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Experimental study of flow through compressor Cascade

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ABSTRACT

The objective of this research work is to study the behaviour of flow at the inlet, within the blade passage and at the exit of a compressor cascade. For this purpose, a cascade with six numbers of aerofoil blades was designed and constructed. The cascade was fitted on the cascade test tunnel. Out of six blades two were instrumented for measuring the pressure distribution on the pressure and suction surface. The blades had a parabolic camber line, with a maximum camber position at 40% of the chord from the leading edge of the blade. The profile of the blade was C4, height of the blade was 160 mm, chord length was 80 mm, camber angle was 45° and stagger angle was 30°. Similarly, the length of the cascade was 300 mm, span was 160 mm, pitch was 60 mm, the actual chord of the cascade was 80 mm, the axial chord of the cascade was 70 mm, the stagger angle of the cascade was 30° and the pitch-chord ratio was 0.75. The data was taken and analyzed at −500% of the axial chord before the cascade, −25% of the axial chord before the leading edge, 25%, 50%, 75% and 150% of the axial chord from the leading edge of the blade. The readings were taken from the cascade wall to the mid span position along the pitch wise direction. The angle of incidence was also changed during the experiment and varied from $i = -50°, -30°, -10°$ to 5°.

1. Introduction

The effectiveness of jet engines has been halved during the last thirty years, thanks in part to more effective turbine and compressor blade design methods [1]. These methods were improved by experimental verification. Experience shows that experiments are indispensable especially in the region of transonic flow in which there is great interest today. The quasi-two-dimensional flow through compressor or turbine blading can be simulated by the flow through a plane CASCADE, i.e., by a row of blades having identical shapes and constant spacing along the blade height [1]. The cascade is used to divert a flow stream with an account of minimal loss. The turbine usually shows tolerance to the blade design and alignment errors because the blades of a turbine stage perform under a favorable pressure gradient while compressor blades are prone to aerodynamic losses because these have to work under adverse pressure gradients due to the diffusing nature of the flow field [2]. The blades of an axial compressor and axial turbine have high solidity which makes the flow structure in these machines highly complex as the flow around each blade is affected by the presence of the adjacent blades. These blades are therefore said to form a cascade [2,3]. The pressure ratio developed by a cascade depends on its aerodynamic characteristics. There are various types of shapes used in compressor blading. These range from the NACA series [4,5], C series, and DCA series. The aerodynamic parameters for compressor blades are camber, solidity, camber line shapes and thickness chord ratio. The peculiar geometry of their blades causes the flow to be three dimensional. The passage flow in

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Nomenclature

Re	Reynolds Number
Ma	Mach Number
S	Blade Pitch
l	Blade Chord (Actual Chord of Blade)
h	Blade Height
t	Blade Thickness
e	Axial Chord of Blade
C_P	Static Pressure Coefficient
NACA	National Advisory Committee for Aeronautics
DCA	Double Circular Arc

Greek symbols

α	Air Angle
β	Blade Angle
ν	Stagger Angle
θ	Camber Angle
i	Angle of incidence
δ	Deviation
$\in$	Fluid Deflection

these machines is entirely affected by pressure gradient, tip clearance, cross flows, secondary flows, and boundary layer effects [2,6]. Hence, understanding cascade flow is required, which results in systematic improvement of the aerodynamic art for design of these passages.

The heart of the design of an axial turbomachinery is the specification of a blade of an axial turbine or compressor. There have been many attempts to find solutions to these problems. A summary of these works have been discussed by Scholz [7], Roundbash [8], and Gostlow [9]. Compsty [10] has reported the work of Emery and Felix [11] in which it has been suggested that the shape of a compressor blade has an insignificant effect on its performance at low Mach numbers. Their tests on C4 and NACA65 series cascades revealed the same results. In another study, the flow development in S shaped profiles in a cascade tunnel was studied by Bacur [12]. Andrews [13] reported that the leading edge radius, the camber line shape and thickness chord ratio have a small effect on cascade performance. A detailed investigation of inter-passage flow in a baseline and modified versions of a two-stage axial compressor was carried out by Serovy et al. [14] and similarities in their aerodynamic performance was observed. In another study, Harrvey and Pullen [15] obtained a loading parameter for an axial flow turbine cascade by an accounting sweep of the blade. They did a validation of results with the experimental data of linear cascade tests of low pressure ratio axial turbines. Barrows et al. [16] tested cascades of varying aspect ratios between 1.5 and 3. Results of an off design performance of a turbine cascade at its mid span with varying Reynolds numbers, Mach numbers, and incidences were also studied by Mustaphe et al. [17]. Yamsaki et al. [18] developed a CFD code to compute unsteady aerodynamic forces on a vibrating annular cascade. They compared it with the linearized theory and they found the two to be almost similar. In another study, Basharat [2] constructed and tested an axial flat plate cascade for evaluating its aerodynamic performance. In his study, he found that the Reynolds number, incidence and blade angle of the cascade control the aerodynamic performance of the axial cascade. He also studied the variation of free stream velocity in the cascade tunnel, the variation of the angle of incidence with the blade angle, the variation of deviation angle, the variation of deflection angle, the variation of total pressure loss coefficient, the variation of static pressure rise coefficient, the variation of lift coefficient, and the variation of drag coefficient with blade angle and angle of incidence.

2. Experimental study

In this section, the experimental details are provided through the experimental set-up, air supply unit, inlet section, cascade blades, instrumentation of blade, cascade, and pressure probes.

2.1. Experimental set-up

The object is to study the behaviour of flow at the inlet, within the blade passage and at the exit of the compressor cascade. For this purpose, the flow is required to be surveyed at the inlet, within the blade passage and at the exit of the compressor cascade. To carry out systematic studies, a test rig was designed and fabricated. The schematic of experimental set up is shown in Fig. 1 and the picture of the experimental set up is shown in Fig. 2(A).

2.2. Air supply unit

The working fluid through the unit was air. A relatively large mass flow rate of air with pressure of few mm of water gauge was needed. A 2900 RPM blower was used to create such a flow. For the experimental a purpose blower with a cascade tunnel was used, after dismantling the cascade for experimentation. An impeller with backward curved vane, having suction pipe of diameter 270 mm and a discharge pipe of diameter 250 mm, was used. Flow control was achieved by a butterfly valve installed at the suction duct of the blower. For this experiment, the blower was operated at full throttle condition.

2.3. Inlet section

The uniform flow was to be achieved at the cascade inlet. This was done by using a settling chamber and contraction cone. The settling chamber was a rectangular tank into which the blower discharged the air. The contraction cone was used to make a uniform flow with minimum boundary layer effect. Both the contraction cone and setting chamber were fabricated from a M.S. (Mild Steel)