A Linear Multivariable Dynamical Model of a Supersonic Inlet-Engine Combination

Yanchen Guan,* Shin Yarng,† and Jiahnbo Yarng‡
Northwestern Polytechnical University, Xi'an, China

A linear multivariable dynamical model of a supersonic inlet-engine combination, which can be used for the integrated control design of the combination, is presented in both state space and frequency domain and its simulation. The inlet portion is modeled by applying and extending Willoh's method of inlet dynamical analysis with the piecewise lumped volumes of the subsonic duct to both the downstrem and upstream perturbation cases. The engine portion is primarily modeled on the linearized one-dimensional channel flow with the experimental data of the engine components considering variable specific heat of gas. The steady-state flow matching of the inlet and engine is carried out by varying the opening of the bypass doors. The stiff differential equations of the model are solved by the combined Newton-Raphson and Runge-Kutta methods with different time steps for different time intervals. Then, the dynamics of the inlet-engine combination is simulated digitally. The results from the simulation are compared with experimental data.

Nomenclature

A = area, ft^2
a = speed of sound, ft/s
AMP = amplitude, dB
C = coefficient
F = thrust, lbf
j = $\sqrt{-1}$
I = compressor inlet guide vane angle, deg
K = gain
L = length, in.
M = Mach number
N = engine speed, rpm
P = total pressure, psia
P_S = static pressure, psia
PHA = phase angle, deg
PR = pressure recovery of inlet
s = Laplace operator
T = total temperature, °R
t = time, s
Δt = computation time step, s
v = velocity, ft/s
W = weight flow rate (air or fuel), lb/s
X = any known value
Y = displacement, in.
β = oblique shock semiangle, deg
Δ = disturbance, change, deviation
ζ = damping ratio
θ,σ,τ = transport time lag of inlet, s
$\Lambda(s),\Phi(s),\Psi(s),\Theta(s)$ = Laplace transform of deviation vectors $\Delta R(t)$, $\Delta U(t)$, $\Delta X(t)$, and $\Delta Z(t)$
ρ = specific gravity of air, lb/in^3
ϕ = flow coefficient of inlet
$\psi(j\omega)$ = frequency response
ω = frequency, Hz
$A,B...L,O,P,Q,\Gamma,\Pi$ = matrices
I_0 = unit matrix
R,U,X,Z = response, control, state, and disturbance vectors, respectively
$L(s)$, $V(s)$ = transfer matrix of output deviation vector to control deviation vector $\Delta U(t)$ and disturbance deviation vector $AZ(t)$

Superscripts

$(\bar{\ })$ = average value
$(\tilde{\ })$ = Laplace transform of nondimensional small perturbation
$(\dot{\ })$ = time derivative

Subscripts

$a,b,1,2,\ldots,n,n+1,\ldots$, CI,CD,$T$,$N$,$E$ = station number of the inlet-engine combination, Fig. 1a
B = main burner
BP = bypass
BL = bleed
CD = compressor discharge
CI = compressor intake
E = exit
EN = engine
F = fuel
FA = afterburner fuel
GV = inlet guide vane
H = freestream
IEC = inlet-engine combination
IN = inlet
M = metal
N = nozzle
SP = spike
SW = normal shock wave
T = turbine

Presented as Paper 84-1496 at the AIAA/SAE/ASME 20th Joint Propulsion Conference, Cincinnati, Ohio, June 11-13, 1984; received Nov. 8, 1984; revision received April 13, 1985.

*Professor, Department of Aero-Engine Engineering.
†Assistant Professor, Department of Aero-Engine Engineering.
‡Master's Degree Candidate, Department of Aero-Engine Engineering.

Introduction

FIGURE 1a is a cross-sectional view of a typical supersonic propulsion system of the inlet-engine combination. The inlet is an axisymmetric mixed-compression type with a translating centerbody and bypass door. The engine is a one-spool, multistage axial compressor with a variable inlet guide