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ROYAL OBSERVATORY, HONG KONG

TECHNICAL NOTE NO. 56

COMPARISON OF WINDS AND WIND SHEAR BETWEEN SWISSAIR DATA AND ANEMOMETER RECORDS

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JULY 1980

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1. INTRODUCTION

In August 1978, Swissair started to supply the Royal Observatory with Automatic Integrated Data System (AIDS) data recorded during their in-bound flights as a contribution to the Wind Shear Detection and Prediction Project (hereinafter called 'Project') in Hong Kong. The first batch of data lasted until the end of March 1979 and a total of 156 sets of reports were received during this period. Later on, the data supply resumed from April 1979 to September 1979.

All these data have been punched onto Hollerith cards and transferred onto magnetic tape. Analyses have been made by the computer for the evaluation of low-level wind shear information, mean winds and mean temperatures at different levels on the approaches to the Hong Kong International Airport.

Comparisons have also been made between the wind information extracted from the AIDS data and those from the anemometer records from August 1978 to March 1979 with a view to evaluating the relationship between them.

This report describes the method and results of comparison. Some cases of significant wind shear associated with moderate to severe turbulence experienced by the aircraft have been discussed. A selection of mean winds, mean temperatures and mean vector differences of winds at different levels on the approach to Runway 13 (RWY 13) based on AIDS data and reproduced by the Royal Observatory Computer Division are given in Appendices I-IV.

2. AIDS DATA

AIDS data were recorded on the DC-10 in-bound flights of Swissair along the approach to RWY 13. The data consist of wind direction, wind speed, temperature, radio altitude, pressure altitude and glide path deviation and are printed out at one second intervals.

The print-out wind data show instantaneous aircraft winds. The radio-altimeter gives the height of the aircraft above the ground. It cannot show accurate heights above the aerodrome level when flying over hills or buildings. However, when the aircraft has entered the flat terrain of the aerodrome, it gives accurate heights above the ground apart from possible instrument errors.

The pressure-altimeter is set at 1013.25 mbar and the reading represents height above MSL if corrections for the barometric pressure and temperature of the air column have been applied.

3. CORRECTION FOR THE PRESSURE ALTITUDE

The pressure altitudes presented in the AIDS data were corrected to the actual elevations of the aircraft above MSL by a method described in the Smithsonian Meteorological Tables (Reference 1) as follows:

$$A = T\left(\frac{Z_1}{T_1} - \frac{Z_2}{T_2}\right)$$

where A = actual elevation (m) of the aircraft above sea level,

T = actual mean temperature (K) of the air column between sea level and A, (extracted from AIDS data),

Z_1= altitude (m) at flight level in the standard atmosphere corresponding to the pressure at flight level, (indicated on the pressure altimeter of the aircraft),

Z_2= altitude (m) in the standard atmosphere corresponding to the pressure at MSL, i.e. QFF, (calculated from the formula below),

T_1= mean temperature (K) of the standard atmosphere air column between sea level (1013.2 mbar) and Z_1, (calculated from the formula below),

T_2= mean temperature (K) of the standard atmosphere air column between sea level (1013.2 mbar) and Z_2 , (calculated from the formula below),

Z_2 is determined by the following formula :

$$\frac{QFF}{1013.25} = \left(\frac{288 - 0.0065Z_2}{288}\right)^{5.256}$$

T_1 and T_2 are given by :

$$T_1 = 288 - 0.0065\left(\frac{Z_1}{2}\right)$$

$$T_2 = 288 - 0.0065\left(\frac{Z_2}{2}\right)$$

4. RUNWAY APPROACHES AND ANEMOMETERS

Figure 1 is a map of Hong Kong International Airport showing the two approaches and also the locations of the anemometers. The true orientation of the runway is 134°. Due to the hills, the approach surface to RWY 13 is non-standard and based on a curved line of approach (Reference 2). Aircraft landing from the northwest onto RWY 13 must make a curved Instrument-Guidance-System (IGS) approach, while for those landing from the southeast onto RWY 31, an Instrument-Landing-System (ILS) approach can be made.

Wind measuring sensors used for the 'Project' are the combined cup generator and vane system, British Meteorological Office pattern, MK4. There are five anemometers, one at each end of the runway (SE and NW), the other three at Lye Yue Mun (LYM), Kowloon Tsai (KLT) and Yau Yat Chuen (YYC). For aircraft approaching RWY 31 (31 Approach) or departing from RWY13 (13 Departure), winds recorded at LYM anemometer and the SE anemometer are used to assess the wind shear and for aircraft approaching to RWY13 (13 Approach) or departing from RWY 31 (31 Departure), the YYC anemometer and the NW anemometer are used. The KLT anemometer is located near the curved portion of the glide path and therefore provides information on the severity of lateral winds on that portion of the approach.

As AIDS data were recorded on in-bound flights along the approach to RWY 13, only the three anemometers, NW, KLT and YYC, are involved in this comparison. Table 1 gives the altitudes of the anemometer heads and the true orientations of the glide path nearest to these anemometers. (Note : feet and knots are used in this report because they are still the common units used by aviators to measure altitudes and wind speeds. Metric figures have been included where necessary.)

TABLE 1. ANEMOMETER ALTITUDE AND GLIDE PATH ORIENTATION

Anemometer	Altitudes of anemometers (ft above MSL)	True orientation of glide path nearest to the anemometer (degree)
NW	48 (14.6 m)	134
KLT	346 (105.5 m)	107
YYC	210 (64.0 m)	087

5. METHOD OF EXTRACTING INFORMATION FROM AIDS DATA FOR COMPARISON

The method of extracting AIDS data for comparison with anemometer records is based on the flight time from the anemometer site to the touch-down point (T/D) on the runway. These flight times are given in Table 2.

TABLE 2. METHOD OF EXTRACTING WIND DATA FROM AIDS

For comparison with anemometer winds at	Data extracted from AIDS at
NW	4 seconds before T/D
KLT	28 seconds before T/D
YYC	40 seconds before T/D

The times required from various points on the glide path nearest to the anemometers to T/D were supplied by the Civil Aviation Department and are based on the assumption that the aircraft flies in still air conditions, on a 3.1° glide path with a constant speed of 143 kn to T/D from the point 20 seconds to T/D and 147 kn from crossing the 'Coast Line' (of the Kowloon Peninsula) to the point 20 seconds to T/D. The touch-down point is taken as 1000 ft (305 m) beyond the 13 Displaced Threshold.

6. COMPARISON OF LONGITUDINAL COMPONENTS OF WINDS

As the aim of the 'Project' is to determine the 'lifting' or 'sinking' effect of wind variations due to changes of headwind or tailwind (Reference 3), only the longitudinal components of winds are used to calculate the wind shear. Therefore, only the longitudinal components of winds from the AIDS data and from the anemometer records are compared in this report.

In resolving winds into longitudinal components, the following sign convention has been adopted :

TABLE 3. SIGN CONVENTION FOR THE LONGITUDINAL COMPONENTS OF WINDS

Sign of longitudinal wind component	Orientation of longitudinal wind component at point on glide path nearest to anemometer		
	NW	KLT	YYC
	(degree)	(degree)	(degree)
'+'	from 134	from 107	from 087
'-'	from 314	from 287	from 267

Winds recorded by the anemometers used for the 'Project' and for this comparison are 2-minute means while those extracted from the AIDS data are instantaneous aircraft winds.

Figures 2, 3 and 4 show the comparison of longitudinal components of winds over the NW end of runway, KLT and YYC. Regression lines obtained are given in Table 4.

TABLE 4. RELATIONSHIP BETWEEN LONGITUDINAL COMPONENT OF WINDS FROM AIDS DATA AND FROM ANEMOMETER RECORDS

Location	Linear regression	Correlation coefficient	No. of cases
NW	$y = 0.90x + 0.93$	0.71	151
KLT	$y = 0.84x + 2.92$	0.68	135
YYC	$y = 1.01x + 2.97$	0.75	136

In Table 4,

y = longitudinal components of winds (kn) extracted from AIDS data,

x = longitudinal components of winds (kn) recorded by anemometers

Two attempts have been made to stratify the cases with a view to improving the relationship. The first attempt was to classify the cases into groups of :

occurrence of thunderstorms, occurrence of squally showers, occurrence of heavy rain, passage of fronts, passage of troughs, passage of tropical cyclones, onset of monsoons, onset of sea breezes.

Unfortunately, due to lack of data, this method of stratification could not be used.

The second attempt was to classify the cases into groups of synoptic patterns as follows :

(a) with an anticyclone centred over China,

(b) with an anticyclone centred over the East China Sea, the Pacific or Japan,

(c) with a trough or a cold front in the vicinity of Hong Kong,

(d) with a tropical cyclone or a depression near Hong Kong.

A fairly uniform distribution of cases was obtained in each group by using the above classification. Linear regressions were derived for each of the above groups at all three locations of anemometers. Unfortunately, there was no obvious improvement in the relationship after stratification. The results are therefore not presented in this report.

The flight level of the aircraft, after being corrected by the method described in Section 3, usually differed from that of the nominal 3.1° glide path. Average flight levels of the Swissair aircraft nearest to the anemometers between August 1978 and March 1979 are shown in Table 5 together with the altitudes of the anemometer heads reproduced for comparison purposes :

TABLE 5. AVERAGE FLIGHT LEVELS OF THE AIRCRAFT WHEN NEAREST TO THE ANEMOMETERS

Location	Average flight level of aircraft	Altitude of anemometer heads
	(ft above MSL)	(ft above MSL)
NW	35 (10.7 m)	48 (14.6 m)
KLT	386 (117.6 m)	346 (105.5 m)
YYC	545 (166.1 m)	210 (64.0 m)

7. LIMITATIONS IN THE COMPARISON

The differences between the winds from the AIDS data and from the anemometer records shown in the previous section can be attributed to the following :

(a) Height differences - the height of the anemometer is different from the flight level of the aircraft, (e.g. the aircraft above YYC is, on average, more than 300 ft or 100 m, higher than the anemometer)

(b) Spatial difference - the anemometer is not exactly under the central line of the glide path, (e.g. the KLT anemometer is about 1300 ft or 400 m away).

(c) Difference in the mean wind periods - winds in AIDS data are instantaneous aircraft winds while those extracted from the anemometer records are 2-minute means.

(d) The winds selected from the AIDS data, using the method described in Section 5, may not be the ones exactly when the aircraft was nearest to the anemometer due to variations of aircraft flying speed.

(e) The winds extracted from anemometer records may not be the ones when the aircraft was nearest owing to the lack of synchronization between them.

8. COMPARISON OF WIND SHEAR

In this report, wind shear between two locations is taken as the difference in longitudinal components of winds (kn) at these two places per 100 ft (30.5 m) of height difference between them. For the wind shear between KLT and NW, the procedure is always to subtract algebraically the value at KLT from the value at NW, similarly for the wind shear between YYC and NW, it is always to subtract algebraically the value at YYC from that at NW. With this procedure and the sign convention for the longitudinal component of winds mentioned in Section 6, the '+' shear always causes a 'lifting' effect and the '-' shear always causes a 'sinking' effect.

Figure 3a shows the comparison of wind shears between NW/KLT calculated from AIDS data and those calculated from anemometer records. Figure 3b shows the same comparison between NW/YYC. Regression equations are given in Table 6.

TABLE 6. RELATIONSHIP OF WIND SHEAR BETWEEN AIDS DATA AND ANEMOMETER RECORDS

Location of shear	Linear regression	Correlation coefficient	No. of cases
KLT/NW	$y = 0.59x - 0.57$	0.52	137
YYC/NW	$y = 0.30x - 0.52$	0.64	138

In Table 6,

y = wind shear (kn/100 ft) calculated from AIDS data,

x = wind shear (kn/100 ft) calculated from anemometer records.

Stratification according to synoptic patterns as described in Section 6 was again made and regression equations were calculated with a view to improving the relationship. Unfortunately, there was still no obvious improvement. The results are therefore not included in this report.

9. SIGNIFICANT WIND SHEAR

In Hong Kong, significant wind shear at low altitudes is defined as a wind shear exceeding 8 kn/100 ft (0.135 m/s per metre) (Reference 3).

Figure 3a shows that there were no occasions of significant wind shear over KLT/NW during the comparison either from AIDS data or from anemometer records.

Figure 3b shows that there were also no occasions of significant wind shear over YYC/NW as calculated from AIDS data during the comparison. However, from the anemometer records, there were two occasions on which the calculated wind shear met the criterion for significant wind shear.

Table 7 shows the actual winds recorded on these two occasions and the calculated wind shear. The actual winds recorded were not strong, but the opposite directions of the longitudinal components of winds at the two anemometers caused the wind shear to reach the significant level.

Table 7 also shows that while the differences in the variations of longitudinal components of winds between the anemometer records and the AIDS data at the two locations were not significantly large, the variation of altitudes experienced by the aircraft from YYC to NW was about 3 times the altitude difference between the anemometer heads. This explains why the actual wind shear experienced by aircraft is generally less than that calculated from the anemometer records as shown in Figures 3a and 3b.

Under certain wind conditions, the curved line of approach to RWY 13 tends to enhance the wind shear. If the glide path orientation at YYC was also 134° instead of 087°, the wind shear calculated from the anemometer records for the two examples in Table 7 would be 4.9 kn/100 ft on 13.12.78 and 8.1 kn/100 ft on 17.2.79 respectively (compared with 8.3 and 9.6 in Table 7).

TABLE 7. OCCASIONS OF SIGNIFICANT WIND SHEAR CALCULATED FROM ANEMOMETER RECORDS

Date of occurrence		13/12/78		17/2/79	
		Anemometer	AIDS	Anemometer	AIDS
NW : Wind recorded	(deg/kn)	150/10	124/11	150/10	123/14
Glide path orientation	(deg)	134	134	134	134
Longitudinal component	(kn)	9.6	10.8	9.6	13.7
Anemometer altitude	(ft above MSL)	48		48	
Aircraft altitude, corrected	(ft above MSL)		35		35
YYC : Wind recorded	(deg/kn)	210/07	150/06	260/06	195/06
Glide path orientation	(deg)	087	087	087	087
Longitudinal component	(kn)	-3.8	2.7	-6.0	-1.9
Anemometer altitude	(ft above MSL)	210		210	
Aircraft altitude, corrected	(ft above MSL)		484		523
Variation of wind component	(kn)	13.4	8.1	15.6	15.6
Variation of altitude	(ft)	162	449	162	488
Wind shear calculated	(kn/100 ft)	8.3	1.8	9.6	3.2

The fact that all wind shears calculated from AIDS data were less than 8 kn/100 ft, as shown in Figures 3a and 3b, does not mean that significant wind shear is unlikely in Hong Kong. It just happened that during these Swissair landings, no significant wind shear occurred. However cases of significant wind shear in monsoons and also during the passage of tropical cyclones have been described by Tsui (Reference 4) and cases in squally showers by Chen and Lee (Reference 5). Examples of significant wind shear associated with turbulence are given in the next section.

10. TURBULENCE

In response to a programme designed in August 1976, wind data from aircraft arriving at and departing from the Airport (between 1000 ft and T/D) together with turbulence reports were received in the Airport Meteorological Office. Table 8 shows winds reported at 1000, 800, 600, 400, 200 ft and the surface by aircraft on four occasions in 1978 when moderate to severe turbulence was experienced. Longitudinal components of winds and magnitudes of significant wind shear are also indicated.

Case No. 1 shows significant wind shear between 200 ft and the surface when winds decreased from 37 kn to 24 kn and backed from 100° to 070°.

Case No. 3 shows significant wind shear between 400 and 200 ft when winds maintained almost the same direction but the speed decreased from 35 kn to 20 kn. It is notable that this change of wind speed between the two levels occurred on the curved portion of the approach where the orientation of the glide path changes from 098° at 400 ft to 134° at 200 ft. Calculations show that the change of orientation increased the magnitude of the wind shear.

Aircraft approaching RWY 13 in strong easterlies encounter strong headwinds at first, but as they descend below 400 ft and turn along the curved path to align with the runway, they lose about 30 percent of the headwind (cosine 45° = 0.71). If the winds also happen to decrease in speed (which is quite usual), there is a fairly high possibility of the wind shear (sinking) reaching the significant level. Aircraft departing on RWY 31 in strong easterlies would be affected by increasing tailwinds when climbing up the curved portion of the glide path which would have the same sinking effect.

As east is the prevailing direction of winds in Hong Kong, special attention should therefore be taken to the possibility of significant wind shear below 400 ft when aircraft is on 13 Approach or 31 Departure in strong easterlies.

TABLE 8. WIND AND WIND SHEAR ON OCCASIONS WHEN MODERATE TO SEVERE TURBULENCE WERE EXPERIENCED BY AIRCRAFT

Case No.	Date/Time (GMT)	Winds (dddff) and longitudinal componants (ff.f) at 1000 ft *(087°)	800 ft (087°)	600 ft (087°)	400 ft (098°)	200 ft (134°)	surface (134°)	Magnitudes of significant wind shear and layer
1	780810/1344	09046 45.9	09344 43.8	09836 35.3	09140 39.7	10037 30.7	07024 10.5	10.1 kn/100 ft (sinking) 200 ft/surface
2	781001/1045	09036 36.0	07433 32.2	08530 30.0	09520 20.0	09226 19.3	09024 17.3	no significant wind shear calculated
3	781016/1340	08136 35.8	07836 35.6	07139 37.5	07535 32.2	08620 13.4	08018 10.6	9.4 kn/100 ft (sinking) 400 ft/200 ft
4	781109/0604	00324 2.5	08724 24.0	08525 25.0	08824 23.6	- -	10017 14.1	10.8 kn/100 ft (lifting) 1000 ft/800 ft

* Figures in bracket show the average orientations of the aircraft on the glide path at the heights indicated.

Tsui (Reference 4) has shown that due to the curvature of the approach, a uniform flow from the north-northeast (030°) or from the south-southwest (210°) of 17 kn at both YYC and at the NW anemometer would be sufficient to trigger an alarm of significant wind shear by the anemometer system for 31 Departure or 13 Approach.

For an aircraft on 31 Departure or 13 Approach with a uniform flow in one of these two directions, 030° and 210°, winds of 26 kn would cause significant wind shear below 400 ft along the curved portion of the glide path.

Case No. 4 indicates significant wind shear between 1000 and 800 ft when winds maintained the same speed of 24 kn but veered from 003° at 1000 ft to 087° at 800 ft.

Any abrupt change in wind direction and/or speed results in significant wind shear. Among winds reported by aircraft in Hong Kong since 1976, wind speed changes of 20 kn and direction changes of more than 100° over a height difference of 200 ft have been found. Elsewhere, reports of wind direction changes of 180° and speed changes of 50 kn or more within 200 ft of the ground have been recorded (Reference 6). It should be noted that a rapid change in wind direction over a very short distance in moderate or even light wind conditions can sometimes result in significant wind shear.

In case No. 2 calculations show that there was no significant wind shear below 1000 ft although the winds were quite strong. The case was associated with the passage of Typhoon Lola in the South China Sea and the winds were gusty. It seems that the turbulence was caused by the gustiness of the strong winds.

11. CONCLUSIONS

1. Winds recorded by anemometer at YYC are on average slightly lower in speed than those experienced by the aircraft flying above.

2. The calculated values of wind shear between YYC and NW based on winds recorded by anemometers are generally higher than those experienced by the aircraft. This is a useful safety factor.

3. The correlation between winds from anemometer records and from aircraft reports is higher at YYC than that at KLT.

4. Pilots landing along the descent path to RWY 13 or departing along the climb path on RWY 31 in strong easterly winds should be prepared for significant wind shear (sinking) below 400 ft especially on the curved portion of the glide path.

5. Pilots should also be aware of the possibility of sudden changes in wind direction and/or speed in very short distances. Wind speed changes of 20 kn and wind direction changes of more than 100° over 200 ft of altitude have been reported in Hong Kong, and wind direction changes of 180° and speed changes of 50 kn or more have been reported elsewhere.

6. It should be noticed that for 13 Approach or 31 Departure, rapid changes in wind direction can sometimes result in significant wind shear below 400 ft altitude in moderate or even light wind conditions.

7. Turbulence experienced by the aircraft is more likely to be sometimes caused by the gustiness of the strong winds and not by wind shear.

REFERENCES

1.	Smithsonian Institution	1963	Smithsonian Meteorological Tables, 6th revised edition, second reprint.
2.	Department of Civil Aviation, Hong Kong.	1978	Aeronautical Information Publication.
3.	Director of Civil Aviation, Hong Kong	1979	Wind Shear Warning System, Aeronautical Information Circular (AIC) 2/1979, Hong Kong International Airport.
4.	Tsui, K.S.	1979	Low-level Wind Shear Detection System at Hong Kong International Airport, presented at WMO Technical Conference on Aviation Meteorology held in Geneva.
5.	Chen, T.Y. and H.N. Lee	1978	Wind Shear at Hong Kong International Airport in Four Squally Shower Situations, Royal Observatory Technical Note No.46
6.	Federal Aviation Administration Department of Transportation, Washington, D.C., U.S.A.	1979	Advisory Circular, AC 00-50A

NOTE ON THE APPENDICES I - IV

1. Appendices I-IV are based on 227 flights which made 230 approaches to Runway 13, HKIA.

2. Heights are in feet above mean sea level. Heights above 100 ft are computed from the pressure altimeter readings corrected for mean layer temperatures and QFFs. For flights below 100 ft (or 74 ft above ground), radio altimeter readings were used.

3. Mean 100 ft vector difference, $\overrightarrow{V}_{100V}$ is defined as the vector mean of the vector difference of 7-second mean winds 100 ft apart.

$$\overrightarrow{V}_{100V} = \overline{(\overrightarrow{V}_H - \overrightarrow{V}_{H-100})}$$

4. Mean 100 ft wind shear, V_{100S} is defined as the scalar mean of the modulus of the vector difference of 7-second mean winds 100 ft apart.

$$V_{100V} = \overline{|\overrightarrow{V}_H - \overrightarrow{V}_{H-100}|}$$

5. For each flight, the 7-second mean wind nearest to but not exceeding 30 ft from the indicated level was selected. Appendix I gives the mean of all the winds near each hundred ft level.

6. Appendix II gives the mean temperatures at 100 ft intervals. It was computed in a way similar to Appendix I, except that the original observations are not 7-second means, but actual or interpolated temperatures.

7. Appendix III gives the mean 100 ft vector difference. Each entry is the mean of the vector difference of the 7-second mean winds 100 ft apart. As there are very few 7-second mean winds near the 0 ft level, most of the entries in the 100 ft - 0 ft row are zeros.

8. Appendix IV gives the mean 100 ft wind shear. Each entry is the mean of the modulus of the vector difference of the 7-second mean winds 100 ft apart.

9. In addition to the above computations, some other elements were also found, e.g. location of low level jets, longitudinal and cross wind shear along the approach path, 3-second wind shear and 3-second vector differences. These are not included in the publication but are available at the Royal Observatory, Hong Kong.

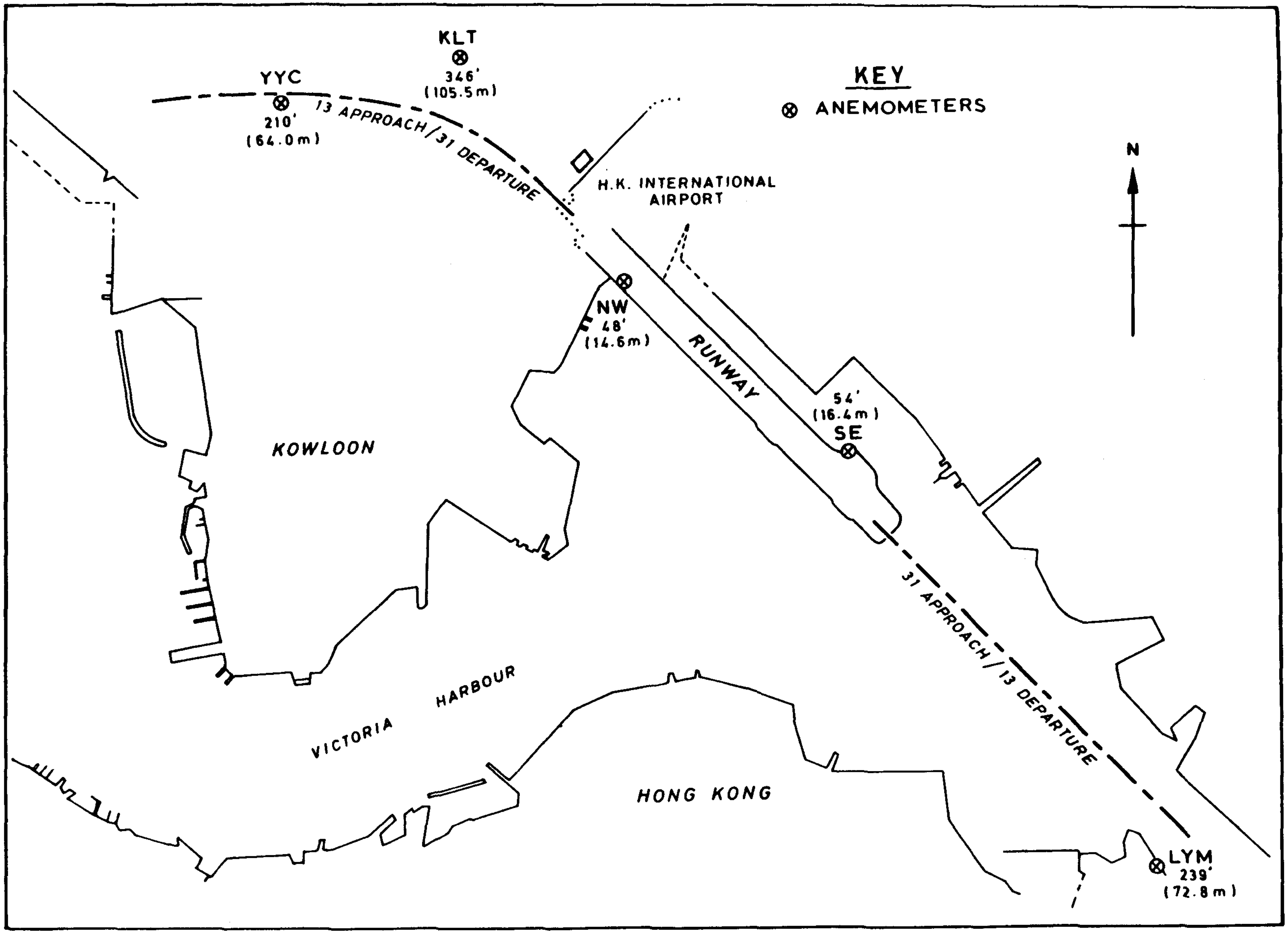

Figure 1. Positions of anemometers and approaches around Hong Kong International Airport.

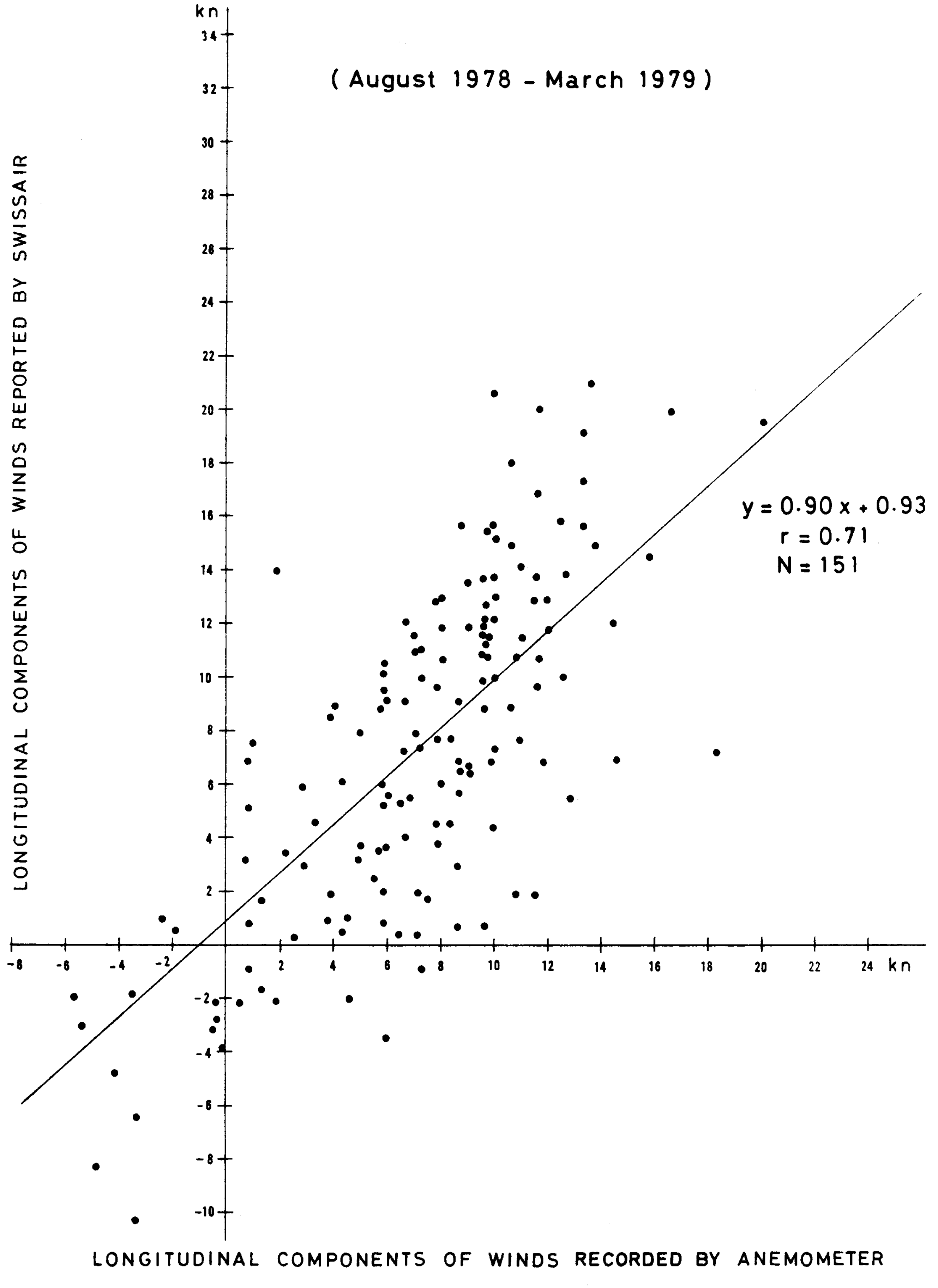

Figure 2a. Comparison between winds measured by Swissair (AIDS) with winds measured by anemometer over the NW end of the runway.

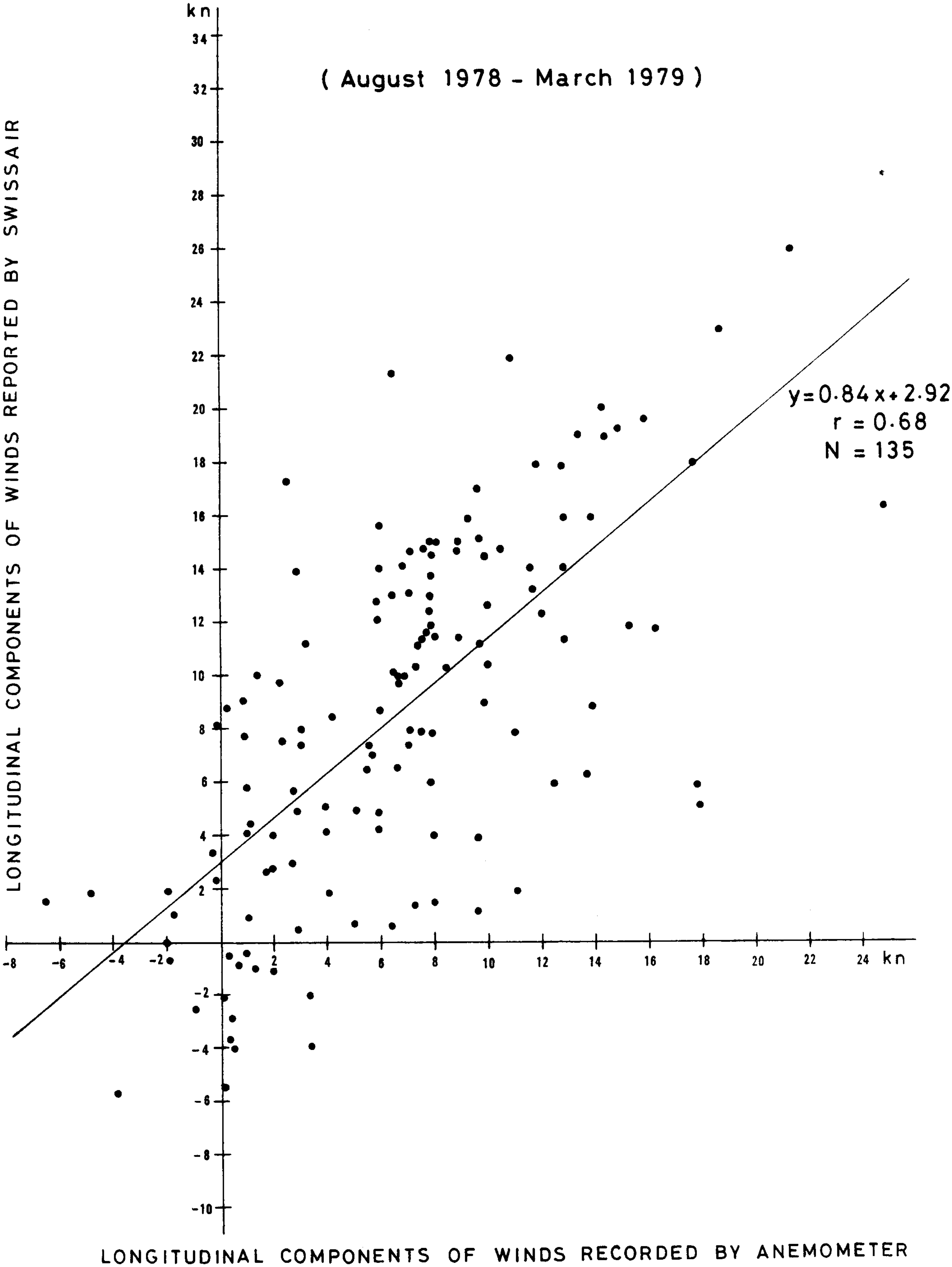

Figure 2b. Comparison between winds measured by Swissair (AIDS) with winds measured by anemometers over Kowloon Tsai.

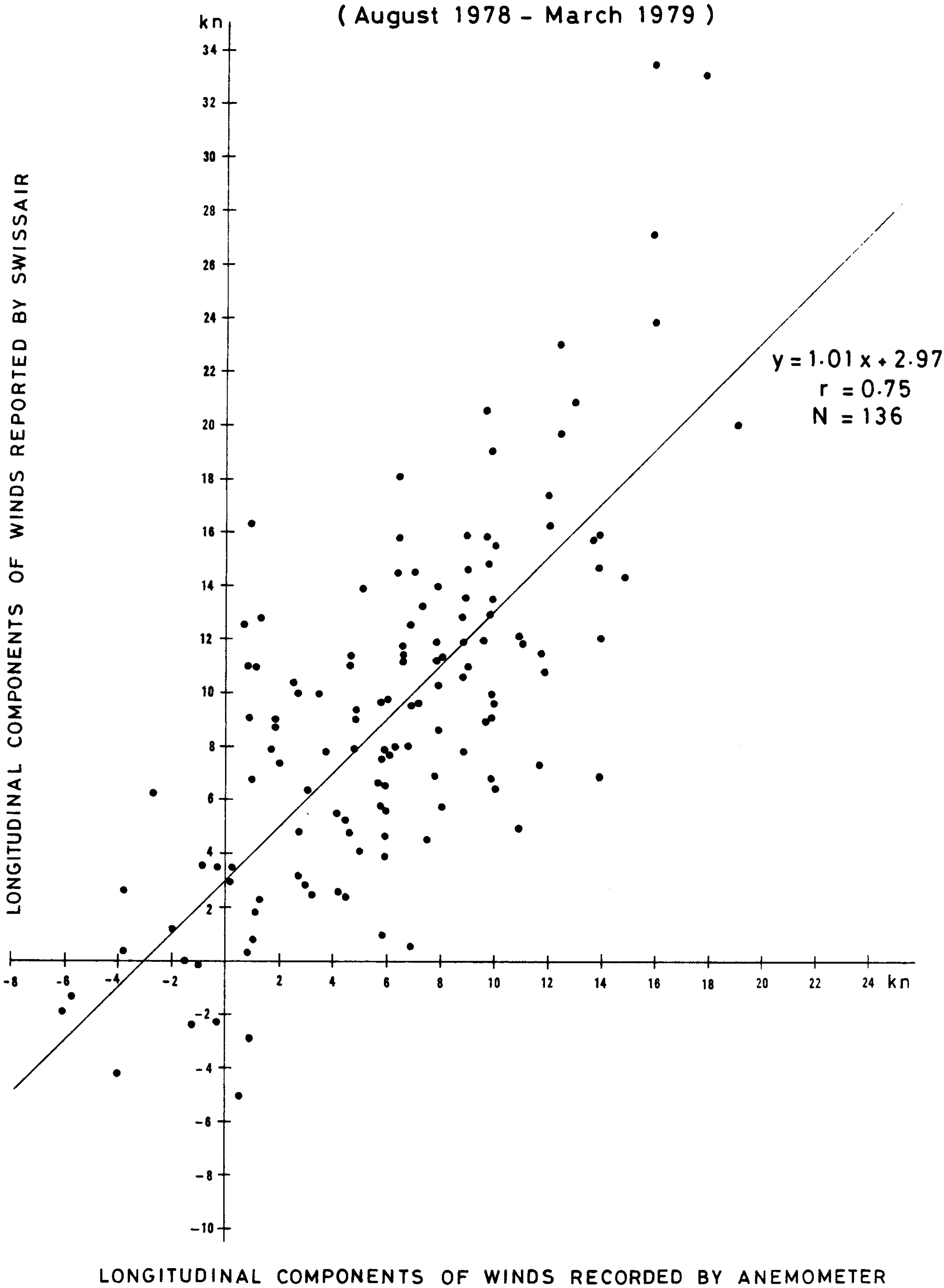

Figure 2c. Comparison between winds measured by Swissair (AIDS) with winds measured by anemometer over Yau Yat Chuen.

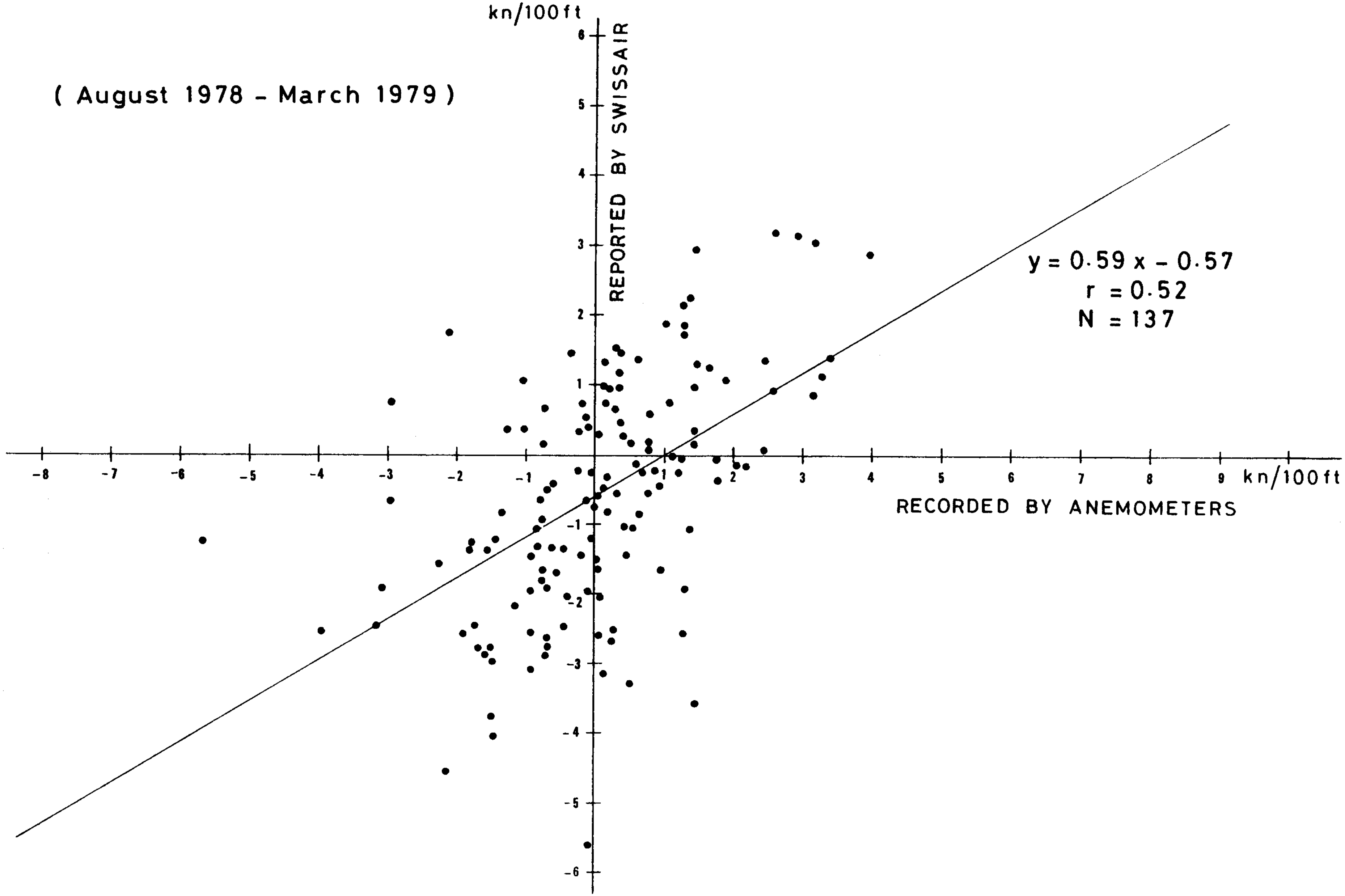

Figure 3a. Comparison between wind shear measured by Swissair (AIDS) with wind shear measured by anemometers at Kowloon Tsai and NW end of runway.

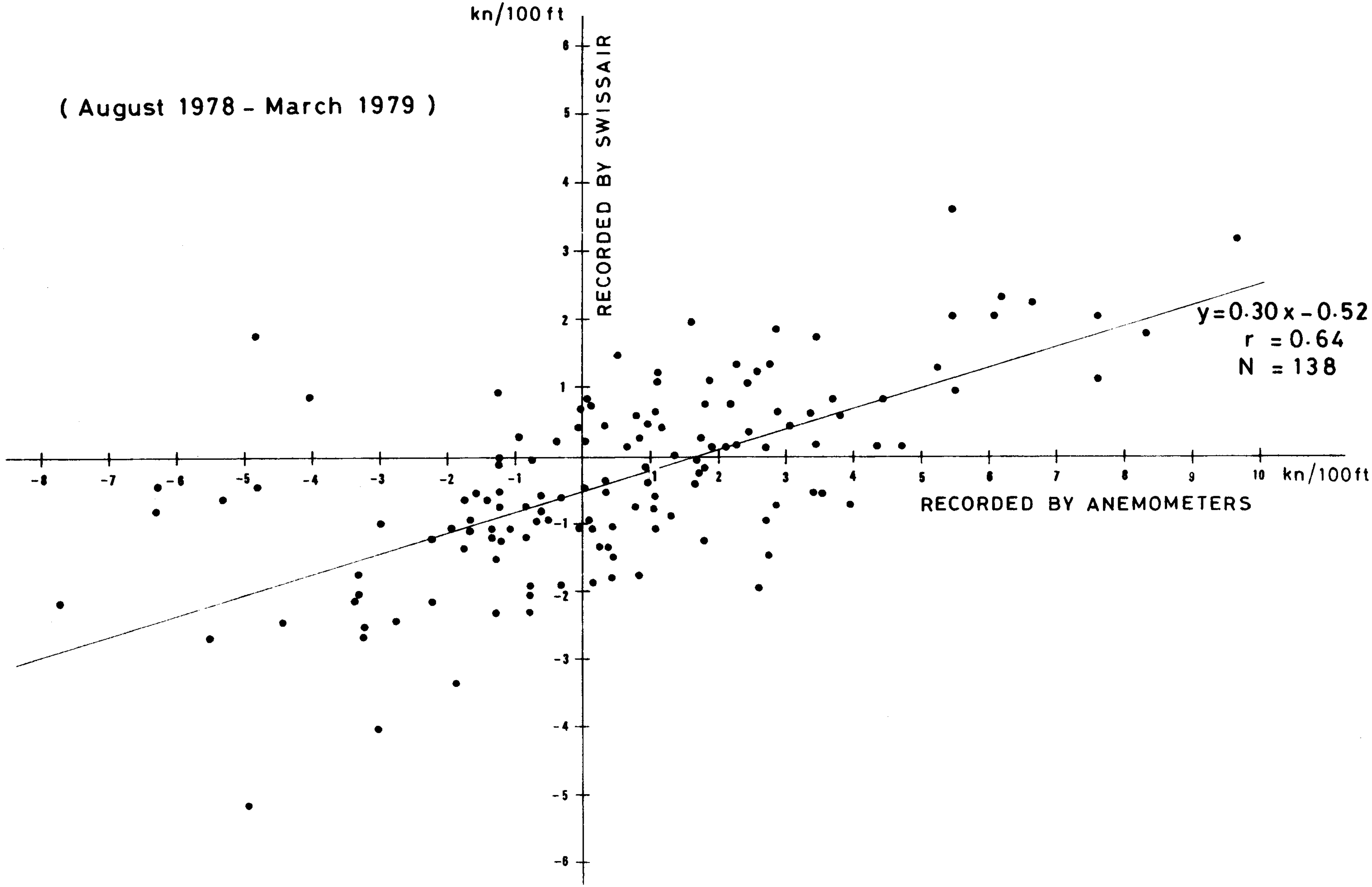

Figure 3b. Comparison between wind shear measured by Swissair (AIDS) with wind shear measured by anemometers at Yau Yat Chuen and NW end of runway.

Appendix I. Mean winds (in degrees and knots) reported by Swissair in the approaches to Runway 13

Hong Kong International Airport

ALTITUDE ABOVE MSL (ft)	JAN 1979	FEB 1979	MAR 1979	APR 1979	MAY 1979	JUN 1979	JUL 1979	AUG 1978,79	SEP 1978,79	OCT 1978	NOV 1978	DEC 1978
5000	208/07	208/17	207/20	184/09	170/08	163/21	144/16	099/14	083/19	101/24	114/11	048/03
NO. OF OBS	7	7	11	7	7	2	2	5	6	6	1	4
4500	197/06	203/11	201/18	160/08	179/06	161/14	154/12	103/18	088/19	090/18	079/13	100/04
NO. OF OBS	19	15	26	17	20	5	4	20	19	17	8	9
4000	172/06	189/08	195/18	156/08	150/05	154/14	144/10	102/18	086/19	084/17	070/13	082/07
NO. OF OBS	17	15	27	18	21	6	4	21	18	17	9	9
3500	160/05	160/08	178/18	142/12	134/06	154/14	132/10	100/18	088/19	077/17	066/13	083/08
NO. OF OBS	15	15	26	17	19	6	4	22	19	17	10	8
3000	126/05	153/08	168/18	127/11	135/07	152/14	141/12	101/18	089/17	073/16	065/13	076/07
NO. OF OBS	17	14	27	18	21	6	4	21	19	17	10	9
2500	108/06	131/07	158/15	120/11	123/07	149/14	149/11	099/17	085/14	072/16	066/11	069/09
NO. OF OBS	18	14	26	18	18	6	4	22	19	17	10	8
2000	102/07	108/08	146/14	104/12	108/09	139/13	144/09	098/17	086/15	074/17	069/10	074/09
NO. OF OBS	18	14	27	17	19	6	3	22	20	17	10	8
1500	100/07	092/08	129/12	087/11	096/09	130/11	156/09	093/16	090/15	071/15	073/09	078/09
NO. OF OBS	18	19	27	18	21	8	5	26	22	18	15	12
1400	100/07	090/07	128/12	091/11	094/10	126/12	149/09	094/15	087/14	071/15	075/09	077/09
NO. OF OBS	18	19	27	16	21	9	7	26	24	19	17	13
1300	100/08	089/07	124/12	086/11	093/10	124/13	146/09	094/16	086/15	073/14	077/09	076/08
NO. OF OBS	19	19	27	18	20	9	7	26	24	20	16	14
1200	096/07	087/07	115/12	085/11	096/10	122/13	148/08	092/16	088/14	074/14	078/09	081/08
NO. OF OBS	20	19	27	19	21	9	7	25	24	20	15	14
1100	094/07	089/07	115/11	085/10	092/09	118/13	149/08	094/15	087/14	075/15	076/09	081/07
NO. OF OBS	20	19	26	19	22	9	7	25	24	19	16	16
1000	095/08	088/07	112/11	085/09	086/09	117/12	145/07	093/14	087/14	076/13	076/09	080/08
NO. OF OBS	20	19	27	19	22	9	6	25	24	20	17	16
900	091/07	082/07	108/11	085/10	088/09	119/12	140/07	093/15	088/14	077/13	079/09	083/06
NO. OF OBS	20	19	27	19	22	9	7	26	24	19	17	15
800	093/08	084/06	104/10	080/09	089/09	120/12	143/07	094/14	085/13	079/13	082/09	084/07
NO. OF OBS	19	18	27	19	20	9	7	26	24	20	17	16
700	092/08	088/07	104/09	077/09	092/09	114/11	144/07	094/14	085/13	081/13	084/09	087/07
NO. OF OBS	20	19	27	19	21	9	7	26	24	20	17	16
600	097/08	089/06	104/09	080/08	093/09	114/12	149/08	097/15	087/12	081/12	093/08	087/07
NO. OF OBS	19	19	27	19	21	9	7	25	24	20	17	16
500	105/07	104/06	112/08	089/07	104/08	112/12	153/08	105/14	093/12	087/11	104/08	097/07
NO. OF OBS	20	18	27	19	22	9	7	26	24	20	17	16
400	121/08	117/06	129/09	109/07	113/08	116/14	155/08	113/14	102/12	097/11	106/08	102/06
NO. OF OBS	20	18	27	19	21	8	7	26	24	19	17	16
300	123/08	120/06	133/09	114/06	116/08	124/12	152/09	113/13	103/10	096/11	107/08	112/06
NO. OF OBS	20	17	27	19	22	9	7	26	24	19	17	16
200	124/08	111/06	121/10	112/06	115/09	114/12	140/09	110/14	098/12	099/10	106/08	108/07
NO. OF OBS	18	17	26	19	22	9	7	25	23	20	16	15
100	114/08	100/07	105/10	096/07	101/09	105/12	123/11	104/13	092/12	096/11	105/09	104/08
NO. OF OBS	19	18	27	18	20	9	6	26	24	19	16	15
0	-----	-----	-----	-----	099/15	102/08	-----	-----	-----	118/19	-----	-----
NO. OF OBS	0	0	0	0	1	1	0	0	0	1	0	0

Appendix II. Mean temperatures (^{o}C) reported by Swissair in the approaches to Runway 13

Hong Kong International Airport

ALTITUDE ABOVE MSL (ft)	JAN 1979	FEB 1979	MAR 1979	APR 1979	MAY 1979	JUN 1979	JUL 1979	AUG 1978,79	SEP 1978,79	OCT 1978	NOV 1978	DEC 1978
5000	11.86	14.57	14.64	16.14	17.43	19.50	19.50	19.00	19.17	15.83	16.00	12.00
NO. OF OBS	7	7	11	7	7	2	2	5	6	6	1	4
4500	12.84	13.40	15.27	16.53	18.10	20.20	20.25	19.55	19.16	17.06	15.00	12.11
NO. OF OBS	19	15	26	17	20	5	4	20	19	17	8	9
4000	13.24	13.47	15.56	17.56	18.76	20.50	21.25	20.43	20.06	17.76	15.44	12.11
NO. OF OBS	17	15	27	18	21	6	4	21	18	17	9	9
3500	14.20	13.47	16.08	18.29	19.53	21.67	21.75	21.36	20.95	18.24	15.30	12.25
NO. OF OBS	15	15	26	17	19	6	4	22	19	17	10	8
3000	13.82	13.79	16.22	18.22	20.24	22.33	22.75	22.05	21.63	18.88	15.90	12.33
NO. OF OBS	17	14	27	18	21	6	4	21	19	17	10	9
2500	14.28	14.64	16.65	18.61	20.72	22.83	24.00	22.82	22.68	19.59	16.70	13.25
NO. OF OBS	18	14	26	18	18	6	4	22	19	17	10	8
2000	15.11	15.21	17.78	18.88	21.84	23.83	24.67	23.95	23.80	20.71	17.60	14.25
NO. OF OBS	18	14	27	17	19	6	3	22	20	17	10	8
1500	16.11	16.58	17.89	19.39	22.43	24.25	26.40	25.08	24.73	21.89	18.07	14.92
NO. OF OBS	18	19	27	18	21	8	5	26	22	18	15	12
1400	16.44	16.68	18.07	19.75	22.52	24.67	26.57	25.35	25.25	22.21	18.29	15.00
NO. OF OBS	18	19	27	16	21	9	7	26	24	19	17	13
1300	16.68	17.21	18.04	20.11	22.45	24.89	26.57	25.54	25.38	22.35	18.25	15.07
NO. OF OBS	19	19	27	18	20	9	7	26	24	20	16	14
1200	16.70	17.32	18.37	20.16	22.95	25.33	27.14	25.84	25.67	22.65	18.47	15.93
NO. OF OBS	20	19	27	19	21	9	7	25	24	20	15	14
1100	16.85	17.58	18.35	20.26	23.14	25.22	27.43	26.04	25.96	22.79	18.94	16.13
NO. OF OBS	20	19	26	19	22	9	7	25	24	19	16	16
1000	17.25	17.84	18.56	20.37	23.36	25.67	27.50	26.16	26.21	23.15	19.53	16.38
NO. OF OBS	20	19	27	19	22	9	6	25	24	20	17	16
900	17.50	18.05	18.78	20.47	23.55	25.78	28.14	26.50	26.42	23.53	19.76	16.67
NO. OF OBS	20	19	27	19	22	9	7	26	24	19	17	15
800	17.47	18.22	18.93	20.74	23.80	26.11	28.29	26.77	26.71	23.80	20.06	16.94
NO. OF OBS	19	18	27	19	20	9	7	26	24	20	17	16
700	18.05	18.47	19.11	20.79	23.95	26.44	28.43	27.08	26.96	23.95	20.29	17.13
NO. OF OBS	20	19	27	19	21	9	7	26	24	20	17	16
600	18.21	18.89	19.56	21.16	24.24	26.78	28.86	27.20	27.38	24.40	20.59	17.31
NO. OF OBS	19	19	27	19	21	9	7	25	24	20	17	16
500	18.45	19.39	19.59	21.37	24.59	27.00	29.29	27.54	27.54	24.65	20.82	17.94
NO. OF OBS	20	18	27	19	22	9	7	26	24	20	17	16
400	18.60	19.11	19.96	21.68	24.95	27.25	29.43	27.77	27.83	24.79	21.06	18.19
NO. OF OBS	20	18	27	19	21	8	7	26	24	19	17	16
300	18.95	19.82	20.33	21.74	25.09	27.67	29.57	28.08	28.21	25.16	21.47	18.31
NO. OF OBS	20	17	27	19	22	9	7	26	24	19	17	16
200	19.39	19.76	20.73	22.05	25.32	27.78	30.29	28.36	28.39	25.60	21.63	18.60
NO. OF OBS	18	17	26	19	22	9	7	25	23	20	16	15
100	19.21	19.94	20.70	22.22	25.55	28.33	30.17	28.54	28.67	25.74	22.00	18.73
NO. OF OBS	19	18	27	18	20	9	6	26	24	19	16	15
0	20.00	20.39	21.04	22.63	25.82	28.33	30.86	29.00	29.48	26.00	22.13	19.14
NO. OF OBS	20	18	27	19	22	9	7	27	23	20	15	14

Appendix III. Mean 100-ft vector difference (in degrees and knots) reported by Swissair in the approaches to Runway 13

Hong Kong International Airport

ALTITUDE ABOVE MSL (ft)	JAN 1979	FEB 1979	MAR 1979	APR 1979	MAY 1979	JUN 1979	JUL 1979	AUG 1978,79	SEP 1978,79	OCT 1978	NOV 1978	DEC 1978
5000-4900	003/00.68	334/01.17	325/00.86	165/00.68	151/00.28	183/01.17	088/01.47	195/00.80	338/00.47	301/01.69	190/03.17	251/01.06
NO. OF OBS	6	7	11	7	7	2	2	5	6	6	1	4
4500-4400	259/00.77	217/00.63	304/00.42	261/01.02	245/00.61	350/00.91	170/00.54	346/00.20	280/00.48	159/00.47	174/00.76	248/00.52
NO. OF OBS	18	15	26	17	20	5	4	20	19	17	8	8
4000-3900	225/00.06	246/00.83	273/01.01	243/00.84	244/00.32	035/00.37	352/00.46	229/00.33	003/00.52	093/00.26	177/00.42	219/00.53
NO. OF OBS	16	15	27	16	21	6	4	21	18	17	9	9
3500-3400	307/00.59	302/00.35	290/01.27	297/01.30	319/00.76	281/00.21	252/00.47	146/00.39	242/00.62	091/00.86	109/00.29	177/00.60
NO. OF OBS	15	15	26	17	19	6	4	22	19	17	10	8
3000-2900	215/00.95	222/00.85	205/00.59	265/00.35	251/00.62	114/00.35	190/00.46	163/00.38	107/00.76	195/00.35	144/00.21	228/00.18
NO. OF OBS	16	14	27	18	21	6	4	21	19	17	10	8
2500-2400	243/00.25	244/00.14	249/00.62	213/00.57	207/00.65	305/00.10	270/00.30	158/00.45	096/00.56	303/00.59	292/00.34	246/01.19
NO. OF OBS	18	14	26	18	18	5	4	22	18	17	10	7
2000-1900	117/00.71	163/00.72	198/01.55	241/00.41	212/00.76	172/01.56	108/01.04	224/00.29	175/00.73	014/00.48	082/00.58	248/01.38
NO. OF OBS	18	14	27	16	19	6	3	22	18	17	9	8
1500-1400	275/00.24	119/00.41	206/00.36	265/00.14	019/00.22	174/00.36	317/00.55	060/00.10	206/00.57	009/00.31	353/00.44	006/00.47
NO. OF OBS	18	19	27	16	20	8	5	26	22	18	15	11
1400-1300	040/00.29	160/00.23	203/00.86	220/00.16	142/00.33	287/01.02	244/00.42	285/00.13	226/00.52	360/00.42	346/00.26	303/00.55
NO. OF OBS	18	19	27	16	20	9	7	26	24	19	16	12
1300-1200	206/00.28	212/00.20	205/01.78	108/00.46	300/00.44	261/00.78	085/00.26	129/00.39	027/00.72	318/00.32	091/00.26	349/00.56
NO. OF OBS	19	19	27	18	19	9	7	25	24	20	15	13
1200-1100	163/00.24	051/00.33	152/00.88	088/00.61	138/00.98	202/00.81	134/00.50	038/00.57	201/00.39	354/00.40	057/00.06	352/00.12
NO. OF OBS	20	19	26	19	21	9	7	25	24	19	15	14
1100-1000	324/00.28	104/00.53	219/00.20	079/00.70	177/00.90	132/01.45	158/01.80	114/00.92	158/00.10	078/01.02	242/00.31	239/00.17
NO. OF OBS	20	19	26	19	22	9	6	25	24	19	16	16
1000- 900	163/00.64	174/00.66	175/00.73	266/00.28	348/00.27	054/00.47	272/01.04	279/00.46	060/00.77	021/00.57	314/00.41	046/00.95
NO. OF OBS	20	19	27	19	22	9	6	25	24	19	17	15
900- 800	298/00.43	353/00.36	157/00.98	163/00.80	027/00.56	310/00.77	016/00.45	089/00.53	145/00.78	006/00.53	004/00.55	258/00.43
NO. OF OBS	19	18	27	19	20	9	7	26	24	19	17	15
800- 700	285/00.20	340/00.35	109/01.38	152/00.60	319/00.41	166/01.58	013/00.13	301/00.16	106/00.40	334/00.53	352/00.31	006/00.34
NO. OF OBS	19	18	27	19	19	9	7	26	24	20	17	16
700- 600	047/00.65	082/00.67	105/00.34	050/00.95	061/00.28	324/00.29	029/00.73	024/00.92	049/00.87	089/00.70	009/01.43	090/00.46
NO. OF OBS	19	19	27	19	21	9	7	25	24	20	17	16
600- 500	019/01.20	017/01.44	020/01.28	038/01.80	037/01.88	238/00.50	007/00.98	019/01.96	025/01.35	041/01.95	015/01.55	008/01.17
NO. OF OBS	19	18	27	19	21	9	7	25	24	20	17	16
500- 400	360/02.28	355/02.22	024/02.48	013/02.44	355/01.29	003/02.15	107/00.42	019/01.88	008/01.81	019/01.72	085/00.79	062/00.89
NO. OF OBS	20	17	27	19	21	8	7	26	24	19	17	16
400- 300	085/00.50	100/00.74	027/00.77	084/01.10	098/00.60	086/01.32	294/00.76	118/00.61	088/01.22	201/00.42	336/00.23	024/01.10
NO. OF OBS	20	17	27	19	21	8	7	26	24	18	17	16
300- 200	133/00.32	208/00.49	230/02.06	170/00.23	281/00.69	206/02.15	244/01.72	220/00.70	231/01.36	345/00.65	211/00.50	239/00.52
NO. OF OBS	18	16	26	19	22	9	7	25	23	19	16	15
200- 100	230/01.55	240/01.45	210/02.80	229/02.24	217/02.50	219/01.89	216/02.16	183/01.22	210/01.22	219/00.78	280/00.20	257/01.06
NO. OF OBS	17	17	26	18	20	9	6	25	23	19	15	15
100- 0	-----	-----	-----	-----	342/03.31	092/04.98	-----	-----	-----	313/10.19	-----	-----
NO. OF OBS	0	0	0	0	1	1	0	0	0	1	0	0

Appendix IV. Mean 100-ft wind shear (kn/100 ft) reported by Swissair in the approaches to Runway 13

Hong Kong International Airport

ALTITUDE ABOVE MSL (ft)	JAN 1979	FEB 1979	MAR 1979	APR 1979	MAY 1979	JUN 1979	JUL 1979	AUG 1978,79	SEP 1978,79	OCT 1978	NOV 1978	DEC 1978
5000-4900	0.86	1.65	2.13	1.14	1.60	1.60	2.17	2.42	1.50	2.66	3.17	1.22
NO. OF OBS	6	7	11	7	7	2	2	5	6	6	1	4
4500-4400	1.20	1.27	1.68	2.12	1.03	1.06	1.11	0.92	1.08	1.53	1.29	1.15
NO. OF OBS	18	15	26	17	20	5	4	20	19	17	8	8
4000-3900	0.93	1.80	1.98	2.39	1.35	1.49	0.85	0.89	1.73	1.26	1.18	1.33
NO. OF OBS	16	15	27	16	21	6	4	21	18	17	9	9
3500-3400	1.47	1.72	3.58	2.67	1.85	1.46	1.73	1.18	1.64	1.90	1.76	1.24
NO. OF OBS	15	15	26	17	19	6	4	22	19	17	10	8
3000-2900	1.43	1.58	1.67	1.08	1.44	2.15	0.73	0.98	1.75	1.71	0.92	0.89
NO. OF OBS	16	14	27	18	21	6	4	21	19	17	10	8
2500-2400	1.10	1.37	1.67	1.46	1.57	1.35	0.63	1.45	2.08	2.24	1.43	1.22
NO. OF OBS	18	14	26	18	18	5	4	22	18	17	10	7
2000-1900	1.62	2.05	2.39	1.89	2.29	1.86	1.57	1.27	1.92	2.50	1.38	1.84
NO. OF OBS	18	14	27	16	19	6	3	22	18	17	9	8
1500-1400	1.31	1.53	1.84	1.17	1.85	1.17	1.20	1.40	2.04	2.12	1.57	1.83
NO. OF OBS	18	19	27	16	20	8	5	26	22	18	15	11
1400-1300	1.44	1.36	2.02	1.33	1.55	1.92	1.00	1.69	1.72	2.01	1.22	2.26
NO. OF OBS	18	19	27	16	20	9	7	26	24	19	16	12
1300-1200	1.36	1.68	2.68	1.69	1.71	1.42	0.97	1.49	2.12	2.16	1.55	1.16
NO. OF OBS	19	19	27	18	19	9	7	25	24	20	15	13
1200-1100	1.31	1.80	2.10	1.97	1.67	1.65	1.20	1.72	2.13	2.22	2.32	1.42
NO. OF OBS	20	19	26	19	21	9	7	25	24	19	15	14
1100-1000	1.50	1.61	2.40	2.79	1.59	2.33	2.39	2.10	2.10	2.85	2.03	1.75
NO. OF OBS	20	19	26	19	22	9	6	25	24	19	16	16
1000- 900	1.61	1.86	2.19	2.32	1.66	2.36	1.97	1.69	2.68	2.74	1.87	1.89
NO. OF OBS	20	19	27	19	22	9	6	25	24	19	17	15
900- 800	1.49	1.79	2.38	1.70	1.81	2.64	1.02	1.73	2.43	2.72	1.91	1.46
NO. OF OBS	19	18	27	19	20	9	7	26	24	19	17	15
800- 700	1.56	1.11	2.61	2.19	2.02	2.82	1.65	2.14	2.61	3.18	1.89	1.86
NO. OF OBS	19	18	27	19	19	9	7	26	24	20	17	16
700- 600	1.82	1.96	2.50	2.55	2.29	2.02	1.48	2.41	2.46	2.34	2.32	2.11
NO. OF OBS	19	19	27	19	21	9	7	25	24	20	17	16
600- 500	2.11	2.87	3.17	3.11	2.66	1.56	1.54	3.09	2.32	3.13	2.82	2.19
NO. OF OBS	19	18	27	19	21	9	7	25	24	20	17	16
500- 400	2.86	3.19	3.53	3.76	2.82	2.51	2.38	3.28	2.79	3.31	2.36	2.12
NO. OF OBS	20	17	27	19	21	8	7	26	24	19	17	16
400- 300	1.71	1.81	2.82	2.20	2.56	2.61	2.07	2.23	2.87	2.46	2.24	2.60
NO. OF OBS	20	17	27	19	21	8	7	26	24	18	17	16
300- 200	2.24	3.28	3.32	2.27	2.02	3.15	3.08	2.69	3.13	3.63	2.37	3.02
NO. OF OBS	18	16	26	19	22	9	7	25	23	19	16	15
200- 100	2.52	2.46	3.66	3.14	3.58	3.57	2.94	2.84	3.06	4.19	2.98	2.36
NO. OF OBS	17	17	26	18	20	9	6	25	23	19	15	15
100- 0	----	----	----	----	3.31	4.98	----	----	----	10.19	----	----
NO. OF OBS	0	0	0	0	1	1	0	0	0	1	0	0