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A study of high level Clear Air Turbulence reports received from aircraft

N. C. RAI SIRCAR and K. P. VARGHESE

Regional Meteorological Centre, Bombay

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ABSTRACT. In this paper, a study has been made of the high level clear air turbulence reports received from jet aircraft in relation to the wind field at the cruising levels. It is seen that such turbulence is mainly experienced near trough lines and in areas having large east-west wind gradient. Charts showing the various types of situations leading to the generation of the clear air turbulence have been presented and discussed in some detail. The illustrations may be of use to forecasters in indicating this hazard in weather forecasts supplied for the operations of jet aircraft on the international routes passing over Bombay.

1. Introduction

The occurrence of turbulence in the lower and middle troposphere has normally a dual origin—orographic and thermal. The former type is usually confined to only a few thousand feet above the ground. In the case of mountain waves, it may, however, extend to a high level depending on the elevation and orientation of the mountains. The thermal type, on the other hand, originates in the convection currents produced by thermal instability. This latter type of turbulence is ordinarily associated with large Cumulus or Cumulonimbus clouds and may be sometimes felt even upto 30,000 ft particularly in the tropics. The pilots can avoid such turbulence by avoiding flying through convective clouds. High level aviation has revealed that flying conditions may also be bumpy even in the higher troposphere where the sky is either clear or covered with cirrus clouds. This type of turbulence is commonly known as clear air turbulence. Clear air turbulence may be experienced at lower levels also but in the present study only such cases as were present in levels above 30,000 ft have been considered.

Although clear air turbulence is less intense and risky than that which may be found in active Cumulonimbus clouds, it may nevertheless cause the air travel very uncomfortable particularly when the speed of aircraft is high. It may also be mentioned that such turbulence is encountered suddenly and unexpectedly without any visual warning as is provided by the presence of convective clouds in the case of thermal turbulence in the lower levels. It is, therefore, very desirable that weather forecasts supplied for the operations of jet aircraft indicate the areas likely to have clear air turbulence. In order to be able to supply such information with confidence, a study of the available turbulence reports with reference to the prevailing wind circulations may be found very useful. The in-flight and post-flight aircraft reports are the only source from which clear air turbulence reports are available. The ICAO also appreciated the importance of such a study and, therefore, recommended that all pilots should record detailed information relating to turbulence whenever encountered in flight and report the same to Meteorological Offices. Unfortunately, response from most of the international airlines in this regard is not quite encouraging. However, during the past few years a fairly good number of turbulence reports were received from the Air India International (AII) Boeing 707 flights at levels between 30,000 ft and 40,000 ft and these reports have been studied in this paper.

Clear air turbulence would appear to arise from internal friction of the atmosphere leading to breakdown in the smooth flow. This may occur when the rate of change of wind with height surpasses a certain limit or when the rate of change of wind with the horizontal distance becomes sufficiently great. Due to paucity of upper air stations in the area under study, the authors, for the purpose of the study, had to rely mainly on the wind data received from aircraft reports. Such data are available for only one level, namely, the cruise level and therefore a study of the vertical wind shear has not been possible. It may be mentioned that all the turbulence reports available for this study were recorded in areas having changes in wind speed or direction or both at the flight level. The speed changes were either in the direction of the wind flow or at right angle to it. The directional changes were associated with high level troughs. Some typical instances are illustrated below and discussed in some detail.

2. Turbulence associated with a trough line

(*a*) On the night of 18 November 1962 there were two Air India International Boeing flights—one from Cairo and the other from Aden. The details of the flights are as follows—

Flight No.	106/90	210/90
Flying level	34000 ft	36000 ft
Captain	Hirani	Bhatia
Departure Cario/Aden	1949 GMT on 8-11-62	2102 GMT on 8-11-62
Arrival Bombay	0040 GMT on 9-11-62	0030 GMT on 9-11-62

The flight from Cairo reported severe turbulence near Muscat while that from Aden commenced experiencing moderate turbulence shortly after take-off and continued to experience the same upto about longitude 58°E. The wind and temperature reports received from the flights are plotted in Fig. 1 (a). The 0000 GMT upper air data for 300-mb level received from the radiosonde stations in the area concerned are also plotted on the same chart. It is seen that a sharp trough line passed through the turbulence area. The upper winds to the west to this line were westerly or northwesterly while those to the east were southwesterly. The wind shift was more marked near the spot where the severe turbulence was experienced. From the altitudes of these two flights it would appear that the turbulence layer was over 2000 ft deep.

(*b*) Turbulence reports were also received from a west-bound flight on the night of 23 December 1960. The details of the flight are given below—

Flight No.	111/103
Flying level	36000 ft
Captain	Bilimoria
Departure Bombay	1940 GMT on 23-12-60
Arrival Beirut	0115 GMT on 24-12-60

The data received from the above flight are plotted in Fig. 1(b). It is seen that turbulence occurred in the region of the trough line and it was severe close to the trough line while moderate slightly away from the above line. The turbulence was apparently due to the large wind shift (in both speed and direction) caused by the well-marked upper air trough.

(*c*) Another interesting instance showing severe turbulence reports near the trough line is shown in Fig. 1(c). The flight was from Bombay to Aden on 20 December 1962 during the period 0705 to 1105 GMT. Captain Pedder was the commander of the flight. Clear air turbulence was experienced by him between 64° and 60° E at flight level 35,000 ft and also at 39,000 ft. It is thus seen that the turbulence layer was more than 4000 ft in depth in this particular case.

3. Turbulence associated with strong horizontal wind shear (east-west)

(*a*) On the night of 5 February 1962, a flight from Cairo reported turbulence at a height of 42,000 ft over the Arabian Sea

Fig. 1(a)

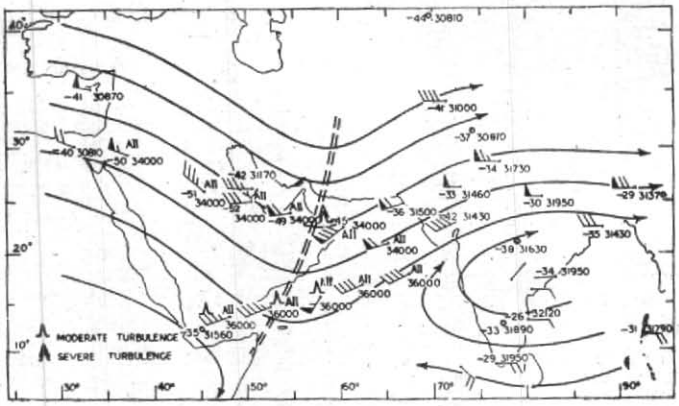


Fig- 1(b)

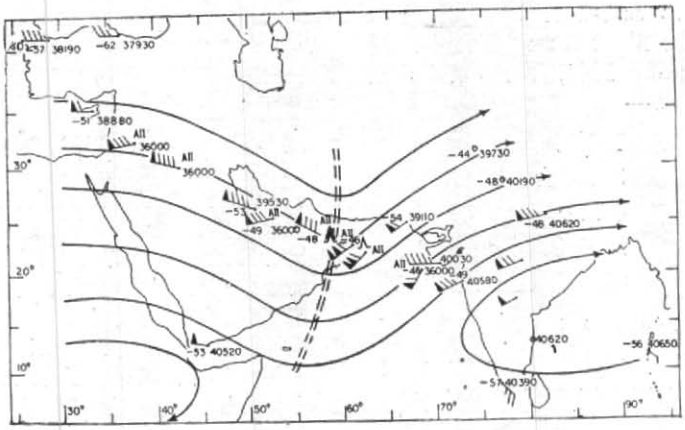
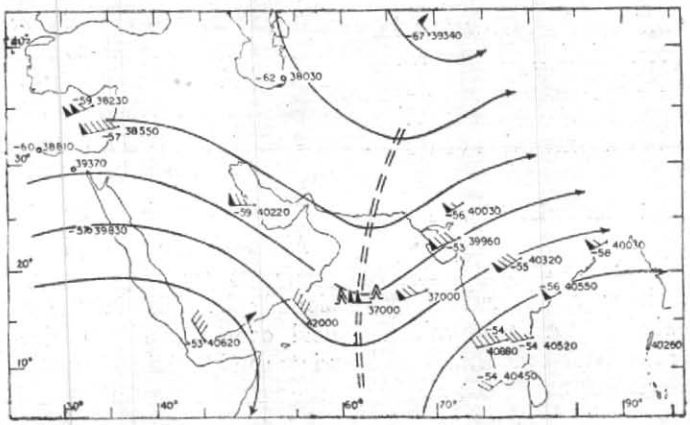


Fig. 1(c)



Figs. 1(a) to 1(c). Turbulence in association with trough line

off Muscat. The following are the details of the flight—

Flight No	116/10
Flying level	38000 to 42000 ft
Captain	Bose
Departure Cairo	1949 GMT on 5-2-62
Arrival Bombay	0021 GMT on 6-2-62

The aircraft reports are plotted in Fig. 2(a). It is seen that there was strong east-west wind gradient (about 22 knots per degree longitude) in the area of turbulence. Elsewhere, the gradient was relatively much low and no turbulence was also experienced.

(*b*) Another interesting instance of turbulence due to east-west wind shear is available from the flight from Cairo on the night of 15 March 1961, the details of which are as below—

Flight No.	106/22
Flying level	38000 ft
Captain	Gilder
Departure Cairo	2245 GMT on 15-3-61
Arrival Bombay	0305 GMT on 16-3-61

Severe turbulence was experienced once just west of Bahrein and again over the Arabian Sea as shown in Fig. 2 (b). It is seen that strong east-west wind shear was present at both the spots of turbulence and absent elsewhere. At the spot west of Bahrein, there was also directional shear in addition to considerable east-west wind gradient. The accumulation or removal of air into or from a region due to strong east-west wind gradient causes vertical motions resulting in the generation of turbulence.

4. Turbulence associated with horizontal wind shear (north-south)

(*a*) As most of the international flights over Bombay are either west-bound or east-bound, sufficient wind data are not available for proper study of the north-south horizontal wind shear. Two instances of turbulence of this type are shown in Fig. 3 (a). The two turbulence reports were received from two different planes, their particulars being as follows—

Flight No.	116/02	108/62
Flying level	38000 ft	38000 ft
Captain	Dhillon	Birdi
Departure Cario/Bahrein	2005 GMT on 7-1-63	0201 GMT on 8-1-63
Arrival Bombay	0027 GMT on 8-1-63	0450 GMT on 8-1-63

The two turbulence reports from the same area and from two different planes confirm the correctness of the observations and the fact that the area was really having turbulence. The data are plotted in Fig. 3(a) and it is seen that the isotachs ran nearly east-west and were more crowded in the area of turbulence where the north-south wind shear was about 10 knots per degree latitude.

(*b*) Another instance of turbulence encountered in association with high north-south wind gradient is given in Fig. 3 (b). Captain Screwwala on his flight over Cairo-Palam-Bombay route experienced turbulence once near Sharjah and again near Baroda. The aircraft left Cairo at 2210 GMT of 9 February 1963 and arrived at Bombay at 0545 GMT of 10 February 1963. The cruise height was 34,000 ft between Cairo and Palam and 31,000 ft between Palam and Bombay. The turbulence near Sharjah was due to the presence of a trough line there, while that near Baroda was associated with strong north-south wind gradient. The wind near Surat was 60 knots while that at Ahmedabad was 105 knots. Thus a strong gradient of about 20 knots per degree latitude was present over this area.

5. Turbulence associated with light variable winds

Although the winds in the higher troposphere are generally strong, these may occasionally be light in the anticyclonic wind field over the Bay of Bengal during the winter and transition months. Two instances of turbulence experienced in the region of light variable winds over the central Bay of Bengal are shown in Figs. 4(a) and 4(b).

Fig. 2(a)

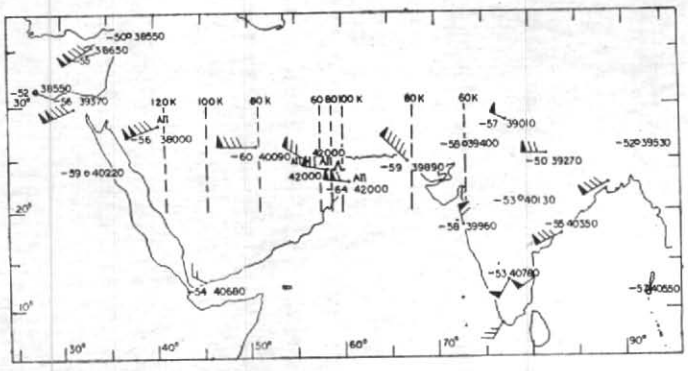
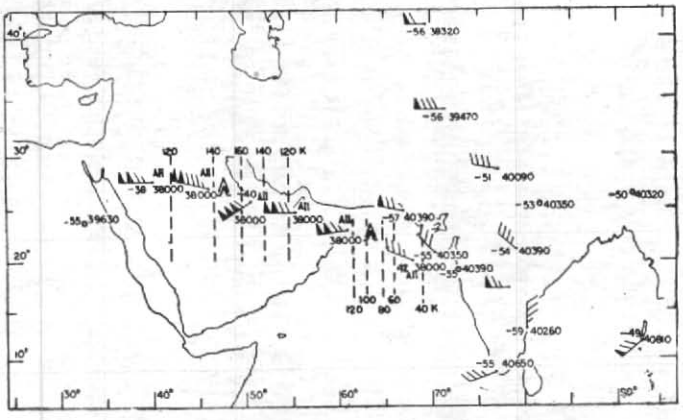


Fig. 2(b)



Figs. 2(a) and 2(b). Turbulence associated with strong East-West wind gradient

The reports were received from two Bangkok-Bombay flights, details of which are given below—

Flight No.	407/01	407/05
Flying level	32000 ft	32000 ft
Captain	Mistry	Hirani
Departure	1345 GMT	1429 GMT
Bangkok	on 9-1-63	on 16-1-63
Arrival	1722 GMT	1814 GMT
Bombay	on 9-1-63	on 16-1-63

It is seen from Fig. 4(b) that the Captain experienced severe turbulence in the region of light variable winds. This would suggest that large change in the direction may cause considerable vertical motion even though the wind speed may not be strong. It would have been interesting to study if the vertical wind shear had any contribution towards the development of severe turbulence in this particular case but unfortunately the necessary data are not available.

6. Frequency of occurrence of turbulence of the different types

In the present study, the cases of turbulence of moderate and severe intensities alone have been taken into account. According to the international definitions, turbulence is said to be (*i*) light when it is only perceptible, (*ii*) moderate when it is found difficult to walk in the plane and (*iii*) severe when loose objects become dislodged. Pilots do not usually record light turbulence for which no symbol has also been assigned by the W.M.O. Further, vibrations or light turbulence may also be experienced when the functioning of the engine or the structural design of the plane is not perfect.

Fig. 3(a)

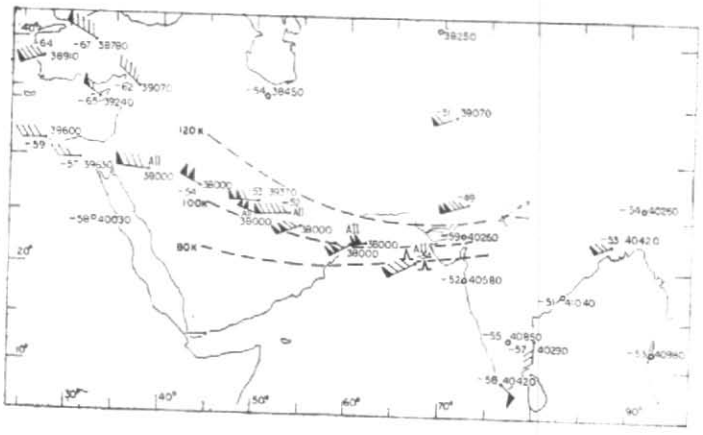
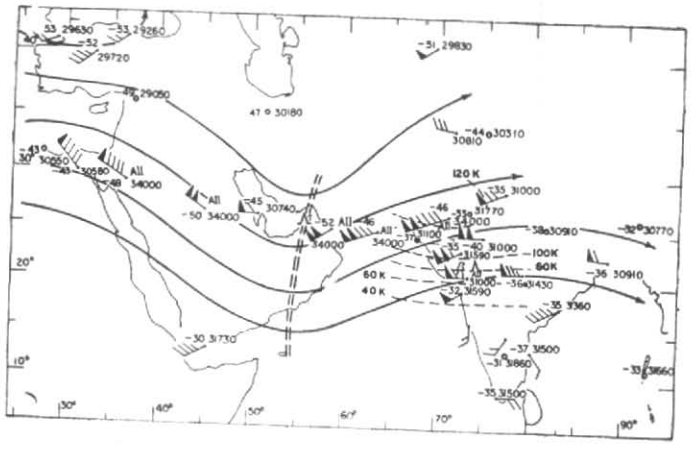


Fig. 3(b)



Figs. 3(a) and 3(b). Turbulence associated with strong North-South wind gradient

In all, 85 reports have been examined in this study and the statistics are given in Table 1. It will be seen that 56 per cent of the reports were associated with trough lines, about 24 per cent with strong east-west horizontal wind shear, about 14 per cent with strong north-south horizontal wind shear and about 6 per cent with light variable winds. A good number of the turbulence reports received from areas with a trough line or high east-west wind gradient was severe.

7. Conclusions

The statistics in Table 1 would suggest that the region in the neighbourhood of a trough line is the most favourable area for development of clear air turbulence. The meteorological department of the Trans-World Airlines, U.S.A. has made a study of the clear air turbulence reports received from their flights. They have also noticed that turbulence is quite common in the vicinity of trough lines and the severe ones too, usually occur in these areas. Near a trough line, wind change occurs both in direction and speed and this helps development of strong vertical motion. Therefore, if a well-marked trough line is present at 300 and 200-mb levels, a forecaster can confidently indicate the possibility of turbulence near this line in the flight forecasts supplied for jet planes.

Next to trough lines, the areas with strong

Fig. 4(a)

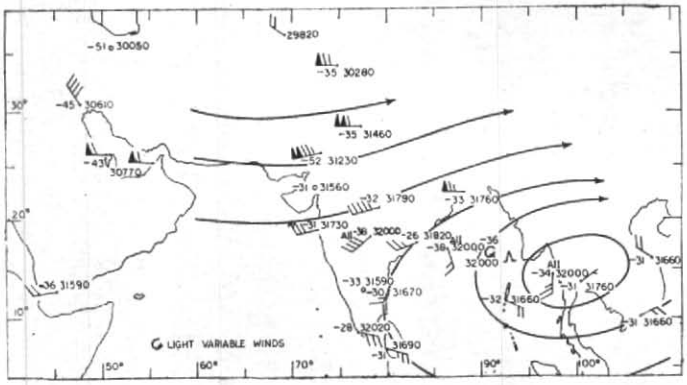
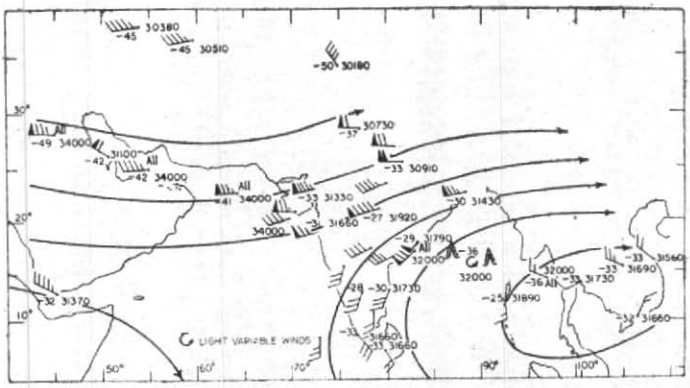


Fig. 4(b)



Figs. 4(a) and 4(b). Turbulence in association with light variable winds

east-west wind shear appear to be the most susceptible spots for development of turbulence. From the instances of turbulence reports of this type examined in this note, it is seen that the east-west wind shear varied widely from 6 knots to 22 knots per degree longitude, the average being about 12 knots.

The number of available turbulence reports due to north-south wind shear is only 12. Strong north-south shear is usually associated with a jet stream. The subtropical jet is located close to and north of the Bombay-Cairo route, causing strong north-south wind shear practically all along this route on most days during the winter season. It is rather surprising that pilots do not experience turbulence on this route on many days. When it occurs, it occurs only at one or two isolated spots, instead of along the whole route. One of the authors of the present note went on a proving flight to Cairo in an Air India International Boeing plane. There was a well-marked jet stream just north of the route, the maximum wind speed recorded by the captain enroute being 150 knots near Bahrein. The cruise height was 38,000 ft. The flight, in fact, was very smooth without any turbulence anywhere. Therefore, the general notion that turbulence should normally be expected near a jet stream deserves more detailed

TABLE 1

Statistics of Clear Air Turbulence of the various types

Type of upper air situations	No. of severe turbulence reports	No. of moderate turbulence reports	Total
Trough line	16	32	48
East-west wind gradient	8	12	20
North-south wind gradient	3	9	12
Light variable winds	2	3	5
Total	29	56	85

TABLE 2

Statistics of occurrence of turbulence in Cirrus clouds

Type of upper air situations	No. of turbulence reports under different amount of *Ci* clouds			
	Nil	1-2/8	3-5/8	>5/8
Trough line	24	19	4	1
East-west wind gradient	11	7	1	1
North-south wind gradient	7	3	2	0
Light variable winds	2	3	0	0
Total	44	32	7	2

examination. Since wind speed drops off more rapidly to the north than to the south of the sub-tropical jet stream and the shear is cyclonic to the north, turbulence should be expected to be more frequent on the northern side of it. But due to few flights and lack of aircraft reports from the above area, this aspect could not be examined in this study.

Turbulence due to light variable winds can occur only over the Bay of Bengal and only during the winter and transition seasons. During the monsoon months strong easterly winds prevail over the above area in the high levels. Light variable winds at 30,000 or 40,000 ft over the Bombay-Cairo route and the neighbouring areas are very rare and as such this type of turbulence can hardly be expected there.

It has also been examined whether horizontal temperature distribution had any bearing on the development of turbulence but the instances studied in this note do not provide any clear indication in support of the existence of any such significant relationship.

According to a recent study of high level turbulence reports by the Trans-World Airlines, U.S.A., more turbulence may be expected in Cirrus clouds than in clear air. This aspect has also been examined in this paper. Table 2 gives statistics of occurrence of turbulence when (*i*) the sky was clear, (*ii*) covered with 1-2/8 Cirrus, (*iii*) covered with 3-5/8 Cirrus and (*iv*) covered with more than 5/8 Cirrus. It will be seen that as many as 76 out of the total of 85 reports were received from areas which were either clear or only lightly clouded (1-2/8th) with Cirrus clouds. Thus, the findings of the authors of the present paper is different from that of the T.W.A., so far as the possibility of occurrence of turbulence in Cirrus clouds is concerned.

8. Acknowledgement

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