About The WakeWatch Chirp SODAR

This memo sets out the basics of the capability of the WakeWatch chirp Sound-Detection-And-Ranging (SODAR) system and shows how much greater range, resolution and update rate can be achieved when compared to other systems.

It is well recognised that SODAR technology is particularly appropriate for monitoring the development of Low-Level-Jets (LLJ) that cause wind shear due to its operability in low cloud or low visibility conditions that may accompany temperature inversions and gust fronts. Further, the chirp SODAR is particularly suitable for detecting long lived aircraft wake vortices that are present above temperature inversion layers where the air is very clear due to the low level of particulates in the air above inversion layers.

SODAR Systems.

Sound-Detection-And-Ranging (SODAR) systems that use acoustic pulses to measure the lower atmosphere use two types of pulses, non-coded pulses and pulse coding. The non-coded systems often use multiple simple pulses while the coded systems use pulse coding that results in pulse compression. A linear chirp signal is used for acoustic sounding of the atmosphere as it offers the best spatial and temporal resolution while increasing the system gain while also providing Doppler tolerance.

SODAR Theory.

The theory of pulse compression for RADAR was first described for use in RADAR in 1960 in Ref. 1 and more recently in Ref. 2. Pulse compression is a signal processing technique commonly used by RADAR, SONAR and Ultrasound systems to increase the range and resolution as well as the signal to noise ratio when compared to simple pulse systems. Such pulse compression systems are used to detect point targets or distributed targets in a plane orthogonal to the pulse compression beam such as in Medical Ultrasound where the internal structure of objects that have depth are not able to be imaged.

Pulse compression has not previously been used in SODAR because it was thought that such a system could only be used to image surfaces (as above) and could not be used to image a distributed target such as the atmosphere which has depth. There was also some doubt that using a wider bandwidth signal would not allow the measurement of Doppler shift because of a lack of correlation of the wider bandwidth signal backscattered from the atmosphere. The results achieved clearly show that these two issues do not compromise the operation of the pulse compression SODAR. The images of atmospheric structure clearly show very high resolution images of the atmosphere and secondly, the Doppler shift caused by the wind clearly is an effective means of measuring wind speed. The chirp SODAR system has been calibrated against a reference LIDAR provided by DTU in a neutral atmosphere however, the LIDAR operation in unstable and stable atmospheres was found to be unreliable in terms of both wind speed accuracy and availability (see calibration data).

The theory for the operation of SODARs has been developed over the last 60 years and is now well understood with many papers and books published. A good account of systems that use a conventional (not pulse compressed) pulse is given in Ref. 3. The first use of acoustic pulse compression for a SODAR system is first disclosed by A Martin (Ref. 4) in Patent application US6755080B2 in 2000 but it has taken some 21 years of work to develop a fully operational system due to the complexities of such a system.

Operational Capability.

The improvement achieved by the chirp SODAR when compared to conventional non-chirp SODAR systems is around +35dB.

The operational improvements are achieved by the use of special baffles, high quality antennas and chirp pulse compression which also reduces the transmit power required and improves the range and spatial and temporal resolution as shown in Table 1.

The noise tolerance is also improved (enabling the chirp SODAR to operate in noisy environments) while also reducing the radiated noise level.

The wind speed accuracy does not depend on the received S/N, at S/N rations above 3dB.

Parameter	**common simple pulse SODAR (red is worse)**	**pulse compression SODAR (red is worse)**
Typical range min-max, greater range with longer aver time	30m-90m	10m-420m
Update rate for above range	10 minutes	15 seconds (better temporal resolution)
Resolution	17m	1m (better spatial resolution)
Radiated noise	87dBa @ 5m	65dBa @ 5 m
Noise tolerance	< 60dBa @ 5m	< 76dBa @ 5m
Number of antennas	1	4
Wind Noise tolerance for no degradation	Wind speed < 60km/hr	Wind speed < 90km/hr

Beam offset angle	30 degrees	7 degrees [1]
Beam subtraction to reduce system errors	no	yes
Antenna gain	20dB (frequency dependent)	25dB (frequency dependent)
Doppler measurement method	Direct FFT, results in poor resolution	Phase accumulation, results in very high resolution
Max rain rate	0mm/hr.	Range reduced above about 2 mm/hr. to < 160m.
Availability at 330m	< 50% for long averaging times	> 90% without averaging, excluding rain events.

Table 1. Comparing operational differences between common simple pulse and chirp pulse compression SODARs.

Airport Operations and Safety.

The greatest need for safety at an airport is for reliable met measurements within 400m of the ground as that is the region where the probability of accidents are highest. SESAR and ICAO programs specifically call for met improvements to improve safety through improved met measurements near the ground, particularly real-time measurements.

The greatest need for safety is for improvements in the met awareness within 100m of the ground on approach as this is where wind shear and wake vortex encounters have the greatest potential to cause a serious upset. As such dangerous wind shear and wakes can rapidly evolve it is necessary to have measurement systems that can measure in real-time and update in less than 30 seconds.

A detailed description of aviation related wind shear is given by BOM in;

http://www.bom.gov.au/aviation/data/education/wind-shear.pdf

The types of wind shear as described in the above reference as;

- Vertical wind shear is defined as change of horizontal wind direction and/or speed with height.
- Horizontal wind shear is the change in wind speed and/or direction at the same level.

[1] Reduces the standard deviation of the wind speed measurement and is especially important at high update rates to maintain wind speed accuracy such as is available for a chirp pulse compression SODAR.

- Updraft and downdraft wind shear is the change in vertical wind velocity across adjacent columns of air. This type of shear is often encountered with convective activity.

"Significant wind shear is often encountered with and in the vicinity of:

- Thunderstorms
- Frontal systems
- Sea breezes
- Frictional shearing
- Temperature inversions
- Obstacles
- Rotors
- Wake vortices"

The Wake Watch chirp SODAR systems have a unique capability to detect all of the above wind shear effects (especially above 10m) including the wind shear associated with inversion layers and obstacles in that no other technology has this comprehensive capability.

The WakeWatch chirp SODAR measures directly above the sensor and measures the wind close to the runway approach/departure point where the effects of wind shear are most likely to be felt between 10m and 100m.
Above about 100m the wind shear is less likely to be dangerous and the wind is more constant with less shear so that wind above about 100m, 4000m from the runway end is very similar to the wind above 100m close to the runway. This is because wind shear effects are dominated by the coupling of the wind to the ground. This means that wind measured along the glide slope above 100m will be very similar to wind measured directly above the runway threshold.

FAQ's.

- How does a chirp SODAR work?

A chirp SODAR is a very sensitive means of detecting the small acoustic signals "backscattered" by the air from small scale turbulence initiated by temperature differences in the air. It is different to a pulsed RADAR or LIDAR in that it uses simultaneous transmission-receiving sequences and samples the return signals to produce a time sequence of measurements that start from 10m above the ground. The altitude sampling time corresponds to the roundtrip time between the transmit time and the receive time for the sound to reach an altitude.

As the air is moving the backscattered acoustic signal frequency is shifted when compared to the emitted signal frequency. This is the so called Doppler Effect such as the frequency shift that can be heard when a train is passing. Measuring the Doppler shift along one beam axis gives the corresponding radial wind speed along that axis.

As the wind is three dimensional (North - South, East - West and Vertical) we need to make measurements along at least three different directions from the antenna to obtain all the wind components. WakeWatch uses 4 beams tilted 7 degrees towards North, South, East, West, with the vertical component obtained from the sum of the 4 beams. The Doppler shift measured by opposite beams North, South and East, West, can then be subtracted from each other to minimise any system induced errors to leave only the Doppler shift due to the horizontal wind.

- What is impact of snow and fog on chirp SODARs

Snowflakes are significantly bigger than rain drops are detected by SODARs. Furthermore snowflakes impacting the antenna generate a negligible acoustic noise.

Regarding fog, as it is associated with small scale turbulence initiated by temperature differences and consequently, chirp SODARs work well in fog.

- What is impact of ambient acoustic noise

When the ambient acoustic noise increases, the ratio between the signal which is backscattered from the air and the noise decreases. Above a certain noise level no more useful signal detection is possible. Typically our SODARs can measure in up to 76dBA ambient noise environments.

- What is impact of ground clutter

Our SODAR antennas achieve almost 60dB directivity between the main lobe and the so called secondary lobes between transmitter and receiver which are almost parallel to the ground. This level of attenuation means that echoes from nearby obstacles (trees, buildings, meteorological towers etc...) are very small and are barely noticeable.

- What is impact of high winds

High winds are of course associated with high surface winds. These generate aerodynamically a high ambient noise and therefore reduce the altitude range and at the extreme will forbid any measurement. The acoustic enclosure is designed to prevent the flow of wind over the acoustic antenna preventing turbulence induced noise so that it can measure in winds up to 25 m/s at ground level without any range degradation.

- What is impact of rain on chirp SODARs

The only effect of rain is generating acoustic noise through turbulence caused by the fall of the rain drops. As the antennas are shielded from the rain, the rain drops do not cause any additional antenna noise. As the rain drops size is much smaller than the acoustic wavelength, the rain drops fall speed is not detected by chirp SODARs.

As stated above, as the rainfall rate increases, the rain generated acoustic noise increases, reducing the range of the chirp SODAR. Therefore above a certain rain rate limit the SODAR range will be reduced. With our chirp SODARs the upper limit is typically 2mm/hr. of rainfall rate when the range is reduced to around 160m and depends on atmospheric conditions.

- Advantages and Disadvantages of chirp SODARs when compared to LIDARs.

Advantages

- Works in; fog, dense haze, clear air, through inversion layers and clouds.
- Measures from 10m.
- Much higher spatial and temporal resolution.
- Detects aircraft wake vortices in real time, especially when they are long lived.
- Are much more reliable and durable.
- Do not need repeated recalibration.
- Maintenance is minimal. Replacing the acoustic absorbers every 4 to 5 years.

Disadvantages

- Make some noise.
- Cannot operate if the ambient acoustic noise is above 76dBa.
- Cannot operate very close to large obstacles while the LIDARs can.

References.

1. J. R. Klauder, A. C, Price, S. Darlington and W. J. Albersheim, 'The Theory and Design of Chirp Radars," Bell System Technical Journal 39, 745 (1960).

2. https://en.wikipedia.org/wiki/Pulse_compression. and

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3. Atmospheric Acoustic Remote Sensing , Stuart Bradley , CRC Press/Taylor & Francis, Boca Raton, FL, 2008. $119.95 (271 pp.). ISBN 978-0-8493-3588-4.

4. https://patents.google.com/patent/US6755080B2