CHAPTER 5

THE EFFECT OF GLOBAL AND LOCAL MODES

5.1 Introduction

Due to the discrepancies found between the frequency shifts of some mode shapes the FEM predicted and the actual measured shifts, it was decided to investigate further. It was postulated that the most likely cause for this phenomenon was that the measured frequencies corresponded to global dynamics of the structure. This would mean that the frequency shift might actually be less than predicted by what would be a "local" mode shape of a single blade modelled by the FEM.

The rest of this chapter is devoted to the development of an additional FEM to gain a better understanding of the global behaviour of the system. Furthermore the results obtained from this new model were compared to the measured results.

5.2 The need for extended FEM modelling in systems

The results when using the natural frequency around 280 Hz can be found in Chapter 4. While a readily measurable shift of frequency was found with increasing amounts of damage, the shift was nowhere near as much as expected. At around 40% damage the shift was found to be around 6% compared to the predicted shift of 25%. The reason for this behaviour can be seen in Figure 5.1. While a whole range of different peaks can be found around 270 Hz, the ARMA model did an averaged curve fit. As a result the different peaks were not picked up. This specific power spectral density plot was done for the instrumented, damaged blade with a 1000 Hz sampling frequency and a 4 s sample.

The most likely reason for this behaviour was that this mode was global. This means that the other three fan blades also take part at slightly different local frequencies. As a result these modes are superimposed on each other to give a much more complex behaviour than could be expected from a single blade.

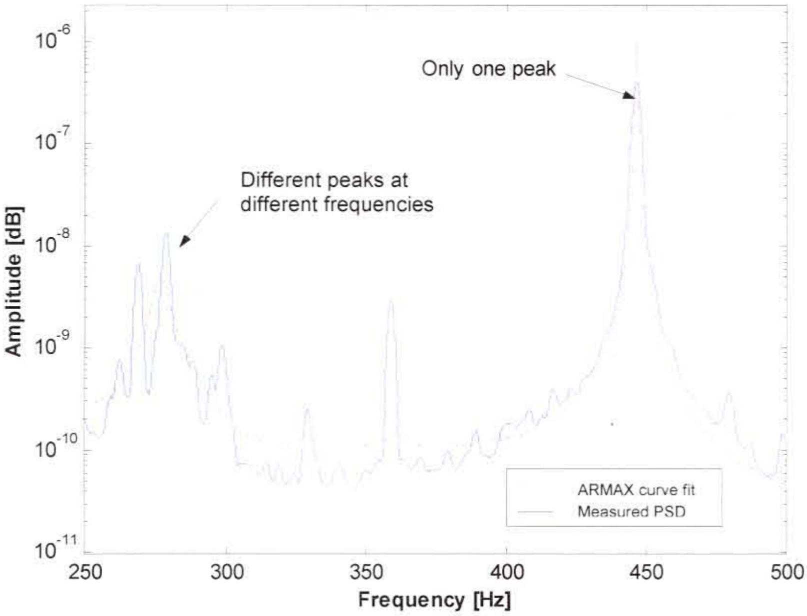

Fig 5.1: Experimental comparison of the third and fourth natural frequencies

Further proof for this hypothesis could be found in the fact that an instrumented, undamaged blade also showed frequency shifts at most of the natural frequencies with increasing amounts of damage (see Figure 5.2).

In sharp contrast with the third natural frequency, the fourth natural frequency produced a very well defined peak at one frequency only. This peak also stayed at virtually the same position on the undamaged blade as can be seen in Figure 5.2. It was to be expected that higher frequencies are more likely to be local mode shapes.

Also readily apparent in Figure 5.2 was the fact that different mode shapes had different sensitivities to the rest of the test structure.

To gain a better understanding of the behaviour of the complete system a simplified finite element model of the hub and blade interface was created. Another possibility would have been to perform a modal analysis on the system. The finite element model approach was preferred due to the following reasons:

- A modal analysis can not be done while the fan is operating. The force input on the system need to be measured and this was realistic only if a modal exciter and force transducer were used.
- The mass of the accelerometer moving from the tip of the blade to the root with different measurements could make a significant difference on the measurements.

- Due to time constraints, only a limited number of measurement points per blade would have been made, reducing the accuracy even further.
- The finite element model was more flexible in terms of inducing damage and provided information about higher mode shapes and symmetrical modes.

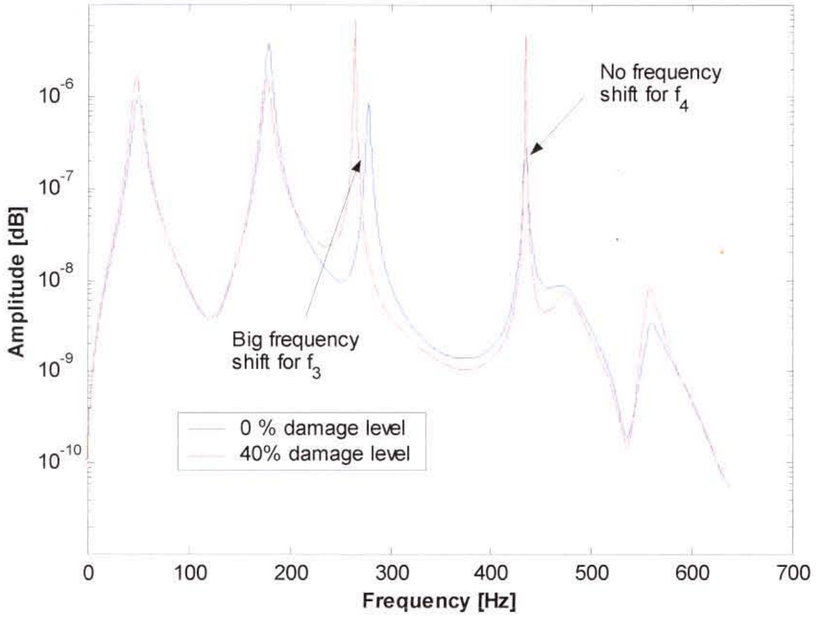

Figure 5.2: ARMA curve fits to undamaged instrumented blade

The finite element model can be seen in Figure 5.3. While it was not an exact representation of the experimental fan blade damage simulator it adequately explained the different shift of frequencies observed during experimental measurements and analysis. Note that the blade seat ring was modelled as aluminium since the experimental fan blade damage simulator was machined from aluminium.

The undamaged mode shapes in the region of 280 Hz can be seen in Figure 5.4. Even for the undamaged case, the first sideways mode shapes differed significantly from each other. It also explains the peak at 294 Hz (see Figure 5.1). Due to the fact that the whole system resonated, these different mode shapes around 280 Hz would have influenced the dynamic behaviour of all the blades. The four mode shapes in the region of 280 Hz for the damaged case can be seen in Figure 5.5. Periodic structures such as a fan, exhibit mode localisation. This can be seen in the top right of Figure 5.5. Only the damaged blade take part in this mode shape.

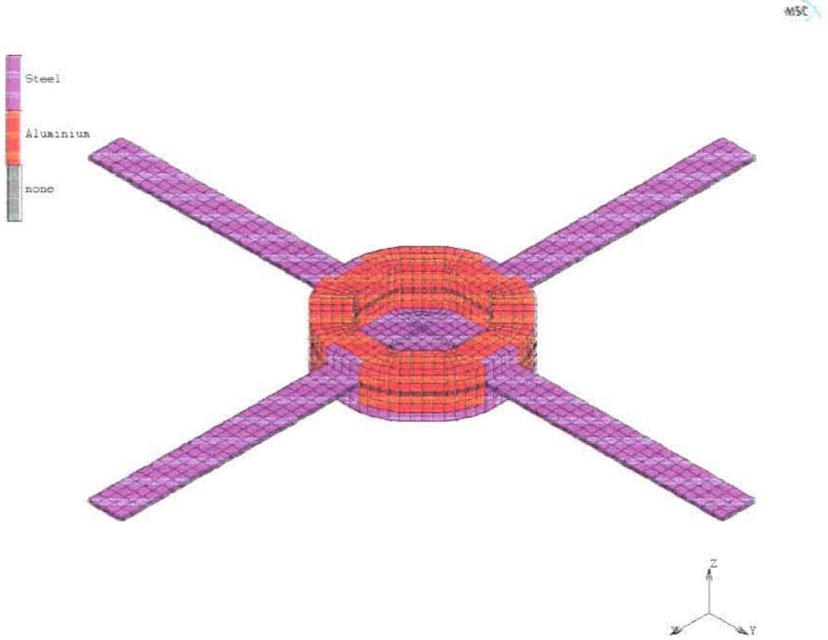

Figure 5.3: The extended finite element model

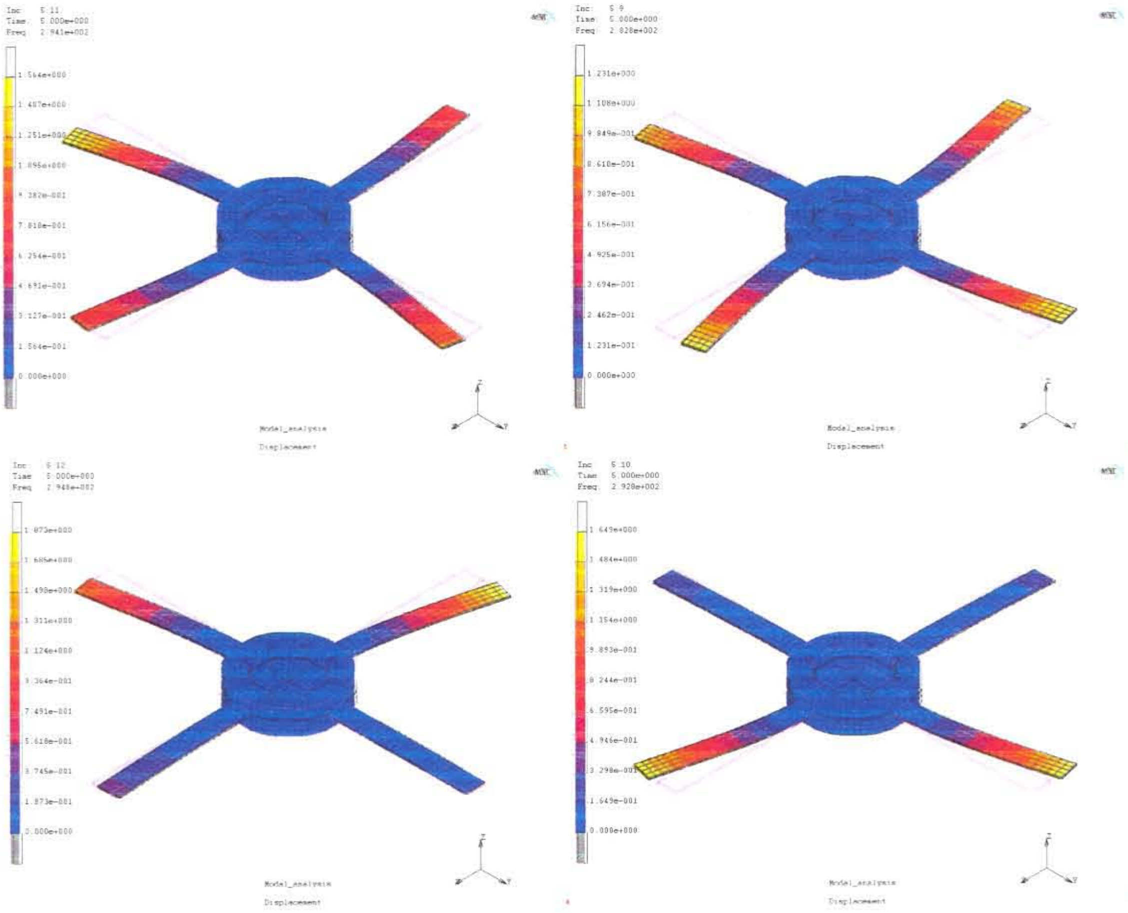

Figure 5.4: Four mode shapes found in the region of the third natural frequency (f ≈ 290Hz)

The frequency values found for the four mode shapes in the region of the third natural frequency (Figure 5.4) can be seen in Table 5.1 (listed clockwise from the top left).

Table 5.1: Comparison at the third mode shape

Undamaged case	25 % Damage case
294.1 Hz	293.7
282.0 Hz.	267.4
292.8 Hz	286.7
294.8 Hz	294.8

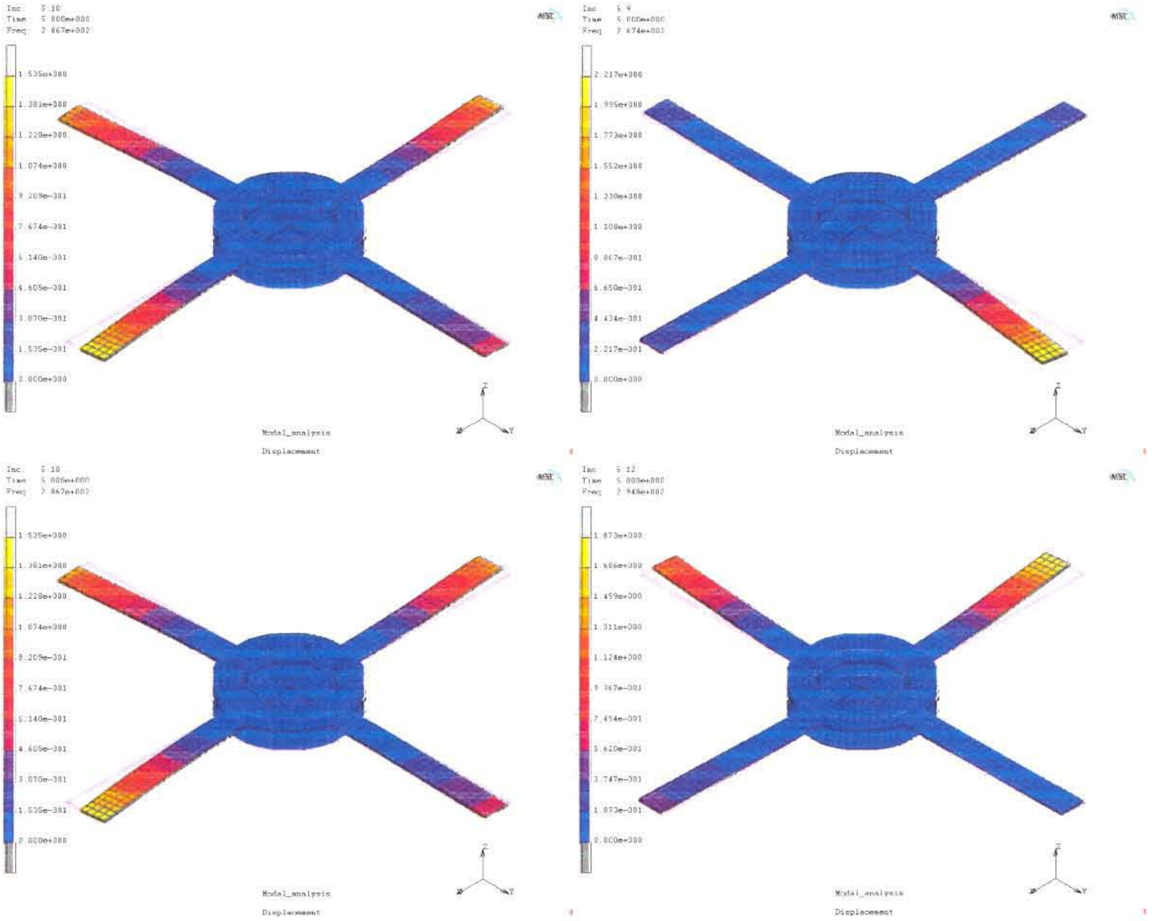

Figure 5.5: The four mode shapes after damage had been induced on one blade.

The fourth mode shape (first torsional) can be seen in Figure 5.6 on the next page. This mode shape provided excellent local damage indicators. The four modes shown here were for the undamaged case. The undamaged case was compared to the damaged case in Table 5.2 (From the top left, clockwise in Figure 5.4). The damaged case can be seen in Figure 5.7

Table 5.2: Comparison at the fourth mode shape

Undamaged case	25 % Damage case
433.4 Hz	429.3
433.6Hz.	433.5
433.8 Hz	433.6
434.0 Hz	433.9

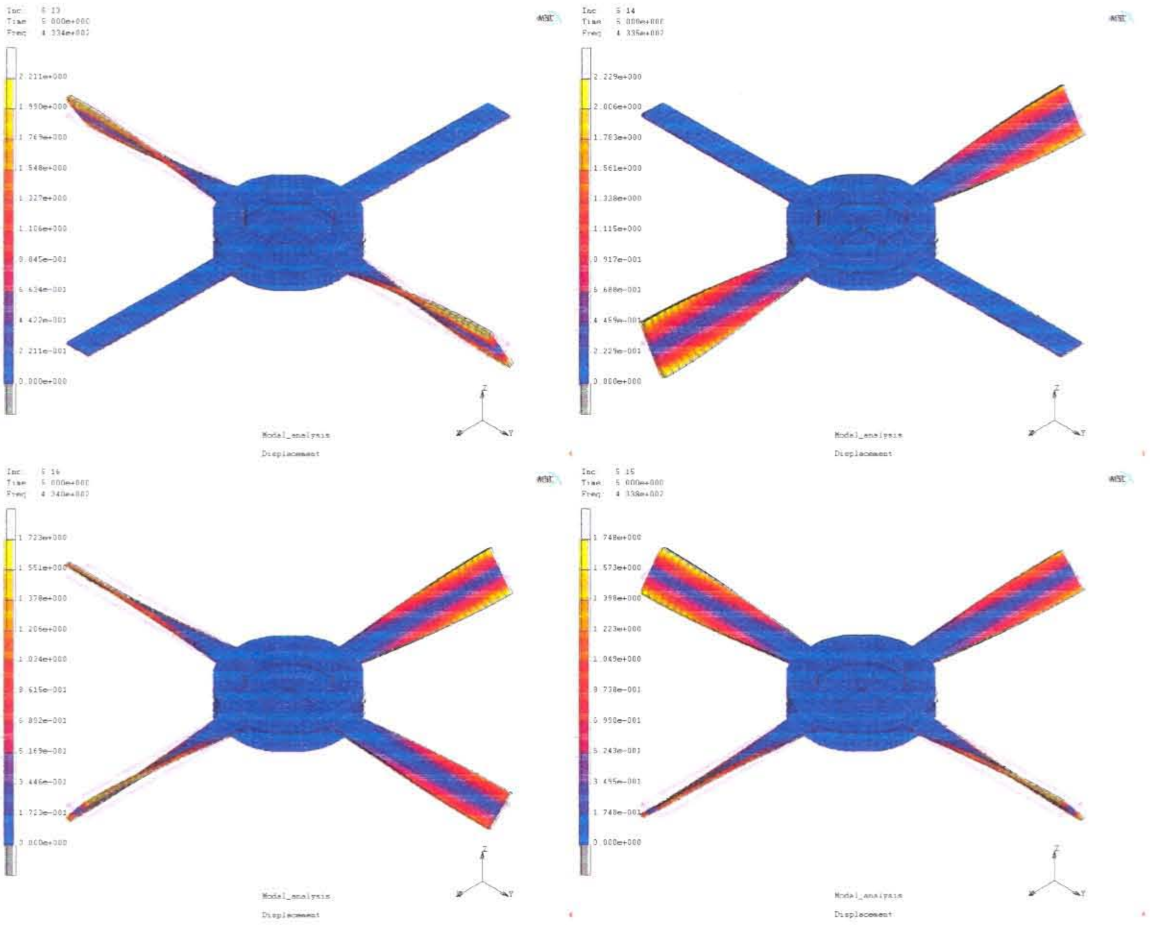

Figure 5.6: The four modes shapes found in the region of f ± 433Hz.

Although this mode shape did not shift by as much as the third natural frequency, the local nature of the mode shape made it much better suited to this problem.

The biggest problem with the third natural frequency in this system was that a whole range of frequencies can be found (see Table 2.4 and fig 2.12). Experimental results confirmed the results found by the finite element analysis. While this frequency can still be useful as a global damage indicator, it was doubtful whether experimental measurements, and even more importantly, ARMA curve fits could be done accurately enough to monitor all the modes in the region of the third natural frequency.

A further advantage of the torsional mode shapes was the fact that all the natural frequencies found were virtually the same and would therefore be significantly easier to measure accurately and repeatedly.

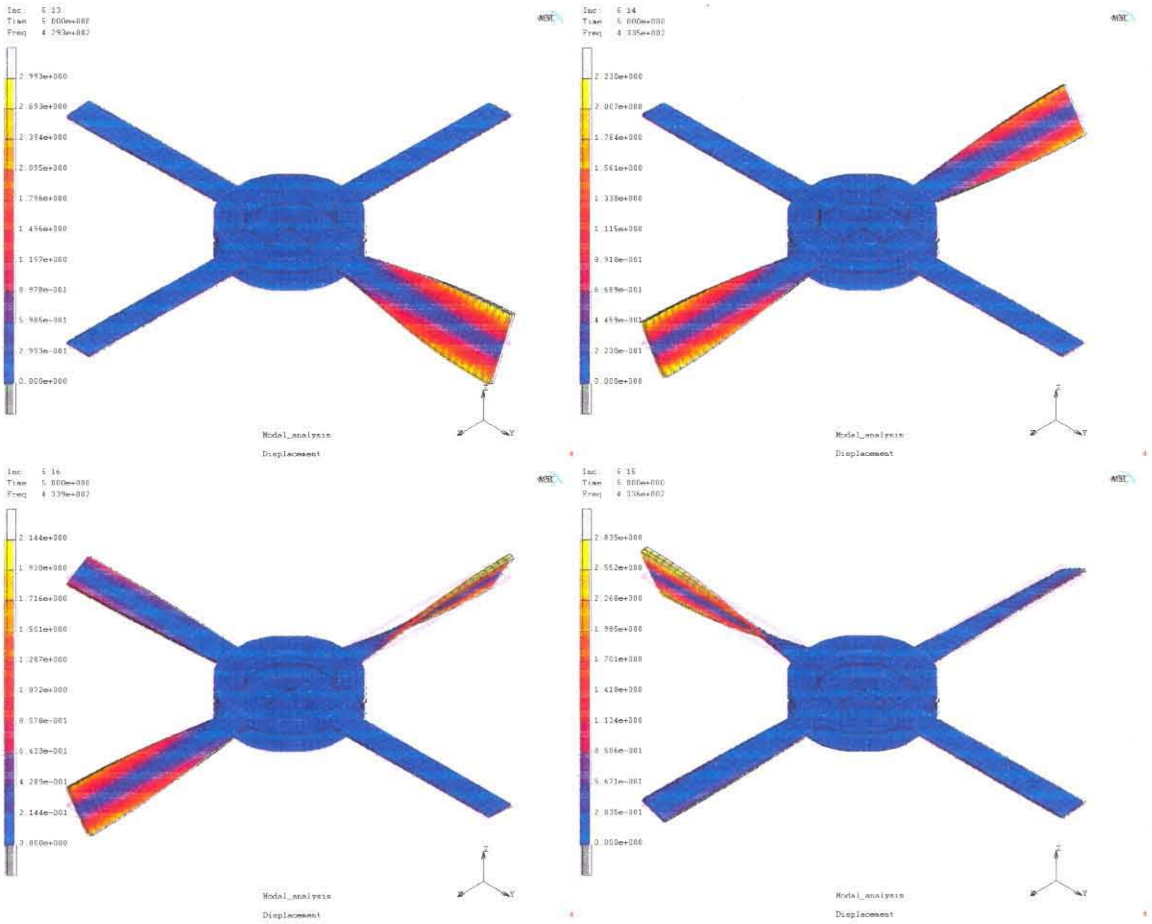

Fig 5.7: The mode shapes after damaged had been induced

As this extended FEM model adequately explained the deviation of FEM results from the results found experimentally, the model was not refined to represent an exact match to the experimental results. For this project the model was used to show correlation between experimental and FEM results. If a simplified laboratory based fan blade damage simulator can be modelled accurately, it is not unreasonable to assume that damage can be detected by using the same technique on the actual fan

5.3 Effects of eight blades

It was also decided to investigate the effect of even more blades on the mode shapes and natural frequencies of a bladed structure. For this purpose, an identical model to the one used in section 5.2 (except for doubling the number of blades to eight) was used. Some of the resultant mode shapes in the region of 280 Hz can be seen in Figure 5.8. Table 5.3 gives the eight natural frequencies found around 280 Hz, while Table 5.4 gives the frequencies found around 433 Hz.

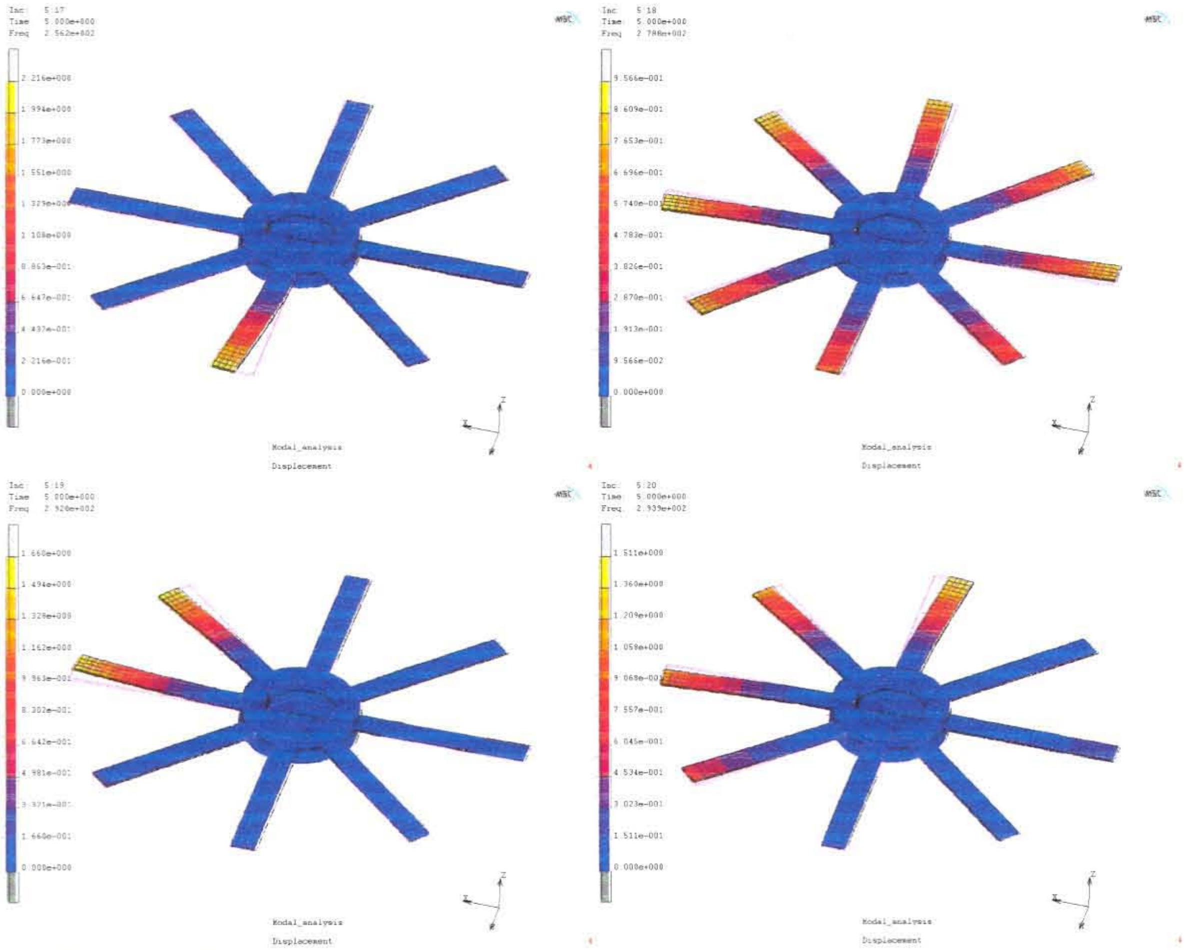

Figure 5.8: Four of the mode shapes and natural frequencies found in the region of 280 Hz

Table 5.3: Comparison at the third mode shape.

Undamaged case		**25 % Damage case**	
269.278	295.019	256.245	295.019
282.033	295.096	278.758	295.095
292.768	296.358	292.767	296.355
293.904	305.989	293.901	304.982

Table 5.4: Comparison at the fourth mode shape.

Undamaged case		25 % Damage case	
429.527	433.794	424.7	433.793
429.577	433.897	429.527	433.896
433.301	434.227	433.044	434.227
433.040	434.435	433.293	434.435

The results showed that an even greater variety of frequencies now emerge around the "base" frequency. Even so, the first torsional mode shape still provided good local damage indicators.

5.4 Conclusions

The following important aspects were observed:

- Even structures such as the experimental fan blade damage simulator that consists of a very rigid (relative to the blades), inner structure still show a predominantly global dynamic behaviour.
- Global modes provide global damage indicators of structure. This means that the shift of frequency may be smaller than predicted due to the fact that the damage was less relative to the whole structure, than predicted by a local modal.
- Local mode shapes could still be found, it seemed as though torsional mode shapes tended to be more local in nature.
- It will be necessary to do extended FEA on a global structure, in conjunction with preliminary measurements of the FD fan at Majuba, to choose a mode that will provide accurate damage classification.
- By using pattern recognition techniques such as neural networks this complex interaction between the blades may emerge as good features for damage level detection.
- The interaction between different blades may also be used to reduce the required number of sensors to less than one per blade.