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Airplane Landing Performance on Contaminated Runways in Adverse Conditions

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A realistic analysis of operational landing and stopping performance of large-transport-category airplanes on contaminated runways in adverse conditions is presented. A new mathematical model of landing flare is introduced. Heaviside step functions were employed to model the time-delayed deployment of ground spoilers, brakes, and thrust reversers and to account for variations in pilot techniques. A simulation model, based on submodels for each landing phase, consists of several distinct systems of simultaneous nonlinear coupled ordinary differential equations, semi-empirical models, and many accompanying algebraic relationships for aerodynamic coefficients and other parameters. The full nonlinear differential model was solved numerically using the simple Heun's predictor-corrector method. Different landing scenarios were simulated to obtain realistic stopping distances as well as the time histories of deceleration and speed. The model accounts for many contaminated runway scenarios, hydroplaning, the effect of wind, the speed-dependent rolling-friction coefficient, and other important parameters. We have presented landing scenarios using average pilot techniques on ice-covered runways for which the Federal Aviation Administration wet-runway safety factor is not sufficient for a safe landing. This mathematical model and the simulation program can be used as an operational landing distance calculator. A sensitivity analysis was performed to estimate the significance of various parameters with the absolute maximum landing distance uncertainty estimated to be 100 ft.

Nomenclature

AR = aspect ratio,
b = wing span, m or ft
C_D = drag coefficient
C_L = lift coefficient
e = Oswald's coefficient
g = gravitational acceleration, $\mathrm{m^2/s}$ or $\mathrm{ft^2/s}$
h = height, m or ft
n = load coefficient
S = wing reference area, $\mathrm{m^2}$ or $\mathrm{ft^2}$
s = landing distance, m or ft
T = thrust, N or lbf
v = airspeed; m/s, ft/s, or kt
v_{so} = stalling airspeed in landing configuration; m/s, ft/s, or kt
W = weight, kg or lbm

Greek

α = angle of attack, deg
γ = glide path angle (gradient); %, deg, or rad
δ = thrust inclination angle, rad or deg
ζ = wind correction factor
θ = pitch angle, rad or deg
Φ = runway inclination (gradient); %, deg, or rad
φ = angle between gear touchdown trajectory and runway, rad or deg
ψ = pitch rate, rad/s or deg /s

Subscripts

A = air
APP = approach
FL = flare
FLGS = flare and groundspeed
FLH = flare height
G = ground (ground effect)
GR = ground roll
GS = ground speed
LD = landing
NGTD = nose gear touchdown
NGUP = nose gear up
R = rolling with brakes off
rb = rolling with brakes on
REF = reference
REV = reverse (thrust)
TAS = true airspeed
TCH = threshold
TD = touchdown
W = wind

I. Introduction

THE final approach and landing constitute only about 2% of the average total flight time, yet almost 50% of all aviation accidents and incidents occur during this phase [1,2]. The reasons for this are many, but the most significant ones are that both the pilot workload and pilot fatigue are at the highest level, coinciding with the narrowest margin of safety. Operating close to the ground in a fast moving aircraft is the most hazardous part of the flight and requires a maximum of the pilot's skills [1]. The majority of landing accidents, though usually not fatal, are either overrun or runway excursion accidents. According to Blake and Elliott [1], there is one landing overrun per 3.6 million flights. In 1990, that would have been one landing overrun every 3 months [1]. The accident statistics have confirmed those figures. Lowery [3] and Gugeler [4] reported that about 42% of all general aviation (GA) accidents occur during the final approach-and-landing phase. Lowery [3] also stated that most of the landing incidents and accidents are indeed overrun accidents in

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