

## **A Comparative Study of**

### **FROST BOSS and ORCHARD RITE**

### **Wind Machine Fans**

#### **Background Physics**

During a radiation frost, wind machines are used to draw down the warmer inversion layer air, above the orchard, and blow it into the orchard. The wind machine fan needs to blow as much air as it can, to the greatest distance possible. This will give the most economical coverage for the wind machine.

In order to reach the greatest distance, the fan needs to produce a strong, uniform wind. The distance the wind can penetrate into the orchard is proportional to the momentum of the wind. This “wind momentum” is the product of the wind flow rate, the wind speed and the air density.

#### **Study Outline**

The purpose of this study is to compare the momentum and hence the penetration potential of two commercially available wind machine fans. The momentum of the wind generated by a wind machine is impractical to measure at more than about 15m from the fan, because the wind stream is influenced significantly by the surrounding air mass drift in the test area and by the natural turbulence of the expanding wind stream.

#### **Methodology**

The measurement of the wind stream is best undertaken where the wind stream contracts to its smallest diameter, thus giving the most defined perimeter to the wind stream. This occurs at a distance, equivalent to about one fan diameter downstream from the fan. Most wind machine fans are between 5.5m and 6m in diameter, so it was decided to measure the momentum of the wind 7m from the fan.

The momentum is obtained by firstly measuring the wind speed at strategic locations in the wind stream, to establish a radial velocity profile. The radial velocity profile is then cut into small segments and multiplied by the annular area of each segment. This gives a segmented flow rate. These flow rates are then multiplied by the segmented wind speed and the air density, to give the segmented momentum. These values are finally added together to give the total momentum.

#### **Measuring Equipment**

In an ideal situation the wind speed would be measured simultaneously in 4 radial quadrants. This would require 21 anemometers connected to a data logging system. Previous research studies have indicated that the wind stream from a wind machine fan is reasonably uniform within radial bands.

For this reason it was decided to use 5 anemometers for this study. The wind speeds were initially measured on both sides of the wind stream to check for symmetry of the wind stream and then all the anemometers were placed on one side of the wind stream to define the velocity profile of the wind stream, at that horizontal location.

## Test Equipment

Fan tower:	Normal configuration with the fan shaft positioned 5.65m above the ground
Engine:	Cummins 6BT turbo-diesel, 150 hp @ 2400 rpm
Anemometers:	Tradewind A1-K analog 3-cup
Position:	7m downwind and in-line with the 6° decline of the fan shaft

## Test Procedure

The gearbox at the top of the tower was held in a fixed position to allow the fan to produce a wind in a fixed direction. The tests were all conducted on still, cold days as early in the morning as possible. The effects of drift were impossible to control and when they did occur the test results were not used, and the test was repeated. The fan test rig was mounted perpendicular to the drift direction, which allowed the effects of drift to be noticed immediately in both the anemometer readings and the deflection of the tail of the wind stream.

The two fans tested were a Frost Boss, extruded aluminium (Grade 6061-T6), 4-blade, 5420mm (17' 9") diameter and an Orchard Rite, solid fiberglass, 2-blade, 6035mm (19'10") diameter. Both fans were the current models available.

Each fan was tested at its normal operating speed, after the engine was fully warmed up. The engine speed was measured with an optical digital tachometer. The time, air temperature and atmospheric pressure were also recorded for each test.

## Experimental Error

The wind speed measurements fluctuated by +/- 1 knot in the central region of the wind stream and by +/- 5 knots towards the perimeter. After 10-15 seconds the wind speed range for each anemometer output was established and recorded. The values used in the charts and calculation tables were estimated mean values. Ideally all the anemometer outputs would be recorded on a data logger, to give a more scientific averaging process. This approach would be adopted if greater accuracy was required.

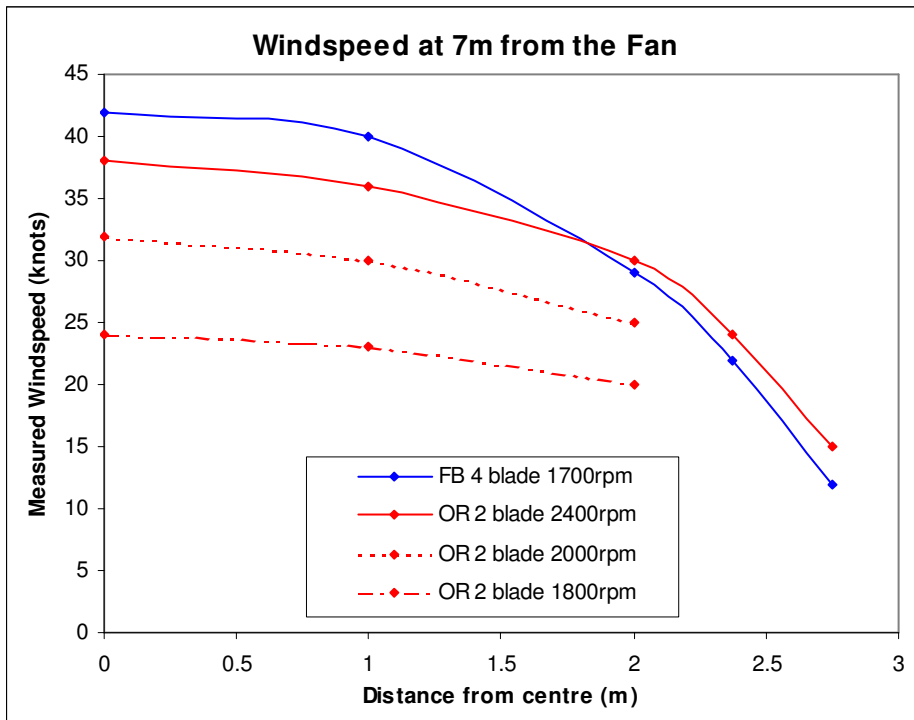
## Test Results

The Frost Boss fan was run at 1700 rpm engine speed. This was 70 rpm less than the maximum speed that the engine could operate with this fan.

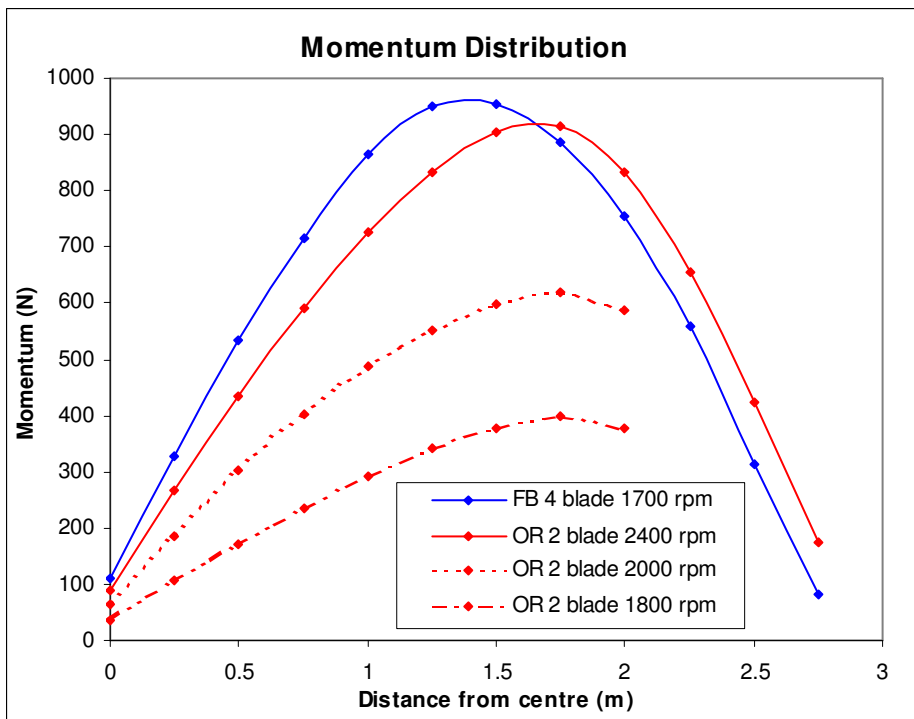
The Orchard Rite fan was run at 2400 rpm engine speed, which was the maximum speed that the engine could operate with this fan. The Orchard Rite fan was also run at 2000 and 1800 rpm, as there are some Orchard Rite fans operating in noise sensitive areas, which are restricted to operating at these speeds.

The first graph shows the velocity profile for each fan. The Frost Boss fan produced more wind speed in the centre of the wind stream and less speed in the outer part of the wind stream compared to the Orchard Rite fan. When the Orchard Rite fan was run at 2000 and 1800 rpm, the wind speed was reduced by 17% and 35% respectively.

The data at this lower speed was collected when the anemometers were in the "symmetry testing" configuration, hence there were no wind speeds recorded beyond 2m for this fan at these lower engine speeds. Irrespective of this, the reduced performance of the Orchard Rite fan when the engine speed was reduced is apparent.



The second graph shows the momentum distribution calculated for each fan. The Frost Boss fan produced significantly more momentum in the inner part of the wind stream, and less in the outer part of the wind stream. The total momentum calculated for each fan was 6970 N for the Frost Boss and 6667 N for the Orchard Rite. This was a difference of 4% in favour of the Frost Boss. When the Orchard Rite fan was run at 2000 rpm, the momentum was reduced by 30%. When it was run at 1800rpm the momentum was reduced by more than 55%.



## **Inferred Results**

During the calculation of momentum, the wind flow rate was determined. This was calculated to be 373 cubic metres/second (790,330 cfm) for the Frost Boss and 380 cubic metres/second (804,500 cfm) for the Orchard Rite. Although this was a 2% increase in favour of the Orchard Rite, the greater wind flow was in the outer region of the wind stream, where the velocity was low, and so it did not translate into a significant increase in momentum.

Unless the wind flow is in a region of high velocity, it will not increase the momentum significantly, because it is the momentum that provides the penetration to the wind stream. The momentum calculation does not take into account the effect of the wind stream's frictional shear against the still air around the wind stream. This frictional shear entrains still air adjacent to the wind stream - but in doing so, the entrained air absorbs energy from the wind stream. This in turn reduces the wind speed at the perimeter of the wind stream hence it's momentum and so it is important that the peak momentum is located centrally in the wind stream, so that the entrained air does not immediately erode it.

In addition to calculating the momentum, it is possible to calculate the power available in the wind stream, as if it were a natural wind passing through a wind turbine generator. Because the wind speed was measured so close to the fan, the energy transferred from the fan to the wind stream was reasonably intact and had not had a chance to get dissipated in the mixing process as the wind stream diffused down stream. Hence the available power in the wind was, in effect, the power given to the wind stream by the fan.

The calculated powers were 82 hp for the Frost Boss fan and 75 hp for the Orchard Rite fan. These powers were then compared to the power input at the fan, at their respective engine speeds, to obtain the fan efficiency. The maximum power quoted for the Cummins engine was reduced by 12% to account for the power absorbed by the radiator fan and the gearboxes in the tower. Hence the estimated fan power inputs at 1700 rpm and 2400 rpm were 117 hp and 134 hp respectively. Using these values, the inferred efficiency for each fan was calculated.

The inferred efficiency of the Frost Boss fan was 70% and the inferred efficiency of the Orchard Rite fan was 56%. This is a significant difference, which indicates that the fan designs are quite different aerodynamically, as well as geometrically.

## **Noise**

The Orchard Rite fan produced a loud, beating sound similar to that of an Iroquois helicopter. The tip speed of the fan was 347 knots (54% the speed of sound) at 2400 rpm engine speed.

The Frost Boss fan produced a quieter, more uniform sound. The tip speed of the fan was 220 knots at 1700 rpm engine speed.

The blade tips of the Orchard Rite fan were travelling 58% faster than the Frost Boss. The blade tips are the major source of aerodynamic noise on a fan.

The engine driving the Orchard Rite fan was turning 700 rpm (41%) faster than the Frost Boss fan, which added to the increased noise levels.

## Summary

- 1) The most important aerodynamic characteristic of a wind machine is the momentum of its wind stream. This "wind momentum" is the product of the wind flow rate, the wind speed and the air density.
- 2) The wind momentum was calculated from strategic wind speed measurements of the wind stream close to the fan.
- 3) The wind momentum of the Frost Boss, 4-blade fan operating at an engine speed of 1700 rpm was 4% greater than the Orchard Rite fan operating at an engine speed of 2400 rpm.
- 4) The wind momentum of the Orchard Rite fan operating at a reduced engine speed of 1800 rpm was less than half the wind momentum produced by the same fan at 2400 rpm.
- 5) The inferred aerodynamic efficiency of the Frost Boss fan was 70% compared to an inferred efficiency of 56% for the Orchard Rite fan.
- 6) The noise output from the Orchard Rite fan and engine was significantly greater than that from the Frost Boss. At the maximum speed tested the blade tips of the Orchard Rite fan were travelling 58% faster than the Frost Boss and the engine was turning 41% faster.

## Conclusions

The Frost Boss, 4-blade fan produced slightly more wind momentum than the Orchard Rite, 2-blade fan and achieved this at a 700 rpm lower engine speed. This lower engine speed resulted in significantly less noise being generated. Reducing the engine speed on the Orchard Rite fan reduced the wind momentum significantly.



Richard Karn     B.E(Mech), M.E(Aero)

Aerodynamic Research Engineer