The Bureau of Meteorology

Aviation services

Turbulence

Hazardous phenomena

Turbulence occurs when airflow becomes chaotic and apparently random, rather than smooth and laminar. In turbulent air, eddies of varying size and intensity travel as vortices in the general airflow before dissipating due to friction.

Introduction

Atmospheric turbulent eddies occur in a range of scales from hundreds of kilometres down to centimetres. Aircraft bumpiness is most pronounced when eddies are about the size of the aircraft, i.e. in the order of one hundred metres or so for commercial aircraft, to tens of metres for smaller aircraft. The reactions of aircraft are dependent on their type, configuration and the speed at which they encounter turbulent zones. Turbulence encounters can result in delays, extra fuel costs, aircraft damage, injuries to passengers and, in worst cases, fatalities and loss of aircraft.

Turbulence may disturb an aircraft's attitude about its major axis, and cause rapid bumps or jolts to be experienced, but in most cases it does not significantly alter the aircraft's flight path.

This compares with wind shear which can cause a change in an aircraft's headwind or tailwind that can displace the aircraft abruptly from its intended flight path, requiring substantial control action to be taken.

Turbulence intensity

Turbulence intensity is specified according to the perceived effect upon aircraft and occupants, as indicated in the following table:

Intensity	Airspeed fluctuations (kt/s)	Vertical gust (ft/s)	G Load	Aircraft reaction	Reaction inside aircraft
Light	5–14	5–19	0.15–0.49	Momentary slight and erratic changes in attitude and/or altitude. Rhythmic bumpiness.	Unsecured objects may be displaced slightly. Cabin service may be conducted, and there may be little to no difficulty walking.
Moderate	15–24	20–35	0.50–0.99	Appreciable changes in attitude and/or altitude. Pilot remains in control at all times. Rapid bumps or jolts. Usually causes variations in indicated airspeed.	Occupants feel definite strain against seatbelts. Unsecured objects are dislodged. Cabin service and walking are difficult.
Severe	≥ 25	36–49	1.0–1.99	Large abrupt changes in attitude and/or altitude. Usually causes large variations in indicated airspeed. Momentary loss of control.	Unsecured objects are tossed about. Occupants violently forced against seatbelts. Cabin service and walking are impossible.
Extreme	≥ 25	≥ 50	≥ 2.0	Aircraft is violently tossed about and is practically impossible to control. May cause structural damage.	

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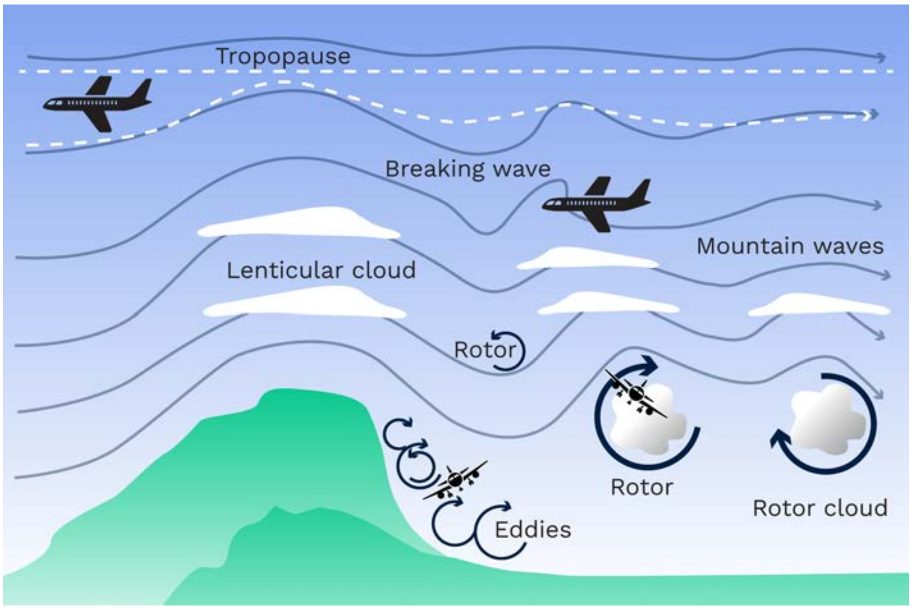
Turbulence types

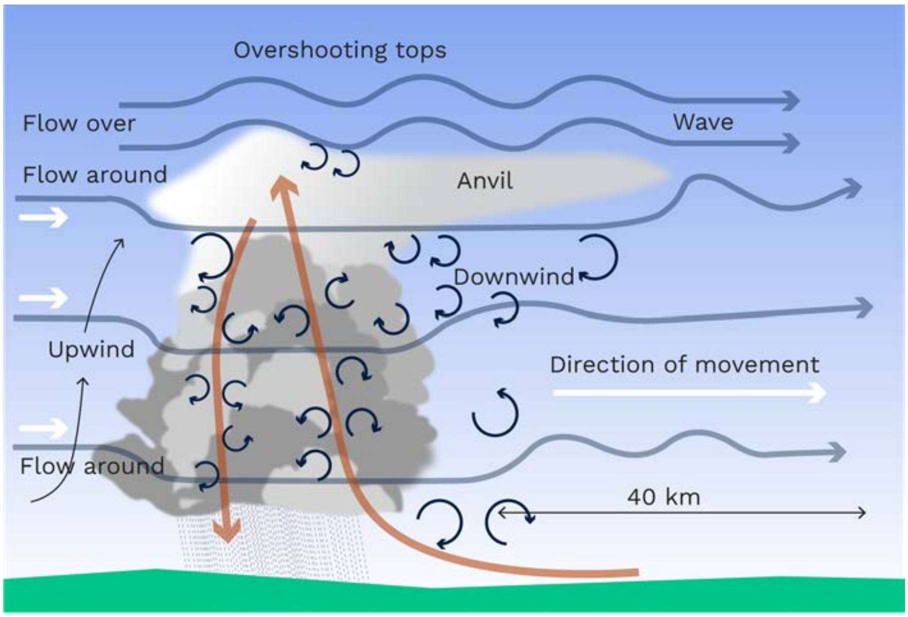
The basic causes of turbulence are wind shear (change in wind strength and direction horizontally and/or vertically) and thermal instability (buoyancy of air) which, working together or independently, produce a local random variation in wind velocity.

The main types of turbulence are detailed in the following table. More than one type may contribute to any single turbulence event.

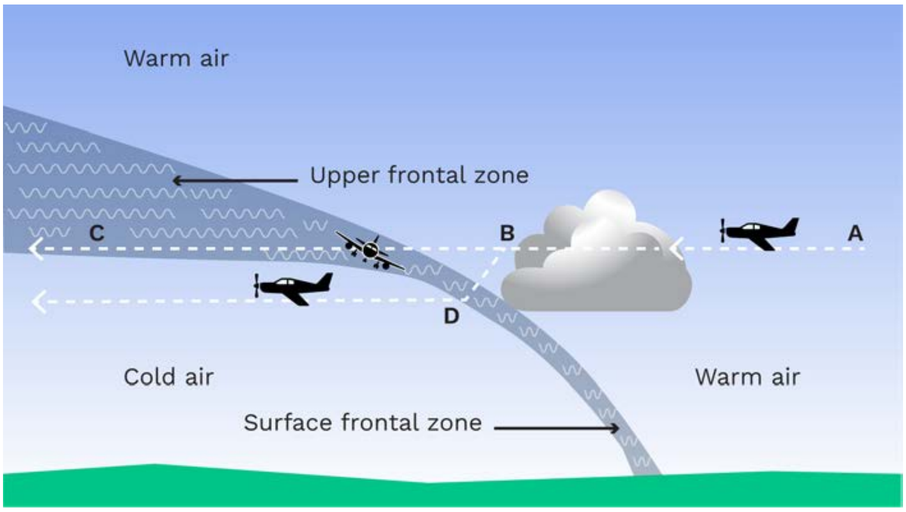
Turbulence types	
Mechanical turbulence	When the air near the surface of the earth flows over obstructions such as bluffs, hills, mountains, or buildings, the normal horizontal wind flow is disturbed and transformed into a complicated pattern of eddies and other irregular movements. The intensity of the turbulence generally increases with the wind speed and surface roughness.
Mountain wave turbulence	Can occur above and downwind of topographic barriers in strong winds and a stable environment. Air will oscillate in a series of waves and rotors as it moves downstream. When air is forced around an obstacle Von Karman vortices may form.
Clear air turbulence (CAT)	High-level turbulence (above 15,000 ft) not normally associated with cumuliform cloud. More prevalent in regions of wind shear, converging winds, horizontal wind deformation, temperature lapse rate discontinuities or strong thermal gradients. The main synoptic features associated with CAT are jet streams, high altitude lows or troughs, or the tropopause.
Thunderstorm turbulence	Turbulence associated within and in the vicinity of thunderstorms or cumulonimbus clouds. The most turbulent areas in towering cumulus and cumulonimbus cloud are the updraft/downdraft boundaries within the cloud, the leading edge of the gust front, above the cloud tops, upper parts of the updraft within the cloud, and in any funnel cloud (tornadoes and waterspouts).
Thermal (convective) turbulence	Localised columns of convective current (a rising column of warm air) resulting from surface heating or cold air moving over warmer ground. For every rising current there is a compensating downward current, usually slower in speed since it covers a broader area, causing turbulence. Sometimes observed as a dust devil.
Frontal turbulence	Turbulence caused by lifting of warm air over the frontal surface leading to instability, or the abrupt wind shift between the warm and cold air masses. The turbulence intensity is determined by the speed of movement of the front, the degree of any mechanical contribution, the wind shear across the frontal zone, any thunderstorms, the atmospheric stability, and any temperature differences across the front.
Low-level jet turbulence	A low-level jet may form in the early morning and are commonly associated with temperature inversions, ahead of cold fronts or upwind of mountain ranges if terrain-blocking is taking effect.
Temperature inversion turbulence	Even though a temperature inversion produces a stable atmosphere, inversions can cause turbulence at the boundary between the inversion layer and the surrounding atmosphere.
Wake vortex turbulence	Wake turbulence is produced by all aircraft, including helicopters, when aerofoils are producing lift. Circulations are shed from the wing tips and evolve into a pair of counter-rotating vortices behind the aircraft. Each vortex is a mass of rotating air and consists of a core and a flow field about the core. The cores of these spinning currents can reach speeds of 180 knots and, when moisture levels are high enough, they become visible, shooting from the wings as thin strands of condensed water vapour. The strength of the vortex is governed by the weight, speed and shape of the wing of the generating aircraft.



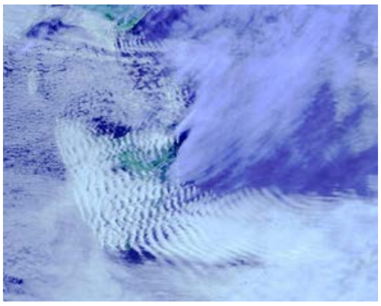
Mechanical turbulence and mountain waves



Turbulence near convective cloud



Frontal zone turbulence. This illustrates 2 possible flight paths. An aircraft with a planned route B to C could be caught in a turbulent zone for a long period of time, while an aircraft tracking B to D would experience turbulence for only a short time.



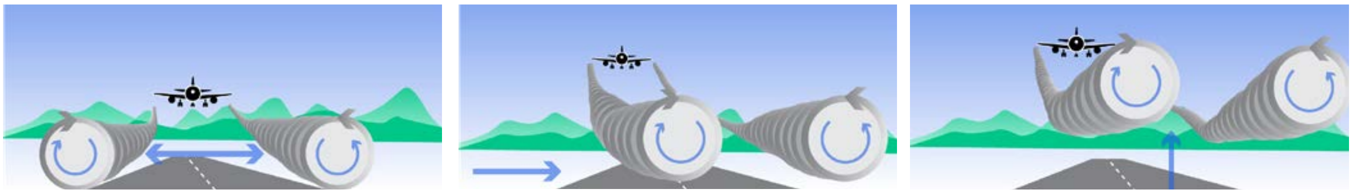
Satellite image of mountain waves over Tasmania, 3 December 2002

Von Karman vortices forming in a stratocumulus field downwind from the volcanic island of Rishiri-to in the northern Sea of Japan. Credit: NASA

Lenticular cloud

Supercell thunderstorm

Roll cloud



Wake vortices
(a) Calm winds: vortices roll apart

(b) Cross winds: shift vortices across the runway

(c) Under certain conditions of atmospheric stability, vortices can bounce off the ground

Detection and monitoring

Turbulence is one of those hazards where, in the absence of cloud, there are little or no visual clues to notify pilots of its presence. Therefore pilots need to be aware of the situations in which turbulence is most likely, and monitor the forecasts, warnings and observations accordingly.

Visual clues for the presence of turbulence include:

- cloud in the form of waves (Kelvin-Helmholtz waves), ripples or billows
- roll clouds
- lenticular clouds above mountains
- thunderstorms or enhanced convection
- raised dust or dust devils
- undular bore (i.e. Morning Glory).

A pilot in command of an aircraft must advise Air Traffic Services (ATS), in the form of a special AIREP, of any encounter of moderate or severe turbulence.

Dust devil

Wake vortices

Forecasts and warnings

Forecasting turbulence is complicated due to the wide range of temporal and spatial resolutions at which it is observed, and because causes are not always clearly defined. More than one mechanism may contribute, or one may dominate the other, e.g. with strong winds, even if significant mountain waves exist, it may be mechanical turbulence, rather than orographic (mountain waves), that has the most significance to aircraft flying close to terrain.

The Bureau of Meteorology forecasts moderate (MOD) and severe (SEV) turbulence. Turbulence forecasts are included in Graphical Area Forecasts (GAF), AIRMET, Aerodrome Forecasts (TAF and TAF3), Significant Weather (SIGWX) charts and SIGMETs.

The presence of turbulence is always implied in forecasts and warnings relating to towering cumulus, cumulonimbus, thunderstorms and tropical cyclones.

Kelvin-Helmholtz waves

Morning Glory. Credit: Wikipedia Commons, Mike Petroff

Further aviation educational resources produced by the Bureau of Meteorology can be found at www.bom.gov.au/aviation/knowledge-centre.

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