



Table of Contents

PREFACE TO THE SECOND EDITION

1. INTRODUCTION

- 1.1 ELEMENTS OF THE AIRPLANE
 - Airframe Components
 - Propulsion Systems
- 1.2 REPRESENTATIVE AIRCRAFT
 - Light General Aviation Aircraft
 - Uninhabited Air Vehicle
 - Variable-Stability Research Aircraft
 - Sailplane
 - Business Jet Aircraft
 - Turboprop Commuter Aircraft
 - Small Jet Transport Aircraft
 - Medium Jet Transport Aircraft
 - Large Jet Transport Aircraft
 - Fighter/Attack Aircraft
 - Jet Trainer Aircraft
 - Hybrid Wing Body Aircraft
 - Supersonic and Hypersonic Transport Aircraft
 - Lifting Reentry Spacecraft
- 1.3 THE MECHANICS OF FLIGHT
 - >> Scalars, Vectors, and Matrices
 - >> Derivatives and Integrals of Time-Dependent Variables
- 1.4 COURSES IN FLIGHT DYNAMICS
- REFERENCES FOR CHAPTER 1

2. EXPLORING THE FLIGHT ENVELOPE

- >> Newton's Laws of Motion
- 2.1 THE EARTH'S ATMOSPHERE
 - Pressure, Density, and the Speed of Sound
 - Viscosity, Humidity, and Rain
 - Wind Fields and Atmospheric Turbulence
- 2.2 KINEMATIC EQUATIONS
 - Translational Position and Velocity
 - Angular Orientation and Rate
 - >> Matrix Inverse
 - Airflow Angles
 - Summary of Axis Systems and Transformations
- 2.3 FORCES AND MOMENTS

- Alternative Axis Systems
- Aerodynamic Forces and Moments
- 2.4 STATIC AERODYNAMIC COEFFICIENTS
 - >> Characteristics of the Fuselage and a Three-Dimensional Wing
 - Lift
 - Drag
 - Pitching Moment
 - Side Force
 - Yawing Moment
 - Rolling Moment
 - Ground Effect
- 2.5 AIRCRAFT PROPULSION
 - Power and Thrust
 - Propulsion Systems
 - Propellers and Ducted Fans
 - Reciprocating Engines
 - Turboprop, Turbofan, and Turbojet Engines
 - Ramjet and Scramjet Engines
 - Electric Powerplants
 - General Thrust Models
- 2.6 FLIGHT PERFORMANCE
 - Straight-and-Level Flight
 - Steady Flight Envelope
 - Cruising Range
 - Gliding Flight
 - Climbing Flight
 - Maneuvering Envelope
 - Steady Turning Flight
- REFERENCES FOR CHAPTER 2

- 3. THE DYNAMICS OF AIRCRAFT MOTION**
- 3.1 MOMENTUM AND ENERGY
 - Translational Momentum, Work, Energy, and Power
 - Energy Height and Specific Excess Power
 - Energy-Changing Maneuvers
 - Angular Momentum and Energy
- 3.2 DYNAMIC EQUATIONS FOR A FLAT EARTH
 - Rigid-Body Dynamic Equations
 - Scalar Equations for a Symmetric Aircraft
 - Avoiding the Euler Angle Propagation Singularity

- . Direction Cosine Matrix
- . Quaternion
- Alternative Reference Frames
 - . Air-Mass-Relative Reference Frame
 - . Alternative Body Frame
 - . Principal Axis Frame
 - . Stability Axes
- >> Eigenvalues and Eigenvectors
- Acceleration Sensed at an Arbitrary Point
- 3.3 DYNAMIC EQUATIONS FOR A ROUND, ROTATING EARTH
 - Geometry and Gravity Field of the Earth
 - Rigid-Body Dynamic Equations for a Spherical Earth
- 3.4 AERODYNAMIC EFFECTS OF ROTATIONAL AND UNSTEADY MOTION
 - Pitch-Rate Effects
 - Angle-of-Attack-Rate Effects
 - Yaw-Rate Effects
 - Roll-Rate Effects
 - Effects of Wind Shear and Wake Vortices
- 3.5 AERODYNAMIC EFFECTS OF CONTROL
 - Trailing-Edge Flaps
 - Wing-Mounted Control Surfaces
 - Elevators, Stabilators, Elevons, and Canards
 - Rudder
 - Ailerons
 - Other Control Devices
 - Isolated Control Surfaces at High Deflection Angle and Angle of Attack
- 3.6 SOLUTION OF NONLINEAR DIFFERENTIAL EQUATIONS
 - Numerical Algorithms for Integration
 - Equations of Motion
 - Continuous Representation of Tabulated Data
 - . Scalar Polynomials
 - . Multivariate Polynomials
 - . Computational Neural Networks
 - Trimmed Solution of the Equations of Motion
- REFERENCES FOR CHAPTER 3
- 4. METHODS OF ANALYSIS AND DESIGN**
- 4.1 LOCAL LINEARIZATION OF DIFFERENTIAL EQUATIONS
 - Stability and Control Derivatives
 - Incorporating Unsteady Aerodynamic Effects

- Symmetric Aircraft in Wings-Level Flight
- Longitudinal Equations of Motion
- Lateral-Directional Equations of Motion
- Stability-Axis Equations of Motion
- 4.2 SOLUTION OF LINEAR DIFFERENTIAL EQUATIONS
 - Numerical Integration and State Transition
 - >> Superposition of linear, time-invariant dynamic responses
 - Static and Quasistatic Equilibrium Response to Inputs
 - Initial Response to Control Inputs
 - Controllability and Observability of Motions
 - Truncation and Residualization
- 4.3 STABILITY AND MODES OF MOTION
 - Stability of Transient Response
 - Fourier and Laplace Transforms
 - Modes of Aircraft Motion
 - Phase Plane
- 4.4 FREQUENCY-DOMAIN ANALYSIS
 - Transfer Functions and Frequency Response
 - Bode Plot
 - >> Bode plot of an isolated zero
 - Nyquist Plot and Nichols Chart
 - Root Locus
- 4.5 DEALING WITH UNCERTAINTY
 - Random Variables and Processes
 - >> Stationary and nonstationary probability density functions
 - Dynamic Response to Random Inputs and Initial Conditions
 - Effects of System Parameter Variations
 - System Survey
 - Monte Carlo Evaluation
 - Stochastic Root Locus
- 4.6 LINEAR AEROELASTICITY
 - Stress, Strain, and Material Properties
 - Monocoque and Semi-Monocoque Structures
 - Force and Moments on a Simple Beam
 - Static Deflection of a Simple Beam under Load
 - Vibrations of a Simple Beam
 - . Bending Vibrations of a Uniform Beam
 - . Torsional Vibrations of a Uniform Beam
 - Coupled Vibrations of an Elastically Restrained Rigid Airfoil
 - Vibrations of a Complex Structure

- The Four-Block Structure
- Fuel Slosh
- 4.7 PILOTING ACTIONS AND AIRCRAFT FLYING QUALITIES
 - Modeling the Pilot
 - Flying Qualities Criteria
 - Levels of Autonomy
 - REFERENCES FOR CHAPTER 4
- 5. LONGITUDINAL MOTIONS**
 - 5.1 LONGITUDINAL EQUATIONS OF MOTION
 - 5.2 REDUCED-ORDER MODELS OF LONG-PERIOD MODES
 - Second-Order Phugoid-Mode Approximation
 - . Equilibrium Response to Control and Disturbance
 - . Controllability and Observability
 - . Eigenvalues, Natural Frequency, and Damping Ratio
 - . Eigenvectors
 - . Root Locus Analysis of Parameter Variations
 - . Frequency Response
 - . Root Locus Analysis of Feedback Control
 - . Time Response
 - Effects of Compressibility
 - Effects of Altitude Variation
 - . Air Density, Sound Speed, and Gravity Variations
 - . Ground Effect
 - Effects of Wind Shear
 - 5.3 REDUCED-ORDER MODEL OF THE SHORT-PERIOD MODE
 - Second-Order Approximation
 - . Equilibrium Response to Control and Disturbance
 - . Controllability and Observability
 - . Eigenvalues, Natural Frequency, and Damping Ratio
 - . Eigenvectors
 - . Root Locus Analysis of Parameter Variations
 - . Frequency Response
 - . Root Locus Analysis of Feedback Control
 - . Time Response
 - Effects of Compressibility and High Angle of Attack
 - 5.4 COUPLED PHUGOID/SHORT-PERIOD DYNAMICS
 - Residualized Phugoid Mode
 - Fourth-Order Model
 - . Equilibrium Response to Control

- . Eigenvalues and Root Locus Analysis of Parameter Variations
- . Transfer Functions and Frequency Response
- . Response to Disturbances
- . Root Locus Analysis of Feedback Control
- . Time Response
- Longitudinal Flying Qualities
- 5.5 CONTROL MECHANISMS, STICK-FREE STABILITY, AND TRIM
 - Elevator Control Mechanism
 - Short-Period/Control-Mechanism Coupling
 - Control Force for Trimmed Flight
 - Elevator Angle and Stick Force per g
 - "Tail-Wags-Dog" Effect
- 5.6 LONGITUDINAL AEROELASTIC EFFECTS
 - Truncated and Residualized Aeroelastic Models
 - Coupling of the Short Period with a Single Elastic Mode
 - . Equilibrium Response to Control
 - . Eigenvalues and Root Locus Evaluation of Parameter Variations
 - . Control and Disturbance Transfer Functions
 - . Frequency Response and the Effects of Feedback Control
 - . Effects of Elasticity on Time Response
- REFERENCES FOR CHAPTER 5

- 6. LATERAL-DIRECTIONAL MOTIONS**
- 6.1 LATERAL-DIRECTIONAL EQUATIONS OF MOTION
- 6.2 REDUCED-ORDER MODEL OF THE DUTCH ROLL MODE
 - Equilibrium Response to Control and Disturbance
 - Controllability and Observability
 - Eigenvalues, Natural Frequency, and Damping Ratio
 - Eigenvectors
 - Root Locus Analysis of Parameter Variations
 - Frequency Response
 - Root Locus Analysis of Feedback Control
 - Time Response
- 6.3 REDUCED-ORDER MODEL OF ROLL AND SPIRAL MODES
 - Equilibrium Response to Control and Disturbance
 - Controllability and Observability
 - Eigenvalues, Natural Frequency, and Damping Ratio
 - Eigenvectors
 - Root Locus Analysis of Parameter Variations
 - Frequency Response

- Root Locus Analysis of Feedback Control
- Time Response
- 6.4 COUPLED LATERAL-DIRECTIONAL DYNAMICS
 - A Truncated Dutch roll/Roll Model
 - Residualized Lateral-Directional Models
 - . Residualized Dutch Roll Mode
 - . Residualized Dutch Roll and Spiral Modes
 - . Residualized Roll-Spiral Modes
 - Fourth-Order Model
 - . Equilibrium Response to Control
 - . Eigenvalues and Root Locus Evaluation of Parameter Variations
 - . Eigenvectors
 - . Transfer Functions and Frequency Response
 - . Response to Disturbances
 - . Root Locus Analysis of Feedback Control
 - . Time Response
 - Lateral-Directional Flying Qualities
 - . Flying Qualities Criteria
- 6.5 CONTROL MECHANISMS, NONLINEARITY, AND TIME DELAY
 - Rudder Control Mechanism
 - Dutch Roll/Rudder Coupling
 - Quasilinear Representation of Nonlinearity
 - Quasilinear Root Locus Analysis
 - Roll-Spiral/Aileron Coupling
 - Spoiler Nonlinearity and Time Delay
- 6.6 LATERAL-DIRECTIONAL AEROELASTIC EFFECTS
 - Equilibrium Response to Control
 - Eigenvalues and Root Locus Analysis of Parameter Variations
 - Response to Initial Conditions and Step Control Inputs
 - . Directional Fuselage Bending Forced by Sideslip Perturbations
 - . Asymmetric Wing Twisting Forced by Sideslip Perturbations
 - . Asymmetric Wing Twisting Forced by Roll-rate Perturbations
- REFERENCES FOR CHAPTER 6
- 7. COUPLED LONGITUDINAL AND LATERAL-DIRECTIONAL MOTIONS**
 - 7.1 SMALL-AMPLITUDE MOTIONS
 - Effects of Rotating Machinery
 - Asymmetric Inertial and Aerodynamic Properties
 - Asymmetric Flight Condition and Constant Angular Rate
 - . Nonzero Sideslip Angle

- . Nonzero Roll Angle
- . Nonzero Angular Rate
- Coupling Controls
- 7.2 INERTIAL COUPLING OF PITCH AND YAW MOTIONS
 - Fifth-Order Model of Coupled Dynamics
 - Truncated and Residualized Fourth-Order Models
 - Response to Controls During Steady Rolling
- 7.3 MULTIPLE EQUILIBRIUM POINTS
 - Second-order Examples of Multiple Equilibria
 - . Cubic-Spring Effect
 - . Cubic Damper Effect
 - Effects of Cross-Coupling and Control on Rolling Equilibrium
 - . Description of the Phenomenon
 - . Characterization of Solutions
 - . Bifurcation Analysis
- 7.4 FLIGHT AT HIGH ANGLE OF ATTACK
 - High-Angle-of-Attack Aerodynamics and Control Effects
 - Fully Developed Spins
 - Simulated Motions of a Business Jet Aircraft
 - Stability of High-Angle-of-Attack Maneuvers
 - Pilot-Aircraft Interactions at High Angle of Attack
 - REFERENCES FOR CHAPTER 7
- 8. FLIGHT CONTROL DESIGN**
 - The Evolution of Flight Control
 - Flight Control Modes and Redundancy
 - Overview
 - 8.1 OPEN- AND CLOSED-LOOP COMMAND RESPONSE
 - Equilibrium Open-loop Response
 - Equilibrium Closed-loop Response
 - >> Digital Flight Control
 - 8.2 LINEAR-QUADRATIC OPTIMAL CONTROL
 - Linear-Quadratic Regulator
 - >> Criteria for Guaranteed Stability of the Linear-Quadratic Regulator
 - . LQ Regulators for a Longitudinal Dynamic Model
 - . LQ Regulators for a Lateral-Directional Dynamic Model
 - . Pre-Filtered Command Inputs to the LQ Regulator
 - . Transient Commands to the LQ Regulator
 - Output Weighting and Implicit Model Following
 - Explicit Model Following

- Integral Compensation
 - . Proportional-Integral LQ Regulator
 - . Proportional-Filter LQ Regulator
 - . Washout Filter
 - >> Sampled-Data LQ Regulator
- 8.3 OPTIMAL STATE ESTIMATION
 - Kalman-Bucy Filter
 - >> Discrete-Time Kalman Filter
 - Extended Kalman Filter
 - Parameter Estimation
 - Measurement Bias and Covariance Estimation
 - Disturbance Bias and Covariance Estimation
- 8.4 LINEAR-QUADRATIC-GAUSSIAN OPTIMAL CONTROL
 - LQG Regulator
 - Dealing with Aeroelasticity
 - >> Sampled-Data LQG Control
- 8.5 CONTROL SYSTEM ROBUSTNESS
 - Modal Properties of the LQ Regulator
 - Stability Margins and Robustness of LQ Regulators
 - Stochastic Robustness Analysis and Design
 - Stability Margins and Robustness of LQG Regulators
- 8.6 GAIN-SCHEDULED AND NEURAL NETWORK CONTROL
 - Gain Scheduling
 - Neural Network Control
- 8.7 NONLINEAR-INVERSE-DYNAMIC CONTROL
 - Lie Derivatives
 - Inverting a Linear, Time-Invariant System
 - Relative Degree of Differentiation
- 8.8 ADAPTIVE AND FAILURE-TOLERANT CONTROL
 - Machine Learning and Adaptive Critic Control
 - . Action Network
 - . Critic Network
 - Parameter-Adaptive LQG Control
 - Multiple-Model Parameter Estimation
 - Failure Detection, Identification, and Reconfiguration
 - . Failure Detection
 - . Failure Identification
 - . Control Law Reconfiguration
 - >> Entropy and Mutual Information
- REFERENCES FOR CHAPTER 8

9. EPILOGUE

APPENDICES

- A. CONSTANTS, UNITS, AND CONVERSION FACTORS**
- B. NONLINEAR SIX-DEGREE-OF-FREEDOM AIRCRAFT SIMULATION**
 - B.1 Main Program for Analysis and Simulation (FLIGHT.m)
 - B.2 Mathematical Model of the Aircraft (AeroModel.m)
 - B.2.1 Low-Angle-of-Attack, Mach-Dependent Model (AeroModelMach.m)
 - B.2.2 High-Angle-of-Attack, Low-Subsonic Model (AeroModelAlpha.m)
 - B.2.3 User-Defined Model (AeroModelUser.m)
 - B.2.4 Preliminary Modeling for Dynamic Analysis (ModelBuild.m)
 - B.3 Supporting Functions
 - B.3.1 Equations of Motion (EoM.m)
 - B.3.2 Cost Function for Aerodynamic Trim (TrimCost.m)
 - B.3.3 Rotation Matrices (DCM.m and RMQ.m)
 - B.3.4 Linear System Matrices (LinModel.m)
 - B.3.5 Wind Field (WindField.m)
 - B.3.6 Atmospheric State (Atmos.m)
- C. LINEAR SYSTEM ANALYSIS AND CONTROL SYSTEM DESIGN**
 - C.1 MAIN PROGRAM FOR LINEAR ANALYSIS AND SIMULATION (SURVEY.M)
 - C.2 Analyses and Functions
 - C.2.1 Reduced-Order Models (LonLatDir.m)
 - C.2.2 Natural Frequency (NatFreq.m)
 - C.2.3 Eigenvalues and Eigenvectors (StabMode.m)
 - C.2.4 Initial-Condition Response
 - C.2.5 Response to Control Step Input
 - C.2.6 Response to Control Time Profile
 - C.2.7 Equilibrium Response to Constant Control Perturbation
 - C.2.8 Controllability and Observability
 - C.2.9 Transfer Functions
 - C.2.10 Human-Pilot Transfer Function
 - C.2.11 Stability Margins
 - C.2.12 Bode Plots
 - C.2.13 Nyquist Plots
 - C.2.14 Nichols Charts
 - C.2.15 Root Locus Plots
 - C.3 MAIN PROGRAM FOR LINEAR-QUADRATIC CONTROL LAW DESIGN

(LQDESIGN.M)

C.4 ANALYSES AND FUNCTIONS FOR CONTROL LAW DESIGN

C.4.1 COMMAND AND CONTROL EFFECTOR SELECTION (LATOL.M AND

LONOL.M)

C.4.2 LINEAR-QUADRATIC CONTROL LAW (LQ CONTROL.M)

C.4.3 TIME RESPONSE PLOTS (LQPLOT.M)

C.4.4 CONTROL SYSTEM ROBUSTNESS (ROBUST.M)

D. PAPER AIRPLANE SIMULATION

E. EXERCISES

INDEX

BIO SKETCH