Reprint No. 86

A LOW-LEVEL WIND SHEAR DETECTION SYSTEM

BY

G. J. BELL

&

K. S. TSUI

Reprinted from Weather February 1981
Vol. 36 No. 2
p. 42 – p. 46

A LOW-LEVEL WIND SHEAR DETECTION SYSTEM

By G. J. Bell and K. S. Tsui
Royal Observatory, Hong Kong

DURING the period 1973–1976, eight aircraft accidents occurred worldwide as a result of wind shear on final approaches to landings (Whitmore and Cokeley 1976). The most disastrous of these accidents involved a Boeing 727 approaching JFK Airport, New York during a thunderstorm in 1975. In the aviation context, wind shear is a change of wind velocity, including updraughts and downdraughts, of such an intensity as to abruptly displace an aircraft from its intended flight path. The magnitude of a wind shear depends on the rate of change of wind velocity along the flight path. Significant wind shear can be associated with inversions, cold, warm and sea-breeze fronts, thunderstorms, tropical cyclones, monsoons, strong winds and topographical features (Tsui 1979).

INCREASED HAZARD

Wind shear has always been a factor affecting take-off and the last phases of landing, but it is a greater hazard for modern jet aircraft. This arises primarily because their greater inertia causes them to retain their velocity with respect to ground giving airspeed and hence lift variations when changing winds are encountered. Other factors which increase the hazard include: (1) All-weather operations which increase the probability of aircraft encountering wind shear; (2) the higher landing speeds of jet aircraft which increase the suddenness of wind-shear effects and give pilots less time to interpret visual clues and to respond to them; (3) most modern jet aircraft approach at near minimum-drag speed so that any sudden change in airspeed will increase drag and complicate recovery and finally (4) an increase of power in propeller aircraft increases airflow over the wings giving immediate extra lift before the aircraft accelerates – this extra lift is not available to jet aircraft.

THUNDERSTORM DOWNBURSTS

UK Aeronautical Information Circulars (e.g. No. 118/1966) have long warned that

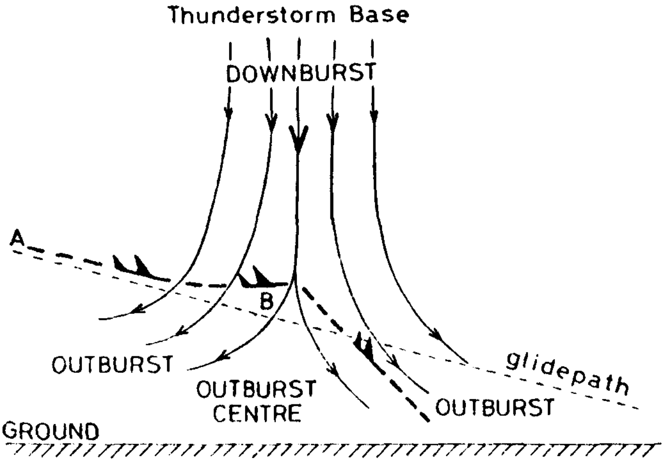

Fig. 1. A thunderstorm downburst turning into outbursts near the ground

'Winds caused by the outflow of cold air from the base of a thunderstorm cell have been known to change in shallow layers of a few hundred feet by as much as 50 knots in speed and 90° or more in direction'. The thunderstorm involved in the 1975 JFK Airport crash was studied by Fujita (1976) using radar, satellite and other information. This study increased our knowledge of these severe storms and introduced new terms. Fujita called localised intense downdraughts of more than 3·7 ms^{-1} at 100 m above the surface 'downbursts'. A downburst impinging on the surface at an 'outburst centre' rapidly spreads outwards as an 'outburst' (Fig. 1).

The effects of a downburst on an aircraft approaching to land are illustrated in Fig. 1. From point A to point B, the headwind component increases and the aircraft experiences temporary lift above the glidepath. At B, the horizontal component of the wind reverses in direction and the aircraft suddenly experiences a tailwind which results in reduction of lift and rapid loss of altitude, a situation exacerbated by the downdraught prevailing at B.

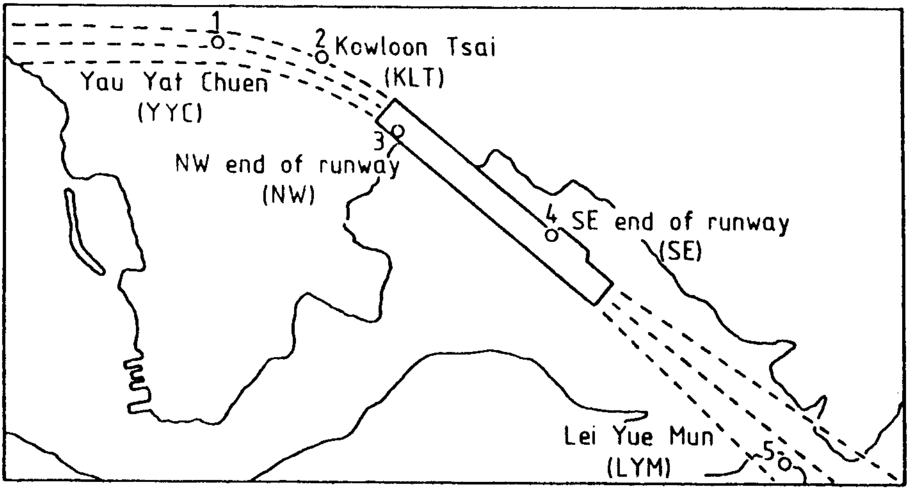

Fig. 2. Locations of the five anemometers for Hong Kong low-level wind shear detection system

The conditions could be aggravated further if the pilot at B reduces power in an attempt to compensate for the temporary lift which he experienced between A and B. The net result could be that the aircraft would sink dangerously far below the glidepath or even stall, and crash short of the runway.

ORIENTATION OF APPROACH OR TAKE-OFF PATH

The importance of the glidepath orientation is not generally realised. To illustrate the problem consider an aircraft coming in to land on Runway 13 (Fig. 2) using Hong Kong's Instrument-Guidance-System (IGS) to the final curved approach. As the aircraft turns for the final touchdown, the wind component along the flight path can change abruptly although the wind might actually be uniform in direction and speed over the area. This special type of 'turning shear' is of course artificial but is just as significant as natural wind shear. This hazard is not generally recognised because there are very few airports which require such a sharp turn at low levels. For an airport with several

TABLE 1. Heights of anemometer heads above msl and alignment of glidepath adjacent to the anemometers from the true north

	YYC Yau Yat Chuen	KLT Kowloon Tsai	NW North West	SE South East	LYM Lei Yue Mun
Height (metres)	64	105	14	16	73
Alignment (deg)	087	107	134	134	134

LYM guards the approach to Runway 31. For a standard approach along a 3° glidepath, LYM is about 55 s from touchdown and the height of the aircraft there should be around 225 m. YYC and KLT are on the curved approach to Runway 13. YYC is about 41 s from touchdown and the height of the aircraft above that point should be around 165 m.

runways, it is sometimes possible to avoid a severe *longitudinal* wind shear condition by a proper choice of runway orientation even though the wind structure is the same everywhere in the airport area.

WIND SHEAR DETECTION

Clearly it would contribute to aircraft safety if pilots could be warned of any significant wind shear that they were likely to encounter during take-off or landing. Accordingly, a prototype warning system was designed and installed at Hong Kong International Airport in 1978–1979. It consists of a microprocessor and five cup anemometers, one at each end (SE and NW) of the runway and three additional ones (Fig.2) covering the two approaches to the airport. Table 1 shows the heights of the anemometer heads above mean sea-level and the alignment from the true north of the glidepath adjacent to these anemometers.

Readings from the five anemometers are telemetered to a microprocessor at the Airport Meteorological Office which computes two-minute mean winds for the five

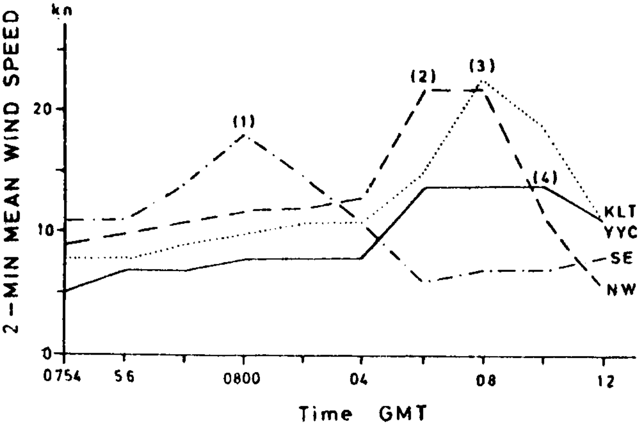

Fig. 3. Passage of a gust-front on 27 June 1978. The numbers of the curves indicate the arrival sequence of the gust-front at the anemometers

locations. Wind shears in knots per 30 m of altitude change for the two ends of the runway are calculated from the two-minute mean winds and the height differences between the anemometer pairs LYM-SE and NW-YYC. Only the longitudinal wind components are considered so as to determine the initial 'lifting' or 'sinking' effect of the wind variations. The magnitude of this longitudinal wind shear for each end of the runway is displayed on a video terminal together with an appropriate description selected from 'lifting', 'sinking' or 'no shear'. When the magnitude of the wind shear equals or exceeds a predetermined value (8 kn per 30 m of altitude) the indication reads 'significant lifting' or 'significant sinking', as appropriate, and blinks on the video terminal to alert the duty air traffic controller to warn aircraft landing or taking off at that time.

Readings of the KLT anemometer are not utilised for the calculation of the longitudinal wind shear data. The microprocessor computes the two-minute mean lateral wind component and the maximum one-second gust for that location. This provides information on the strength of lateral winds on the curved portion of the IGS-approach.

The anemometers do not measure the vertical component of the wind so that the system does not monitor vertical air currents likely to occur in the vicinity of heavy showers or thunderstorms. Effects of wake turbulence on the system are minimal because 2-min mean winds are used in the calculation of the wind shear.

EXAMPLES OF SIGNIFICANT WIND SHEAR

The anemometer array has also been useful for tracking gust fronts associated with showers or thunderstorms. On 27 June 1978 an active squall-line developed in the

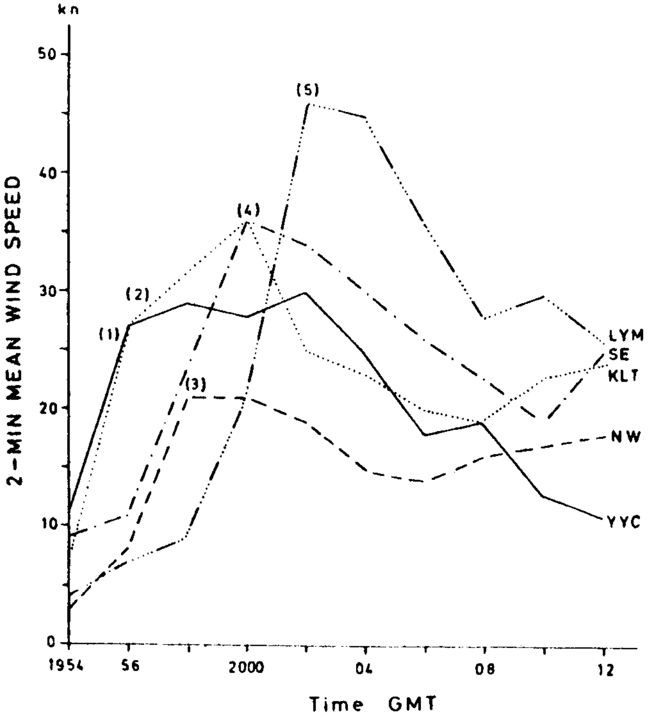

Fig. 4. Passage of a gust-front on 26 February 1980. The numbers on the curves indicate the arrival sequence of the gust-front at the anemometers

summer monsoon (Chen and Lee 1978) and crossed the array (Fig. 3). A sudden increase in the 2-min mean wind speed was first indicated by the SE anemometer (LYM was not installed at that time) and this was followed within the next 10 min by similar increases at NW, KLT and YYC. The wind-shear detection system registered significant sinking wind shear (13·9 kn per 30 m) between the anemometers NW-YYC at 0810 GMT.

On 26 February 1980, a cold front moved southwards across Hong Kong. Fig. 4 shows the passage of the associated gust-front which arrived first at YYC, then at KLT, NW, SE and finally LYM. Significant lifting wind shear (maximum 14·2 kn per 30 m) was indicated between the anemometers NW-YYC at 1956, 1958, 2000, 2002 and 2004 and significant sinking wind shear (8·6 kn per 30 m) for LYM-SE anemometers at 2004.

FLIGHT COMPARISONS

The indications of the wind shear detection system were compared with the recordings of flight conditions made on board all Swissair DC-10 aircraft, using Aircraft Integrated Data Systems (AIDS), which landed at Runway 13 during 1978–79 (Chen 1980). This was done to assess the errors that might arise because the anemometers cannot be directly on the glidepath.

The aircraft position, height and the wind being encountered were recorded at intervals of one second during all approaches. Correlation of the two-minute mean winds at YYC, KLT and NW with the flight winds when the DC-10 was nearest each anemometer yielded the regression equations:

YYC: $Y=1{\cdot}01\,x+2{\cdot}97$ ($r=0{\cdot}75$, $N=136$)
KLT: $Y=0{\cdot}84\,x+2{\cdot}92$ ($r=0{\cdot}68$, $N=135$)
NW: $Y=0{\cdot}90\,x+0{\cdot}93$ ($r=0{\cdot}71$, $N=151$)

where Y is the longitudinal wind component experienced by the aircraft and x is the longitudinal wind component derived from the anemometer readings.

CONCLUSION

Although the anemometers cannot be completely in the flight path of aircraft and detect with precision low-level jets or flight-level winds and although they do not measure vertical air currents, the system has been shown to provide timely and useful warnings of low-level wind shear on many occasions.

REFERENCES

Chen, T. Y. (1980) Comparison of winds and wind shear between Swissair data and anemometer records. *Hong Kong Royal Obs.* Tech. Note No. 56, p. 27

Chen, T. Y. and Lee, H. N. (1978) Wind shear at Hong Kong International Airport in four squally shower situations. *Hong Kong Royal Obs.* Tech. Note No. 46, p. 35

Fujita, T. T. (1976) Spearhead echo and downburst near the approach end of a JFK Airport runway, N.Y. City. *S.M.R.P. Res.* Paper No 137, Univ. of Chicago, p. 51

Tsui, K. S. (1979) Low-level wind shear detection system at Hong Kong International Airport, Paper No. 31. *Proc. WMO Tech. Conf. on Aviation Met.*, 5–9 Nov. 1979, Geneva

Whitmore, C. A. and Cokeley, R. C. (1976) Windshears on final approach. *29th Ann. International Air Safety Seminar and Aviation Safety Tech. Exposition*, Anaheim, California, p. 40