

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 attitude lead during roll and increases the magnitude of the angle of attack from which the aircraft can recover from stall.

Key Words: Roll: Attitude control; attitude control; roll; roll control; roll control system; perturbation techniques.

Summary — A method for design of a roll control system for an aircraft using nonlinear synthesis is developed, and the performance of a nonlinear system synthesized by use of this method is compared to the performance of a linear system designed by use of linear quadratic optimal control theory. Comparisons are made on the basis of aeroelastic responses at high angles of attack. It is found that the nonlinear controller reduces the attitude lead during roll and increases the angle from which the angle of attack at 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 aeroelastic, 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/A-18. Synthesis of the linear and nonlinear controllers is presented in the second section. The most 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

$$m\ddot{x} = m\dot{v}^2 - \cos\alpha D + L \cos\alpha + L \sin\alpha, \quad (1)$$

$$m\ddot{v} = m\dot{v}^2 - \cos\alpha D - L \cos\alpha - L \sin\alpha, \quad (2)$$

$$I_x\ddot{\theta} = M_x, \quad I_x \cos\alpha - I_x \sin\alpha = \dot{\theta} \quad (3)$$

where

m = mass of aircraft

v = velocity of aircraft in X direction

α = angle of attack measured clockwise from the horizon as shown in Fig. 1

θ = moment of inertia of aircraft about X axis

L = wing lift

D = tail lift

$\dot{\theta}$ = rolling angle of attack

M_x = tail angle of attack

I_x = wing moment

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Nonlinear Automatic Control

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Nonlinear Automatic Control:

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 fundamentals of the theory of nonlinear control systems with special emphasis on the differential geometric approach. The book is intended as a graduate text as well 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 teaching 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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Nonlinear and Adaptive Control of Complex Systems A.L. Fradkov,I.V. Miroshnik,V.O.

Nikiforov,2013-06-29 This volume presents a theoretical framework and control methodology for a class of complex dynamical systems characterised by high state space dimension multiple inputs and outputs significant nonlinearity parametric uncertainty and unmodeled dynamics A unique feature of the authors approach is the combination of rigorous concepts and methods of nonlinear control invariant and attracting submanifolds Lyapunov functions exact linearisation passification with approximate decomposition results based on singular perturbations and decentralisation Some results published previously in the Russian literature and not well known in the West are brought to light Basic concepts of modern nonlinear control and motivating examples are given Audience This book will be useful for researchers engineers university lecturers and postgraduate students specialising in the fields of applied mathematics and engineering such as automatic control robotics and control of vibrations

Static Methods in the Design of Nonlinear Automatic Control Systems N.

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Nonlinear Control Systems using MATLAB® Mourad Boufadene,2018-09-24 The development of computer software for nonlinear control systems has provided many benefits for teaching research and the development of control systems design MATLAB is considered the dominant software platforms for linear and nonlinear control systems analysis This book provides an easy way to learn nonlinear control systems such as feedback linearization technique and Sliding mode control Structure variable control which are one of the most used techniques in nonlinear control dynamical systems therefore teachers students and researchers are all in need to handle such techniques and since they are too difficult for them to handle such nonlinear controllers especially for a more complicated systems such as induction motor satellite and vehicles dynamical models Thus this document it is an excellent resource for learning the principle of feedback linearization and sliding mode techniques in an easy and simple way Provides a briefs description of the feedback linearization and sliding mode control strategies Includes a simple method on how to determine the right and appropriate controller P PI PID for feedback linearization control strategy A Symbolic MATLAB Based function for finding the feedback linearization and sliding mode controllers are developed and tested using several examples A simple method for finding the approximate sliding mode controller parameters is introduced Where the program used to construct the nonlinear controller uses symbolic computations such that the user should provide the program with the necessary functions $f(x)$ $g(x)$ and $h(x)$ using the symbolic library

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