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Clear air turbulence (CAT) in India and neighbourhood

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ABSTRACT. The present study of CAT over India and neighbourhood has been based on the inflight and post flight reports received and on the debrief reports given by national and international operators during the period January 1966 to December 1969. CAT has been studied in its spatial and vertical distribution on the basis of available data. The effects of various upper air flow patterns, such as westerly and easterly jets and wind discontinuity etc contributing to the occurrence of CAT, have also been studied. An attempt has also been made in this paper towards the detection of favourable conditions for occurrence of CAT. The role of temperature distribution and pools of cold and warm air in the upper air have been discussed. Some typical examples of the phenomenon have been illustrated.

1. Introduction

Clear Air Turbulence (CAT) is a phenomenon consisting of random, three dimensional eddies that cause an aircraft to follow an erratic path while traversing the turbulent region. Turbulence that occurs in thunderstorms and other rain producing clouds is designated as convective turbulence. Mountain wave turbulance is occasionally a violent type of clear air turbulence.

Hazards of CAT came to be known to aviators only with the arrival of high level flying in jet age. In regard to the effects of turbulence that of light intensity is recognised as an annoyance or inconvenience. Moderate turbulence is uncomfortable to passengers and accumulated effects (in metal fatigue) may affect flight safety. Severe turbulence is dangerous and on rare occasions, it is capable of causing structural failure and loss of aircraft. Even though moderate or severe CAT is infrequent, unexpected encounter with them is a matter of serious concern.

In the event of flying in a thunderstorms area, aviators are generally forewarned to take necessary precautions to minimise adverse effects of severe turbulence in various ways by pinning the passengers to their seats, by loosening the aircraft controls and at times by slightly changing the course of flight. Similarly, if the forecasters could include in flight forecasts the areas of CAT, flying can be made trouble-free by the change of cruising level etc. Study of causes which give rise to CAT conditions and the analysis and forecast of this invisible turbulence are, therefore, desired by the Airlines and the public. However, attempts to forecast this hazard with fair degree of accuracy have not attained a high level of efficiency owing to meagre data.

Efforts were made at Delhi (Palam) Airport to obtain reports of CAT from Captains of jet aircraft. The aircraft reports received during the period January 1966 to December 1969 were analysed and some of the results are discussed in this study.

2. Space distribution of CAT observations

The number of occasions of CAT occurrence reported were plotted on a map (Fig. 1) in areas of 5-degree squares along the various air routes through Delhi. This shows certain areas of preferential occurrence of CAT in association with certain pressure systems and prevalent wind patterns. On Delhi-Bombay route maximum cases, including some severe CAT occurrences, were observed between Jaipur and Mandsore in assoication with jet axis and trough in the westerlies. Jharsuguda was also reported to be another vulnerable area for CAT occurrence, though we could not get observations for this area as it was not directly on the route to Delhi.

Along the Delhi-Calcutta route, Farrukhabad, Lucknow and Gaya reporting points were observed to be equally favourable for the occurrence of CAT on most occasions in association with westerly jet and trough in the westerlies. On Calcutta-Bangkok route moderate CAT cases were reported at Akyab, mostly in association with easterly wave. Over Rangoon and Bangkok most of the cases were of light CAT in association with easterly wave.

On Delhi-Tehran route areas of Birjand, Kamar and Kandhar were observed to be vulnerable to CAT mostly in association with westerly jet and troughs in the westerlies at 300 and 200 mb.

On Moscow route, CAT was experienced on maximum number of occasions at Termez. Karabura, Uralsk and Aktinbinsk were also favourable

TABLE 1

Number of occasions of CAT at flight level

Flight level	Intensity of CAT		
	Light	Moderate	Severe
390	2	0	0
380	2	0	1
370	12	14	2
360	5	10	3
350	18	20	2
340	1	3	1
330	35	55	5
320	13	25	3
310	17	20	3
300	0	2	0
290	5	9	2
280	3	8	3
270	0	4	0
260	2	2	0
250	1	2	0
250	3	5	0
Total	119	179	25

TABLE 2

Number of occasions of CAT in different months of the year

	Intensity of CAT		
	Light	Moderate	Severe
Jan	11	19	2
Feb	10	24	8
Mar	6	21	3
Apr	21	43	4
May	16	18	3
Jun	6	10	1
Jul	8	14	0
Aug	10	2	0
Sep	8	3	1
Oct	8	5	1
Nov	8	11	0
Dec	7	9	2
Total	119	179	25

TABLE 3

Weather situations associated with occasions of moderate to severe turbulence above 20,000 ft

Weather situation	No. of occasions		
	Light	Moderate	Severe
Near jet stream	50	83	18
Probably near jet stream (*i.e.* jet stream certainly present but details of wind speed etc not available)	16	23	2
Upper trough	24	32	2
Upper low	5	6	2
Strong upper winds but not a well-defined jet stream	10	18	1
Unclassified	14	17	Nil
Total	119	179	25

TABLE 4

Clear air turbulence in association with clouds

	Intensity of CAT		
	Light	Moderate	Severe
Clear skies	70	120	22
Clouds present below CAT level	21	30	2*
Clouds at CAT level but on sides	2	3	0
High clouds (Cirrus family)	17	16	1
Clouds uncertain	9	10	0
Total	119	179	25

*In one case *Cb* was present 3000 ft below the flight level where severe CAT was experienced

regions. These occurred mostly in association with westerly jets and wind discontinuity in association with troughs in westerlies. In some cases extratropical lows moving in westerlies gave rise to easterly to NE strong winds, reaching sometimes 60 to 80 knots, in whose association also the CAT was observed.

Some of the individual cases depicting the occurrence of CAT in association with the pressure systems and wind flow patterns at 300 and 200 mb as applicable will be discussed later in this study.

A distribution of CAT observations with respect to flight levels is shown in Table 1. It shows maxi-

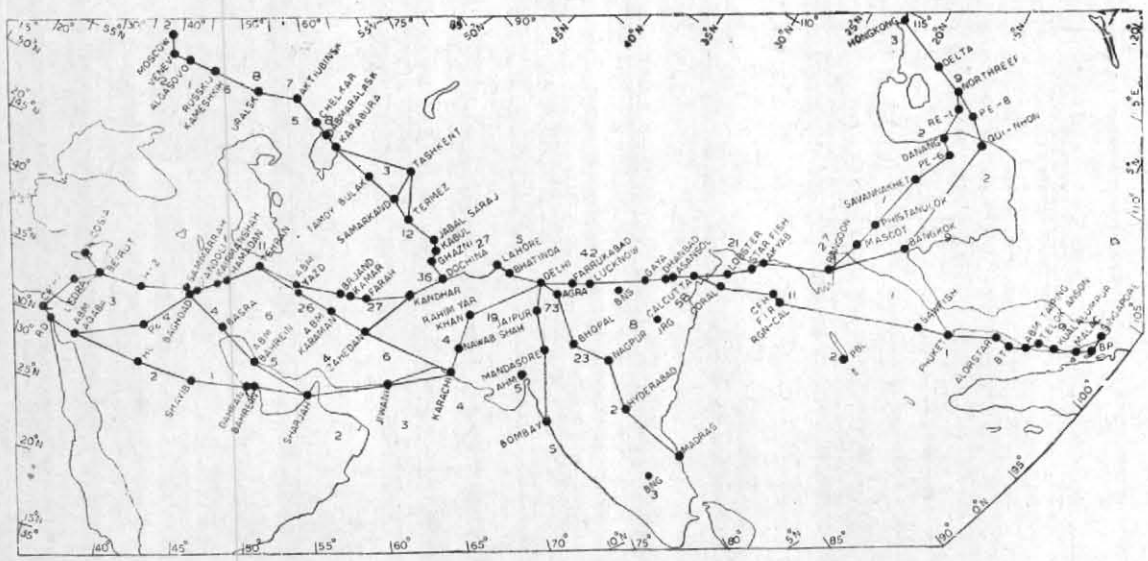

Fig. 1
Space distribution of Clear Air Turbulence (CAT)

mum cases at flight level 330 while about 68 per cent cases lie between flight levels 310 and 350. The occurrence of severe CAT was not reported in this sample below flight level 280. The frequency of severe CAT was more at flight levels 280, 310, 320 and 360 with maximum occurrence at 330.

The frequency distribution of CAT (Table 2) with reference to different months of the year shows maximum occurrence in the month of April though the number of severe CAT is maximum in the month of February.

No severe CAT is noticed in the months of July, August and November, though light and moderate CAT was observed during these months in association with easterlies. As far as severe CAT is concerned, it sharply rises from December to a maximum in February and then falls steadily through March, April and May and sharply diminishes through June to nil in July and August. The second maximum in April is perhaps due to varying synoptic patterns at 300 and 200 mb and consequent withdrawal phase of jet stream from Indian region. A few cases were also available in September and October which were mainly connected with wind discontinuity.

Association of CAT with the weather situations is shown in Table 3. Maximum cases of moderate/severe CAT were observed to be in the vicinity of jet stream. The second maximum occurred in the vicinity of upper air troughs at 300/200 mb. One case of severe turbulence and 18 cases of moderate turbulence were noticed with strong winds (greater than 30 kt but less than 60 kt) but not constituting a well-defined jet stream.

However, several cases of moderate CAT still remained to be classified under special WX situations mostly due to lack of data. In some cases when data were available no definite conclusion could be drawn. Perhaps, orography might have played a role in some of these cases. However, it is a matter of further investigation.

The occurrence of CAT was also studied in relation to the presence of clouds (Table 4) or otherwise. More than 66 per cent cases of CAT were observed under clear skies. In one case of severe CAT the *Cb* was observed to be 3000 ft below the CAT level. One case of severe and 16 of moderate turbulence were observed in *Ci* clouds.

Nearly sixty per cent of total cases of turbulence and about 80 per cent severe turbulence occurred in association with jet streams. A few of the typical cases are discussed below belonging to different types of synoptic situations.

3. CAT in association with jet streams (horizontal and vertical wind shears)

A severe CAT was experienced by IAC between Nagpur and Gwalior at flight level 320 at 1310Z of 12 February 1967. In this case 110 kt westerly jet at 300 mb shifted from 27°N at 00 Z of 12 February to south at about 23°N on 12 Z chart (Fig. 2). However, the jet position at 200 mb (Fig. 3) remained unchanged (*i.e.*, 27°N) from 00 to 12 Z of this date and the strength was over 140 kt. This provided a strong vertical wind shear (8 kt/1000 ft) on the route in addition to the strong horizontal wind shears on both sides of jet stream where CAT occurred. Strong temperature gradient, *i.e.*, about 5°C/100 km at 00Z, 300 mb on the north of the jet

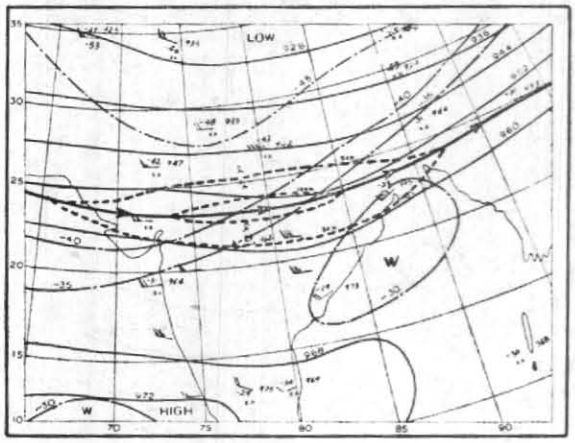

Fig. 2. 300 mb 12 GMT, 12 Feb 1967

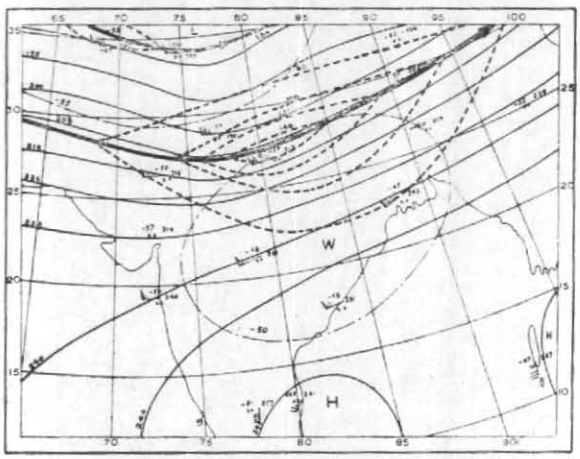

Fig. 3. 200 mb 12 GMT, 12 Feb 1967

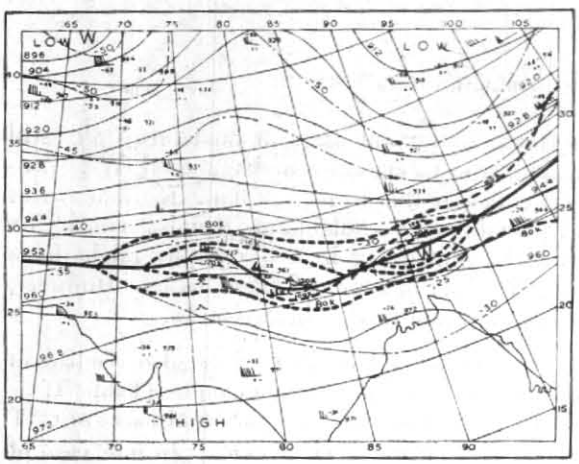

Fig. 4. 300 mb 12 GMT, 26 Feb 1967

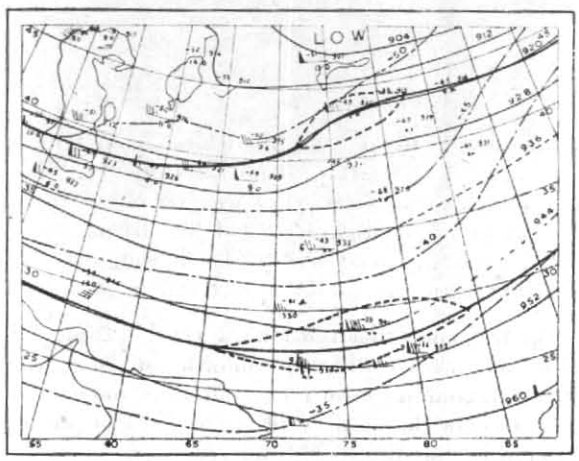

Fig. 5. 300 mb 12 GMT, 21 Apr 1969

shifted to further south at 1200 Z chart with Nagpur temperatures rising by 4°C. Shift of the strong temperature gradient to further south conld be responsible for the shifting of jet maxima southwards at 300 mb chart. While at 200 mb chart (Fig. 3) the temperature gradient of about 5°C/100 km to the south of jet was maintained with warmest temperature occurring just to the south of jet axis along 27°N.

3.1. *Strong low pressure areas movin geastwards*

Turbulence is often experienced in association with steep low pressure areas moving eastwards across the Moscow-Delhi route. These low pressure areas give rise to transitory NE or N' ly jets and also westerly jets even if it does not exist in a normal way. Air India reported turbulence between Uralsk and Karabura at 1200Z at flight level 330 on 3 January 1969. Tubulence occurred all along the trough to the left of it and began at a position where the northeasterly jet almost ended in 300 mb chart of 1200 Z on 3 January 1969. A cold pool of air existed in the region where turbulence began and a warm pool of air at CAT level (*i.e.* FL 330) to the west of low pressure system where turbulence ended.

4. CAT in association with sharp wind discontinuity

Indian Airlines Caravelle reported severe CAT at about 1400Z at flight level 310 for about 150 km between Lucknow and Farrukhabad on 16 March 1969. A steep trough existed near Lucknow on 12Z chart of 16 March 1969 as low pressure area moving from west had weakened into a trough. A steep wind discontinuity existed in the CAT area as the northwesterly 60 kt wind backed to westerey 15 kt at Lucknow. The trough on 300 mb chart moved away eastwards by about 4 degrees Long. by 00Z on 17th.

5. CAT in association with bending of Jet in cyclonic shears and anticyclonic shear

(*i*) IAC reported moderate to severe turbulence between Banaras and Lucknow at flight level 285 at 1255 Z on 26 February 1967.

(*ii*) IAC reported moderate to severe turbulence over Jaipur at flight level 330 and slight over Mandasore at 1530 Z on 26 February 1967.

Jet core of maximum winds over Delhi of about 155 kt passed through Banaras and further eastwards at 300 mb of 26th to about 20 kt. Hence this CAT exists in the cyclonic shear of jet.

While between Delhi and Jaipur a strong anticyclonic shear of the order of 20 kt/100 km exists on 300 mb 1200Z chart of 26th (Fig. 4) and severe CAT is experienced over Jaipur. Thereafter the winds quickly fell in strength towards Mandasore, where, only slight CAT was experienced.

6. Severe CAT in weak wind fields in association with jet

6.1. *CAT in association with sharp horizontal wind shear*

Air India 136 from Cairo-Delhi reported seven CAT at flight level 330 at 1930 Z between Multan and FIR DLH on 21 April 1969. Though the wind reported at the time of CAT occurrence was only westerly 35 kt, it is apparent from the 300 mb charts of 12Z of 21 April 1969 (Fig. 5) and 00 Z of 22 April 1969 (Fig. 6) that there existed a strong horizontal (cyclonic) wind shear in the area of CAT which had strengthened with time as the jet maxima had moved further north by 00Z of 22nd by about 100 km. It is also worth noting that the temperatures had showed a rise, with the passage of time but the temperature gradient had increased considerably in the CAT region.

6.2. *CAT in association with vertical wind shear*

(*i*) Air India reported moderate CAT between 0100 and 0230Z from Uralsk to Termez at flight level 328 on 23 May 1969.

(*ii*) BOAC flight experienced severe CAT from Birjand to Kandhar at 2345Z at flight level 330 on 22 May 1969.

It is apparent from 00Z 300 mb chart of 23 May 1969 (Fig. 7) that a 110-kt strong westerly jet exists just north of Uralsk. Winds rapidly weaken to south along route with anticyclonic shear of the order of 8 kt/100 km upto Karabura and thereafter the westerlies veer to northwesterly and weaken further near Termez along the trough.

A comparison with 200 mb chart (Fig. 8) of 00Z showed southward shift of the jet axis dipping further southwards along the route near Karabura, about 65°E along the route. The windfield at 200 mb was weaker than that at 300 mb over Termez onwards the winds at 200 mb again strengthened into a westerly jet of 120 kt. Thus the wind field was changing all along the route and CAT was experienced after Karabura upto Termez

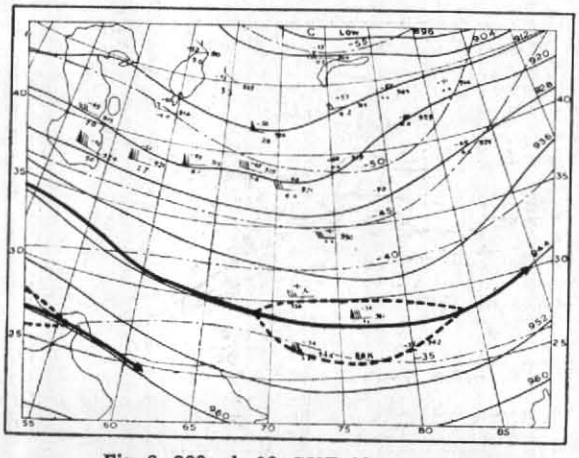

Fig. 6. 300 mb 00 GMT, 22 Apr 1969

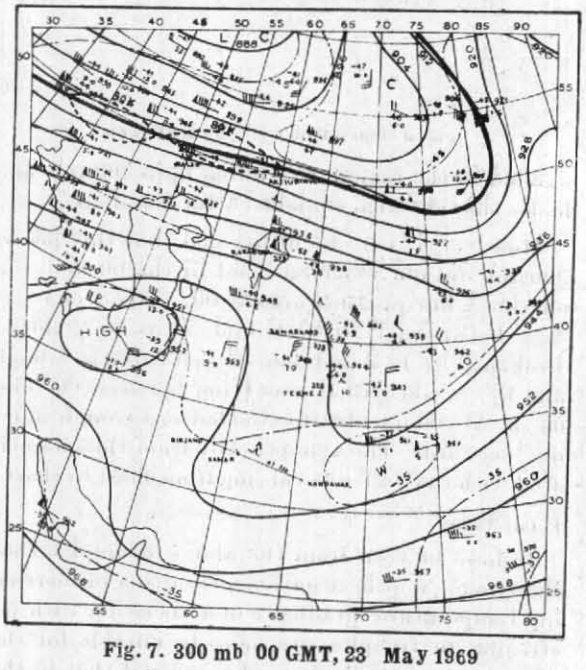

Fig. 7. 300 mb 00 GMT, 23 May 1969

and beyond at flight level 328. At Termez the flight ascended to level 370 and entered a warm pool of air where the turbulence ended. Further onwards at Kabul the temperature at flight level 370 rose by 5°C and confirmed the existence of a a warm pool of air at 200 mb (Fig. 8) which was continuous down to 300-mb level also.

(*ii*) On 23 May 1969 (Fig. 7) a steep trough existed from SW to NE with axis about 63 °E along the route from Tehran to Delhi. The CAT was experienced on both sides of this trough. No jet existed in this area at 300 mb chart and the wind field was weak; but over 200 mb chart (Fig. 8) of the same time 120-kt strong westerly jet was present which was responsible for producing vertical wind shear of about 8kt/1000′ in the region of CAT. Temperatures were rising along the route from 65°E onwards as warm pool

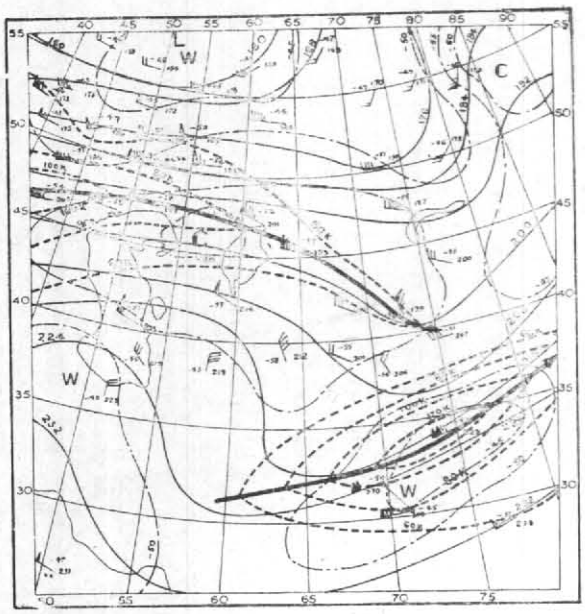

Fig. 8. 200 mb 00 GMT, 23 May 1969

existed in the region extending upto 200 mb and hence the CAT also vanished after Kandhar.

However, it may be mentioned that this jet at 200 mb did not exist on 22nd in the 00 and 12Z charts. A low pressure area at 00Z 300 mb chart of 22nd between 53° to 57°E and 30° to 35°N slowly weakened by 12 Z and moved eastwards as trough and by 00 Z on 23rd, it was lying between 60° and 65° E. At 200 mb also it extended as a trough moving eastwards. The synoptic situation thus associated with the CAT was varying from chart to chart.

7. Conclusion

It may be seen from the above examples that changing synoptic situations, resulting in increasing temperature gradients in association with jet streams or troughs, are more favourable for the occurrence of CAT. It is also noticed that in the regions of warm air or isothermal layers the CAT diminishes in strength and afterwards vanishes.

Situation with synoptic features like jet trough or strong winds over mountains or high ground were more favourable areas for the occurrence of CAT. Areas where the jet showed bending or spliting were also found to be favourable for CAT occurrence.

Severe CAT is also observed to occur not only in the regions of strong winds associated with the jet but also in the vicinity of jet where comparatively weaker wind field with strong wind shear exists.

In the easterlies (slight) CAT has occurred even in relatively weaker wind fields.

In order to forecast CAT, it is essential to forecast the synoptic patterns accurately at a particular time and place and also the associated temperature patterns.

Since the CAT is a very transitory and short-lived phenomenon at a particular place its areas are only a few 100 km in length and few km in breadth and a few thousand feet in thickness. Discussions with various Commanders of national and international flights reveal that on several occasions it escapes detection. There were occasions when a second flight traversing the same route after a couple of hours of the report of CAT does not find its existence. Since the charts of 500-300 and 300-200 mb are separated by about 10,000-ft thick layers it becomes difficult to study the exact nature of CAT and determine the exact quantity of vertical wind shear or temperature gradient essential for CAT occurrence. Similarly, the sparse network of RS/RW stations over India and neighbourhood makes it difficult even to find exact values of horizontal and vertical temperature and wind gradients essential for CAT occurrence. However under such circumstances the aircraft observations are of great help in filling the gap and determining at least qualitatively the nature of this phenomenon even though the nature of data thus available is selective in terms of reporting points and flight levels.

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