FAILURE OF THE PROTOTYPE WINDFLOW 500 TURBINE'S GEARBOX HOLDING-DOWN BOLTS IN A RAPID WIND SHIFT ON 10 MARCH, 2005

SUMMARY REPORT ON THE CAUSES AND REQUIRED REMEDIES

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Introduction

On Thursday March 10, at about 6.10pm, a rapid change in wind direction and speed resulted in large out of balance forces on the rotor of the prototype Windflow 500. This caused the bolts which secure the gearbox to the pallet to break. The gearbox and rotor then fell to the ground.

A full engineering report on the incident has been prepared. This is a summary of that report. Our preliminary review of the available data gives the following sequence of events over the 110 second period. (T = 0 is arbitrarily set as the last recorded occurrence when the nacelle yaw angle was the same as the wind direction).

1. What happened? (Sequence relating to diagrams overleaf)

Diagram 1. Turbine operating normally. Wind coming from the NNW about 47 km/h, nacelle facing the wind and rotor turning at about 48 rpm.

Diagram 2. Wind changes direction quickly (100° in 89 seconds) and increases to 68 km/h from the SW. Turbine's nacelle turns (yaws) to follow the wind direction but only turns 35° in the same time. Nacelle is now sideways to the wind so rotor has slowed down to 41 rpm, initiating a shut-down.

Diagram 3. Within the next two seconds (from T = 89 to T = 91) several things happen:

- blades pitch to slow the rotor down as part of normal shut-down
- wind direction shifts a further 7° south
- wind speed increases to 90 km/h with a gust at 97 km/h

Diagram 4. The combination of these events create high reverse loads on the upper vertical blade and cause the bolts holding the gearbox on the pallet to yield and break.

Diagram 5. At T = 93.5, the gearbox topples forward out of the nacelle and the gearbox and attached rotor fall to the ground.

Diagram 6. Blade hits the tower on the way down and breaks before hitting the ground.

Diagram 7. Both blades break into several pieces on impact with the ground.

2. What failed and why?

In such a severe wind shift, the nacelle did not yaw fast enough and the turbine began to shut down as it sensed an underspeed situation. This resulted in reverse loads on the rotor which subjected the gearbox bolted joint to overturning moments which were more than 2.87 times the maximum design moment.

3. What needs to be improved to prevent a recurrence?

While the event was worse than the relevant 1 in 50 year International Electrotechnical Commission (IEC) design load case, we need to ensure that the turbine design can cope with such an event. The wind shift happened once, it can happen again. Three modifications to the control system will prevent a recurrence of this event, should a similar wind shift occur. Any one of these modifications on its own could have prevented the event, so the effect of the three of them will be to add three layers of defence against a recurrence.

1. The effective yaw rate will increase in such circumstances

2. The underspeed shut-down software will be amended so that an underspeed will not trigger a shut-down in similar circumstances.

3. The shut-down software will be amended so that the brake is applied rather than blade pitching in certain circumstances.

Strengthening the gearbox holding-down bolts to the same as other joints, or strengthening other joints to the same proportion is not necessarily the best solution, as this would then raise the prospect of other modes of failure in a gross-overload situation. It is far better to avoid the overloads.

Having said that, Grade 12.9 instead of Grade 8.8 bolts could be used which will increase the yield strength of the bolted joint by 50% and increase the safety factor from 2.87 to 4.30.

4. Would a 3-bladed turbine have failed?

A 3-bladed turbine may possibly have failed because the wind shift was more severe than the IEC load case and therefore it may have been outside its design envelope. On the other hand, it may not have failed because the equivalent bolted joint has to withstand much higher fatigue moments, therefore its ultimate strength would be higher. This goes hand in hand with the fact that 3-bladed designs are much heavier.

In the end, the question of whether a 3-blader would have failed is irrelevant. What matters is that the 2-bladed Windflow turbine will not experience a similar failure again. Consistent with our overall design philosophy, we will ensure those high moments are not experienced.

5. Where does Windflow go from here?

The fact remains that it was an unusually severe wind shift. The yaw and shut-down routines had been designed with a wide range of scenarios in mind, but not a wind shift of over 100º in such a short time and with such high winds.

The software and control remedies will prevent a recurrence of the event should a similar wind shift occur. In addition we will thoroughly check the software for any other adverse situations which could arise during shut-down, and we will re-check the main IEC design load cases for potential overloads on the gearbox and other joints.

We will rebuild the prototype turbine (“Neil”) with parts which have already been made for the first production run of six (now five) turbines.

We will complete the prototype monitoring and IEC certification process which has been commenced at Gebbies Pass. As part of this we will commission and test the new yaw and shut-down routines in a robust simulation of the events of 10 March, 2005. And we will ensure that it gets as thorough a testing as Nature can provide at that site when future SW fronts come through.

The rebuild is estimated to take three months with at least three months of running and testing recommended for the new machine before we erect any of the other new turbines. Meanwhile assembly and factory testing of the others can continue as funds allow. Other aspects of the Te Rere Hau and other projects (resource consent and electrical connection) are likely to delay site construction until the fourth quarter of 2005 so the rebuild work will not delay those projects significantly.

In fact there are some advantages in rebuilding Neil – new, rationalised designs for the hydraulics and other sub-systems will be able to be tested on the prototype ahead of the others. And any potential IEC re-certification issues (due to differences between the prototype and production machines) will be minimised.

In summary, the events described in this report have undoubtedly been a setback to the company. However they are explainable, and most importantly avoidable in future. Thus the process of rebuilding will result in a stronger, more resilient design for commercialisation.

WINDFLOW 500 PROTOTYPE EVENT, 10 MARCH, 2005