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Cyclic Life Establishment of First Stage Compressor Blade - Aircraft Jet Engine

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ABSTRACT
In this project an attempt is made to identify the cyclic life, modal efficacies for assessing the life that is declared by the Original Engine Manufacturer. Using the Goodman diagram and knowing the mean stress of the blade for all rpm conditions.
Keywords **-** Blade Performance, Compressor Blade, Cyclic Life, Designing , Fatigue, Good man diagram , Reverse engineering, S-n curve.

I. INTRODUCTION

In this project, the first stage compressor rotor blade of an existing fighter class engine is taken for the design analysis so that it gives an insight regarding design of a compressor rotor blade. In order to model the blade for the purpose of analysis, the manufacturing drawings supplied by OEM (Original Engine Manufacturers) are used to obtain the major dimensions, co-ordinates of the profile, dimensions of the root etc., and wherever the dimensions are having a shortcoming, the existing hardware is used and checked & incorporated for the non-available data.

The modeling of the blade is done in CATIA V5 and the analysis is done using ANSYS 12.1. As usual for the purpose of the analysis, is required material properties like Young's modulus, density, Poisson's ratio are used for this purpose that are obtained from the open literature in respect of this material. The rotor blade is the rotating component and therefore it has to be analysed for its vibratory modal values so that it gives a fair idea of the frequency of the harmonics of the blade intersecting with engine orders. In totality it has been identified a cyclic life (Zero-Max-Zero) using Goodman diagram and S-N diagram, and Campbell diagram is used for identifying the crossovers, so that an understanding is possible as far as the functionality aspects of the blade. It is also contemplated to do a few simulations of the defects, which are commonly encountered in a gas turbine engine during its operation. An attempt is also made to go into a simple modification and its efficacies in terms of life, vibrational modes and overall pressure ratio improvements etc.

II. MODELING

For the modeling purpose and in order to get accurate results when importing to the analysis, the compressor first stage rotor blade is divided into eleven sections after plotting the co-ordinates in the sketching for all eleven sections.

The hardware of the blade is available and hence the blade is used for a reverse engineering process. It is to be noted that in this case the tolerance of the blade may not be available for the simple reason that this blade could have been reworked either in-situ at operating units or at the overall unit for removal of undesirable discontinuities. Therefore the blades and its co-ordinates per se would only give a limited input as far as the design outputs are concerned.

Each section is then integrated along with its adjoining sections till the root portion. The root portion is separately modeled and stitched to the profile as per the boundary conditions available in the drawing. Modeling of the blade normally is done using CAD packages which can be easily ported to the analysis packages.

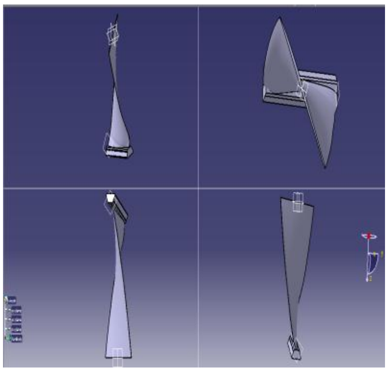
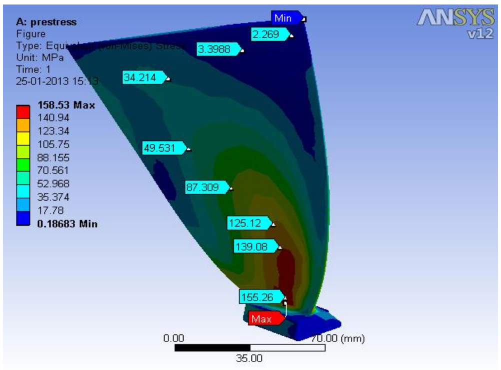


Fig 1.1 Actual compressor rotor blade

III. ANALYSIS OF THE PROBLEM

To initiate solution calculations, use **ANSYS Main Menu and** selecting **Solution → Solve → Current LS**. After reviewing the summary information about the model, click **OK** button to start the solution. When this command is issued, the

ANSYS program takes model and loading information from the database and calculates the results. Results are written to the results file and also to the database. The only difference is that only one set of results can reside in the database at one time, while a number of result sets can be written to the results file. Once the solution has been calculated, the ANSYS postprocessors can be used to review the results.



And the stress values for various rpm are tabulated in Table 2.1 and bending and the torsional frequencies for 10000 rpm for the post mod blade is shown in the above as Fig 2.1 and its values for various rpm are tabulated in Table 2.2.

σ_{mean} Values	10,000 rpm	16.7 kg/mm2
	9,600 rpm	15.3 kg/mm2
	8,500 rpm	14.6 kg/mm2
	4,200 rpm	13.9 kg/mm2

Tab. 2.1 Stress value for pre mod

RPM	MODES	BENDING FREQUENCY (Hz)	TORSION FREQUENCY (Hz)
4200	1	196.75	1462.2
	2	598.65	1948.1
	3	1106.3	2273.8
	4	1490.6	3047.6
8500	1	208.61	1465.2
	2	605.97	1950.7
	3	1096.6	2276.4
	4	1490.7	3045.8
9600	1	212.82	1466.2
	2	610.23	1951.6
	3	1097.08	2277.4
	4	1496	3045.1
10000	1	215.05	1466.6
	2	612.52	1951.9
	3	1098.4	2277.7
	4	1498.9	3044.8
11260	1	222.57	1468
	2	624.29	1953.2
	3	1113.1	2279
	4	1522.3	3043.9
11460	1	223.54	1468.2
	2	625.33	1953.4
	3	1113.4	2279.2
	4	1523.6	3043.8

Tab 2.2 Values for bending and torsional mode for pre mod blade

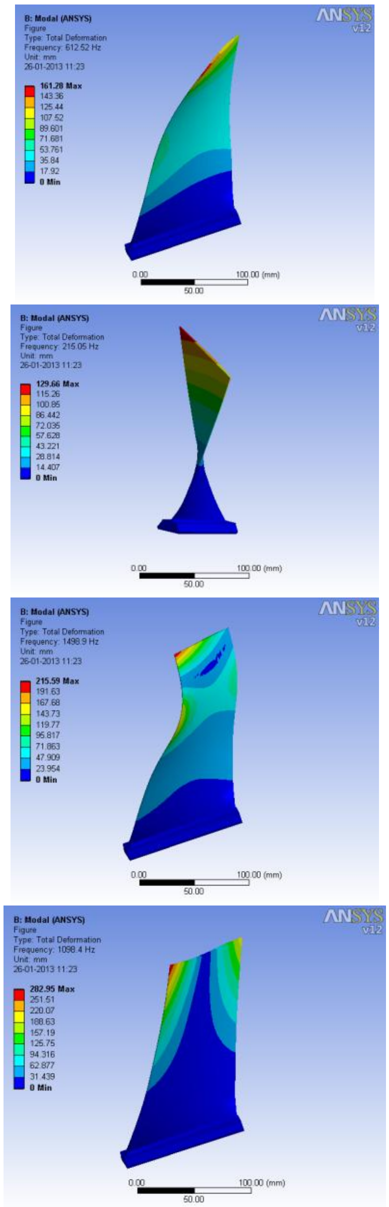
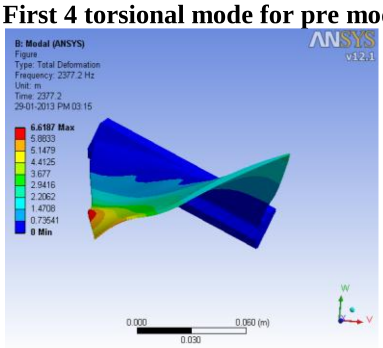


Fig 2.1 First 4 torsional mode for pre mod blade



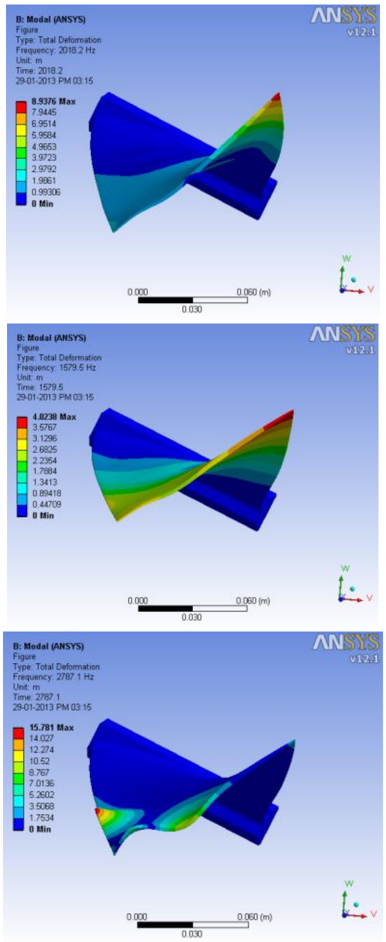


Fig2.2 First 4 torsional mode for pre mod blade

IV. CYCLIC LIFE ANALYSIS

A conventional and normal methodology is by bringing out the cycle under various categories like zero-max-zero, idle-max-idle, 90%-max-90% etc., and these are tabulated to reach an appropriate equivalent zero-max-zero stress cycles. This procedure however is called as the evaluation methodology to arrive at the cyclic life of a component, while doing so zero-max-zero is coined as' A', idle-max-idle is coined as 'B', and 90%-max-90% as 'C', and the following relation is used to evaluate the equivalent LCF cycle.

$$\textbf{Equivalent LCF cycle} = A + \frac{B}{4} + \frac{C}{40}$$

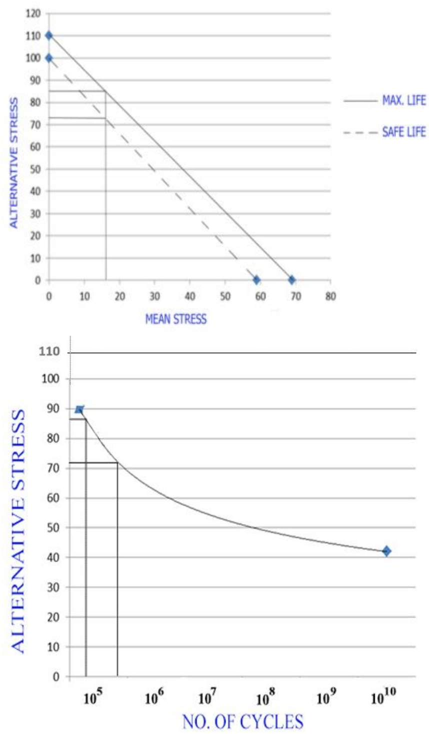
Components which are subjected to cyclic loads encounter both mean and alternating cycles, two standard curves evolved from the mechanical properties of the material are used to assess the cyclic life. The nomenclatures of these curves are as follows

1. S-N diagram

It could be seen that the S-N curve consists of alternating stress on y-axis and number of cycles on the x-axis. This curve is having a major discrepancy in the sense whether the curve is drawn based upon nominal values or "MINUS 3σ" of which the latter is having a major approval from the industries generating and utilizing it. When it is said that "MINUS 3σ" values are to be used for the calculation purpose of cyclic life, it is imperative that the specimens are to be drawn from the component only, so that a desirable consistency is possible.

V. Modified Goodman diagram

On the same line the Good man diagram is drawn with y axis having alternating stresses whose maximum is governed by the U.T.S of the material and for the mean the yield point is taken as a maximum value a combination of $\sigma_{alternative}$ and σ_{mean} of the component and to avoid failure the point should lie within the triangle formed for that material. It is indeed to draw a line at 45° from the origin intersecting the hypotenuse which in turn gives the design operating combination of $\sigma_{max}$and $\sigma_{alternative}$.



Graph 4.1 S-N surve and Goodman diagram

The point that is obtained from the operating component gives the mean stress value which when projected on the hypotenuse can give the magnitude of the alternating stress for the given mean stress. Aligning the S-N curve with Goodman diagram can give an estimate of no of cycles that a component can with stand depending upon the intercept of the alternating stress on the SN curve.

This method is otherwise called as a Graphical method arrival of stress based cyclic evaluated.

Since the component is only encountering slightly more than the ambient temperature the temperature effect on the component is safely neglected. Thus the cyclic life is obtained for a component is calculated, which is fitted on the gas turbine engine of the aircraft.

VI. ESTIMATION OF EQUIVALENT LCF CYCLE

A **flight recorder** is an electronic recording device placed in an aircraft for the purpose of facilitating the performance of an aircraft after each sortie and a typical FDR plot be shown in Fig 4.1. Besides this is also an aid for aircraft accident and incident investigations.

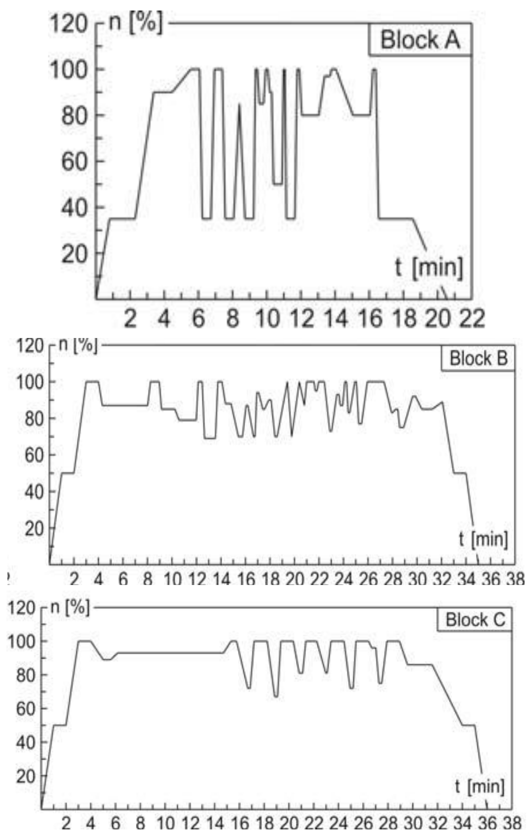


Fig 5.1 Flight data for typical fighter class aero engine Block A-B-C

For this reason, flight data recorders (FDR) are required to be capable of surviving the conditions likely to be encountered in a severe aircraft accident. FDR devices are placed onboard on aircrafts that stores the history of several parameters such as aircraft position, velocity, fuel flow rate, ambient and engine RPM temperature and so on. A total of approx. 105 parameters are available in the dataset, of which the ones primary interest to us are the fuel flow rate, throttle setting, velocity, position (latitude/longitude), ambient temperature, fan speed etc.

Equivalent LCF cycles is calculated using the above plotted blocks of rotation frequency of first stage low pressure compressor rotor where, as already mentioned ‘A’ represents zero-max-zero, ‘B’ represents Idle-max-Idle and ‘C’ represents 90%-max- 90%. And these are used in the relation (Equivalent LCF cycle) and these are used in the relation for each blocks as shown below.

Equivalent LCF cycle = A + $\frac{B}{4}+\frac{C}{40}$

From Block A:
A=1
B=1+1+1=3
C=1+1+1=3

Equivalent LCF cycle $= 1 + \frac{3}{4}+\frac{3}{40}$
= 5.36 cycles/hour

And in the Block A the cold end component will have 1300 hrs as the operational life.

From Block B:
A=1
B=1
C=1+1+1+1+1+1+1=7

Equivalent LCF cycle $= 1 + \frac{1}{4}+$=1.475 cycles for35 minutes = 2.528 cycles/hour

And in the Block B the cold end component will have 2700 hrs as the operational life.

From Block C:
A=1
B=1
C=1+1+1+1+1+1+1+1=8

Equivalent LCF cycle $= 1 + \frac{1}{4}+\frac{8}{40}$
=2.417 cycles/hour

And in the Block C the cold end component will have 2900 hrs as the operational life.

VII. CONCLUSION

The first stage compressor rotor blade of fighter aircraft class engine has been analysed for its mean stress, alternating stress and engine cross over frequencies. This attempt is repeated for all the operating rpm conditions which are identified as sensible rpm's. Knowing this it is possible to extract the cyclic life of the blade and it was identified that this blade is having infinite life although the failure mode for the rotor blades is normally high cycle fatigue.

The gas turbine engines meant for fighter class aircraft undergo major manoeuvres and hence the critical components of the engine also encounter variable higher stresses during engine operation. In this project an attempt is made to evaluate the following:

1. Mean stresses at the blade at various rpm conditions.
2. Alternating stresses at various rpm conditions.
3. Modal frequencies of the blade due to bending and its harmonics.
4. Modal frequencies of the blade for its torsional mode and its harmonics.

The above exercises carried out during the project served as a eye opener towards abinitio design of the blade in respect of axial flow compressors meant for fighter class application.

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