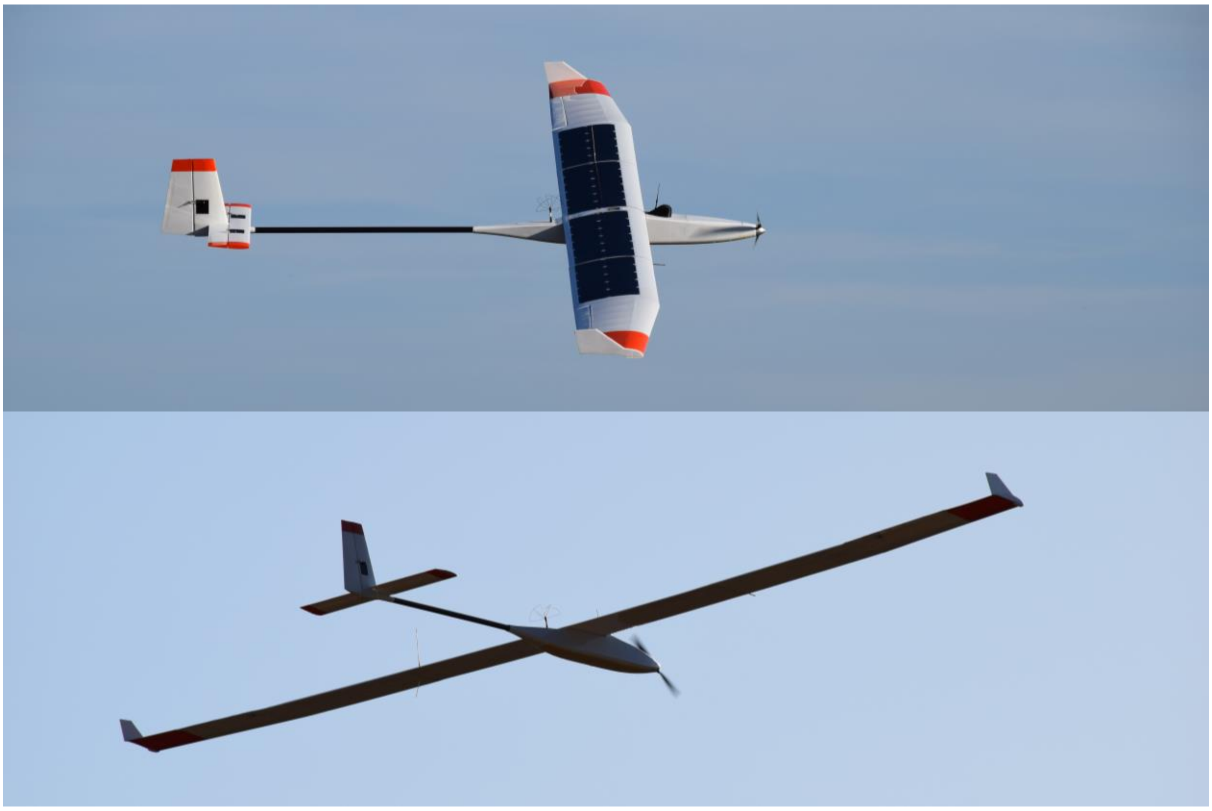
PROJETO DE AERONAVES
AIRCRAFT DESIGN – 10403

2020/2021



LIVESTOCK MONITORING SOLAR UAV

UAV-20

Project Description

CONTENTS

1. INTRODUCTION

The international aerospace sector has been increasingly using 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 advancement 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 much more attractive cost-benefit ratio. 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 the past 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 economic viable is also important.

In the past few years electric propulsion for aircraft has seen tremendous developments and a widespread use. Its application ranges from the model aircraft, UAVs, sailplanes, ultralight and general aviation aircraft. Because batteries have a limited energy density, resulting in flights of short duration, the use of fuel cells for battery charging is an interesting option that has already been exploited. Conventional propulsion with a piston engine allows flights with longer duration and with the help of an alternator coupled to the engine batteries, that provide on-board power for systems, can recharge these in flight. To avoid consumption of gasoline to produce electricity, the incorporation of photovoltaic cells on the aircraft can provide part or all of the electrical energy required on board. In some situations a hybrid propulsion system may be preferred.

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.

2. REQUIREMENTS

The current requirements present a need for an autonomous solar UAV (also capable of being remotely piloted) with the capability to fly efficiently for prolonged periods of time at medium to high altitudes and monitor livestock in difficult terrain regions. 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 professor and all teams 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, reliability and ease of repair are essential to maintain high levels of operational readiness of the UAV.

2.1. Mission

The UAV must be designed for the following mission: it must take-off from an airfield (or be launched by external means), then climb to a cruise altitude of no less than 9000 m, stay up there for at least one week, and return to base. The objective of the operation is to track and monitor livestock in isolated mounted areas (high mountains) within a regional area of 500 km in radius in an efficient manner. The payload covered in this need comprises high definition, high zoom, video and photo cameras, high performance computing hardware and a telemetry system with a mass of up to 10 kg.

It is desirable, though not mandatory, to have a vehicle that can perform two-month flights to ease operations and maintain persistence monitoring with as few vehicles as possible.

The vehicle should be able to be disassembled into components of no more than 2 m in length, so that it can fit in a small van.

2.2. Performance

The vehicle must show the following performance figures (ISA conditions):

Take-off	from an airfield (less than 60 m) or external launcher
Cruise speed	above 7 m/s
Maximum speed	at least 15 m/s
Flight operational endurance	at least 7 days
Data link range	at least 500 km (or satellite)
Operational ceiling	at least 9000 m
Landing	on an airfield (less than 120 m) or other means

2.3. Propulsion

Electric motors must be selected for this UAV. The propellers must be selected to match the motore performance according to the UAV performance required. The aircraft can either have tractor or pusher propellers and can have as many propulsion units as required. In selecting the motor, careful attention must be given to its durability and reliability. Proper cooling of the motor must be provided. Tilting of the motors/engines may be considered (or not) to fulfil specific operational needs. The batteries must be sized to provide both the required maximum power and endurance and must be complemented with photovoltaic cells to allow for continuous flight over long periods of time.

2.4. Wings

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 must be designed for high $C_L^{3/2}/C_D$. The structure should use high specific strength and high specific stiffness materials to allow for an empty weight as low as possible.

2.5. Fuselage

The fuselage should be slender and light, yet possess the necessary internal space for systems and payload. It should have high tolerance on payload weight. Equipment substitution and payload access should be quick and simple to perform. A separate pod for the payload may be considered. The payload compartment should be capable of carrying the payload in a proper arrangement. The payload compartment should have at least the reference dimensions 250 mm × 150 mm × 200 mm (length × width × height) and should be accessed very quickly to install and uninstall the cameras.

2.6. Tail

The tail, when present, must be small and effective. It should use in their structure the same materials selected for the wings.

2.7. Landing Gear

The choice of using a landing gear will depend on the concept of operations proposed. If it exists, it must be rugged, yet simple and small.

2.8. Payload

The payload (up to 10 kg) must be well secured in the fuselage or pod to avoid any movement during flight. The payload can be considered as a box holding the needed systems. It must be guaranteed that all systems work well in a wide range of temperatures from negative to positive. Heating and cooling may be required for some equipment. Adequate power must be provided for the full duration of the flight.

2.9. Weight and Balance

The centre of gravity (CG) travel must be such that no negative impact on the stability or on the normal operation of the UAV is imposed for any payload weight transported on board. It is important that the maximum take-off mass of the UAV is kept as low as possible. The vehicle should be capable of flying without partial load payloads.

2.10. Controls and Systems

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 actuated by reliable 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 must be charged by photovoltaic cells.

2.11. Design Airworthiness Requirements

The design airworthiness requirements that should be used in the structural sizing are the EASA CS-VLA, CS-LSA or CS-23. The design manoeuvre limit load factors are, in principle, +3 and -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.

3. 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 also other analysis computer programs. All drawings should be, preferably, done in CATIA V5.

3.1. 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.

3.2. 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.

3.3. 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.

3.4. 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.

3.5. 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.

3.6. 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.

3.7. Time plan

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

Month	S	S	O	O	O	O	N	N	N	N	N	D	D	D	D	J	J	J	J	F	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	22
Lectures																						
Concept of operations																						
Layout																						
Aerodynamics/Stability																						
Propulsion/Performance																						
Systems																						
Structure/Materials																						
Test																						
Presentations																						
Report																						
Exams																						

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

3.8. Design Teams

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

	Student's Name	Nº	Team	E-mail	Task
01	Tiago Morão	37461	A	tgmt98@gmail.com	layout
02	Mariana Lousada	37597	A	mariana.lousada@ubi.pt	aerodynamics/stability
03	Rafael Domingues	37853	A	rafaelsi.domingues@gmail.com	propulsion/performance
04	António Moreira	37961	A	antonio.moreira@ubi.pt	systems
05	João Pedrosa	38376	A	ricardo.pedrosa@ubi.pt	structures/materials
06	Viktor Zombori	37386	B	viktor_zombori@hotmail.com	layout
07	Francisco Dias	38267	B	francisco-dias-8@hotmail.com	aerodynamics/stability
08	Kateryna Shvydyuk	37708	B	katerynaolsh@gmail.com	propulsion/performance
09	Filipe Senra	38051	B	filipesenra98@hotmail.com	systems
10	Sullivan Gonçalves	38239	B	sullivan.goncalves@ubi.pt	structures/materials
11	Alex Almeida	37179	C	alexalmeida24@gmail.com	layout
12	Marta Gouveia	38974	C	marta.gouveia@ubi.pt	aerodynamics/stability
13	João Gonçalves	35569	C	jfrancisco.goncalves12@gmail.com	propulsion/performance
14	Diogo Simão	33620	C	diogosimao96@gmail.com	systems
15	Marcos Rosa	38970	C	marcos.rosa@outlook.pt	structures/materials
16	Alexandre Pavia	37292	D	alexpavia98@gmail.com	layout
17	Jorge Magalhães	38226	D	jorge.filipe.magalhaes@gmail.com	aerodynamics/stability
18	Edson Leite	36913	D	edsonlbleite@hotmail.com	propulsion/performance
19	Gonçalo Luís	37855	D	goncalo.luis@ubi.pt	systems
20	Marcos Pereira	37703	D	marcos.regino.9@gmail.com	structures/materials
21	José Atilano	38501	D	jose.pedro.silva.atilano@ubi.pt	?
22	André Rodrigues	37707	E	andre.filipe.rodrigues@ubi.pt	layout
23	Filipa Balça	37356	E	filipa.balca@ubi.pt	aerodynamics/stability
24	Francisca Basílio	38031	E	francisca.carlos@ubi.pt	propulsion/performance
25	Liliana Domingues	37399	E	liliana.domingues@ubi.pt	systems
26	Mariana Silveira	37483	E	mariana.silveira@ubi.pt	structures/materials
27	Heitor Silva	35890	F	heitorsilva191196@gmail.com	layout
28	Jorge Rodrigues	37213	F	jorge.filipe.rodrigues@ubi.pt	aerodynamics/stability
29	Luís Marques	35839	F	luis.marques@ubi.pt	propulsion/performance
30	Venira Pina	34955	F	venidepina@ubi.pt	systems
31	Rose Teixeira	38075	F	rose.teixeira@ubi.pt	structures/materials
32	Bárbara Penouço	38248	G	barbara.penouco@ubi.pt	layout
33	Mariana Ribeiro	39020	G	mariana.s.ribeiro@ubi.pt	aerodynamics/stability
34	Rúben Santos	39022	G	ruben.almeida.santos@ubi.pt	propulsion/performance
35	Francisco C. Branco	39082	G	francisco.castello.branco@ubi.pt	systems
36	Pedro Neto	37143	G	pedro.matos.neto@ubi.pt	structures/materials
37	Diogo Santos	34985	H	a34985@ubi.pt	layout
38	Elmano Lopes	35956	H	elmano.lopes@ubi.pt	aerodynamics/stability
39	Flávio Lopes	36269	H	flavio.lopes@ubi.pt	propulsion/performance
40	Marcos Lopes	36280	H	marcos.lopes@ubi.pt	systems
41	Fernanda Silva	45514	H	cavalcante.silva@ubi.pt	structures/materials
42					
43					
44	Carlos Silva	44383		diogo.fazendeiro.silva@ubi.pt	
45	Pablo Bernejo	45537		pcrehb00@estudiantes.unileon.es	
46					
47					
48					
49					
50					

4. ASSESSMENT

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

4.1. Test

The test covers all the topics discussed during classes up to the date of the test (14 December 2020 – week 13). The test is divided into two parts: the first is closed book and the second is open book.

4.2. Presentations

There will be 3 oral presentations: one for the concept of operations (12 October 2020 – week 4); one for the conceptual design (16 November 2020 – week 9); and one for the complete design (4 January 2021 – week 16). In the presentations, each design team (all elements of the team must participate in the presentation) must describe to the other teams its concepts, design philosophy, analysis 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 that exist. 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; and technical content.

4.3. Report

Each team must write up a design report that should contain all relevant steps taken in the UAV design process, including concept of operations, layout, decisions made, major calculations, results, etc.. Sketches necessary to fully understand the design and a three-view drawing with all major dimensions and aircraft characteristics should also be included. 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 together with the original CAD drawings (15 January 2021 – week 17).

4.4. 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.

4.5. 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.

1.		Frequência (F = 0.3T + 0.2P + 0.5R)		100
	T	Test	14-12-2020 (09h30)	30
	P	Presentations	12-10-2020 ; 16-11-2020 ; 04-01-2021 (11h00)	20
	R	Report	15-01-2021 (24h00)	50
2.		Exam (E = 0.3T + 0.2P +0.5 R1)		100
	R1	Report (normal period)	??-01-2021 (??h30)	50
	R1	Report (recourse period)	??-02-2021 (??h30)	50
3.		Exam (E = 0.3T + 0.2P +0.5 R2)		100
	R2	Report (special period)	??-07-2021 (??h00)	50

5. REFERENCES

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.

5.1. Notes

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

5.2. Text Book

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

5.3. 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
05. Jenkinson, Lloyd R., Marchman III, James F., *Aircraft Design Projects for Engineering Students*, Butterworth-Heinemann, 2003
06. Corke, T. C., *Design of Aircraft*, Pearson Education, Inc., 2003
07. Howe, D., *Aircraft Conceptual Design Synthesis*, Professional Engineering Publishing, 2000
08. Jenkinson, L. R., Simpkin, P., Rhodes, D., *Civil Jet Aircraft Design*, Arnold, 1999
09. Brandt, S. A., Stiles, R. J., Bertin, J. J., Whitford, R., *Introduction to Aeronautics: A Design Perspective*, AIAA Education Series, 1997
10. Roskam, J., *Airplane Design* – Volumes I to VIII, The University of Kansas, 1990
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

5.4. 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
33. S. Hoerner, *Fluid-Dynamic Drag, Hoerner Fluid Dynamics*, 1965
34. S. Hoerner, *Fluid-Dynamic Lift, Hoerner Fluid Dynamics*, 2nd Edition, 1985
35. Stelio Frati, *L'Aliante*, Editore Ulrico Hoepli, Milano, 1946
36. Ted L. Lomax, *Structural Loads Analysis for Commercial Transport Aircraft – Theory and Practice*, AIAA Education Series, 1996
37. *The Metals Black Book – Volume 1 – Ferrous Metals*, Casti Publishing Inc, 1995
38. *The Metals Red Book – Volume 2 – Nonferrous Metals*, Casti Publishing Inc, 1995
39. T. H. G. Megson, *Aircraft Structures for Engineering Students* – 2nd edition, Edward Arnold, 1990
40. Tony Bingelis, *Firewall Forward – Engine Installation Methods*, EAA Aviation Foundation, 1992
41. Tony Bingelis, *Sportplane Construction Techniques – A Builder's Handbook*, EAA Aviation Foundation, 1992
42. Tony Bingelis, *The Sportplane Builder – Aircraft Construction Methods*, EAA Aviation Foundation, 1992