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Transient Numerical Analysis of a Tandem Compressor Stage

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ABSTRACT: Minimizing the number of axial flow compressor stages for a specific work output, and thereby lowering the engine size and weight has always been the designer's goal. A major limitation on the pressure rise in a subsonic axial-flow compressor stage is boundary layer separation on the blade suction surface. One method of mitigating the suction surface separation is to employ tandem airfoil blades. Tandem blading is a method of increasing the flow deflection by delaying the separation in diffusing cascade arrangements. The basic concept is that a new boundary layer forms on the second (aft) airfoil, allowing for high overall loading without the large flow separations that would be seen with a single airfoil. The unsteady 3D flow fields in a single-stage compressor with tandem blades under designed conditions are simulated numerically to investigate the stage performance and the aerodynamic interaction between the blade rows. In this work, the Time Transformation method (TT) to stage modeling has been employed to predicting stage compressor performance. In the compressor, three main aerodynamic structures are responsible for the unsteadiness of the flow: the wakes, the corner stalls and the tip-clearance flows. The study of the aerodynamic structures is the subject of this paper.

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1- Introduction

A major limitation on the pressure rise in a subsonic axial-flow compressor stage is boundary layer separation on the blade suction surface and endwalls. One method of mitigating the suction surface separation is to employ tandem airfoil blades [1].

Unsteady computations are necessary if blade row interactions effects are relevant, for example for detailed optimization of a compressor at off-design conditions towards the aerodynamic stability limit, or for structural mechanical tuning of the blades [2]. In the compressor, four main aerodynamic structures are responsible for the unsteadiness of the flow: the wakes, the potential effects, the tip-clearance flows and the wall boundary layers developing at hub and shroud [3]. The goal of this project is to evaluate the aerodynamic structures of a tandem compressor stage.

2- Time Transformation Method

The time transformation method handles the problem of unequal pitch by transforming the time coordinates of the rotor and stator in the circumferential direction in order to make the models fully periodic in transformed time. The time transformation method applies the phase shifted boundary conditions.

Mathematically, the condition of enforcing the flow periodic boundary conditions on both rotor and stator passages, respectively, is given by:

$$U(x,y,t)=U(x,y+P_r,t+\Delta T) \tag{1}$$

$$U(x,y,t)=U(x,y+P_S,t+\Delta T) \tag{2}$$

Alternatively, we can apply the following set of space-time transformations to the problem above as:

$$x'=x \tag{3}$$

$$y'=y \tag{4}$$

$$t'=t-\lambda y \tag{5}$$

where $\lambda=\Delta T/P$.

The transformed set of equations now has regular periodic boundary conditions as:

$$U(x',y',t')=U(x',y'+P_r,t') \tag{6}$$

$$U(x',y',t')=U(x',y'+P_s,t') \tag{7}$$

And the periodicity is maintained at any instant in time in the computational domain.

3- Case Study

The Table 1 gives some information about its aerodynamic performances and its main geometric characteristics.

4- Solution Method

All simulations in this work were performed using ANSYS CFX pre-Release 15.0. ANSYS CFX solves the Navier-Stokes equations using an implicit element-based finite-volume formulation. The viscous flow is modeled using the *k*-*ε* turbulence model.

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Table 1. Aerodynamic performances

Parameter	Value
n_d	7300 rpm
ψ	0.89
ϕ	0.91
Λ	0.57
$c_{r,s}$	5-5 cm
$N_{r,s}$	25-26
$\sigma_{eff} r,s$	1.6-1.66
$C_{eff}\, r,s$	8.87-9.16 cm
$C\, r,s$	5-5 cm

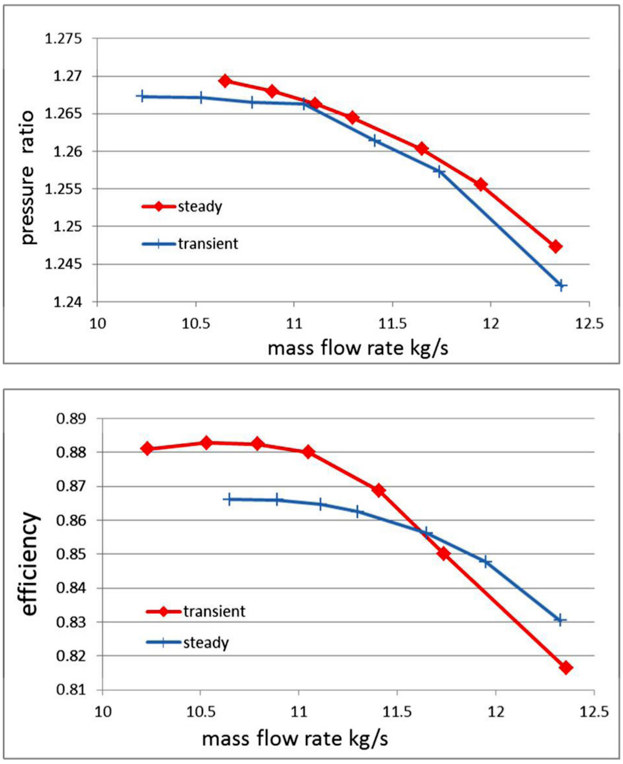

Fig. 2. Comparison of Characteristic map

5- Validation

The compressor used in this work is known as NASA stage 67, and the decision to use it was due to the great number of experimental test data information [4] available. The Fig. 1 compare the pressure ratio prediction from the steady & transient method to experimental test data.

The transient method predicted very nearly the same overall performance as the experimental test data.

6- Results and Discussion

The overall compressor performance for the 100% speedline is shown in Fig. 2 for the total pressure ratio and the isentropic efficiency.

A comparison between steady and transient simulation is given in Fig. 2 which shows reduction in the stalling mass flow rate with transient simulation and range extension roughly 25 percent.

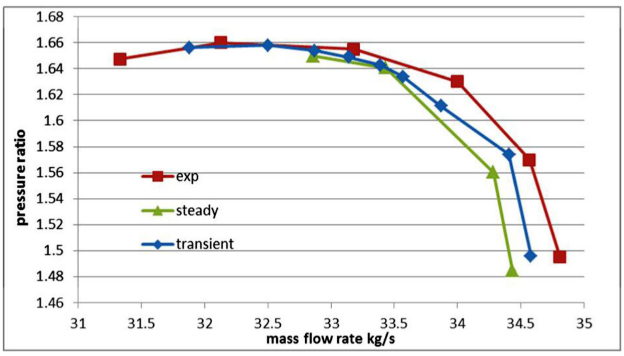

Fig. 1. Comparison of pressure ratio

To understand the cause of this difference is presented in Fig 3 and 4. In Fig 3, contours of Static Pressure for tandem stage have been shown in stator inlet with steady simulation. In Fig 4, contours of Static Pressure (transient average) for tandem stage have been shown in stator inlet with transient simulation.

In unsteady simulation the wake of the rotor blade periodically distorts the boundary layer on the surface of the stator blade and improves the stall margin, but in steady simulation the wake of the rotor blade Lost in the interface.

7- Conclusion

Three-dimensional unsteady calculations were numerically conducted in order to investigate the flow and

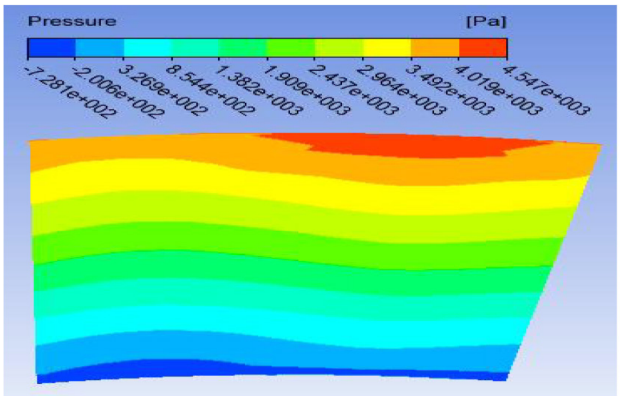

Fig. 3. Static Pressure Contours at inlet stator in steady simulation

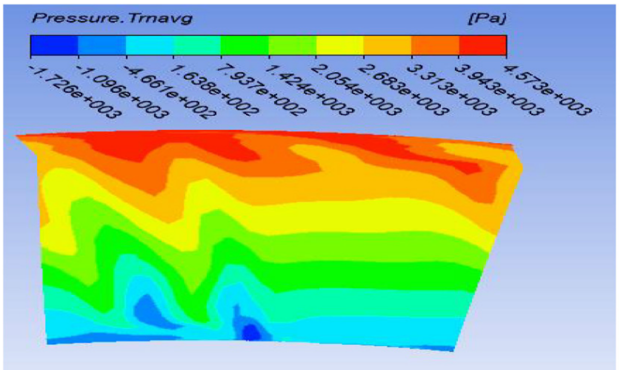

Fig. 4. Static Pressure Contours at inlet stator in transient simulation

the performance of a tandem compressor stage. It was shown that unsteady flow structures offered better performance since the propagation of the blade wakes enhanced the stall margin.

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