Australian Government
Bureau of Meteorology

Instrument Test Report 677

The Conversion Equation of the Synchrotac 706 Anemometer

John Gorman
Regional Instrument Centre
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Authorisation

Bruce W Forgan
Supervisor
Regional Instrument Centre, OEB

Distribution (email) **STAW, STNM, STIE, STES, SRLR, SROG, SROO, SRPP,SRSI, SRUM, STCC, SRDS, SRCA, R Hutchinson, STHY, SRWR, SRFW, LIB.**

Aim

This note describes the methodology used to determine the suitability of the conversion equation used in the Synchrotac 706 anemometer/Almos AWS combination. This equation has been examined by using data from wind tunnel measurements and field data using a collocated high precision sonic anemometer.

1. Background

Model 706 Synchrotac anemometers form the backbone of the Bureau's surface wind network, with approximately 500 Synchrotac 706s deployed in the Automatic Weather Station (AWS) network, and many more employed to measure wind run. Over the coming years the wind run instruments at Bureau staffed sites will be converted from mechanical to electronic wind run.

In the past Synchrotac 706s have been calibrated in wind tunnels and found to meet most aspects of the Bureau specification for wind speed measurement [1]. For the Synchrotac 706 the Bureau's Almos AWS currently utilize the following relationship between output frequency *F*, and wind speed, S_s:

$$S_s = 1.095 * F + 1.57 \ (kn) \qquad (1).$$

$$or \quad S_s = 0.567 * F + 0.81 \ (m/s)$$

where the subscript *s* implies Synchrotac measurements. The coefficient 1.095 (0.567) is referred to as the "wind scale", and the offset term is referred to as the "wind offset" in the Almos software. These constants are user configurable in the Almos software.

Recent work within the Regional Instrument Centre (RIC) has suggested that Synchrotac 706 anemometers may not meet the Bureau specification with respect to distance constant [2]. In order to assess the impact of the longer distance constant of the Synchrotac 706 with respect to the Bureau's wind record one was collocated with a 3 dimensional ultrasonic anemometer in a location of high turbulence.

2. Experimental

The Synchrotac model 706 serial number 81268 was typical of this model having a 10-pole alternator as the transducer. This produces an AC waveform with 5 cycles being equal to one revolution. The output of the Synchrotac 706 was processed by an Almos AWS serial number 26218 running software version 6A that applied (1). The 1-second wind speed output (with a resolution of 1 kn) of the Almos was logged on a PC.

The 3 dimensional ultra sonic anemometer was an RM Young Model 8100. The ultrasonic anemometer was set to return a value every second comprising the average of 2 samples taken over a second and this data stream was logged by the PC for comparison with the Almos data.

Both anemometers were new and were supplied with calibration certificates by their respective manufacturers. The Synchrotac 706 had also been calibrated twice in the CSIRO Atmospheric Research wind tunnel (see Appendix 1). The low speed calibration of the Synchrotac 706 was also checked within the RIC low speed wind tunnel. For some experiments the output of the Synchrotac 706 was measured using a

HP frequency meter model 53131A serial number 3736A23981. The output of the meter was logged on a PC for later analysis. The working reference for the RIC wind tunnel is a TSI Model 8384-M-GB hot wire anemometer serial number 01040518 last calibrated on June 2003 at the CSIRO Atmospheric Research.

For the field measurements, the ultrasonic anemometer was found to produce artificially high readings during rain events and any data collected during rain events has been discarded.

The anemometers were mounted approximately 1.5 meters apart on a cross arm approximately 7.5 m above the ground as shown in figure 1. Due to the possibility of wind shadowing of one anemometer by the other, only data collected when the wind direction was within +/-60 degrees of the perpendicular to the cross arm were included in this study. The site was in Melbourne’s eastern suburbs within a residential area subject to highly turbulent surface winds. For this study wind direction was not considered except to limit the comparison sector.

Figure 1. Collocated instruments and mast. The ultrasonic is at the right hand end of the cross arm, the Synchrotac in the centre and a Vaisala WAA151 on the left end.

3. Results

For the field experiments the wind speed and direction were represented by the vertical component of the wind vector, w, and the components in the horizontal plane u and v. The magnitudes of the 2 and 3 dimensional wind speed are defined as:

$$S_{2d} = (|u|^2 + |v|^2)^{0.5} \qquad (2)$$

$$S_{3d} = (|u|^2 + |v|^2 + |w|^2)^{0.5} \qquad (3)$$

where u,v and w are the respective perpendicular wind vectors.

3.1 Instantaneous wind speed

Figure 2 shows a time series plot of the wind speed from the Synchrotac 706/Almos and the S_{2d} ultrasonic, and clearly demonstrates the ‘smoothing’ property of the Synchrotac 706, given the large inertia of the cup assembly removing the fine structure in the wind record.

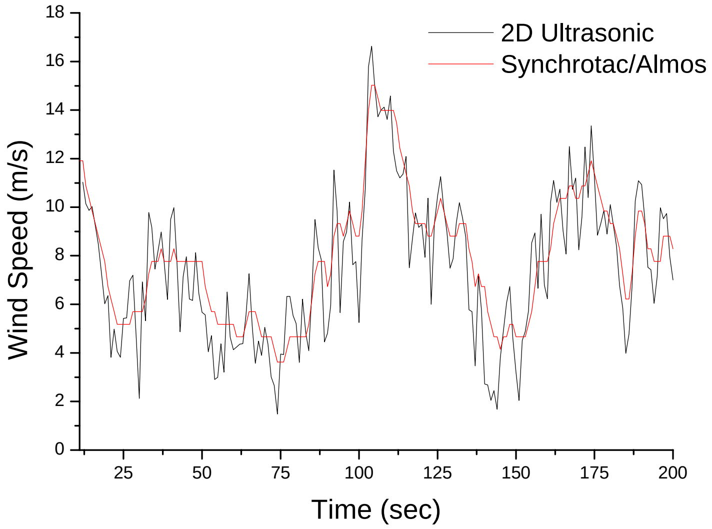
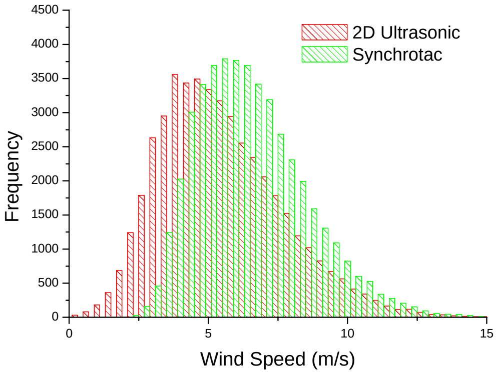
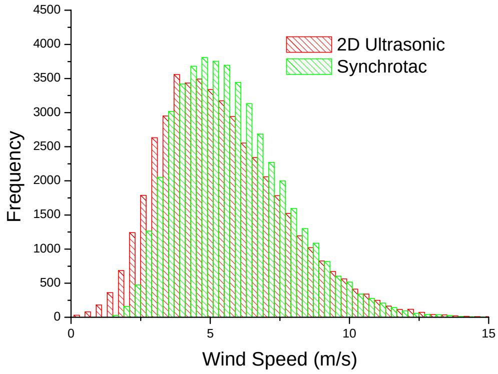


Figure 2. Time series of 1-second samples from the Synchrotac/Almos and the ultrasonic anemometer (18 October 2003).

Typical results appear in figure 3, where the wind speed occurrence is plotted against wind speed. Figure 3 shows that according to the ultrasonic anemometer a wind speed of 4 m/s occurred more often than any other during the measurement interval.

The removal of the “wind offset” term in (1) as shown in in figure 3b makes the wind speed distribution of the Synchrotac/Almos more closely align with that determined by the ultrasonic anemometer. The distribution of Synchrotac/Almos wind speeds is biased higher when (1) is applied.





(a) (b)

Figure 3. Comparison of the frequency distributions of wind speed for a typical 2-hour period on 14 October 2003: green columns are from the Synchrotac 706; red columns are for the ultrasonic. The ultrasonic data are the same in (a) and (b), but for (b) the Synchrotac 'wind offset' term is removed.

Figure 3 also illustrates the effect on the wind record of the start speed of the Synchrotac 706, and confirms laboratory work that estimated the start speed of this device to be approximately 1 m/s [3]. It is evident that for true wind speeds between 0 and 3 m/s the Synchrotac 706 fails to detect as many low wind speed events, however for wind speeds greater than 3 m/s the Synchrotac 706 detects more wind events than the ultrasonic anemometer due to the 'overspeeding' of the Synchrotac 706 in turbulent conditions [2].

Figure 4 shows the difference in wind speed between the two anemometers for this data set. For all data in this study difference is defined as $(S_{2d}\text{-}S_s)$ where S_s is the Synchrotac/Almos reading. Figure 4 shows a systematic bias between S_s and S_{2d} (the maximum wind speed during this period was 15 m/s).

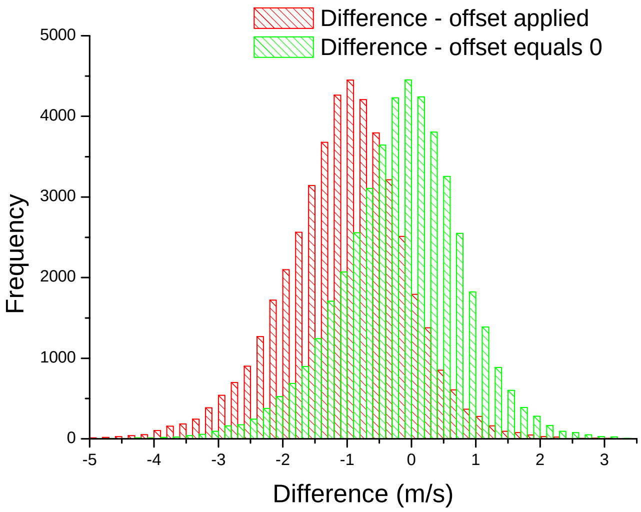


Figure 4. The frequency distributions of difference in instantaneous wind speed for $(S_{2d}\text{-}S_s)$ (red) and S_s with the offset term in (1) set to zero (green).

Alternatively the data can be analyzed in terms of wind run R where:

$$R = \int_0^t S dt \qquad (3)$$

The results for the 14 of October 2003 are presented in Table 1. The Synchrotac/Almos combination overestimates the wind run by approximately 18 % during turbulent wind. When the offset term in (1) is set to zero the difference in wind run drops to less than 1 %.

Table 1. Calculated wind runs for the Synchrotac/Almos and ultrasonic anemometers (14 October 2003).

Formula	Wind Run (m)	% Of 2D
Ultrasonic 2D	112469	100.0
Ultrasonic 3D	114268	101.6
Synchrotac/Almos eqn (1)	133369	118.6
Synchrotac/Almos – eqn (1) offset = 0	112068	99.6

The average difference over this 8-hour period for all data pairs are outlined in Table 2. The average difference between the S_{2d} and S_s is approximately -0.93 m/s and in good agreement with the value of the wind offset term in (1). When this offset is removed from each Almos datum the average difference falls to 0.02 m/s.

Table 2. Calculated average difference for the Synchrotac 706 and ultrasonic anemometers (14 October 2003).

	2D (m/s)
Average Raw Difference	-0.93
Average Difference Bias Removed	0.02

An equivalent analysis was performed on data from a calm day with a sample presented in figure 5. It can be seen that removal of the wind-offset term produces better agreement between the two anemometers. The maximum wind speed was 5 m/s and the frequency histograms are presented in figure 6. Again the bias in the wind record is evident when (1) is applied and the removal of the wind offset term corrects the wind speed spectrum of the Synchrotac 706. The stepping in the figure shows the 1 kn resolution of the Almos wind speed data.

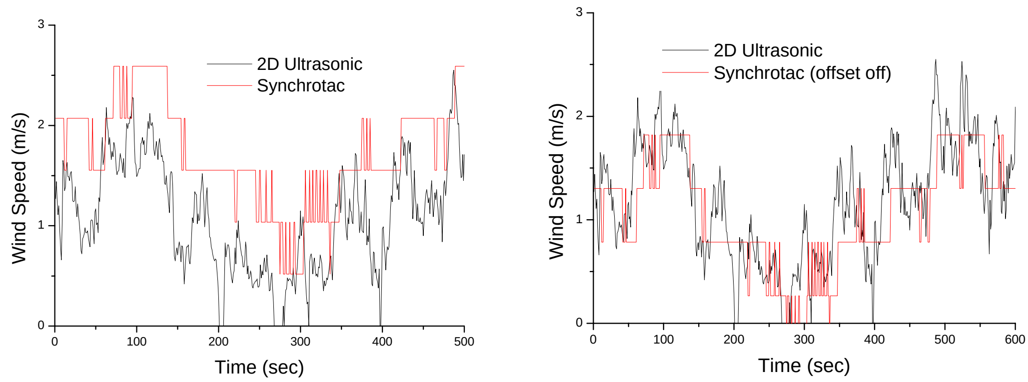
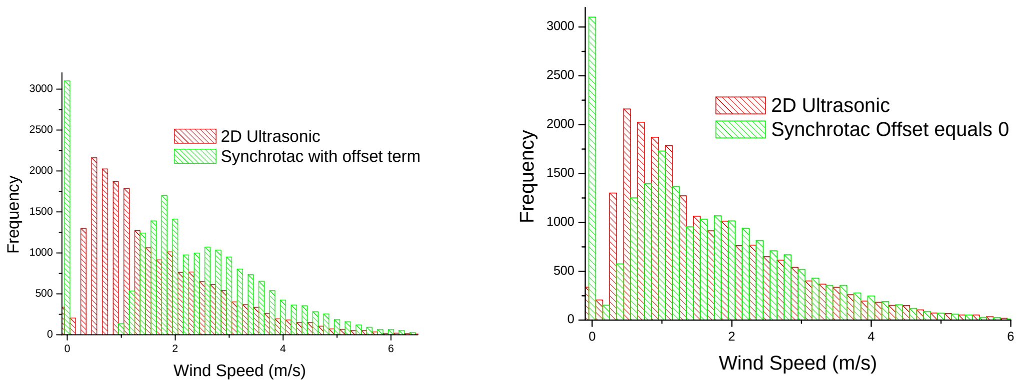


Figure 5. Time series of 1-second samples from the Synchrotac/Almos and the ultrasonic anemometer (16 October 2003).



(a) (b)

Figure 6. Comparison of the frequency distributions of wind speed for a typical 8 hour period during a calm day; green columns are from the Synchrotac; red columns are for the ultrasonic as per figure 3.

On 16 October 2003 the percentage difference in wind run was significantly higher. The Synchrotac/Almos wind run was approximately 50 % higher than the 2D ultrasonic wind run and after the wind offset was removed the Synchrotac/Almos wind run was approximately 2 % lower than the 2D ultrasonic. The underestimation of wind run when the offset term is removed is due to the higher starting speed of the Synchrotac 706.

3.2 10 minute mean

The basic Bureau wind measurement is the 10-minute mean wind speed. These were calculated from the data streams of 1-second samples from each anemometer and the results for a typical 16-hour period are displayed in figure 7. The Synchrotac/Almos overestimates the 10-minute mean in almost all cases due to the positive wind offset term in (1) and the large inertia of the cup assembly.

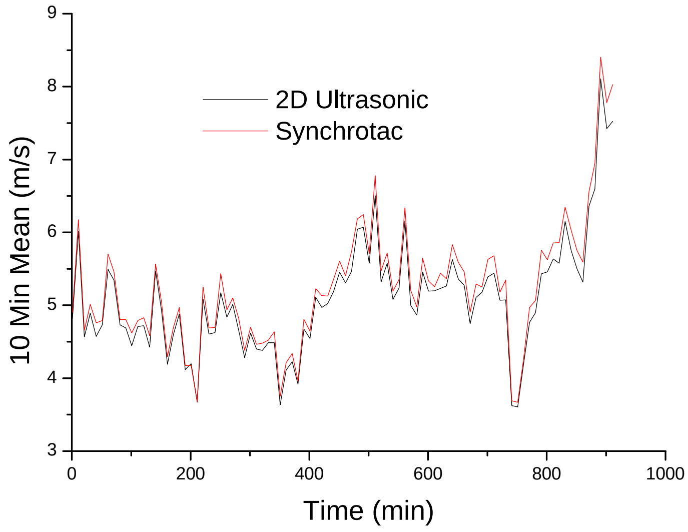
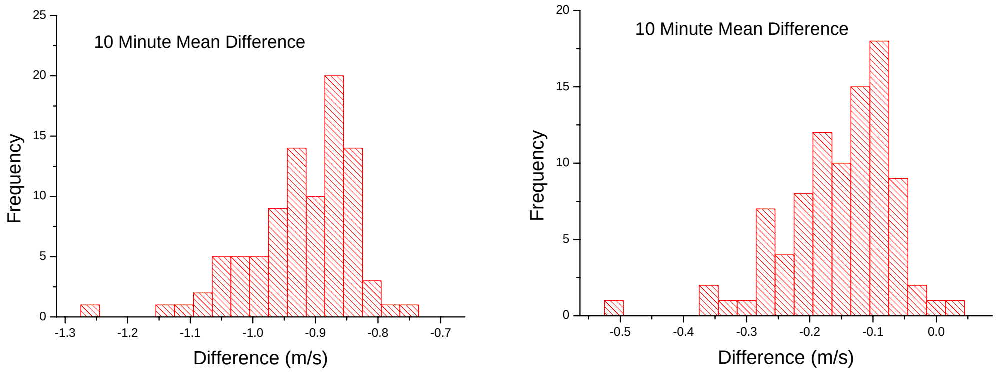


Figure 7. 10-minute means for 18 October 2003 returned by each instrument. In this case the Synchrotac/Almos offset has been removed.

The difference between the 2D ultrasonic 10-minute mean and that of the Synchrotac 706 is presented in figures 8.



(a) (b)

Figure 8. Comparison of the frequency distributions of 10-minute mean for a 16-hour period during 18 October 2003. Figure (a) plots Almos raw data while figure (b) plots Almos data with bias removed).

Figure 8 demonstrates that eliminating the wind-offset term can reduce the difference in determination of the 10-minute mean when compared with the ultrasonic. However, the Synchrotac/Amos will still overestimate the 10-minute mean due to its overspeeding property [2].

3.3 10 minute maximum

The 10-minute maximum gust values for the same period as figure 8 are displayed in figure 9. The maximum wind gust speed is determined from a rolling 3 second average of the data. The maximum gust value is the maximum value detected in the previous 10-minutes for the 3 second average speeds. The same algorithm was applied to the 2D ultrasonic stream.

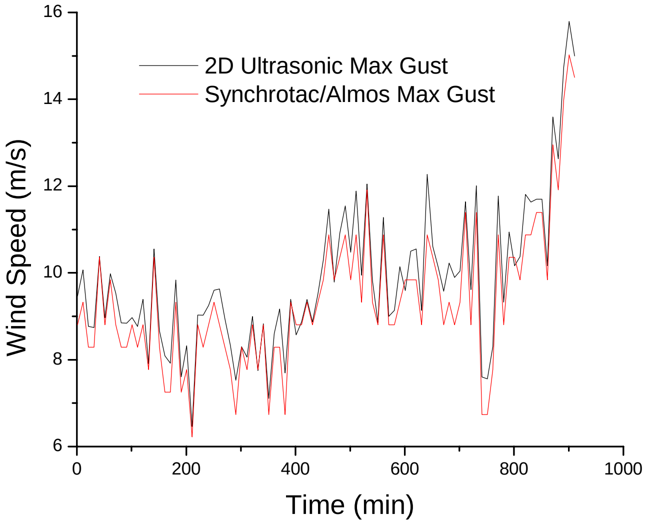


Figure 9. 10-minute maximum gusts returned by each instrument. In this case the Synchrotac/Almos offset in (1) has been removed.

Histogram plots of the difference in 10-minute maximum gusts are presented in figure 10, demonstrating that the magnitude of the difference in maximum gust is similar whether the Synchrotac/Almos wind offset term in (1) is applied or not, only the sign of the difference changes.

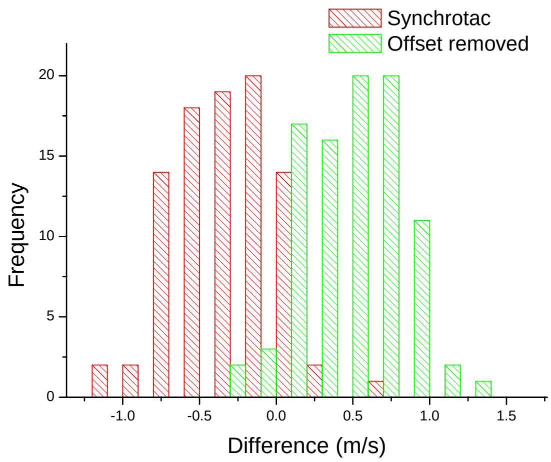


Figure 10. Comparison of the frequency distributions of the difference in 10-minute maximum gust differences for a 16-hour period; (1) data are (red) and (1) data with offset removed are green.

3.4 Ex-field Synchrotac 706

To test the hypothesis that the wind offset term should be included because it "compensates" for the loss of wind run due to increased bearing friction in [6] an ex-field Synchrotac 706 (S/N 68560) that had failed the rundown test was collocated with the ultrasonic anemometer for approximately a month and the data analysed. For this trial the output of the Synchrotac 706 was processed by the Almos AWS. The average rundown time for the Synchrotac 706 used was 9.1 seconds, well below the fail criterion of 20 seconds [6]. The turn on wind speed for this anemometer was found to be 0.8 m/s in wind tunnel testing.

Typical collocation data are shown in figure 11. It is evident from this graph that the increased bearing friction seen in the failed Synchrotac 706 does not significantly affect the performance of the device when compared with a new Synchrotac 706. Wind run data, with and without the wind offset term applied are presented in Table 2 and figure 12 and confirms that addition of the offset term increases rather than reduces the percentage difference in wind run.

Table 2. Calculated wind runs differences for an ex-field Synchrotac/Almos and the ultrasonic anemometer.

Date	Mean Wind Speed	Difference in wind run with offset applied (%)	Difference in wind run with without offset applied (%)
20 Dec. 2003	2.81	26.6	-2.2
23 Dec. 2003	1.18	37.6	-14.0
31 Dec. 2003	1.96	42.4	1.15
19 Jan. 2004	5.50	18.3	3.6

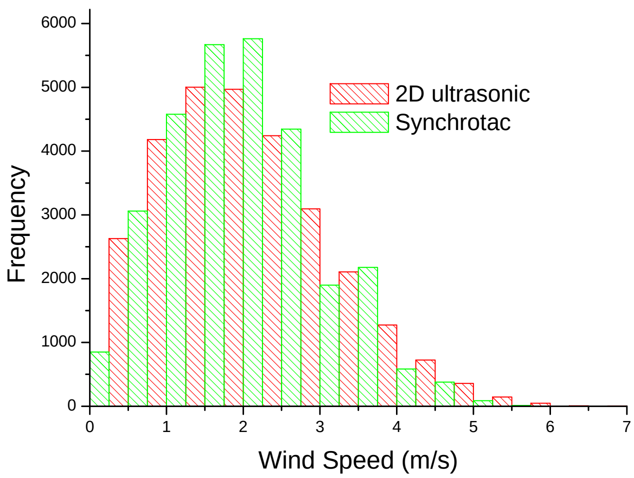


Figure 11. Wind speed frequency distribution for a 'failed' Synchrotac 706 compared with the ultrasonic data for a 12-hour period during 31 December 2003.

The difference in wind run for a number of days was plotted versus the mean wind speed for the day. The results are shown in figure 12 along with the data that would have arisen if the offset term were set to zero. From this plot it can be seen that the difference in mean wind speed is small if the day's mean wind speed is greater that 3 m/s with the offset term removed. If the offset term is included in (1) then the difference is larger and changes sign for wind speeds above 2 m/s. Also plotted in figure 12 (black line) is the theoretical difference that would arise due to the application of the 0.81 m/s wind offset term.

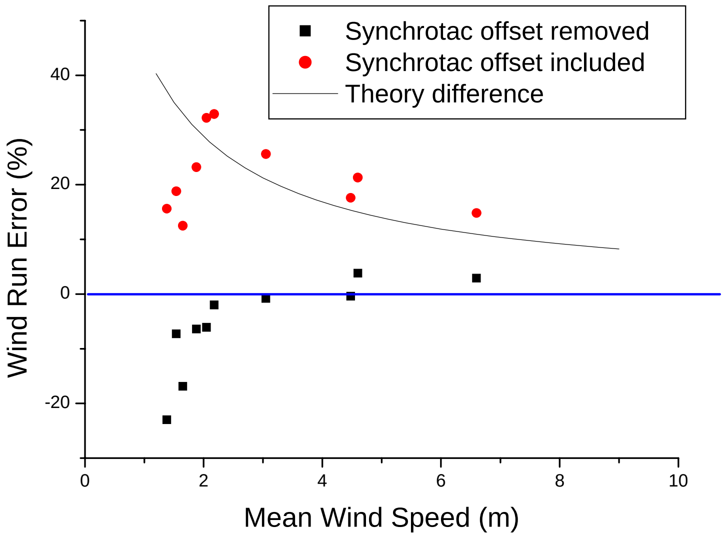


Figure 12. Difference in daily mean wind run for the failed Synchrotac 706 versus mean wind speed for that day. The black curve is the expected error in wind run if the offset term is applied.

4. Discussion

This report has demonstrated that an anemometer impacts on the wind record in two ways. Firstly there is the uncertainty to which the anemometer reports the instantaneous wind speed (for simplicity we consider here only the 2D wind speed). Secondly there is the uncertainty with which the device integrates the passing wind to produce a wind run. Complicating this picture is the impact of the systems and algorithms used to digitize the anemometer output into wind data. In order to convert the behavior of a cup anemometer in wind data a mathematical model of the device must be made. That is, a relationship between wind speed and anemometer output.

In the past the Bureau model of an anemometer has been based on the measured relationship between the device output (e.g. frequency or voltage) and the assumed wind speed in a wind tunnel [4]. In the initial testing of the Synchrotac 706 a simple linear equation of the form $y = mx$ was employed to characterize the response of the Synchrotac 706, where y was the frequency output and m was a constant, and x was equal to the reference wind speed. Effort has been expended by the Bureau to refine that fit [5].

The relationship between frequency and wind speed supplied by the Synchrotac 706 manufacturer states that the "Transfer Coefficient" is equal to 0.35 Rev m^{-1}. This equates to 1.75 Hz s m^{-1} for a 5 pulse per revolution anemometer. This implies a "wind scale" of 1.10 kn Hz^{-1} compared with the currently applied value of 1.095; a difference of less than 1%. The wind offset term in (1) does not appear in either the manufacturer's specification or in the Instrument Test Report that recommends the Synchrotac 706 for Bureau use [4].

While the results section of this paper focused on the impact of the wind offset term on the reported wind run it is also apparent that its application will impact on wind tunnel calibrations. Figure 13 shows the current Bureau specification for maximum correction versus true wind speed (black lines) and the characteristic responses of the two most extreme Synchrotacs 706s measured in recent [5] wind tunnel calibrations. That is, the Synchrotac 706 that had the lowest (0.54) and highest (0.58) 'wind scale' terms as determined by a line of best fit of true wind speed against frequency.

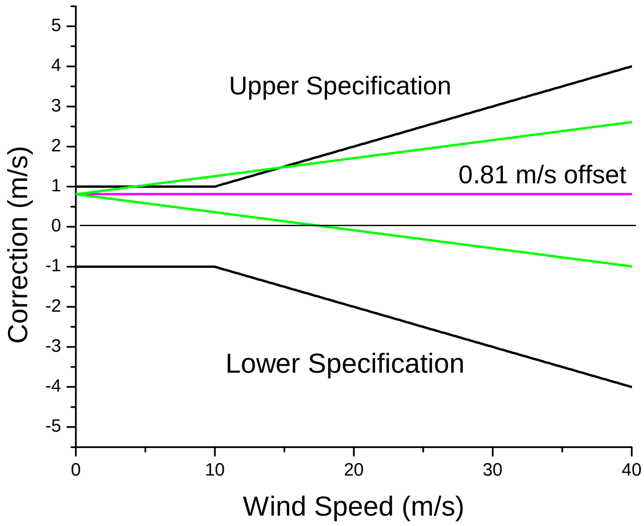


Figure 13. Plot of the current Bureau specification for anemometer wind speed (black lines) and the response characteristics (green) of the most extreme Synchrotacs 706s tested.

Figure 13 demonstrates that the application of the wind offset term is likely to lead to some Synchrotac 706s failing the Bureau specification in the range 5 to 15 m/s. It is also evident that removal of the offset term would lead to the Synchrotac 706 defined by the upper green line passing the specification.

Anecdotally the offset term is applied to "compensate for the turn on speed of the Synchrotac". That is to say that a stopped Synchrotac 706 will not produce an output until the wind speed is increased to above 0.5 m/s. However when a new Synchrotac begins rotating it does not rotate at zero RPM. In fact wind tunnel testing within the RIC has demonstrated that new Synchrotacs tested stabilized rapidly with an output close to the turn-on speed. Therefore when the Synchrotac 706s had stabilized the output frequency equated to a wind speed of approximately that of the reference wind speed. If the offset term is added to this then the wind speed computed will have additional error. Figure 14 shows this behavior of a new and ex-field (failed) Synchrotac 706 in the region of wind speed around the turn on speed.

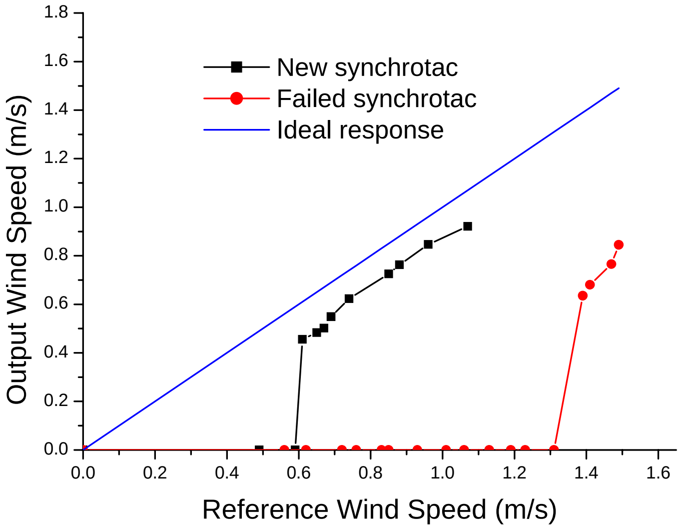


Figure 14. Plot of the responses of a new (black) and failed (red) Synchrotac 706 in the region around the turn on speed. No offset term was applied.

In can be seen in figure 14 that the response of the new Synchrotac 706 is within 0.1 m/s of the ideal however the failed Synchrotac (red) is approximately 0.7 m/s of the idealized response. If the response of the failed Synchrotac 706 is plotted over a larger range as in figure 15 then it can be seen that at higher wind speeds the response of the Synchrotac is close to ideal without the offset term.

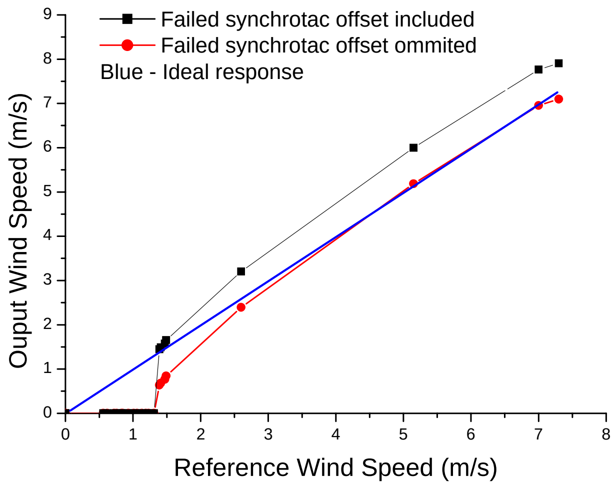


Figure 15. Response characteristic of the failed Synchrotac 706 shown in figure 14 plotted over a wider range.

The RIC wind tunnel was also employed to investigate the stall and turn-on speeds of a Synchrotac 706 and the results are shown in Figure 16. That is, if wind speed is slowly decreased then at what wind speed is the last valid output received from the Synchrotac 706, or for increasing speed the first valid output.

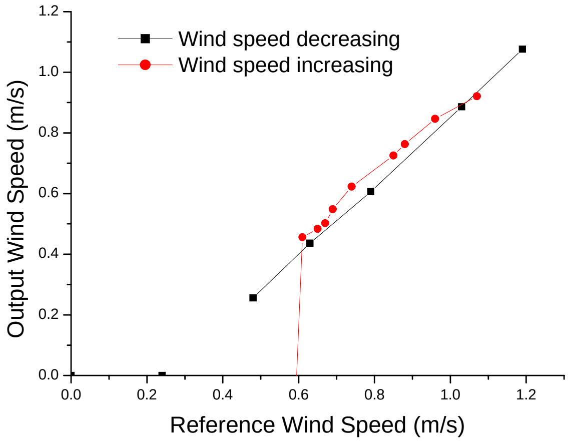


Figure 16. Plot of the output response of a new Synchrotac 706 in increasing (red) in then decreasing (black) air flow. No offset term applied.

It should be noted that the stall speed of the device (0.39 m/s) is considerably lower than the turn-on speed (0.6 m/s). Therefore if the Synchrotac is already rotating it will measure a wind speed of 0.5 m/s. If the Synchrotac 706 is stopped it will not output 0.5 m/s. This hysteresis has important implications for the wind record since in the region between 0 and 1 m/s the output of the Synchrotac 706 depends not only on the current wind speed but the conditions that prevailed prior to the measurement.

The results above show that the offset term calculated from turn on speed or the difference between the turn on output of the Synchrotac and the ideal response curve is inappropriate because:

1. the Synchrotac 706 start speed depends on its service life (figure 14);
2. typically is only relevant at low wind speeds (figure 15); and
3. decreases with increasing wind speed.

5. Conclusions

1. The current parameterization of the relationship between Synchrotac 706 output frequency and true wind speed as applied in the Bureau’s Almos AWS is based on incorrect assumptions.
2. For mean wind speeds between 2 and 8 m/s the use of the wind offset term has a significant impact (> 10%) on wind run data.
3. The application of the wind-offset term to Synchrotac/Almos will likely place some wind speed data outside the current uncertainty specification [1].
4. Further collocation work is required to confirm that removing the wind offset from the Almos algorithm will improve the Bureau’s wind record under low wind speed conditions.

5. Available literature and wind tunnel calibrations suggest that the relationship between wind speed and frequency for a 5 pulse Synchrotac 706 is approximately 0.57 Hz s m^{-1}.

6. The Bureau should examine the impact of the use of the wind-offset term in Almos systems on the wind climate record.

7. The implementation of (1) employed by the Almos AWS should be examined, specifically the engineering conversion of input frequency to wind speed and also the meteorological QA/QC post processing of this data within Almos.

References

[1] *Guidance Specification (Functional) for a General Purpose Automatic Weather Station (AWS)* ES-A2659, - Bureau of Meteorology, 1989

[2] Gorman J, *Synchrotac 706 Rundown Time,* Technical Note TN008_2003 Bureau of Meteorology, July 2003

[3] Benbow D, *Properties of the McVan Instruments SYN706 Series Synchrotac*, TN2003-10, Bureau of Meteorology, Nov. 2002

[4] Hysing.P, *Anemometer Test Report*, Instrument Test Report 633, Bureau of Meteorology, 1993

[5] M.Berechree, *Repeatability of the Monash Wind Tunnel*, Instrument Test Report 668, Bureau of Meteorology, 2002

[6] Commonwealth Bureau of Meteorology, *Inspections Handbook, Annex 41*, p.2

CSIRO

Atmospheric Research

NATA Accredited Laboratory
Number: 245

ANEMOMETER CALIBRATION REPORT

TEST DETAILS

Type of Test:	High speed
Range of Test:	1.24 m/s to26.58 m/s
Test Report Number:	036/57/01
Test Date:	18 September, 2001
Wind Tunnel Operator:	Julie Mclean
Officer in Charge of Tests:	Tom Beer

INSTRUMENT DETAILS

Instrument Manufacturer:	McVan
Instrument Model:	SYN 732
Serial Number (Instrument):	81268
Serial Number (Probe):	81268

CLIENT DETAILS

Test Report Client:	Bureau of Meteorology
Despatch Address:	Bureau of Meteorology 150 Lonsdale St. Melbourne
Invoice Client:	Michael Berechree
Invoice Address:	Accounts Department 150 Lonsdale St. Melbourne
Purchase Order Number:	Visa

REPORT APPROVED BY OIC: per M. Hibberd

DATE OF APPROVAL: 27 September 2001

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CSIRO Atmospheric Research
107-121 Station Street Aspendale VIC 3195 Australia
Postal Address: PMBI Aspendale VIC 3195 Australia
Tel: +61 3 9239 4400 Fax: +61 3 9239 4444 Web: www.dar.csiro.au
Chief of Division: Dr Graeme Pearman Email: chief@dar.csiro.au

CSIRO
Atmospheric Research

ANEMOMETER CALIBRATION REPORT

NATA Accredited Laboratory
Number: 245

TEST REPORT NUMBER: 116/58/02
SERIAL NUMBER (INSTRUMENT): 81268
SERIAL NUMBER (PROBE): 81268
PLANT NUMBER: n/a
INSTRUMENT TYPE: SYN 732
INSTRUMENT MANUFACTURER: McVan
INSTRUMENT SIGNAL OUTPUT: Frequency
SIGNAL OUTPUT RESOLUTION: 0.001 Hz
RANGE OF TEST: 1.33 to 27.41 m/s
WORKING STANDARD USED: 7325
UNCERTAINTY OF PRIMARY STANDARD: ± 1% or 0.05 m/s (whichever is greater in the range 0.30 to 27 m/s)
ORDER OF POLYNOMIAL FIT TO DATA: 2
AMBIENT TEMPERATURE DURING TEST: 24.5 °C

Instrument Output* (Hz)	1.625	1.927	2.371	2.814	3.701	4.587	5.472	6.357
True Speed (m/s)	1.33	1.50	1.75	2.00	2.50	3.00	3.50	4.00
± Total Uncertainty in Calibration** (m/s)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Instrument Output* (Hz)	7.242	8.126	9.893	11.657	13.420	15.180	16.939	18.696
True Speed (m/s)	4.50	5.00	6.00	7.00	8.00	9.00	10.00	11.00
± Total Uncertainty in Calibration** (m/s)	0.05	0.05	0.06	0.07	0.08	0.09	0.10	0.11

Instrument Output* (Hz)	20.450	22.203	23.953	25.702	27.448	29.193	30.935	32.676
True Speed (m/s)	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00
± Total Uncertainty in Calibration** (m/s)	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19

Instrument Output* (Hz)	34.414	36.150	37.885	39.617	41.348	43.076	44.802	47.233
True Speed (m/s)	20.00	21.00	22.00	23.00	24.00	25.00	26.00	27.41
± Total Uncertainty in Calibration** (m/s)	0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.27

* See Note 5
** Total Uncertainty in Calibration includes uncertainties associated with the primary standard and instrument resolution.

REMARKS: Actual start speed 1.30 m/s, stall speed less than 0.70 m/s.

Approved: M.H.