Note in the Eddy Kinetic Energy Distribution in Relation to the Jet Stream

By
Elmar R. Reiter

Prepared in the course of research on upper-level winds under contract ARDS-450 with Federal Aviation Agency

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In a very interesting and well-written paper Kao and Hurley (1962) presented some data on the distribution of mean total and eddy kinetic energy in the vicinity of the jet stream throughout the year. Their findings go very well with results obtained from other studies of the jet stream structure (Reiter, 1961a; 1962).

A few of these jet stream characteristics, which might help to interpret some of the results obtained by Kao and Hurley, shall be pointed out here.

The most significant findings are the northeastward shift of the maxima of mean eddy kinetic energy as compared with the position of the maxima of the mean total kinetic energy. Kao and Hurley try to explain this by considering a jet stream with a sinusoidal meridional wind profile, upon which a standing and a traveling wave are superimposed simultaneously.

On the average, however, jet streams do not show a sinusoidal meridional decay of wind speed. Usually in strong jet streams the horizontal shear on the anticyclonic side exceeds the shear along the cyclonic side.

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This is not evident from Arakawa's (1951) instability criterion (Fig. 1). Actually, much higher shears are observed in nature along the cyclonic side of a jet stream, than are given by the criterion

$$- \frac{\partial u}{\partial y} = \Omega \sin\phi + \frac{2u}{R} \tan \phi \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

which yields by integration

$$u = (u_o + R\Omega\cos \phi_o) \frac{\cos^2\phi}{\cos^2\phi_o} - R\Omega\cos \phi \quad \ldots\ldots\ldots\ldots \quad (2)$$

Riehl, Berry and Maynard (1955) found the empirical relationship

$$u = 15 + (u_o - 15) \cdot e^{-\frac{n}{150}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

for strong jet streams. u is the zonal wind speed, u_o the speed in the jet core, Ω the earth's angular velocity, R the earth's radius, ϕ the geographic latitude, and ϕ_o the latitude of the jet core, and n the distance in km from the jet axis.

Even for weaker jets the cyclonic shear exceeds the anticyclonic one somewhat in magnitude (Reiter 1958; 1962).

On the anticyclonic side, the limiting value

$$\frac{\partial u}{\partial y} = 2\Omega \sin \phi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

is generally realized in strong jets. Integration yields

$$u = u_o + R2\Omega (\cos\phi_o - \cos \phi) \quad \ldots\ldots\ldots\ldots\ldots \quad (5)$$

In a limited region south of the jet axis even small values of negative absolute vorticity may occur at times (Reiter, 1961b; 1961c).

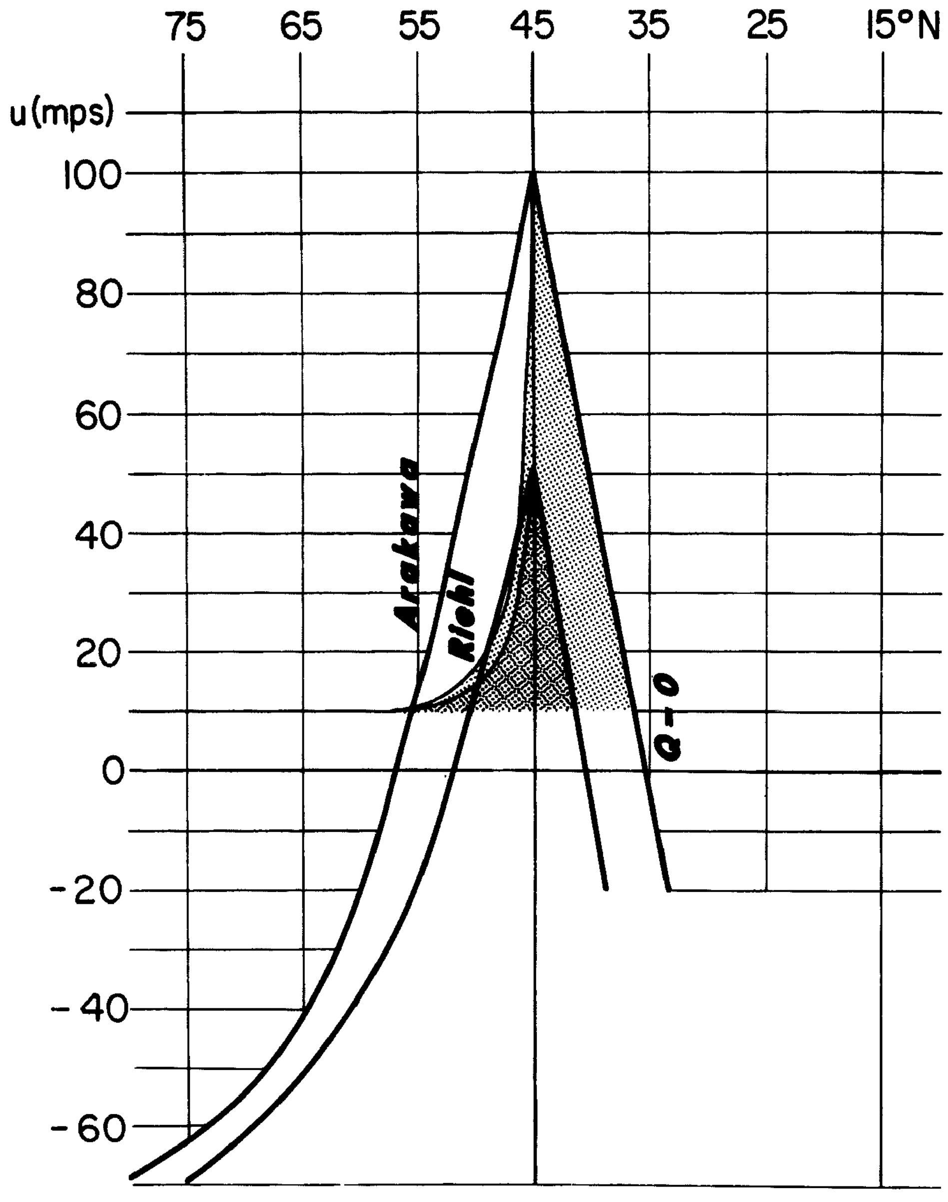

Fig. 1: Hypothetical zonal jet streams at 45°N, with 50 and 100 mps core speeds, respectively. Heavy lines indicate shears on the cyclonic side according to Arakawa (eq. 2), thin lines and shaded areas according to Riehl, et al. (eq. 3). On the anti-cyclonic side shears are given by equation 5.

Davis (1951) pointed out that this asymmetry in horizontal shear conditions is the reason why the mean jet stream position usually appears close to the southern boundary of the belt, within which the jet axes may fluctuate during the period under consideration (Fig. 2). By the same reason the horizontal shears of mean jet streams appear to be less on the cyclonic side than on the anticyclonic side, contrary to what is experienced in individual jet streams (see for instance Petterssen, 1950). This is also evident from the example given in Fig. 2.

This diagram also contains the mean eddy kinetic energy component $\overline{u'^2}$ for the three jet streams used in this example. It turns out that the maximum eddy kinetic energy is located over the northern most of the three jet maxima. Three peaks appear in the distribution, corresponding to the three jet maxima. It may be assumed, however, that with a sufficiently large sample of jet streams spread evenly over the whole latitudinal range, the secondary eddy energy maxima would disappear, and a smooth distribution similar to the one indicated in Fig. 2 would result. The maxima of mean eddy kinetic energy would still be to the north of the maxima of mean total kinetic energy, due to the asymmetry of horizontal shears around the jet stream.

This northward displacement of the eddy kinetic energy maxima which appears in Figs. 1 and 2 of Kao's and Hurley's paper, therefore is mainly due to the term $\overline{u'^2}$. The simultaneous eastward displacement is in all probability caused by the v'-component, and by a wider range of fluctuation of the jet axis. The theoretical example of a standing and a superimposed traveling jet stream wave, considered by Kao and Hurley, may indeed, be helpful to explain some of the observed patterns.

During the winter months a highly persistent jet stream is observed over Eastern Asia and over the Japanese islands. This jet stream is associated with the Indian winter monsoon regime, and it is one of the most stable

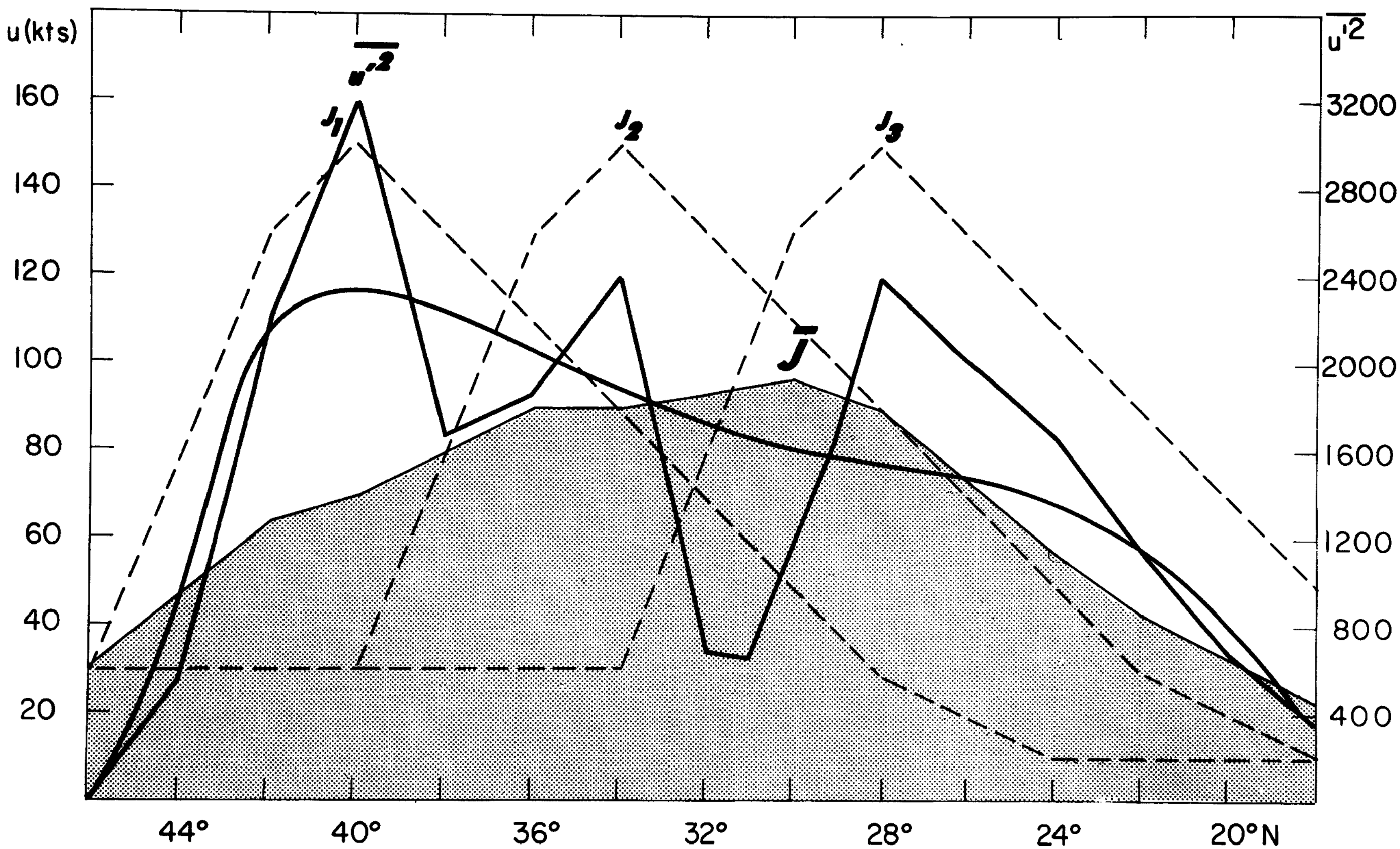

Fig. 2: Averaging of three hypothetical zonal jet streams (J_1, J_2, J_3; dashed lines); the shaded area indicates the mean jet stream, $\overline{J}$; the full jagged line gives twice the mean eddy kinetic energy of these three jet streams and the smooth full line stands for a probable distribution of mean eddy kinetic energy if more cases had been averaged.

phenomena of the general circulation of the atmosphere. The "guiding" influence of the Himalayas (Reiter, 1961a; Reiter and Heuberger, 1960) reaches far downstream into the Western Pacific. The interdiurnal oscillations of the jet axis increases with increasing distance from the mountain range, thus causing a maximum of eddy kinetic energy northeast of the mean jet maximum.

Similar conditions prevail over the Eastern United States, only that the jet stream position here is less stable than over Asia, due to the large north-south extent of the Rocky Mountains. Accordingly, the mean eddy kinetic energy maximum here shows higher values than over the Western Pacific, whereas the mean total kinetic energy of the jet stream is weaker. It might be noted here that such maps as those that have been prepared by Kao and Hurley are of value in flight-route planning, as they give a good indication of the steadiness of the wind regime.

As pointed out by Kao and Hurley, the summer pattern is more diffuse, due to the weaker jet streams and the lack of steering of the current over Southeastern Asia during this season. The separation between the maxima of mean total and mean eddy kinetic energy also is less during summer than during winter, probably due to the fact that in weak jet streams the horizontal shear conditions tend to be more symmetric than in stronger jets (see Fig. 1).

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