In order to achieve the full test loads whilst not overloading the point at which the forces are introduced, it was necessary to reduce the aerodynamic drag of the blade. During a flapwise fatigue test, the blade moves through the air as if it was a bluff body, so it has a high drag coefficient.

In addition to this, the blade is moving along a sinusoidal path, so it encounters the entrained air from the first half of the cycle during the second half. This leads to a higher drag coefficient than if the blade was moving at the same velocity under steady aerodynamic conditions. During the XL Blade project, ORE Catapult developed new testing equipment (called windbreakers) in order to reduce the aerodynamic drag sufficiently to allow the test loads to be achieved.

1.1.1 CFD Analysis

As part of the XL Blade project, CFD analysis was performed to determine the aerodynamic forces induced as the blade flaps. It was important to understand the relationship between the 3 parameters which control the amount of drag the blade experiences as it flaps. These are:

- Chord length – a bigger frontal area leads to more drag
- Amplitude of the motion – higher amplitudes for a given frequency will lead to higher velocity, increasing the drag on the blade
- Test frequency – higher frequencies for a given amplitude will lead to greater velocities, and thus higher speeds.

The drag force is calculated using (1), in which F_D is the drag force, ρ is the air density, A is the frontal area, C_D is the drag coefficient and v is the velocity.

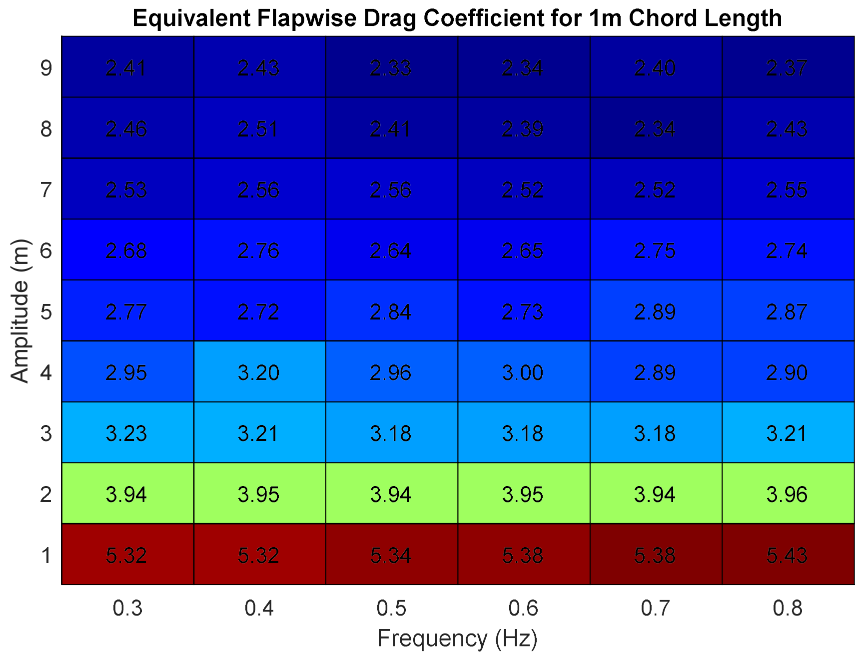
$$F_D = -\frac{1}{2}\rho A C_D |v| v \tag{1}$$

As the blade is moving in a sinusoidal path its velocity is constantly varying. The drag coefficient is dependent on the Reynold's number, which is proportional to velocity, so in order to use a single drag coefficient for the whole cycle, we must determine the equivalent drag coefficient. This was achieved by performing unsteady 2D CFD simulations of a 1m length of blade for 10 cycles using an overset mesh. The work done by aerodynamic drag on the blade W_{DS} during the simulations was calculated by summing the product of force and distance moved during the step for every time step.

The theoretical formula for energy done by aerodynamic drag is given in equation (2), in which W_{DT} is the work done by aerodynamic drag according to theory, N is the number of cycles, ω is the angular frequency and $\hat{x}$ is the amplitude of the blade motion. The remaining symbols have already been defined.

$$W_{DT} = N\frac{8}{6}\rho A C_D \omega^2 \hat{x}^3 \tag{2}$$

By equating W_{DS} to W_{DT} and rearranging for C_D we can get the equivalent drag coefficient for the whole cycle. A cohort of simulations covering chord lengths of 1m, 2m and 3m, amplitudes of 1 to 9m in 1m steps and frequencies of 0.3Hz to 0.8Hz in 0.1Hz steps was performed for a total of 162 simulations. Together, this covers the vast majority of situations that would be encountered in blade testing. After performing the initial 1m chord simulations as shown in Figure 1, it was clear that frequency did not have any real effect, so the 2m chord and 3m chord simulations were only performed for 0.5Hz.



Amplitude (m)	0.3	0.4	0.5	0.6	0.7	0.8
9	2.41	2.43	2.33	2.34	2.40	2.37
8	2.46	2.51	2.41	2.39	2.34	2.43
7	2.53	2.56	2.56	2.52	2.52	2.55
6	2.68	2.76	2.64	2.65	2.75	2.74
5	2.77	2.72	2.84	2.73	2.89	2.87
4	2.95	3.20	2.96	3.00	2.89	2.90
3	3.23	3.21	3.18	3.18	3.18	3.21
2	3.94	3.95	3.94	3.95	3.94	3.96
1	5.32	5.32	5.34	5.38	5.38	5.43

Figure 1 - C_D for range of amplitudes and frequencies for 1m chord length

It became apparent that the important relationship for the drag coefficient was the ratio of the chord length to the amplitude of the motion, as shown in Figure 2.

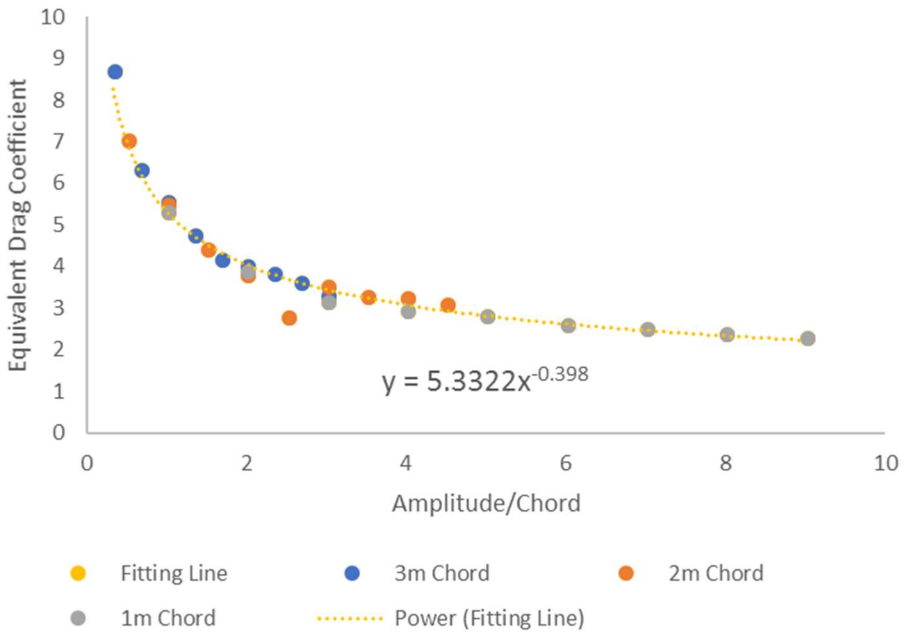


Figure 2 - Summary of C_D versus amplitude over chord for aerofoil shape

The drag coefficient tends towards the value C_D for a plate (about 2) for high amplitude-chord ratios. However, this was not low enough to achieve the actuator force limit, so we decided to create a shell around the blade tip which would have a lower drag coefficient. Windbreakers are reasonably widely used within blade fatigue testing, but they would usually have a low drag elliptical shape. In the case of a bi-axial test, the blade would be moving in the edgewise direction as well as the flapwise direction, so a cylindrical windbreaker profile was chosen which would decrease the drag in the flap direction without preventing the test loads from being achieved in the edgewise direction.

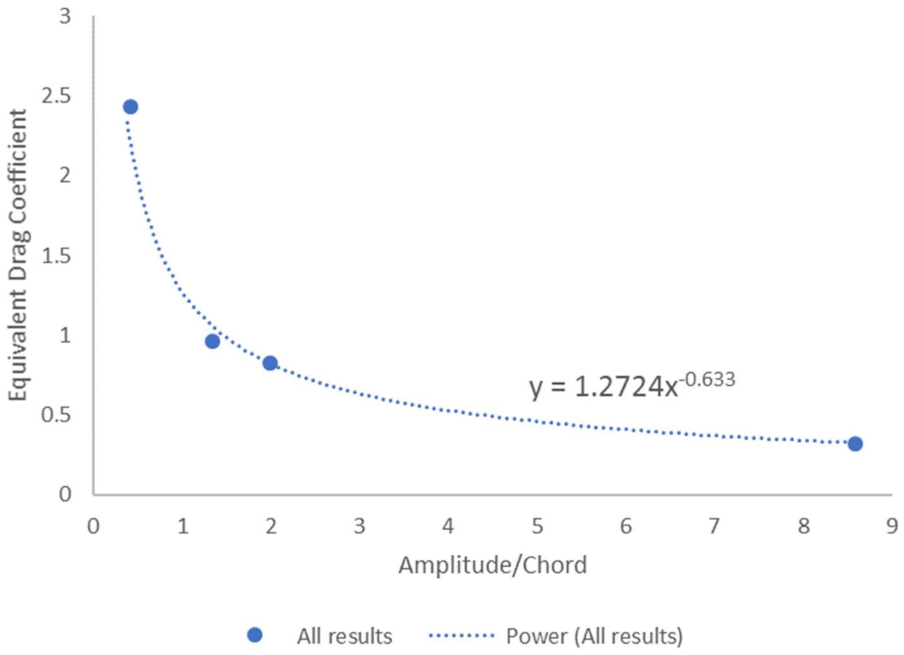


Figure 3 - Summary of C_D versus amplitude over chord for circle

The drag coefficient for each section of the blade can then be interpolated according to the amplitude of the motion, the chord length, the blade thickness and whether windbreakers are present as shown in Figure 4.

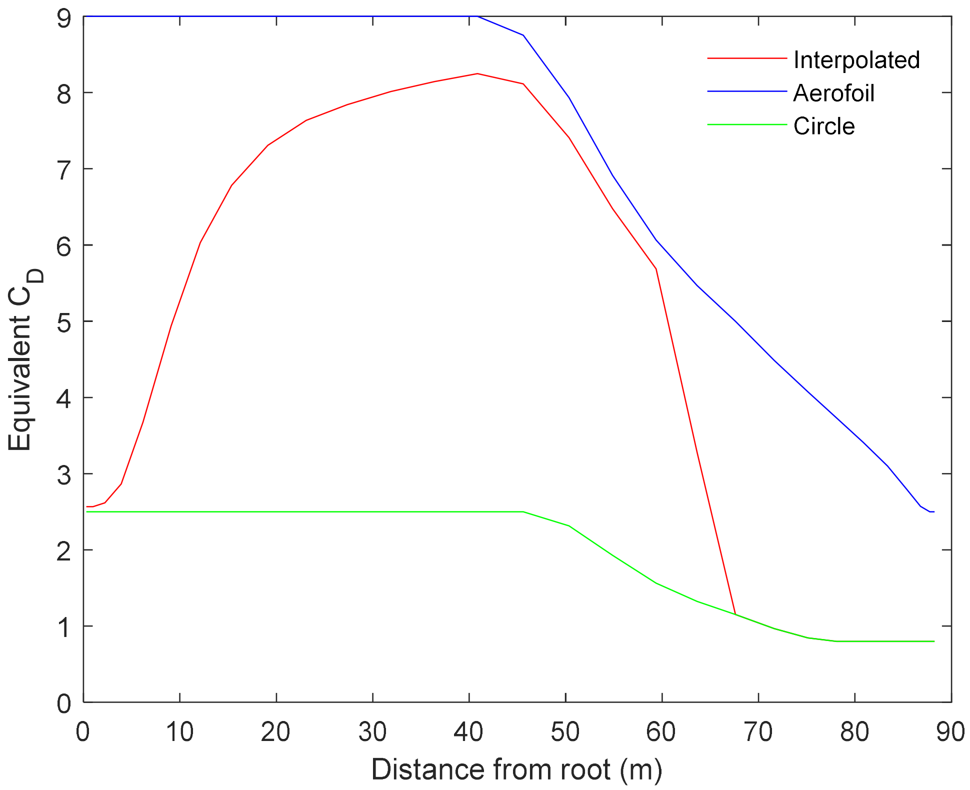


Figure 4 - Equivalent C_D interpolation (windbreakers start at 65m)

Test simulations using Blade Test Optimiser showed that the addition of windbreakers in conjunction with the reduced test frequency (arising from the greater mass on the tip) would be sufficient to allow the test loads to be achieved without exceeding the force limit. The reduced test frequency also reduced oil demand, which was also very close to the limit.