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Aerodynamic Stability Analysis of Two Heterogeneous UAVs in Close Formation Flight System

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Abstract: The close formation flight of UAVs has many significant advantages over single vehicle flight. The aerodynamic stability analysis of two heterogeneous UAVs in close formation flight is detailed in the present paper. The issues of altitude changes and the associated shifts or changes in centre of gravity or moments, the equivalent actuator control surface deflections etc. are explained with the help of simulations. The short period frequency variations with these changes are also correlated with the help of pole–zero diagrams.

Keywords: Control, Close Formation Flight, Heterogeneous UAVs, Wing Vortex

1. Introduction

The Close Formation Flight (CFF) of Unmanned Aerospace Vehicles (UAVs) has diverse advantages such as fuel saving, cost reduction and preciseness in image capturing and data collection etc. The formation flight studies of heterogeneous Unmanned Aerial Vehicles (UAV's) in a stability analysis view point is hardly difficult to find. The proposed formation flight model in this paper consists of two members, namely 'leader' and' 'follower'. The induced drag reduction caused by vortex effect of leader wing tips in close formation is made use of in this stability analysis work.

2. Literature Review

The most important control techniques used among available literature spanned over the last two decades are Intelligent Management Control Approach [1], Co-operative Control [2], Constraint Forces Approach [3], 3D Potential Field Approach [4], Co-operative tracking control [5], Constrained Adaptive Back-stepping Approach [6] and Vision based Scheme [7]. Proud, A. et al formulated PID feedback tracking control on two member system [8]. Dogan et al presented Linear Control Approach for formation reconfiguration [9]. Vanek and Balint applied Model Predictive Controltoreal-timetrajectory tracking of UAV formations [10]. Model Predictive Control Algorithm in non-linear dynamics is implemented by Saffarian and Fahimi [11]. The Decentralized Control Design Procedure for obstacle avoidance and collision is done by Haibo Min [12]. The aerodynamics associated with wing vortex effect and the resulting drag reduction is of special focus on the studies of F. Chichka et al. [13]. The simulation of aerodynamic cross-coupling vortex effects [14] is a useful reference for the present study.

After a brief review of relevant literature the stability analysis of two heterogeneous UAVs engaged in close formation flight and their associated aerodynamic interactions are detailed in section-III. The formation consensus of these UAVs from different altitude levels for drag reduction results in centre of gravity (c. g.) shifts and moment changes are quantitatively estimated and simulated in section-IV. These c. g. shifts and moment changes produces short period roots or frequency transitions, as illustrated by a pole–zero diagram at the end before conclusion. The aero stability analysis of the mechanical characteristics of two heterogeneous fixed-wing UAVs during a transformation to a close formation flight is highlighted in the present paper.

Aerodynamic Stability Analysis Of Two Heterogeneous Uavs

Ensheng Dong

Aerodynamic Stability Analysis Of Two Heterogeneous Uavs:

Proceedings of UASG 2019 Kamal Jain,Kourosh Khoshelham,Xuan Zhu,Anuj Tiwari,2020-02-22 This volume gathers the latest advances innovations and applications in the field of geographic information systems and unmanned aerial vehicle UAV technologies as presented by leading researchers and engineers at the 1st International Conference on Unmanned Aerial System in Geomatics UASG held in Roorkee India on April 6 7 2019 It covers highly diverse topics including photogrammetry and remote sensing surveying UAV manufacturing geospatial data sensing UAV processing visualization and management UAV applications and regulations geo informatics and geomatics The contributions which were selected by means of a rigorous international peer review process highlight numerous exciting ideas that will spur novel research directions and foster multidisciplinary collaboration among different specialists *Scientific and Technical Aerospace Reports* ,1995 **Proceedings of 4th 2024 International Conference on Autonomous Unmanned Systems (4th ICAUS 2024)** Lianqing Liu,Yifeng Niu,Wenxing Fu,Yi Qu,2025-04-01 This book includes original peer reviewed research papers from the 4th ICAUS 2024 which provides a unique and engaging platform for scientists engineers and practitioners from all over the world to present and share their most recent research results and innovative ideas The 4th ICAUS 2024 aims to stimulate researchers working in areas relevant to intelligent unmanned systems Topics covered include but are not limited to Unmanned Aerial Ground Surface Underwater Systems Robotic Autonomous Control Navigation and Positioning Architecture Energy and Task Planning and Effectiveness Evaluation Technologies Artificial Intelligence Algorithm Bionic Technology and their Application in Unmanned Systems The papers presented here share the latest findings in unmanned systems robotics automation intelligent systems control systems integrated networks modelling and simulation This makes the book a valuable resource for researchers engineers and students alike **Proceedings of the 2nd Aerospace Frontiers Conference (AFC 2025)** Press of Acta Aero et Astro Sinica,2025-11-11 This book includes original peer reviewed research papers from the 2nd Aerospace Frontiers Conference AFC 2025 held in Beijing China on Apr 11 14 2025 The topics covered include but are not limited to Overall Design and Autonomous Intelligence Technology of Intelligent Unmanned Aerial Vehicles Aerodynamics of Aerospace Vehicles New Aerospace Propulsion Systems Intelligent and Morphing Aircraft Technology Recent Advances and New Challenges in Aircraft Strength Technology Complexity Sciences in Aerospace Intelligent Control and Trajectory Planning of Aerospace Vehicles Frontiers in Low Altitude Traffic Intelligent Sensing and Processing of Aerospace Information Space Intelligent Control Technology Dynamics and Control of Space Unmanned Systems Lightweight Design and Evaluation in Aerospace Equipment making the book a valuable asset for researchers engineers and university students alike **International Aerospace Abstracts** ,1999 **Holistic Approach to Quantum Cryptography in Cyber Security** Shashi Bhushan,Manoj Kumar,Pramod Kumar,Renjith V. Ravi,Anuj Kumar Singh,2022-08-09 This new book discusses the concepts while also highlighting the challenges in the field of quantum cryptography and also covering

cryptographic techniques and cyber security techniques in a single volume It comprehensively covers important topics in the field of quantum cryptography with applications including quantum key distribution position based quantum cryptography quantum teleportation quantum e commerce quantum cloning cyber security techniques architectures and design cyber security techniques management software defined networks and cyber security techniques for 5G communication The text also discusses the security of practical quantum key distribution systems applications and algorithms developed for quantum cryptography as well as cyber security through quantum computing and quantum cryptography The text will be beneficial for graduate students academic researchers and professionals working in the fields of electrical engineering electronics and communications engineering computer science and information technology *Aeronautical Engineering* ,1992 A selection of annotated references to unclassified reports and journal articles that were introduced into the NASA scientific and technical information system and announced in Scientific and technical aerospace reports STAR and International aerospace abstracts IAA **NASA SP.** ,1992 Aeronautical Engineering: A Cumulative Index to a Continuing Bibliography (supplement 274) ,1992 **Advanced UAV Aerodynamics, Flight Stability and Control** Pascual Marqués,Andrea Da Ronch,2017-07-11 Comprehensively covers emerging aerospace technologies Advanced UAV aerodynamics flight stability and control Novel concepts theory and applications presents emerging aerospace technologies in the rapidly growing field of unmanned aircraft engineering Leading scientists researchers and inventors describe the findings and innovations accomplished in current research programs and industry applications throughout the world Topics included cover a wide range of new aerodynamics concepts and their applications for real world fixed wing airplanes rotary wing helicopter and quad rotor aircraft The book begins with two introductory chapters that address fundamental principles of aerodynamics and flight stability and form a knowledge base for the student of Aerospace Engineering The book then covers aerodynamics of fixed wing rotary wing and hybrid unmanned aircraft before introducing aspects of aircraft flight stability and control Key features Sound technical level and inclusion of high quality experimental and numerical data Direct application of the aerodynamic technologies and flight stability and control principles described in the book in the development of real world novel unmanned aircraft concepts Written by world class academics engineers researchers and inventors from prestigious institutions and industry The book provides up to date information in the field of Aerospace Engineering for university students and lecturers aerodynamics researchers aerospace engineers aircraft designers and manufacturers *Aerodynamics, Stability and Control Computational Analysis for UAVs* Carlos Pérez Arroyo,Pol Sintes Arroyo,Xavier Prats,José I. (José Ignacio) Rojas,2007 *A Cumulative Index to a Continuing Bibliography on Aeronautical Engineering* ,1986 **Government Reports Annual Index** ,1976 **CRREL Bibliography** ,1998 *Analysis of Linked Aircraft Aerodynamics and Flight Dynamics* Edgar Adrian Cuji,2011 In this research I have analyzed different aircrafts with nonconventional wings The analyses have included aerodynamic modeling flight dynamics and trajectory optimization Two different nonconventional aircrafts are analyzed a V

shape morphing wings and a Linked UAV system A modern adaptation of Prandtl s liftingline method is utilized to analyze the aerodynamics of both systems This method can compute the aerodynamic forces for a system of lifting surfaces with arbitrary camber sweep dihedral position and orientation The V shape morphing wings consist of a wing configuration that has two panels an out of plane dihedral section and a horizontal section An analysis of the aircraft turning dynamics shows that by manipulating the dihedral angles of the V shape wings either by symmetric or asymmetric wing shape changes can affect the turning capabilities of an aircraft to perform a variety of different missions depending on the importance of each of the turning performance measurements A linked UAV concept where individual UAVs link at high altitude creates an aerodynamically efficient system of aircraft which has long endurance capabilities and can cruise for extended periods with significantly reduced power loads This dissertation presents an analysis of close proximity aerodynamics and aircraft dynamics of two Linked UAVs As the UAVs approach each other for wingtip docking there are strong aerodynamic coupling between their wings tips An aerodynamic disturbance intensity field has been generated utilizing both simulation and wind tunnel data to determine a trajectory for the two UAVs to approach each other for midair docking Finally two optimal trajectories a 2 D and 3 D docking trajectories are generated and compared Dynamic wind tunnel test are performed to compare different midair wingtip docking trajectories The results of the optimization concludes that a trajectory with a span wise approach is more desirable since it goes through the least aerodynamic disturbances and requires less control effort to perform the midair docking maneuver **Comparative Evaluation of Computational Techniques for Estimating UAV Aerodynamic, Stability and Control Derivatives** Robert Ritchie,2013 **Aerodynamic Characteristics and Longitudinal Stability of Tube Launched Tandem-Scheme UAV** Illia S. Kryvokhatko,2018 Tube launched unmanned aerial vehicles UAV are often implemented with aerodynamic scheme with forward and rear wings so called tandem scheme Specificity of such UAV is that immediately after launch they have a flight path in which wings are turned from position along the fuselage to flight position in which sweep angles are about zero UAV aerodynamic characteristics for different wing rotation angles were researched by computational fluid dynamics CFD methods Ansys 16 software Quantitative results prove that UAV is unstable with wings rotation angles up to 60 because rear wings produce lift ahead of center of gravity Therefore low time of wings unfolding is required For high angles of wings rotation low sweep angles UAV model is stable in a wide range of angles of attack Local aerodynamic defects were found in the area of the rotation units of both wings Longitudinal vortex along the left side of fuselage was observed but it does not result in significant roll moment Further research might include UAV dynamics modelling based on calculated aerodynamics characteristics or flight tests Dynamic System Identification and Modeling of a Rotary Wing UAV for Stability and Control Analysis Matthew D. McEwen,Naval Postgraduate School (U.S.),1998-06-01 This thesis presents a method for the dynamic system identification and simulation model development of a small rotary wing UAV Using aerodynamic parameterization and linear state space modeling techniques the

Bergen Industrial UAV was modeled for computer simulation to analyze its inherent stability and control characteristics The NPS designed JANRAD software was utilized to determine the stability and control derivatives used in the simulation model The identification of the UAV dynamic model will aid in the development of closed loop controllers capable of autonomous UAV control The fidelity of the simulation model was verified by comparing the simulation responses with data collected from on board sensors during test flight   **Robust Aeroservoelastic Stability Analysis** Rick Lind,Marty Brenner,2012-12-06 The series Advances in Industrial Control aims to report and encourage technology transfer in control engineering The rapid development of control technology impacts all areas of the control discipline New theory new controllers actuators sensors new industrial processes computer methods new applications new philosophies new challenges Much of this deVelopment work resides in industrial reports feasibility study papers and the reports of advanced collaborative projects The series offers an opportunity for researchers to present an extended exposition of such new work in all aspects of industrial control for wider and rapid dissemination The high performance control systems applications in aerospace and astronautics almost have a tradition of exploiting the most advanced control theoretical developments first The optimal control and ffitering paradigm associated with the names of Kalman Bucy Anderson and Moore found application in the astronautics of the 1960 S and 1970 S At the beginning of the 1980 S control theory moved on to robustness singular values and mu analysis This new work was associated with the names of Zames Doyle Glover Balas among others The Advances in Industrial Control monograph series have published several volumes over the years which have archived the applications experience garnered from applying robust control to the aerospace sector problems Rick Lind and Marty Brenner add to this set with their volume on robust aeroservoelastic stability This volume reports the application of the structured singular value to aeroelastic and aeroservoelastic aerospace problems   *Evolving Self-organized Behavior for Homogeneous and Heterogeneous UAV Or UCAV Swarms* Ian C. Price,2006

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