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Piloted Simulator Evaluation Results of New Fault-Tolerant Flight Control Algorithm

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A high-fidelity aircraft simulation model, reconstructed using the digital flight data recorder of the 1992 Amsterdam Bijlmermeer aircraft accident (flight 1862), has been used to evaluate a new fault-tolerant flight control algorithm in an online piloted evaluation. This paper focuses on the piloted simulator evaluation results. Reconfiguring control is implemented by making use of adaptive nonlinear dynamic inversion for manual fly-by-wire control. After discussing the modular adaptive controller setup, the experiment is described for a piloted simulator evaluation of this innovative reconfigurable control algorithm applied to a damaged civil transport aircraft. The evaluation scenario, measurements, and experimental design, as well as the real-time implementation are described. Finally, reconfiguration test results are shown for damaged aircraft models including component as well as structural failures. The evaluation shows that the fault-tolerant flight control algorithm is able to restore conventional control strategies after the aircraft configuration has changed dramatically due to these severe failures. The algorithm supports the pilot after a failure by lowering workload and allowing a safe return to the airport. For most failures, the handling qualities are shown to degrade less with a failure than the baseline classical control system does.

Nomenclature

C	=	dimensionless coefficient
$\bar{c}$	=	mean aerodynamic chord, m
F	=	steering force
g	=	gravity constant, $\mathrm{m/s^2}$
$\mathbf{I}$	=	inertia matrix, $\mathrm{kg \cdot m^2}$
L, M, N	=	combined aerodynamic and thrust moment around the body X–Y–Z axis, Nm
m	=	mass, kg
p, q, r	=	roll, pitch, and yaw rate around the body X–Y–Z axis, rad/s
S	=	wing area, $\mathrm{m^2}$
u_b, v_b, w_b	=	airspeed velocity components along the body X–Y–Z axis, m/s
u_e, v_e, w_e	=	airspeed velocity components along the Earth-fixed X–Y–Z axis, m/s
V	=	airspeed, m/s
X, Y, Z	=	combined aerodynamic and thrust forces along the body X–Y–Z axis, N
$\mathbf{x}$	=	state vector
α, β, γ	=	angle of attack, sideslip angle, and flight-path angle, rad
δ	=	control surface deflection, rad
ν	=	virtual input
ρ	=	air density, $\mathrm{kg/m^3}$
ϕ, θ, ψ	=	roll, pitch, and yaw angle, rad

Subscripts

a; e; r	=	aileron, elevator and rudder
$a_{\mathrm{ir}}, a_{\mathrm{il}}, a_{\mathrm{or}}, a_{\mathrm{ol}}$	=	inner right, inner left, outer right, and outer left ailerons
comm	=	commanded
$e_{\mathrm{ir}}, e_{\mathrm{il}}, e_{\mathrm{or}}, e_{\mathrm{ol}}$	=	inner right, inner left, outer right, and outer left elevators
f_o, f_i	=	outer and inner flaps
i_h	=	incidence angle of the stabilizer, rad
l, m, n	=	combined aerodynamic and thrust moment around the body X–Y–Z axis, Nm
l, r	=	left and right
r_u, r_l	=	upper and lower rudders
sp	=	spoiler
0	=	constant term

I. Introduction

WITHIN the aviation community, especially for commercial transport aircraft design, all developments focus on improving safety levels and reducing the risks that cause critical failures. When one analyzes recent aircraft accident statistics, it is clear that a significant portion is attributed to "loss of control in flight." A recent worldwide civil aviation accident survey for the 1989–2003 period, conducted by the Civil Aviation Authority of The Netherlands and based on data from the National Aerospace

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