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1. Definition & Necessary Conditions

Definition: Clear Air Turbulence (CAT) is the bumpiness experienced by aircraft at high altitudes in cloud-free conditions, *excluding Ci clouds*. It is caused when bodies of air moving at widely different speeds meet. The Upper Troposphere (**23,000–39,000 ft**) near the Tropopause is the most susceptible region. CAT is most frequently found in regions of jet streams. Unstable atmosphere enhances CAT. At lower altitudes it may occur near mountain ranges.

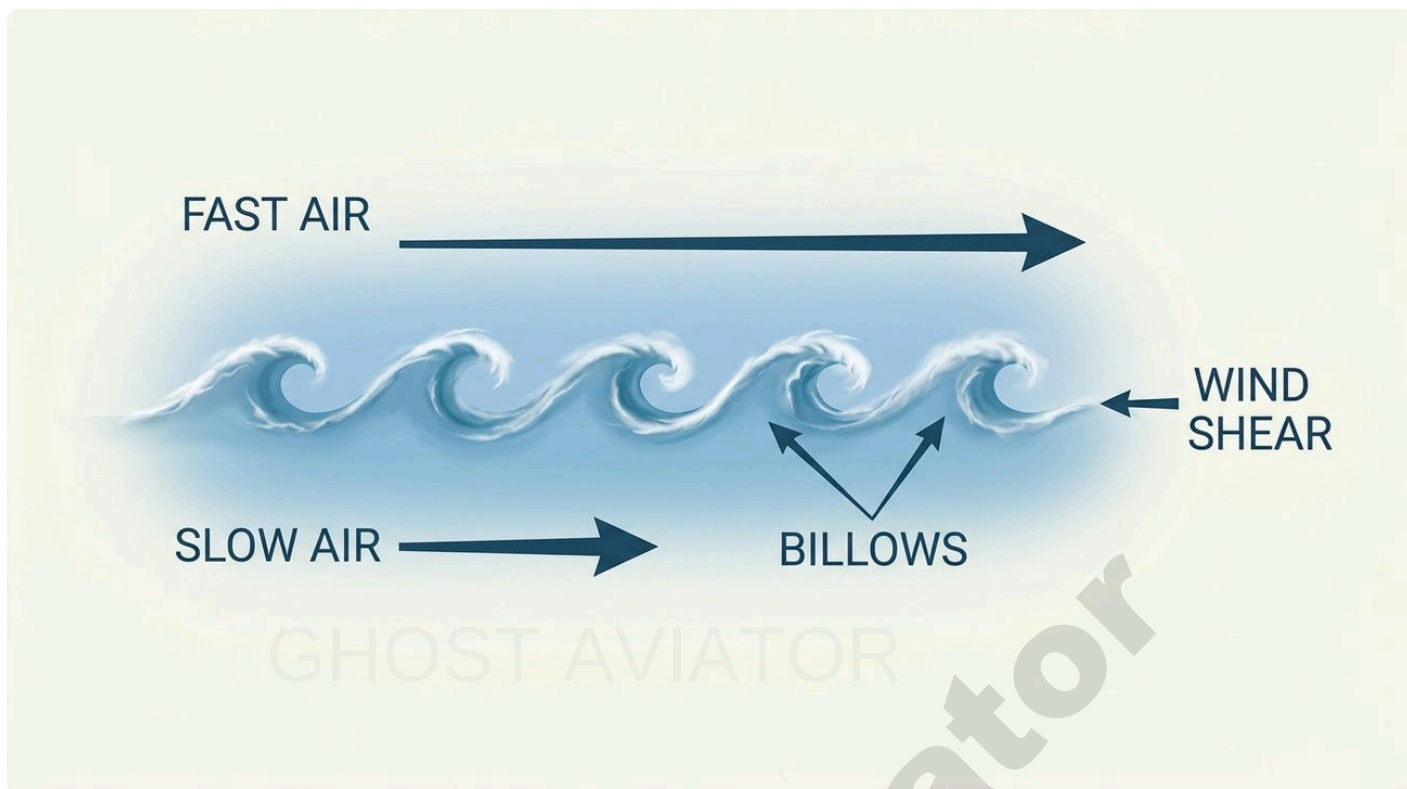
Necessary Conditions

1. **Marked horizontal or vertical wind shear**
2. **Steep lapse rate** in the atmosphere

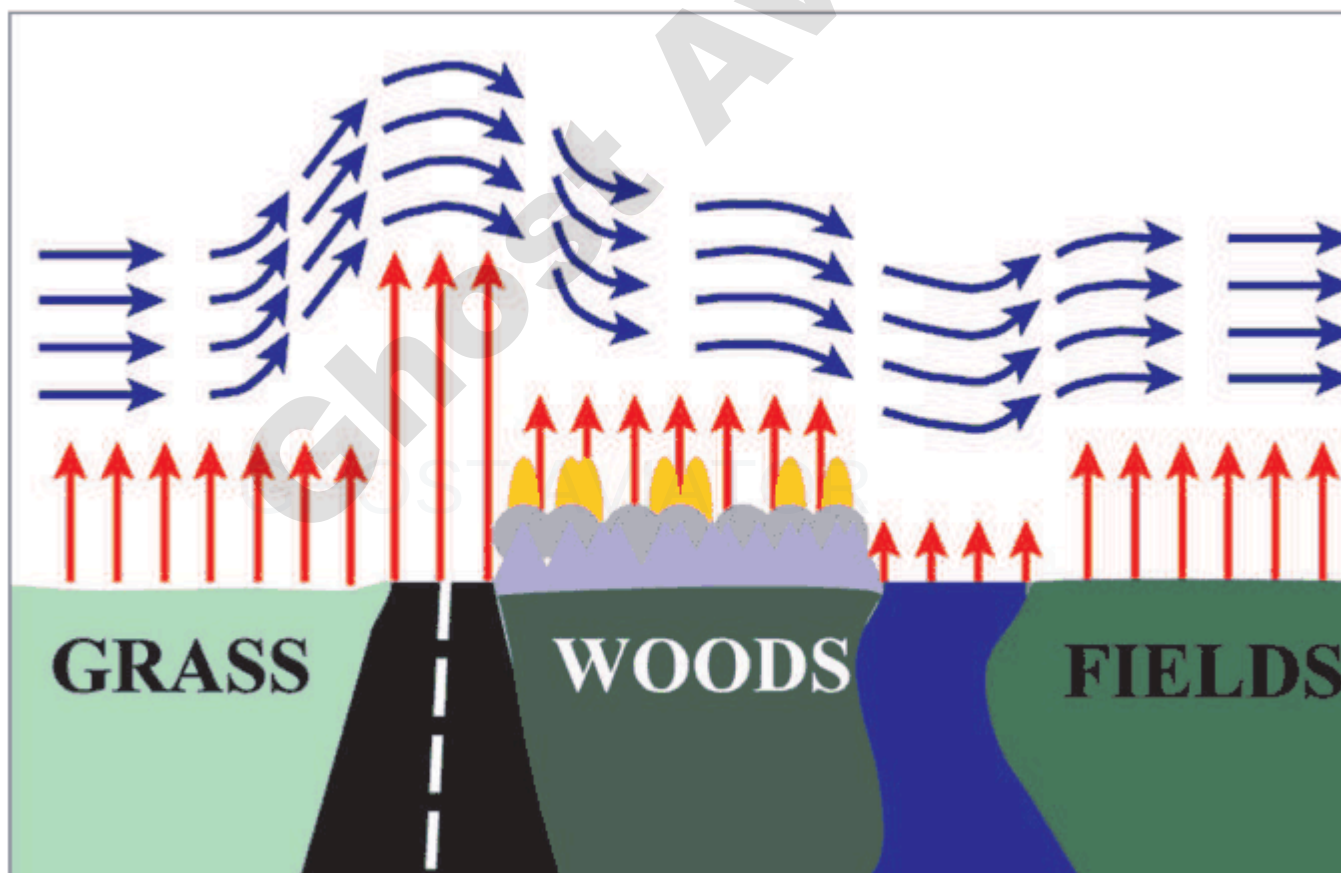
Instructor's Note: Remember "SHEAR + STEEP LAPSE = CAT". Both conditions are normally present just below the tropopause, especially near the jet stream core.

2. Causes & Sources of CAT

Lower Stratosphere: Even when the lapse rate is small or negative, a marked decrease of wind speed with height may give rise to temporary zones of CAT.



Kelvin-Helmholtz billows



Thermal turbulence

Sources of CAT

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flowchart TD

```
A[CAT Sources] --> B[Jet Stream Fringes\nnot in core]
A --> C[Upper Level Frontal Zones\nStrong temp contrasts]
A --> D[Mountain Waves\nGravity wave breakdown]
A --> E[CB Cloud Tops\nWaves downstream of thunderstorms]
B --> B1[Most CAT occurs here\nLower stratosphere vicinity]
D --> D1[Mountain wave + Jet stream\nSevere CAT – more on leeward side]
E --> E1[Train of lenticular clouds\ninvisible on leeward side of CB]
```

Warning: CAT is NOT within the jet stream core — it is on the **fringes**. Most CAT occurs on the fringes of a jet stream and in the vicinity of upper level frontal zones where temperature contrasts are strong.

Mountain Wave + Jet Stream Combined Effect: Mountain waves amplify gravity waves and propagate them vertically towards the stratosphere. These waves may generate smooth up and downdrafts or may breakdown and cause CAT. Severe CAT is more frequent on the **leeward side of high ground** than over the plains.

Thunderstorm-induced CAT: CAT occurs when strong winds encounter the tops of thunderstorm clouds, resulting in waves that extend well downstream from the cloud. Sometimes a train of lenticular clouds can be noticed on the leeward side of the CB cloud.

3. CAT Over India

Aspect	Details
Frequency & Regions	Highest over N, Central, NE India from October to May — due to Sub Tropical Jet stream (STJ). Over S India in July and August — due to peak activity of Tropical Jet stream (TJ).
Intensity	Most CAT in India is moderate . Severe CAT can occur from December to February when STJ is at its peak.
Horizontal Dimensions	~120 km N–S direction; ~250 km E–W direction (patchy phenomenon)
Vertical Extent	A CAT zone may be about 2000 ft , but may extend through a deep layer.

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Mnemonic — CAT in India:

"STJ brings CAT in Winter (Oct–May) over N India; TJ brings CAT in Summer (Jul–Aug) over S India"

Dimensions: **120 × 250 km** (N–S × E–W). Think: "narrow N–S, wide E–W"

4. Aviation Hazards

Aviation Hazards of CAT:

1. CAT causes **discomfort** to crew and passengers.
2. In CAT, **difficulty may be experienced in controlling** an aircraft.
3. CAT is encountered **suddenly** and is amplified by the mountain waves.

5. Avoidance

Avoidance Procedures:

1. Avoid flying close to a **Jet stream**.
2. Climb up or descend down, or turn **N or S** to get out of CAT (since CAT extends ~120 km N–S, a N/S deviation exits the zone).
3. Avoid flying below the tropopause — about **1 km above the tropopause** may be clear of CAT.

flowchart LR

```
A[Encountering CAT] --> B{Escape Options}
B --> C[Climb / Descend\nChange altitude]
B --> D[Turn North or South\n~120 km exits N-S zone]
B --> E[Fly 1 km above\ntropopause]
B --> F[Avoid flying close\nto Jet Stream]
```

6. Quick Revision Summary

Quick Revision — Chapter 16: Clear Air Turbulence

- CAT = bumpiness in cloud-free air, **excluding Ci clouds**
- Most susceptible zone: **23,000–39,000 ft** near Tropopause
- Necessary conditions: **Wind Shear + Steep Lapse Rate**
- Occurs on **fringes** of jet stream (NOT in core)
- CAT India (N/Central/NE): **Oct–May** (STJ); S India: **Jul–Aug** (TJ)
- Severe CAT in India: **Dec–Feb**
- CAT dimensions: **120 km N–S** , **250 km E–W** , **~2000 ft** deep
- Escape: Climb/Descend, Turn N/S, or fly **1 km above tropopause**
- Leeward side of mountains = more severe CAT
- CAT is **sudden** — no visible warning

7. Practice Q&A

Q1. CAT (Clear Air Turbulence) is most frequently found in which region of the atmosphere?
(a) Surface layer (b) Near the jet streams at upper troposphere (c) In the stratosphere above 50,000 ft (d) In cumulus cloud regions

✓ Correct Answer: (b) Near the jet streams at upper troposphere (23,000–39,000 ft near tropopause)

✗ Distractors: (a) Surface layer has friction turbulence, not CAT. (c) 50,000 ft is well into stratosphere — beyond typical jet stream level. (d) CAT specifically excludes cloud regions (Ci excluded).

💡 Instructor's Note: CAT = Cloud-free, near tropopause. The word "Clear" in CAT is the key — no clouds, high altitude.

Q2. Most CAT in India occurs on the fringes of the jet stream. The maximum frequency of CAT over North India is during:
(a) July–August (b) October–May (c) June–September (d) March–June

✓ Correct Answer: (b) October–May — due to Sub Tropical Jet stream (STJ) activity over N, Central and NE India

✗ Distractors: (a) Jul–Aug is when Tropical Jet stream is active over S India. (c) Jun–Sep is SW Monsoon — STJ retreats. (d) Partially overlaps but Oct is when STJ starts strengthening.

💡 Instructor's Note: STJ → Winter months (Oct–May) → North India. TJ → July–Aug → South India. Never confuse these two.

Q3. The average horizontal dimensions of a CAT zone in India are approximately:
(a) 50 km N–S, 100 km E–W (b) 120 km N–S, 250 km E–W (c) 500 km N–S, 500 km E–W (d) 300 km N–S, 100 km E–W

✓ Correct Answer: (b) 120 km N–S, 250 km E–W

✗ Distractors: The other dimensions are not given in the text. CAT is a patchy phenomenon — relatively small in N–S extent, hence turning N or S is an effective escape manoeuvre.

💡 Mnemonic: "120 × 250" — Think of it as a "narrow band" N–S. Turning 120+ km N or S gets you out.

Q4. To escape from CAT, a pilot should:

(a) Maintain current altitude and speed through it (b) Turn East or West (c) Climb/Descend or turn North or South (d) Reduce speed and descend to low level

✓ Correct Answer: (c) Climb/Descend or turn North or South — or fly about 1 km above the tropopause

✗ Distractors: (a) Maintaining altitude prolongs exposure. (b) E–W dimension is ~250 km — much harder to exit E/W. (d) Low level flight introduces other hazards.

💡 Remember: CAT is narrow N–S (120 km) → Turn N or S is most efficient escape. Vertical escape: 1 km above tropopause.

Q5. Severe CAT in India is most likely during:

(a) June–July (b) December–February (c) March–May (d) August–October

✓ Correct Answer: (b) December–February — when the Sub Tropical Jet Stream (STJ) is at its peak intensity

✗ Distractors: (a) Jun–Jul = SW Monsoon, STJ weakens. (c) Mar–May = STJ retreating. (d) Aug–Oct = Monsoon withdrawal, STJ not yet at peak.

💡 "STJ peaks in Deep Winter (Dec–Feb)" → Severe CAT peaks then. Most CAT otherwise is moderate.

8. Master Reference Tables

All Numerical Values

Parameter	Value
CAT susceptible altitude	23,000–39,000 ft
CAT N–S dimension	~120 km
CAT E–W dimension	~250 km
CAT vertical depth	~2000 ft (can extend deeper)
Safe altitude above tropopause	~1 km above tropopause

CAT Over India — Season Summary

Region	Season	Jet Stream	Intensity
N, Central, NE India	Oct–May	Sub Tropical Jet (STJ)	Moderate; Severe Dec–Feb
South India	Jul–Aug	Tropical Jet (TJ)	Moderate