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Flying Qualities for a Twin-Jet Transport in Severe Atmospheric Turbulence

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Atmospheric turbulence is the leading cause of serious personal injuries in nonfatal accidents of commercial aircraft. One main type of motion that causes flight injuries in atmospheric turbulence is the sudden plunging motion with an abrupt change in altitude. To assess the possibility of designing a control system to mitigate such plunging motion, the dynamic stability characteristics must be known. The main objective of the present paper is to evaluate the dynamic stability characteristics and, more generally, the flying qualities of a twin-jet transport aircraft encountering severe atmospheric turbulence through digital six-degree-of-freedom flight simulations in transonic flight. The fuzzy-logic thrust model and unsteady aerodynamic models are used to estimate the nonlinear unsteady aerodynamics while performing numerical integration of flight dynamic equations. The flying qualities are based on the instantaneous eigenvalues of all flight modes obtained during time integration. It is shown that the real part of eigenvalues for the plunging mode (i.e., damping characteristics) is largely positive and can be used as a key parameter in describing the flying qualities in plunging.

Nomenclature

a_n	=	normal accelerations, g
b	=	wing span, m
C_x, C_z, C_m	=	longitudinal aerodynamic force and moment coefficients
C_y, C_l, C_n	=	lateral-directional aerodynamic force and moment coefficients
$\bar{c}$	=	mean aerodynamic chord, m
h	=	altitude, m
I_{xx}, I_{yy}, I_{zz}	=	moments of inertia about the x, y, and z axes, $kg \cdot m^2$
I_{xy}, I_{xz}, I_{yz}	=	products of inertia, $kg \cdot m^2$
k_1, k_2	=	longitudinal and lateral-directional reduced frequencies
L, M, N	=	moments acting along the (x, y, z)-body axes of the aircraft, $N \cdot m$
L/D	=	lift-to-drag ratio
M	=	Mach number
m	=	aircraft mass, kg
$\dot{m}_f$	=	fuel flow rate, kg/hr
N_1	=	the rpm of the compressor, rpm
p, q, r	=	body axis roll rate, pitch rate, and yaw rate, deg ./s
$\bar{q}$	=	dynamic pressure, kpa
S	=	wing reference area, m^2
T, W	=	thrust and aircraft weight in flight, N
T/W	=	thrust-to-weight ratio
T_2	=	time to double or halve the amplitude, s
t	=	time, s
X, Y, Z	=	forces acting on the aircraft body-fixed axes about the x, y, and z axes, N
α, $\dot{\alpha}$	=	angle of attack, deg and time rate of angle of attack, deg/s
α_m, α_g	=	angles of attack due to motion only and the total angle of attack, deg
β, $\dot{\beta}$	=	sideslip angle, deg and time rate of sideslip angle, deg/s
γ	=	climb angle, deg
δ_a, δ_e, δ_r	=	control deflection angles of aileron, elevator and rudder, deg
ζ	=	damping ratio
λ_r, λ_i	=	eigenvalue in real (i.e., in phase) and imaginary (i.e., out-of-phase) parts
ϕ, θ, ψ	=	Euler angles in roll, pitch, and yaw, deg
ω_n	=	natural frequency

I. Introduction

ONE of the objectives in NASA's flight safety program, which was initiated in 1997, has been establishing hazard indices for flight in atmospheric turbulence. So far, the proposed hazard index has been all related to structural loads. In [1], the turbulence hazard is quantified in terms of the root-mean-square (rms) normal loads over a moving 5 s interval to define the severity of turbulence. The correlation coefficient of the rms normal loads to the peak loads is determined to be 0.89 in 102 cases. The estimation was based on the assumption of continuous turbulence. However, experience indicates that most flight injuries in atmospheric turbulence have been caused by sudden plunging motion with a localized region of strong turbulence.

To predict the hazard levels for any aircraft, the effects of altitude, aircraft type, weight, airspeed, etc., must be considered. Therefore, flight dynamic equations should be employed. There have been

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