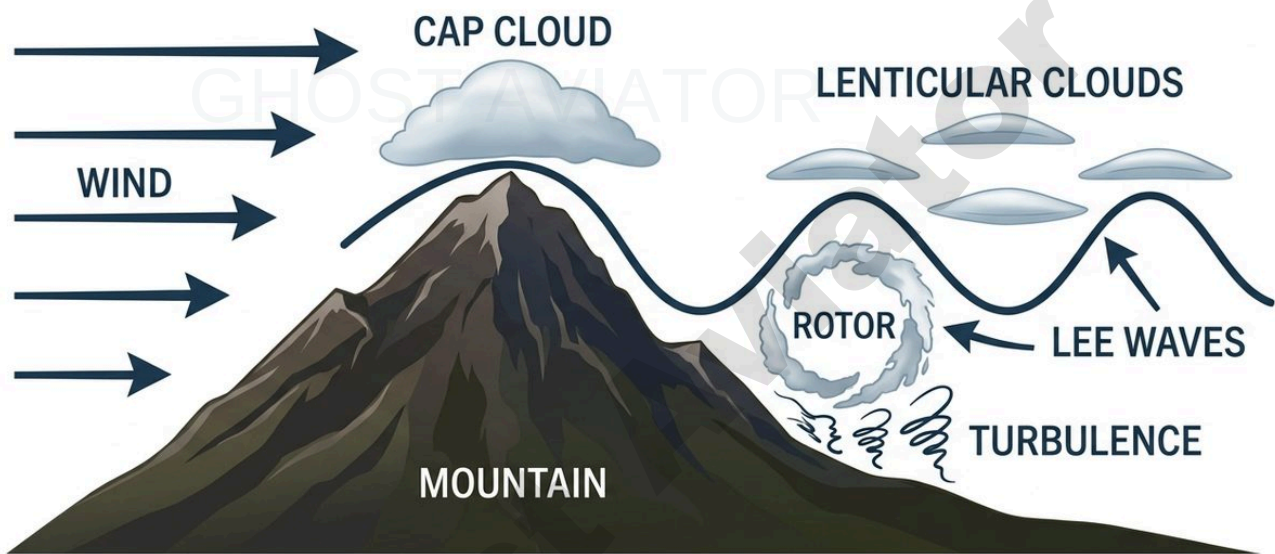


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1. Definition & Necessary Conditions

Definition: Mountain Wave is defined as oscillations of high scale and height due to disturbance in the horizontal air flow caused by high ground. When an airstream strikes a mountain range under suitable stability conditions, **a train of waves is generated on the leeward side of the range** — called *Mountain Wave*. Flying over such terrain is bumpy and unsafe.



A mountain wave and its features

Necessary Conditions for Mountain Waves

Wind:

- A definite air flow across the ridge within **30°** perpendicular to the ridge.
- Wind speed of at least **7 m/s** for smaller mountains and **15 m/s** for larger mountains.
- A deep steady directional flow over a significant height band, strengthening with height.

Stability:

- **Stable layer** below the ridge.
- **Stable air above** the crest of the ridge, with less stable air above.

flowchart TD

```
A[Mountain Wave Formation] --> B[Wind Conditions]
A --> C[Stability Conditions]
B --> B1[Flow within 30° of perpendicular\nto ridge]
B --> B2[Min 7 m/s small mountains\nMin 15 m/s large mountains]
B --> B3[Deep steady directional flow\nStrengthening with height]
C --> C1[Stable layer BELOW ridge]
C --> C2[Stable air ABOVE crest\nLess stable air higher up]
```

Mnemonic — Necessary Conditions: "WIND MUST BLOW ACROSS THE RIDGE (*within 30°*), FAST ENOUGH, THROUGH STABLE AIR"

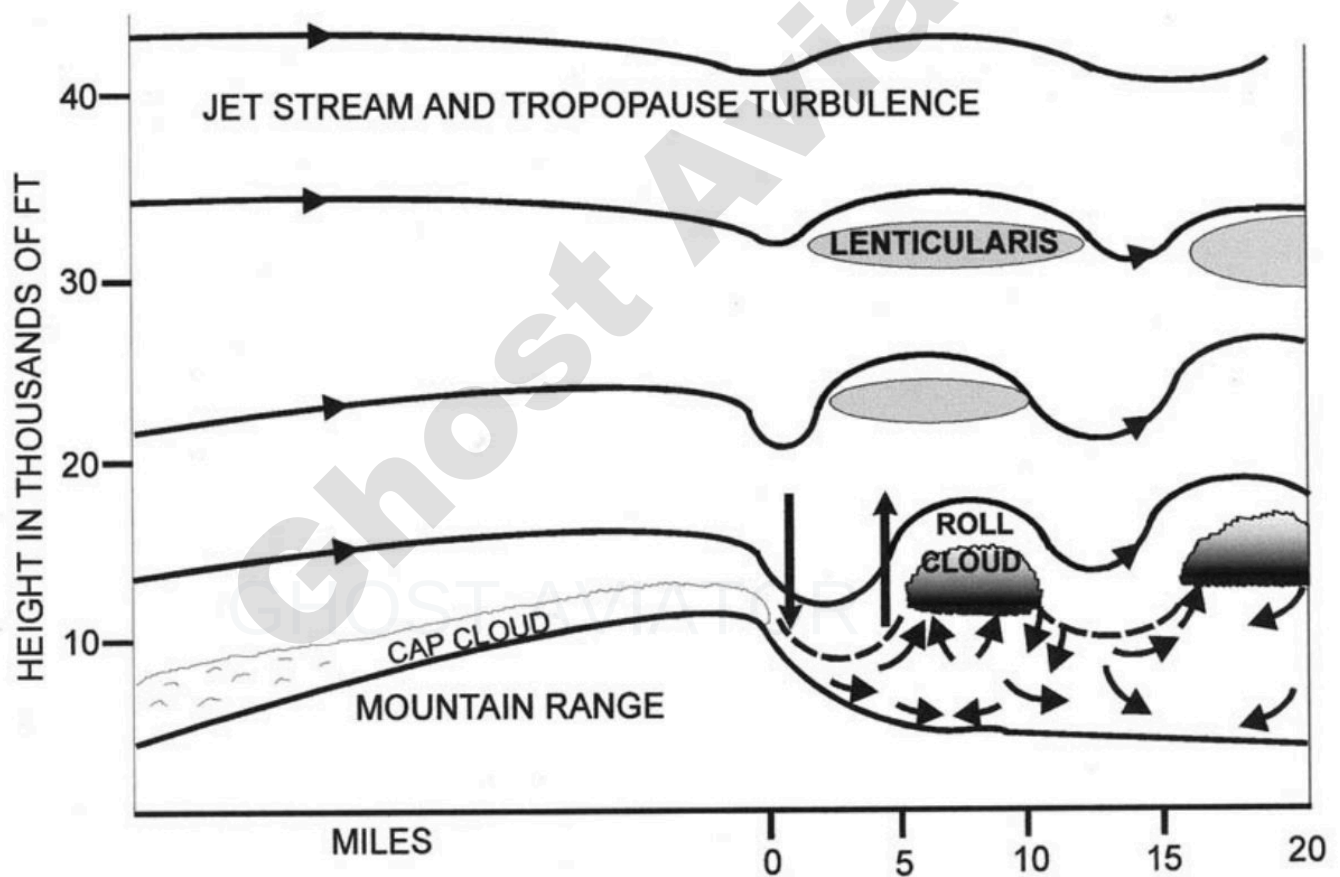
2. Vertical Currents

In mountain waves there are alternate areas of rise and sink. **Areas of sink occur immediately downward of the ridge.** Vertical currents associated with mountain waves can be intense and extensive. Over large mountains, vertical currents of **10 to 25 m/s** are not uncommon.

Critical Hazard: An aircraft flying *parallel* to a ridge, if caught in the **down current**, would suffer constant loss of height till the whole length of the ridge is traversed. An aircraft caught in up currents would constantly gain height. **Adequate terrain clearance is therefore essential while flying over mountains.**

3. Associated Clouds

Cloud Type	Location	Description
Cap Cloud	Covers mountain top	Strong winds may sometimes sweep them down the lee slope — like Fohn Wall.
Rotor/Roll Cloud	Leeward side below crest, first wave	Most hazardous; associated with rotor streaming. Strongest rotor is normally in the first wave crest, level or slightly above the crest.
Lenticular Clouds	Leeward side, a few thousand feet above crests	Lens-shaped, form at successive crests of waves. Appear stationary (form on upwind side, dissolve on downwind side). Ragged edges = turbulence indicator. May look like "cloud fall" — Fohn Wall.
ST, SC, AS, CI, Nacreous	Upper stratosphere	Formed in humid atmosphere at various levels due to mountain waves extending to great heights.



Mountain wave and its clouds

Waterfalls: On large lee slopes, the clouds sometimes sweep down like a cloud fall — they resemble waterfalls and are called **Fohn Wall**. Mountains have a tendency to increase the cloud cover and also cloud depth.

Rotors: When winds are strong at lower levels but weaken or reverse at higher levels, violent rotors form on the lee slope and move downwind from the ridge. These are called **Rotor Streaming**.

4. Visual Recognition

Visual Recognition Guide:

1. **Lenticular clouds** on leeward side, few thousand feet above crests → **ragged edges indicate turbulence**
2. **Rotor Clouds** → Strongest rotor is in the **first wave crest**, level or slightly above the crest
3. **Cap Cloud** → Covers mountain top; strong winds may sweep it down the lee slope (Fohn Wall)

5. Turbulence

Flying over mountains is not always turbulent. It is smooth in certain regions and turbulent in others due to additional wind shears. However, **the transition from smooth to turbulent motion is extremely abrupt and without any warning.**

Severity:

- Wave cloud outlines that are not smooth but have ragged appearance = indication of turbulence.
- Severe turbulence occurs in cap cloud and rotor clouds.
- **Worst kind of turbulence** = in rotor clouds, similar to that of violent TS. Both vertical and horizontal gusts occur.
- Acceleration of **2 to 4g** is not uncommon; at times **7g** has also been exceeded.
- Size, speed, and aerodynamic characteristics of aircraft determine bumpiness.
- In extensive mountain ranges, one wave system generated by one range is modified by further ridges downstream → may result in **violent turbulence**.

6. Altimeter Errors & Hysteresis Effect

Altimeter Errors in Mountain Waves: Aircraft in mountain waves are subjected to rapid height fluctuations due to up and down currents. The aneroid capsules of the altimeter are **unable to respond correctly** to these fluctuations. This is called the **Hysteresis Effect**.

- Altimeters also give erroneous readings if the temperature differs from ISA.
- If colder than ISA → readings are **too high**.
- If warmer than ISA → readings are **too low** (vice versa).
- **Hence altimeter readings are not reliable and deceptive when used for terrain clearance.**

Exam Tip: Hysteresis = altimeter lag in rapidly changing pressure. Cold air = altimeter reads HIGH (actual height is LOWER than indicated). Mnemonic: "*Cold = High reading = Lower actual altitude = DANGER for terrain clearance*"

7. Seasonal & Diurnal Variation

Diurnal: After sunset, atmosphere becomes stable at lower levels due to radiational cooling. Winds also weaken in lower layers. This results in formation of waves on the lee side of small and medium height mountains → called **Evening Waves**. These waves continue throughout, till warming up after sunrise destroys the stability structure. For large mountains, this effect is negligible.

Seasonal: In winters, winds are steady and strengthen with height, and the atmosphere has suitable stability → **Mountain waves are more frequent in winters.**

8. Extent

- Mountain waves may extend **100–200 km** downstream and **vertically sometimes well into the Stratosphere**.
- Wavelength of mountain waves is about **10 km** or more.
- Lee waves of long amplitude produce **rotors** in the crests of waves.
- If the mountain range is long, a succession or train of lee waves may be seen.

9. Aviation Hazards

Mountain Waves — Aviation Hazards:

1. **Strong up and down currents** may make it difficult to maintain altitude and loss of control.
2. **Turbulence**, often severe, up to great heights, may lead to **structural damage**.
3. **Unexpected winds** of large magnitude may cause loss or gain of altitude.
4. **Increase in frequency and intensity of icing**.
5. **Errors in pressure altimeter** (Hysteresis effect).

10. Quick Revision Summary

Quick Revision — Chapter 17: Mountain Waves

- Waves form on **leeward side** of ridge under suitable stability + wind conditions
- Wind must be within **30°** of perpendicular; min **7 m/s** (small) / **15 m/s** (large)
- Vertical currents: up to **10–25 m/s** over large mountains
- Clouds: Cap → Rotor/Roll → Lenticular (all leeward); Nacreous/CI in upper stratosphere
- Worst turbulence = **Rotor clouds** (like violent TS); g-loads **2–4g**, max **7g**
- Altimeter error = **Hysteresis Effect**; cold ISA → reads HIGH (actual lower)
- Extent: **100–200 km** downstream; wavelength **~10 km**; into stratosphere vertically
- More frequent in **winters**; evening waves form in smaller mountains at sunset
- Ragged lenticular clouds = turbulence warning
- Flying parallel to ridge in down-current = constant height loss — maintain terrain clearance

11. Practice Q&A

Note: The following Q&A are sourced from the textbook question bank — "Questions on CAT and Mountain Waves"

Q1. For mountain waves to form there should be flow of air across the ridge, generally within of the perpendicular to the ridge.

(a) 30° (b) 45° (c) 60°

✓ Correct Answer: (a) 30°

✗ Distractors: 45° and 60° are too oblique — the flow must be nearly perpendicular (within 30°) to effectively create the wave pattern on the leeward side.

💡 Mnemonic: "30° — close to perpendicular" — think of it as nearly straight-on flow to the ridge.

Q2. For mountain waves to form, the wind speed for small mountains should be at least:

(a) 15 m/s (b) 10 m/s (c) 7 m/s

✓ Correct Answer: (c) 7 m/s for small mountains

✗ Distractors: 15 m/s is the threshold for larger mountains. 10 m/s is not a specified value in the text.

💡 Remember: Small = 7 m/s; Large = 15 m/s. Think: "larger mountains need more wind to generate waves."

Q3. For mountain waves to form, the wind speed for large mountains should be at least:

(a) 15 m/s (b) 10 m/s (c) 7 m/s

✓ Correct Answer: (a) 15 m/s for large mountains

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✗ Distractors: 7 m/s is for small mountains. 10 m/s not specified.

💡 Pair Q2 and Q3 together: Small = 7, Large = 15.

Q4. For mountain waves to form there should be air below the ridge and less stable air above.

(a) Stable (b) Unstable (c) Indifferent

✓ Correct Answer: (a) Stable — stable air below the ridge is required

✗ Distractors: Unstable air below the ridge would cause convective activity rather than wave formation. The wave mechanism requires the stable layer to act as a "lid" that deflects flow upward.

💡 "Stable below = wave formation; Unstable below = convective turbulence instead"

Q5. The worst kind of turbulence is encountered in the vicinity of rotor clouds.

(a) Rotor Clouds (b) Lenticular Clouds (c) Cap Clouds

✓ Correct Answer: (a) Rotor Clouds — worst turbulence, similar to violent TS

✗ Distractors: (b) Lenticular clouds indicate wave position and have ragged edges in turbulence, but not the worst zone. (c) Cap cloud has turbulence but rotor is worse.

💡 Rotor = Roll = worst! The rotor is the churning region below the wave crest — like a washing machine in the sky.

Q6. In Mountain waves the Rotor clouds form in:

(a) Troughs (b) Ridges (c) Valley

✓ Correct Answer: (a) Troughs — rotor clouds form in the troughs of mountain waves

✗ Distractors: (b) Ridges have lenticular clouds at wave crests. (c) Valley is a geographic term — not where the atmospheric wave trough is.

💡 Wave anatomy: Crest = Lenticular, Trough = Rotor/Roll cloud. Think: "lowest point = most chaotic rotation."

Q7. Clear air turbulence is often encountered:

(a) At the boundary of a jet stream (b) In the wake of a passing airplane (c) In the wake of a larger airplane at take off and landing (d) All of the above

✓ Correct Answer: (a) At the boundary of a jet stream — CAT is found at the fringes/boundary of jet streams

✗ Distractors: (b) Wake turbulence from passing aircraft is wake turbulence, not CAT. (c) Wake turbulence at T/O & landing is mechanical, not CAT. (d) Not all — only (a) is correct for CAT specifically.

💡 CAT = high altitude, cloud-free, at JET STREAM BOUNDARIES. Wake turbulence is a completely different phenomenon.

Q8. Most CAT occurs on the of a jet stream and in the vicinity of upper level frontal zones where temperature contrasts are strong.

(a) Fringes (b) Within the core (c) Axis

✓ Correct Answer: (a) Fringes — NOT within the core

✗ Distractors: (b) Within the core — the core has high wind speed but relatively uniform flow. CAT requires wind shear, which is maximum at the fringes. (c) Axis is same as core region.

💡 "CAT at the FRINGES" — the core is smooth but fast; the edges have shear. Like a river — most turbulent at banks, not centre.

Q9. CAT is the bumpiness experienced by aircraft at high altitudes. Over North India its maximum frequency is during:

(a) Oct–May (b) Jul–Aug (c) Jun–Sep

✅ Correct Answer: (a) Oct–May — due to STJ over North India

❌ Distractors: (b) Jul–Aug = TJ active over S India. (c) Jun–Sep = SW Monsoon; STJ displaced northward and weakened over India.

💡 STJ = Winter = Oct–May = North India CAT. TJ = Jul–Aug = South India CAT.

Q10. When approaching an area where mountain waves have been reported, a pilot should expect:

(a) Possible presence of roll clouds and lenticular clouds (b) Intense up draughts and down draughts on the lee side of the mountains (c) Moderate to severe turbulence as far as 20 to 30 nm from range on leeward side (d) All of the above

✅ Correct Answer: (d) All of the above

❌ Distractors: Each option alone is true — lenticular/rotor clouds, intense vertical currents, and turbulence extending far downstream are all characteristics of mountain wave areas.

💡 Mountain waves = all hazards together: visual cues (clouds), structural (turbulence), operational (vertical currents). Expect ALL when waves reported.

12. Master Reference Tables

All Numerical Values

Parameter	Value
Wind direction — angle to ridge	Within 30° of perpendicular
Min wind speed — small mountains	7 m/s
Min wind speed — large mountains	15 m/s
Vertical currents over large mountains	10–25 m/s
Typical g-load in rotor turbulence	2–4g (extremes up to 7g)
Wave extent downstream	100–200 km
Wavelength of mountain waves	~10 km or more
Turbulence from mountain waves (leeward)	Up to 20–30 nm from range

Cloud Types in Mountain Waves

Cloud	Position	Significance
Cap Cloud	Mountain top	Fohn Wall if swept down lee slope
Rotor/Roll Cloud	Wave trough, leeward	WORST turbulence — like violent TS
Lenticular (ACSL)	Wave crests, leeward, above	Stationary; ragged = turbulence
ST/SC/AS/CI/Nacreous	Upper levels into stratosphere	Wave extends to great heights