



Howden

A Chart Industries Company

ACC fan dynamics

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It is possible that ACC fan blades and / or the connection bolts fail when experiencing high dynamic loads.

In this presentation:

- An overview will be provided regarding the sources and consequences of dynamic /cyclical blade loads.
- Howden has identified some sites where elevated dynamic loads have expedited fan failures. At these sites measurements were recorded and solutions implemented.
- Development work has been performed to confirm that a stronger hub design with a more rigid bolt-to-bolt connection can be used to avoid bolt failure due to fatigue that was caused by high dynamic loads.

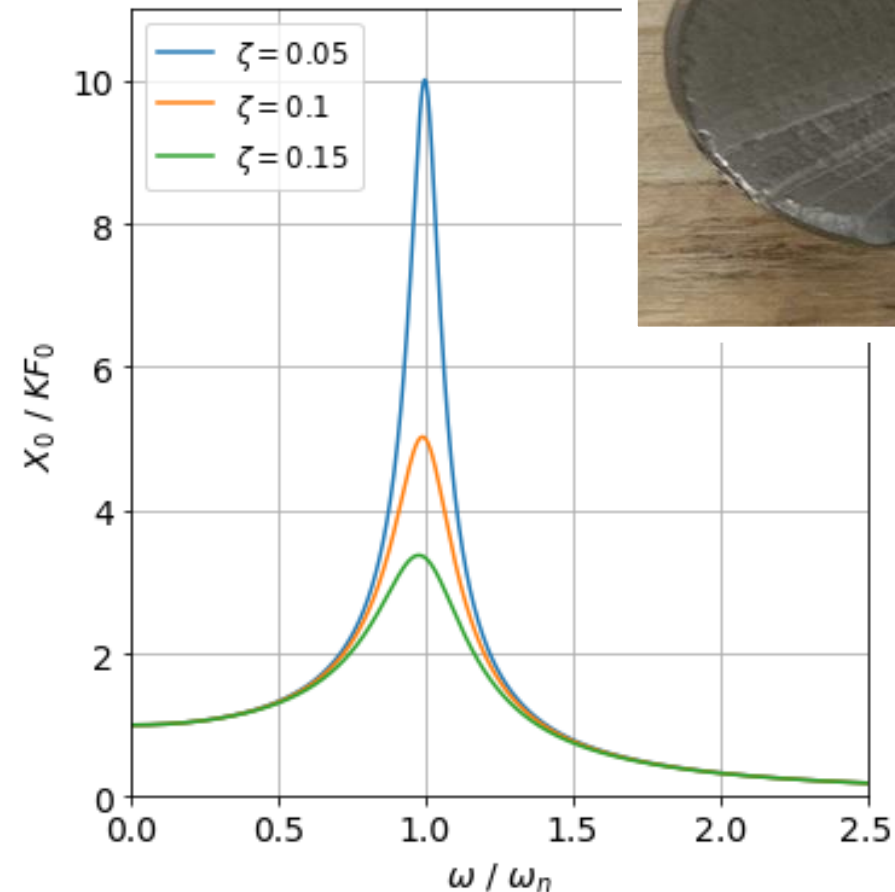


The response of a fan blade is a product of the dynamic input forces and its own mechanical characteristics.

The frequency of these forces depend on the fan speed and locations of flow obstructions.

The mechanical properties of the blades can potentially cause these dynamic forces to be amplified. This is known as resonance and can lead to fatigue damage over time.

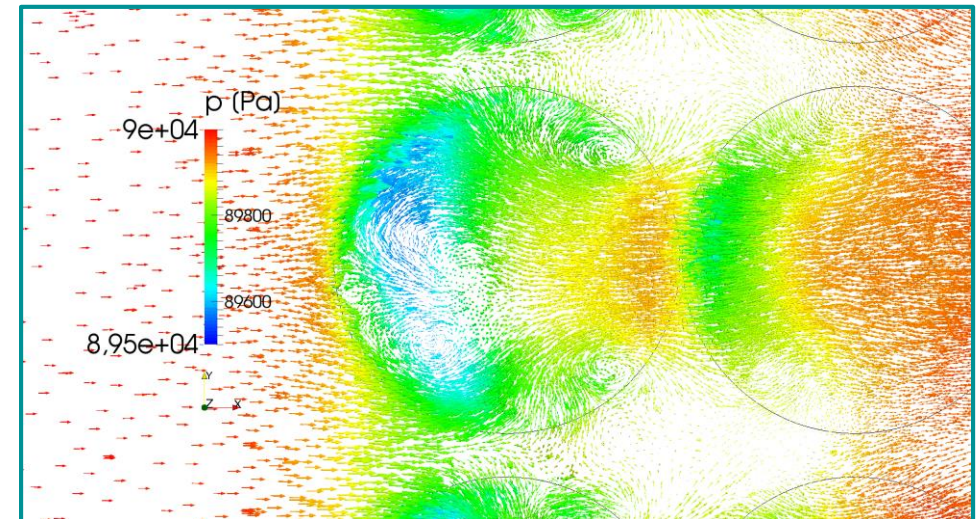
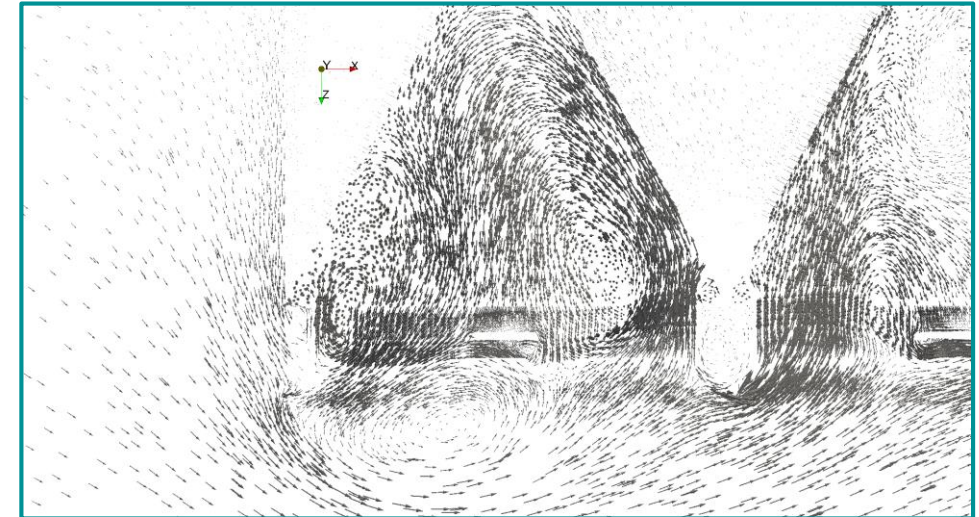
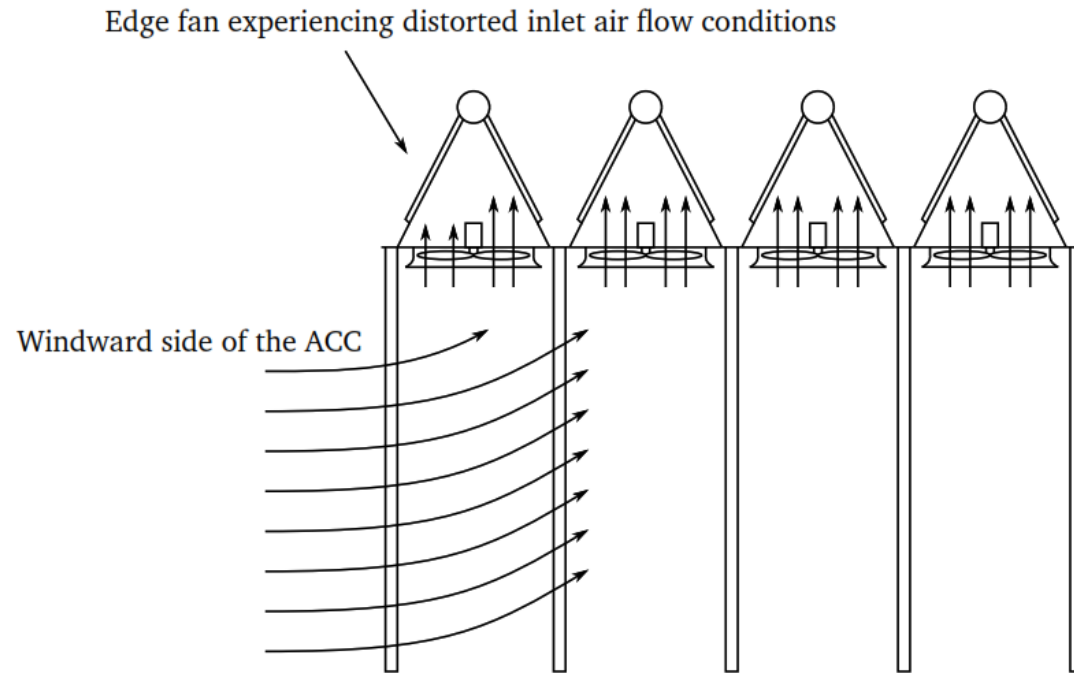
The fans need to be strong enough to deal with the amplified loads, if they occur. However, it is preferable that these amplifications are avoided altogether.



Typical ACC fan loads

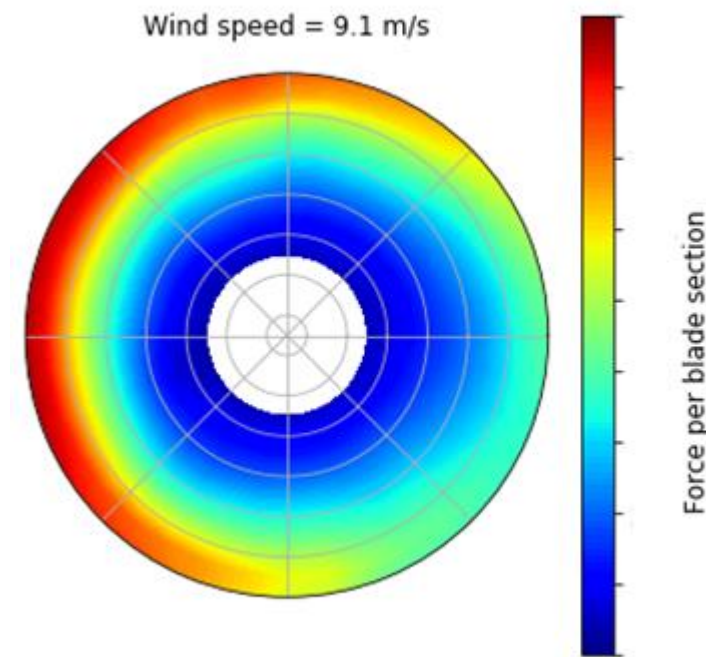
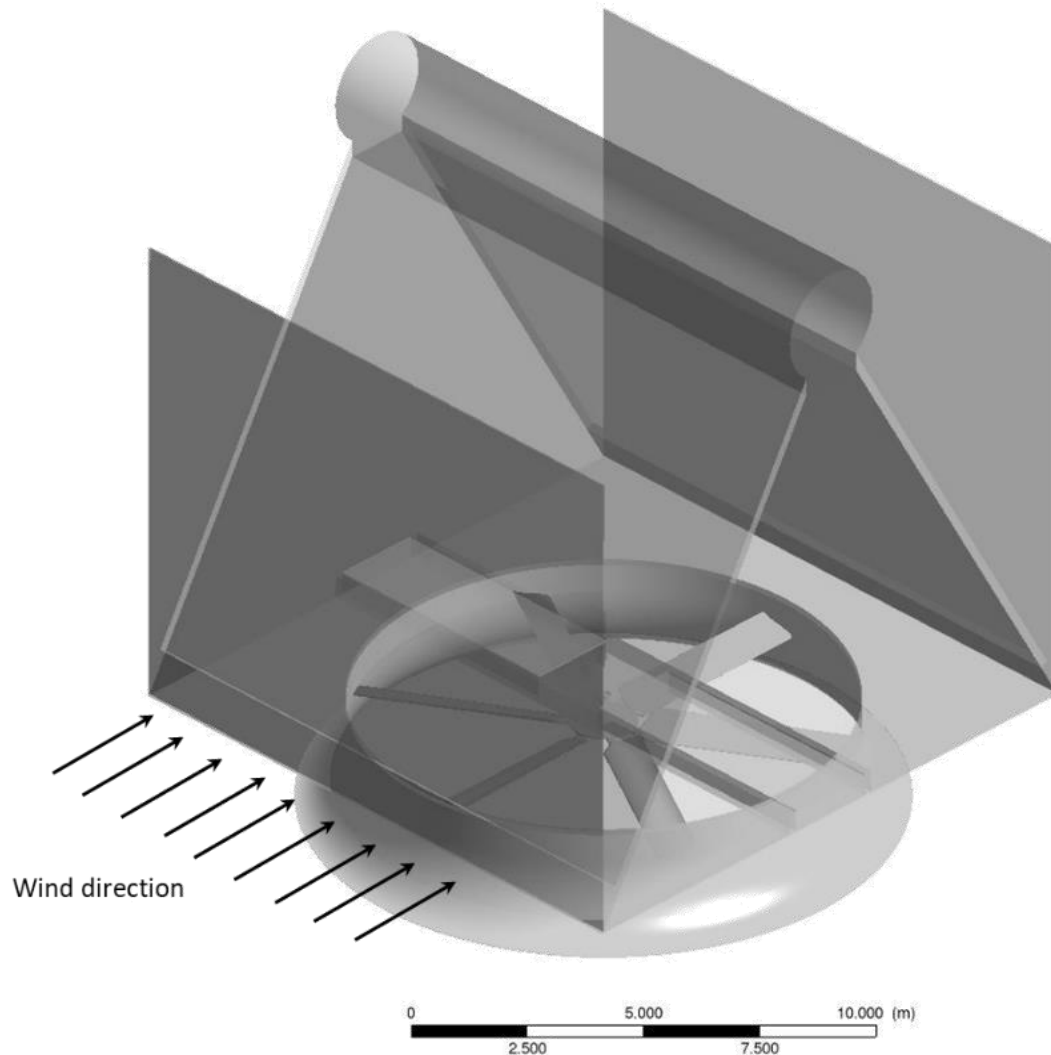
ACC fans experience flow distortions due to obstructions, such as the fan bridge, and the crosswind.

Crosswinds cause distorted inlet air flow. Various CFD simulations show these air flow patterns.



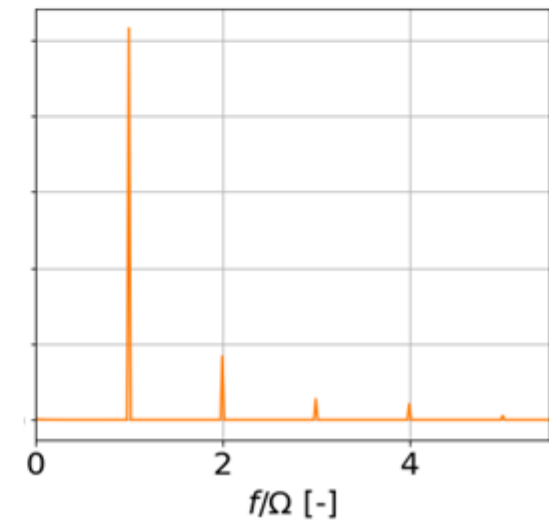
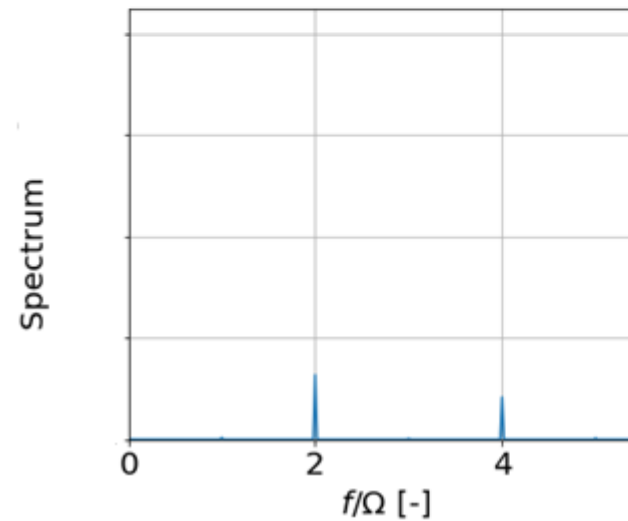
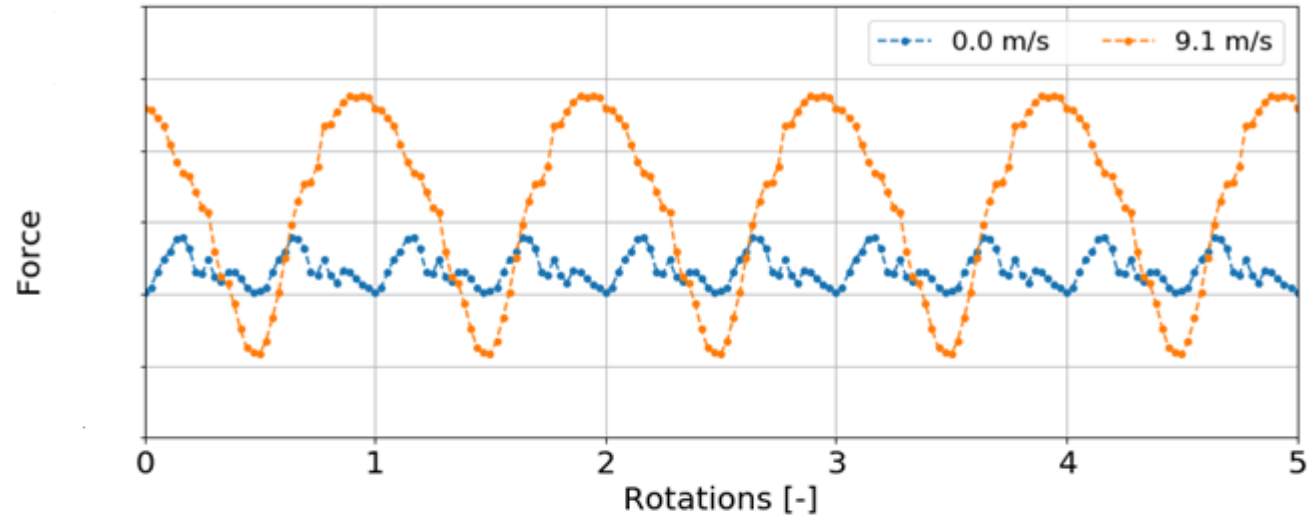
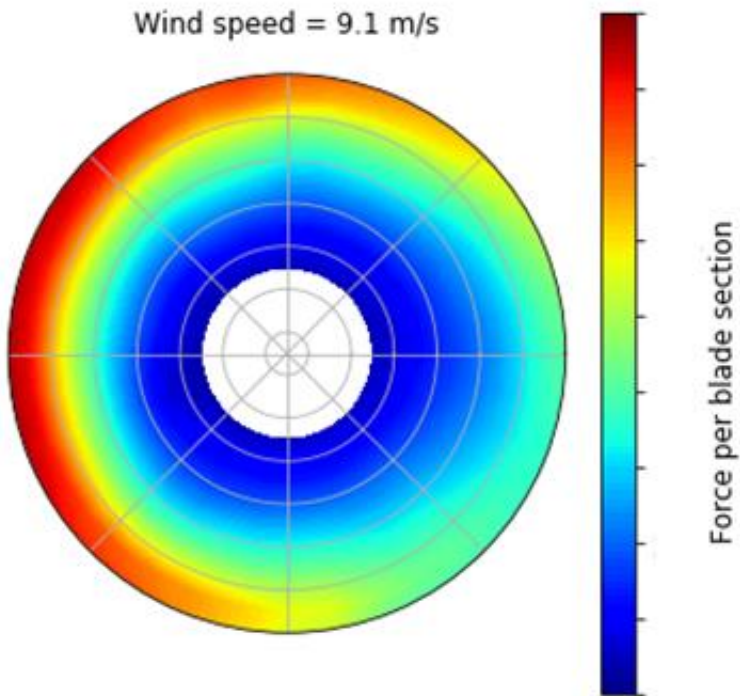
Howden has recently performed a CFD investigation to better define these loads in the time and frequency domains.

The simulations showed an expected increase in blade load on the windward side of the fan.

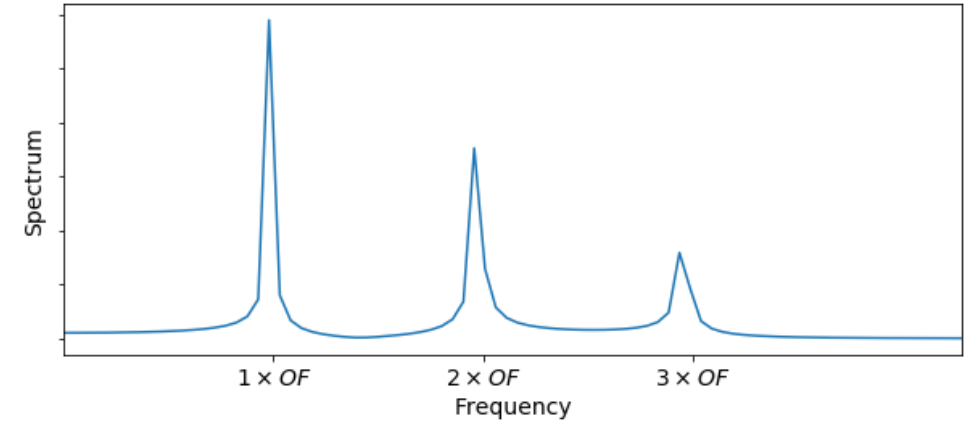
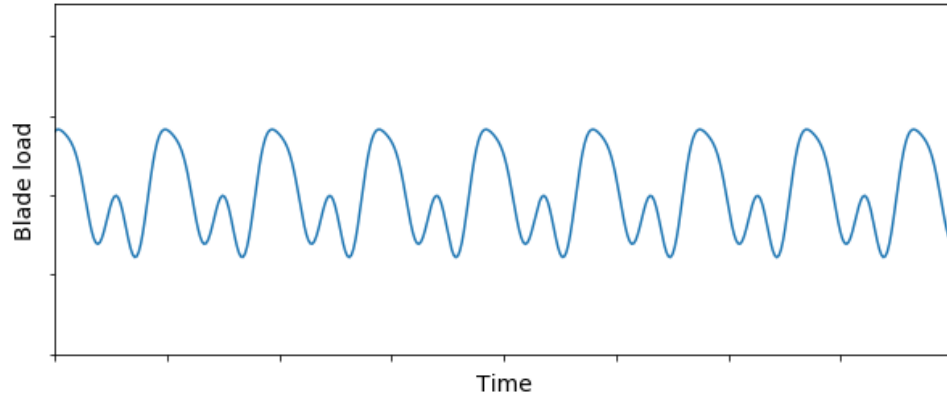


Typical ACC fan loads

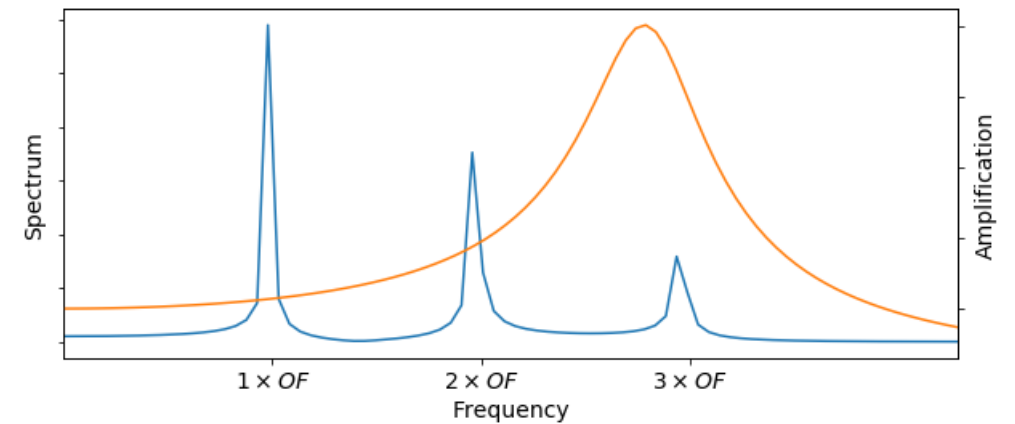
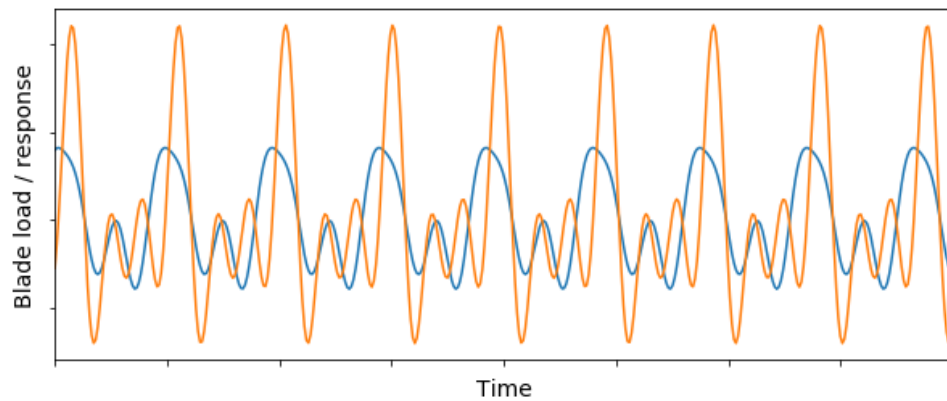
Simulated wind loading results in multiple peaks within the frequency spectrum at higher harmonics of the fan speed.



Putting everything together



Applied forces can lead to large responses due to interactions between the blade natural frequency and higher harmonics of the fan speed



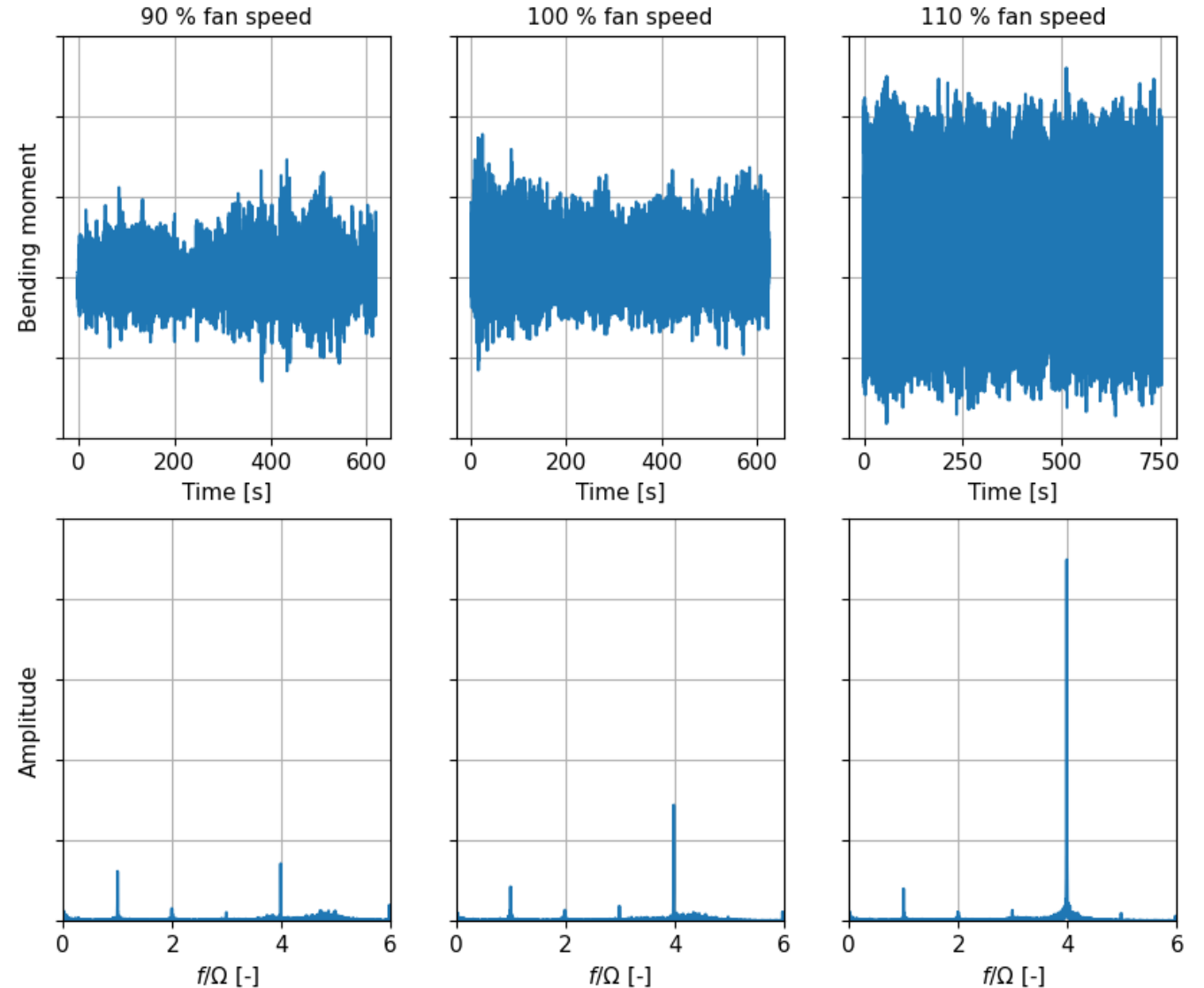
Case studies

Case 1

Isolated U-bolt failures on site.

Strain gauge measurements showed resonance at 4x fan speed.

Performance measurement showed the blade angle could be increased while reducing the fan speed to avoid the issue while maintaining performance.



Case 2

Dominion Energy, Brunswick County VA

Two recurring issues on site at Dominion Energy, Brunswick County:

- Blade separation at leading edge
- Blade clamping bolt failures (straight bolts)

Strain gauge measurements were performed on the fan blades to determine the loads during operation.

The measurements showed an amplification of dynamic loads with higher fan speeds while still remaining within the design limits.



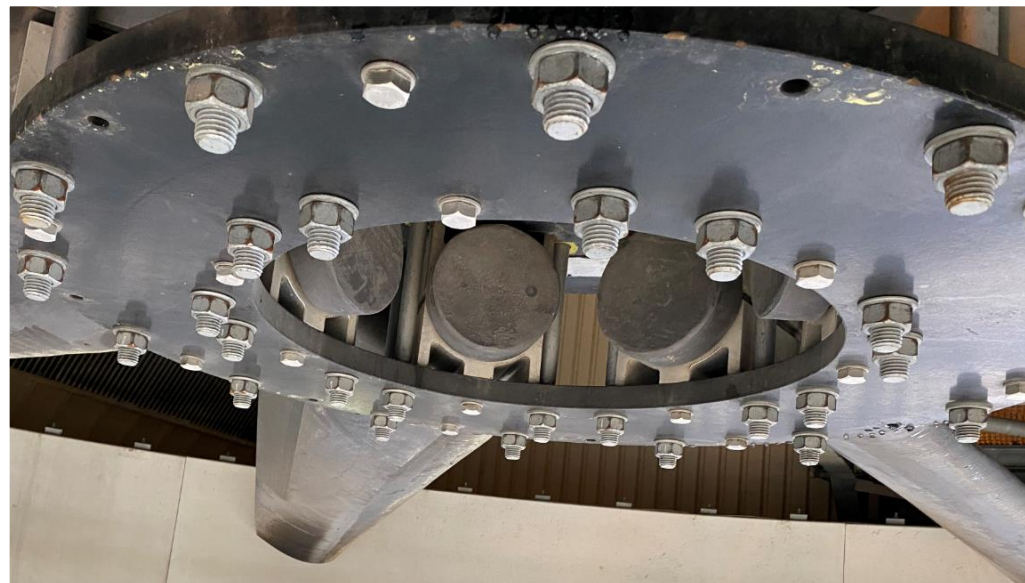
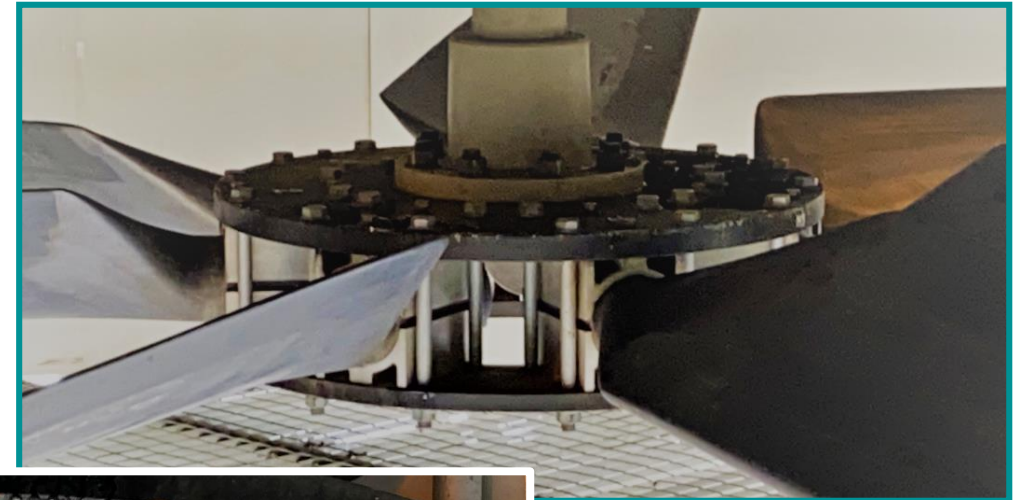
Case 2

Dominion Energy, Brunswick County VA

After testing the bonding material strength the blades on site were upgraded with additional laminate on the leading edge.

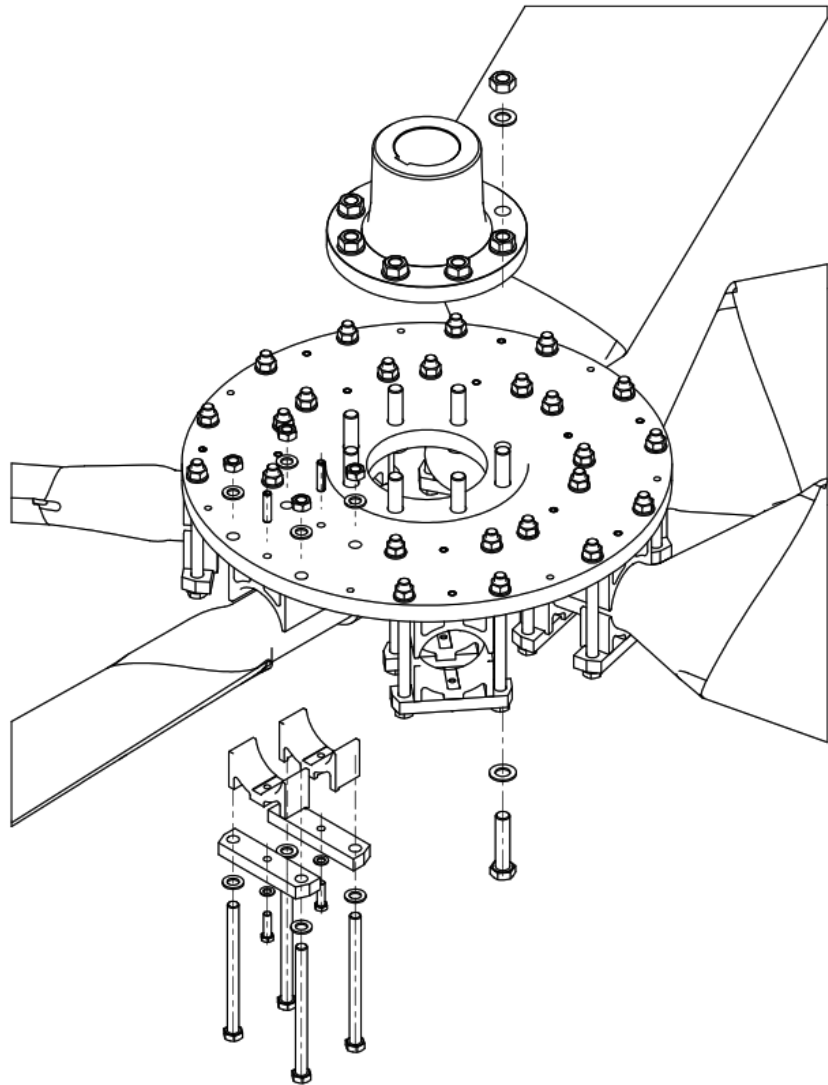
To reduce the effect of bolt preload loss and eliminate fatigue failure of the bolts it was decided by Dominion Energy - Engineering and Howden to increase the rigidity of the blade clamping bolts by adding a secondary hub ring.

The hub-ring consists of a ring connecting all of the clamping pieces, thereby increasing the bolted joint rigidity and reducing the effect of cyclical loading. This prevents bolts loosening and eventual failure.

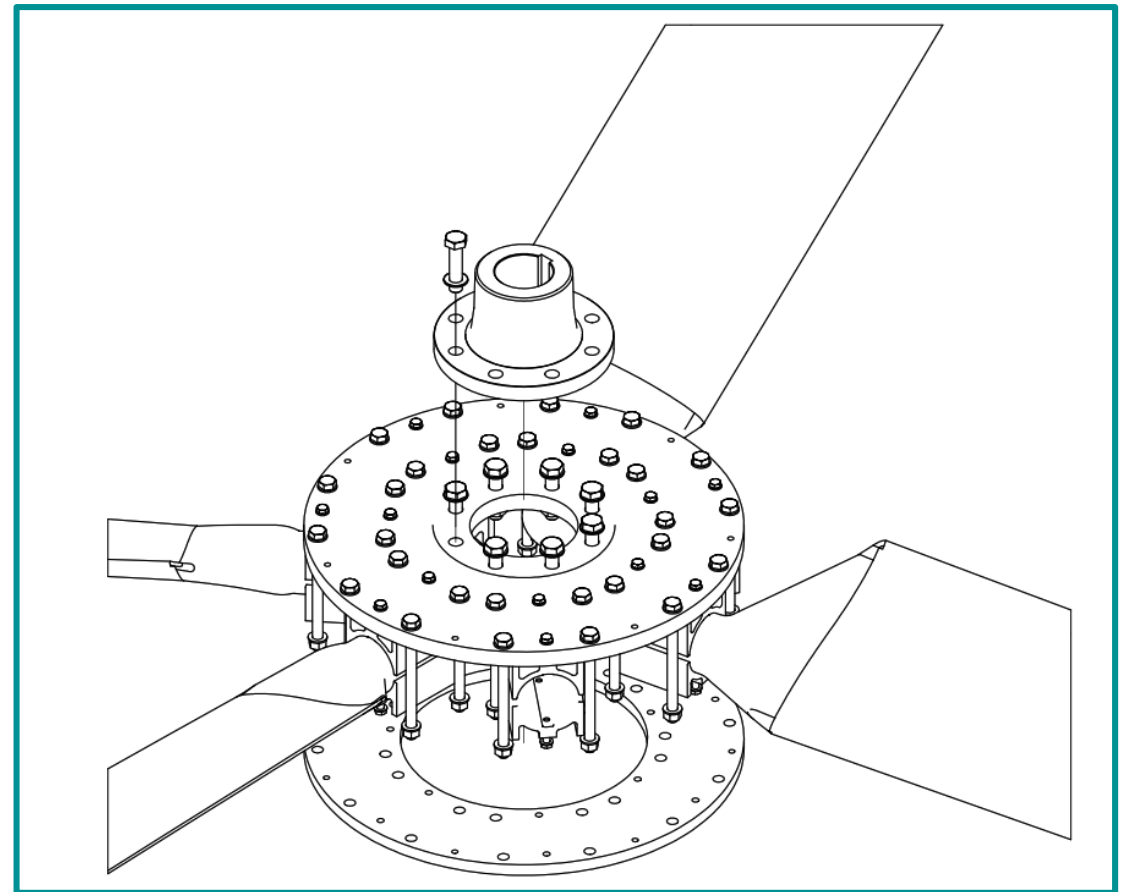


Case 2

Dominion Energy, Brunswick County VA



As a result, close collaboration between a vendor and user resulted in a robust solution for existing fans experiencing issues.



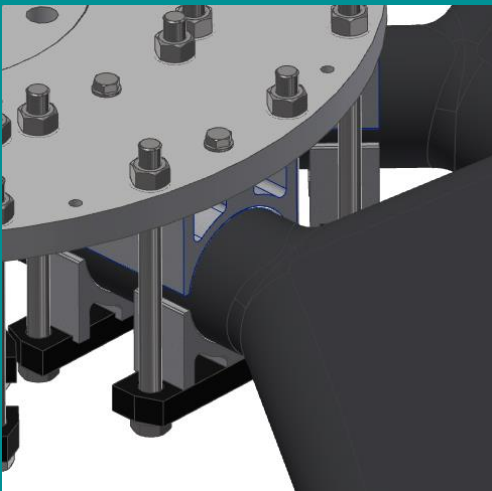
Case 2

Dominion Energy, Brunswick County VA

On site, the hub ring was installed, without dismantling the entire fan, making for an excellent retrofit solution when problems are faced:

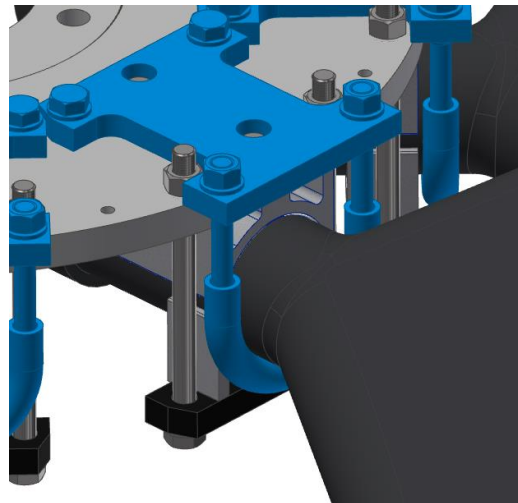
Step 0:

Situation on site with installed straight bolts



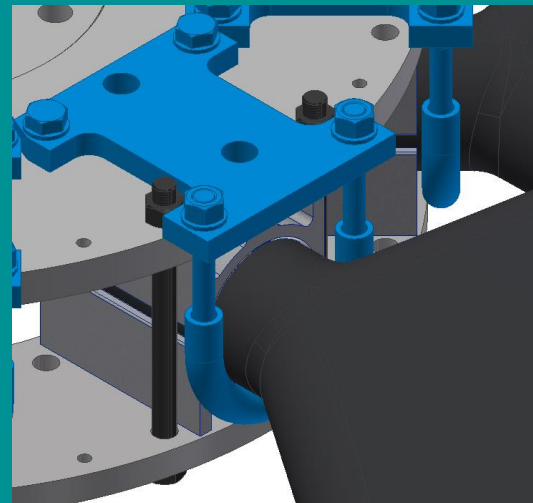
Step 1:

Remove the 'rear' bolts and insert the temporary support jigs to hold the blades in place.



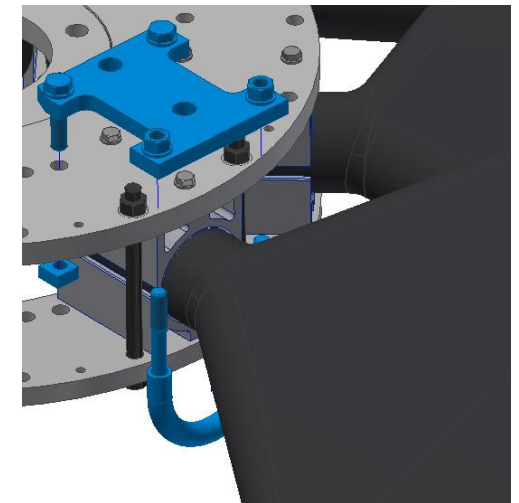
Step 2:

Lift the ring into place and replace the front bolts.



Step 3:

Remove the temporary support jigs and replace the rear bolts.



Case 3

Straight bolt failures shortly after installation, showing signs of fatigue failure at edge fans primarily.

Howden Netherlands performed on-site measurements to determine root cause of the failures.

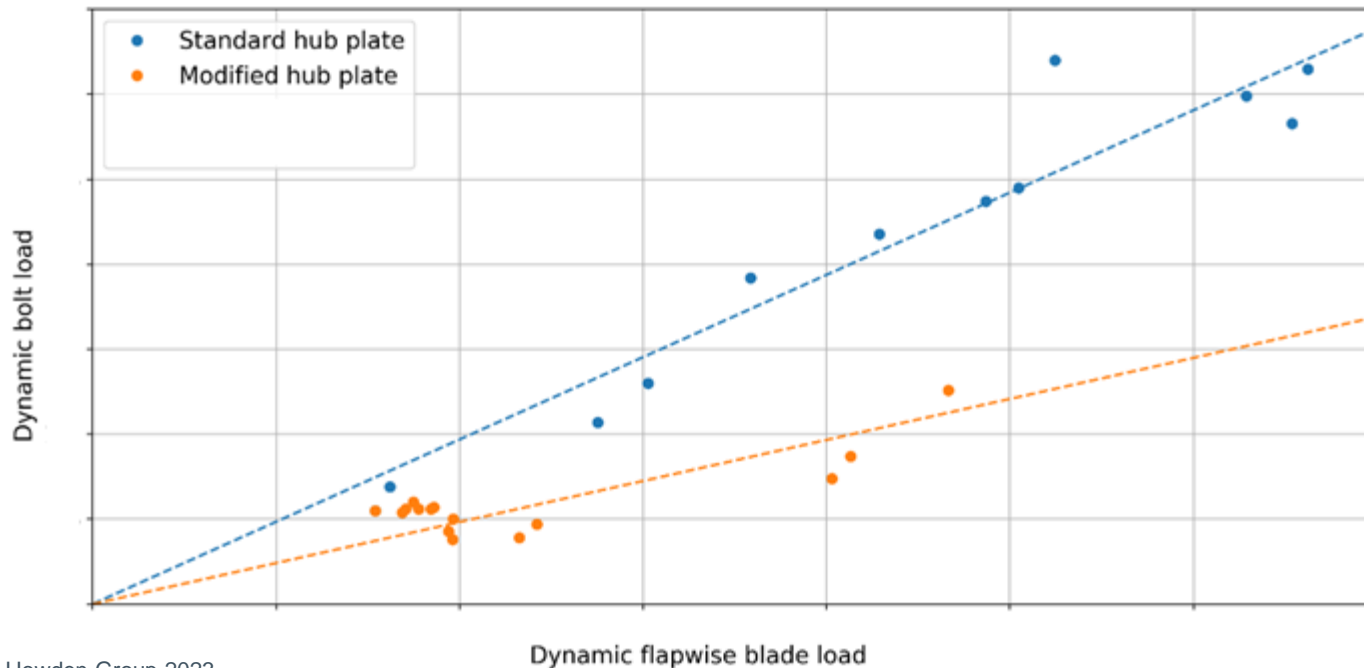
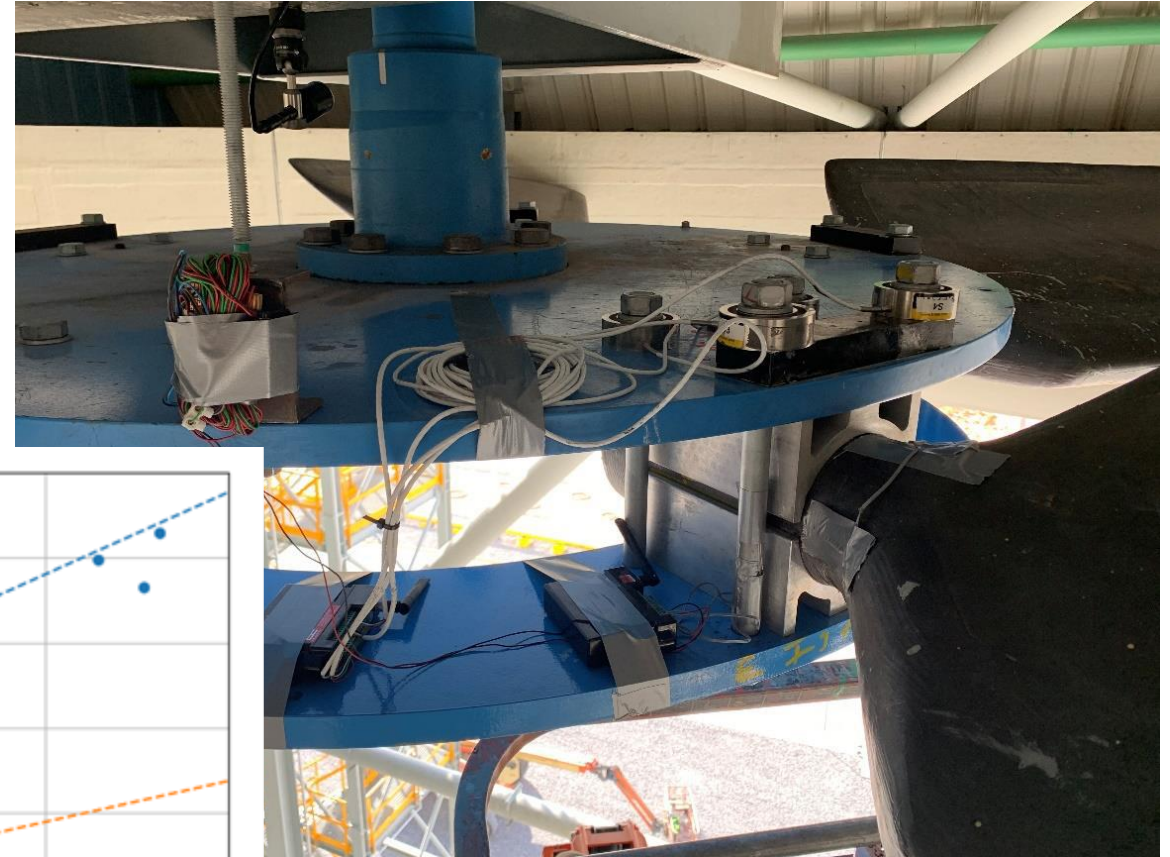


Case 3

Measurements showed high dynamic loads due to winds and resonance at 3x fan speed.

Hub-ring solution introduced to change blade natural frequency due to the increased stiffness of the blade fixation.

Also had the effect of reducing equivalent dynamic bolt loads.



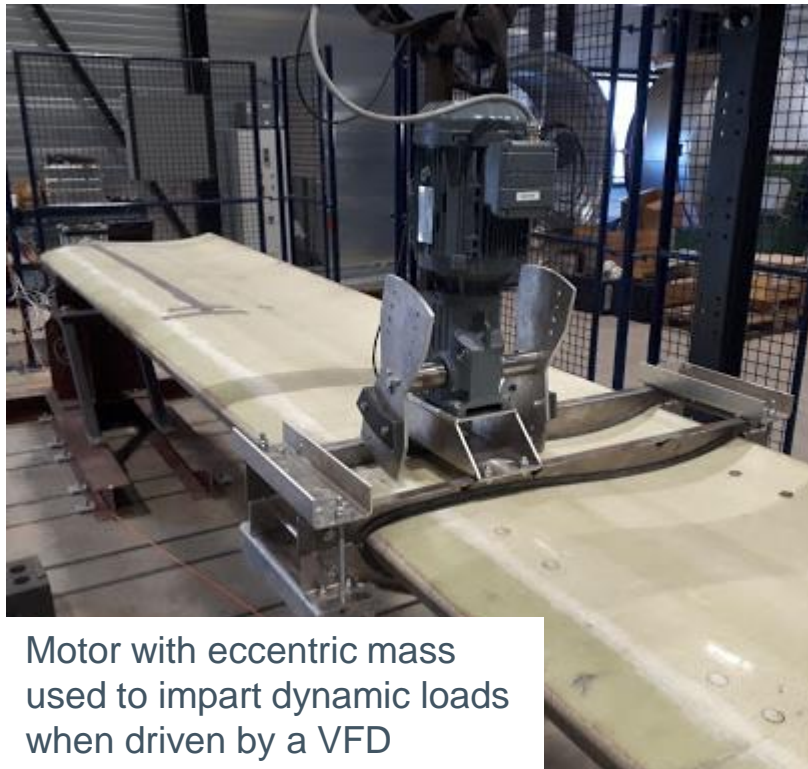


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Development work

Testing of the hub-ring assembly

Dynamic testing rig used to investigate blade and bolt loads for a single hub vs. hub-ring assembly.



Motor with eccentric mass used to impart dynamic loads when driven by a VFD

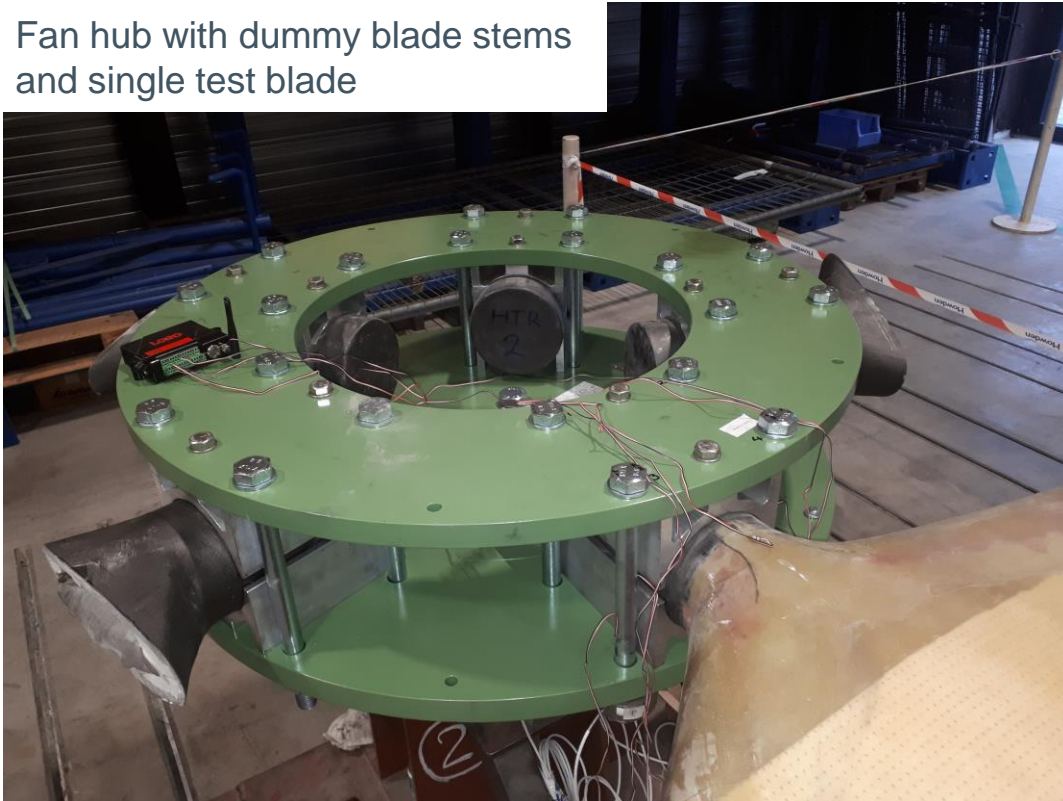


36DLF blade attached to a hub assembly on a rigid support

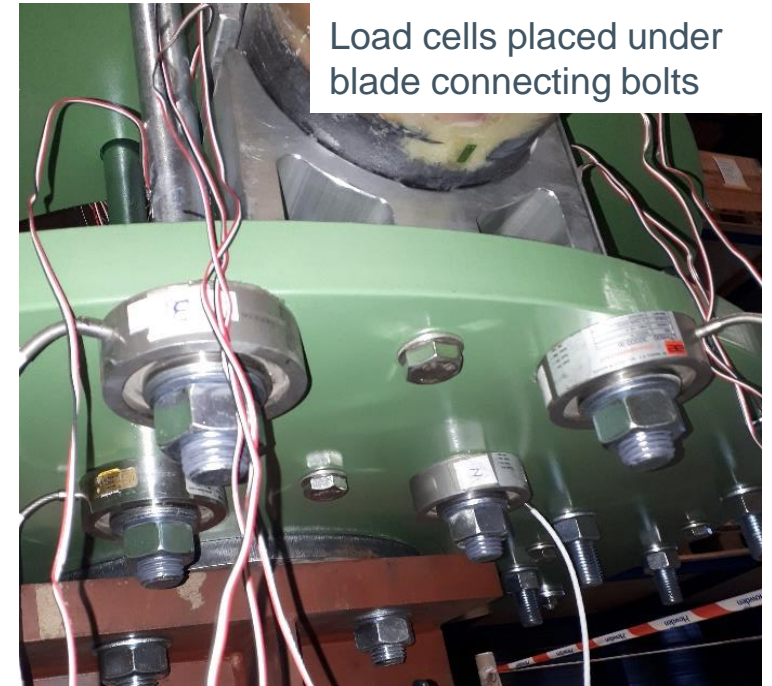
Testing of the hub-ring assembly

Fan blade and bolts instrumented with strain gauges. Strain gauges on bolts are used to measure bolt bending.
Load cells placed under on the nuts to measure axial loads.

Fan hub with dummy blade stems and single test blade



Strain gauges attached to bolts



Load cells placed under blade connecting bolts

Testing of the hub-ring assembly

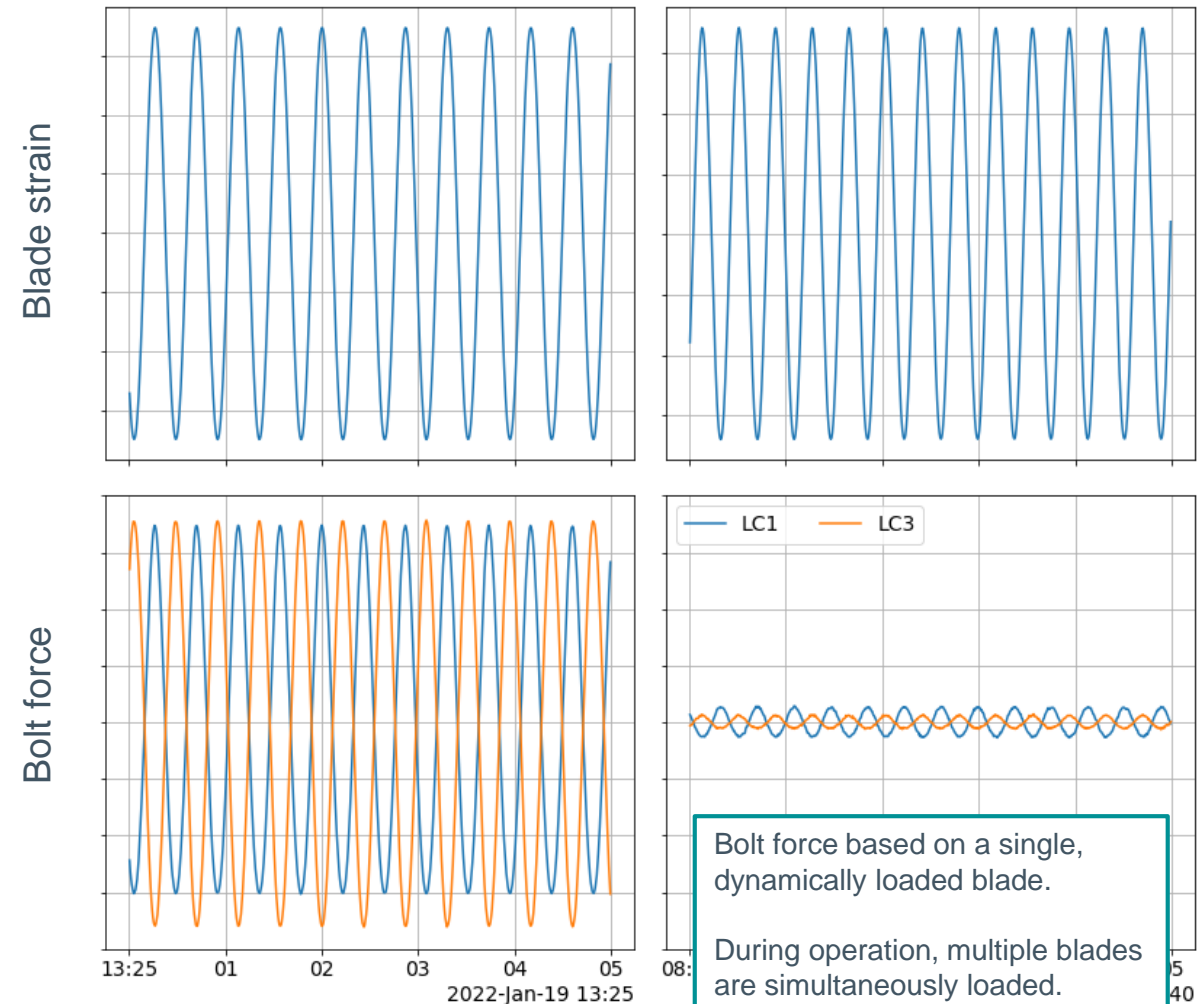
The excitation frequency is tuned to obtain the same strain amplitude on the blade.

Under these conditions the bolt loads are reduced dramatically.



Standard hub

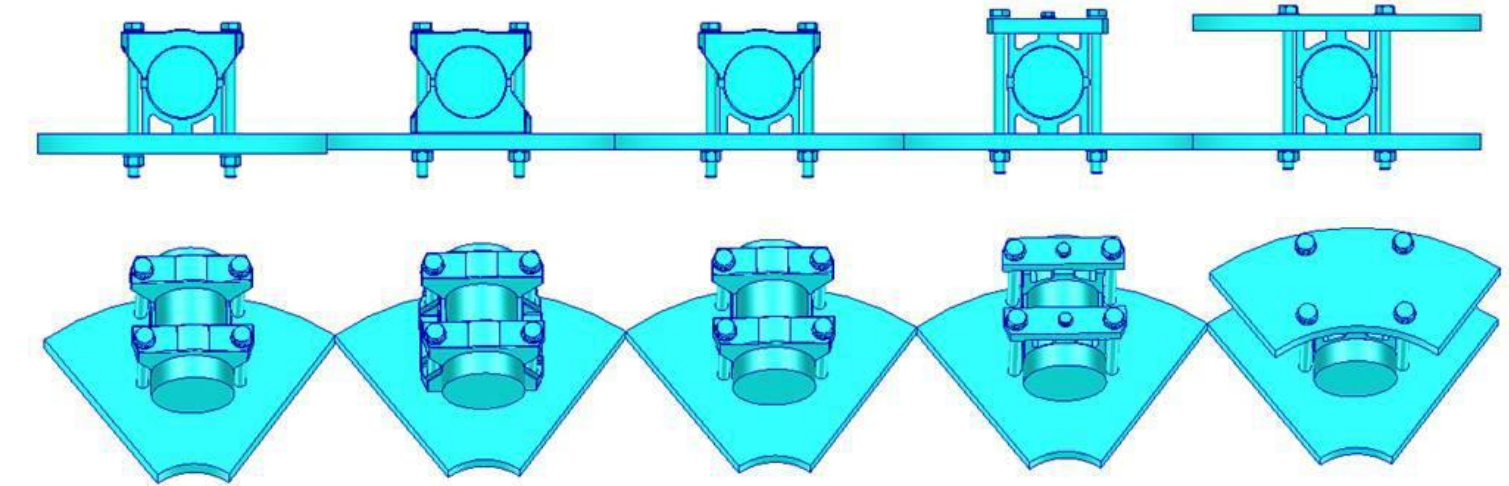
Hub-ring



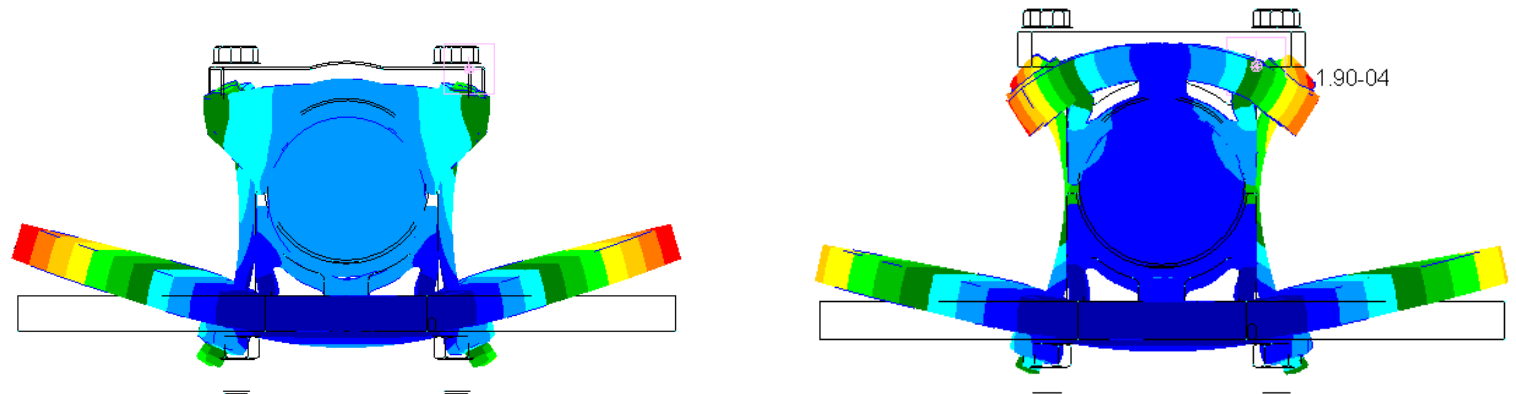
Testing of the hub-ring assembly

FEA performed by Howden to investigate:

- Bolt preload
- Plate deflection
- Bolt bending
- Influence of plate thickness(es)



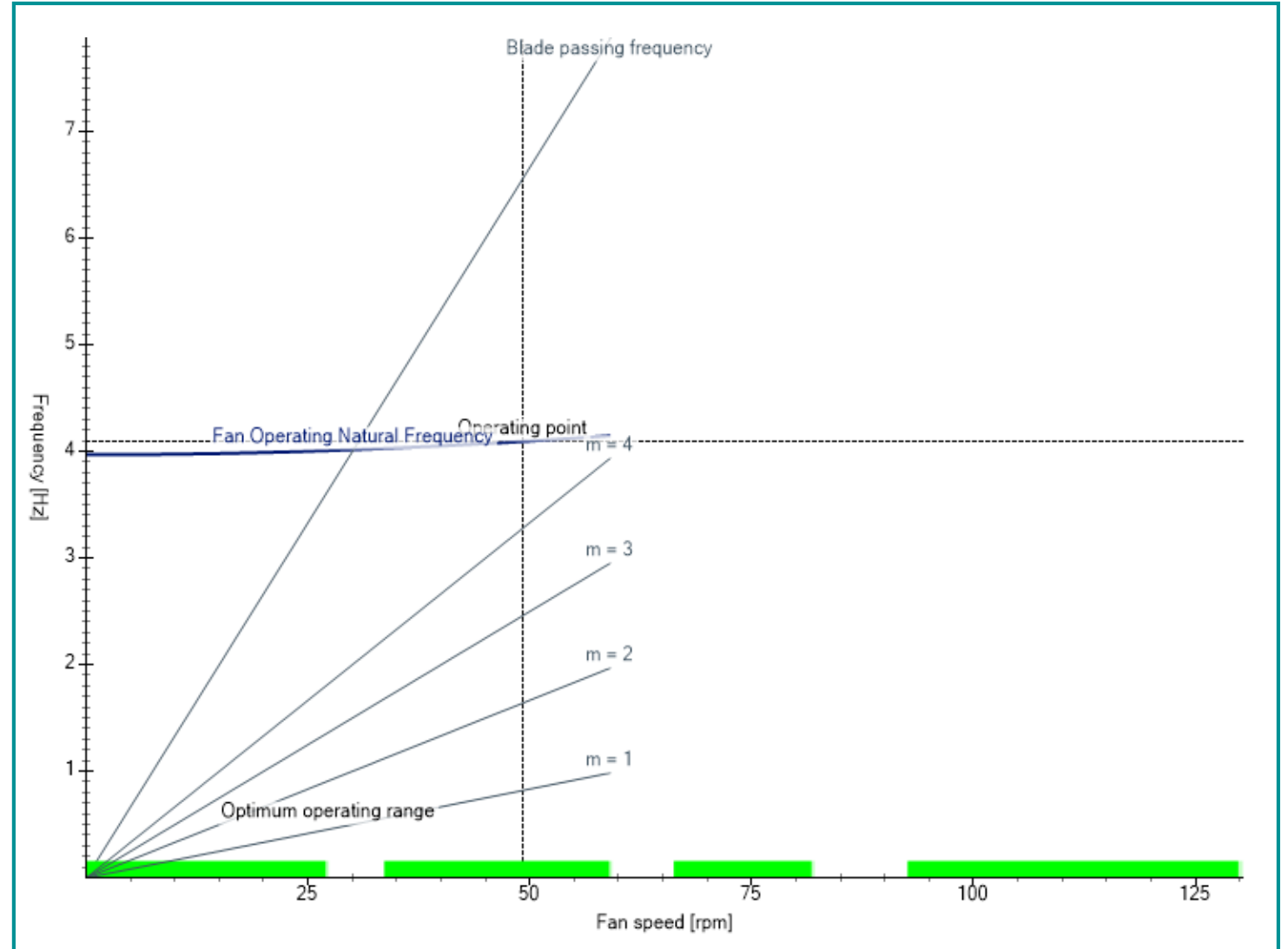
Supported by lab tests under static load conditions.





Additional checks at higher harmonics to help avoid high dynamic loads when performing fan selections.

These checks are applied to large ACC fans where issues occur most commonly.



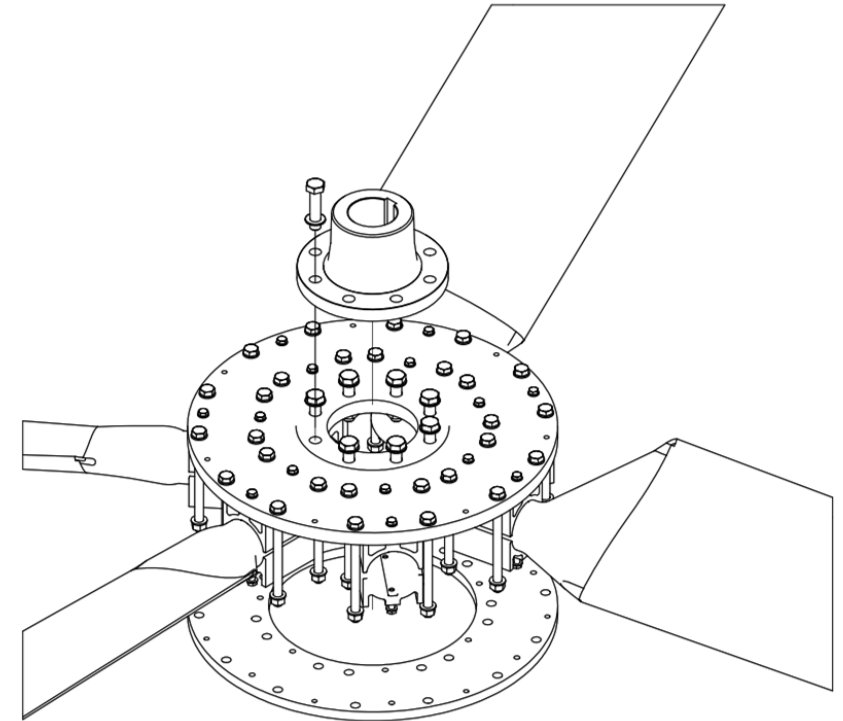


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Summary / what next?

In summary:

- Howden has performed measurements at multiple sites where there have been failed blades or bolts. These measurements have helped to identify the root causes of these failures and implement solutions.
- When blade attachment bolts suffer fatigue failure the root cause is typically identified as an amplification of dynamic loads due to side winds that can be exacerbated by a loss in preload.
- The hub-ring assembly has proven to be an excellent retrofit solution for sites where there are problems with high dynamic loads. This solution has been tested on site and the design has been refined through testing in the laboratory and numerical simulations.



In situations where high dynamic loads are expected it will be possible to offer the hub-ring as a solution for new projects in the latest version of Howden Select.



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Thank you

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