AIAA Journal
Vol. 47, No. 11, November 2009

Comparison of Direct and Indirect Combustion Noise Mechanisms in a Model Combustor

M. Leyko*
Snecma Groupe SAFRAN, 77550 Moissy-Cramayel, France
F. Nicoud†
Université Montpellier II, 34095 Montpellier, France
and
T. Poinsot‡
Institut de Mécanique des Fluides de Toulouse, 31400 Toulouse, France

DOI: 10.2514/1.43729

Core noise in aeroengines is due to two main mechanisms: direct combustion noise, which is generated by the unsteady expansion of burning gases, and indirect combustion noise, which is due to the acceleration of entropy waves (temperature fluctuations generated by unsteady combustion) within the turbine stages. This paper shows how a simple burner model (a flame in a combustion chamber terminated by a nozzle) can be used to scale direct and indirect noise. An analytical formulation is used for waves generated by combustion. The transmission and generation of waves through the nozzle is calculated using both the analytical results of Marble and Candel (Marble, F. E., and Candel, S., "Acoustic Disturbances from Gas Nonuniformities Convected Through a Nozzle," *Journal of Sound and Vibration*, Vol. 55, 1977, pp. 225–243.) and a numerical tool. Numerical results for the nozzle verify and extend the analytical approach. The analytical relations for the combustion and the nozzle provide simple scaling laws for direct and indirect noise ratio as a function of the Mach number in the combustion chamber and at the nozzle outlet.

Nomenclature

$\mathcal{A}$ = nozzle cross-sectional area, m^2
$\mathcal{A}_c$ = throat nozzle cross-sectional area, m^2
$\mathcal{A}_f$ = combustor cross-sectional area, m^2
c = speed of sound, m/s
c_p = massic heat capacity at constant pressure, J/K/kg
c_v = massic heat capacity at constant volume, J/K/kg
ℓ_f = flame length, m
ℓ_n = nozzle length, m
$\mathcal{M}$ = Mach number
$\dot{m}$ = mass flow rate, kg/s
$\mathrm{PW}\{\phi\}$ = spectral power density of ϕ computed with Welch's method
p = thermodynamic pressure, Pa
$\dot{Q}$ = heat release rate, W
$\dot{q}$ = heat release rate per volume unit, W/m^3
r = massic ideal gas constant, J/K/kg
s = massic entropy, J/K/kg
T = temperature, K
t = time, s
u = gas velocity, m/s
w^S = dimensionless entropy wave
w^+ = dimensionless acoustic wave propagating downstream
w^- = dimensionless acoustic wave propagating upstream
x = x-axis value, m
y = y-axis value, m
z = z-axis value, m
γ = specific heat capacities ratio
δ = Dirac distribution
η = ratio between indirect and direct noise
ρ = mass density, kg/m^3
$\bar{\phi}$ = temporal mean value of ϕ
ϕ' = temporal fluctuation value of ϕ
Ω = reduced angular pulsation
ω = angular pulsation, rad/s

Subscripts

[AA] = acoustic response of the nozzle to an acoustic perturbation
[CC] = response of the combustion chamber to a heat release fluctuation
[SA] = acoustic response of the nozzle to an entropy perturbation
ϕ_t = total quantity of ϕ
ϕ_0 = quantity ϕ upstream from the combustor
ϕ_1 = quantity ϕ downstream from the combustor and upstream from the nozzle
ϕ_2 = quantity ϕ downstream from the nozzle

I. Introduction

OVER the last five decades, jet and external aerodynamic noises of aircraft have been substantially reduced. Further developments will be needed for modern aircraft design in order to meet the increasingly restrictive rules about noise reduction. Although drastic reductions have already been achieved on fan and jet noise, the relative importance of other noise sources has increased and the contribution of these sources must be controlled if further global noise reduction is to be achieved. Among these sources, the noise created by the turbulent flame within the combustor is already identified as nonnegligible at takeoff, especially in the midfrequency range. Two main mechanisms have been identified in the 1970s regarding noise propagation and generation from the combustion chamber to the far field (Fig. 1):

Received 10 February 2009; revision received 3 July 2009; accepted for publication 4 July 2009.

*Ph.D. Student, Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique, 31057 Toulouse, France; leyko@cerfacs.fr.

†Professor.

‡Research Director, Associate Fellow AIAA.