Wind Measurement Results for ALFLEX Flight Trials

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ABSTRACT

The flight trials of ALFLEX (Automatic Landing Flight Experiment) vehicle were brought to successful conclusion on August 15th, 1996, at Woomera Airfield in South Australia. The period of flight trials was in winter season which was especially bad weather conditions such as mostly cross winds and tail winds for ALFLEX vehicle approaching runway 18; therefore, wind measurement was extremely important. This paper describes the method of flight GO-NOGO decision which was specified by wind restrictions for ALFLEX trials that was given by both the data of Surface Wind Display System (WDS) and the analysis data of upper surface wind observation equipments (OMEGA Sonde and GPS Sonde), and the comparison of these wind measurement results with the wind data calculated from ADS sensor which is installed on the ALFLEX nose boom end.

1. Introduction

All trial plans for ALFLEX flight experiments at Woomera Airfield were successfully completed. There were many cases under the condition of the cross wind and tail wind for ALFLEX vehicle approaching RWY 18; therefore, both measurement equipment of the surface wind display system (WDS) and the upper surface wind measurement equipment (Sonde) were indispensable for GO-NOGO decisions for ALFLEX flights. Here is described the methods of GO-NOGO decisions and future reflection points were shown from the comparison results with calculated wind measurement data.

2. Composition of Measured Wind Data

The composition of measured wind data in the flight experiment of ALFLEX are constituted by three wind data of Surface Wind Display System(following WDS), upper surface wind observation equipments (Sonde) and the wind data of calculated from ADS_IMU(following ADS_IMU) sensors which are installed on the ALFLEX vehicle.

2.1 Surface Wind Display System

The hardware of WDS is consisted by wind transmission sensor, distance extension amplification demodulator (modem), RS232C output transmitter and personal computer system. We had recorded completely the surface wind data during the periods of the ground running tests, hanging flight tests and the free flight trials of phase 1 and phase 2. This display system was effective in the GO-NOGO decision of ALFLEX flight trials. WDS is able to detect the wind speed and direction near where the ALFLEX was designed to touch down, by using a sensor which be placed at the right side of RWY 18 such as coordinates x=360m y=180m from runway coordinate axis original point and with a height of 20 ft above runway center line level. The personal computer recorded completely the surface wind data at a sampling frequency of 4Hz. The designed wind restriction for ALFLEX are applied by using specified the requirements of all-weather automatic landing systems (MIL-F-9490D) considering reasonable combinations of head wind to 25 knots, tail wind to 10 knots, and cross wind to 15 knots, also considering the ALFLEX scale ratio L=0.37.

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Furthermore, the designed 100% and 60% restrictions of ground height 20 ft omniazimuth were given by using Polynomial of Cosine (NASA-CR-114401) function as follows.

$$u = \sqrt{L}U_{6.1}(0.46\log(\frac{H}{L}) + 0.64)$$

$$U_{6.1} = u_{cross} + \frac{1}{2}(u_{head} - u_{tail})\cos\varphi + \frac{1}{2}(u_{head} + u_{tail} - 2u_{cross})\cos^2\varphi$$

$$U_{0.6} = 0.6U_{6.1}$$

$$\varphi = (\psi - \psi_{RWY})\frac{\pi}{180}$$

These wind restriction profile and numerical values for each altitude are shown in Fig.1 and Table 1.

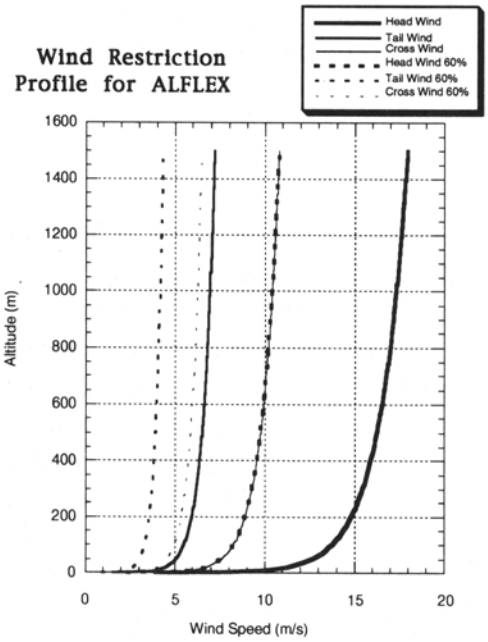


Fig. 1 Designed Wind Profile

Table 1 Designed Wind Restriction

ALT	100%	(m/s)		60%		(m/s)
(m)	Head	Tail	Cross	Head	Tail	Cross
6.1	9.38	3.75	5.63	5.63	2.25	3.37
100	13.75	5.50	8.25	8.25	3.30	4.95
500	16.27	6.50	9.76	9.76	3.90	5.85
1000	17.35	6.94	10.41	10.41	4.16	6.24
1500	17.98	7.19	10.79	10.79	4.31	6.47

U is the wind restriction at height 20 ft (6.1 m); therefore, **U**head is the head wind restriction, **U**tail is the tail wind restriction and **U**cross is the cross wind restriction. U6.1 and U0.6 are designed as 100% and 60% wind restriction of diagonal direction for approaching runway heading to $\psi_{RWY} =$ 185.816 degree (true bearing). WDS is displayed both circles of the wind restriction and mean surface wind for one minute by vector expression in real time (see Fig.2); therefore, the surface wind decision has become easy by using this expression method.

Also, the past vector history displaying for 30 minutes is able to predict the future surface wind. According to recorded wind data for 3 hours, the evaluation and analysis are possible by using both expression of the time history (see Fig. 2) and vector expression of the play back function during the experiment or after completion of the experiment. The results of surface wind measured for 13 times flight trials are shown in Table 2.

Table 2 Results of Surface Wind Measurement

FLT No.	Mean for 1 minute		Mean for just T/D	
	H/T Wind / Cross m/s	Percentage %	H/T Wind / Cross m/s	Percentage %
F101	H4.1	44.1	H3.0	32.0
	R1.8	31.2	R0.6	10.0
F002	H3.7	39.8	H5.4	58.0
	R2.6	45.8	R0.9	17.0
F103	T1.5	40.0	T1.9	50.0
	R2.6	46.1	R3.1	55.0
F004	H7.9	84.6	H9.1	98.0
	R2.4	43.1	R1.9	34.0
F005	T5.6	149.7	T5.7	154.0
	R3.6	64.8	R3.3	61.0
F006	T2.7	71.3	T2.8	75.0
	R3.0	52.8	R4.2	77.0
F007	T2.4	64.6	T1.4	38.0
	R1.8	31.3	R2.2	39.0
F008	H3.1	32.5	H3.7	40.0
	R5.5	97.8	R4.9	87.0
F009	H6.1	65.2	H3.6	39.0
	L1.0	17.2	L0.4	6.0
F010	T0.6	15.9	H0.5	12.0

	L0.0	0.7	L0.2	2.6
F011	T5.1	136.0	T4.0	107
	R2.1	36.6	R3.0	54.0
F012	H3.1	33.0	H2.6	28.0
	L0.1	1.0	R0.1	1.0
F013	H6.4	70.0	H6.3	68.0
	R0.8	14.0	R0.9	16.0

note： H.....Head Wind
T.....Tail Wind
R.....Right Cross Wind
L.....Left Cross Wind

2.2 Upper Surface Wind Observation System(Sonde)

The upper surface wind measurement was carried out by using Sondes and a labor borrowing contract of the Australia Meteorological Agency. These equipment made in Vaisala, both the Omega Sonde and GPS Sonde were used. The system diagram is shown Fig. 3. The type of Sonde for upper surface wind measurement was the Omega Sonde to be released 1 hour before ALFLEX takeoff and the GPS Sonde almost 10 minutes after landing. GPS Sonde of a measuring precision could not be adopted before the takeoff; data was not obtained because there is a case in which the satellite rock off just balloon release and climbing. GPS Sonde is more promising than Omega Sonde, however it was not obtained the reliance as an equipment of ALFLEX takeoff propriety decision before the takeoff. The data of upper surface wind was observed from surface to altitude 10000 ft were brought to Flight Control Facility through both the data of hard copy and text files in which a floppy disk, then we decided flight GO-NOGO by comparing of analyzed wind data by 1500 m with designed wind restriction profiles which is same function as used to the surface wind decision. Designed upper surface wind restriction profiles of 100% and 60% each altitude are as follows.

$$u_{hl} = \sqrt{L}U_{6.1h}K_{Hm}$$

$$u_{tl} = \sqrt{L}U_{6.1t}K_{Hm}$$

$$u_{cl} = \sqrt{L}U_{6.1c}K_{Hm}$$

$$K_{Hm} = 0.46\log(\frac{H_m}{L}) + 0.64$$

where

Hm：measured height (m)

U6.1h, U6.1t, U6.1c：wind restriction value at 6.1 m above ground level (m/s)

uhl, utl, ucl：wind restriction value at measured height (m/s)

$$U_{hml} = u_{cl} + \frac{1}{2}(u_{hl} - u_{tl})\cos\varphi_h + \frac{1}{2}(u_{hl} + u_{tl} - 2u_{cl})\cos^2\varphi_h$$

$$U_{0.6hml} = 0.6U_{hml}$$

$$\varphi_h = (\psi_h - \psi_{RWY})\frac{\pi}{180}$$

where

Uhml：100% wind restriction at the measured height (m/s)

U0.6hml：60% wind restriction at the measured height (m/s)

The wind speed for each direction which was given by using Sonde sounding data were compared with designed upper wind restriction profiles; this two-dimensional method was effective for ALFLEX flight GO-NOGO decisions. On the other hand, we tried to display of three-dimensional method, but the first was clearly better than the second method; therefore, the two-dimensional method was adopted. A sample trend profile of F101 both Sonde sounding data and two sample profiles of the flight GO or NOGO was decided by using the Omega Sonde sounding data are shown Fig. 4.

【Flight GO-NOGO Decision Conditions】

Flight GO-NOGO decisions relative to wind conditions for the ALFLEX automatic landing experiment should be desired points which are airspeed, sink rate, and attitude just before ALFLEX touch down. The cross wind control law of the ALFLEX automatic landing system is designed only in the club law just before touch down; therefore, especially the danger of tire bursts are accompanied by the over limiting cross wind. The following conditions were set in order to efficiently carry out the flight experiment in almost cross and tail wind weather conditions.

(1) The surface wind restrictions are done within 60% in phase of 1, and within 100% in phase of 2.

(2) The upper surface wind restriction is done within 100% in which the result analyzed at the measured value of the Omega Sonde data was released before 1 hour.

(3) It is confirmed by the result of the simulation by using the Sonde data measured before every flight, and, it was decided by the result of the simulation in the case of which either deviate from the restrictions of the surface wind or the upper surface wind.

2.3 Wind Estimation from ADS_IMU Sensors which are installed on ALFLEX vehicle

The wind data estimation of the airframe is calculated from ADS_IMU sensors by using the following relational expression. Airframe Airspeed = Airframe Inertia Speed − Wind Speed. Airframe airspeed is estimated by the ADS sensor using static pressure, dynamic pressure and outside air temperature of an ADS output, using angle of attack and angle of sideslip of ADS output in the shape of the airframe coordinate component in respect of the true airspeed. As it is obtained from airframe acceleration, airframe angular velocity and attitude angle of IMU output bases LT on the other airframe inertia speed, and applying the Kalman filter to obtain the airframe position as an airframe coordinate component. If these differences are taken, the speed of the atmospheric disturbance (wind) is estimated in the shape of the airframe coordinate component, and it is converted into the runway coordinate component using the airframe attitude of the IMU output.

3. Comparisons of The Wind Data

Here is described the result of comparison obtained by three methods of measuring and estimating the wind data. It must assumed that these measured and estimated wind data do not perfectly synchronize to GPS time such as WDS is almost GPS time, Sonde is UTC time and ADS_IMU estimated wind data was synchronized. The method of comparison used to interpolate the Uw, Vw components of each wind using identical time series data to touch down from released time of ALFLEX. In the small sampling frequency, wind data of WDS and Sonde were evaluated by collecting the data number by linear interpolation. On the evaluation of low frequency turbulent component by the moment of ALFLEX touch down from a flare, the comparison was carried out based on the coordinate of each measurement point in the identical runway coordinate and transit time of the wave. However, Ww is not discussed here.

3.1 Comparison of Sonde Data with ADS_IMU Estimation

The wind of same altitude around the ALFLEX flight measured by Sondes was assumed to be uniformly changing with time, and time interpolation was done. The result is shown in Fig. 5.

The wind data at altitude of 1500 m from the surface were interpolated according to Sondes measured data around ALFLEX flight and were compared with the wind data estimated from ADS_IMU. The result is shown in Fig. 6.

On Vw by altitude 1500 m from the surface, there are even deviations for the time interpolation value of the Sondes at a fixed width in the positive and negative, and they resemble each other; however, there is a positive bias at the Uw component. This tendency was seen in all 13 times cases, and it seems to bias it on the airspeed compensation error. It can be asked that it agrees with correcting these, according to the right of the figure well, and that the time interpolation data of the Sondes is similar to the true value. The content of the compensation is based on the presentation of "aerodynamic characteristic estimation of ALFLEX".

3.2 Comparison of Surface Wind Data with ADS_IMU Estimation

The wind data measured from WDS and estimated by ADS_IMU can be expressed in the same identical runway coordinate, also these time bases are measured in the same GPS time. Case F005 with comparatively strong wind was chosen, and the Uw and Vw components were compared on surface wind measured at an advanced 6.1 m and the wind of ADS_IMU estimate from advanced 10 m to ALFLEX touch down after the airspeed error correction. The result is shown in Fig. 7.

It can be said that the correlation had appeared on these to some extent and that the wind data estimated from the in measured values by ADS_IMU sensors and the measured values from WDS at ALFLEX touch down was able to measure the same wave.

4. Conclusion

The period by automatic landing experiment of ALFLEX in Woomera was the time in which the Southern Hemisphere seasonally changed to mid-winter from the autumn. Woomera is located in the Southern Hemisphere unlike Japan which is located in the Northern Hemisphere; therefore, the direction of the injection of high pressure and low pressure is opposite by Coriolis force. According to the delay of the experiment schedule, the surface wind of right cross wind and tail wind increased when approaching runway 18; because the center of high pressure went to the north side the latitude of the high pressure moved from west to east in the time in which the automatic landing experiment begins, then the wind shifted to a west and north-west wind as the day progressed. The strong jet stream (westerlies) came into the high altitude, and it had an effect at altitudes of 10000 ft or less. In these weather conditions, WDS and Sonde equipments were used as the decision became the equipment which was indispensable for the flight propriety decision of ALFLEX, and it was shown to be very effective through actual operation. Some data like the following were obtained by comparing wind data which these measured with the ADS_IMU estimate.

(1) The wind restriction profile was calculated by using the wind direction data measured in each altitude of the Sonde sounding, and it was proven that the flight GO-NOGO decision can be made using the technique compared with measured Sonde data in the two-dimensional profile.

(2) It is possible to deduce the near true value by interpolating measured Sondes data around the flight such as the environment around Woomera in which there are small effects due to ground obstacle. This technique seems viable for use in future flight experiments.

(3) The Uw component of the wind estimated at ADS_IMU had more positive bias than the wind measured by Sondes data interpolation; therefore, the airspeed from ADS output was smaller than in practice.

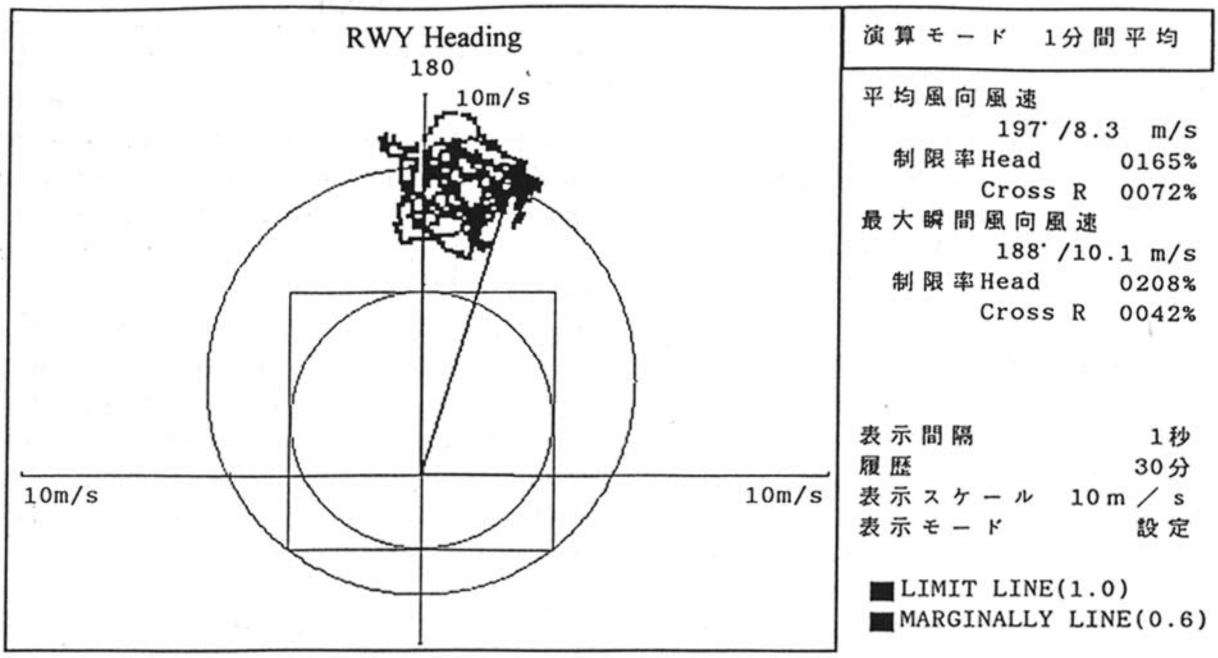
(4) In order to evaluate low frequency turbulent flow components which affect the flight characteristics of the experimental aircraft in flare, it is desirable that the surface wind display system should synchronize completely with GPS time and that higher sampling frequency be realized.

(5) According to the result compared of the surface wind with estimated of ADS_IMU for ALFLEX in flare, it almost corresponded, but did not come in correlation. It is desired that there is a measurement point of the surface wind for the right and left of the approaching runway, and the wind measuring it more correctly based on the transit time difference wave and space could be applied to in future flight experiments.

References

1) MIL-F-9490D: Flight Control Systems-Design, Installation and Test of Piloted Aircraft, General Specification for
2) NASA-CR-114401: Study of Automatic and Manual Terminal Guidance and Control System for Space Shuttle Vehicles(Aug. 01,1971)
3) MIL-F-8785C: Flying Qualities of Piloted Airplanes
4) Digicora Handbook
5) Mikio Hino: Spectrum Analysis (1986)

Vector Expression of Surface Wind (F004)



Time History Expression of Surface Wind (F004)

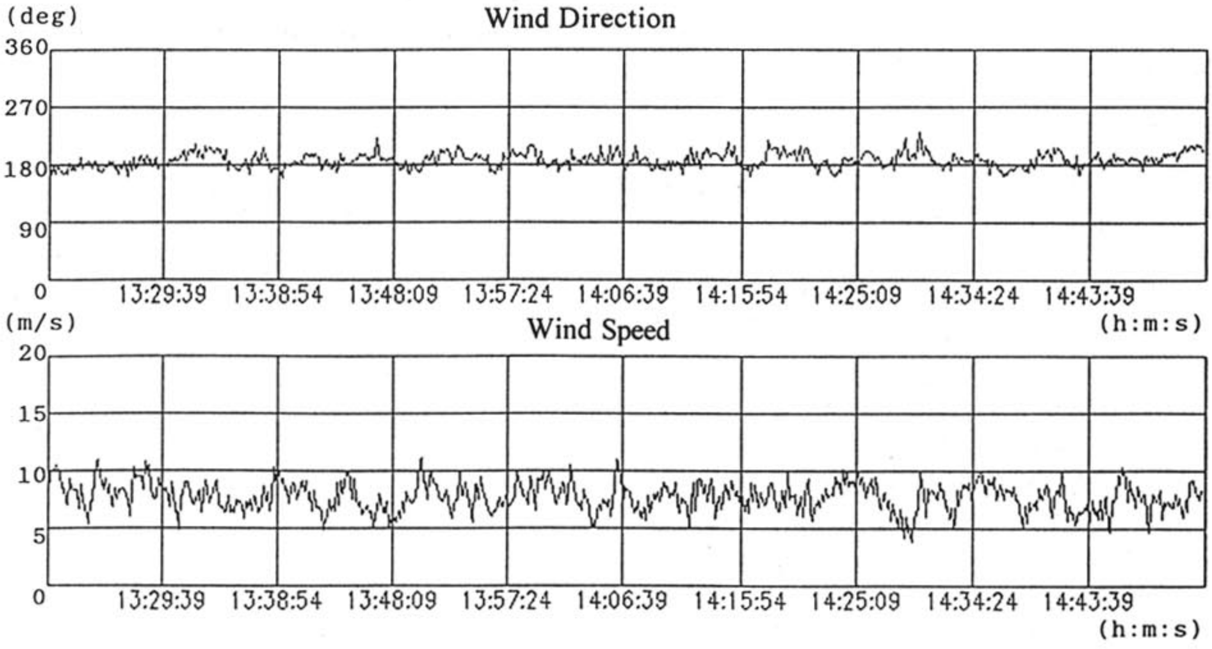
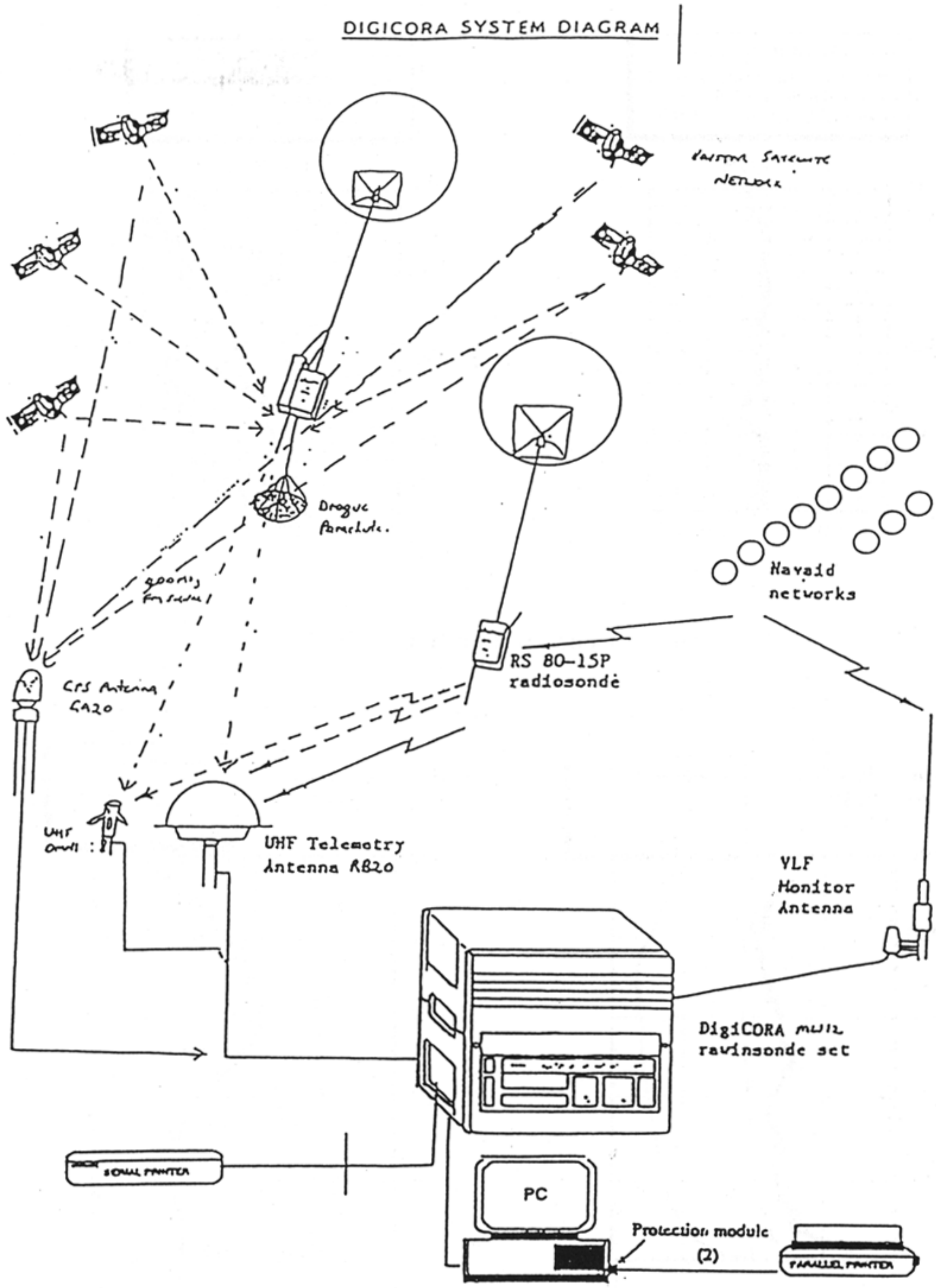
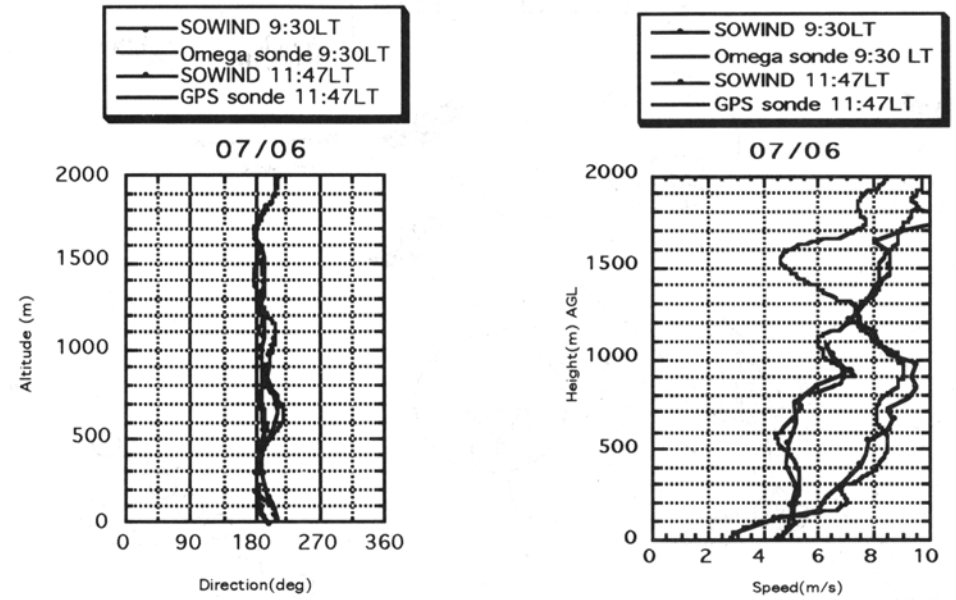


Fig. 2 Expression of Wind Display System

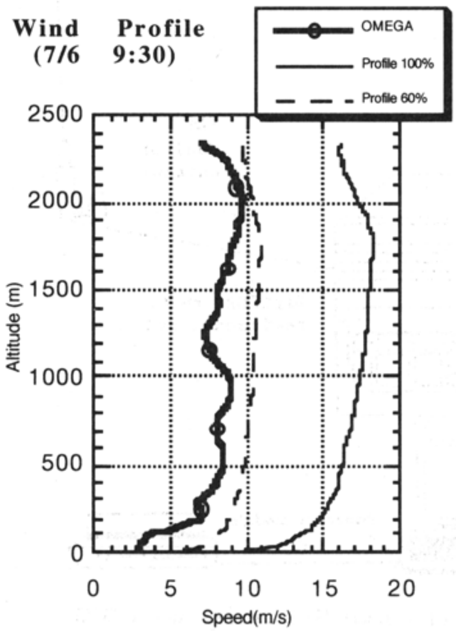


Vaisala GPS receiver system consists of a local GPS antenna and a GPS processor card. The local signal is connected from the antenna to the GPS processor. The remote GPS signal is detected in the radiosonde GPS receiver and transmitted in digital form to the ground station.

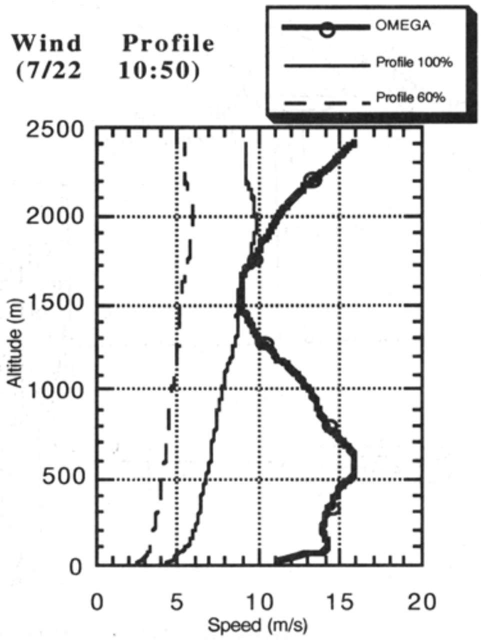
Fig 3 System Diagram of Upper Surface Wind



Trend of Upper Surface Wind (F101)

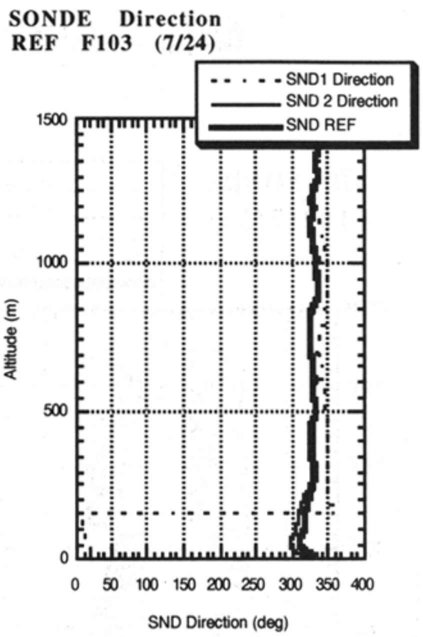


Wind Profile of GO Decision (F101)

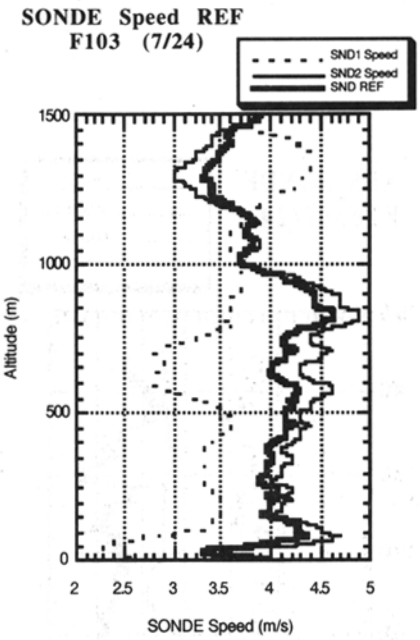


Wind Profile of NOGO Decision

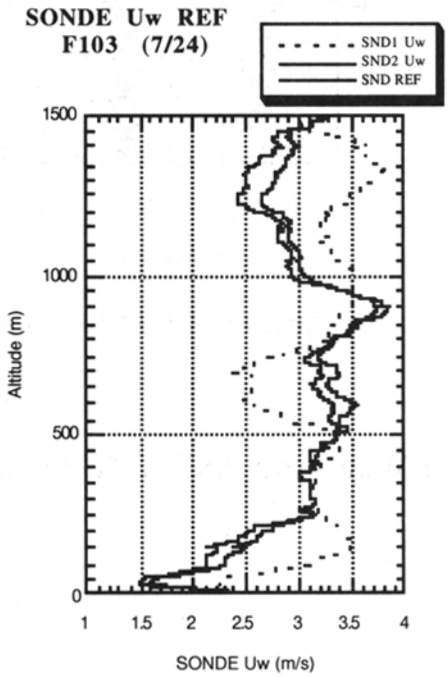
Fig. 4 Profile for Flight GO-NOGO Decision



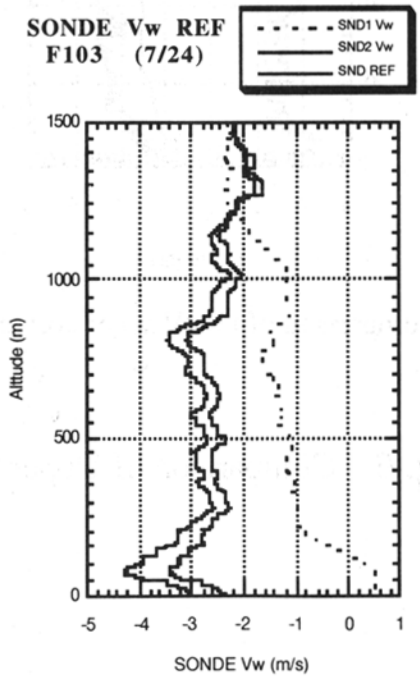
Time Interpolation of Direction



Time Interpolation of Speed



Time Interpolation of Uw



Time Interpolation of Vw

Fig. 5 Time Interpolation of Upper Surface Wind

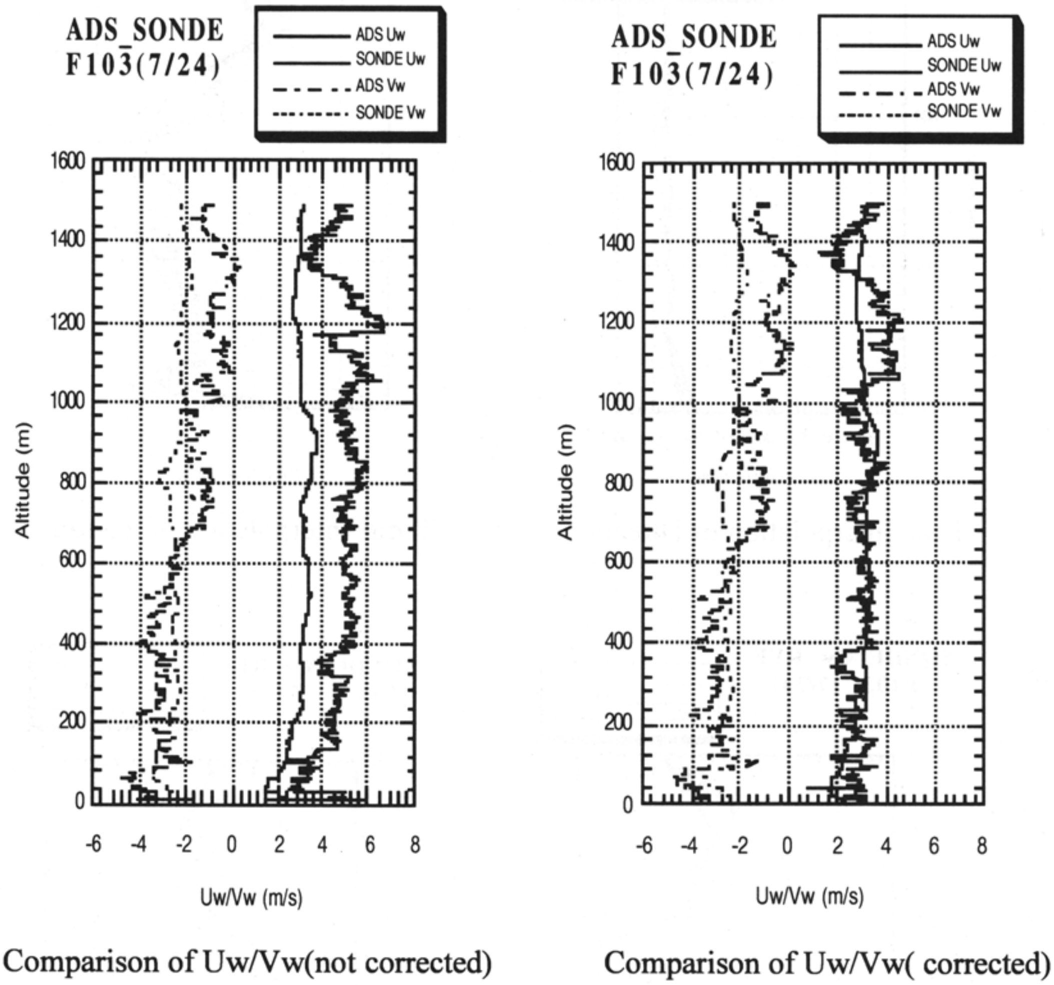
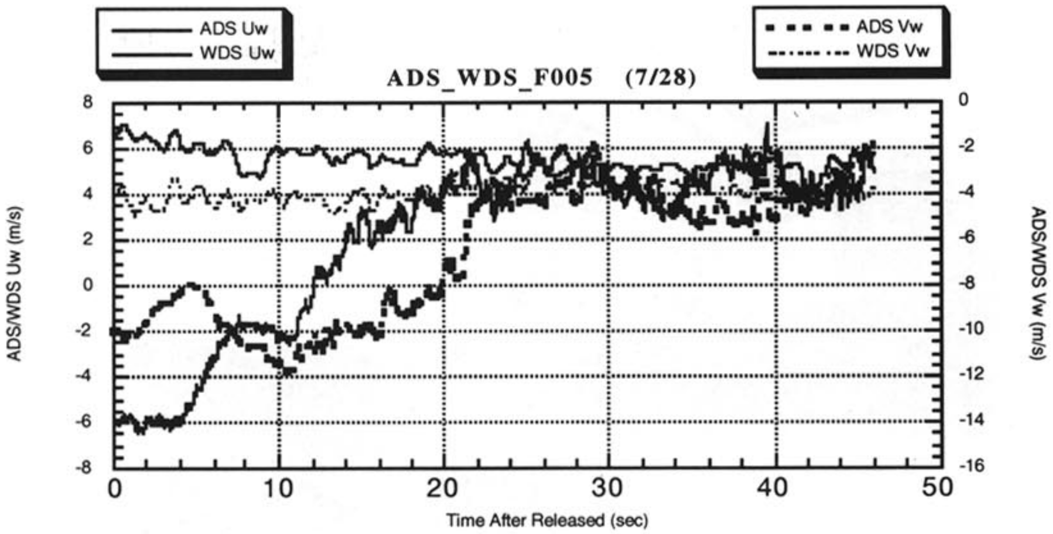
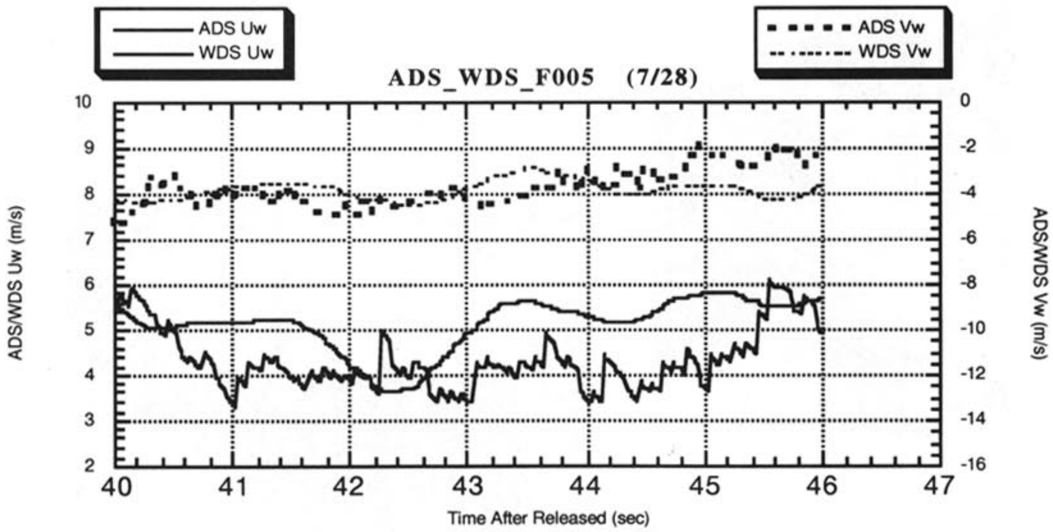


Fig. 6 Comparison of Upper Surface Wind with ASD_IMU Estimation



Uw/Vw Comparison of WDS with ADS_IMU Estimation (F005)



Time History of Uw/Vw between Altitude 10m and T/D
(Enlarged Upper Graphcopy)

Fig. 7 Comparison of Surface Wind(WDS) with ADS_IMU Estimation