Aircraft Control And Simulation Dynamics Controls Design And Autonomous Systems

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Aircraft Control and Simulation Springer Science & Business Media
Flight Dynamics takes a new approach to the science and mathematics of aircraft flight, unifying principles of aeronautics with contemporary systems analysis. While presenting traditional material that is critical to understanding aircraft motions, it does so in the context of modern computational tools and multivariable methods. Robert Stengel devotes particular attention to models and techniques that are appropriate for analysis, simulation, evaluation of flying qualities, and control system design. He establishes bridges to classical analysis and results, and explores new territory that w.

Flight Dynamics, Simulation, and Control CRC Press
This book offers a unified presentation that does not discriminate between atmospheric and space flight. It demonstrates that the two disciplines have evolved from the same set of physical principles and introduces a broad range of critical concepts in an accessible, yet mathematically rigorous presentation. The book presents many MATLAB and Simulink-based numerical examples and real-world simulations. Replete with illustrations, end-of-chapter exercises, and selected solutions, the work is primarily useful as a textbook for advanced undergraduate and beginning graduate-level students.

Helicopter Flight Dynamics CRC Press
Aircraft operating as so-called High Altitude Platform Systems (HAPS) have been considered as a complementary technology to satellites since several years. These aircraft can be used for similar communication and monitoring tasks while operating at a fraction of the cost. Such concepts have been successfully tested. Those include the AeroVironment Helios and the Airbus Zephyr, with an endurance of nearly 624 hours (26 days). All these HAPS aircraft have a high-aspect-ratio wing using lightweight construction. In gusty atmosphere, this results in high bending moments and high structural loads, which can lead to overloads. Aircraft crashes, for example from Google's Solara 50 or Facebook's Aquila give proof of that fact. Especially in the troposphere, where the active weather takes place, gust loads occur, which can lead to the destruction of the structure. The Airbus Zephyr, the only HAPS aircraft without flight accidents, provides only a very small payload. Thus it does not fully comply with the requirements for future HAPS aircraft. To overcome the shortcomings of such single-wing aircraft, so-called multibody aircraft are considered to be an alternative. The concept assumes multiple aircraft connected to each other at their wingtips. It goes back to the German engineer Dr. Vogt. In the United States, shortly after the end of World War II, he experimented with the coupling of manned aircraft. This resulted in a high-aspect-ratio wing for the aircraft formation. The range of the formation could be increased correspondingly. The engineer Geoffrey S. Sommer took up Vogt's idea and patented an aircraft configuration consisting of several unmanned aerial vehicles coupled at their wingtips. However, the patent does not provide any insight into the flight performance, the flight mechanical modeling or the control of such an aircraft. Single publications exist that deal with the performance of coupled aircraft. A profound, complete analysis, however, is missing so far. This is where the present work starts. For the first time, a flying vehicle based on the concept of the multibody aircraft will be analyzed in terms of flight mechanics and flight control. In a performance analysis, the aircraft concept is analyzed in detail and the benefits in terms of bending moments and flight performance are clearly highlighted. Limits for operation in flight are shown considering aerodynamic optimal points. The joints at the wingtips allow a roll and pitch motion of the individual aircraft. This results in additional degrees of freedom for the design through the implementation of different relative pitch and bank angles. For example, using individual pitch angles for individual aircraft further decreases the induced drag and increases flight performance. Because the lift is distributed symmetrically, but not homogenously along the wingspan, a lateral trim of the individual aircraft in formation flight becomes necessary. The thesis presents a new method to implement this trim by moving the battery mass along half the wingspan, which avoids additional parasite drag. Further, a complete flight dynamics model is provided and analyzed for aircraft that are mechanically connected at their wingtips. To study this model in detail, a hypothetical torsional and bending spring between the aircraft is introduced. If the spring constants are very high, the flight dynamics model has properties similar to those of an elastic aircraft. Rigid-body and formation eigenmotions can be clearly distinguished. If the spring constants are reduced towards zero, which represents the case of the multibody aircraft, classical flight mechanics eigenmotions and modes resulting from the additional degrees of freedom are coupled. This affects the eigenstructure of the aircraft. Hence, normal motions with respect to the inertial space as known from a rigid aircraft cannot be observed anymore. The plant also reveals unstable behavior. Using the non-linear flight dynamics model, flight controllers are designed to stabilize the plant and provide the aircraft with an eigenstructure similar to conventional aircraft. Different controller design methods are used. The flight controller shall further maintain a determined shape of the flight formation, it shall control flight, bank and pitch angles, and it shall suppress disturbances. Flight control theories in the time domain (Eigenstructure assignment) and in the frequency domain (H-infinity loop-shaping) are considered. The resulting inner-control loops yield a multibody aircraft behavior that is similar to the one of a rigid aircraft. For the outer-control loops, classical autopilot concepts are applied. Overall, the flight trajectory of the multibody aircraft above ground is controlled and, thus, an actual operation as HAPS is possible. In the last step, the flight controller is successfully validated in non-linear simulations with complete flight dynamics. Flugzeuge in der Form von sogenannten Höhenplattformen (engl. High-Altitude Platform Systems, HAPS) werden seit einigen Jahren als kostengünstige Ergänzung zu teuren Satelliten betrachtet. Diese Flugzeuge können für ähnliche Kommunikations- und überwachungsaufgaben eingesetzt werden. Zu den gegenwärtigen Konzepten solcher Fluggeräte, die bereits erfolgreich im Flugversuch eingesetzt wurden, zählen der Helios von AeroVironment und der Airbus Zephyr, der eine Flugdauer von fast 624 Stunden (26 Tagen) erreicht hat. Alle diese HAPS-Flugzeuge besitzen einen Flügel langer Streckung, der in Leichtbauweise konstruiert ist. Hieraus resultieren in böiger Atmosphäre hohe Biegemomente und starke strukturelle Belastungen, die zu überbelastungen führen können. Flugunfälle beispielsweise von Googles Solara 50 oder Facebooks Aquila belegen dies. Insbesondere in der Troposphäre, in der das aktive Wetter stattfindet, treten Böenlasten auf, die die Struktur zerstören können. Der Airbus Zephyr, der bisher als einziges HAPS-Flugzeug frei von Flugunfällen ist, besitzt nur eine sehr geringe Nutzlast. Daher kann er die Anforderungen an zukünftige HAPS-Flugzeuge nicht vollständig erfüllen. Um die Schwachstellen solcher Ein-Flügel-Konzepte zu überwinden, wird in dieser Arbeit ein alternatives Flugzeugkonzept betrachtet, das als Mehrkörperflugzeug bezeichnet wird. Das Konzept geht von mehreren, an den Flügelspitzen miteinander verbundenen Flugzeugen aus und beruht auf Ideen des deutschen Ingenieurs Dr. Vogt. Dieser hatte in den USA kurz nach Ende des Zweiten Weltkrieges bemannte Flugzeuge aneinanderkoppeln lassen. Hierdurch ergab sich ein Flugzeugverbund mit einem Flügel langer Streckung. Damit konnte die Reichweite des Verbundes gesteigert werden. Geoffrey S. Sommer griff die Idee von Vogt auf und lies sich eine Flugzeugkonfiguration patentieren, die aus mehreren, unbemannten Flugzeugen besteht, die an den Enden der Tragflächen miteinander gekoppelt sind. Die Patentschrift gibt jedoch keinen Einblick in die Flugleistungen, die flugmechanische Modellierung oder die Regelung eines solchen Fluggerätes. Vereinzelt existieren Veröffentlichungen, die sich mit den Flugleistungen von gekoppelten Luftfahrzeugen beschäftigen. Eine tiefgreifende, vollständige flugmechanische Analyse fehlt jedoch bisher. Hier setzt die vorliegende Arbeit an. Ein Fluggerät basierend auf dem Konzept des Mehrkörperflug-zeugs wird erstmalig hinsichtlich der Flugmechanik und Flugregelung untersucht. In einer Flugleistungsbetrachtung wird das

Flugzeugkonzept genau analysiert und die Vorteile hinsichtlich der Biegemomente und der Flugleistungen klar herausgestellt. Die Grenzen des Einsatzes im Flugbetrieb werden mithilfe aerodynamischer Optimalpunkte aufgezeigt. über die Lager an den Flügelspitzen, die eine relative Roll- und Nickbewegung der Flugzeuge untereinander ermöglichen, ergeben sich durch die Einstellung unterschiedlicher Längslage- und Hängewinkel zusätzliche Freiheitsgerade im Entwurf. Die Verwendung unterschiedlicher Nicklagewinkel der einzelnen Flugzeuge reduziert beispielsweise den induzierten Widerstand weiter und steigert die Flugleistung. Durch die symmetrische, entlang der Spannweite jedoch nicht homogene Auftriebsverteilung ist auch eine laterale Trimmung der einzelnen Flugzeuge in der Formation notwendig. Hier stellt die Arbeit eine neuartige Möglichkeit vor, um diese Trimmung ohne zusätzlichen parasitären Widerstand mittels Verschiebung der Batteriemasse entlang der Halbspannweite umzusetzen. Weiterhin wird ein vollständiges flugdynamisches Modell für über mechanische Lager verbundene Luftfahrzeuge aufgestellt und analysiert. Für diese Analyse wird eine hypothetische Torsions- und Biegefeder zwischen den Flugzeugen modelliert. Sind die Federsteifigkeiten hinreichend hoch, besitzt das flugdynamische Modell Eigenschaften, die einem elastischen Flugzeug entsprechen. Starrkörper- und elastische Eigenbewegungsformen sind in diesem Fall klar separiert. Bei immer weiterer Reduzierung, bis auf eine Federsteifigkeit von Null, kommt es zu Kopplungen zwischen den klassischen, flugmechanischen Eigenbewegungsformen und den Moden aus den zusätzlichen Freiheitsgraden. Dies stellt den Auslegungsfall für das Mehrkörperflugzeug dar. Hierbei verändert sich die Eigenstruktur (engl. eigenstructure) des Flugzeugs und normale, bei einem starren Flugzeug beobachtbare Bewegungen gegenüber dem inertialen Raum sind nicht mehr erkennbar. Zusätzlich zeigt die Strecke instabiles Verhalten. Basierend auf dem nichtlinearen, flugdynamischen Modell werden mit verschiedenen Methoden Regler entworfen, die die Regelstrecke stabilisieren und dem Flugzeug eine Streckenstruktur zuweisen, die derjenigen klassischer Flugzeuge ähnelt. Zudem soll durch die Regler eine vorgegebene Form des Flugzeugverbundes beibehalten werden, die Fahrt, der Längs- und Rolllagewinkel sollen geregelt und Störungen unterdrückt werden. Als Auslegungsverfahren werden Theorien der Zustandsregelungen im Zeitbereich (Eigenstrukturvorgabe) und Frequenzbereich (H-infinity loop-shaping) verwendet. Hierdurch wird durch die inneren Regelschleifen ein Verhalten des Mehrkörperflugzeugs erzielt, das dem eines starren Flugzeugs entspricht. Für die äußeren Regelschleifen werden anschließend klassische Konzepte von Autopiloten verwendet. Im Ergebnis ist eine Regelung des Flugweges über Grund des Mehrkörperflugzeugs und somit ein tatsächlicher Betrieb als HAPS möglich. Die Funktionalität des Reglers wird abschließend in nichtlinearen Simulationen mit vollständiger Flugdynamik verifiziert.

Flight Mechanics Modeling and Analysis John Wiley & Sons

Advanced Control of Aircraft, Spacecraft and Rockets introduces the reader to the concepts of modern control theory applied to the design and analysis of general flight control systems in a concise and mathematically rigorous style. It presents a comprehensive treatment of both atmospheric and space flight control systems including aircraft, rockets (missiles and launch vehicles), entry vehicles and spacecraft (both orbital and attitude control). The broad coverage of topics emphasizes the synergies among the various flight control systems and attempts to show their evolution from the same set of physical principles as well as their design and analysis by similar mathematical tools. In addition, this book presents state-of-art control system design methods - including multivariable, optimal, robust, digital and nonlinear strategies - as applied to modern flight control systems. Advanced Control of Aircraft, Spacecraft and Rockets features worked examples and problems at the end of each chapter as well as a number of MATLAB / Simulink examples housed on an accompanying website at http://home.iitk.ac.in/~ashtew that are realistic and representative of the state-of-the-art in flight control.

Helicopter Flight Dynamics Butterworth-Heinemann

Das komplett vierfarbig gedruckte Handbuch bietet Studierenden, Ingenieuren und Wissenschaftlern sowie ambitionierten Luftfahrtinteressierten detaillierte Einblicke in die faszinierende Technik der Luftfahrzeuge. Ausgehend von den Grundlagen, werden in den Hauptkapiteln - Einführung (Historie, Einteilung der Luftfahrzeuge) - Aerodynamik (u. a. Strömungsmechanik, Konfigurationsaerodynamik, Transportflugzeuge, Kampfflugzeuge, Hubschrauber, Flügelentwurf, Hochauftrieb, Heck- und Leitwerksaerodynamik, Aeroakustik, Numerische Methoden, Versuchstechnik) - Flugmechanik (u. a. Flugleistungen, Stabilität, Steuerung, Flugdynamik) - Luftfahrzeugstrukturen (u. a. Luftfahrtwerkstoffe, Strukturtheorie, Konstruktionsphilosophien, Bauweisen, Strukturdynamik, Adaptive Strukturen, Strukturversuche) - Antriebe (u. a. Propeller- und Turbopropantriebe, Strahltriebwerke, Triebwerkssysteme) - Flugführung (u. a. Koordinatensysteme, Flugzustandserfassung, Sensoren, Navigationssysteme, Systemarchitekturen, Navigationsverfahren, Landesysteme) - Luftfahrzeugsysteme (u. a. Klimaanlagen, Bordstromversorgung, Ausrüstung, Feuerschutz, Kraftstoffsystem, Hydraulikversorgung, Eis- und Regenschutz, Fahrwerk, Beleuchtung, Sauerstoffanlage, Pneumatikversorgung, Wasser-/Abwasseranlage, Hilfstriebwerk) vor allem die Abläufe und Methoden für die Entwicklung, den Bau und den Betrieb von Luftfahrzeugen beschrieben.

Atmospheric and Space Flight Dynamics John Wiley & Sons

The Book The behaviour of helicopters and tiltrotor aircraft is so complex that understanding the physical mechanisms at work in trim, stability and response, and thus the prediction of Flying Qualities, requires a framework of analytical and numerical modelling and simulation. Good Flying Qualities are vital for ensuring that mission performance is achievable with safety and, in the first and second editions of Helicopter Flight Dynamics, a comprehensive treatment of design criteria was presented, relating to both normal and degraded Flying Qualities. Fully embracing the consequences of Degraded Flying Qualities during the design phase will contribute positively to safety. In this third edition, two new Chapters are included. Chapter 9 takes the reader on a journey from the origins of the story of Flying Qualities, tracing key contributions to the developing maturity and to the current position. Chapter 10 provides a comprehensive treatment of the Flight Dynamics of tiltrotor aircraft; informed by research activities and the limited data on operational aircraft. Many of the unique behavioural characteristics of tiltrotors are revealed for the first time in this book. The accurate prediction and assessment of Flying Qualities draws on the modelling and simulation discipline on the one hand and testing practice on the other. Checking predictions in flight requires clearly defined mission tasks, derived from realistic performance requirements. High fidelity simulations also form the basis for the design of stability and control augmentation systems, essential for conferring Level 1 Flying Qualities. The integrated description of flight dynamic modelling, simulation and flying qualities of rotorcraft forms the subject of this book, which will be of interest to engineers practising and honing their skills in research laboratories, academia and manufacturing industries, test pilots and flight test engineers, and as a reference for graduate and postgraduate students in aerospace engineering.

Development of a Simulation Tool for Flight Dynamics and Control Investigations of Articulated VTOL Unmanned Aircraft John Wiley & Sons

Explore Key Concepts and Techniques Associated with Control Configured Elastic Aircraft A rapid rise in air travel in the past decade is driving the development of newer, more energy-efficient, and malleable aircraft. Typically lighter and more flexible than the traditional rigid body, this new ideal calls for adaptations to some conventional concepts. Flight Dynamics, Simulation, and Control: For Rigid and Flexible Aircraft addresses the intricacies involved in the dynamic modelling, simulation, and control of a selection of aircraft. This book covers the conventional dynamics of rigid aircraft, explores key concepts associated with control configured elastic aircraft, and examines the use of linear and non-linear model-based techniques and their applications to flight control. In addition, it reveals how the principles of modeling and control can be applied to both traditional rigid and modern flexible aircraft. Understand the Basic Principles Governing Aerodynamic Flows This text consists of ten chapters outlining a range of topics relevant to the understanding of flight dynamics, regulation, and control. The book material describes the basics of flight simulation and control, the basics of nonlinear aircraft dynamics, and the principles of control configured aircraft design. It explains how elasticity of the wings/fuselage can be included in the dynamics and simulation, and highlights the principles of nonlinear stability analysis of both rigid and flexible aircraft. The reader can explore the mechanics of equilibrium flight and static equilibrium, trimmed steady level flight, the analysis of the static stability of an aircraft, static margins, stick-fixed and stick-free, modeling of control surface hinge-moments, and the estimation of the elevator for trim. Introduces case studies of practical control laws for several modern aircraft Explores the evaluation of aircraft dynamic response Applies MATLAB®/Simulink® in determining the aircraft’s response to typical control inputs Explains the methods of modeling both rigid and flexible aircraft for controller design application Written with aerospace engineering faculty and students, engineers, and researchers in mind, Flight Dynamics, Simulation, and Control: For Rigid and Flexible Aircraft serves as a useful resource for the exploration and study of simulation of flight dynamics.

Aircraft Dynamics: From Modeling to Simulation Createspace Independent Publishing Platform

Flight dynamicists today need not only a thorough understanding of the classical stability and control theory of aircraft, but also a working appreciation of flight control systems and consequently a grounding in the theory of automatic control. In this text the author fulfils these requirements by developing the theory of stability and control of aircraft in a systems context. The key considerations are introduced using dimensional or normalised dimensional forms of the aircraft equations of motion only and through necessity the scope of the text will be limited to linearised small perturbation aircraft models. The material is intended for those coming to the subject for the first time and will provide a secure foundation from which to move into non-linear flight dynamics, simulation and advanced flight control. Placing emphasis on dynamics and their importance to flying and handling qualities it is accessible to both the aeronautical engineer and the control engineer. Emphasis on the design of flight control systems Intended for undergraduate and postgraduate students studying aeronautical subjects and avionics, systems engineering, control engineering Provides basic skills to analyse and evaluate aircraft flying qualities

Präzisere Echtzeit-Flugsimulation kleiner Nutzflugzeuge durch Integration feingranularer Teilmodelle Springer-Verlag

This is the first book to focus on the use of nonlinear analysis and synthesis techniques for aircraft control. It is also the first book to address in detail closed-loop control problems for aircraft "on-ground" – i.e. speed and directional control of aircraft before take-off and after touch down. The book will be of interest to engineers, researchers, and students in control engineering, and especially aircraft control.

Flight Simulation Software John Wiley & Sons

Aircraft Control and SimulationJohn Wiley & Sons

A Simulation Study of the Flight Dynamics of Elastic Aircraft. Volume 2: Data Universitätsverlag der TU Berlin

Good flying qualities are vital for ensuring that mission performance is achievable with safety and, in the first edition of Helicopter Flight Dynamics, a comprehensive treatment of design criteria was presented. In this second edition, the author complements this with a new chapter on degraded flying qualities, drawing examples from flight in poor visibility, failure of control functions and encounters with severe atmospheric disturbances. Fully embracing the consequences of degraded flying qualities during the design phase will contribute positively to safety. The accurate prediction and assessment of flying qualities draws on modelling and simulation discipline on the one hand and testing methodologies on the other. Checking predictions in flight requires clearly defined 'mission-task-elements', derived from missions with realistic performance requirements. High fidelity simulations also form the basis (or the design of stability and control augmentation systems, essential for conferring level one flying qualities. The integrated description of flight dynamic modelling, simulation and flying qualities forms the subject of this book, which will be of interest to engineers in research laboratories and manufacturing industry, test pilots and flight test engineers, and as a reference for graduate and postgraduate students in aerospace engineering.

Flight mechanics and flight control for a multibody aircraft Princeton University Press

Upset flight dynamics are characterised by unstable, highly nonlinear behaviourof the aircraft aerodynamic system. As upsets often lead to in-flight loss-of-control (LOC-I) accidents,it still poses a severe threat to today's commercial aviation. Contributing to almost everysecond fatality in civil aviation while representing merely 10% of the total accidents (both fataland nonfatal), the International Air Transport Association has classified LOC-I as the “highestrisk to aviation safety”. Considerable effort has been undertaken in response by academics,manufacturers, commercial airlines, and authorities to predict and prevent LOC-I events as wellas recover from upset conditions into the nominal flight envelope. As result, researchers fromboth aeronautical engineering and system theory have made significant contributions towardsaviation safety; however, approaches from engineering and theory are rather disparate. This thesistherefore focuses on the application and transfer of system theoretical results to engineeringapplications.In particular, we have found simple polynomial models for aircraft dynamics, despite commonin the system theoretical literature, failing to represent full-envelope aerodynamics accurately.Advanced fitting methods such as multi-variate splines, on the other hand, are unsuitable forsome of the proposed functional analysis methods. Instead, a simple piecewise defined polynomialmodel proves to be accurate in fitting the aerodynamic coefficients for low and high angles ofattack. State-of-the-art bifurcation analysis and analysis based on sum-of-squares programmingtechniques are extended for this class of models and applied to a piecewise equations of motionof the Generic Transport Model (GTM). In the same spirit, we develop a model for a small,fixed-wing aircraft based on static continuous fluid dynamics (CFD) simulations. In the lackof dynamic coefficients from CFD, we identify a pitch-damping model comparing bifurcationanalysis and flight data that predicts well dynamics and stability of deep-stall flight.Previous developments in sum-of-squares programming have been promising for the certificationof nonlinear dynamics and flight control laws, yet their application in aeronauticalengineering halted. In combination with piecewise polynomial modeling, we are able to re-applythis technique for analysis in an accurate but computationally feasible manner to verify stablerecovery. Subsequently, we synthesise inherently stable linear and polynomial feedback laws fordeep-stall recovery. We further extend the estimation of regions of attraction for the piecewisepolynomial model towards an improved algorithm for local stability analysis of arbitrary switchingsystems, such as splines, thus making our work available for future analysis and certificationof highly accurate algebraic models.With highly nonlinear dynamics and critical state and input constraints challenging upsetrecovery, model-predictive control (MPC) with receding horizon is a powerful approach. MPCfurther provides a mature stability theory contributing towards the needs for flight control certification.Yet, for realistic control systems careful algebraic or semi-algebraic considerationsare necessary in order to rigorously prove closed-loop stability. Employing sum-of-squares programming,we provide a stability proof for a deep-stall recovery strategy minimising the loss ofaltitude during recovery. We further demonstrate MPC schemes for recovery from spiral andoscillatory spin upsets in an uncertain environment making use of the well-known and freelyavailable high-fidelity GTM desktop simulation.The results of this thesis are thus promising for future system theoretic approaches in modeling,analysis, and control of aircraft upset dynamics for the development and certification offlight control systems in order to prevent in-flight loss-of-control accidents.

Flight Control Systems Springer

Presenting research papers contributed by experts in dynamics and control, Advances in Dynamics and Control examines new ideas, reviews the latest results, and investigates emerging directions in the rapidly-growing field of aviation and aerospace. Exploring a wide range of topics, key areas discussed include:* rotorcraft dynamics* stabilization of

CRC Press

Flight Simulation Software comprehensively covers many aspects of flight simulation; from software design to flight control systems, navigation systems and visual systems. It provides working software taken from flight simulators and demonstrates a variety of different systems that can be used in flight simulation. Delving into software design, programming languages, computer graphics and parallel processing, this book is detailed and covers a wide range of topics for flight simulation software. The author-a noted expert on the topic- uniquely presents flight control systems and displays, allowing readers a fresh outlook on how they view aspects of flight simulation. Written for engineers in industry and senior undergraduate/graduate students, Flight Simulation Software provides the basis of teaching across several disciplines, making this accessible for a wide audience.

Modelling and Simulation for Autonomous Systems Universitätsverlag der TU Berlin

Die Technologien und Anwendungsgebiete für UAV und kleine Nutzflugzeuge haben im zivilen Bereich in letzter Zeit eine rasante Entwicklung erfahren. Da der Betrieb dieser Systeme mit erheblichen Sicherheitsrisiken für den Luftverkehr verbunden ist, wird für die Soft- und Hardwareentwicklung der erforderlichen komplexen und sicherheitskritischen Avioniksysteme ein Prozess benötigt, der eine vergleichbare Zuverlässigkeit wie die für die Entwicklung von CS-25-Flugzeugen gebräuchlichen Methoden bietet. Dafür werden detaillierte, aber dennoch echtzeitfähige Simulationsmodelle benötigt, die die spezifischen Besonderheiten dieser kleineren Luftfahrzeuge berücksichtigen, die häufig der CS-23-Kategorie zuzuordnen sind. Solche spezialisierten Modelle sind wegen des üblicherweise auf klassischen Nachweismethoden beruhenden Entwicklungsprozesses und der bisher geringen wirtschaftlichen Bedeutung dieser Flugzeugklasse kaum verfügbar. Die hierzu benötigten Modellierungsansätze haben sich auf Komponentenebene in anderen Anwendungsbereichen zwar prinzipiell etabliert, ihre Integration in eine systemdynamische Echtzeitflugsimulation ist aber in der Regel nicht trivial. Der wissenschaftliche Beitrag der Arbeit betrifft diesen Integrationsprozess und die damit verbundenen Herausforderungen und erforderlichen Maßnahmen, die neben einer effizienten Implementierung u.a. die Ableitung quasistationärer Ersatzmodelle für hochfrequente Teildynamiken und die effiziente numerische Behandlung unstetiger und nichtlinearer Phänomene betreffen. Dabei müssen spezifische Merkmale kleiner Nutzflugzeuge berücksichtigt werden, die eine direkte Übertragung entsprechender Modelle aus dem CS-25-Bereich oder militärischen Anwendungen ausschließen. Ein Beispiel für die Simulation eines solchen Nutzflugzeuges stellt das flugmechanische Modell dar, das für das Motorsegelflugzeug STEMME S15 zur Entwicklung eines hochdynamischen, vollauthoritären automatischen Flugsteuerungssystems aufgebaut wurde. Das Modell zeichnet sich durch sehr detaillierte und feingranulare Ansätze bei der Modellierung verschiedener Teilsysteme (Aerodynamik, Triebwerk, Geländemodell, Fahrwerk, Aktuatorik, Sensorsysteme, etc.) aus, die im Rahmen eines Überblicks skizziert werden. Eine detaillierte Darstellung aller Einzelheiten der Modellbildung und der Implementierung im Rahmen der Echtzeitsimulation erfolgt exemplarisch für die Aktuatorik und das Fahrwerk. Bei den eingesetzten Aktuatoren handelt es sich um rotatorische, elektromechanische Stellantriebe mit Wellgetriebe (HDT, Harmonic Drive Transmission), die über ein mechanisches Steuergestänge mit den Stellflächen verbunden sind. Das Fahrwerk ist als nicht einziehbares, gummibereiftes Dreibeinfahrwerk ausgeführt. Für die Stoßdämpfung werden neben der natürlichen Strukturelastizität Elastomerfederpakete eingesetzt. Die Bugradlenkung erfolgt mit Hilfe von Steuerseilen. Ein besonderes Augenmerk bei der Modellbildung liegt auf nichtlinearen Eigenschaften und Störeinflüssen des mechanischen Übertragungsweges, der Nachgiebigkeit der Ansteuerung sowie der Strukturelastizität und Seitenführungsdynamik des Fahrwerks. Diese Effekte können Verhalten und Leistungsfähigkeit des Regelungssystems maßgeblich beeinflussen. Für beide Teilsysteme wird die mathematische Modellbildung, die Implementierung und die Parameterbestimmung in einer Ausführlichkeit beschrieben, die die Ergebnisse für den Fachmann nachvollziehbar macht. Die entwickelten Teilmodelle werden zunächst einzeln durch speziell darauf ausgelegte Experimente validiert. Anschließend wird die erfolgreiche Integration in die echtzeitfähige Gesamtsimulation anhand von ausgesuchten Fallstudien dokumentiert. Die gewählten Beispiele demonstrieren den Nutzen für den Entwicklungsprozess und die Relevanz der detaillierten Modellbildung. Abschließend werden die erreichten Ergebnisse zusammengefasst, Verbesserungspotentiale aufgezeigt und weiterführende Fragestellungen angesprochen. New civil applications for UAV and smaller utility aircrafts have been rapidly unclosed by recent advances in UAV-Technology. The operation of these systems implies a considerable safety risk. For the soft- and hardware development of the complex and safety critical avionic systems involved a process is required, which is able to guarantee a comparable reliability like methods used for the development of CS-25 aircraft. This calls for detailed, but still real time capable simulation models, which adequately account for the characteristics of these smaller aircraft typically attributed to the CS-23 category. Such models are rarely available yet, due to the still minor commercial relevance of this aircraft class, as well as the common development process, which primary relies on classical verification methods based on experimental and calculative evidence. The required modelling approaches on a component level are established in other applications. However, their integration into system dynamical real-time flight simulation is seldom trivial. The contribution of this work concerns this integration process. Challenges and methods are addressed, comprising not only an efficient implementation, but also the derivation of analogous quasi stationary models for higher frequency sub dynamics as well as numerical methods able to cope with discontinuous and nonlinear model behavior. Specific attributes of CS-23-type aircraft have to be considered though, impeding a direct reuse of equivalent models common for CS-25 and military aircrafts. The flight mechanical model which has been established for the motor glider STEMME S15 in order to enable the development of a high bandwidth, full authority automatic flight control system can be considered as a representative example for the simulation of such small utility aircraft. The model is characterized by a high level of detail applied for the modelling of various subsystems (aerodynamics, power plant, ground model, landing gear, actuation and sensor systems, etc.) which will be outlined in a general overview. The modelling approaches for the actuators and the landing gear as well as their implementation into the real time simulation will be exemplified in all detail. The actuators employed may be characterized as rotative electro mechanic servo motors equipped with a harmonic drive transmission (HDT). They are linked to the control surfaces by means of a mechanical control rod assembly. The undercarriage is designed as non-retractable tricycle gear with pneumatic rubber tires. Suspension is provided by elastomer pads in addition to the natural structural elasticity. Control cables are used to steer the nose gear. During modelling, special attention has been payed to the mechanical transmission path being prone to various nonlinear parasitic effects, as well as to the control weakness, structural elasticity and slippage characteristics of the landing gear. These effects may significantly influence the control system behavior and performance. The mathematical modelling approach, the implementation as well as the parameter determination is described in a level of detail allowing the results to be followed and reproduced by the experts. The developed sub models will first be individually validated by experiments specifically designed for that purpose. Afterwards the successful implementation in the real-time flight simulation of the entire aircraft will be documented using selected case studies. These examples greatly demonstrate the benefit to the FCL\footnote{Flight Control Laws} development process as well as the relevance of the detailed modelling concepts chosen. Finally the achievements will be summarized and potential improvements as well as subsequent research topics will be identified.

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An updated and expanded new edition of an authoritative book on flight dynamics and control system design for all types of current and future fixed-wing aircraft Since it was first published, Flight Dynamics has offered a new approach to the science and mathematics of aircraft flight, unifying principles of aeronautics with contemporary systems analysis. Now updated and expanded, this authoritative book by award-winning aeronautics engineer Robert Stengel presents traditional material in the context of modern computational tools and multivariable methods. Special attention is devoted to models and techniques for analysis, simulation, evaluation of flying qualities, and robust control system design. Using common notation and not assuming a strong background in aeronautics, Flight Dynamics will engage a wide variety of readers, including aircraft designers, flight test engineers, researchers, instructors, and students. It introduces principles, derivations, and equations of flight dynamics as well as methods of flight control design with frequent reference to MATLAB functions and examples. Topics include aerodynamics, propulsion, structures, flying qualities, flight control, and the atmospheric and gravitational environment. The second edition of Flight Dynamics features up-to-date examples; a new chapter on control law design for digital fly-by-wire systems; new material on propulsion, aerodynamics of control surfaces, and aeroelastic control; many more illustrations; and text boxes that introduce general mathematical concepts. Features a fluid, progressive presentation that aids informal and self-directed study Provides a clear, consistent notation that supports understanding, from elementary to complicated concepts Offers a comprehensive blend of aerodynamics, dynamics, and control Presents a unified

introduction of control system design, from basics to complex methods Includes links to online MATLAB software written by the author that supports the material covered in the book
Advances in Dynamics and Control John Wiley & Sons
Spacecraft Dynamics and Control: The Embedded Model Control Approach provides a uniform and systematic way of approaching space engineering control problems from the standpoint of model-based control, using state-space equations as the key paradigm for simulation, design and implementation. The book introduces the Embedded Model Control methodology for the design and implementation of attitude and orbit control systems. The logic architecture is organized around the embedded model of the spacecraft and its surrounding environment. The model is compelled to include disturbance dynamics as a repository of the uncertainty that the control law must reject to meet attitude and orbit requirements within the uncertainty class. The source of the real-time uncertainty estimation/prediction is the model error signal, as it encodes the residual discrepancies between spacecraft measurements and model output. The embedded model and the uncertainty estimation feedback (noise estimator in the book) constitute the state predictor feeding the control law. Asymptotic pole placement (exploiting the asymptotes of closed-loop transfer functions) is the way to design and tune feedback loops around the embedded model (state predictor, control law, reference generator). The design versus the uncertainty class is driven by analytic stability and performance inequalities. The method is applied to several attitude and orbit control problems. The book begins with an extensive introduction to attitude geometry and algebra and ends with the core themes: state-space dynamics and Embedded Model Control. Fundamentals of orbit, attitude and environment dynamics are treated giving emphasis to state-space formulation, disturbance dynamics, state feedback and prediction, closed-loop stability. Sensors and actuators are treated giving emphasis to their dynamics and modelling of measurement errors. Numerical tables are included and their data employed for numerical simulations. Orbit and attitude control problems of the European GOCE mission are the inspiration of numerical exercises and simulations. The suite of the attitude control modes of a GOCE-like mission is designed and simulated around the so-called mission state predictor. Solved and unsolved exercises are included within the text - and not separated at the end of chapters - for better understanding, training and application. Simulated results and their graphical plots are developed through MATLAB/Simulink code.

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