

The Meso-structure of Jet Streams*

By ELMAR R. REITER, Department of Meteorology and Geophysics, University of Innsbruck, Austria

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Summary

The evaluation and detailed analysis of "Project Jet Stream" flight data of the 1956-1957 phase reveals a structure in the fields of wind velocity, temperature and divergence with wave lengths in the order of magnitude of 20 to 100 km. This "meso-structure" is rather long-lived and may extend over hundreds of kilometers. Some speculations as to the possibility of soaring in the jet-stream region will be made.

During the 1956-1957 season a number of research flights have been conducted by "Project Jet Stream", using a specially instrumented B-47 E airplane. The flights have mostly been made over the England States and near the Atlantic Seaboard although several cross-country flights to the Pacific coast have also been carried out. While during previous investigations detailed research has been centered on the subtropical jet stream in the Florida region, the present setup of research flights allows a rather thorough study of polar-front jets.

It should be emphasized that the findings from these research flights do not necessarily hold for other regions of the hemisphere as well. The upper-air currents over the United States owe their peculiarities to the presence of the large mountain barrier of the Rocky Mountains. While, for instance, over Europe and the Eastern Atlantic a clear distinction between polar-front and subtropical jet usually is possible (Essenwanger 1953), with the latter one at times assuming a rather stable position along the North African coastline, there are many cases in evidence over North America, where the two jet streams merge, and where a transition from a polar-front jet into a subtropical jet is indicated (Reiter 1960 e, f, g). It would be a highly worth-while undertaking, therefore, to check any conclusions with respect to the macro-structure of jet streams, their behavior in space and time, which can be drawn from "Project Jet Stream" measurements, over other areas of the globe.

The measurements available at present permit not only a statistical treatment in order to obtain a "mean" jet stream (Saucier 1958, Brundidge 1958, Brundidge and Goldman 1958), but by virtue of their high quality they reveal part of the meso-structure of the jet stream, which we define as small fluctuations in windspeed, temperature and derived quantities, having wave lengths of approximately 10^4 to 10^5 m. This would be the order of magnitude required by "jet fingers" (parallel streaks of high velocity separated by velocity minima), by inertia-gravity type waves and by cloud sheets.

During the research flights of "Project Jet Stream" readings of geographical position, pressure altitude, wind speed and direction, and temperature (plus a few additional parameters) are available approximately every 30 seconds. With a true airspeed of about 450 knots this corresponds to a point of measurement nearly every 7 km. If we allow for certain irregularities in the recordings of the instruments, we may accept a trend in the measurements as being real, when it

extends at least over three consecutive points of measurement. Thus, the atmospheric structure may be determined to details larger than 20 km of horizontal distance.

Even when these more or less erratic fluctuations in the instrument readings are disregarded, there is still quite a bit of structural detail left. Fig. 1 shows a set of measurements taken from Flight No. 9, flown on 10 January 1957. This example contains exceptionally large fluctuations both, in temperature and wind speed at two successive levels (indicated by heavy and thin lines, and upright and slant figures, respectively). These fluctuations have been caused by standing waves to the lee of the Alleghenies. Somewhat smaller fluctuations, which are still quite significant, can be detected in the absence of orographic influences. (Reiter 1960b, c, d, e, f, g).

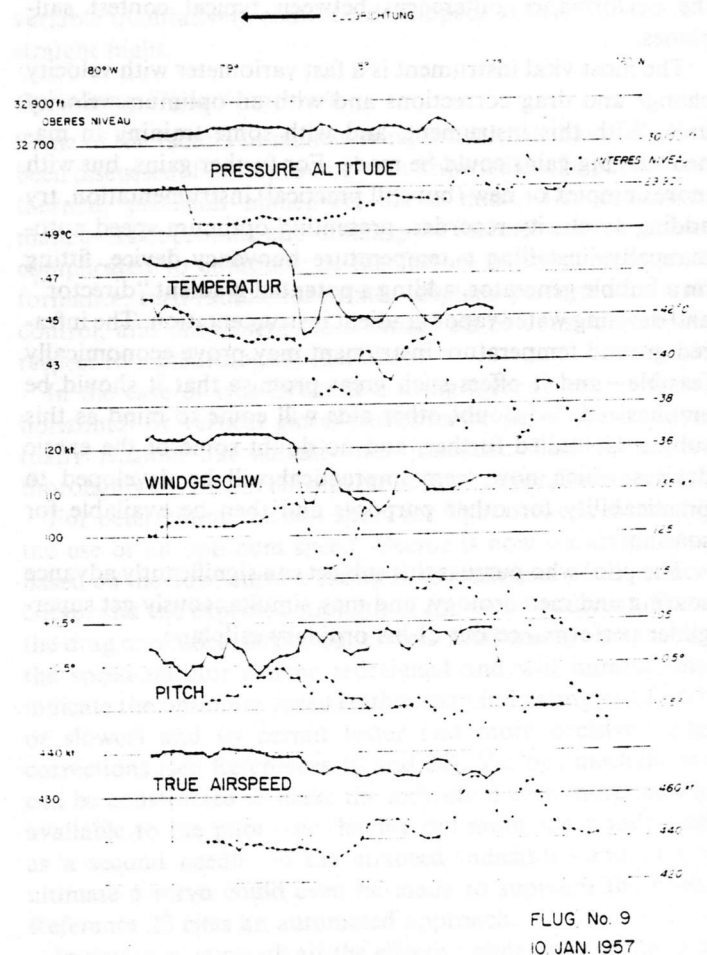


Fig. 1 Measurements of pressure altitude, temperature, wind speed, pitch and true airspeed at two different levels (values for upper level labelled on left-hand side with upright numbers) in nearly the same geographical position over the Alleghenies. (Taken from Flight No. 9, 10 Jan. 1957)

If these fluctuations are smoothed out, too, one arrives at a well defined basic field of motion which is to a large extent free from the contingency of small-scale perturbations. This second smoothing has been carried out graphically, equalizing the areas with positive and negative anomalies in such a fashion, that large-scale trends in horizontal wind-speed and temperature gradients have been preserved. Thus, in the

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example of fig. 5 even the basic field of motion will show a rather significant structural detail in the form of a very strong horizontal wind shear between 34° and 35° N, with rather weak gradients to either side of this area.

The detailed features of the fields of wind and temperature and of derived quantities, which still are retained after the second process of smoothing have to be considered significant, and not produced only by random fluctuations.

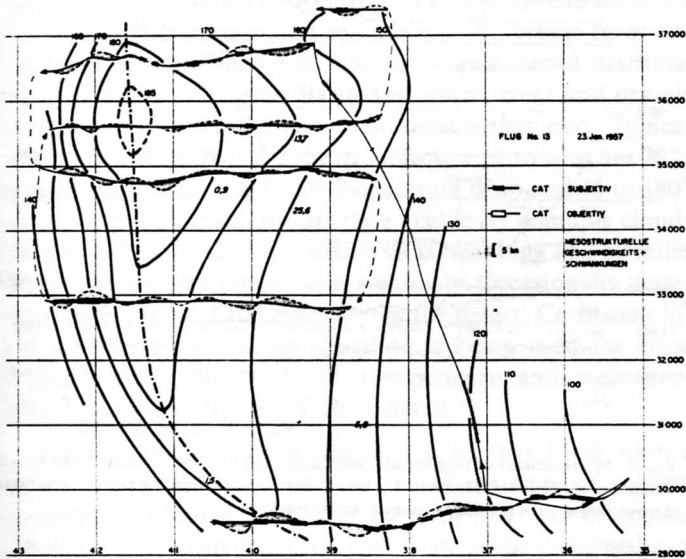


Fig. 2 Double-smoothed field of wind speed, Flight No. 13, 23 Jan. 1957 (heavy solid lines are isotachs in knots), with meso-structure of speed (shaded areas) and clear-air turbulence (CAT) entered along flight route. Jet axis indicated by dash-dotted line

Fig. 2 shows an example of the basic field of motion obtained after the two smoothing processes described above (heavy solid lines = isotachs in knots). The shaded areas which have been entered along the flight route of Flight No. 13 indicate the meso-structure of wind speed (amplitudes in knots can be measured from the flight route serving as base line; the scale of these amplitudes is given in the right-hand part of the diagram), which would have to be added to the analysis of the basic field of motion (solid isotachs) in order to gain the total wind speed as measured by the aircraft. It is evident from this figure, that the meso-structure of the wind field may be rather large in some places.

In fig. 3 an analysis of potential temperature (light solid lines) is shown for the same flight-cross section as in fig. 2, from which the position of the jet axis has been taken, too. From this case, and from all others analyzed so far (Reiter, *op. cit.*) it appears, that below the jet stream core there is a marked stable and baroclinic zone, which is in all probability identical with Endlich's "jet stream front" (Endlich and McLean 1957). Another "jet stream front" with strong negative baroclinicity extends above and to the left of the jet core (not evident in fig. 3). In addition there are stable and baroclinic zones on the anticyclonic side of the jet stream, which have no direct connection with the stratosphere (hatched areas in fig. 3). They are of meso-scalar magnitude inasmuch as they usually do not appear on the smoothed radiosonde-reports from teletype data. They are, however, very markedly present in the aircraft data, even when the two smoothing processes have been executed. They can also be detected from original radiosonde runs (Danielsen 1959).

An additional feature which can be taken from fig. 3, and which has been detected from other flight cross-sections as well, is the "isentropo hump" – an upward bulge of the isen-

tropes slightly to the right of the jet axis (looking downstream), which indicates the presence of differential vertical motion in this area (Reiter 1960 f, g), and which can also be seen from many isobaric charts, especially around the 250-mb level, in the form of a cold pocket to the south of the jet stream. The significance of this cold area lies in the fact, that it is *not* balanced geostrophically. Wind speeds usually still increase with height on the northern slope of this hump. Because of its small diameter (order of magnitude usually less than 1° lat.) this "isentropo hump" probably should be taken as a mesoscale detail of the temperature field near the jet stream core. Nevertheless, it seems to be of some significance in the dynamics of the jet stream.

From the analyses carried out so far it has been evident, that largest amplitudes of meso-structure of wind speed, as well as most cases of clear-air turbulence (in fig. 2 indicated by small marks along the flight route) are located in the immediate vicinity of stable and baroclinic zones (Reiter 1960 a). This fact may be of some significance for turbulence warnings and for evasive measures to be taken in-flight.

The heavy solid lines in fig. 3 show isotachs (knots) of the component of flow *normal* to the direction of flow at the point of maximum wind speed in this cross section. It appears from this figure, that the maxima of this "normal component" (positive for southerly flow) are sandwiched in between the small-scale stable layers mentioned earlier. Thus, these layers assume further significance in the comprehension of the structure of the atmosphere: They separate atmospheric slices with slightly different wind directions, containing slightly different bodies of air from different origin. Apparently it is within these layers that some of the larger-scale mixing processes take place.

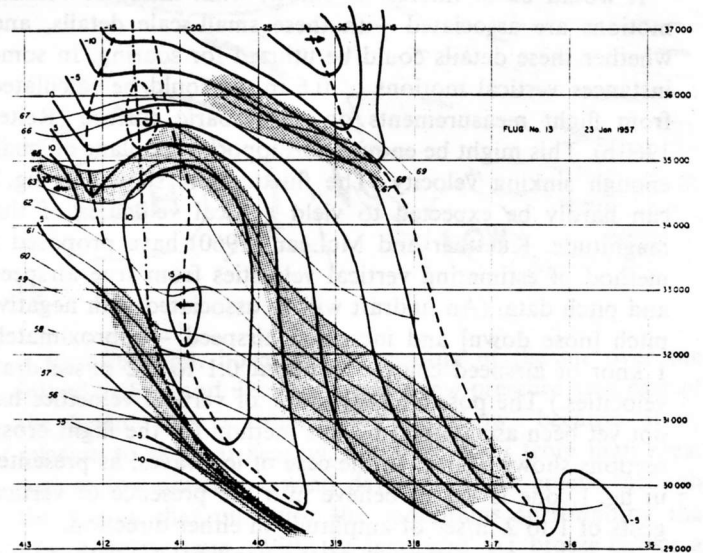


Fig. 3 Potential temperature (light solid lines °C) and "normal component" (explained in text, heavy solid lines = isotachs in knots) for Flight No. 13. Shaded areas indicate stable and baroclinic zones. Jet axis as in fig. 2. Dashed lines stand for maxima and minima of normal component

From the pattern of "normal component" and from isobaric charts one is able to estimate horizontal divergence. Fig. 4 gives a distribution of this quantity. Shaded areas indicate horizontal divergence $D = \partial u / \partial x + \partial v / \partial y$. This diagram shows, that the large-scale distribution of D , which one would expect from radiosonde data only, with divergence to the left and convergence to the right of the jet axis on the leading edge of a jet maximum, has quite a bit of detail superimposed. The slightly divergent area to the anticyclonic

side of the jet axis, for instance, does not follow this cut-and-dried pattern.

Superimposed upon the divergence distribution of fig. 4, we should still expect meso-scalar fluctuations of wave lengths in the order of 50 to 100 km, similar to the ones indicated in fig. 2, and mainly produced by the variations of "normal component". Cloud observations, especially of cirrus bands, confirm this conclusion.

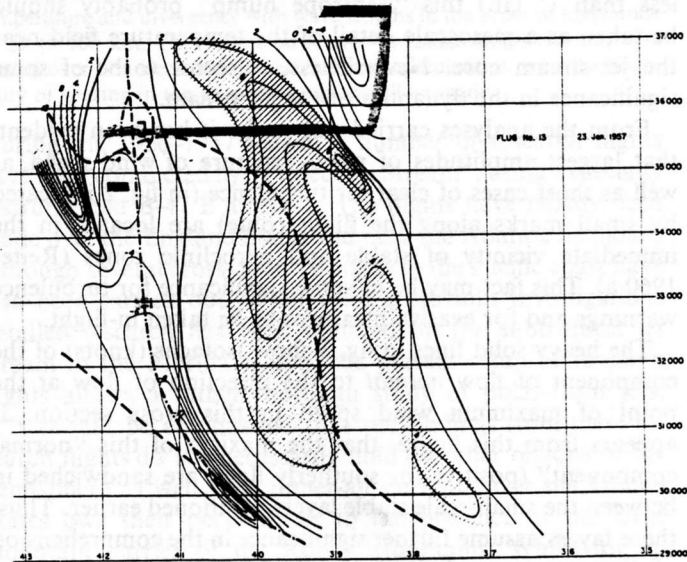


Fig. 4 Evaluation of the term $\partial v/\partial y$ from fig. 3 in units 10^{-5} sec^{-1} . Jet axis as in fig. 2. The dashed line stands for normal component $v = \Phi$. Light shaded areas show horizontal divergence, assuming $\partial u/\partial x$ to be $-3.6 \times 10^{-5} \text{ sec}^{-1}$. The small, densely-shaded area indicates a haze layer, the dotted stripes mark the occurrence of contrails

It would be of interest to know, what kinds of vertical motions are associated with these small-scale details, and whether these details could be utilized for soaring. In some instances vertical motions of 0,6 m/sec could be calculated from flight measurements on an isobaric surface (Reiter 1960 b). This might be enough to support a sailplane of small enough sinking velocity. The fluctuations shown in fig. 2 can hardly be expected to yield vertical velocities of this magnitude. Kuettner and McLean (1960) have proposed a method of estimating vertical velocities from true airspeed and pitch data. (An updraft will be associated with negative pitch [nose down] and increased airspeed – approximately 1 knot of airspeed change to about 0.1 to 0.2 m/sec draft velocities.) The possible magnitude of vertical velocities has not yet been ascertained by this method for the flight cross-sections shown above. In the case of lee waves, as presented in fig. 1, one is led to believe into the presence of vertical gusts of 1 to 2 m/sec of amplitude in either direction.

That the meso-structure of the wind field is rather long-lived can be demonstrated with the aid of fig. 5. It shows an example of measurements from Flight No. 12, 18 Jan. 1957, in the course of which the aircraft passed at nearly the same level and the same position twice, almost one and a half hours apart. From these and from other measurements on isobaric surfaces it appears, that the meso-structural features of the wind field orient themselves along narrow bands parallel to isentropic surfaces, extending at times over several hundreds of kilometers. Therefore one may conclude, that the meso-structure of jet streams as revealed from "Project Jet Stream" data is by no means a "random phenomenon", but it follows a well organized pattern instead, which, at times, may be rather stable in its setup. Further studies and

an understanding of these details may shed some light on the behavior of atmospheric flow and mass exchange at these levels.

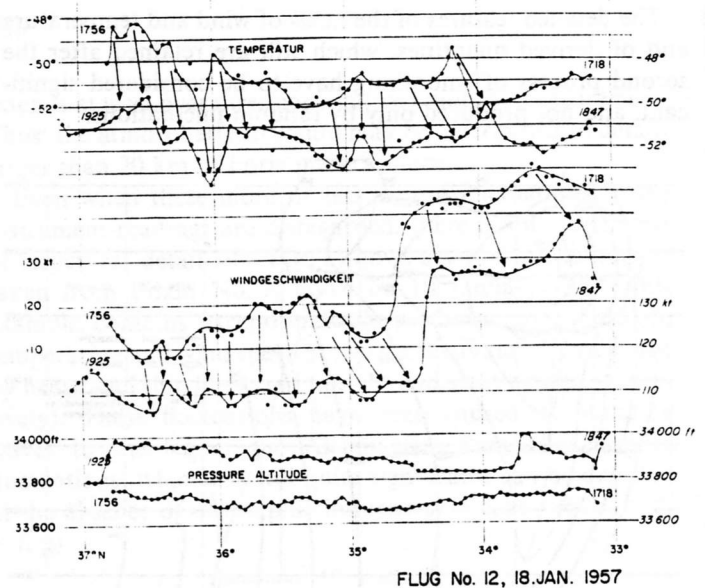


Fig. 5 Measurements of temperature, wind speed and pressure altitude at two runs of Flight No. 12, 18 Jan. 1957, about 1½ hours apart and not differing greatly in altitude. Arrows indicate the continuity of meso-scalar features

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