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Design of Nonlinear Automatic Flight Control Systems*

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A nonlinear aircraft automatic flight control system, developed for use at high angles of attack, reduces altitude loss during stall and increases the magnitude of the angle of attack from which the aircraft can recover from stall.

Key Word Index—Aerospace control; attitude control; closed loop systems; control applications; nonlinear control systems; perturbation techniques.

Summary—A method for the synthesis of nonlinear automatic flight control systems is developed, and the performance of a control system synthesized by use of this method is compared to the performance of control systems designed by use of linear quadratic optimal control theory. Comparisons are made on the basis of aircraft dynamic response at high angles of attack. It is found that the nonlinear controller reduces the altitude loss during stall and increases the magnitude of the angle of attack from which the aircraft can recover from stall.

1. INTRODUCTION

Modern high-performance aircraft often operate in flight regimes where nonlinearities significantly affect dynamic response. For example, fighter aircraft may operate at high angles of attack where the lift coefficient cannot be accurately represented as a linear function of angle of attack or at high roll rates where nonlinear, inertia, cross-coupling may result in instabilities. In such situations, dynamic response may be improved if controller design is based on nonlinear rather than linear models of aircraft dynamics.

A number of investigators have studied the problem of using optimal control theory as the basis for the design of suboptimal feedback controllers for nonlinear systems and a systematic procedure has been developed for systems in which the nonlinearities can be expressed as a power series in the state vector[1–9]. This procedure has been applied to only a few problems of practical interest and results previously reported[10, 11] do not indicate that nonlinear control produces clear-cut improvements in dynamic response when compared with controllers designed using linear quadratic optimal control theory.

The objective of this paper is to apply nonlinear feedback control theory to the design of a flight control system which can provide acceptable dynamic response over the entire range of angle of attack which a modern high performance aircraft may operate. Control system performance is particularly critical at large angles of attack as the uncompensated dynamic characteristics of the aircraft may result in abnormal and sometimes hazardous flying qualities.

The paper is divided into three major sections. In the first section, the nonlinear equations describing the longitudinal motion of an aircraft are developed. The general equations are derived and are applied to a specific aircraft, the F-8 Crusader. Synthesis of the linear and nonlinear controllers is presented in the second section. The easiest known nonlinear case is given the majority of attention. Evaluation of the linear and nonlinear control systems are presented in the third section. It is found that the nonlinear system results in considerably improved dynamic response when compared with the linear system.

2. NONLINEAR DYNAMICAL MODEL

The forces considered and the coordinate system used are shown in Fig. 1. The drag is small compared with the lift and weight and is neglected in this analysis. The lift is separated into its wing and tail components[12].

The basic equations of longitudinal motion are

$$m\dot{u} = -mw\dot{\theta} - mg\sin\theta + L_w\sin\alpha + L_t\sin\alpha_t \quad (1)$$

$$m\dot{w} = mu\dot{\theta} + mg\cos\theta - L_w\cos\alpha - L_t\cos\alpha_t \quad (2)$$

$$I_y\ddot{\theta} = M_w + l_w L_w\cos\alpha - l_t L_t\cos\alpha_t + c\dot{\theta} \quad (3)$$

where

m = mass of aircraft

u = velocity of aircraft in X direction

w = velocity of aircraft in Z direction

θ = angular displacement about Y axis, measured clockwise from the horizon as shown in Fig. 1

I_y = moment of inertia of aircraft about Y axis

L_w = wing lift

L_t = tail lift

α = wing angle of attack

α_t = tail angle of attack

M_w = wing moment

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Nonlinear Automatic Control

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Introduction To Nonlinear Automatic Control Systems Tomovic R., **Nonlinear Automatic Control** John E. Gibson,1964 **Nonlinear Automatic Control** John Egan Gibson,1963 Introduction to Nonlinear Automatic Control Systems Rajko Tomovic,1966 **Nonlinear Control Systems** Alberto Isidori,1995-08-11 The purpose of this book is to present a self contained description of the fun damentals of the theory of nonlinear control systems with special emphasis on the differential geometric approach The book is intended as a graduate text as weil as a reference to scientists and engineers involved in the analysis and design of feedback systems The first version of this book was written in 1983 while I was teach ing at the Department of Systems Science and Mathematics at Washington University in St Louis This new edition integrates my subsequent teaching experience gained at the University of Illinois in Urbana Champaign in 1987 at the Carl Cranz Gesellschaft in Oberpfaffenhofen in 1987 at the University of California in Berkeley in 1988 In addition to a major rearrangement of the last two Chapters of the first version this new edition incorporates two additional Chapters at a more elementary level and an exposition of some relevant research findings which have occurred since 1985 *Introduction to Nonlinear Automatic Control Systems* Rajko Tomovic,Paul Pignon,1966 *Introduction to nonlinear automatic control systems, tr* Rajko Tomović, Nonlinear Control Systems II Alberto Isidori,1999-09-22 This eagerly awaited follow up to Nonlinear Control Systems incorporates recent advances in the design of feedback laws for the purpose of globally stabilizing nonlinear systems via state or output feedback The author is one of the most prominent researchers in the field **Some Problems in Nonlinear Automatic Control Systems** R. T. Hughes,1967 **Automatic Control: Nonlinear control. Singular perturbation and nonlinear programming. Control systems design** International Federation of Automatic Control. World Congress,1988 **CONTROL SYSTEMS, ROBOTICS AND AUTOMATION - Volume I** Heinz Unbehauen,2009-10-11 This Encyclopedia of Control Systems Robotics and Automation is a component of the global Encyclopedia of Life Support Systems EOLSS which is an integrated compendium of twenty one Encyclopedias This 22 volume set contains 240 chapters each of size 5000 30000 words with perspectives applications and extensive illustrations It is the only publication of its kind carrying state of the art knowledge in the fields of Control Systems Robotics and Automation and is aimed by virtue of the several applications at the following five major target audiences University and College Students Educators Professional Practitioners Research Personnel and Policy Analysts Managers and Decision Makers and NGOs The Absolute Stability of Nonlinear Automatic Control Systems B. Zh Maygarin,1965 **Automatic Control** International Federation of Automatic Control. World Congress,1988 Nonlinear Control Systems II Alberto Isidori,2012-10-21 This eagerly awaited follow up to Nonlinear Control Systems incorporates recent advances in the design of feedback laws for the purpose of globally stabilizing nonlinear systems via state or output feedback The author is one of the most prominent researchers in the field Introduction to Nonlinear Automatic Control Systems ... Translated by Paul

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