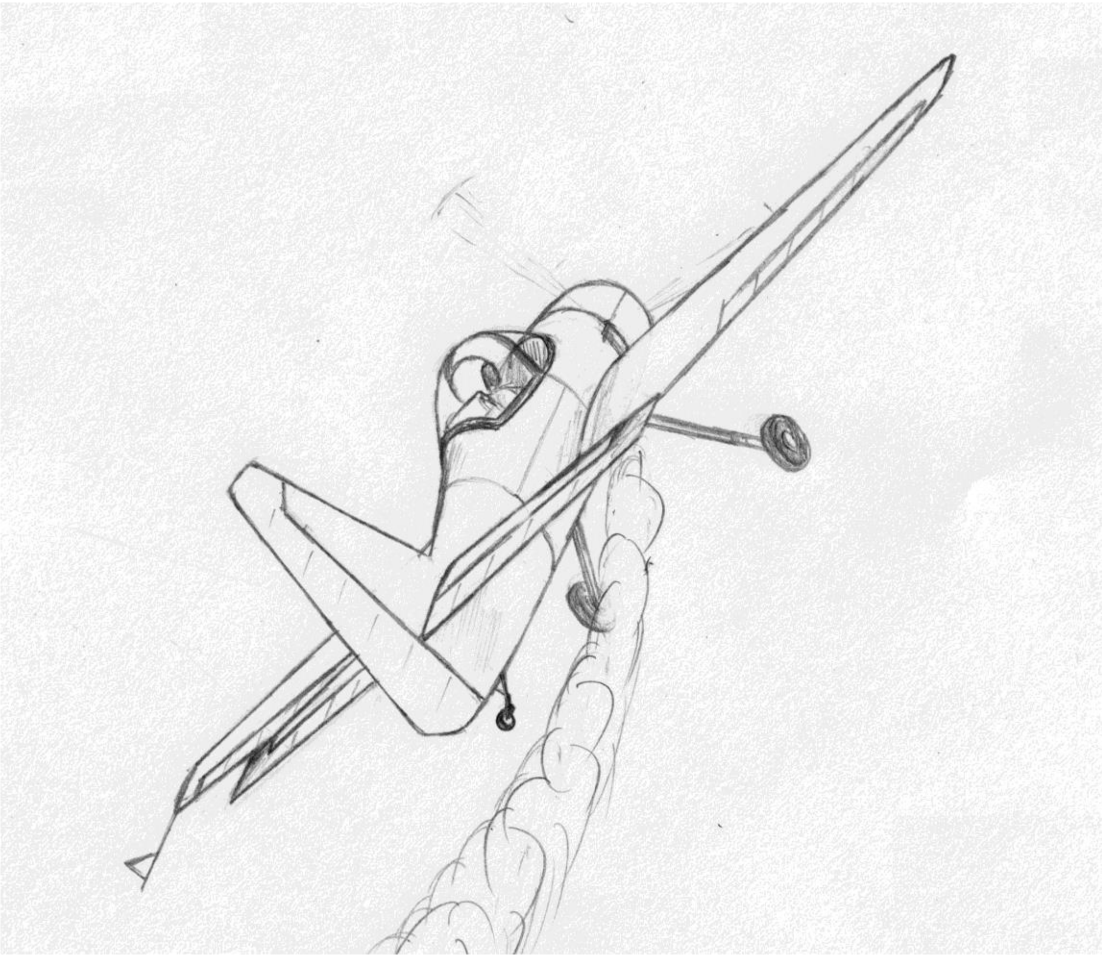
PROJETO DE AERONAVES
AIRCRAFT DESIGN – 10403

2023/2024



Curricular Unit Description

and

Design Project Description

PART I
THE CURRICULAR UNIT

1. OBJECTIVES

Students should acquire skills in the development of an aircraft subject to specific requirements and constraints, know how to apply aircraft design standards, develop integration, decision and compromise capabilities in a multidisciplinary team project and know how to communicate their results effectively.

With this UC students should be able to:

- describe the traditional aircraft design process and adapt it to specific cases;
- develop simple programs for the analysis and conceptual/preliminary design of an aircraft;
- integrate knowledge from various areas of science and engineering in the development of a multidisciplinary design project;
- carry out the conceptual and preliminary design of an aircraft to meet specific requirements;
- analyse design results and identify the most relevant parameters for the optimization of a given aircraft;
- effectively communicate project results;
- work in a team.

2. SYLLABUS

I. Introduction
1. Introduction to the curricular unit. 2. The aircraft design process. 3. Airworthiness standards for aircraft design.

II. Conceptual Design
4. Sizing from a conceptual drawing. 5. Selection of the airfoil and geometry of the wings and tail. 6. Initial sizing. 7. Configuration and drawing. 8. Configuration considerations. 9. Cabin, passengers and payload. 10. Integration of the propulsive system and the power system. 11. Landing gear and other systems. 12. Case studies.

III. Sizing, Analysis and Optimization
13. Aerodynamics. 14. Propulsion. 15. Structures and loads. 16. Weight and balance. 17. Stability and control. 18. Performance. 19. Cost analysis. 20. Optimization.

IV. Design of a New Aircraft
21. Concept of operations. 22. Aircraft design. 23. Development of analysis and optimization tool. 24. Sizing and analysis. 25. Oral presentations. 26. Written report.

3. SYLLABUS/OBJECTIVES

The contents of this curricular unit are structured in four blocks, the first three consisting of oral exposition and discussion of topics and the fourth consisting in practical and application of the knowledge. Those were designed with the main objective to develop teamwork skills in a complex multidisciplinary project in which theoretical and practical, technical and scientific knowledge of various areas is necessary, in which the critical thought and compromise is essential and, at the same time, to foster the spirit of innovation through research of new scientific and technological information (outside the syllabus of the course) so that the requirements of a given project can be met.

In essence, the syllabus is designed so that students can deepen, develop and integrate knowledge from different areas (aerodynamics, propulsion, structures, materials, flight performance, flight stability and dynamics, systems, etc.) to produce a viable and optimized aircraft design.

4. TEACHING METHODOLOGIES

This curricular unit is structured in two parts: one essentially theoretical and the other essentially practical. In the first part, the material is transmitted orally with multimedia slideshow support and additional information written on the blackboard. In the second part, methods for building a spreadsheet tool for analysis and optimization are taught and a new aircraft design is partially developed based on specific design requirements.

5. TEACHING METHODOLOGIES/OBJECTIVES

The methodologies adopted for this curricular unit follow the trends of similar curricular units in other universities and the experience acquired by the University of Beira Interior in the development of several unmanned aircraft and in various research and development work. This curricular unit has four weekly hours of theoretical-practical lectures and is structured in two parts: one part (2 hours) essentially theoretical and the other (2 hours) essentially practical.

In the first part, the materials (blocks I, II and III) are orally transmitted using multimedia slides and supplementary information written on the board. The slides are made available online to students in pdf format for their individual study and for reference, as they are built in the form of notes. In this part, examples of application are also presented. The discussion of the topics presented is fostered during the contact hours for better understanding by the students and for the development of their critical thought.

In the second part (block IV), methodologies are taught for the construction of an analysis and optimization spreadsheet tool. With this basis and with the knowledge of the theoretical part, students develop in teams (typically 5 students) the conceptual design and preliminary design of a new aircraft to meet the requirements provided by the teacher. During these classes, the exchange of ideas among teams is also encouraged and short oral presentations concerning the design progress are made throughout the semester. A large volume of this work must be performed outside the class period due to the considerable amount of required work. This project allows the student to develop analytical and synthesis skills, also using knowledge acquired in other curricular units, and to acquire critical decision and teamwork skills in the development of a complex system. At the end of the curricular unit the design is orally presented, and a written design report is submitted.

Although the professor monitors the developed students' work during the contact hours, both in the theoretical and practical lectures, a considerable amount of individual work outside the class is necessary by the students, regarding the study of the syllabus of the curricular unit, the study of other related subjects contained in the bibliographic references and the realization of the design work. This individual work promotes the autonomy and critical capacity of the student.

To support the teaching of this curricular unit, different but essential teaching/learning resources are used, namely:

- Video projector
- Books, articles, and other bibliography
- Notes
- Computer
- Internet
- Spreadsheets
- Analysis software for: airfoils, wings, propellers, flight stability, etc.
- CAD/CAE software
- Aircraft models developed previously at UBI and others

PART II
THE DESIGN PROJECT

Long Range Cargo UAV

LRC-23

6. INTRODUCTION

The international aerospace sector has increasingly used in recent years unmanned aerial vehicles (UAV - Unmanned Aerial Vehicle) for missions of various types, such as: aerial photography, military reconnaissance, atmospheric research at high altitude, radio communication, surveillance, fire detection, technology development, etc. Despite the technology involved, UAVs have dimensions smaller than manned aircraft, making their operation more flexible and more economical. The increasing automation and communication capabilities and the evolution of available materials has allowed the operation of these aircraft at distances and altitudes greater than ever, increasing their potential by making them equal, or even superior, to other aircraft that need to carry on board systems for crew support. For short distance surveillance applications, the investment required for the development and operation of a UAV is comparatively lower than equivalent manned aircraft so that its use in these tasks results in a cost-benefit ratio much more attractive. The UAV sector is the only sector of the aerospace industry with significant growth in the last 30 years, with an average growth rate of over 14% per year.

The UAV sector is rapidly flourishing, and, in many cases, it is a source of concepts and technologies for manned aircraft. Currently, most UAVs in operation have military applications. The use of UAVs in civil applications is, however, growing rapidly with the appearance of new concepts of operation and the creation and maturation of appropriate legislation. Portugal needs to stay in this important aerospace area in order to be more autonomous in the development of technological means essential to the sustainability of its resources and its regional and national economic maturity, to employ its qualified manpower and to be a competitive exporter of technology.

Portugal also needs the use of UAVs in various areas of activity. Monitoring of forest areas which in recent years have succumbed to fires is an important example. The application of surveillance unmanned aerial vehicles allows a high degree of uptime and availability in the tasks of this nature and is a complementary means of ground surveillance and satellite monitoring already in use. The application of new UAV concepts to new civil scenarios that can be economically viable is also important.

The main objective of this subject is to show students what the conceptual design of an aircraft is and what steps are necessary to follow given mission and performance requirements, design constraints, design methods and the need for optimization. To achieve this, the knowledge gained will be applied to the design of a new aircraft subjected to specific requirements. The optimization of the project is of extreme importance in the development of a new aircraft.

This project description presents the requirements that the aircraft must respond to in terms of mission, configuration, performance, systems, materials, and design standards. It also describes the necessary tasks to be performed during the semester and the work plan to follow. This project requires dedication and continuous work to ensure that deadlines are met, and results lead to a good design.

7. REQUIREMENTS

The current requirements present a need for an autonomous UAV (also capable of being remotely piloted) with the capability to fly efficiently over long distances to deliver high priority cargo over a network of regional airfields/airports. The requirements for this aircraft are listed below and during the course of the project they must be respected. Possible changes in the requirements will be discussed and agreed upon by the teacher and all the elements involved in the project.

It is required to perform the conceptual and preliminary design of a UAV taking into account some specific design requirements. The aircraft must have good flying qualities to allow easy and precise flying. The vehicle’s structure and aerodynamics must be carefully designed to achieve low power consumption levels. Simplicity, robustness, and ease of repair are essential to maintain high levels of operational readiness of the UAV.

7.1. Mission

The UAV must be designed for the following mission: it must take-off from an airfield, then climb to a cruise altitude of no less than 2500 m, cruise for at least 2500 km to the destination airfield, descend and land. The objective of the operation is to deliver high priority cargo to a single airfield or a series of airfields within a regional area of 1000 km in diameter in a timely and efficient manner. The cargo covered in this need comprises general goods, medicines, food, or luxury products, which at times may require special handling, with a mass up to 350 kg. The turnaround time should be as low as possible yet less than 30 minutes to allow for urgent cargo dispatching. The aircraft must be capable of operating from airfields with grass, unpaved or tarmac surfaces. Flight operations should be possible in rainy weather conditions and in wind speeds up to category 7 in the Beaufort Wind Scale (50-61 km/h), except for take-off and landing.

It is desirable, though not mandatory, to have a vehicle that can complete the journey through as many airfields as possible in the area given above during the daylight period in a

Winter day in Central Europe (around 8 hours). There may be a centrally placed airfield from which the vehicle operates and to which it returns at the end of the journey.

7.2. Performance

The vehicle must show the following performance figures (ISA – *Internacional Standard Atmosphere* conditions):

Take-off	from an airfield (less than 500 m)
Maximum stall speed in landing configuration	111 km/h
Cruise speed	200 km/h
Range	2500 km
Data link range	at least 200 km (or satellite)
Service ceiling	at least 6500 m
Landing	on an airfield (less than 500 m)

7.3. Propulsion

Certified piston engines must be selected for this UAV. A single piston engine is suggested but not mandatory. The propellers must be selected to match the engine performance according to the required UAV performance. The aircraft should have tractor propellers unless otherwise justified by improved overall performance. In selecting the engine, careful attention must be given to its durability and reliability. Proper cooling of the engine must be provided.

7.4. Wings

The aircraft shall have a fixed high wing configuration, with a maximum wingspan of 19 m. The wings must be well designed, both aerodynamically and structurally, so that the overall efficiency of the vehicle is high and to allow the required mission to be accomplished with low energy requirements. According to the mission, the wings can be designed for high lift-to-drag ratio. The structure should use high specific strength and high specific stiffness materials to allow for an empty weight as low as possible.

7.5. Fuselage

The fuselage should be slender and light yet possess the necessary internal space for cargo and systems. It should have high tolerance on payload weight and position. Equipment substitution and payload access should be quick and simple to perform. The payload compartment should be capable to hold the cargo in a proper manner without undesired movements. The payload compartment should have the reference dimensions 3 m × 1.5 m × 1.5 m (length × width × height) and should be accessed very quickly to load and unload the cargo.

7.6. Tail

The aircraft should be of the conventional tail configuration. The tail must be small and effective. It should use in their structure the same materials selected for the wings.

7.7. Landing Gear

A rugged but simple landing gear must be used. It can be either fixed or retractable, based on performance and weight considerations. The aircraft shall have a minimum wheel size (all wheels) of 6.00×6” and use at least 6.00×6’’ 8-ply tyres in the main landing gear. The aircraft shall have either hydraulic disc brakes or electromechanical braking on each of the mainwheels.

7.8. Payload

The design must cater for the mass of cargo in the range of 0 to 350 kg. The payload must be well secured in the fuselage to avoid any movement during flight. For some types of cargo, such as medicines or food, a temperature- and humidity-controlled container can be used. Appropriate electrical power must be provided to the container in these cases.

7.9. Weight and Balance

A Maximum Take-Off Mass (MTOM) of 750 kg is allowed. The CG travel must be such that no negative impact on the stability or on the normal operation of the aircraft is imposed for any payload weight transported on board. It is important that the maximum take-off mass of the aircraft is kept as low as possible. The vehicle should be capable of flying with partial load payloads (see 7.8).

7.10. Controls and Systems

The vehicle should be autonomous and remotely piloted. The control system will include autopilot boards (or at least physical space for those) which are not required to be selected. Control surfaces must be sized and must be actuated by servo mechanisms. All electronic and electric components and mission equipment must be placed within the fuselage according to their function and in such a way as to allow its quick preparation or replacement. The electric system should be powered by batteries which can be charged by an alternator driven by the engine.

7.11. Design Airworthiness Requirements

The aircraft must be designed broadly to CS-23 Amendment 6 or equivalent FAR. Stall and performance limitations, and acceptable means of compliance, may be taken from CS-23 Amendment 4. The aircraft’s design manoeuvre limit load factors will be +3/-3, but those should be checked with a V-n diagram. All work performed in the design should aim at achieving high levels of safety, reliability, and performance.

8. TASKS

There are several tasks in the design project that must be carried out according to the time plan below. All tasks depend on each other so that there must be a close interaction and updating between them. The design process is also iterative in nature, but perfection is not possible nor is necessary, but an effort must be put forward to achieve a good optimization level in the outcome.

The necessary calculations may be performed with the help of spread sheets and other analysis computer programs. All drawings should be developed in CATIA V5 or similar.

8.1. Concept of Operations

The exact mission profile and the way it is going to be operationally implemented must be defined and explained. The design of the vehicle will follow from the concept of operations (CONOPS) proposed to respond to the mission requirements.

8.2. Layout

The layout and functionalities of the vehicle must be selected so that the requirements are fully met. This task is very important because it integrates all needs of the other parts of the project into a viable configuration. A preliminary three-dimensional (3D) study of all major components must be performed, and these must be incorporated in the aircraft structure. 3D drawings must be produced in a CAD system for the complete UAV.

8.3. Aerodynamics and Stability

The aerodynamic study must cover the selection of the aerofoils, geometry and size of the lifting surfaces, nacelles, and the computation of the aerodynamic characteristics of the whole vehicle (C_L, C_D e C_M). It must be assured that all choices made in the overall design do not impair the aerodynamic performance. A study of the stability and control of the UAV must also be performed.

The aerodynamic work must concentrate on the wings design and tail sizing. These must be optimized having in mind the necessary compromises for different flight conditions.

8.4. Propulsion and Performance

The propulsive system (motor, propeller, power source) must be selected and sized according to the requirements. An estimate of the vehicle’s performance (speeds, times, battery, and solar energy usage, etc.) must be carried out.

8.5. Systems

A study of the landing gear system (if it exists), of the control system and of the electric system must be performed. These studies should include not only the selection of the main components and definition of its functionalities but also the positioning of components and cables routing inside the aircraft. Commercially available components are preferred to speed up both design and building processes. A database containing such data as suppliers, working characteristics, mass, power consumption and price of all components selected must be produced.

8.6. Structure and Materials

The type of structure and materials for the different components of the vehicle must be selected and defined adequately keeping in mind their configuration and function. Preliminary sizing of the wing must be performed. A database containing such data as suppliers, physical characteristics, mechanical characteristics, and price of all materials selected must be produced. A study on the manufacturing processes to be used must be carried out together with estimates of weight and balance and total cost of the UAV.

8.7. Time plan

The table below presents the time plan with the tasks required to complete de project.

Month	S	S	O	O	O	O	O	N	N	N	N	D	D	D	D	J	J	J	J	F	F
Task \ Week	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21
Lectures	18	25	02	09	16	23	30	06	13	20	27	04	11	18		01	08				
Concept of operations																					
Layout																					
Aerodynamics/Stability																					
Propulsion/Performance																					
Systems																					
Structure/Materials																					
Test													14								
Presentations				10					16												
Report																					
Exams																					

Legend:
- Lectures
- Design work
- Weeks without lectures
- Assessment

8.8. Design Teams

The design is carried out by groups of 5 students. All students should work hard for the project objectives to be fulfilled in time.

	Student's Name	Nº	Team	E-mail	Task
01	Daniel Pinto	44963	A		layout
02	Joana Limpo	44021	A		aerodynamics/stability
03	Rafael Simões	44059	A		propulsion/performance
04	Francisco Ramos	43356	A		systems
05	Simão Pereira	43604	A		structures/materials
06	Marta Dias	47088	B		layout
07	Ema Marques	44070	B		aerodynamics/stability
08	António Pelouro	45397	B		propulsion/performance
09			B		systems
10	Samuel Ferreira	41369	B		structures/materials
11	António Vilaça	43693	C		layout
12	Manuel Azevedo	44357	C		aerodynamics/stability
13	Diogo Lopes	44463	C		propulsion/performance
14	Leonor Patrício	43615	C		systems
15	Liane Moura	44473	C		structures/materials
16	Vasco Gabriel	45392	D		layout
17	Rafael Rodrigues	44152	D		aerodynamics/stability
18	Erika Marques	43418	D		propulsion/performance
19	Miguel Sousa	45402	D		systems
20	Rafael Fernandes	43421	D		structures/materials
21	Tomás Figueiredo	43825	E	tomas.figueiredo@ubi.pt	layout
22	Diego Côrte-Real	43300	E	diego.corte.real@ubi.pt	aerodynamics/stability

23	Miguel Marques	44671	E	miguel.s.marques@ubi.pt	propulsion/performance
24	Inês Rebelo	44598	E	ines.rebelo@ubi.pt	systems
25	Catarina Oliveira	43988	E	almeida.oliveira@ubi.pt	structures/materials
26	Simão Ribeiro	43823	F		layout
27	Manuel Matos	43654	F		aerodynamics/stability
28	Leonardo Ferreira	43744	F		propulsion/performance
29	Tiago Nave	43809	F		systems
30	Petro Kashevko	44040	F		structures/materials
31	João Campos	43854	G	joao.miguel.campos@ubi.pt	layout
32	Egor Ukolov	43882	G	egor.ukolov@ubi.pt	aerodynamics/stability
33	Matilde Figueiredo	43330	G	matilde.figueiredo@ubi.pt	propulsion/performance
34	Dany Cardoso	44605	G	dan.cardoso@ubi.pt	systems
35	Joel Castro	39719	G	guedes.castro@ubi.pt	structures/materials
36			H		layout
37			H		aerodynamics/stability
38			H		propulsion/performance
39			H		systems
40			H		structures/materials
			I		layout
			I		aerodynamics/stability
			I		propulsion/performance
			I		systems
			I		structures/materials
46			J		layout
47			J		aerodynamics/stability
48			J		propulsion/performance
49			J		systems
50			J		structures/materials
51			K		layout
52			K		aerodynamics/stability
53			K		propulsion/performance
54			K		systems
55			K		structures/materials

9. ASSESSMENT

The grade of this subject is given based on one written test (T), three oral presentations (P) and one report (R).

9.1. Test

The test covers all the topics discussed during classes up to the date of the test (14 December 2023, 18:00 – week 13). The test is divided into two parts: the first is closed book and the second is open book.

9.2. Presentations

There will be 3 oral presentations: one for the concept of operations (10 October 2023 – week 4); one for the conceptual design (16 November 2023 – week 9); and one for the complete design (9 & 11 January 2024 – week 17). In the presentations, each design team (all elements of the team must participate in the presentations) must describe to the other teams its concepts, design philosophy, analyses, and results. The first and second presentations should take only 5 minutes each while the last presentation should take 20-30 minutes, depending on the number of teams. The presentation files should be handed in at the end of each presentation session.

All presentations will be assessed based on:

- Oral expression and quality of the information on the slides;
- Relevance and scope of the presented information;
- Objectivity and coherence of the discussed topics;
- Adequate understanding of the discussed matters and knowledge of the developed design;
- Usage of the available time;
- Technical content.

9.3. Report

Each team must write up a design report that should contain all relevant steps taken in the aircraft design process, including:

- A description of the concept of operations;
- A description of the main features and innovations in your design, and justification of your design decisions (sketches may be used to illustrate these concepts);
- A three-view general arrangement drawing of your design with all major dimensions and aircraft characteristics;
- Estimates of the aerodynamic properties, flight envelope, loadings, strength, weight, stability, control and performance of your vehicle design;
- A mass breakdown of the aircraft, including reasonable estimates or calculations for each major component of the aircraft;
- A systems breakdown, including reasonable estimates or calculations for each major component.

The number of pages is limited to around 30, using letter size 12 and single line spacing. The report should be handed in *pdf* format at the last day of lectures (12 January 2024 – week 17).

9.4. Exam

There will be no written exam. If students fail the “Frequência” assessment or wish to improve their final grade, they must hand in an improved report of their design project at the dates of the exam, in weeks 19 and/or 21.

9.5. Grade

The mark of this subject is given by $F = 0.3T + 0.2P + 0.5R$ and approval is obtained if $F \geq 10$. The same is true for the exam final mark, but in this case the presentations and test are not repeated, only a improved/reviewed design report is handed-in.

1.	Frequência (F = 0.3T + 0.2P + 0.5R)		100
T	Test	14-12-2023 (18h00)	30
P	Presentations	10-10-2023 ; 16-11-2023 ; 09 & 11-01-2024	20
R	Report	12-01-2024 (24h00)	50

2.	Exam (E = 0.3T + 0.2P +0.5 R1)		100
R1	Report (*época normal*)	??-01-2024 (??h30)	50
R1	Report (*época recurso*)	??-02-2024 (??h30)	50

3.	Exam (E = 0.3T + 0.2P +0.5 R2)		100
R2	Report (*época especial*)	??-07-2024 (??h30)	50

10. BIBLIOGRAPHY

The books listed below can be used for the design. The design reports of previous years may also be useful as general guideline and source of ideas. However, one must bear in mind that the information contained in them may be incorrect. A lot of information can also be found in the internet using appropriate search criteria.

10.1. Notes

00. Gamboa. P.V., Apontamentos de Projeto de Aeronaves, ~600 acetatos, UBI, 2020

10.2. Text Book

01. Raymer, D. P., *Aircraft Design: A Conceptual Approach* – 5th edition, AIAA Education Series, 2012

10.3. Aircraft Design Books

02. Gudmundsson, S., *General Aviation Aircraft Design: Applied Methods and Procedures*, Elsevier, 2014.
03. Torenbeek, E., *Advanced Aircraft Design: Conceptual Design, Analysis and Optimization of Subsonic Civil Airplanes*, Hoboken, New Jersey: John Wiley & Sons, 2013.
04. Gundlach, J., *Designing Unmanned Aircraft Systems: A Comprehensive Approach*, AIAA Education Series, 2012
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06. Corke, T. C., *Design of Aircraft*, Pearson Education, Inc., 2003
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11. Stinton, D., *The Design of the Aeroplane*, Blackwell Science, 1983
12. Torenbeek E., *Synthesis of Subsonic Airplane Design*, Delft University Press, 1982
13. Barros, C., *Introdução ao Projecto de Aeronaves* – Volumes 1 & 2, CEA/UFMG, 1979
14. Pazmany, L., *Light Airplane Design*, Pazmany Aircraft Corporation, 1963

10.4. Other Books

15. Abbot & Doenhoff, *Theory of Wing Sections*, Dover Publications Inc, 1959
16. Barnaby Wainfan, *Airfoil Selection – Understanding and Choosing Airfoils for Light Aircraft*, 1988
17. Barnes W. McCormick, *Aerodynamics, Aeronautics and Flight Mechanics* – 2nd edition,

John Wiley & Sons Inc, 1995
18. Bernard Etkin, Lloyd Duff Reid, *Dynamics of Flight, Stability and Control* – 3rd edition, John Wiley & Sons Inc., 1996
19. Bill Clarke, *The Cessna 172* – 2nd edition, Tab Books, 1993
20. Darrol Stinton, *Flying Qualities and Flight Testing of the Airplane*, AIAA Education Series, 1996
21. David A. Lombardo, *Aircraft Systems –Understanding Your Airplane*, Tab Books, 1988
22. Euroavia, *Future Trainer Concept*, 1999
23. Geoff Jones, *Building and Flying Your Own Plane*, Patrick Stephens Limited, 1992
24. Ian Moir & Allan Seabridge, *Aircraft Systems*, Longman Scientific & Technical, 1992
25. *Jane's All the World Aircraft*, 1995
26. Certification Specifications for Light Sport Aeroplanes (CS-LSA), Initial Airworthiness, EASA, 2011, and Amendment 1 (2013)
27. Certification Specifications for Very Light Aeroplanes (CS-VLA), Initial Airworthiness, EASA, 2003, and Amendments 1 to 5 (2009 to 2017)
28. Certification Specifications for Normal, Utility, Aerobatic and Commuter Aeroplanes (CS-23), Initial Airworthiness, EASA, 2003, and Amendments 1 to 5 (2009 to 2020)
29. Ladislao Pazmany, *Landing Gear Design for Light Aircraft* – Volumes I & II, Pazmany Aircraft Corporation, 1986
30. John Cutler, *Understanding Aircraft Structures*, Blackwell Science, 1999
31. Martín Cuesta Alvarez, *Vuelo con Motor Alternativo*, Paraninfo, 1981
32. Robert C. Nelson, *Flight Stability and Automatic Control*, McGraw-Hill, 1989
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35. Stelio Frati, *L'Aliante*, Editore Ulrico Hoepli, Milano, 1946
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