

# Designing Unmanned Aircraft Systems

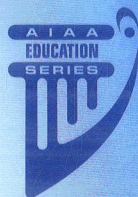
A Comprehensive Approach

---

Jay Gundlach



Joseph A. Schetz  
Editor-In-Chief



# CONTENTS

Preface	xv
Acknowledgments	xix
Nomenclature	xxi
Acronyms	xli
<b>Chapter 1</b> Overview of Unmanned Aircraft Systems	1
1.1 Introduction	2
1.2 Defining an Unmanned Aircraft	2
1.3 Motivation for Employment of Unmanned Aircraft	3
1.4 Distinction Between Manned and Unmanned Aircraft	5
1.5 Moral, Ethical, and Legal Issues for UASs	11
1.6 Brief History of Unmanned Aircraft	12
1.7 Introduction to System Elements and Architectures	21
References	22
Problems	23
<b>Chapter 2</b> Unmanned Aircraft Categories	25
2.1 Introduction	26
2.2 Micro Air Vehicles	26
2.3 Small Unmanned Aircraft	29
2.4 Small Tactical Unmanned Aircraft Systems	31
2.5 Tactical Unmanned Aircraft Systems	32
2.6 Medium-Altitude Long Endurance	34
2.7 High-Altitude Long Endurance	36
2.8 Ultra Long Endurance	38
2.9 Uninhabited Combat Aerial Vehicles	38
2.10 Manned Aircraft Conversions	40
2.11 Air-Launched Unmanned Aircraft	45
2.12 Targets	45
2.13 Rotorcraft	47
2.14 Other Vertical Takeoff and Landing	48
2.15 Solar-Powered Aircraft	50

2.16	Planetary Aircraft	52
2.17	Lighter Than Air	53
2.18	Research Unmanned Aircraft	54
	References	55
	Problems	56
<b>Chapter 3</b>	<b>Initial Unmanned-Aircraft Sizing</b>	<b>57</b>
3.1	Introduction	58
3.2	Simple Weight Relationships	58
3.3	Flight Performance	68
3.4	Simple Aerodynamics Methods	74
3.5	Initial UA Sizing Process	78
3.6	Examples	79
	References	83
	Problems	83
<b>Chapter 4</b>	<b>Unmanned-Aircraft Geometry and Configurations</b>	<b>85</b>
4.1	Introduction	86
4.2	Aircraft Geometry Relationships	86
4.3	Configuration Drivers	102
4.4	Wing System Configurations	105
4.5	Tail Configurations	128
4.6	Fuselage System Configurations	131
4.7	Propulsion Integration	131
4.8	Launch and Recovery System Integration	138
4.9	Survivability Impacts on Configuration	142
4.10	Transportability and Storage Impacts on Configuration	143
4.11	In-Flight Reconfiguration	144
4.12	Modularity and Airframe Growth	147
4.13	Manufacturing Configuration Drivers	147
4.14	Rotorcraft Configurations	148
	References	148
	Problems	149
<b>Chapter 5</b>	<b>Aerodynamics</b>	<b>151</b>
5.1	Introduction	152
5.2	Flight Regime	152
5.3	Boundary Layers	154
5.4	Coordinate Systems and Aerodynamic Coefficients	157
5.5	Airfoils	159
5.6	Three-Dimensional Lift Distribution Methods	161

5.7	Pitching Moment	171
5.8	Drag	173
5.9	Miscellaneous Drag	183
	References	183
	Problems	184
<b>Chapter 6</b>	<b>Mass Properties</b>	<b>187</b>
6.1	Introduction	188
6.2	Mass Properties Throughout the Aircraft Life Cycle	188
6.3	Conceptual Design Weight Estimation Methods	204
6.4	Weight Management	226
6.5	Weight Engineering of Other System Elements	230
	References	231
	Problems	231
<b>Chapter 7</b>	<b>Structures</b>	<b>233</b>
7.1	Introduction	234
7.2	Structural Concepts	234
7.3	Materials	244
7.4	Unmanned Aircraft Loads	250
7.5	Shell Structure Analysis	251
7.6	Wing Sizing	263
7.7	Fuselage Analysis and Sizing	276
7.8	Structures Manufacturing	282
	References	285
	Problems	286
<b>Chapter 8</b>	<b>Propulsion Systems</b>	<b>289</b>
8.1	Introduction	290
8.2	Propellers	290
8.3	Reciprocating Engines	296
8.4	Turbofans and Turbojets	306
8.5	Turboshafts and Turboprops	314
8.6	Electric Motors	317
8.7	Batteries	322
8.8	Fuel Cells	326
8.9	Solar Power	333
8.10	Hybrid Electric	340
8.11	Pulsejets	341
8.12	Rockets	342
8.13	Gliders	343

<b>8.14</b> High-Altitude Propulsion	345
<b>8.15</b> Miscellaneous Propulsion Types	347
References	350
Problems	350
<b>Chapter 9</b> Flight Performance	353
<b>9.1</b> Introduction	354
<b>9.2</b> Operating Environment	354
<b>9.3</b> Mission Profiles	356
<b>9.4</b> Constraint Analysis	358
<b>9.5</b> Flight Performance Analysis	361
Reference	378
Problems	378
<b>Chapter 10</b> Avionics, Flight Software, and Subsystems	381
<b>10.1</b> Introduction	382
<b>10.2</b> Avionics	382
<b>10.3</b> Flight Software	406
<b>10.4</b> Subsystems	408
References	417
Problems	417
<b>Chapter 11</b> Launch and Recovery	419
<b>11.1</b> Introduction	420
<b>11.2</b> Physics of UA Launch and Recovery	420
<b>11.3</b> Conventional Launch and Recovery	428
<b>11.4</b> Vertical Takeoff and Landing	430
<b>11.5</b> Rail Launchers	433
<b>11.6</b> Rocket Launch	437
<b>11.7</b> Air Launch	439
<b>11.8</b> Hand Launch	441
<b>11.9</b> Tensioned Line Launch	443
<b>11.10</b> Gun Launch	448
<b>11.11</b> Ground-Vehicle Launch	448
<b>11.12</b> Skid and Belly Recovery	449
<b>11.13</b> Net Recovery	450
<b>11.14</b> Cable-Assisted Recovery	452
<b>11.15</b> Parachutes	456
<b>11.16</b> Deep Stall	458

11.17	UA Impact Attenuation	459
11.18	Nonrecoverable	461
11.19	Water Launch and Recovery	462
11.20	Other Launch and Recovery Techniques	464
	References	467
	Problems	467
<b>Chapter 12</b>	<b>Communication Systems</b>	<b>471</b>
12.1	Introduction	472
12.2	Radio-Frequency Physics	472
12.3	Elements of Communication Systems	474
12.4	Link Budget Analysis	475
12.5	Antennas	490
12.6	Antenna Integration	494
12.7	Communication System Types	499
12.8	Modulation Techniques	503
12.9	Interception, Detection, and Jamming	504
12.10	RF Performance Simulation	505
12.11	Line-of-Sight Communications	506
12.12	Beyond Line-of-Sight Communications	507
12.13	Frequency Management	512
	References	514
	Problems	514
<b>Chapter 13</b>	<b>Physics of Remote Sensing and in Situ Measurement</b>	<b>517</b>
13.1	Introduction	518
13.2	Electromagnetic Spectrum Characteristics	518
13.3	Aerial Remote Sensing	521
13.4	Optical Systems	523
13.5	Radar	541
13.6	Synthetic Aperture Radar	543
13.7	Light Detection and Ranging (LiDAR)	551
13.8	In Situ Measurements	552
	References	552
	Problems	553
<b>Chapter 14</b>	<b>Missions and Payloads</b>	<b>555</b>
14.1	Introduction	556
14.2	Military Missions	557
14.3	Science and Research Missions	590

<b>14.4</b> Commercial and Civil Missions	595
References	600
Problems	601
<b>Chapter 15</b> Mission Systems Integration	603
<b>15.1</b> Introduction	604
<b>15.2</b> Optical Payload Assembly Layout, Actuation, and Stabilization	604
<b>15.3</b> Sizing for Performance	608
<b>15.4</b> Field-of-Regard Requirements	610
<b>15.5</b> Payload Placement and UA Configuration for Field of Regard	618
<b>15.6</b> RF Payload Integration	620
<b>15.7</b> Airframe Mechanical Integration	620
<b>15.8</b> Imagery Products	625
<b>15.9</b> Software Integration	629
<b>15.10</b> Avionics and Power Interfaces	630
<b>15.11</b> Payload Data Management	631
<b>15.12</b> Ground Element Integration	633
<b>15.13</b> Payload Interface Control	633
<b>15.14</b> Payload Modularity	635
References	635
Problems	636
<b>Chapter 16</b> Command, Control, Tasking, Processing, Exploitation, and Dissemination	639
<b>16.1</b> Introduction	640
<b>16.2</b> Control Element Functions and Personnel Roles	640
<b>16.3</b> Mission Planning and Execution	641
<b>16.4</b> Overview of Ground Element Types	653
<b>16.5</b> Portable Ground Control Stations	654
<b>16.6</b> Remote Viewing Terminals	656
<b>16.7</b> Launch and Recovery Elements	656
<b>16.8</b> Mission Control Elements	658
<b>16.9</b> Tasking, Processing, Exploitation, and Dissemination (TPED)	658
<b>16.10</b> Hardware	659
<b>16.11</b> Training	662
<b>16.12</b> Interoperability	662
References	664
Problems	664

<b>Chapter 17</b>	Reliability, Maintainability, Supportability, and Transportability	665
17.1	Introduction	666
17.2	Reliability	666
17.3	Availability	675
17.4	Maintainability	676
17.5	Supportability	679
17.6	Footprint	684
17.7	Logistics and Transportability	686
17.8	Organization, Training, and Personnel	689
17.9	Facilities	690
17.10	System Responsiveness	692
	References	694
	Problems	694
<b>Chapter 18</b>	System Synthesis and Mission Effectiveness	697
18.1	Introduction	698
18.2	Balancing the System	698
18.3	System Architecture Selection	699
18.4	System Performance Metrics	700
18.5	Operations Analysis Modeling	701
18.6	Survivability	704
18.7	Systems Engineering	709
18.8	Optimization	709
18.9	Design Environments	719
	References	726
	Problems	726
<b>Chapter 19</b>	Cost Analysis	729
19.1	Introduction	730
19.2	Cost Modeling	730
19.3	Life-Cycle Cost Approach	732
19.4	Program Influences on Cost	733
19.5	UAS Cost Data	738
19.6	Preacquisition Costs	740
19.7	Research, Development, Test, and Evaluation Cost	741
19.8	Production Cost	755
19.9	Operations Cost	758
19.10	Commercial Development	764
19.11	Services Contracts	764

<b>19.12</b>	UAS Company Startups and Investments	765
	References	766
	Problems	766
<b>Chapter 20</b>	Product Definition and Requirements Development	769
<b>20.1</b>	Introduction	770
<b>20.2</b>	Market Surveys and Competitive Analysis	770
<b>20.3</b>	Customer Requirements Generation	773
<b>20.4</b>	Developer Product Definition	776
<b>20.5</b>	Government Acquisition	782
	References	784
	Problems	785
	Index	787
	Supporting Materials	807