Meteorology: Atmospheric Jet Streams in the Aerospace Age

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Meteorology

Atmospheric Jet Streams in the Aerospace Age

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An engineer familiar with jet propulsion must consider the term *jet stream* a little strange for an atmospheric current. And, technically, he would be correct. The term implies simply that a given air current carries within it a core of substantially higher-velocity air as compared with the outskirts. Yet to the meteorologist—once accustomed to thinking in terms of currents with uniform speed over 1,000 miles wide—the discovery of high-speed cores, with energy an order of magnitude higher than that of the sluggish wind envelope, was sufficiently startling to produce a dramatic label.

The course of modern meteorology has been guided by this discovery in many ways. Jet streams affect surface weather; the principal cloud and weather systems are associated with it. But it is in problems of aerospace science and technology that the most direct account must be taken of the atmospheric wind concentration. We shall look briefly at a few of these problems.

Multiple Jet Streams

Following first discovery, the concept was proposed of a single dominant jet stream per hemisphere. But observations soon rudely upset this simple picture. It is now clear that jet streams will be encountered simultaneously at various latitudes and altitudes. At this time we have definite knowledge of the following currents:

(1) The middle-latitude jet stream (lat. 35–60): core speed occasionally above 200 knots, mean height 35,000 ft. A westerly current with wavelike meander, often of strong amplitude.

(2) The subtropical jet stream of winter: lat. 25–35, core speeds occasionally approaching 300 knots, mean height 40,000–45,000 ft. Westerly, with three large waves in northern hemisphere.

(3) The tropical easterly jet stream, mainly across Asia at lat. 15N May–October: speeds seldom above 100 knots, mean altitude 50,000 ft. Little or no meander.

(4) The polar night jet stream, roughly around the poles from west at lat. 60–65 in winter: core height at least 75,000 ft, velocities recorded above 200 knots. Strong meanders and asymmetries of position are common with respect to the North Pole. The great altitude of this current has hindered adequate observation. Upper limits of height and speed as yet are uncertain.

Besides these four wind systems, there is fragmentary evidence of jet streams in the mesosphere and higher. With improvement in balloon and rocket techniques of measurement, it should be possible to describe these currents in the next decade, assuming a realistic effort. All supersonic and space vehicles will encounter these high-speed currents; yet information to date is only minimal.

Wind Shear

The name *jet stream* implies the presence of strong wind shear, both across the current and vertically, otherwise the term *core* would have no meaning.

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Quite broadly, most of the energy of a jet stream is contained in a cross section 300 miles wide and 10,000 ft thick. Thus, space vehicles released only 200 miles apart may encounter very different wind structures during ascent. Large shears of the horizontal wind along the vertical may be a problem on one path and not on the other. Shears of 10 knots/1,000 ft frequently are observed, especially above the layer of maximum wind. Such shears on occasion have persisted over vertical distances of 10,000 ft, with notably higher values of maximum shear within the shearing layer. The subtropical jet stream in particular is subject to strong shears. This current, hardly detectable at low levels, may set in suddenly above 30,000 ft. Moreover, strong shears with opposite sign follow each other very quickly across the level of maximum wind, with vertical separation between strong opposite shears as little as 1,000–2,000 ft on occasion.

Flight Planning

Except for a system of completely rigid airways, both vertical and lateral shears of the jet stream are important in planning the flight of vehicles which maintain an altitude or change it only slowly. Many have had the idea that wind would have little importance in jet aircraft operation. In view of the rapid fuel consumption of jets, however, wind has proved to remain a significant factor. Substantial time can be saved in flight planning for the common aviation system with inclusion of the upper winds in flight planning, especially during upstream flights. For subsonic jets, these savings often amount to 10 percent and more of great circle route flight time.

In order that the jet stream structure be a useful input to the Air Traffic Control System, it must be possible to process the information rapidly and present it in a form suitable for airways management. In principle, this problem has been solved with high-speed computers. A method exists for quantitative representation of the winds, measured by balloon ascents, as a function of height using Fourier analysis. Several techniques exist which permit rapid horizontal analysis of the wind field,—notably, fitting by quadratic surfaces. With these tools, the complete wind distribution can be at the disposal of the Air Traffic Control computers within minutes after termination of the balloon runs. About 8 years ago, the concept of the "layer of maximum wind" was proposed as a means of reducing the three-dimensional flight planning problem to two dimensions. At the present juncture, this restriction is of no advantage, since three-dimensional flight planning with current wind observations is feasible.

The quantitative wind analysis also should lead to substantial advances in wind prognosis during the next few years. Forecast experiments, by and large, have proved disappointing. But this author suspects that this was due in part to the fact that both initial and final wind fields were poorly known; hence, the forecaster worked under an unreasonable handicap. The difficulty has been overcome in principle. Therefore, prospects are good that new experiments will deliver much improved techniques for jet stream prediction to the Air Traffic Control System.

Clear-Air Turbulence

The haziest subject of jet stream meteorology is clear-air turbulence, thought to be associated with unstable vertical temperature stratification and/or large wind shear—vertical, horizontal, or both. Therefore, one has looked to the jet stream as the obvious energy source for such turbulence. Indeed, the more severe cases of turbulence occur frequently, though by no means exclusively, near high-speed cores. No actual experiment, however, has been conducted which would describe the precise structure of the atmosphere in the layer with clear-air turbulence. Hence, the mechanisms proposed to account for the turbulence are supported at best by circumstantial evidence, much of which is very weak.

It is not surprising, then, that skepticism regarding the description of clear-air turbulence and its causes remained alive. At least one interesting alternative exists—the turbulence may not be true turbulence. We may postulate gravity waves at an interface marked by stable temperature lapse rate. An aircraft passing along such an interface will experience the sensation of turbulence. Circumstantial evidence does exist in support of this viewpoint. If correct, it follows that the "turbulence" is not restricted to the troposphere, but may occur at any altitude in the stratosphere and beyond, with implications for supersonic flight. Fragmentary reports of encounters with turbulence above the tropopause exist.

In the view of this author, a reasonably conducted experiment is more than overdue. Adequate instrumentation is available; and the experimental design follows readily from the problem. Missing in the past has been sufficient interest in the problem to warrant the expensive operation.

Outlook

Jet streams occur in so many climate belts of the globe and in so many layers of the atmosphere that they must be a parameter for all aerospace users—sometimes perhaps unimportant, sometimes of considerable consequence. With the rapid advance in high-atmospheric measuring techniques, the outlook for definition and description of jet streams with core above the tropopause is favorable. An optimistic forecast also has been offered concerning the utilization of jet streams in flight planning. On the other hand, the author sees no immediate hope of clearing up the muddle about clear-air "turbulence."

A cheerful factor is the interest of Governmental agencies in supporting research on the jet stream with jet aircraft instrumented for meteorological research. Besides the aerospace problems mentioned, we have problems directly in the meteorological domain. For instance, we do not know as yet why high-speed cores form within the atmosphere and how they are maintained. There are practical corollaries of such questions—such as, "Can atomic debris cross jet streams?"

For insight into these problems, the U.S. Navy and Air Force have conducted several jet stream experiments in the last decade. A high mark in interagency cooperation was set during February–March 1962, when the U.S. Weather Bureau's Research Flight Facility and the USN's Weather Research Facility conducted a joint experiment with three aircraft off the eastern coast of the United States. This experiment was designed to produce data suitable for dynamic and energetic computations over a volume containing a portion of a jet stream. It is considered unique in this respect.

Although the number of missions flown must be greatly increased in the future, it is, nevertheless, this type of operation which holds most promise for the solution of jet stream problems and the associated problems of aerospace users.

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