The Answer is Blowin' in the Wind
- The Use of Recorded/Derived Wind Data in Investigations

Neil A. H. Campbell MO3806

Neil graduated in 1983, with a Bachelor of Engineering degree (Electronics), from the University of Western Australia. In 1986 he joined the Bureau of Air Safety Investigation as a flight recorder specialist. Neil took a leave of absence during 1994-1995 and managed the flight data analysis program for Gulf Air in Bahrain. During 1998 he was a member of the ICAO Flight Recorder Panel that developed changes to ICAO Annex 6. In February 2000, Neil joined the Corporate Safety Department of Cathay Pacific Airways Limited in Hong Kong. During 2001 and 2002 he held the position of Manager Air Safety. In December 2003 he rejoined the Australian Transport Safety Bureau as a Senior Transport Safety Investigator.

CONTENTS

1. INTRODUCTION

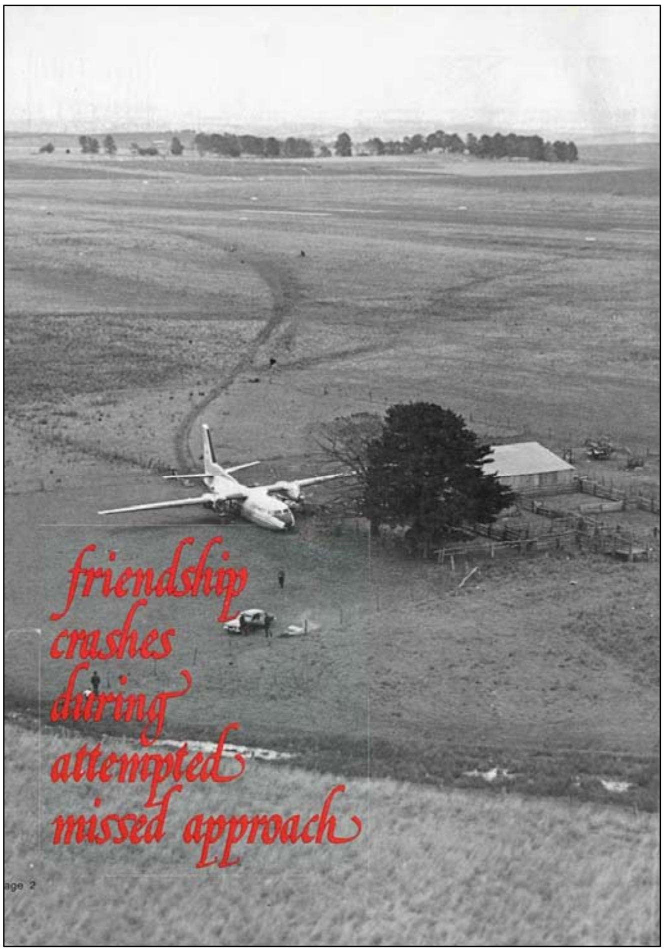
Many flight data recorder (FDR) or quick access recorder (QAR) parameters, such as GPS latitude and longitude, are typically highly accurate. It is easy to assume that other parameters are equally accurate however some, such as wind speed and direction, require careful interpretation. Wind is often a key factor in takeoff and landing incidents and accidents and has the following characteristics:

- It is a vector quantity with a magnitude (speed) and direction
- It varies with time, position and altitude
- Its effects are transient and may leave little direct evidence and
- It is a 3 dimensional quantity with a vertical as well as a horizontal component

2. CASE STUDY 1: F-27 Bathurst, Australia 31 May 1974[1]

During approach the aircraft encountered turbulence and drifted to the left of the runway centre-line. The rain intensity increased and a go-around was commenced. Despite climb-power being set, 34 seconds later the aircraft impacted the ground (Figure 1).

Figure 1:



[1] Accident Investigation Report F-27-100 VH-EWL 31 May 1974, Air Safety Investigation Branch, Department of Transport, October 1976. *Note: In 1982, the Air Safety Investigation Branch (ASIB) was re-organised to become the Bureau of Air Safety Investigation (BASI). On 1 July 1999, the multi-modal Australian Transport Safety Bureau was created by combining BASI with other agencies.*

The aircraft was only fitted with a basic six parameter[2] analogue FDR which did not record any wind information directly. The FDR showed a reduction in indicated airspeed and pressure altitude but this characteristic could occur for many reasons. Limited parameters also meant that the aircraft manufacturer was unable to derive any wind data. Fortunately there were no serious injuries to any of the crew or passengers. Apart from the crew, valuable evidence was obtained from the passengers (one of whom was a pilot) and other eyewitnesses on the ground who were experienced in F-27 operations at Bathurst. The aircraft was also available for a thorough examination. No pre-existing problems were found with the aircraft and the investigation team concluded that:

> **The cause of the accident was that during the go-around the climb performance of the aircraft was adversely affected by an unpredictable encounter with a large change in the horizontal wind component, and an associated downdraught, at a height too low to effect recovery.**

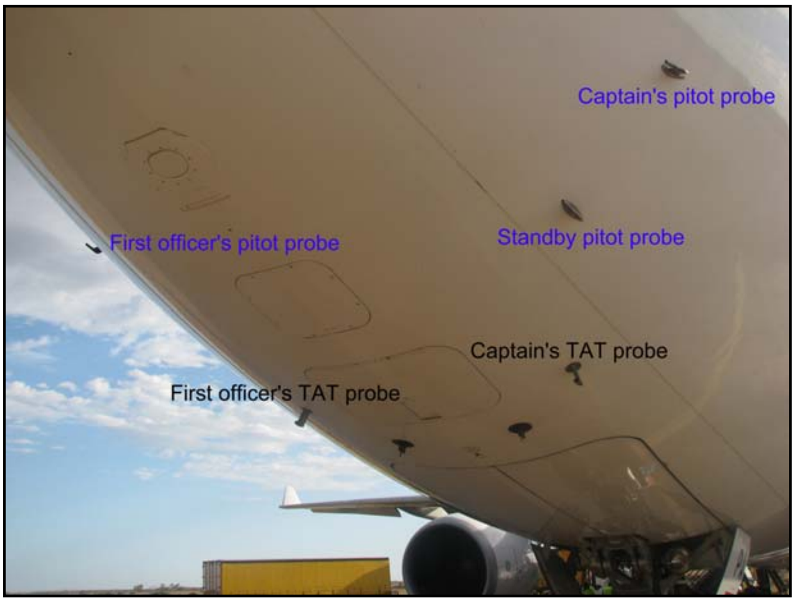
Note that this is a good description of a microburst but that the term 'microburst' was not defined until the early 1980's. The magnitudes of the changes in wind speeds and directions involved could not be quantified except that they exceeded the climb capability of the aircraft.

If there had been no survivors and the aircraft had been destroyed then it is likely that the cause of this accident would have been undetermined and not attributed to weather effects. Unlike the F-27, modern aircraft can derive wind information through their inertial reference units. So is the problem for investigators, of determining the wind that an aircraft encountered, over?

3. ONBOARD SOURCES OF RECORDED WIND DATA

Modern airliners are fitted with inertial reference units often in combination with air data computers to form Air Data Inertial Reference Units (ADIRUs). ADIRUs are an important source of data for the FDR as they provide air data parameters (such as computed airspeed, true airspeed, Mach number, pressure altitude, total air temperature and angle of attack) as well as inertial parameters (such as pitch, roll, heading, latitude, longitude, groundspeed, track, drift, wind speed and direction). Typically airliners are fitted with two or three ADIRUs. The sensors for the air data parameters are located on the surface of the aircraft:

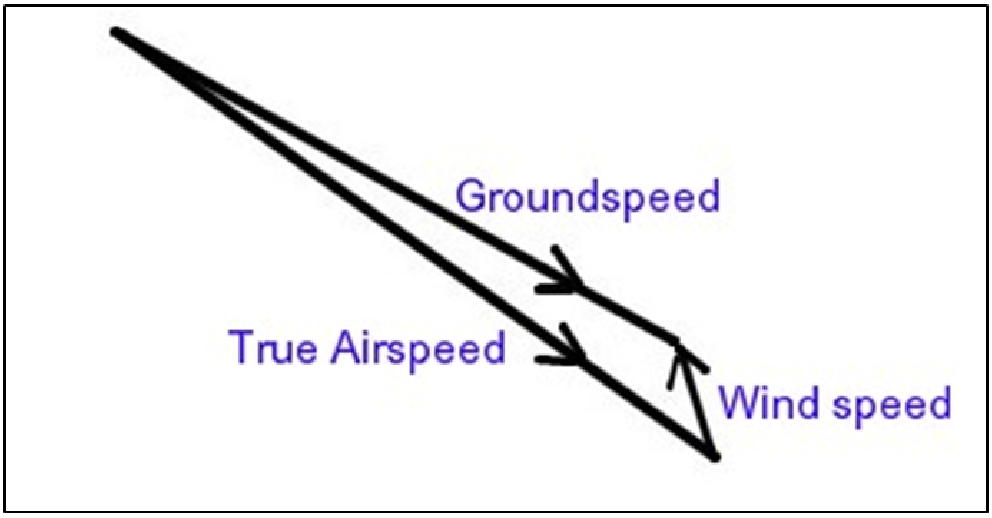
Figure 2: Example of air data sensors (A330 aircraft)



[2] The six parameters were pressure altitude, indicated airspeed, vertical acceleration, magnetic heading, microphone keying and elapsed time.

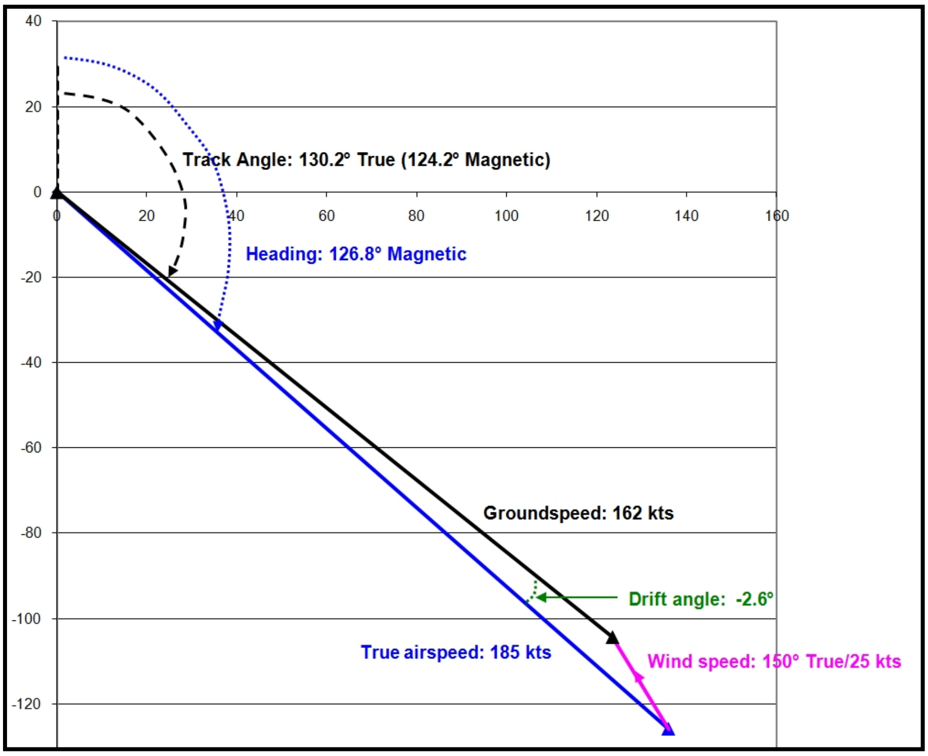
The sensors (accelerometers and laser ring gyros) for the inertial parameters are located inside an ADIRU. This means that ADIRU wind speed and direction data is derived rather than directly measured. Wind is the difference vector between an aircraft's velocity over the ground and its velocity through the air.

Figure 3: Wind vector diagram



Groundspeed and track are directly determined by the inertial part of the ADIRU while true airspeed is determined from the directly-sensed parameters computed airspeed, total air temperature and pressure altitude. Wind speed and direction are then indirectly derived as the difference vector between groundspeed/track and true airspeed/heading.

Figure 4: Example of a wind vector



4. LIMITATIONS OF RECORDED WIND DATA

When an aircraft is airborne, this difference vector between groundspeed/track and true airspeed/heading is a good approximation to the real wind vector as long as certain assumptions are met. By definition, the groundspeed is in the horizontal plane while an ADIRU assumes that the true airspeed vector is also in the horizontal plane, so an ADIRU derived wind is the horizontal wind component only. An ADIRU also assumes that sideslip[3] and angle of attack are zero. As a result, ADIRU-derived wind is a good approximation to the real wind during steady-state conditions and not dynamic conditions.

Some aircraft, such as the B737 NG, record on the FDR wind data calculated by the Flight Management Computer (FMC) as well as wind data from an ADIRU[4]. The FMC and ADIRU calculate wind data differently as the FMC takes into account the (inertial) angle of attack but, like the ADIRU, assumes that sideslip is zero.

Note that when the aircraft is on the ground, an ADIRU cannot account for landing gear forces so the wind data recorded by the FDR should be completely ignored until the aircraft is airborne.

5. CASE STUDY 2: A320 Hamburg, Germany 1 March 2008

During an attempted landing on runway 23 at Hamburg, the left wingtip made contact with the ground. During the approach, the wind was reported as 300° at 33 kts, gusting to 47 kts. The German Federal Bureau of Aircraft Accident Investigation (BFU) conducted an investigation into this serious incident[5].

Figure 5: Video of this approach is available online[6]

[3] Apart from the A380, which is equipped with beta (sideslip) vanes, commercial airliners are not fitted with sideslip sensors.
[4] Aerodynamic Performance Study, 737-800 ET-ANB, Boeing, 29 August 2011.
[5] Investigation Report 5X003-0/08, BFU, released March 2010.
http://www.bfuweb.de/cln_030/nn_226462/EN/Publications/Investigation_20Report/2008/Report__08__5X003__A320__HamburgCrosswindlanding,templateId=raw,property=publicationFile.pdf/Report_08_5X003_A320_Hamburg-Crosswindlanding.pdf
[6] http://www.youtube.com/watch?v=ueJeC2pxxbM

As a modern airliner, the A320 is fitted with an FDR that records 100's of parameters including wind speed and direction. The BFU report made this comment on the wind information recorded by the FDR:

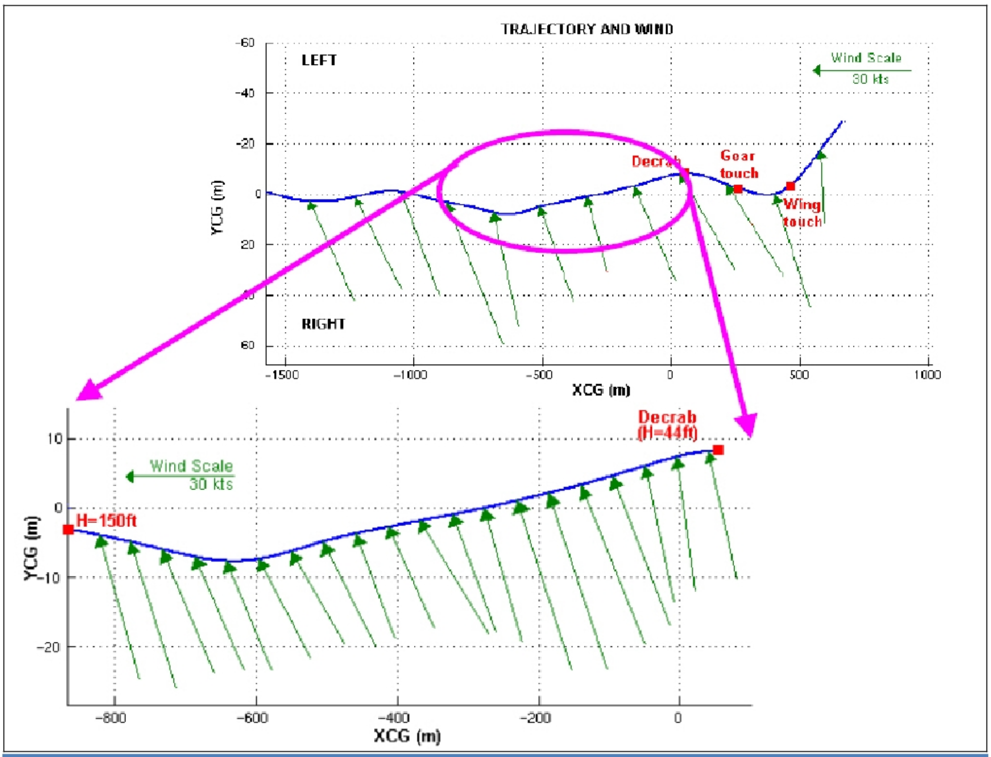
> **Windcalculation by the Air Data Inertial Reference System**
>
> Wind speed and direction is calculated by the Air Data Inertial Reference System and is shown in the cockpit on the Navigation Display (ND). According to the aircraft manufacturer this calculated wind information is inaccurate and operationally unsuitable by wind speeds below 50 kt and by landings under crosswind influence.

Surprisingly, the investigation made no use of the wind data recorded by the FDR but did use wind data that was derived by Airbus as described below:

> The wind velocity is measured at airports as described in paragraph 1.7 of this report, but this only provides average values for wind speed and direction, which is insufficient for this investigation. The attempt was therefore made to determine the true continual value of wind speed and direction, using the aircraft manufacturer's comprehensive aircraft behaviour data and record of sidestick inputs.
>
> The aircraft manufacturer evaluated the data using a special computer program. The results were documented in the form of a power point presentation made available to the BFU and representatives of the operator.

For information, the derived wind data is shown in Figure 6.

Figure 6: This wind analysis did not use wind data recorded by the FDR



Diag. 16: Wind vector during descent from 150 ft to 44 ft Source: Airbus

It is evident that the aircraft manufacturers prefer to use wind information that is derived using a 'special computer program' rather than using the recorded FDR wind.

6. KINEMATIC CONSISTENCY PROGRAM

The Boeing process uses a 'kinematic consistency program[7]' to derive wind for flight test and investigation purposes. The program uses FDR data, such as the acceleration parameters, to produce derived groundspeed, drift and altitude parameters. These derived parameters are then compared with the recorded groundspeed, drift and altitude parameters. Inevitably there will be differences due to inherent sensor errors. All sensors have errors to some degree and the kinematic consistency program removes sensor biases (offsets), allows for sensor location effects (e.g. the accelerometer location may be offset from the centre of gravity) and allows for limited sampling rates. Through an iterative process, the differences between the derived and recorded parameters will be minimised.

The advantages of the kinematic consistency program are that it results in:

- More accurate wind data than that recorded by the FDR
- Continuous data rather than sampled values and
- Vertical wind data in addition to the horizontal component that is recorded by the FDR

7. CASE STUDY 3: MD11 Hong Kong, 22 August 1999

The aircraft crashed during landing on runway 25L at Hong Kong International Airport. The airport was under the influence of severe tropical storm 'Sam' at the time with associated strong winds and heavy rain. The Hong Kong Civil Aviation Department investigated the accident[8] but following representations by some of the interested parties, a Board of Review[9] was appointed.

The actual wind conditions were important for the investigation and Boeing derived wind data using its kinematic consistency program. The limitations of this technique were discussed by a Boeing expert during the Board of Review hearings and included:

- Limited sampling rates
- FDR longitudinal acceleration parameter was unserviceable
- Sideslip angle was not recorded by the FDR
- Angle of attack data had to be re-calculated

The Boeing expert 'suggested that the derived winds were valid within an error margin of 10-15%'. Discussion showed that 'the calculated sideslip angle and the exercise of engineering judgement used in the analysis might further affect the accuracy of the calculations'.

[7] For a more detailed description refer to: US Patent US 2005/0096801 A1, 5 May 2005.
[8] Aircraft Accident Report 1/2004, Boeing MD11 B-150 Hong Kong International Airport, 22 August 1999, Civil Aviation Department Hong Kong, released December 2004. http://www.cad.gov.hk/english/n1.html
[9] Report of the Board of Review on the Accident to Boeing MD-11 B-150, pp 24-27, E. Lin, W. Lowe and P. Sheppard. http://www.cad.gov.hk/reports/main2.pdf

8. CASE STUDY 4: A340 Melbourne, Australia 26 October 2005

The A340 landed during gusting crosswind conditions on runway 16 at Melbourne. The aircraft touched down with 15° of yaw which resulted in tyre damage. This event was investigated by the Australian Transport Safety Bureau (ATSB). The report[10] commented on the wind data calculated by the ADIRUs and recorded by the FDR:

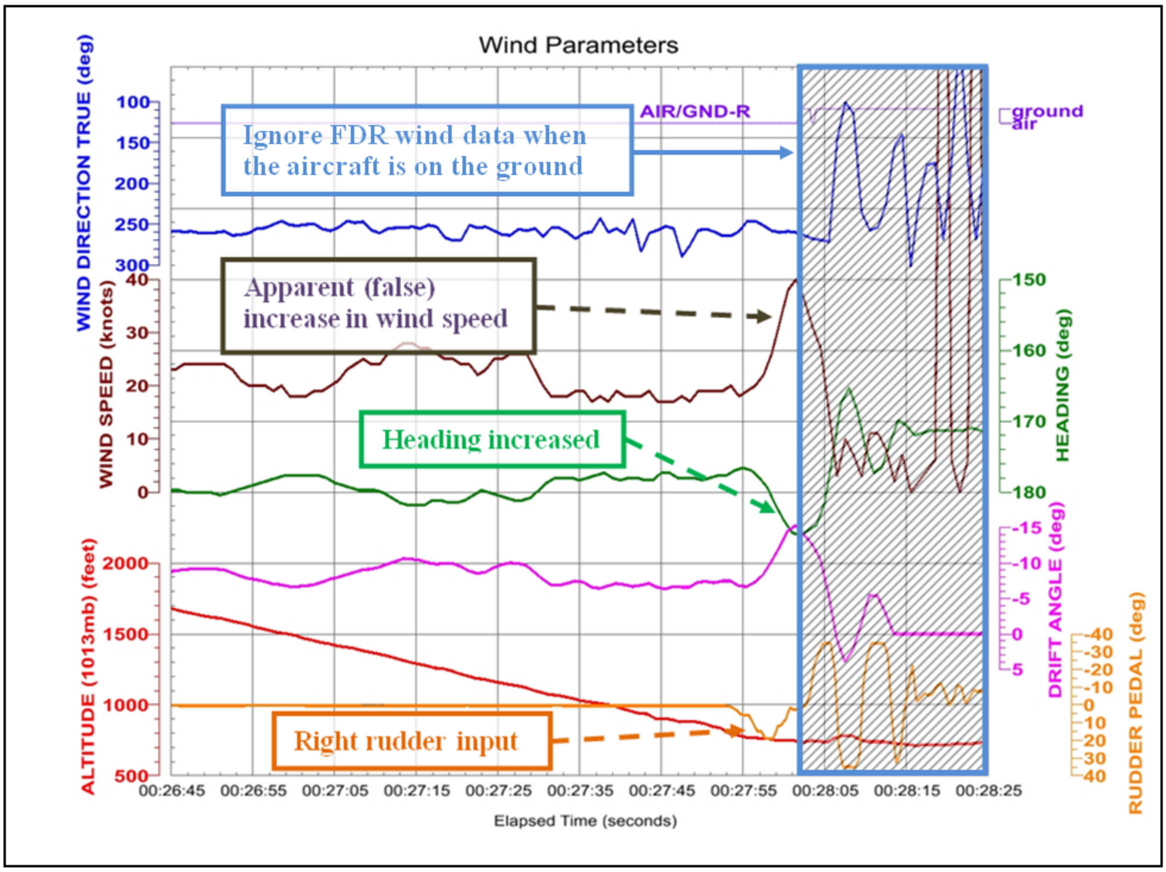
> The IRS-derived wind speed and direction that was displayed to the crew was computed by the aircraft's ADIRUs as follows:
>
> - **Wind speed.** The wind speed was computed from the difference between the aircraft's GS and TAS. For a computed wind speed of greater than 50 kts, the accuracy of those parameters was:
>   - wind speed, ± 12 kts
>   - wind direction, ± 10 degrees.
> - **Wind direction.** The wind direction was computed from the difference in the aircraft's track (TRK) and heading (HDG).
>
>   That wind was computed about 10 times per second, and was displayed on the crew's NDs.
>
> In addition, the aircraft manufacturer advised that the true track accuracy was ±2.3 degrees with a GS of 200 kts, and that the true heading accuracy was ±0.4 degrees.
>
> The aircraft manufacturer cautioned that, as a result of the accuracy of the various parameters used to compute the wind speed and direction, crews should use the displayed wind speed and direction 'with care'.
>
> The ADIRUs were located in the aircraft electrical and electronic compartment beneath the cockpit. Because of their location forward of the aircraft centre of gravity (CG), transient yaw accelerations could affect the derived wind speed and direction data presented to the crew. However, once any transient yaw stabilised, the value of the derived wind speed and direction would equal that experienced at the aircraft's CG.

The transient yaw effect is demonstrated in Figure 7 where a right rudder input from the crew resulted in a right yaw (increase in heading) and an apparent (false) increase in wind speed.

When the aircraft is on the ground, an ADIRU has no way of accounting for non-wind effects such as landing gear forces and the recorded FDR wind data should be ignored.

[10] ATSB Investigation Report 200505311, published June 2007.
http://www.atsb.gov.au/publications/investigation_reports/2005/aair/aair200505311.aspx

Figure 7: A rudder input produced an apparent (false) change in wind speed



9. CONCLUSIONS

Investigators should take into account the following points regarding wind data recorded by an FDR or QAR:

- Completely ignore recorded wind data when the aircraft is on the ground
- Interpret recorded wind data with caution during dynamic situations
- Request the aircraft manufacturer to derive wind data when investigating serious incidents/accidents
- Ask what assumptions/engineering judgements were made in using their program (such as sideslip angle)
- Try and validate the results using:
  - Ground-based observations
  - Data from preceding/following aircraft
  - Crew observations
  - Onboard reactive/predictive[11] windshear detection systems

---

[11] The reactive windshear detection function is generally performed by the ground proximity warning computer while the predictive windshear detection function is generally performed by the weather radar processor.