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Low level wind shear over Bombay airport

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सार — इस पत्र में, बम्बई हवाई अड्डे की 1985 से 1989 तक 329 निम्नस्तरी पवन अपरूपण (एल. एल. डब्ल्यू. एस.) रिपोर्टों पर आधारित महत्वपूर्ण जलवायुविक लक्षण प्रस्तुत किए गए हैं। मानसून ऋतु में एल. एल. डब्ल्यू. एस. नामक घटना की अधिकतम आवृत्ति, मुख्यतः तड़ित झंझाओं और झोंकेदार तेज हवाओं के कारण हुई है। मानसून ऋतु के अतिरिक्त, एल. एल. डब्ल्यू. एस. की घटना समुद्र और स्थल समीर तथा रात्रि के दौरान सतही तापमान की रात्रिचर वृद्धि से संबंधित है। एल. एल. डब्ल्यू. एस. की घटना का वरीय समय 0000 से 0600 भा.मा.स. और 1800 से 2400 भा. मा. स. के मध्य है। प्रबल और प्रचण्ड एल. एल. डब्ल्यू. एस., निम्न मेघ छादन और न्यूनतम दृश्यता की समकालिक घटनाएं, बम्बई हवाई अड्डे पर वायुयान के उड़ान भरने और उतरने के समय वायुयान के प्रचालन पर प्रतिकूल प्रभाव डालती हैं।

ABSTRACT. Significant climatological features based on 329 Low Level Wind Shear (LLWS) reports from 1985 to 1989 at Bombay airport are presented. The monsoon season has the highest frequency of occurrence of LLWS mainly due to thunderstorms and strong gusty winds. Other than monsoon season, occurrence of LLWS is related to sea and land breeze and nocturnal increase of surface temperature during night. The preferred time of occurrence of LLWS is between 0000 to 0600 IST and 1800 to 2400 IST. The simultaneous occurrence of strong and severe LLWS, low cloud ceiling and very poor visibility has an adverse effect on aircraft operations at Bombay airport during landing and take-off.

Key word — Low level wind shear (LLWS), Land breeze, Sea breeze, Thunderstorm, Bombay airport.

1. Introduction

Low Level Wind Shear (LLWS) in the lowest layers up to 500 m from the ground affect the aircraft landing and take-off operations at the aerodrome. The presence of well marked and severe wind shear in final approach path and the take-off and final climb out areas has been the cause of many fatal aircraft accidents world over.

At present there is no instrumental system at Bombay airport for detection and measurement of low level wind shear. The aircrafts during landing and take-off if encounter LLWS are required to report it to the control tower. The wind shear information reported by aircrafts is included as supplementary information in the current weather reports.

LLWS has been taken as the wind shear reported by aircraft along the final approach path or along the runway and the take-off and initial climb out area.

Pending the development and provision of reliable instrumentation for monitoring LLWS, forwarning for significant LLWS cannot be given by the forecaster. However, a comprehensive analysis of wind shear reports may reveal characteristics of LLWS at Bombay airport.

The present study aims at analysing the wind shear reports over five years from 1985 to 1989 to identify the types of LLWS, their diurnal and seasonal variations and their association with the weather systems. For this purpose the current weather register of Bombay airport for the five years period from 1985 to 1989 were utilized. 329 wind shear reports were identified which were analysed in detail to determine the climatological feature of LLWS over Bombay airport. LLWS reports may have a bias towards the period and day when bunching of flights takes place. It is also dependent on the alertness of the pilots to describe precisely the encounter of LLWS.

2. Features of LLWS

2.1. *Level of wind shear*

LLWS was reported at levels from the 15 to 900 m above ground level during final approach of the aircrafts on RWY 27 and RWY 09.

Table 1 gives the frequency of LLWS in various layers. Each LLWS report has been considered as a separate occurrence. It may be seen the frequency is maximum in the layer between 60 and 150 m followed by significantly higher values in the layers from 150 m to 300 m.

TABLE 1

Levels at which LLWS reported at Bombay airport during the period 1985-1989

	Reported levels					
	Ground to 60 m	60 to 150 m	150 to 300 m	300 to 600 m	600 to 900 m	At final approach sector RWY 27
No. of LLWS reported by aircraft	21	54	46	17	6	185

2.2. *Character of low level wind shear*

LLWS reports were classified into four categories: light, moderate, strong and severe following the recommendation of fifth Air Navigation Conference :

Character	*Description*
Light	0-4 kt inclusive per 30 m
Moderate	5-8 kt inclusive per 30 m
Strong	9-12 kt inclusive per 30 m
Severe	above 12 kt inclusive per 30 m

The montly frequency of the LLWS of various categories are presented in the Table 2. The monthly mean frequency of occurrence of LLWS is 5.5. The highest number of occurrence is seen in the month of July followed by August.

TABLE 2

LLWS reported by aircrafts at Bombay airport during the period 1985 - 1989 (monthwise frequency)

Month	No. of occasions when LLWS reported					Frequency per month
	Light	Moderate	Strong	Severe	Total	
Jan	6	Nil	6	Nil	12	2.4
Feb	7	4	9	2	22	4.4
Mar	7	3	13	3	26	5.2
Apr	10	2	2	6	20	4.0
May	10	2	Nil	1	13	2.6
Jun	13	5	8	4	30	6.0
Jul	31	9	19	15	74	14.8
Aug	30	1	6	4	41	8.2
Sep	11	Nil	2	Nil	13	2.6
Oct	9	Nil	3	1	13	2.6
Nov	15	7	13	3	38	7.6
Dec	10	5	12	Nil	27	5.4
Total	159	38	93	39	329	5.5

Even when there have been reports of strong LLWS by few aircrafts on a particular day or night the other aircrafts have not reported LLWS during the same day or night. This indicates that LLWS is transitory in nature.

2.3. *Diurnal distribution of LLWS*

Table 3 gives the frequency distribution of LLWS during different times of the day. It is seen from the table that the frequency shows maximum of 65 in the late night. The most probable time of occurrence is between 1800 and 0600 IST of the next day. However, the bunching of flights at Bombay airport might have some effect on this frequency distribution.

TABLE 3

Three hourly frequency of LLWS at Bombay airport

Time (IST)		No. of occasions				
From	To	Light	Moderate	Strong	Severe	Total
0001	0300	29	5	18	13	65
0301	0600	20	6	25	5	56
0601	0900	9	6	7	2	24
0901	1200	17	3	12	2	34
1201	1500	12	5	10	2	29
1501	1800	17	5	9	3	34
1801	2100	31	2	2	2	37
2101	2400	24	6	10	10	50
Total		159	38	93	39	329

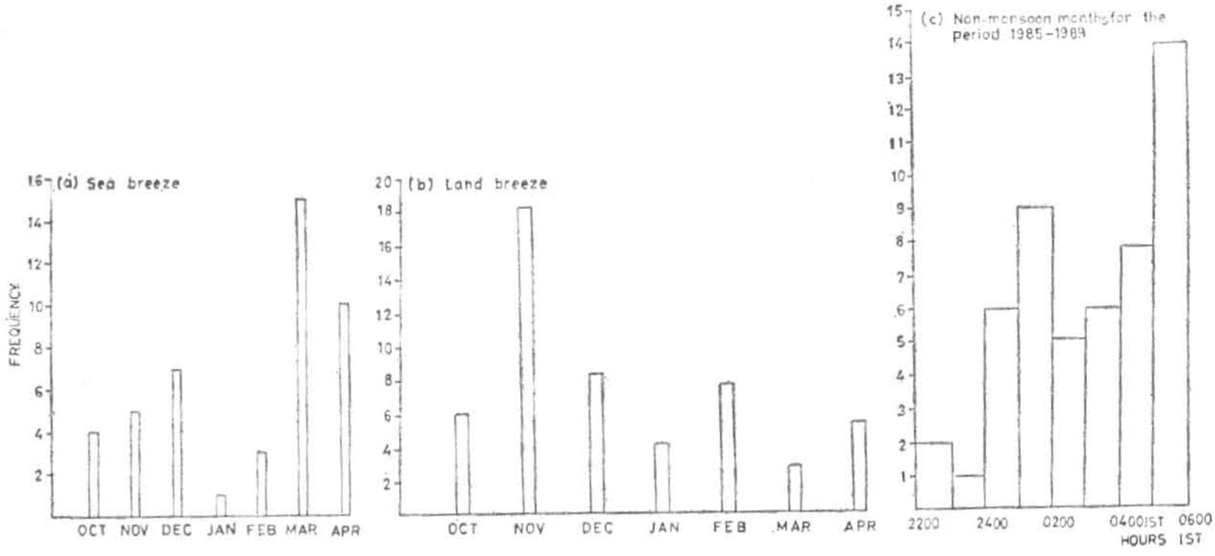
2.4. *Seasonal distribution of LLWS*

Table 4 gives the frequency of occurrence of LLWS during different seasons of the year. The monsoon season shows highest number of occurrence followed by post-monsoon season.

TABLE 4

Seasonal distribution of LLWS

Season	Frequency				
	Light	Moderate	Strong	Severe	Total
Winter (Jan & Feb)	13	4	15	2	34
Summer (Mar-May)	27	7	15	10	59
Monsoon (Jun-Sep)	85	15	35	23	158
Post-monsoon (Oct-Dec)	34	12	28	4	78



Figs. 1(a-c). Monthwise frequency of LLWS associated with : (a) sea breeze, (b) land breeze, and (c) hourly frequency of LLWS associated with land breeze at Bombay airport during non-monsoon months for the period 1985-1989

2.5. *Some typical wind shear reports and comparison of surface wind data recorded at RWY 27, RWY 09 and P.T.D. anemometer*

Case (i) — Date 28 May 1985 "wind shear at final approach RWY 27" reported by SU-338/IC-166 at 1820 IST.

Wind recorded at	*1730 IST*	*1820 IST*	*1830 IST*
RWY 27 (6 m)	180/27 kt	180/14 kt	180/10 kt
RWY 09 (6 m)	200/20 kt	190/26 kt	180/18 kt
P.T.D.A. (18 m)	200/12 kt	200/12 kt	200/11 kt

Case (ii) — Date 4 July 1985 " wind shear in approach sector RWY 27'' reported by AI-204/707 at 1042 IST.

Wind recorded at	*1030 IST*	*1042 IST*	*1130 IST*
RWY 27 (6 m)	240/18 kt	250/22 kt	260/18 kt
RWY 09 (6 m)	240/14 kt	300/24 kt	240/14 kt
P.T.D.A. (18 m)	250/11 kt	250/13 kt	250/09 kt

Case (*i*) and (*ii*) show the occurrence of horizontal and vertical shears with magnitudes 4.5 kt/km and 4.5 kt/6 m respectively.

3. Weather systems associated with LLWS

3.1. *Land-sea breeze systems*

3.1.1. *Sea bre eze* — Over Bombay airport, adjacent to Arabian Sea, sea breeze and land breeze circulation and their transition from one to the other are expected to lead to considerable wind shear in the lower levels.

Mukherjee *et al.* (1985) have studied land breeze and sea breeze at Bombay. Table 5 gives the time of onset and duration of sea breeze during non-monsoon months. The surface wind at Bombay is westerly throughout the day during the months May-September and hence land breeze and sea breeze effects cannot be separated. The association of sea breeze and LLWS during non-monsoon months is given in Fig. 1(a). It is seen that the highest number of occurrence in the month of March is closely followed by April. The sea breeze is mainly associated with light to moderate LLWS (Table 3).

TABLE 5

Average time of onset and duration of sea breeze at Bombay airport (Santacruz) (value are rounded of to the nearest hour)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Time (IST)	14	14	14	13	13	12	12
Duration (Hrs)	8	7	7	6	8	9	9

3.1.2. *Typical case* — On 24 March 1987 light wind shear was reported at 1200 IST by an aircraft. Examination of autographic records at Santacruz for 24 March 1987 showed that onset of sea breeze occurred at 1145 IST when wind direction changed from ESE to WSW with wind speed 08 kmph to 10 kmph respectively as shown in Fig. 2(a).

3.1.3. *Land breeze* — It is obvious that land breeze is lighter than sea breeze. Still it is associated with marked or strong LLWS.

Due to ground friction the wind very near to the ground is light and there is LLWS close to the ground. Normally coupling between air layer, in a nocturnal ground inversion formed due to radiative cooling on a clear winter night, is reduced to nil. With the result the momentum lost due to surface friction at ground is not readily replaced from layers above. Therefore, wind at the ground during night decreases sharply to calm or light variable and the wind above increases at the time to double the gradient wind as suggested by Blackadar (1957) The wind shear increases with the progress of night [Fig. 1(c)]. Thus, there is an in-built system of LLWS at night.

At night the land gets cooled faster than sea. If the pressure at sea level between land and sea remains same, at some height above, the pressure over land is reduced and the air at that level travels from sea to land.

This causes increase in pressure at a lower level over land. Air moves from land to sea. But due to strong friction near the ground the land breeze circulation starts a bit above ground. At the lowest level at Bombay heat island develops (Mukherjee and Daniel 1976). This causes urban wind at night which is northerly at Bombay airport. Mukherjee *et al.* (1985) found that at Bombay during night the wind direction changes from northwesterly to northeasterly in two pulses. In the first pulse the change is northerly direction due to urban wind and the second it is northeasterly owing to onset of land breeze. The mean time of these pulses are shown in Table 6. Land breeze is from northeast and completely sets in after the second pulse. It is at the time of onset of land breeze that the LLWS becomes strong. Normal direction at 150 m asl at Bombay during October to April is northeasterly. Land breeze added to these makes the LLWS strong enough to be felt by an aircraft.

TABLE 6

Time (IST) of change in wind direction at Bombay

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	
1st pulse	—	24	22	22	22	02	02	At night
2nd pulse	24	04	24	01	04	04	04	

From mid-night to 0600 IST the occasions of strong LLWS are quite high (Table 3). The association of land breeze and LLWS during non-monsoon months is given in Fig. 1(b). It is seen that highest number of occurrence in the month of November followed by December. Fig. 1(c) gives the frequency distribution of LLWS associated with land breeze during night/early morning in the non-monsoon months. The preferred time of occurrence of LLWS is between 2400 and 0600 IST.

3.1.4. *Nocturnal rise in surface temperature* — Normally, the surface temperature at a place in fine weather during night goes on decreasing till sunrise or it may show minor fluctuations due to light wind. But it was observed on many occasions over Bombay airport surface temperature increased instead of decreasing.

Blackadar (1957) while discussing the growth of nocturnal inversions has suggested that large wind shears which develop within the inversion layer themselves supply the turbulent energy to overcome the stability. Consequently the existing inversion and vertical wind gradient break up, resulting in surface temperature rise and strong and turbulent flow at the ground.

Haurwitz (1941) while discussing the nocturnal radiative cooling has also stated that if wind starts blowing at the ground during nocturnal inversion, it brings down potentially warmer air from layer above due to turbulent mixing of the wind. Thus, the surface temperature can rise in the night due to transfer of heat downward from layers aloft in the inversion layer, caused by turbulent mixing by the onset of strong and gusty land breeze during night.

Dayakishan (1979) reported cases when temperature rise has been 3°C or more over Bombay airport. He attributed this nocturnal rise in surface temperature to onset of strong and gusty land breeze. According to him strong and gusty land breeze causes turbulent mixing in the lower layers so as to bring warmer air from above in the inversion layer.

Table 7 gives the number of occasions of LLWS associated with nocturnal increase in surface temperature. It is seen that highest number of occurrence in the month of December followed by November.

TABLE 7

No. of occasions of LLWS associated with nocturnal increase in surface temperature (1985-1989)

Rise in temp. (°C)	Jan	Feb	Mar	Apr	Oct	Nov	Dec
1.0-2.0	—	2	—	—	1	2	—
2.1-3.0	2	1	3	2	—	2	6

3.1.5. *Typical cases* — (a) On 9 January 1986, SU-537 reported marked wind shear on final approach RWY 27 at 0542 IST. Autographic record at Santacruz on 9 January 1986 presented in Fig. 2(b). At 0500 IST the surface wind started picking up when the onset of land breeze occurred.

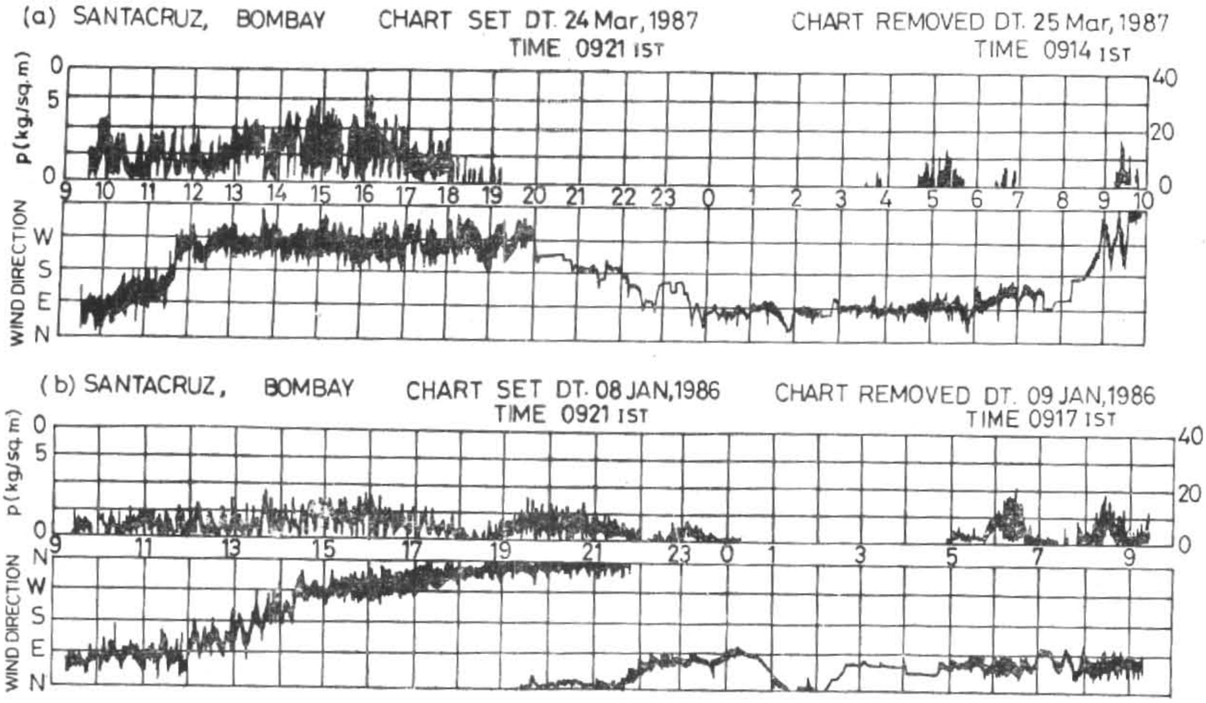
(b) On 3 February 1989, AI-809 reported strong wind shear at 0610 IST. Wind at 240 and 60 m, 040/30 kmph.

Time (IST)	Surface wind recorded at RWY 27	Surface temperature (°C)
0510	Calm	21.0
0540	Calm	20.4
0610	030/34	22.7
0640	100/04	22.3
0710	Calm	21.9
0740	Calm	20.7

From the above table, it is seen that on 3 February 1989 there was nocturnal increase of surface temperature in the early morning.

3.2. *LLWS not related to any synoptic feature*

Out of 329 reports of LLWS 22 reports cannot be related to any significant features. In absence of facilities like closer network anemometers synoptically favourable conditions for the occurrence of such types of LLWS cannot be identified.



Figs. 2(a & b). Anemograph of Santacruz : (a) 24-25 March 1987, and (b) 8-9 January 1986

3.3. *LLWS related to convective activity*

Distribution of LLWS in monsoon and post-monsoon seasons associated with different convective features is given in Table 8.

TABLE 8

Distribution of LLWS reports in monsoon and post-monsoon seasons over Bombay airport (1985-1989)

Weather system	Frequency of LLWS
No. of occasions related to thunderstorm activity	56
No. of occasions when CB present	98
No. of occasions when CB not present	42

Bhaskara Rao and Dekate (1971) have studied the effect of vertical wind structure on some aspects of convective activity at Bombay. Thunderstorm activity at Bombay is maximum in the transition period before onset of the southwest monsoon (from beginning of May to middle of June) and after the withdrawal of the monsoon (from middle of September to end of October). During this period the thunderstorms develop in the afternoons and evenings over the hills to the east of the station. They drift with the easterly winds and strike the station giving some precipitation. Some of them cause easterly squalls.

In the months of July and August, on strong monsoon days wind in the lower level is westerly whereas in the upper level it is easterly and thunderclouds are not well developed. Strong movement of clouds is associated with downdraft causing gusts and squalls.

(*a*) *Typical case of LLWS during thunderstorm activity*

On 11 June 1989 at 0240 IST wind shear reported at final approach RWY 27 current weather at 0240 IST.

Surface Wind (RWY 27) : 150/04 kt

Clouds : 3ST010/4SC015/1CB030/8AS100
CB to north top 7 km.

Visibility recorded 1200 m in thunderstorms.

(*b*) *Typical case of LLWS in precipitation and CB present*

On 20 August 1987 at 1240 IST marked wind shear in approach sector RWY 27 current weather at 1240 IST.

Surface wind (RWY 27) : 250/16 kt.

Clouds : 4ST008/2CU020/1CB030/8AS080
CB overhead top 10 km.

Visibility recorded 0800 m in continuous rain.

(*c*) *Typical case of LLWS in precipitation when CB not present*

On 14 June 1989 at 0440 IST wind shear at final approach RWY 27 reported by AI-405 current weather at 0440 IST.

Surface wind (RWY 27) : 240/08 kt.

Clouds: 6 ST 008/5SC015/5CU 025/8AS080.

Visibility recorded 0500 m in heavy rain shower.

During the strong monsoon conditions over Bombay there may be simultaneous occurrence of LLWS, poor visibility and very low cloud ceiling. These cases have

TABLE 9

Occurrence of LLWS in association with poor visibility and low cloud ceiling at Bombay airport in monsoon season during the period 1985-1989

Visibility	Cloud ceiling less than 5 oktas					Cloud ceiling 5 oktas or more				
	<150 m	150-300 m	300-600 m	600-900 m	Total	<150 m	150-300 m	300-600 m	600-900 m	Total
<500 m	—	—	—	—	—	—	1	—	—	1
500-1000 m	—	7	—	—	7	6	3	—	—	9
1000-1500 m	—	7	3	1	11	3	5	1	—	9
1500-2000 m	—	6	1	—	7	—	2	—	—	2
2000-3000 m	—	25	18	—	43	3	5	2	—	10
3000 m	—	2	5	—	7	—	—	1	—	1
Total	—	47	27	1	75	12	16	4	—	32

been examined in detail and results presented in the Table 9. From the table it is seen that there were 107 occasions when LLWS was encountered under low cloud ceiling and visibility. Out of these 107 cases, 18 cases of LLWS were related with cloud ceiling below 300 m and cloud amount 5 oktas or more and visibility varying from 500 to 1500 m. These three adverse weather conditions when occur simultaneously can be potential aviation hazard for aircrafts during landing and take-off at Bombay airport.

4. Conclusions

The following features of LLWS emerge from this study :

(*i*) The most probable layer for occurrence of LLWS at Bombay airport lies between 60 and 300 m.

(*ii*) The monthly mean frequency of occurrence of LLWS is 5.5. The monsoon season has the highest frequency of 14.8 in the month of July followed by 8.2 in August. The maximum frequency of 7.6 occurs in the post-monsoon season in the month of November whereas in the summer season it is 5.2 in the month of March. In winter season the highest number of occurrence is in the month of February.

(*iii*) The preferred time of occurrence of LLWS between 0000 to 0600 IST and 1800 to 2400 IST.

(*iv*) The presence of horizontal and vertical wind shears have been indicated by the surface wind instruments at the time of reports of LLWS.

(*v*) Outside monsoon months strong to severe LLWS has been reported in association with land breeze activity with maximum frequency in the month of November followed by December. Light to moderate LLWS was found to be associated with sea breeze with maximum frequency in the month of March followed by April.

(*vi*) LLWS is associated with nocturnal increase of surface temperature especially during November and December.

(*vii*) During monsoon and post-monsoon seasons most of the LLWS are associated with thunderstorms and strong gusty winds.

(*viii*) The simultaneous occurrence of strong and severe LLWS, very low cloud ceiling and very poor visibility poses potential danger to the safety of aircraft during landing and take-off operation.

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