Proceedings of the International Conference on Aerospace Science and Technology
26 - 28 June 2008, Bangalore, India

INCAST 2008-005

Design and Evaluation of a Controlled Diffusion Aerofoil Blade for a LP Compressor Stator

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ABSTRACT: A methodology based on geometric construction of CDA profiles and CFD flow simulation has been used to design a stator blade of a 3-stage LP compressor. The designed CDA blade is shown to perform better in terms of efficiency, pressure ratio and stall margin of the compressor compared to the original MCA blade.

1. INTRODUCTION

The gas turbine engine, which is being developed by Gas Turbine Research Establishment (GTRE) Bangalore, has a 3-stage transonic LP Compressor. This compressor has conventional multiple-circular arc sections for both rotor and stator blades. As a part of continuous effort to push the performance of the compressor to higher efficiency and better stall margin, various improvement strategies are being explored. One of the strategies to be considered is the replacement of present stator blade design by controlled diffusion aerofoil (CDA) design. As a first step, it was decided to redesign the 3rd stage stator with a CDA blade as this stator was found to be prone to early stall due to boundary layer separation at the hub. It is expected that by controlling the diffusion on the suction surface of the aerofoil as is the case in CDA design, significant flow separation can be avoided over a wide range of inlet Mach number, resulting in lower losses and wider incidence range for critical Mach number

Propulsion Division, National Aerospace Laboratories (NAL) Bangalore, has acquired the capability to design compressor blade sections with CD aerofoils and evaluate their performance both analytically and experimentally [1]. The methodology that we have adopted is based on a heuristic graphical approach. It is an interesting approach revealed in a US patent specification by Lubenstein et.al. [2] which is now available in open literature. In this approach, the desired profile is generated using a flexible camber line and a specified thickness distribution. The method is essentially a graphical one, and does not reveal how the desired objectives are attained. Anbarasu and Pai [3] have converted this graphical method into a computer program (CDA profile generator), which has been used to carry out research in the area of controlled diffusion aerofoil in NAL in the past. This program has been used to generate the blade sections of the 3rd stage stator of the LP compressor of GTRE under the geometrical and flow constraints prevalent in the current configuration as the new blade is expected to be a retrofit design.

2. METHODOLOGY

The inputs for the CDA profile generator program are chord, pitch, maximum thickness, inlet and exit blade angle. The inlet blade angle is obtained from prescribe inlet flow angle and assumed incidence angle, while the exit blade angle is obtained from prescribed exit flow angle and estimated flow deviation from Carter's rule. The program constructs a mean camber line, establishes the thickness distribution about the chord line and fits the thickness distribution over the camber line so as to form the suction and pressure surfaces. The output of the program is the CDA profile section with stagger, camber and, leading and trailing edge radii. A number of profiles were generated for different inlet blade angle i.e. by assuming different incidence angles, keeping other parameters as prescribed. The optimum profile was selected by carrying out 2-D Navier-Stokes flow calculation on these profiles and choosing the profile giving the lowest peak surface Mach number and, acceptable losses and flow deviation. This exercise was repeated for seven sections (hub to tip) of the stator blade under consideration. The new CDA blade so formed was next analyzed for its performance in actual compressor configuration. The original 3rd stage stator MCA blade was replaced by the new CDA blade and complete 3-D multi-stage viscous flow simulation in the LP compressor was carried out employing a commercial CFD code "Tascflow" at GTRE [4]. Computations were made for different pressure ratios and performance characteristics were obtained at design speed. For improving the performance, new incidence angles were selected after careful observation of computed flow fields. In the next iteration cycle, these new incidence angles were used to design the CDA blade again. Three iteration cycles were carried out to obtain 3 different blades (CDA-1, CDA-2 and CDA-3). The design CDA-3 blade showed noticeable improvement in efficiency and stall margin compared to the original MCA blade.

3. RESULTS

As noted above, three design iterations were carried out to arrive at the final CDA-3 blade as a replacement of the original MCA blade for the 3rd stage stator of the LP compressor. We will, therefore, present here some results related to these two blades only. Seven 2-D sections from hub to tip define each blade. Figure 1 shows three such MCA and CDA-3 profiles, which are located at hub (section-1), mid-span (section-4) and tip of the blade (section-7). Figure 2 shows the surface Mach number distribution obtained from 2-D flow simulation at design condition for the three sections. For each case, in general, lower peak value and more gradual variation of Mach number on suction surface for CDA-3 profile can be observed in the figure. Such Mach number distribution may avoid the possibility of flow separation and improve the flow quality in the stator blade. Figure 3 shows the result of 3-D multi-stage simulation of the complete LP compressor in which the original 3rd stage stator blade (MCA) was replaced by CDA-3 blade. Higher pressure ratios and higher choked mass flow along with better efficiency for the configuration with CDA-3 blade suggest improvement in compressor performance.

4. CONCLUSIONS

A methodology based on geometric construction of CDA profiles and CFD flow simulation has been used to design 3rd stage stator of a 3-stage LP compressor. Improvements in efficiency, pressure ratio and stall margin are noticed for the compressor retrofitted with CDA-3 blade as compared to the original MCA blade.

ACKNOWLEDGEMENT

The 3-D multi-stage flow simulation in the compressor was carried out at GTRE by the scientists in Compressor Group of GTRE. The authors are grateful to them for according permission to include their results (Figure 3) in this paper.

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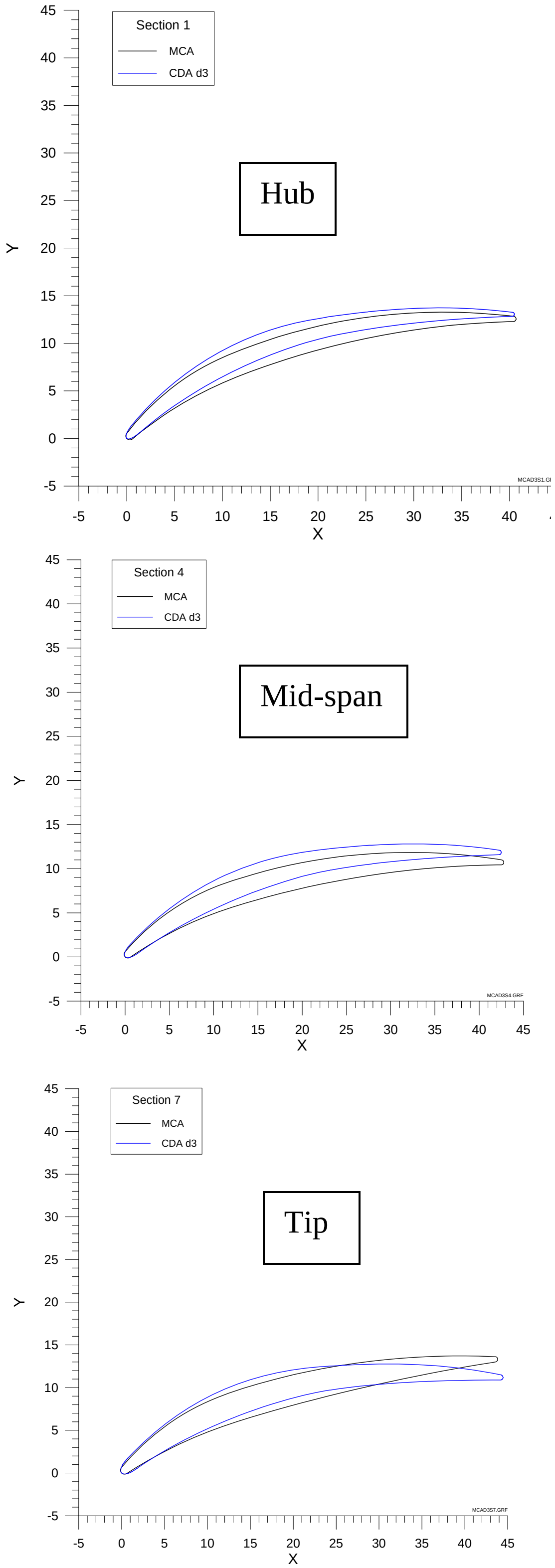


Figure.1. Comparison of MCA and CDA-3 profiles of three sections (hub, mid-span and tip)

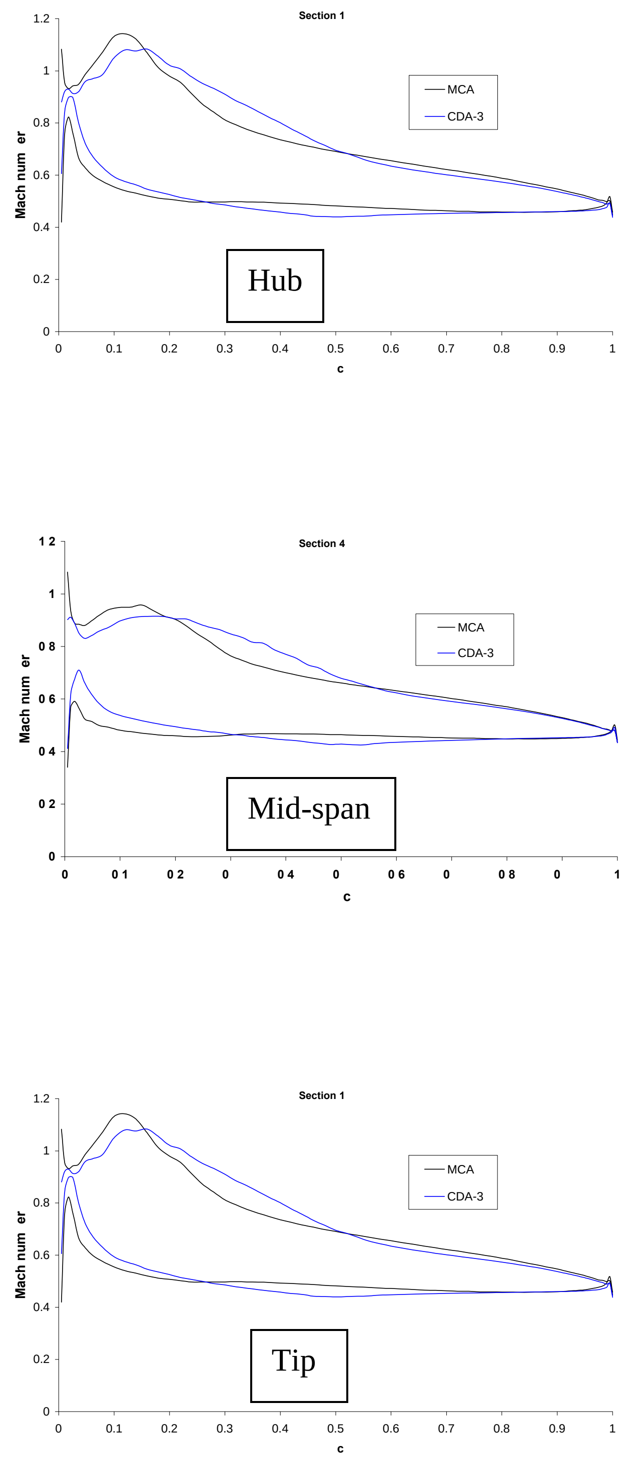
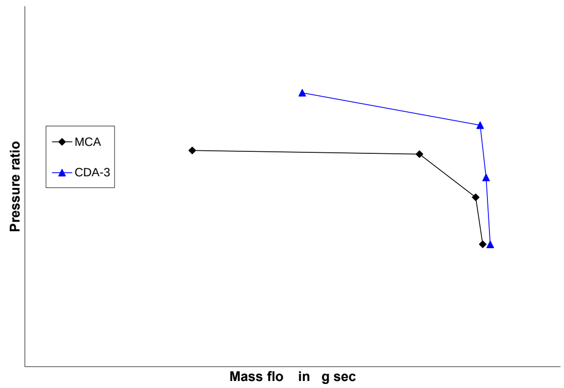
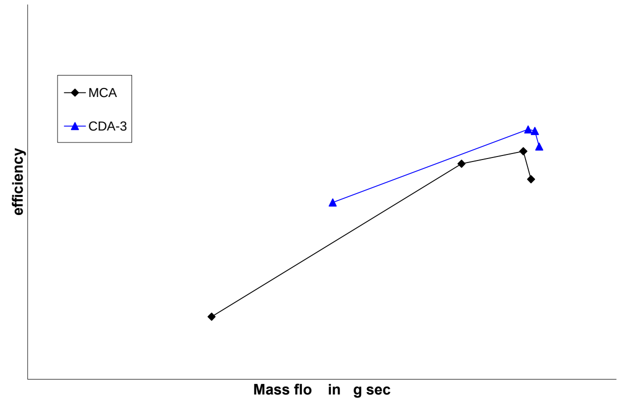


Figure.2. Surface Mach number distribution for MCA and CDA-3 profiles of three sections (hub, mid-span and tip)





(a) Pressure ratio vs. Mass flow

(b) Efficiency vs. Mass flow

Figure.3. Comparison of results for the LP Compressor with different 3rd stage stator blades (MCA and CDA-3) [Ref. 4]