# THE USE OF A JET STREAM NOMOGRAM

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Abstract: In an attempt to determine the horizontal structure of the jet stream the U.S. Navy undertook a series of aircraft traverses at 30,000 feet pressure altitude. The results were published by Riehl, Berry and Maynard (1955) who constructed a typical wind velocity profile through a jet core and suggested two empirical equations likely to give a good fit for any jet stream. The graphical solutions of these equations were sketched by Mr. R.H. Clarke, formerly of Central Analysis Office, Bureau of Meteorology, as a nomogram, by which the velocity and position of the jet maximum could be obtained, given a suitable traverse of the jet from a wind on the cold side to a wind on the warm side.

The nomogram and its method of use are described here together with results of its application, and some interim comments on its value in routine analysis.

## 1. INTRODUCTION

In an endeavour to determine the horizontal wind structure of jet streams a series of aircraft traverses at 30,000 feet pressure altitude was undertaken during 1952-1953 by aircraft of the U.S. Navy. The results of these flights were published by Riehl, Berry and Maynard (1955).

By considering profiles of absolute vorticity and wind speed, as calculated from flight results, it was deduced as an empirical result that:

1. The absolute vorticity is discontinuous at the jet stream axis so that wind and vorticity distributions can be discussed separately on the warm and cold sides of the axis.

2. The wind distribution on the warm side of the jet can be represented by a set of individual curves, and on the cold side by a single curve.

In a natural $(s, n)$ coordinate system with the $s$ axis pointing downstream and $n$ axis perpendicular to it and to the right of the wind (southern hemisphere), the absolute vorticity is

$$\zeta = f + k_s V - \frac{\partial V}{\partial n}$$

where $f = 2\omega \sin\varphi$ = Corioli's parameter

$V$ = horizontal wind speed

$k_s$ = streamline curvature assumed as (20 deg. latitude)$^{-1}$ at 300 mb, this being the largest value observed.

On the warm side of the jet stream the result was obtained: $\zeta = 0.1 \times 10^{-4}$ sec$^{-1}$ as the best fit over a distance of 300 to 400 km, obtained by graphing flight results. (Absolute vorticity against distance from the jet axis).

On the cold side an obvious association was noted between high wind speed and high vorticity which was verified by a scatter diagram of these two quantities. Hence the wind distribution on the cold side was excellently fitted by

$$\zeta / V = k$$

where $k$ has the value (150 km)$^{-1}$.

Solved graphically for $V$ this may be represented by a single curve.

We can thus represent the wind field on the cold side by a single curve and that on the warm side by a set of individual curves. The two relations

$\zeta = kV$ and $\zeta$ = 0.1 or 0.2 ($\zeta$ measured in $10^{-4}$ sec$^{-1}$) will always give

(1) a complete wind distribution

(2) the position and intensity of the jet centre given two reliable winds on the outskirts of the jet stream and on opposite sides of the maximum. The data considered of course must be close to the horizontal plane of the jet maximum.

By assuming straight flow the graphical solution of these equations was drawn by Mr. R.H. Clarke as a nomogram which has been under test in Central Analysis Office. The test has not been long enough for conclusive results but the results of one month of application together with some comments are included here.

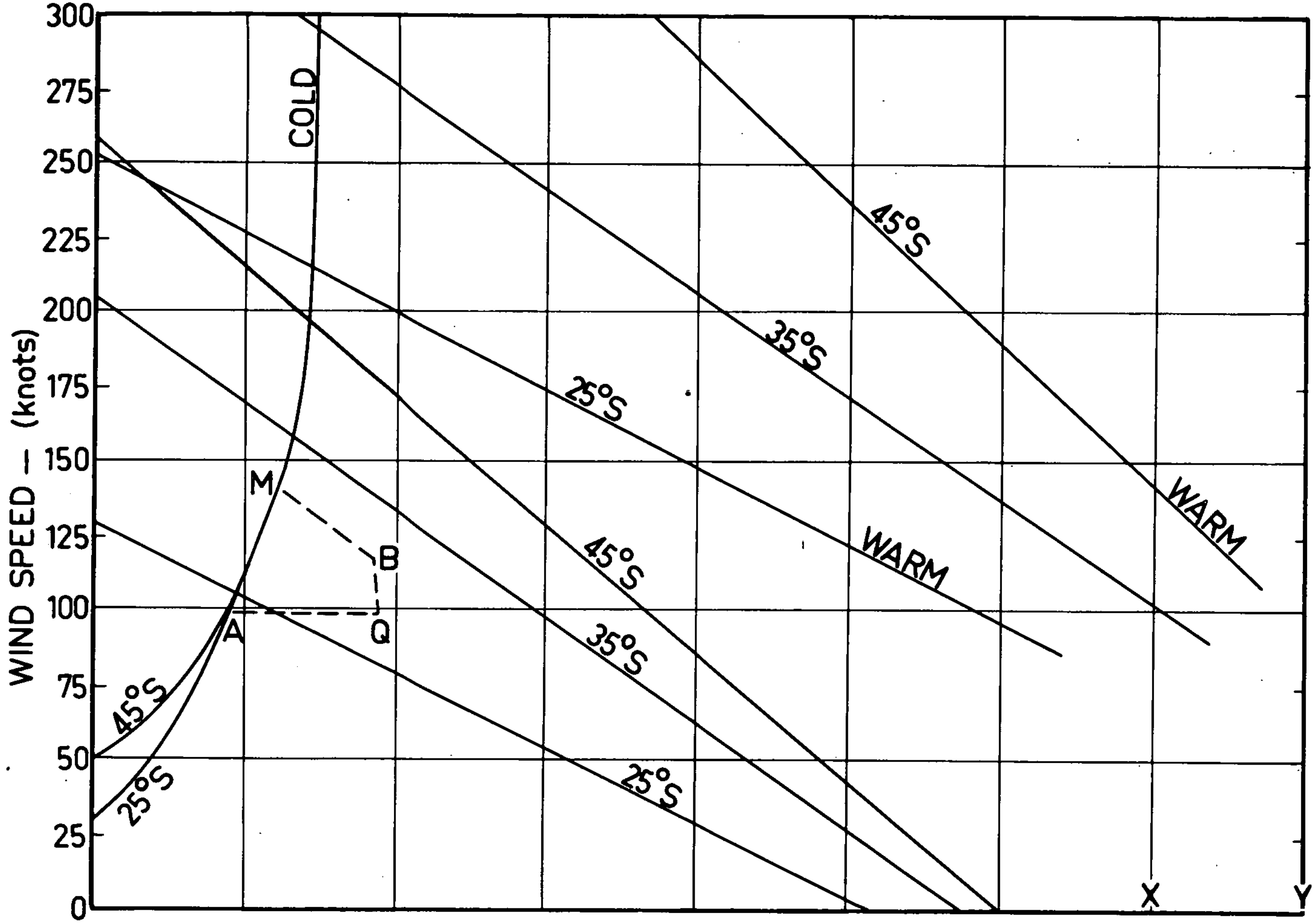
The nomogram as shown in Figure 1 has wind velocity (knots) as ordinate, distance in intervals of 30 nautical miles along the abscissa, and is designed for use with a map scale of 1 in 20 million.

The curve at left of Figure 1 represents the solution of $\zeta = kV$ for 45°S and for 25°S whilst the straight lines represent the solution of $\zeta = 0.1$ for 25°S, 35°S and 45°S, assuming straight flow for both solutions.

Consider two winds of 100 and 120 knots on the outskirts of the jet stream at points A (on the cold side) and B (on the warm side) respectively such that AB is 300 nautical miles, approximately perpendicular to the jet stream, and B is at, say, 37°S. Find the point A on the cold curve representing a velocity 100 knots. Step off the distance AQ = 300 nautical miles horizontally and then proceed vertically to the point B representing a velocity 120 knots, distant 300 miles from A. From B proceed along BM parallel to the warm curve for 35°S meeting the cold curve at M. The value represented by M on the vertical scale is the estimated jet maximum (140 knots) and its position is given by the horizontal displacement from A to M (110 nautical miles north of point A) on the scale of a 1 in 20 x $10^6$ chart.

## 2. DISCUSSION OF DATA

The nomogram was applied to 200 mb charts from 21 May to 30 June, 1957. During this period 40 maxima were suitable for test and 32 were unsuitable, since strategically placed winds were not available. The following conditions must be satisfied before the nomogram can be used.




DISTANCE
(for use with scale 1 in 20,000,000. XY = 5° Latitude = 300 nautical miles)

Fig 1. Nomogram for jet stream maximum.

1. The two winds must be placed on the outskirts of the jet, on opposite sides of it so that the line joining them is approximately perpendicular to the wind flow.

2. The observations should fall within a layer of limited thickness near the level of the strongest wind.

3. The jet maximum should be south of 25°S.

4. The wind flow should be approximately straight. Examination of two months' charts suggested that about half the jet maxima observed could be tested by the nomogram.

For the 40 cases considered the wind maximum by nomogram was obtained, also the best possible maximum from the wind data, history and continuity and for comparison the geostrophic wind $V_g$. The few cases attempted north of 25°S gave unreasonable results. The result of the test can be expressed:

Jet maximum (mean) by nomogram = 1.4 $V_g$

Jet maximum (mean) by ordinary methods = 1.2 $V_g$

On only three occasions was a higher maximum obtained by ordinary methods than by the nomogram.

## 3. SUMMARY OF RESULTS

The results at this stage indicate that the nomogram may be a useful aid on slightly less than half of the possible observed maxima provided the user is well aware of the conditions under which it can be applied.

The results of 40 cases suggest one or more of the following possibilities may apply:

1. The 200 mb constant pressure level may not be close enough to the level of strongest wind. This could be investigated.

2. The nomogram may tend to over-estimate the value of the maximum.

3. The daily constant pressure analyses may under-estimate the maximum wind speed.

## 4. ACKNOWLEDGEMENTS

Acknowledgement is due to Mr. R.H. Clarke, formerly of Central Analysis Office, Bureau of Meteorology, who constructed the profiles from the formulae obtained by Riehl, Berry and Maynard (1955). The appendix of the present paper is adapted from the paper by Riehl, Berry and Maynard, to whom acknowledgement is due.

## REFERENCE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|---|---|---|
| Riehl, H.<br>Berry, F.A.<br>Maynard, H. | 1955 | J. Met., 12, pp 26-35 |


## APPENDIX

(from Riehl, Berry and Maynard 1955)

The absolute vorticity in natural coordinates is

$$\zeta = f + k_s V - \frac{\partial V}{\partial n} \quad (1)$$

where $f$ is the Coriolis parameter (taken as $10^{-4}$ sec$^{-1}$)

$V$ is the horizontal wind speed

$k_s$ is the streamline curvature (taken as the contour radius at 300 mb).

On the warm side of the jet maximum it was found that

$\zeta$ = 0.1 x $10^{-4}$ sec$^{-1}$ over a distance of 300 to 400 km.

$\zeta$ = 0.2 x $10^{-4}$ sec$^{-1}$ for distances greater than 400 km.

Assuming straight flow

$$\frac{\partial V}{\partial n} = f - 0{\cdot}1 \quad (2)$$

which gives $V$ in m sec$^{-1}$ when $n$ is measured in km.

On the cold side of the jet maximum an excellent fit was given by

$$\zeta = Vk \tag{3}$$

From (1) and (3)

$$f + (k_s - k)V - \frac{\partial V}{\partial n} = 0 \tag{4}$$

As the largest value of $k_s$ found was (20 deg. lat)$^{-1}$ and $k$ was found to be (150 km)$^{-1}$, $k_s$ was neglected compared with $k$ to give

$$f - kV - \frac{\partial V}{\partial n} = 0$$

Integrating with constant $f$ and $V = V_0$ when n = o, we have

$$V = \frac{f}{k} + \left(V_0 - \frac{f}{k}\right)e^{-kn} \tag{5}$$

Substituting the values of $f$ and $k$

$$V = 15 + (V_0 - 15)e^{-n/150} \tag{6}$$

Equations (2) and (6) give the curves on the warm and cold sides, respectively, of the jet maximum and form the basis of the nomogram (Fig. 1).