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HIGH ACCURACY COMPUTATION OF FLUID-STRUCTURE INTERACTION IN TRANSONIC CASCADES

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Abstract

A coupling strategy for simulating fluid-structure interaction phenomena is formulated and applied to the prediction of flutter in transonic cascades. The flow is governed by the Euler equations and discretized using a finite volume (FV) flux-splitting scheme. The structure is modeled using an isoparametric finite element (FE) formulation. The coupling strategy successfully reconciles these two formulations at the fluid-structure interface by enforcing both kinematic and kinetic boundary conditions. In particular, the conservation laws applicable to the combined fluid-structure system are preserved across the interface. Since the primary mechanism driving aeroelastic phenomena involves energy exchange occurring at the interface, this highly accurate coupling mechanism is believed to improve the predictive capability of the scheme. The coupled equations are advanced simultaneously in time using an implicit time integration method. Results obtained using the coupling method are presented for cascade geometries operating in transonic flow.

Nomenclature

[B]	strain-displacement matrix defined in Eq.(30)
c	chord length; acoustic speed
[C]	stress-strain matrix
e	specific energy
E	Young's Modulus
[J]	Jacobian defined in Eq.(28)
[K]	FE stiffness matrix
[M]	FE mass matrix
$\underline{\hat{n}}$	surface or edge normal vector
P	fluid pressure
q	extrapolated flow variable; total flow velocity
$\underline{q}$	vector of generalized nodal degrees of freedom for FE model
$\underline{Q}$	flux vector defined in Eq.(5)
Q^{e}_{kseg}	energy flux integral for segment, kseg, defined in Eq.(42)
$\underline{R}$	position vector
[R]	coupling matrix defined in Eq.(47)
s	distance along aerofoil surface; distance between two points
S	surface of a FV
t	time
u,v	flow velocity components
U, V	FE deformations along Cartesian directions
$\underline{U}, \underline{V}$	nodal deformation vectors along Cartesian directions
u_n	flow velocity resolved along edge normal
$\overline{U}_n$	difference between flow and mesh velocities resolved along edge normal
V	cell volume
$\underline{W}$	vector of conserved variables defined in Eq.(5)
X, Y	Cartesian coordinates; mesh position
$\underline{Z}$	state vector for combined fluid-structure system obtained by concatenating $\underline{Z}_f$ and $\underline{Z}_s$
$\underline{Z}_f, \underline{Z}_s$	fluid and structural state vectors defined in Eq.(56) and 57 respectively
α	pitch angle
Δ, ∇	forward and backward difference operators respectively
∇	gradient (del) operator
γ	ratio of specific heats for air
γ_{XX}	shear strain
$\varepsilon_{XX}, \varepsilon_{YY}$	longitudinal strains in X and Y directions
$\underline{\Phi}$	vector of FE shape functions
ρ	density
ξ, η	FE natural coordinates
υ	Poisson's ratio
$\underline{(\cdot)}$ (underline)	vector quantity
$[\cdot]$ (square brackets)	matrix quantity
$\dot{(\,)}$	differentiation w.r.t. time

Superscripts & Subscripts

$(\cdot)^{\pm}$	upstream/downstream components of flux-split quantities
$(\cdot)_{ie}$	pertains to finite element, ie.
$(\cdot)_{,x}$	comma notation: derivative of argument w.r.t. x.
$(\cdot)_{X}$	component in the X-direction.

Introduction

Aeroelastic stability calculations for cascades have been undertaken by a several researchers in recent years [1-4]. These investigators have taken advantage of the rapid improvement in fluid dynamic solvers as well as established capabilities of advanced finite element methods for computing structural deformations [1,2]. Until recently, however, the important issue of fluid-structure coupling in transonic cascade flutter calculations has not been fully addressed. Proper modeling of the coupling is critical since, for important problems such as cascade flutter, phasing error and non-conservative spatial discretization of the combined

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