Wave (FMCW) SAR. Finally, Chapter 8 brings all of these considerations together to how a realistic computer simulation can be assembled.

The style of the book is quite mathematical, as would be expected, but numerous diagrams are used to help explain the concepts. There are also many examples of SAR images, and a colour insert is provided in the centre of the book with these examples. Unfortunately, the book suffers from a number of typos and misspellings. These do not detract from the understanding of the book, but it is a shame that they were not detected and corrected.

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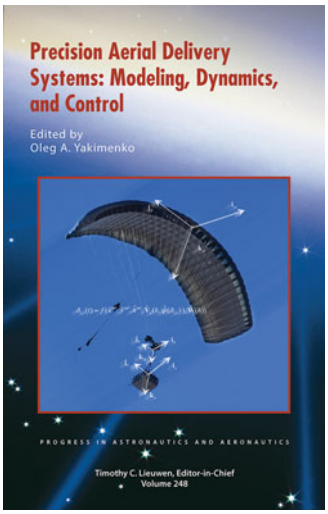


## Precision Aerial Delivery Systems: Modeling, Dynamics, and Control

## Edited by O. A. Yakimenko

*American Institute of Aeronautics and Astronautics, 1801 Alexander Bell Drive, Suite 500, Reston, VA 20191-4344, USA. 2015. Distributed by Transatlantic Publishers Group, 97 Greenham Road, London, N10 1LN. 941pp. Illustrated £115. (20% discount available to RAeS members on request; email: mark.chaloner@tpgltd.co.uk Tel: 020–8815 5994). ISBN 978-1-62410-195-3.*

The last two decades have seen tremendous progress in precision airdrop capability, largely driven by military need and realised by the use of steerable parachutes and advances in mission planning and guidance technologies. Substantial research and development efforts have been directed in particular

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toward autonomous gliding parafoil-payload systems. Such vehicles present considerable technical challenges for precision airdrop, since they have limited control authority and yet are strongly influenced by the prevailing wind conditions. This book is primarily about the modelling, dynamics, guidance, and control of these parafoil airdrop systems. Additionally, consideration is given to guidance and control techniques for improving the precision of round-canopy airdrop systems, noteworthy because round canopies are still very widely used.

The stated aim of the book is to summarise the latest developments in the subject areas, save for some recent theoretical studies not yet proven in field tests. The book certainly summarises many recent and ongoing developments that are in the public domain, especially from government laboratories and academia. However it achieves much more than this; it provides a foundation in the subject areas and practical processes by which to develop guidance and control algorithms for the said airdrop systems. The collective experience and knowledge of Yakimenko and the other contributors is very evident. Indeed, it is a real strength of this book that virtually every topic discussed is backed by the presentation of results from actual flight experience.

At around 950 pages, this is a substantial body of work. There are 828 pages of main text over 11 chapters; 41 pages of appendices; 10 pages of conventions, acronyms, and nomenclature; 29 pages of (an estimated) 400 references; and a 32-page index. According to Yakimenko, almost every chapter contains material not previously published. Nonetheless, most of the material in the main text is based on published works by researchers and practitioners well known and respected in the field. The material has been edited to integrate it together and make the conventions and nomenclature mostly consistent. Generally, this works well.

Although, mostly, the chapters need not be read in sequential order, the coverage and layout of the book largely follow the way one would set about first understanding the challenges and the key drivers, then modelling and analysing the plant and designing the guidance and control algorithms and then flight testing and undertaking parameter identification. The imperative to understand the plant and the key drivers before considering guidance and control is clearly reflected here, as is the reality that the models will be inaccurate to begin with and will need to be refined through testing. So guidance and control laws are not considered until Chapter 7, about half way through the book.

Chapter 1 ‘PADS and Measures of Their Effectiveness’ runs to over 70 pages and provides an essential introduction to parafoil-based Precision Aerial Delivery Systems (PADS). It provides an interesting narrative on how PADS and their military requirements have evolved, especially through the influence of the Joint Precision Air Drop Systems (JPADS) initiative between the US Army and US Air Force, which was so pivotal in driving forward the advances of the last two decades. Importantly, it sets out the JPADS Key Performance Parameters and Measures of Effectiveness; and it categorises and compares the many PADS that were demonstrated for JPADS in the various international Precision Airdrop Technology Conference and Demonstration (PATCAD) events between 2001 and 2009.

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Chapter 2 'Basic Analysis of the Ram-Air Parachute' is a slightly edited version of the well-known seminar paper by Lingard (1995). It is invaluable for providing a basic understanding of the plant and pointers towards the practical design of parafoils; and it offers a low-cost and accessible means of generating initial parameter values. Estimates for the aerodynamic parameters are derived by 'engineering methods' including lifting line theory and empirical knowledge, firstly on just a wing and then on the parafoil, assuming a rigid canopy and making allowances for the additional drag due to the inlet, suspension lines, and payload. Frustratingly, the nomenclature and conventions in this chapter differ from those of the other chapters, though the differences are explained at the outset.

Chapter 3 'Key Factors Affecting PADS Landing Precision' focuses on wind and atmosphere and provides confirmation of the critical importance of these topics, especially for landing precision. Good insight is achieved through presentation of real data sourced from dropsonde and balloon measurements and parafoil flight experiments and also through some interesting simulation results showing the individual contributions of source errors on miss distance. These things need to be understood if landing precision is to be improved beyond what is typically achieved today.

Chapter 4 'Aerodynamic Characterisation of Parafoils' takes the task of deriving aerodynamic estimates to a greater level of fidelity than in Chapter 2, providing more insight and arguably better characterisation. Further analytical approaches are introduced, making use of extended lifting line theory, though not all of the derivations are shown. There is an example of what can be achieved with computational fluid dynamics (CFD) and useful comparisons are made between the analytical approaches and CFD predictions. There is also a fascinating piece on prediction of occurrence of suspension-line vibration, a phenomenon potentially causing a factor-of-three increase in line drag.

Chapter 5 'Equations of Motion' develops a series of plant models for gliding parafoil-based PADS. These vary in their fidelity between 3 and 9 degrees of freedom (DOF) but all make the assumptions in some form that the parafoil and payload are rigid bodies and that the parafoil is fully inflated. Together, they provide a good cross-section of the plant models in common use today for this kind of system. The 7, 8, and 9 DOF versions have the fidelity to represent the relative rotations between the two bodies to increasing degrees and appear to be based on the well-known equations of Slegers and Gorman (c.2010-11). An attractive feature with these equations is in the way the solution to the connected two-body problem is easily and directly solved by matrix inversion.

Chapter 6 'Stability and Steady-State Performance' covers trim, static stability, the dynamic modes and turn performance for gliding parafoil-based PADS. There are some very insightful analyses in this chapter, including: derivations of stability boundaries and their dependency on basic parameters; illustrations for real PADS of how the modes can change with parameter values and between 6 DOF and 7 DOF model representations; comparisons of the modes of a PADS with those of a fixed-wing aircraft and a very interesting finding that the nature of a turn changes from almost

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fully coordinated to almost skid-to-turn as the size of the PADS increases. These things are precisely what are required for a good understanding.

Chapter 7 'Guidance, Navigation and Control' is the key chapter of the book and longest at nearly 140 pages. It provides a good overview of the status on these topics for gliding parafoil-based PADS with traditional means of control, i.e., asymmetric trailing-edge steering only. Practical navigation solutions based on classical complementary filtering are given for estimation of heading, wind, and altitude. Quite a few guidance strategies are elucidated, including the well-known T-Approach and the Draper Labs pre-computed and band-limited approaches. Wind accommodation is addressed, with reference to Chapter 3 and it is shown that winds can be destabilising with some guidance schemes. Various control schemes are described, from the commonly used proportional-integral-derivative (PID) controller based on heading rate with feedforward, to more advanced PID and model-following controllers and an interesting nonlinear dynamic inversion scheme. The chapter provides an excellent foundation.

Chapter 8 'Glide-Angle Control' considers means of changing the glide angle of a parafoil, particularly for the final stages. These include terminal drogue-chute deployment, rigging-angle control and spoilers, noting the typically limited utility of symmetric trailing-edge deflections. It is well known that better glide-angle control can significantly improve landing precision, so it is understandable that these control augmentation methods are the focus of much current research and development interest.

Chapter 9 'Control of Non-Gliding Parachute Systems' is about low-cost solutions for round-parachutes, making small in-flight adjustments to the trajectory to counter unanticipated drifts, thereby improving landing precision. A 6 DOF model is specifically developed for this kind of airdrop system and then used to investigate two potential solutions, one being to distort the canopy, the other to control the reefing. The results are both interesting and encouraging; they suggest significant improvements in precision should be possible compared with an unguided system.

Chapter 10 'Flight Test Instrumentation' covers both on-board (inertial, air data, and video) and ground-based (kineto-tracking camera) instrumentation for gathering flight data for identification of PADS trajectories and model parameters. Observation of canopy-relative motion is considered in terms of both payload-mounted video camera and use of in-canopy sensors, on which there has been much recent research interest. There is also a useful case study, albeit involving now obsolete technology. The meticulous preparation generally required for the success of flight experiments is a key theme.

Chapter 11 'Parametrical Identification of Parachute Systems' follows naturally from the previous chapter and acknowledges the importance of parameter identification for validation of PADS models. It first describes the process of flight path reconstruction before applying two off-line approaches to parameter estimation, these being based on output-error minimisation (between model and flight data) and the Extended Kalman Filter (EKF). The pragmatism of a staged approach (e.g., longitudinal first, then lateral-directional, over carefully selected flight

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segments) is clearly conveyed. Once again, real worked examples are used; a 55-state model based on X-38 PADS aerodynamics is developed for the EKF and results presented.

The coverage of the book is clearly extensive but for completeness it is worth mentioning some topics that are not covered or that are discussed only briefly. The scope does not extend to the extraction of PADS from the carrier aircraft, although an inflation model is developed on a semi-empirical basis in Chapter 2. There is some discussion of safety trace computation, but the detection, handling, and consequences of partial failures are beyond scope. Powered systems or payloads with their own active control mechanisms are beyond scope, though much of the material of the book is still very much applicable or readily extendable to these types of systems. Fluid-structural interaction modelling is discussed only briefly, in Chapter 4. GPS or GPS-INS navigation is assumed and (perhaps understandably, given its generic nature) is not discussed in depth. Also beyond scope are precision landing aids such as beacons or devices to image or profile the landing site.

This first edition contains quite a few typographical errors and there are occasions where the word usage could be improved. Nevertheless, the intended meaning is generally clear enough. Irritatingly, the two separate letters 'AR' are used to denote aspect ratio in the equations. The book is printed in greyscale except for some colour prints of parafoils at the very end. The greyscale sometimes makes it difficult to decipher graphical data, especially where the original figure was (probably) in colour and not so compressed in size (presumably done to keep down the page count). Units of measure tend to be given in both metric and imperial.

Overall, this is an excellent book. For those new to the subject areas, it provides an invaluable introduction; for undergraduate and Masters' students, it has ample material helpful for project and dissertation work; and for practitioners and researchers, it is a very useful account of what has been achieved up to the time of writing. In addition, many of the principles and techniques in the book are applicable to a wide range of applications beyond PADS.

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