

**Paul Gerin Fahlstrom
and Thomas James Gleason**

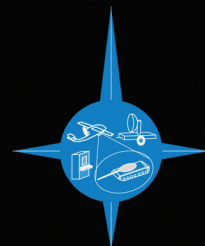
Introduction to UAV Systems

Fourth Edition

Aerospace Series

Editors **Peter Belobaba, Jonathan Cooper,
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INTRODUCTION TO UAV SYSTEMS

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INTRODUCTION TO UAV SYSTEMS

FOURTH EDITION

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Gleason Research Associates, Inc



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Preface

Introduction to UAV Systems, Fourth Edition has been written to meet the needs of both newcomers to the world of unmanned aerial vehicle (UAV) systems and experienced members of the UAV community who desire an overview and who, though they may find the treatment of their particular discipline elementary, will gain valuable insights into the other disciplines that contribute to a UAV system. The material has been presented such that it is readily understandable to college freshman and to both technical and nontechnical persons working in the UAV field, and is based on standard engineering texts as well as material developed by the authors while working in the field. Most equations have been given without proof, and the reader is encouraged to refer to standard texts of each discipline when engaging in actual design or analysis as no attempt is made to make this book a complete design handbook.

This book is also not intended to be the primary text for an introductory course in aerodynamics or imaging sensors or data links. Rather, it is intended to provide enough information in each of those areas, and others, to illustrate how they all play together to support the design of complete UAV systems and to allow the reader to understand how the technology in all of these areas affect the system-level tradeoffs that shape the overall system design. As such, it might be used as a supplementary text for a course in any of the specialty areas to provide a system-level context for the specialized material.

For a beginning student, we hope that it will whet the appetite for knowing more about at least one of the technology areas and demonstrate the power of even the simplest mathematical treatment of these subjects in allowing understanding of the tradeoffs that must occur during the system design process.

For a UAV user or operator, we hope that it will provide understanding of how the system technology affects the manner in which the UAV accomplishes its objectives and the techniques that the operator must use to make that happen.

For a “subject matter expert” in any of the disciplines involved in the design of a UAV system, we hope that it will allow better understanding of the context in which his or her specialty must operate to produce success for the system as a whole and why other specialists may seem preoccupied with things that seem unimportant to him or her.

Finally, for a technology manager, we hope that this book can help him or her understand how everything fits together, how important it is to consider the system-integration issues early in the design process so that the integration issues are considered during the basic selection of subsystem designs, and help him or her understand what the specialists are talking about and, perhaps, ask the right questions at critical times in the development process.

Part One contains a brief history and overview of UAVs in Chapter 1 and a discussion of classes and missions of UAVs in Chapter 2.

Part Two is devoted to the design of the air vehicle including basic aerodynamics, performance, stability and control, propulsion and loads, structures and materials in Chapters 3 through 7.

Part Three discusses the mission planning and control function in Chapter 8 and operational control in Chapter 9.

Part Four has three chapters addressing payloads. Chapter 10 discusses the most universal types of payloads, reconnaissance, and surveillance sensors. Chapter 11 discusses weapons payloads, a class of payloads that has become prominent since its introduction about 10 years ago. Chapter 12 discusses a few of the many other types of payloads that may be used on UAVs.

Part Five covers data links, the communication subsystems used to connect the air vehicle to the ground controllers, and deliver the data gathered by the air-vehicle payloads. Chapter 13 describes and discusses basic data-link functions and attributes. Chapter 14 covers the factors that affect the performance of a data link, including the effects of intentional and unintentional interference. Chapter 15 addresses the impact on operator and system performance of various approaches to reducing the data-rate requirements of the data link to accommodate limitations on available bandwidth. Chapter 16 summarizes data-link tradeoffs, which are one of the key elements in the overall system tradeoffs.

Part Six describes approaches for launch and recovery of UAVs, including ordinary takeoff and landing, but extending to many approaches not used for manned aircraft. Chapter 17 describes launch systems and Chapter 18 recovery systems. Chapter 19 summarizes the tradeoffs between the many different launch and recovery approaches.

Introduction to UAV Systems was first published in 1992. Much has happened in the UAV world in the 20 years since the first edition was written. In the preface to the second edition (1998), we commented that there had been further problems in the development process for tactical UAVs but that there had been some positive signs in the use of UAVs in support of the Bosnian peace-keeping missions and that there even was some talk of the possible use of “uninhabited” combat vehicles within the US Air Force that was beginning for the first time to show some interest in UAVs. At that time, we concluded that “despite some interest, and real progress in some areas, however, we believe that the entire field continues to struggle for acceptance, and UAVs have not come of age and taken their place as proven and established tools.”

In the 14 years since we made that statement, the situation has changed dramatically. UAVs have been widely adopted in the military world, unmanned combat vehicles have been deployed and used in highly visible ways, often featured on the evening news, and unmanned systems now appear to be serious contenders for the next generation of fighters and bombers.

While civilian applications still lag, impeded by the very-real issues related to mixing manned and unmanned aircraft in the general airspace, the success of military applications has encouraged attempts to resolve these issues and establish unmanned aircraft in nonmilitary roles.

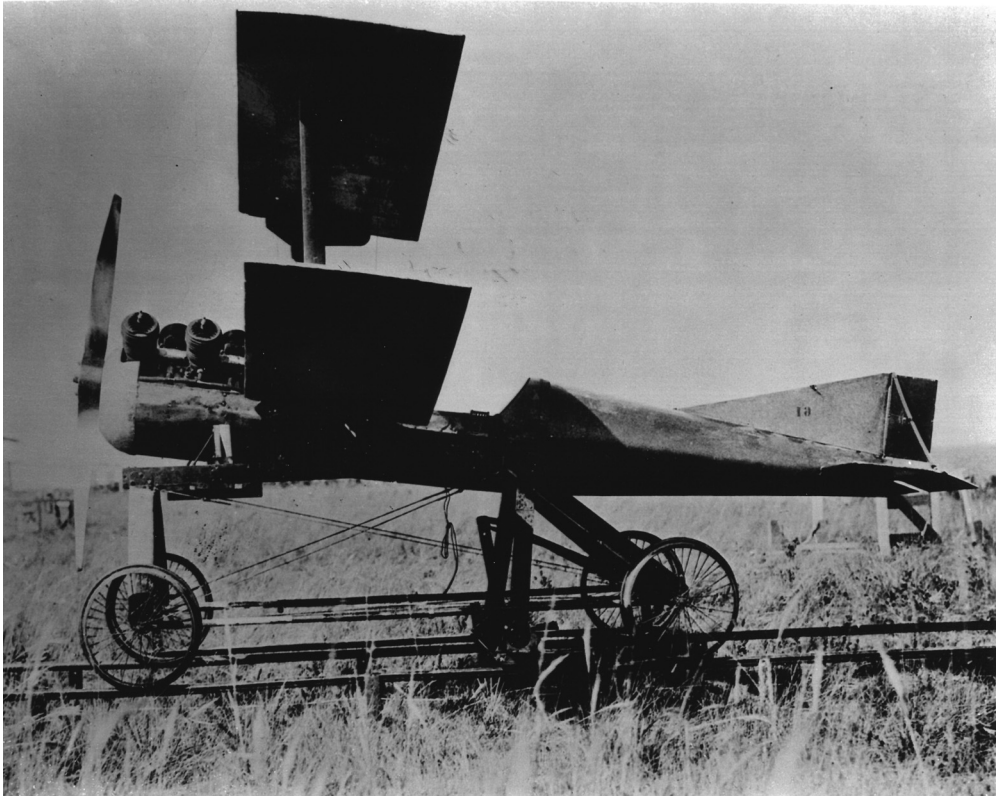
The fourth edition has been extensively revised and restructured. The revisions have, we hope, made some of the material clearer and easier to understand and have added a number of new subjects in areas that have become more prominent in the UAV world during the last decade or so, such as electric propulsion, weapons payloads, and the various levels of autonomy that may be given to an air vehicle. It also revises a number of details that have clearly been overtaken by events, and all chapters have been brought up to date to introduce

some of the new terminology, concepts, and specific UAV systems that have appeared over the last 14 years. However, the basic subsystems that make up a UAV “system of systems” have not greatly changed, and at the level that this text addresses them, the basic issues and design principles have not changed since the first edition was published.

The authors met while participating in a “red team” that was attempting to diagnose and solve serious problems in an early UAV program. The eventual diagnosis was that there had been far too little “system engineering” during the design process and that various subsystems did not work together as required for system-level success. This book grew out of a desire to write down at least some of the “lessons learned” during that experience and make them available to those who designed UAV systems in the future.

We believe that most of those lessons learned are universal enough that they are just as applicable today as they were when they were learned years ago, and hope that this book can help future UAV system designers apply them and avoid having to learn them again the “hard way.”

Paul G. Fahlstrom
Thomas J. Gleason
January 2012



The Kettering Bug (Photograph courtesy of Norman C. "Dutch" Heilman)

Series Preface

This book is a welcome addition to the Aerospace Series, continuing the tradition of the Series in providing clear and practical advice to practitioners in the field of aerospace. This book will appeal to a wide readership and is an especially good introduction to the subject by extending the range of titles on the topic of unmanned air vehicles, and more importantly presenting a systems viewpoint of unmanned air systems. This is important as the range of vehicles currently available provides a diverse range of capabilities with differing structural designs, propulsion systems, payloads, ground systems and launch/recovery mechanisms. It is difficult to see any rationalization or standardization of vehicles or support environment in the range of available solutions.

The book covers the history of unmanned flight and describes the range of solutions available world-wide. It then addresses the key aspects of the sub-systems such as structure, propulsion, navigation, sensor payloads, launch and recovery and associated ground systems in a readable and precise manner, pulling them together as elements of a total integrated system. In this way it is complementary to other systems books in the Series.

It is important for engineers and designers to visualise the totality of a system in order to gain an understanding of all that is involved in designing new vehicles or in writing new requirements to arrive at a coherent design of vehicle and infrastructure. Even more important if the new vehicle needs to interact and inter-operate with other vehicles or to operate from different facilities.

If unmanned air systems are going to become accepted in civilian airspace and in commercial applications then it is vital that a set of standards and design guidelines is in place to ensure consistency, to aid the certification process and to provide a global infrastructure similar to that existing for today's manned fleets. Without that understanding certification of unmanned air vehicles to operate in civilian controlled airspace is going to be a long and arduous task.

This book sets the standard for a definitive work on the subject of unmanned air systems by providing a measure of consistency and a clear understanding of the topic.

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We are grateful to Mr. Eric Willner, Executive Commissioning Editor for John Wiley and Sons, who first suggested a new and revised edition to be published by Wiley and was very patient with us throughout the process of working out the details of how that might be accomplished. Ms. Elizabeth Wingett, Project Editor at John Wiley and Sons, then provided us with guidance through the preparation of the manuscript.

List of Acronyms

AC	alternating current
ADT	air data terminal
AJ	Antijam
AR	aspect ratio
ARM	antiradiation munition
AV	air vehicle
BD	bi-directional
CARS	Common Automatic Recovery System
CCD	charge-coupled device
CG	center of gravity
CLRS	central launch and recovery section
CP	center of pressure
COMINT	communication intelligence
C rate	charge/discharge rate
CW	continuous wave
dB	decibel
dBa	dBs relative to the lowest pressure difference that is audible to a person
dBmv	dBs relative to 1 mv
dBsm	dB relative to 1 square meter
DF	direction finding
ECCM	electronic counter-countermeasures
ECM	electronic countermeasure
ELINT	electronic intelligence
EMI	electromagnetic interference
ERP	effective radiated power
ESM	electronic support measure
EW	electronic warfare
FCS	forward control section
FLIR	forward-looking infrared
FLOT	Forward Line of Own Troops
FOV	field of view
fps	frames per second
FSED	Full Scale Engineering Development
GCS	ground control station

GDT	ground data terminal
GPS	global positioning system
GSE	ground support equipment
Gyro	gyroscope
HELLFIRE	helicopter launched fire and forget missile
HERO	Hazards of Electromagnetic Radiation to Ordnance
HMMWV	High Mobility Multipurpose Wheeled Vehicle
I	intrinsic
IAI	Israeli Aircraft Industries
IFF	identification friend or foe
IMC	Image Motion Compensation
IR	infrared
ISO	International Organization for Standardization
JATO	Jet Assisted Take-Off
JII	Joint Integration Interface
JPO	joint project office
JSTARS	Joint Surveillance Target Attack Radar System
LAN	local area network
Li-ion	lithium ion
Li-poly	lithium polymer
LOS	line of sight
LPI	low-probability of intercept
MARS	mid-air recovery system
MART	Mini Avion de Reconnaissance Telepilot
MET	meteorological
MICNS	Modular Integrated Communication and Navigation System
MPCS	mission planning and control station
MRC	minimum resolvable contrast
MRDT	minimum resolvable delta in temperature
MRT	minimum resolvable temperature
MTF	modulation transfer function
MTI	Moving Target Indicator
N	negative
NASA	National Aeronautics and Space Administration
NDI	nondevelopmental item
NiCd	nickel cadmium
NiMH	nickel metal hydride
OSI	Open System Interconnection
OT	operational test
P	positive
PGM	precision guided munition
PIN	positive intrinsic negative
PLSS	Precision Location and Strike System
RAM	radar-absorbing material
RAP	radar-absorbing paint
RATO	rocket assisted takeoff

RF	radio frequency
RGT	remote ground terminal
RMS	root mean square
RPG	rocket propelled grenade
RPM	revolutions per minute
RPV	remotely piloted vehicle
SAR	synthetic aperture radar
SEAD	Suppression of Enemy Air Defense
shp	shaft horsepower
SIGINT	signal intelligence
SLAR	side-looking airborne radar
SOTAS	Stand-Off Target Acquisition System
SPARS	Ship Pioneer Arresting System
TADARS	Target Acquisition/Designation and Aerial Reconnaissance System
TUAV	tactical UAV
UAS	unmanned aerial system
UAV	unmanned aerial vehicle
UCAV	unmanned combat aerial vehicle
UD	unidirectional
VTOL	vertical takeoff and landing

Part One

Introduction

Part One provides a general background for an introduction to the technology of unmanned aerial vehicle systems, called “UAV systems” or “unmanned aerial systems” (UAS).

Chapter 1 presents a brief history of UAVs. It then identifies and describes the functions of the major elements (subsystems) that may be present in a generic UAS. Finally, it presents a short history of a major UAV development program that failed to produce a fielded UAS, despite significant success in many of the individual subsystems, and teaches useful lessons about the importance of understanding the inter-relationship and interactions of the subsystems of the UAS and the implications of system performance requirements at a total-systems level. This story is told here to emphasize the importance of the word “system” in the terms “UAV System” and “UAS.”

Chapter 2 contains a survey of UAS that have been or presently are in use and discusses various schemes that are used to classify UAV systems according to their size, endurance, and/or mission. The information in this chapter is subject to becoming dated because the technology of many of the subsystems of a UAS is evolving rapidly as they become more and more part of the mainstream after many years of being on the fringes of the aeronautical engineering world. Nonetheless, some feeling for the wide variety of UAS concepts and types is needed to put the later discussion of design and system integration issues into context.

