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# FLUTTER AND FORCED RESPONSE ANALYSIS OF CENTRIFUGAL COMPRESSOR

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**Abstract**: In the modern turbomachinery design trend, blades are getting more and more flexible and loaded, and therefore prone to vibration issues due to forced response and flutter phenomena. a. It has always been important to study the development and improvement of the design of turbomachine, owing to the numerous uses of turbo machining and their high energy consumption, high performance of centrifugal compressor call for a reduction in weight to relax rotor dynamic constraints and a reduction in blade thickness as a way to improve the efficiency. This project we are focused on increasing the efficiencies, reducing the pressure loss by keeping the larger splitter blades and the enhancement of the surge characteristics and the back sweep of the blade will reduce the stall in the compressors will leads to increase the efficiency and the long operating range and this statement can be proved by conducting the forced response analysis on the compressor blades.

**Keywords**: compressor blade, flutter, surge characteristics, forced response.

## I. INTRODUCTION

### A. COMPRESSOR

A compressor is a mechanical device that increases the pressure of a gas by reducing its volume. An air compressor is a specific type of gas compressor. Compressors are similar to pumps: both increase the pressure on a fluid and both can transport the fluid through a pipe. The main distinction is that the focus of a compressor is to change the density or volume of the fluid, which is mostly only achievable on gases. Gases are compressible, while liquids are relatively incompressible, so compressors are rarely used for liquids. The main action of a pump is to pressurize and transport liquids.

Many compressors can be staged, that is, the fluid is compressed several times in steps or stages, to increase discharge pressure. Often, the second stage is physically smaller than the primary stage, to accommodate the already compressed gas without reducing its pressure. Each stage further compresses the gas and increases its pressure and also temperature (if inter cooling between stages is not used).

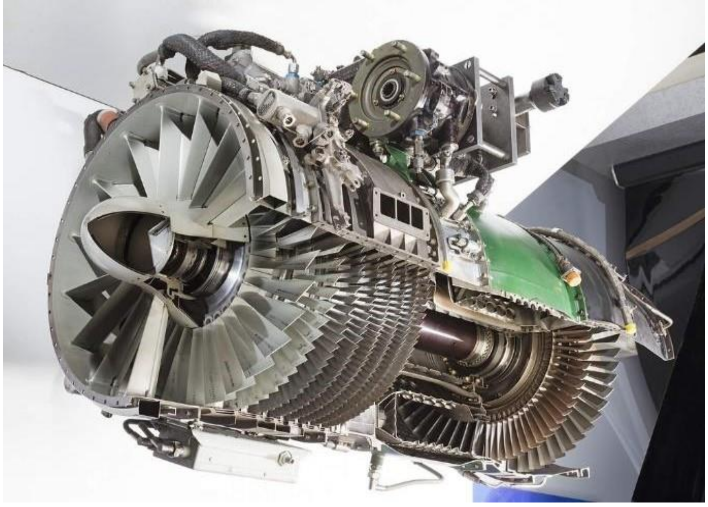

Fig. 1 Compressor

### B. CENTRIFUGAL COMPRESSOR

Centrifugal compressors are the largest available compressors, offer higher efficiencies under partial loads, may be oil-free when using air or magnetic bearings which increases the heat transfer coefficient in evaporators and condensers, weigh up to 90% less and occupy 50% less space than reciprocating compressors, are reliable and cost less to maintain since less components are exposed to wear, and only generate minimal vibration. But, their initial cost is higher, require highly precise CNC machining, the impeller needs to rotate at high speeds making small compressors impractical, and surging becomes more likely. Surging is gas flow reversal, meaning that the gas goes from the discharge to the suction side, which can cause serious damage, specially in the compressor bearings and its drive shaft. It is caused by a pressure on the discharge side that is higher than the output pressure of the compressor. This can cause gases to flow back and forth between the compressor and whatever is connected to its discharge line, causing oscillations.

Fig. 2 Centrifugal Compressor

### C. AXIAL COMPRESSOR

Axial compressors are dynamic rotating compressors that use arrays of fan-like airfoils to progressively compress a fluid. They are used where high flow rates or a compact design are required. The arrays of airfoils are set in rows, usually as pairs: one rotating and one stationary. The rotating airfoils, also known as blades or rotors, accelerate the fluid. The stationary airfoils, also known as stators or vanes, decelerate and redirect the flow direction of the fluid, preparing it for the rotor blades of the next stage. Axial compressors are almost always multi-staged, with the cross-sectional area of the gas passage diminishing along the compressor to maintain an optimum axial Mach number.

Fig. 3 Axial Compressor

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## D. EXISTING CENTRIFUGAL COMPRESSOR

The Rolls-Royce RB.41 Nene is a 1940s British centrifugal compressor turbojet engine. The Nene was a complete redesign, rather than a scaled-up Rolls-Royce Derwent,[1] with a design target of 5,000 lbf (22 kN), making it the most powerful engine of its era. First run in 1944, it was Rolls-Royce's third jet engine to enter production, and first ran less than 6 months from the start of design. It was named after the River Nene in keeping with the company's tradition of naming its jet engines after rivers.

The design saw relatively little use in British aircraft designs, being passed over in favour of the axial-flow Avon that followed it. Its only widespread use in the UK was in the Hawker Sea Hawk and the Supermarine Attacker. In the US it was built under licence as the Pratt & Whitney J42, and it powered the Grumman F9F Panther. Its most widespread use was in the form of the Klimov VK-1, a reverse-engineered, modified and enlarged version which produced around 6,000 lbf (27 kN) of thrust, and powered the Russian built Mikoyan-Gurevich MiG-15, a highly successful fighter aircraft which was produced in vast numbers. An upgraded version of the Nene was produced as the Rolls-Royce Tay.

Fig. 4 Rolls Royce NENE Engine

The Nene was based on the "straight-through" version of the basic whittle -style layout, with the flow going directly through the engine from front to rear, as opposed to a "reverse-flow" type, which reverses the direction of air flow through the combustor section so that the turbine stage can be mounted within the combustor section; this allows for a more compact engine, but increases the combustor pressure losses which has an adverse effect on engine performance. Less thrust is generated with the same fuel flow.

The Nene doubled the thrust of the earlier generation engines, with early versions providing about 5,000 lbf (22.2 kN), but remained generally similar in most ways. This should have suggested that it would be widely used in various designs, but the Gloster Meteor proved so successful with its Derwents that the Air Ministry felt there was no pressing need to improve upon it. Instead a series of much more capable designs using the Rolls-Royce Avon were studied, and the Nene generally languished.

A total of twenty-five Nenes were sold to the Soviet Union as a gesture of goodwill - with reservation to not use for military purposes - with the agreement of Stafford Cripps. Rolls-Royce were given permission in September 1946 to sell 10 Nene engines to the USSR, and in March 1947 to sell a further 15. The price was fixed under a commercial contract. A total of 55 jet engines were sold to the Soviets in 1947.[13][14] Seventeen Soviet engineers trained at the Rolls-Royce factory in Derby in 1947 to maintain and repair the engine. The Soviets reneged on the promise to not use it for military purposes,[14] and reverse engineered the Nene to develop the Klimov RD-45, and a larger version, the Klimov VK-1, which soon appeared in various Soviet fighters including Mikoyan-Gurevich MiG-15

## II. LITERATURE REVIEW

A. **Aeroelastic Investigation of a Transonic Compressor Rotor with Multi-Row Effects** by Pietro Barrecaa[1], Lorenzo Pinellia, Federico Vantia, Andrea Arnonea, a Department of Industrial Engineering, Università degli Studi di Firenze, Via di Santa Marta 3, 50139 Firenze, Italy.

In this paper focused on the flutter results are presented for single and multi-row environment. Blades are getting more and more flexible loaded and therefore prone to vibration issues due to forced response and flutter phenomenon. For this reason, the flutter stability assessment has become a key aspect to avoid high cycle fatigue blade failures. The aim of this paper is to numerically evaluate the influence of CFD aeroelastic and modal analyses have been carried out for one and half compressor stage in transonic conditions. In the paper two different flutter analysis approaches have been used to asses flutter stability.

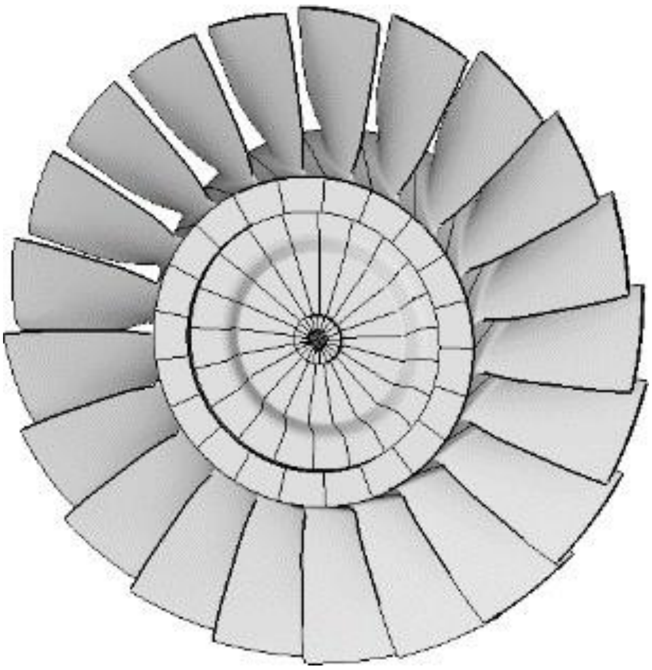


Fig. 5 Rotor Disk

Flutter results for single-row configuration and then for a multi row model which includes rotor/stator unsteady interactions: a good agreement with measured data is shown both cases and also a no negligible impact of rotor blades can be observed.

B. **Forced Response Predictions in Modern Centrifugal Compressor Design** by Caitlin J. Smythe B.S. (Aerospace Engineering) University of California, San Diego.

A computational interrogation of the time-averaged and time-unsteady flow fields of two centrifugal compressors of nearly identical design (the enhanced, which encountered aeromechanical difficulty, and production, which did not encounter any such difficulty) is undertaken in an effort to establish a causal link between impeller-diffuser interactions and the forced response behavior of the impeller blades. Through comparison of timeaveraged flow variable and performance estimates with test rig data, the three dimensional, unsteady, Reynolds-averaged Navier-Stokes flow solver (MSU Turbo) used in this interrogation is found to be adequate to the task of distinguishing the flow fields of the two centrifugal compressor designs.

A computational interrogation of the time-averaged and time-unsteady flow fields of two centrifugal compressors of nearly identical design has been undertaken in an effort to establish a causal link between impeller-diffuser interaction and the forced response behavior of the impeller blades. In this chapter, the contributions are outlined and the results are summarized. A hypothesis is then put forth regarding the causal link between impeller-diffuser interactions and aeromechanical difficulties. Finally, recommendations for future study are delineated.

C. **CFD investigation of flow through a centrifugal compressor diffuser with splitter blades** by M. G. Khalafallah, H. S. Saleh, S. M. Ali and H. M. Abdelkhalek.

This paper is about the aerodynamic losses in centrifugal compressor are mainly associated with the separated flow on the suction sides of impeller and diffuser vanes. The overall performance of such compressor can be improved by adding splitter vanes. By increasing the flow area, the velocity is reduced and the static pressure is increased. Changing the mean flow path radius with guide vanes, which reduces the radial and tangential velocity of the flow increasing the static pressure.

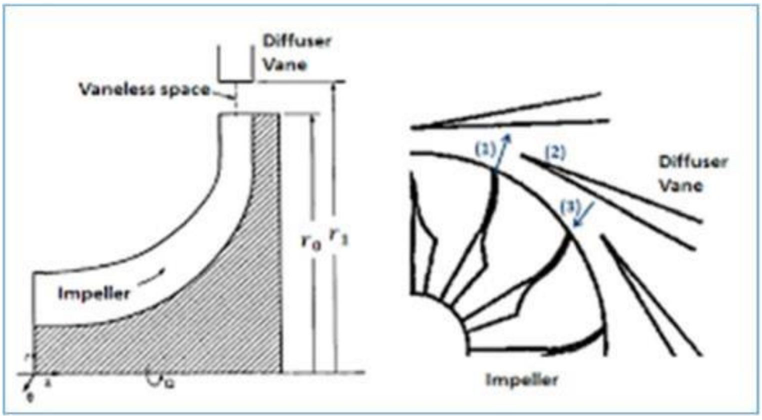


Fig. 6 Vaneless and Vaned Diffuser

So, the flow entering the diffuser is unsteady and distorted, with a large quantity of kinetic energy to be converted to static pressure increase, especially for high-speed compressors. As a result, the diffuser is sandwiched between two extremely complex flow components, both of which have an impact on its flow field and performance. The diffuser's design might have a negative impact on the compressor's overall efficiency. So, it is critical for the designer to understand the impact of various factors on the flow through the compressor in order to design an efficient compressor. In general, providing splitter vanes in the diffuser at chosen location, tends to improve the performance of the centrifugal compressor in terms of high static pressure recovery co efficient and reduce the total pressure loss co efficient.

D. **Effects of Airflow Deflection Angle in Diffuser on Forced Response Caused by Impeller-diffuser Interaction in Centrifugal Compressors** by Sun Penga, Wang Yanrong and Zhang Xiaobo, School of Energy and Power Engineering, Beihang University, China 2 Collaborative Innovation Center for Advanced Aero-Engine, China.

Aeroelasticity has always been a significant issue of compressors. Impeller-diffuser interaction (IDI) produces periodic aerodynamic excitation which forces the blades to vibrate in centrifugal compressors, and eventually causes the damage of blades. Therefore, it is of great importance to investigate the IDI in centrifugal compressors and the effects on the vibration of blades. In this paper, it is discussed in detail that the deflection angle of the airflow in diffuser affects the IDI of the centrifugal compressor and the vibration of blades. Compared with the parameters of axial compressors, the rotating speed of centrifugal compressors is much higher and the blades are slighter, which results in a much larger stress of blades.

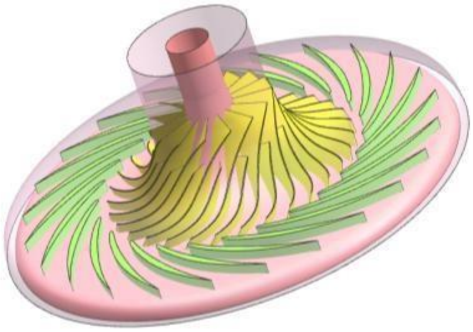


Fig. 7 Model of centrifugal compressor

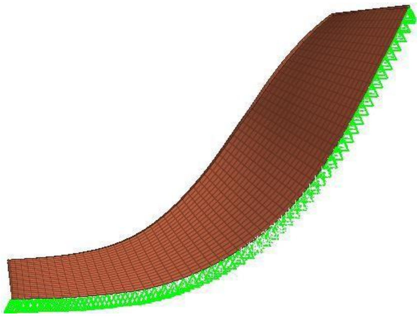
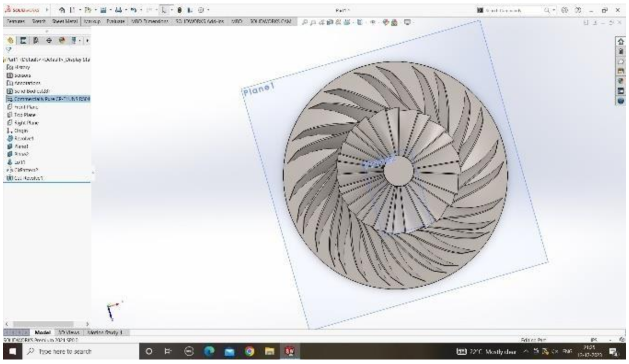
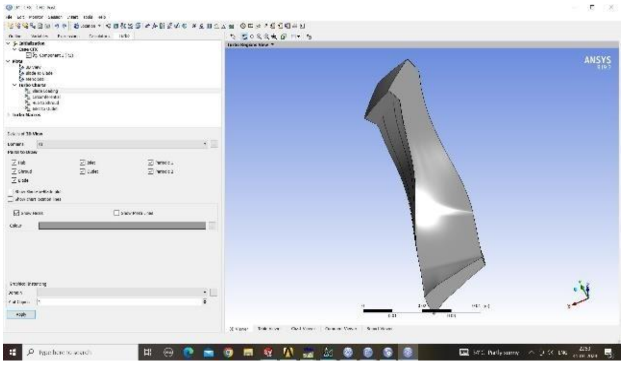


Fig. 8 Finite element model of main blade

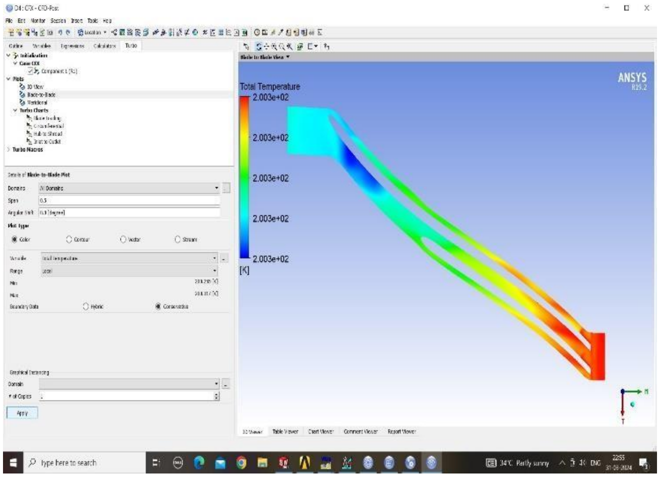
If blades vibrate due to aeroelastic problems during the operation of compressor, especially when resonance occurs, fatigue cracks may appear on blades, resulting in high-cycle fatigue (HCF) problems and the damage of blades. The results show that if deflection angle is positive, the interaction of the diffuser on impeller and the vibration of main blades are decreased. According to the simulation of flow field of a centrifugal compressor and transient analysis of blades, the effects of deflection angle of the airflow in diffuser on the vibration of main blades caused by IDI is clarified. On condition that deflection angle is excessive, pressure fluctuation amplitude increases considerably.

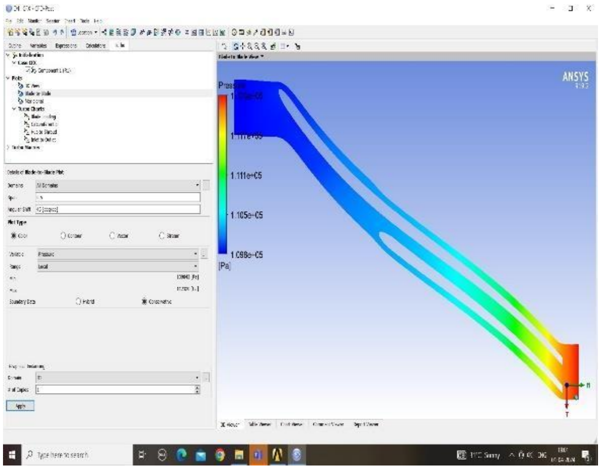
## A. DESIGN OF CENTRIFUGAL COMPRESSOR



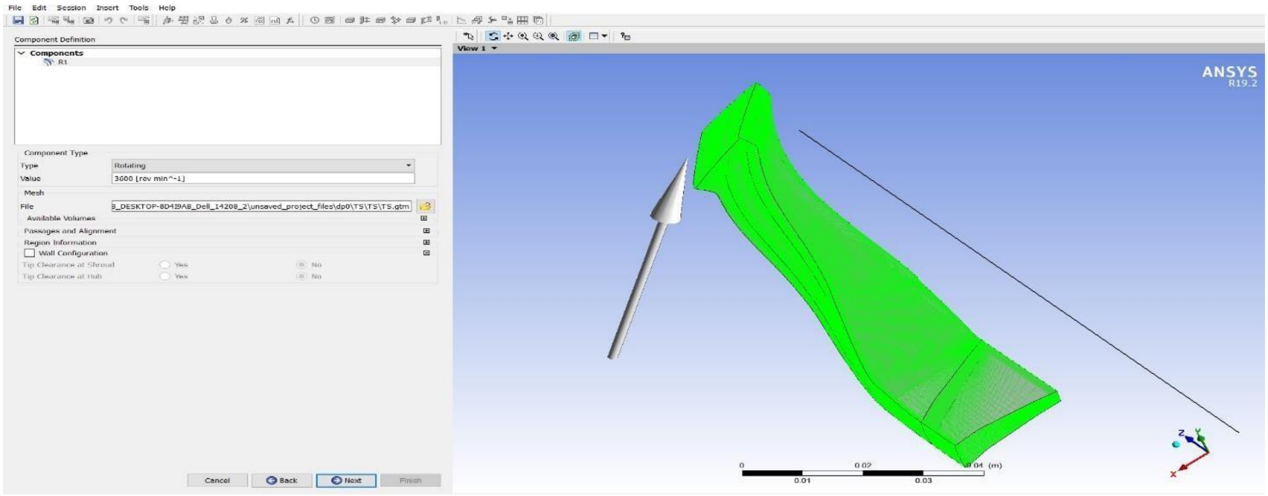


## B. PRESSURE AND TEMPERATURE ANALYSIS OF CENTRIFUGAL COMPRESSOR





## C. MESHING



Component Definition

Components
R1

Component Type
Type: Rotating
Value: 3600 [rev min^-1]

Mesh
File: 3_DESKTOP-8D4I9A8_Dell_14208_2\unsaved_project_files\dp0\TS\TS\TS.gtm
Available Volumes
Passages and Alignment
Region Information
☐ Wall Configuration
Tip Clearance at Shroud ○ Yes ● No
Tip Clearance at Hub ○ Yes ● No

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## III. CONCLUSION

In conclusion, it has always been important to study the development and improvement of the design of turbomachine, owing to the numerous uses of turbo machining and their high energy consumption, and high performance of centrifugal compressor call for a reduction in blade thickness as a way to improve efficiency. This results of an investigation of blade vibration on a high, pressure ratio/high mass flow of centrifugal compressor with thin blades were described. Results of blade vibration measurement are presented for constant rotational speed and various mass flow rates with characteristics stall effect in the impeller inlet tip region resulting in impeller blade excitation.

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