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Adjoint Aerodynamic Optimization of a Transonic Fan Rotor Blade with a Localized Two-Level Mesh Deformation Method

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Abstract

We present an optimization platform for turbomachinery with complex mesh configuration in a parallel computation environment. A continuous adjoint solver for 3-D viscous internal flow is coded under the same parallel framework as the flow solver. To meet the various permitted extents of reshaping on blade surface and to cut down the computational cost in grid perturbation, a localized two-level mesh deformation method is developed based on Gaussian radial basis function (RBF). This method works efficiently for both the O mesh surrounding the blade and the O-H mesh inside tip gap. In the optimization of the transonic NASA Rotor 67 for high adiabatic efficiency with a mass flow rate constraint, an adjoint sensitivity analysis is conducted. The relations between the design sensitive regions and physical phenomena in internal flow are discussed. Flow fields before and after the adjoint optimization are investigated, including shock system, tip leakage flow, and flow separation.

Keywords: Adjoint Method, Aerodynamic Design Optimization, Mesh Deformation, Compressor Rotor, Transonic

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Nomenclature

α	RBF bump decaying rate
β	Flow turning angle
$\boldsymbol{w}$	Flow variable vector
$\dot{m}$	Mass flow rate
η	Adiabatic efficiency
Γ	Geometric boundary
$\hat{u}_i$	Grid velocity components
κ	RBF bump shape factor, $\kappa = h/\lambda$
λ	RBF bump half decay radius, $\lambda = \ln 2/\alpha$
λ_i, $\boldsymbol{k}_i$	Eigenvalues, eigenvectors of matrix A_1
π, θ	Total pressure ratio, total temperature ratio
Ψ	Adjoint variable vector, $\Psi = (\psi_1, \psi_2, \psi_3, \psi_4, \psi_5)^{\mathrm{T}}$
$\mathbf{c}$	Vector comes from the cost function at the outlet
$\mathrm{A}_{s,i}, \mathrm{A}_i$	Jacobian matrices, $\mathrm{A}_{s,i} = \mathrm{A}_i - \hat{u}_i \mathrm{I}_e$
B_s	Source matrix due to rotation
ξ	Weight coefficient of the mass flow rate constraint
a	Local sound speed
B_{IO}	Inlet and outlet boundaries
c_p, c_v	Specific heat at constant pressure, volume
G	Adjoint gradient
h	RBF bump height
I	Cost function
N_i	Unit normal vector components
p, ρ	Pressure, density
s_{gen}	Total entropy generation
S_{ij}	Projected areas
u_i	Velocity components

1. Introduction

Turbomachinery blades are characterized by highly sensitive areas such as the leading edge, suction surface shock region and blade tip, which directly relate to complex flow phenomena like the shock-boundary layer interaction, tip leakage flow, shock-tip leakage vortex interaction. These areas have various geometries as well as levels of design

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