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Hongbin Ju, Ramani Mani

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A Semi-Analytical Method for Oblique Gust - Cascade Interaction

Hongbin Ju[1], Ramani Mani[2]
GE Global Research Center, One Research Circle, Niskayuna, NY 12309

A semi-analytical method is proposed for calculating the response of a linear cascade with spanwise mean flow subject to oblique gusts. It is developed based on the boundary value problems defined by Lloyd and Peake (AIAA paper 2008-2840). A gust strength parameter is introduced and the correct three-dimensional (3-D) response is obtained. The classic similarity rules are extended; the approach can be used to extend any 2-D methods to account for oblique gusts and 3-D mean flows. It is validated against analytical approximations for single-airfoil and cascade responses. The method is used to investigate the effect of gust angle α_g on the unsteady lift and the sound field. It is found that as α_g increases, the 2-D equivalent response varies slightly. However, the 3-D lift is amplified by factor $1/\cos\alpha_g$, and the spanwise phase variation increases. Cascade effects are also studied. The inter-blade phase angle (IBPA) is important even for very low solidity. As the solidity increases, the chordwise distribution of lift is no longer leading-edge dominant. Cascade effects are small only when the cascade blade count is lower than a limit. A statistics analysis reveals that Mach number is the most important parameter for determining this blade count limit, and frequency is the least important.

Keywords: Aeroacoustics; Gust - Cascade Interaction; Turbofan Jet Engine Noise

Nomenclature

(Variables are non-dimensional unless otherwise noted.)

a_0	= sound speed in the mean flow, dimensional, velocity scale
C	= airfoil chord length, dimensional, length scale
$\hat{h}^{\pm}_{mn}(k_1,k_2,k_3)$	= chordwise integrated unsteady lift
$\hat{h}^{+}_{s}$	$=\sqrt{\sum\lvert\hat{h}^{+}_{mn}\rvert^2}$ (summation over all the cut-on modes)
K	$=k_1 M_\xi/\beta_M^2$
K_s	= vortical wavenumber magnitude
$k_1,\ k_2,\ k_3$	= vortical wavenumbers in the ξ, η, and z directions respectively
k_d	$=\omega/a_0$, acoustic wave number
L	= unsteady lift due to oblique gust - cascade interaction
l	= unsteady lift due to 2-D gust - cascade interaction calculated by LINSUB
M	$=U_0/a_0$, Mach number
M_ξ	$=u_{0\xi}/a_0$, Mach number in the ξ direction
m	= spinning mode number
N_v	= number of the blades
n	= radial mode index
p	= acoustic pressure
R	= radius at which annular duct is unwrapped
$\overline{R}_r$	= rth acoustic pressure at the reference blade leading edge calculated by LINSUB
S	= spacing between blades in the linear cascade
$\mathbf{u}=(u_\xi,u_\eta,u_z)$	= unsteady velocity vector & its components

[1]Corresponding author, Aerodynamics and Acoustics Laboratory, juh@ge.com, AIAA Senior Member
[2]Aerodynamics and Acoustics Laboratory, AIAA Associate Fellow