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ORIGINAL ARTICLE

Q1 Numerical study of camber and stagger angle effects on the aerodynamic performance of Q2 tandem-blade cascades

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Abstract Jet engine manufacturers and designers are seeking for lighter and smaller type of axial compressors. Improving the aerodynamic characteristics of blades is carried out by controlling the boundary layer. One way to control the boundary layer is using tandem blades. Tandem-blade cascades are capable of using highly loaded stages for axial compressors because they provide more works than single-blade cascades. In other words, tandem blades help to achieve a specified total pressure ratio with less number of stages. Therefore, one of the most important problems for researchers is to optimize the aerodynamic parameters of tandem blades. Changing the geometrical parameters of blades is a method to achieve this purpose.
In this work, the stagger and camber angle of each blade are first changed while the other geometrical parameters such as overall camber, total stagger angle, the axial overlap, percent pitch and chord ratio are fixed. Secondly, the overall camber angle of tandem blade is changed by increasing the difference between the stagger angle of the first and second blade while the type of two airfoils, axial overlap and percent pitch, overall chord length and overall stagger angle are fixed.
The aerodynamic performances of the generated tandem-blade cascades are obtained using two-dimensional numerical solution of flow. For this, a viscous turbulent flow solver is used for solving the Navier-Stokes equations. In these simulations, inlet Mach number is fixed to 0.6.

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Nomenclature

ABB angle between stagger angle of the first and second blade
AO axial overlap
C chord length
C_L lift coefficient, $C_L = \frac{L_t}{\rho w^2/2 \cdot C_{eff}}$
FB first blade
LE leading edge
Ma Mach number
P pressure
PP percent pitch
SB second blade
S spacing
t vertical spacing between forward blade trailing edge and aft blade leading edge
TE trailing edge
VO vertical overlap
W relative velocity

Greek letters

α inlet flow angle
β gauged incidence angle
$\Delta\beta$ performance range
λ blade stagger angle
θ flow turning angle
φ camber
ψ camber ratio
ξ chord ratio
σ solidity, *C/S*
ω total pressure loss coefficient, $\omega = \frac{P_{t1} - P_{t2}}{\rho w^2/2}$

Subscripts

t total
eff effective
ov overall
11 forward blade inlet station
12 forward blade exit station
21 aft blade inlet station
22 aft blade exit station

1. Introduction

Jet engines have very important role in civil aviation, so that 90% of aircrafts are benefit with them. The efficiency of modern jet engines is improved by increasing turbine inlet temperature accompanied by increasing the total pressure ratio of compressor. Most of manufacturers use multistage axial compressors for heavy-duty gas turbines. Thus, designers are seeking to improve the technical characteristic of these types of compressors. Increasing aerodynamic characteristics helps to find more effective compressor which provide more work with less total pressure loss. It means that designers try to design multi-stage axial compressors with high pressure ratio through fewer stages. Tandem blade configuration is capable of getting more work without high total pressure loss than similar single blade. The main role of tandem blades is to control the blade boundary layer by injecting flow into the boundary layer on the suction surface of the second blade. Tandem blades create a high flow turning angle without separation. Despite this advantages, tandem blades were only used as stator in several commercial engines such as GE J79 [1], an advanced single-stage LP compressor designed by Honeywell [1] and GE MS 7001 EA heavy duty gas turbine [2]. In reference [3], tandem blades were used as rotors just for experimental purposes. It might be because of shortcoming of narrow stability range from design point, as all researchers mentioned.

Therefore, one of the most important research fields in tandem blade is to find configuration which have more stable and wider work range.

Beelte, Staude and Bummert [3,4] were constructed and tested 5-stage axial compressor where its three middle stages had tandem bladed rotor configurations (Figure 1). They showed tandem bladed rotor has higher stage loading capacity as compared to the single bladed one. Moreover, they showed that the operating range of tandem bladed rotor is more limited. Earliest two-dimensional works on tandem blade cascades were found in Ohashi [5], Ihlenfeld [6] and Pal [7] in which vertical and axial overlaps were studied. McGlumphy [1] worked on some design rules which could help manufacturer to use tandem bladed rotors in their compressors. He also focused on percent pitch (vertical overlap) and axial overlap in tandem blade arrangement. He claimed the optimum tandem blade configuration occurs at high percent pitch and low axial overlap value. Canon-Falla [2] studied axial overlap and percent pitch of tandem airfoils too. He used NACA65-12(10) as the first airfoil and NACA65-21(10) as the second airfoil. Similar to the previous researchers, he concluded low axial overlap and high percent pitch give the best performance at design condition. Railly and El-sarha [8], Sieverding [9], Railly and Deeb [10] and Hopwood [11] studied the effects of axial and vertical overlap on its performance and got similar conclusion too. Hoeger and Baier [12] worked on DCA tandem airfoils in high subsonic flow regime and they concluded tandem bladed rotors provides more work and less loss than single bladed ones. Dettmering [13] designed a supersonic tandem stator for a compressor stage. He tried to reduce velocity from supersonic to subsonic regime. He concluded the losses of a tandem bladed stator are lower than a single bladed one for the same flow conditions.

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