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ScienceDirect

Procedia Engineering 99 (2015) 499 – 506

Procedia Engineering

www.elsevier.com/locate/procedia

"APISAT2014", 2014 Asia-Pacific International Symposium on Aerospace Technology, APISAT2014

Influence of Geometric Scaling on Linear Cascade Aerodynamic Performance

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Abstract

A linear cascade has been geometrically scaled according to the similarity theory, a series of three dimensional numerical simulations are conducted on these geometric similar cascades with the CFD software. The differences of the aerodynamic performance between the original and the scaled linear cascades are investigated in details. The result shows that with the increasing of linear cascade size, the shape factor decreases at the same relative arc length position and the location of separation point moves towards trailing edge, resulting in the total pressure loss coefficient decreases and the static pressure raises coefficient increases.

Peer-review under responsibility of Chinese Society of Aeronautics and Astronautics (CSAA)

Keywords: geometric scaling; linear cascade;numerical simulation;aerodynamic performance;boundary layer thickness;computational grid

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1. Introduction

Internal flow of turbomachinery is a very complicated three-dimensional and viscosity physical process. It is known that it is impossible to get the analytical solution of the viscous partial differential equation. For example, inside the flow with high Reynolds number, viscous effect is limited to the very thin flow layers away from the wall. These thin layers are called "boundary layers". The flow internal the thin layers can approximately be predicted by simplified boundary layer equations, while the flow external the thin layers can also be treated as inviscid ideal fluid. The boundary layer equations solutions depend on the solutions of inviscid flow outside the boundary layer, and the

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Peer-review under responsibility of Chinese Society of Aeronautics and Astronautics (CSAA)
doi:10.1016/j.proeng.2014.12.564

boundary layer equations calculations can revise the viscous flow result in return. Therefore the correct data should be the result of the two methods in an iterative process [1].

The boundary layer theory is an efficient tool to study the viscous flow in turbomachinery [1]. For example it can be applied to study the aerodynamic loss mechanism of the turbomachinery and assess the quality of blade design. Due to the fluid viscosity , the velocity changes very rapidly inside the boundary layer, and the velocity increases from zero at the wall to W_e in the small boundary layer distance, while W_e is the inviscid velocity at the boundary edge. Therefore, the blade wall friction stress to the fluid particles isn't neglected. The normal velocity gradient at the wall is zero for the ideal fluid, therefore it doesn't exist the blade wall friction stresses to the fluid. Thus it can be seen, the boundary layer theory will be applied to discuss the loss law of flow in turbomachinery, resulting in the improvement of turbomachinery performance [1, 4, 6].

Geometric scaling makes it difficult to keep compressors all the same, such as the radial clearance will meet many difficulties when scaling. The efficiency and other performances of many scaled compressors are lower than the full scale compressor, and one of the important reasons is that the scaled doesn't guarantee the geometric similarity strictly [7]. It's also hard to ensure the boundary layer similarity during the geometric scaling due to the effect of boundary layer, that is to say, it is very difficult to keep the flow filed similarity. There are boundary layers on the blade surface because of the fluid viscosity, so that there are always friction losses of gas inside boundary layer. When the flow along suction surface and pressure surface is separate to the blade trailing edge, both of the boundary layers mix together become the blade wake which cause prodigious loss. The wake loss decreases the efficiency of the compressor. Hence, geometric scaling for compressors isn't similarity completely according to the similarity theory, which influences the aerodynamic performance of compressors.

The flow in a linear cascade is relatively simpler than the complex flow in a real compressor, which makes it easier to analyze the flow in linear cascade and calculate boundary layer on blade surfaces. Therefore a series of geometric scaled cascades are chosen to research the influence of geometric scaling on aerodynamic performance of the compressor. The influences of geometric scaling on aerodynamic performance of the cascade and flow in the cascade are studied in this paper.

Nomenclature

c	chord length
h	blade span
H	boundary layer shape factor, δ^*/δ^{**}
i	incidence
M	mach number
p	static pressure
p^*	total pressure
Δp	p_2-p_1,
q	dynamic pressure
Re,c	Reynolds number, $\rho Vc / \mu$
Re,δ	Reynolds number, $\rho W_e \delta / \mu$
Re,θ	Reynolds number, $\rho W_e \theta / \mu$
S	relative arc length along the suction surface
t	pitch
V	inlet velocity
W_e	velocity at the outer edge of boundary layer
X_b	axial position of boundary layer separation point
β	flow angle
β_k	inlet blade metal angle
β_{st}	stagger angle
δ	boundary layer thickness
δ^*	boundary layer displacement thickness
θ, δ^{**}	boundary layer momentum thickness
δ^{***}	boundary layer energy thickness
μ	dynamic viscosity
ρ	density
τ_w	wall shear stress
	total pressure loss coefficient
Subscripts	
1	inlet
2	outlet