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ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

SUBJECT: RULES OF THUMB FOR AVOIDING OR MINIMIZING ENCOUNTERS WITH CLEAR AIR TURBULENCE

1. PURPOSE. This Advisory Circular is issued to bring to the attention of pilots and other interested personnel, the "Rules of Thumb" for avoiding or minimizing encounters with clear air turbulence (CAT).

2. BACKGROUND.

   a. CAT is officially defined as "all turbulence in the free atmosphere of interest in aerospace operations that is not in or adjacent to visible convective activity (this includes turbulence found in cirrus clouds not in or adjacent to visible convective activity)." This definition was published in the Department of Commerce Report of the National Committee for Clear Air Turbulence dated December 1966.

   b. Turbulence in clear air is especially troublesome because it is encountered unexpectedly without visual evidence to warn pilots. The Meteorological Services know little about the cause of CAT, thus their forecasts are not sufficiently accurate to avoid it at all times.

   c. The National CAT Committee in its report of 1966 stated that the requirement for airborne remote detection should be given the highest consideration; although forecasting for CAT is improving, precise forecasts of the location and time of local patches of CAT do not appear feasible, any more than times and positions of individual small local thunderstorms can be forecast with pinpoint accuracy. For this reason an airborne device is needed to detect and locate CAT sufficiently ahead of the aircraft to permit the pilot to take evasive action or to prepare for penetration. If such a system could be developed, it would permit pilots to avoid areas of significant CAT in the same manner as they now avoid thunderstorms and squall line turbulence with the use of radar. Closely related to the importance of airborne remote detection is the requirement for prediction of

CAT areas so that preparation to avoid them can be made by pilots during the preflight planning stage. (The Report of the National Committee for Clear Air Turbulence dated December 1966 can be obtained from the Superintendent of Documents, U. S. Government Printing Office, price 35 cents.)

d. In November 1969 the Department of Commerce published the Federal Plan for Clear Air Turbulence. The Plan focuses on a serious atmospheric problem that is of concern to the civil and military aviation services. It describes the coordinated efforts of the Departments of Commerce, Defense, and Transportation (FAA) and of the National Aeronautics and Space Administration to solve this mutual problem.

e. Until an airborne detector can be developed and placed in use, pilots are urged to use the "Rules of Thumb For Avoiding or Minimizing Encounters With Clear Air Turbulence" contained in Appendix 1. These guidelines were developed by the International Civil Aviation Organization's (ICAO) Sixth Air-Navigation Conference of April/May 1969. The "Rules of Thumb" were approved by the ICAO Air Navigation Commission and distributed to all countries who are members of the ICAO for dissemination to concerned aviation personnel.

3. RECOMMENDATION. All pilots and other personnel concerned with flight planning should carefully consider the hazards associated with flight through areas where pilot reports or aviation weather forecasts (CAT forecasts) indicate the presence of clear air turbulence including mountain wave turbulence. The "Rules of Thumb" in Appendix 1 are intended to assist all pilots in avoiding potentially hazardous clear air turbulence areas during flight.

Edward C Hodson

Director
Flight Standards Service

APPENDIX 1. RULES OF THUMB TO ASSIST IN AVOIDING OR MINIMIZING ENCOUNTERS WITH CLEAR AIR TURBULENCE.

Note: The following rules of thumb have been developed for westerly jet streams.

1. Jet streams stronger than 110 knots (at the core) are apt to have areas of significant turbulence near them in the sloping tropopause above the core, in the jet stream front below the core, and on the low-pressure side of the core. In these areas there are frequently strong wind shears.

2. Wind shear and its accompanying clear air turbulence in jet streams is more intense above and to the lee of mountain ranges. For this reason, clear air turbulence should be anticipated whenever the flight path traverses a strong jet stream in the vicinity of mountainous terrain.

3. On charts for standard isobaric surfaces, such as 300 millibars, if 20-knot isotachs are spaced closer together than 60 nautical miles, there is sufficient horizontal shear for CAT. This area is normally on the poleward (low-pressure) side of the jet stream axis, but in unusual cases may occur on the equatorial side.

4. Turbulence is also related to vertical shear. From the winds-aloft charts or reports, compute the vertical shear in knots-per-thousand feet. If it is greater than five knots-per-thousand feet, turbulence is likely. Since vertical shear is related to horizontal temperature gradient, the spacing of isotherms on an upper air chart is significant. If the $5^{\circ}C$ isotherms are closer together than two degrees of latitude (120 nautical miles), there is usually sufficient vertical shear for turbulence.

5. Curving jet streams are more apt to have turbulent edges than straight ones, especially jet streams which curve around a deep pressure trough.

6. Wind-shift areas associated with pressure troughs are frequently turbulent. The sharpness of the wind-shift is the important factor. Also, pressure ridge lines sometimes have rough air.

7. In an area where significant clear air turbulence has been reported or is forecast, it is suggested that the pilot adjust the speed to fly at the recommended rough air speed on encountering the first ripple, since the intensity of such turbulence may build up rapidly. In areas where moderate or severe CAT is expected, it is desirable to adjust the air speed prior to the turbulence encounter.

8. If jet stream turbulence is encountered with direct tailwinds or headwinds, a change of flight level or course should be initiated since these turbulent areas are elongated with the wind, and are shallow and narrow.

9. If jet stream turbulence is encountered in a crosswind, it is not so important to change course or flight level since the rough areas are narrow across the wind. However, if it is desired to traverse the clear air turbulence area more quickly, either climb or descend after watching the temperature gauge for a minute or two. If temperature is rising - climb; if temperature is falling - descend. Application of these rules will prevent following the sloping tropopause or frontal surface and staying in the turbulent area. If the temperature remains constant, the flight is probably close to the level of the core, in which case either climb or descend as convenient.

10. If turbulence is encountered in an abrupt wind-shift associated with a sharp pressure trough line, establish a course across the trough rather than parallel to it. A change in flight level is not so likely to alleviate the bumpiness as in jet stream turbulence.

11. If turbulence is expected because of penetration of a sloping tropopause, watch the temperature gauge. The point of coldest temperature along the flight path will be the tropopause penetration. Turbulence will be most pronounced in the temperature-change zone on the stratospheric (upper) side of the sloping tropopause.

12. Both vertical and horizontal wind shear are, of course, greatly intensified in mountain wave conditions. Therefore, when the flight path traverses a mountain wave type of flow, it is desirable to fly at turbulence-penetration speed and avoid flight over areas where the terrain drops abruptly, even though there may be no lenticular clouds to identify the condition.

NOTE: In this country, civil forecasts of areas of clear air turbulence are made by the Weather Bureau and disseminated (1) in Area Forecasts (FA) over teletypewriter Service A every six hours, (2) on High Level Significant Weather facsimile charts available every six hours, and (3) on a non-scheduled basis as In-Flight advisories (AIRMETS and SIGMETS). In-flight advisories are transmitted over Service A when moderate or greater CAT is forecast or when severe or extreme CAT has been reported. These are made available to aircraft over FSS radio, and, in addition, SIGMET Alerts are broadcast by en route traffic controllers.

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wave pattern. There are, in fact, three jetstreams: the polar front jetstream, the subtropical jetstream, and the polar night jetstream. The polar front jetstream as its name implies, is associated with the polar front or the division between the cold polar and warm tropical air masses. The mean latitude of the jetstream core varies from 25° north latitude during the winter months to 42° north latitude during the summer months.

(1) The polar front jetstream is the center of the planetary wave pattern and as such meanders over a large portion of the hemisphere throughout the year, particularly during the winter months when it is most intense. Although the polar front jetstream varies in altitude, the core is most commonly found around 30,000 feet and it is generally best depicted on the 300 millibar constant pressure map.

(2) The subtropical jetstream is a very persistent circumpolar jetstream found on the northern periphery of the tropical latitudes between 20° and 30° north latitude. It normally forms three waves around the globe with crests over the eastern coasts of Asia and North America and the Near East. Like the polar front jetstream, the subtropical jetstream is most active during the winter months and often intrudes well into the southeastern United States. It is generally higher than the polar front jetstream with the core between 35,000 and 45,000 feet.

(3) The polar night jetstream is found in the stratosphere in the vicinity of the Arctic Circle during the winter months and does not have a significant affect on air travel over the United States and southern Canada.

b. CAT associated with a jetstream is most commonly found in the vicinity of the tropopause and upper fronts. The tropopause is actually an upper front separating the troposphere from the stratosphere. Analyses of the tropopause are issued by the National Weather Service on a scheduled basis. In the absence of other information, the tropopause will generally have a temperature of between -55°C. and -65°C. In some cases, it will be at the top of a cirrus cloud layer. Clouds are very seldom found above the tropopause in the dry stratosphere, except in the summertime when occasionally large thunderstorms will poke through the tropopause and spread anvil clouds in the stratosphere. CAT is most frequently found on the poleward side of the jetstream (the left side facing downwind). It is additionally common in the vicinity of a jetstream maxima (an area of stronger winds that moves along the jetstream).

c. There are several patterns of upper-level winds that are associated with CAT. One of these is a deep, upper trough. The CAT is found most frequently at and just upwind of the base of the trough, particularly just downwind of an area of strong temperature advection. Another area of the trough in which to suspect CAT is along the centerline of a trough where there is a strong horizontal windshear between the northerly and southerly flows. CAT is also found in the back side of a trough in the vicinity of a wind maxima as the maxima passes through.

d. One noteworthy generator of CAT is the confluence of two jetstreams. On occasion, the polar front jetstream will dip south and pass under the subtropical jetstream. The area of windshear between the two jetstreams in the area of confluence and immediately downstream is frequently turbulent.

e. CAT is very difficult to predict accurately, due in part to the fact that CAT is spotty in both dimensions and time. Common dimensions of a turbulent area associated with a jetstream are on the order of 100 to 300 miles long, elongated in the direction of the wind, 50 to 100 miles wide, and 2,000 to 5,000 feet deep. These areas may persist from 30 minutes to a day. In spite of the difficulty forecasting CAT, there are rules that have been developed to indicate those areas where CAT formation is likely.

f. The threshold windspeed in the jetstream for CAT is generally considered to be 110 knots. Windspeed in jetstreams can be much stronger than 110 knots and the probability of encountering CAT increases with the windspeed and the windshear it generates. It is not the windspeed itself that causes CAT; it is the windshear or difference in windspeed from one point to another that causes the wave motion or overturning in the atmosphere that is turbulence to an aircraft. Windshear occurs in all directions, but for convenience it is measured along vertical and horizontal axes, thus becoming horizontal and vertical windshear. Moderate CAT is considered likely when the vertical windshear is 5 knots per 1,000 feet, or greater, and/or the horizontal windshear is 20 knots per 150 nautical miles, or greater. Severe CAT is considered likely when the vertical windshear is 6 knots per 1,000 feet and/or the horizontal windshear is 40 knots per 150 miles or greater.

g. Until practical airborne detectors are developed, pilots are urged to use the "Rules of Thumb to Assist in Avoiding or Minimizing Encounters With Clear Air Turbulence" contained in appendix 1. The majority of these guidelines were developed initially by the International Civil Aviation Organization's (ICAO) Sixth Air-Navigation Conference of April/May 1969, but have been expanded based on recommendations from the Department of Defense, the National Transportation Safety Board, and the Federal Aviation Administration.

5. RECOMMENDATION. All pilots and other personnel concerned with flight planning should carefully consider the hazards associated with flight through areas where pilot reports or aviation weather forecasts indicate the presence of CAT including mountain wave turbulence. The "Rules of Thumb" in appendix 1 are intended to assist pilots in avoiding potentially hazardous CAT during flight.

D.C. Beaudette
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APPENDIX 1. RULES OF THUMB TO ASSIST IN AVOIDING OR MINIMIZING ENCOUNTERS WITH CLEAR AIR TURBULENCE (CAT)

Note: The following "Rules of Thumb" apply primarily to the westerly jetstreams.

1. Jetstreams stronger than 110 knots (at the core) are apt to have areas of significant turbulence near them in the sloping tropopause above the core, in the jetstream front below the core, and on the low-pressure side of the core.

2. Windshear and its accompanying CAT in jetstreams is more intense above and to the lee of mountain ranges. CAT should be anticipated whenever the flightpath traverses a strong jetstream in the vicinity of mountainous terrain.

3. Both vertical and horizontal windshear are, of course, greatly intensified in mountain wave conditions. Therefore, when the flightpath traverses a mountain wave type of flow, it is desirable to fly at turbulence-penetration speed and avoid flight over areas where the terrain drops abruptly, even though there may be no lenticular clouds to identify the condition.

4. On charts for standard isobaric surfaces, such as 300 millibars, if 20-knot isotachs are spaced closer together than 150 nautical miles (2-1/2 degrees latitude), there is sufficient horizontal shear for CAT. This area is normally on the poleward (low-pressure) side of the jetstream axis, but in unusual cases may occur on the equatorial side.

5. Turbulence is also related to vertical shear. From the tropopause height/vertical windshear chart, determine the vertical shear in knots-per-thousand feet. If it is greater than 5 knots per 1,000 feet, turbulence is likely.

6. Curving jetstreams are more apt to have turbulent edges than straight ones, especially jetstreams which curve around a deep pressure trough.

7. Wind-shift areas associated with pressure troughs and ridges are frequently turbulent. The magnitude of the windshear is the important factor.

8. If jetstream turbulence is encountered with direct tailwinds or headwinds, a change of flight level or course should be initiated since these turbulent areas are elongated with the wind and are shallow and narrow.

9. If jetstream turbulence is encountered in a crosswind, it is not so important to change course or flight level since the rough areas are narrow across the wind.

10. If turbulence is encountered in an abrupt wind shift associated with a sharp pressure trough line, establish a course across the trough rather than parallel to it.

11. If turbulence is expected because of penetration of a sloping tropopause, watch the temperature gauge. The point of coldest temperature along the flightpath will be the tropopause penetration. Turbulence will be most pronounced in the temperature-change zone on the stratospheric (upper) side of the sloping tropopause.

12. If possible, when crossing the jet, climb with a rising temperature and descend with a dropping temperature.

13. Weather satellite pictures are useful in identifying jetstreams associated with cirrus cloud bands. CAT is normally expected in the vicinity of jetstreams. Satellite imagery showing "wave-like" or "herringbone" cloud patterns are often associated with mountain wave turbulence. Pilots should avail themselves of briefings on satellite data whenever possible.

14. Last, but not least, monitor your radio--pilot reports can be invaluable and if you get caught by "the CAT," file a PIREP!

Note: In this country, civil forecasts of areas of CAT are made by the National Weather Service and disseminated as follows: (1) in area forecasts every 8 hours (every 6 hours in Hawaii); (2) on high-level significant weather facsimile charts available every 6 hours, and (3) on a nonscheduled basis as in-flight advisories (SIGMETS). SIGMETS are issued when severe or extreme CAT is forecast or has been reported. This information is available to pilots through the en route advisory service (flight watch), in SIGMET alerts broadcast on air route traffic control center frequencies, and over the hazardous in-flight weather advisory service (HIWAS).