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VISCOUS AND INVISCID LINEAR/NONLINEAR CALCULATIONS VERSUS QUASI 3D EXPERIMENTAL CASCADE DATA FOR A NEW AEROELASTIC TURBINE STANDARD CONFIGURATION

T.H. Fransson, M. Jöcker
Chair of Heat and Power Technology
Royal Institute of Technology
Stockholm, Sweden

A. Bölcs, P. Ott
Laboratoire de Thermique Appliquée et de Turbomachines
Swiss Federal Institute of Technology
Lausanne, Switzerland

ABSTRACT

This paper presents a new International Standard Configuration to be added to an already existing set of 10 configurations for unsteady flow through vibrating axial-flow turbomachine cascades. This 11^{th} configuration represents a turbine blade geometry with transonic design flow conditions with a normal shock positioned at 75% real chord on the suction side. Out of a set of test cases covering all relevant flow regimes two cases were selected for publication: A subsonic, attached flow case and an off-design transonic case showing a separation bubble at 30% real chord on the suction side are published. The performed tests are shown to be repeatable and suitable for code validations of numerical models predicting flutter in viscous flows.

The validity of the measured data of the two public cases was examined and comparisons with other tests were conducted. Sometimes a large difference in aerodynamic damping was observed on cases with similar flow conditions. This was investigated at three transonic cases with almost identical inlet flow conditions and only small variations in outlet Mach Number. It was found that the differences in the global damping are due to very local changes on the blade surface in the shock region, which obtain a large influence by the integration because of the discrete measuring points. Hence it is recommended not to look at the global damping for code validations but more precisely to the local values. These show a common tendency, which is reproducible with different numerical methods.

This was demonstrated with a potential model, a linear Euler model, a nonlinear Euler model and a Navier-Stokes solver, all applied to predict flutter of each test case with a 2D/Q3D approach. The limitations of inviscid codes to predict flutter in viscous flow regimes is demonstrated, but also their cost advantage in attached flow calculations. The need of viscous code development and validation is pointed out. This should justify and encourage the publication of thoroughly measured test cases with viscous effects.

NOMENCLATURE

A_i		area elements of data points i projected into bending direction, normalized with c (sign: on ss >0, on ps < 0)	-
c		chord	m
cp	$\frac{(p - p1)}{(pt1 - p1)}$	steady pressure coefficient	-
$\tilde{c}_p(x,t)$	$\frac{c \cdot \tilde{p}(x,t)}{h \cdot (pt1 - p1)}$	unsteady pressure coefficient	-
$\tilde{c}_p, \tilde{c}_{pi}$		amplitude of unsteady pressure coefficient (1st harmonic)	-
e		probe distance	m
f		frequency	Hz
h		bending amplitude	m
H		enthalpy	J/kg/K
IBPA, σ		interblade phase angle	deg.
k	$\frac{2 \cdot \pi \cdot f \cdot c}{2 \cdot v_{2\,exp}}$	reduced frequency based on half chord and experimental outlet velocity	-
M		Mach number	-
p		pressure	Pa
sf	$\frac{(pt1 - p1)_{NOVAK}}{(pt1 - p1)_{EXP}}$	scaling factor in NOVAK	-
v		velocity	m/s
x		chordwise coordinate	m
XI, Ξ_h	$-\sum_i \tilde{c}_{pi} \cdot A_i \cdot \sin\phi_i$	aerodynamic damping due to bending >0: stable, <0: unstable	-
ß		relative flow angle	deg.
γ		stagger angle	deg.
δ		bending direction	deg.
φ, ϕ_i, phi~		phase of unsteady pressure coefficient (1st harmonic)	deg.
τ		pitch	m

Indices

1	inlet
2	outlet
i	data point
is	isentropic
t	total values
tan	tangential
~	unsteady perturbation value (without steady part)