FIN FAN BLADE
CASE STUDY

OWNER:
Global Oil & Gas Company

FACILITY LOCATION:
Ontario, Canada

EQUIPMENT NAME:
Fin Fan Blade

INSPECTOR:
Geoff Clarkson
Chief Technical Officer

ENGINEERING ANALYSTS:
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CONCLUSION

An accurate inspection procedure for fin fan blades is available to identify blades at risk of failure. With this information the Owner will be able to make the right decisions about replacement planning, including controlling scope and within budget cycles.

BACKGROUND

An oil refinery in Ontario, Canada contains a large number of fans with carbon fiber blades that are used to exhaust air through cooling coils. Each Fin Fan has 4 to 6 blades. The design operating life is 25 years, and a significant number of fan blades are more than 37 years old. The owner has reported only 2 blade failures so far. UTComp® was hired to develop an inspection procedure for each blade.

PROJECT DESCRIPTION

This project was done to verify for the Oil Refinery that the UTComp® System is an effective and efficient method of evaluating the fin fan blades. This will provide the Owner with a procedure to assess the structural condition and remaining service life of the Fin Fan fleet by completing non-destructive inspection and verified evaluation with personnel access to only the underside of the fans. The orientation of the blades in service is such that the top can also be partially accessed for inspection.

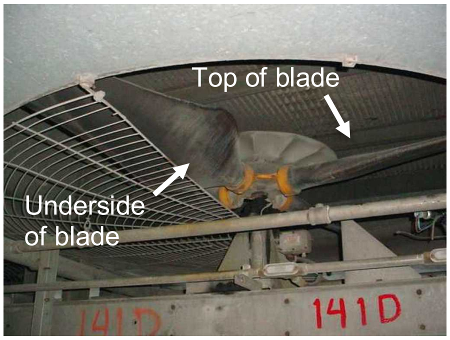

Figure 1 - Fin Fan Blade (In Service)

Four fin fan blades were examined and modeled by UTComp to determine the engineering basis for inspection to prevent blade failures. Non-destructive results have been combined with destructive results to achieve a representative model of the fin fan blades. From the models, the non-destructive results and knowledge of dominant failure modes, an inspection procedure was developed.

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Each composite fin fan blade was expected to have materials and fabrication variations, so the results from this investigation cannot be extended to the existing fleet. Since each blade can be different, it is important to inspect all blades so the blades that are at risk of failure can be identified at an early stage for replacement.

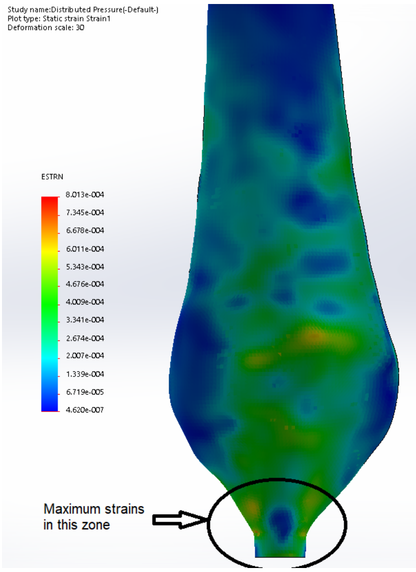

Figure 2: SolidWorks model

UTComp utilized 4 fan blades supplied by the Owner, constructed a computer simulation model of the blade using SolidWorks and verified and refined the model by measuring deflections of the blade under known load conditions. The SolidWorks Model predicted that the area with the highest strains are closest to the hub and can be accessed as seen in Figure 2.

This model was then used to identify the areas of the blade where the greatest changes to flexural modulus are expected to occur in operation. A reduction of flexural modulus is the normal result of fatigue in FRP and will predict fan blade failure. These areas were identified as locations required for non-destructive UTComp inspection of the fan blades with access to the underside surface only and were also identified as zones with highest strains in the SolidWorks model.

Common failure modes that were identified by owner staff are cracking at the transition from the clamped hub to the fan blade and cracking along the leading and trailing edges. They also observed possible cracking in the surface of the blade and delamination at the tip of the blade. The blade that was cut apart showed that the glass fabric was somewhat continuous around the leading and trailing edges, so it was estimated that cracking in these regions may be limited to resin-rich zones and will not have significant effect on blade performance. The fin fan blades used in this investigation did not contain any hub cracks.

Strain was used as the indicator to determine where ultrasonic readings of the blade would be most beneficial. Also, for field inspection of fin fans in service, the underside of the blade is fully accessible, and the top surface is partially accessible. The updated SolidWorks Model (which included the frequency of the blade's rotation) predicted that the top surface and part of the underside of the blade closest to the hub attachment point and an area in the "throat" of the blade experiences the highest strain. Access to the hub attachment point would only be possible by removing the clamps, the "throat" area was used as proxy for UT data collection.

It is very important to note that conventional ultrasonic inspection would not have provided meaningful results regarding changes that have taken place in the blade. Conventional ultrasound is focused on detecting defects and the method required must provide information on structural changes that have taken place in the laminate, usually with no detectable defects. Ultrasonic inspection of the blades will follow procedures and techniques developed by UTComp to determine the effect of operation on FRP stiffness. This is known as the UltraAnanlytix™ system.

Destructive Testing

Samples were cut from a blade for the following destructive tests to verify the fiberglass construction details and mechanical characteristics.

- Loss on ignition to ASTM D 2584
- Lamination sequence analysis
- Flexural modulus to ASTM D790

Figure 3: Load testing

Load Testing

The load that an individual fan blade will experience when in operation was then determined using the Fin-Fan specification sheet. The loads the blade experienced when attached at the hub were calculated. The maximum moment in the hub was determined using the uniformly distributed load or static pressure.

Blade Profile Measurement

The surfaces of the blades were marked out with a 64x64mm (2.5x2.5in) grid. Measurements were taken to each gridline intersection. The blade was then rotated 180 degrees and measurements repeated on the other side.

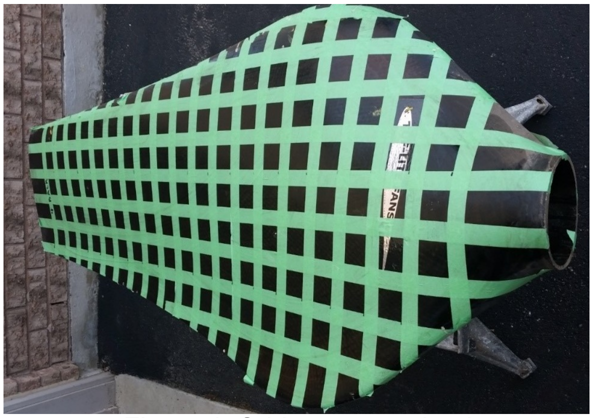

Figure 4: Grid pattern on blade

Ultrasonic Measurement

The blades were placed on a flat horizontal surface for ease of access. Using the 64x64mm grid previously marked, UT readings were collected following the UTComp's UltraAnalytix system. The ultrasonic data files were made into Asset files and analyzed with UTComp's proprietary software to determine the ultrasonic transit time and Percent of Design Stiffness (PDS) at each reading location.

Ultrasonic calibration files were taken where thickness measurements could be made, namely the blades with cut-away hubs. This was analyzed to determine nominal ultrasonic velocity through the blade material. This velocity was then applied to the transit times of the ultrasonic readings from the blade surface to determine the thickness at each location of the grid.

Computer Modeling

A 64x64mm grid was prepared in SolidWorks with cross sections sketched at 64mm intervals using the Blade Profile Measurements and thickness values from Ultrasonic Measurement. A loft feature was then created using the cross-sectional profile sketches to generate the model.

A SolidWorks Finite Element Analysis (FEA) Simulation on the fan blade model was performed with applied orthotropic material properties from ASTM D 790 testing, ASTM D 2584 testing and lamination analysis. Point loads of 6.804kg (15lbs) and 12.247kg (27lbs) were applied at the tip to determine deflection values. The SolidWorks model was validated by comparing deflection values from SolidWorks to those measured from the Load Testing for the same loads. A static pressure load based on an analogous fan specification was applied to the top surface of blade. The client advised that the blade frequency of rotation was 344 rpm. A safety factor of 1.2 was used and a frequency of 6.88 Hz (60 rpm equals 1 Hz) was applied to the SW model. The FEA results were examined for high-strain zones.

RECOMMENDATIONS

To this objective, the recommended inspection procedure would be:

1. Complete inspections while outdoor air temperatures are warmer than 10°C.
2. Examine the trailing edge, tip and leading edge of the blade for evidence of cracking or delamination. If these are found, the blade will be identified for replacement.
3. Examine the bottom surface of the blade for cracks. For any cracks found, take ultrasonic readings using the UTComp System to determine if there are any structural concerns.
4. Collect 15-20 ultrasonic readings from each of the zones marked. The blade will be recommended for replacement as follows:
    a. If average PDS is less than 40%, or
    b. any individual reading is less than 20%, or
    c. any delamination is identified,

    identify the blade for replacement as high risk for hub cracks.

At this time, not including the time required for lockout of access to the fan, this inspection procedure is expected to require about sixty (60) minutes per fan blade.