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ADAPTIVE GRID COMPUTATION OF TRANSONIC FLOWS THROUGH CASCADES AND INVESTIGATION OF CHORDWISE BENDING UPON AEROELASTIC RESPONSE

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Abstract

A new computational analysis for simulating fluid-structure interaction (FSI) phenomena in cascades is used to examine the effects of chordwise flexibility upon aeroelastic blade response. The flow is governed by the Euler equations and discretized using a finite volume (FV) flux-splitting scheme implemented on an unstructured mesh. A 2-D quadratic isoparametric continuum finite element (FE) representation is employed to accommodate blades of arbitrary cross-section. A recently-developed consistent and accurate numerical interface treatment is used to effect the coupling between the fluid and structural domains. This treatment successfully reconciles the basic disparities between the fluid and structural formulations by enforcing both kinematic and kinetic boundary conditions at the interface. The conservation laws applicable to the coupled system are preserved across the interface as are the orders of accuracy of the fluid and structural discretizations. Using a diagonally implicit Runge-Kutta integration scheme, the coupled equations are advanced simultaneously in time thereby minimizing temporal phasing errors. The purpose of the present paper is two-fold: 1) to describe the addition of an adaptive grid capability to an existing code, PARSEC, embodying the new FSI treatment; and 2) to present aeroelastic results obtained using the coupling method for cascades operating in transonic flow and in particular to study the influence of chordwise stiffness upon aeroelastic stability.

Nomenclature

a	acoustic speed
[A]	Jacobian matrix, $\partial \underline{Q} / \partial \underline{W}$
$[A_{ii}]$, $[A_{ij}]$	matrices defined in Eqs.(13)
[B]	strain-displacement matrix defined in Eq.(28)
c	chord length; acoustic speed
Cp	pressure coefficient $Cp \equiv (P - P_\infty) / \frac{1}{2}\gamma P_\infty M_\infty^2$
[C]	stress-strain matrix
e	specific energy
E	Young's Modulus; also error criterion defined in Eq.(21)
$\underline{F}$	generalized force vector
$\underline{F}_x$, $\underline{F}_y$	nodal FE forces in the local xy-frame defined in Eq.(47)
$FX_{c.a.}$, $FY_{c.a.}$	net horizontal and vertical aerodynamic forces referred to the global XY-frame, defined in Eq.(52)
[I]	unit matrix
[J]	Jacobian defined in Eq.(26)
k_X, k_Y, k_θ	supporting spring stiffness
[K]	FE stiffness matrix
m	blade mass per unit length
M	Mach number
M_{is}	isentropic Mach number defined in Eq.(54)
[M]	FE mass matrix
$M_{e.a.}$	net aerodynamic moment about displaced pivot defined in Eq.(52c)
$\hat{\underline{n}}$	surface or edge normal vector
P	static pressure
q	extrapolated flow variable;
$\underline{Q}$	flux vector defined in Eq.(1)
[R]	coupling matrix defined in Eq.(50)
s	distance along aerofoil surface;
S	surface of a FV
t	time
$\underline{u}$	velocity vector with components, {u v}
u, v	flow velocity components; also structural deformations in local xy-frame
$\underline{u}$, $\underline{v}$	FE node deformations in local xy-frame
$\overline{U}_n$	difference between flow and mesh velocities resolved along edge normal
$\overline{U}_{red}$	reduced velocity, $\overline{U}_{red} = 2U_\infty / c\omega_\alpha$
V	cell volume
$\underline{W}$	vector of conserved variables defined in Eq.(1)
x, y	local Cartesian coordinates
$\underline{x}$, $\underline{y}$	FE node coordinates in local xy-frame
X, Y	global Cartesian coordinates
$\underline{\dot{X}}$	mesh velocity vector with components, $\{\dot{X} \quad \dot{Y}\}$
$\underline{Z}$	fluid state vector with components for the i-th cell, $\underline{Z}_i \equiv (\underline{W}\ V)_i$
α	angle of attack; also elemental rotation due to deformation (Eq.(43))
Δ, ∇	forward and backward difference operators respectively
∇	gradient (del) operator
γ	ratio of specific heats for air
γ_{xy}	shear strain
ε_{xx}, ε_{yy}	longitudinal strains in x and y directions
$\underline{\Phi}$	vector of FE shape functions defined in Eqs.(24)
ρ	density
θ	pitch angle
ξ, η	FE natural coordinates
μ	mass ratio, $\mu = 4m/\rho_\infty \pi c^2$

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