay was placed on the base chart and the corresponding axes of the two charts were kept parallel. The head of the vector mean wind is the center of the concentric circles. The head of the vector mean wind was kept on the selected flight path N-E and the overlay was moved until the origin of the vector mean wind fell on the circle of the selected aircraft speed. The percentage of aid, positive outward from this circle, negative inward, was then read on the flight path as the differences between the aircraft speed and the intersection of the circles and the flight path. The aid was as follows:

> The mean wind aid was 40 mph. Centered at 40 mph, 50% of the wind aid extended from 8 to 72 mph; 75% of the aid extended from -14 to 94 mph; and 99% of the aid extended from -70 to 150 mph. It will be noted that mean wind aid could be obtained by use of the vector mean wind.

Also shown in Figure 4 is a schematic illustration of an elliptical distribution.

8. Results

A. Experimental Results

Nashville, Tennessee, data for one season for five years and one pressure surface were used to obtain the wind aid for only one flight path and aircraft speed. Individual wind observations were used to compute wind aid by equation (4). Obtained values from an SVD Wind Aid Rose were made from the computed parameters $\vec{\bar{V}}$ and $\sigma_{\vec{V}}$.

Table 2 shows the cumulative percentage frequency distributions of wind aid through both computing and graphical methods.

Table 2 WIND AID AT NASHVILLE, TENNESSEE

Dec.-Feb., 1947-52, 300 Millibars, Aircraft Speed 500 mph, Flight Path 090° (E), 452 Obs., 1500 GMT

Class Intervals mph	-20 - 1	- 0 +19	20 39	40 59	60 79	80 99	100 119	120 139	140 159	160 179	180 199
Computed Equation (4)	0.4	1.9	11.3	26.1	44.7	69.2	85.4	95.1	98.0	99.6	100.0
S.V.D. Wind Rose	1.0	3.0	10.0	24.0	43.0	65.0	83.0	94.0	98.0	99.5	100.0
Difference	- 0.6	- 1.1	+1.3	+2.1	+1.7	+4.2	+2.4	+ 1.1	+ 0.0	+ 0.1	+ 0.0

It is noted, that in general the differences are less than 2%, although one does reach 4%. Graphic presentation of the results are shown in Figure 5. The line represents the values obtained through use of the SVD Rose. The computed values are shown as triangles. As it represents only one case, further tests were made to substantiate the above results.

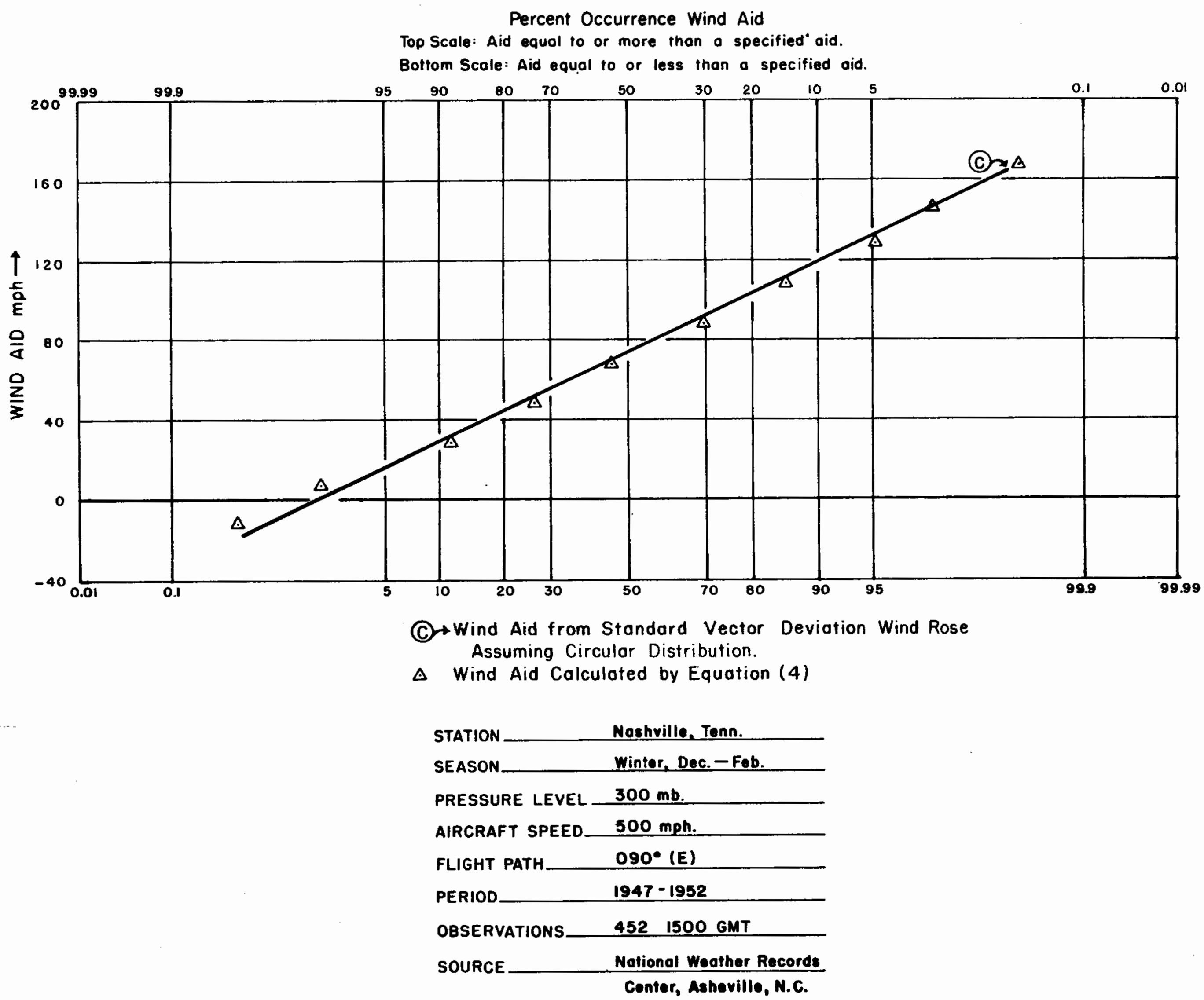


FIG. 5 WIND AID AT NASHVILLE, TENN.

B. Test Results

Forty points were selected over the Pacific, North American continent and the Atlantic. Various levels, seasons and aircraft speeds were used.

The statistical parameters σ_a and σ_b and $\vec{V}$ were computed for the Pacific stations. For the Atlantic stations, the parameters were extracted from charts given in Brooks'[10] paper, "Upper Winds Over the World". Because the wind rose at Bordeaux, France, definitely appeared elliptical, an estimation by eye was made as to the ratio of the major and minor axes and the value of σ_a & σ_b was adjusted so that $\sigma_{\vec{V}}^2 = \sigma_a^2 + \sigma_b^2$. The necessary wind roses were constructed, and two were used as they appear in Figures 6 and 7.

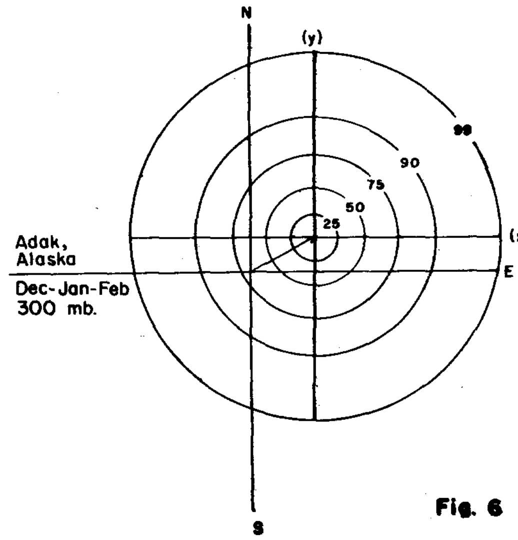


Fig. 6

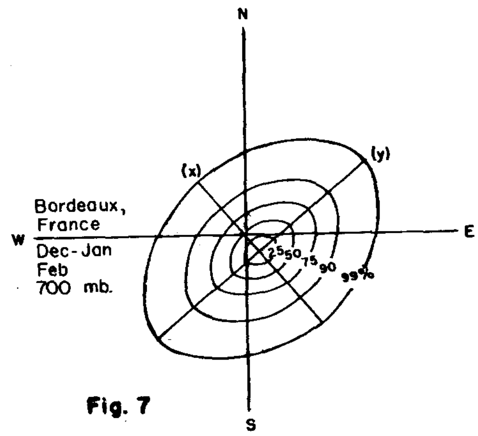


Fig. 7

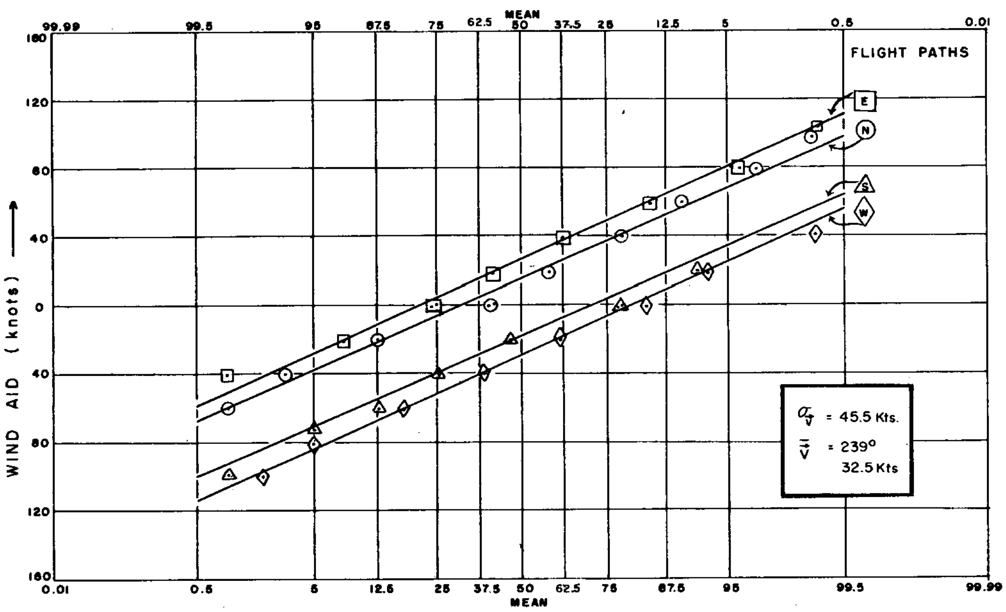
Figures 8 and 9 graphically present, on arithmetic probability paper, the results obtained by use of the two wind aid roses. These are shown by the straight lines, and each distribution for a flight path is labeled; N is for a 360° course, E is for a 090° course, etc.

Superimposed on these lines of Figures 8 and 9 are computed values obtained from the publication, "Wind Aid and Retard"[12]. The agreement is good.

9. Conclusions

The need for wind aid factors is, at times, so urgent that there is insufficient time to effect the required calculations. A quick approximation at the moment may be more valuable than a computed value, a month later. In this case, graphical methods which utilize wind roses may be used to provide acceptable estimates of the required wind aid.

Percent Occurrence Wind Aid
Top Scale: Aid equal to or more than a specified aid.
Bottom Scale: Aid equal to or less than a specified aid.



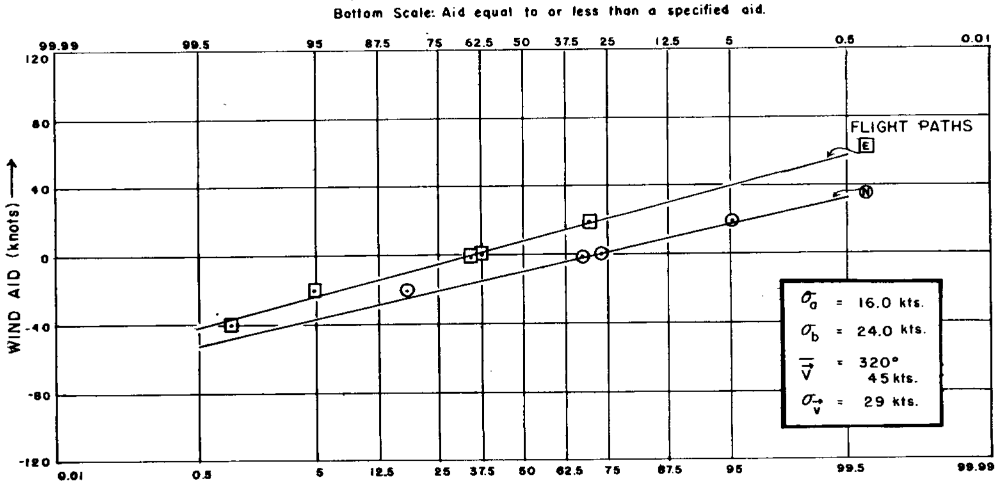
Lines are derived from Standard Vector Deviation Wind Rose.

Points are extracted from Tabulated Wind Aid Values.

STATION Adak, Alaska (Sta 90) PERIOD 1948 - 1953 PRESSURE LEVEL 300 mb.
SEASON Winter, (I) Dec., Jan., Feb. OBSERVATIONS 448 AIRCRAFT SPEED 300 kts.

Fig. 8

Percent Occurrence Wind Aid
Top Scale: Aid equal to or more than a specified aid.
Bottom Scale: Aid equal to or less than a specified aid.



Lines are derived from Standard Vector Deviation Wind Rose.

Points are extracted from Tabulated Wind Aid Values.

STATION Bordeaux, France (144) PERIOD 1948 - 1953 PRESSURE LEVEL 100 mb.
SEASON Winter (I) Dec., Jan., Feb. OBSERVATIONS 452 AIRCRAFT SPEED 300 kts.

Fig. 9

ADDENDUM

Distribution of Atmospheric Winds

Normal circular distribution of winds necessarily implies that sets of upper air winds are homogeneous. Sets of winds which are not homogeneous may be produced by combinations of seasons with different characteristics. Regions near the boundaries of air masses with their different densities and air streams as well as the space near the upper limits of monsoon and trade wind circulations will also have a tendency to produce sets which are not homogeneous. Such distributions will tend to be elliptical. A wind distribution which appears to be elliptical though, may have come from a parent population which is circular.

In making the assumption of circular normal distribution, the mean may be represented by a vector, $\overline{\vec{V}}$, and a standard vector deviation, denoted here as $\sigma_{\vec{V}}$. According to Brooks, this is a standard length taken as a measure of dispersion in all directions about the head of the vector mean in the same way that the standard deviation of a scalar quantity is a standard length taken as a measure of dispersion along a line about a scalar mean. It may be represented by a circle about the head of the vector mean equal to the magnitude of the standard vector deviation, $\sigma_{\vec{V}}$. It has magnitude, but not direction. Figure 10, modified after Hesselberg[5], schematically illustrates this idea.

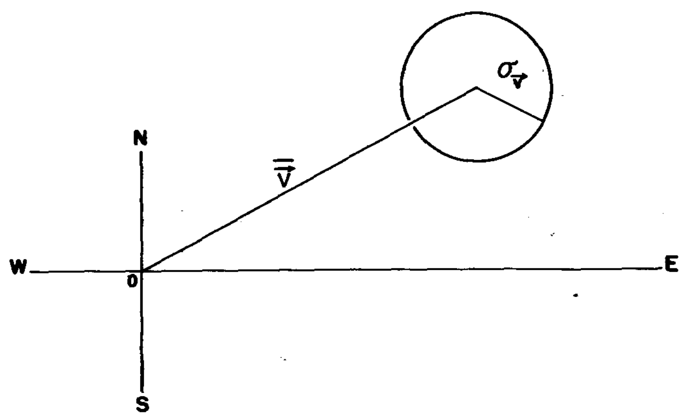


FIG. 10 Mean Vector Wind and Standard Vector Deviation.

The standard vector deviation, $\sigma_{\vec{v}}$, may be defined as follows: $\sigma_{\vec{v}} = \sqrt{\frac{\Sigma v^2}{n} - |\bar{\vec{v}}|^2}$

which is analogous to $\sigma = \sqrt{\frac{\Sigma v^2}{n} - \bar{v}^2}$

where,

$\sigma_{\vec{v}}$ is the standard vector deviation,

σ is the standard deviation of wind speeds,

n is the number of observations,

Σv^2 is the sum of the squares of the speeds,

$|\bar{\vec{v}}|$ is the magnitude of the vector mean wind, and

$\bar{v}$ is the scalar mean wind.

Under the assumption of the circular normal distribution, this circle and other circles, in terms of $\sigma_{\vec{v}}$, enclose certain percentages of the head of all wind vectors plotted from a common origin. These radii can be determined by use of the following equation which is derived from probability function of the bivariate distribution,

$$r = \sigma_{\vec{v}} \sqrt{\ln_e \frac{1}{1-P}} \qquad (7)$$

where

r is the desired radius, and

p is the desired percentage.

Where it is suspected that a particular distribution is not circular, then the standard deviations of the wind components must be obtained along the major and minor axes of the ellipse. Either axis may be along the vector mean wind. The semi-axes of the ellipse which encompasses a certain percentage of the distribution then may be determined by the use of the following equation:

$$r = \sigma_a \sqrt{2 \ln_e \frac{1}{1-P}} \qquad (8a)$$

$$r = \sigma_b \sqrt{2 \ln_e \frac{1}{1-P}} \qquad (8b)$$

where a is the major axis.

In the extraction of wind aid along a selected flight path by means of the parameters $\bar{\vec{V}}$ and $\sigma_{\vec{V}}$, we are not interested in the distribution of the heads of the individual or group of winds. We need the distribution along a selected flight path of the components of the vector differences between the individual winds and the vector mean wind. These differences are centered at the head of the vector mean wind and are distributed in a linear sense along the selected flight path. In this case, the circle centered at the head of the vector mean wind and with a radius of 0.707 $\sigma_{\vec{V}}$, will cut off approximately 68% of the wind aid along a linear flight path. Linear distribution percentages, rather than those of the circular normal distribution, therefore will be used to obtain wind aid. Circles will be used to facilitate the extraction of wind aid along any flight path. The rose thus obtained is a modification of the SVD Wind Rose.

Construction and use of the modified wind rose for wind aid is described in the foregoing paper.

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