

Chapter 10

Miscellaneous topics - 3

Lecture 40

Topics

10.4 Cost analysis

10.5 Outline of sizing and trade studies

10.6 Multidisciplinary optimization (MDO)

10.7 Concurrent engineering

Acknowledgements

Appendix 10.1 – Term paper topics (for self study)

Sample question paper and hints for answers (for self study)

Appendix 10.2 – An example of airplane preliminary design procedure – jet transport (for self study - included under assignment)

10.4 Cost analysis

While purchasing a vehicle generally, the cost of the vehicle, running expenses and maintenance are taken into account. In the case of an airplane the cost analysis is more complex because the design and development of airplane is a very expensive activity and its cost has to be added to the cost of fabrication of the airplane.

Further, use of airplane requires hangars, maintenance facilities and airport equipment. The operation and maintenance of airplane requires significant investment and needs services of a large body of professionals. Earlier way of carrying out the cost analysis was to calculate the direct operating cost and indirect operating cost (see remark 8 below). However, the current approach is to calculate the life cycle cost which is the cost involved over the useful life of the airplane. Based on Ref.1.18, chapter 18, the subdivisions of the life cycle cost are shown in Fig.10.8.

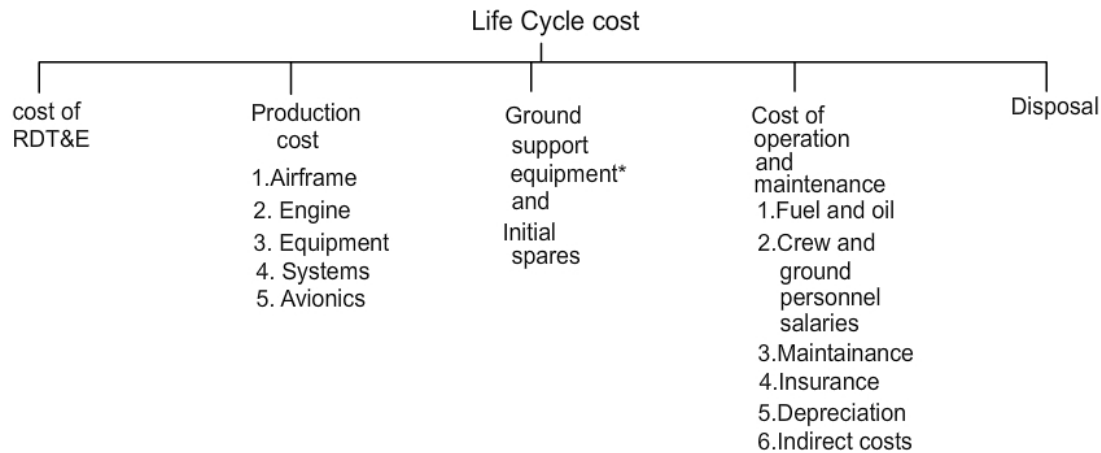
Remarks:

1) RDT & E represent the cost towards research, development, test and evaluation of the airplane. It includes the cost of technology development and research, design engineering, prototype fabrication, flight and ground testing and evaluation of operational suitability. It also includes the cost of certification by the regulating agency. For military airplanes, it includes the cost associated with demonstration of mission capability and compliance with military specifications. RDT & E cost is fixed (non-recurring cost) regardless of how many airplanes are produced. However, the number of airplanes expected to be produced will decide how this cost is apportioned to each airplane.

2) The production cost includes the cost of labour and material to manufacture the airplane including airframe, engine, avionics and other systems. This cost, on one hand includes the tooling cost and on other hand the cost of material and labour for each airplane.

The purchase cost of the civil airplane (civil purchase price) is arrived at based on expenses towards (a) RDT & E, (b) production cost and (c) fair amount of profit. In the case of military airplane the RDT & E cost may be paid by the government.

Generally along with the airplane a certain amount of spares are also purchased which may amount to 10 -15% of the initial cost.



*including those for handling payload

Fig.10.8 Subdivisions of life cycle cost

3) Development of the new airplane requires ground support equipment such as flight simulators, test equipment. Sometimes special construction may be called for, like large hangars for jumbo-jets, special bombproof shelters for new fighters etc.

4) Programme cost :The sum of the costs towards (a) RDT & E, (b) production, (c) ground support equipment, (d) initial spares and (e) special construction, constitute the programme cost.

5) The operations and the maintenance costs include (a) the costs of fuel and oil, (b) salaries of crew and ground personnel, (c) cost of maintenance, (d) insurance (e) depreciation for civil airplane and (f) indirect costs.(see remark 8 below)

6) Disposal cost : For military aircraft the cost of taking to the disposal location is generally ignored. In the case of civil airplanes, the scrap value of the airplane is typically 10% of the purchase price.

7) For military airplanes a life time of 20 years is assumed and the cost of operation, maintenance and disposal is added to the program cost of the airplane. This constitutes the life cycle cost. This cost along with the performance of the airplane decide the choice of the airplane. Since the costs are closely related to the weight of the airplane, lighter airplanes are preferred.

8) The airline operators divide the cost into Direct Operating Cost (DOC) and Indirect Operating Cost (IOC). The DOC is based on the expenses associated

with the flying and maintenance of the airplane. Following Reference 1.14, chapter 12 these can be divided into (a) standing charges, (b) maintenance cost and (c) flight operational cost. The standing charges include cost of depreciation, insurance and loan repayment. The maintenance cost includes cost towards airframe and engine maintenance and overheads. The flight operations cost includes (a) crew salaries, (b) fuel and oil cost and (c) airport fees. The standing charges are calculated on yearly basis. These are divided by the utilization of the aircraft per year (around 4000 hours). This gives standing cost per flying hour.

Based on the experience of the airline the cost of the engine and airframe maintenance (labor and material) are worked out and allocated per hour of flight. The flying cost depends on the flight duration. The cost is worked out and divided by the flight time in hours. Adding the standing charges, maintenance costs and flight cost per hour gives the total DOC per hour.

The stage cost is the cost of flying on a particular route. It is obtained by multiplying DOC per hour by the block time for the flight. The mile cost (or km cost) is obtained by dividing the stage cost by the block distance of the stage. When the mile cost (km cost) is divided by the maximum number of seats on the airplane, it gives the seat mile (or km) cost. It is expressed as cents per seat-km. This cost is an index of the efficiency of the design. The Indirect Operating Cost (IOC) is not dependent on the number of hours flown by the airplane. It includes (a) cost towards depreciation and maintenance on the ground equipment, (b) cost of administrative, technical and customer services, (c) advertising, promotion and sales, and (d) training. IOC is not an insignificant cost. It could be as high as DOC.

Adding IOC and DOC the airline obtains the total operating cost. The revenue from the fraction of the total number of seats which will cover the operating cost is called break even load factor. i.e. if on a hundred seater airplane, the revenue from 55 passengers would cover the operating cost then the break even load factor is 0.55. The profit of the airline depends on attracting more number of passengers than the break even load factor.

9) For additional details on cost analysis, see chapter 18 of Ref.1.11 and chapter 12 of Ref.1.14.

10.5 Outline of sizing and trade studies

At the end of the preliminary design phase, a configuration of the airplane is available. This configuration is called base line configuration. Using this configuration the revised drag polar, fuel required and gross weight can be obtained. Further, parametric studies by varying certain parameters can be carried out to get near optimum shape/parameters. Such studies are called sizing and trade studies. These studies are carried out by varying the parameter (s) around the values chosen in the baseline configuration.

Carrying out such studies here, is outside the scope of the present introductory course material on airplane design. However, references to certain trade and sizing studies are given below and the student is advised to refer them.

(1) Reference 1.18 in chapter 19, considers a fighter airplane with the following design specifications.

(a) Specific excess power (P_s) should be greater than or equal to zero at Mach number (M) of 0.9 at 30000 ft (9144 m) altitude in 5g flight. Recall that

$P_s = (TV - DV)/W$ and 5g flight means load factor(n) of 5.

(b) Take-off distance (s_{TO}) less than 500 ft (152 m)

(c) Time required to accelerate (t_a) from M = 0.9 to 1.5 should be less than 50 s.

The base line configuration is taken as having $W/S = 60 \text{ lbs / ft}^2$ (2783 N/m^2)

$T/W = 1.0$, and $W_0 = 19846 \text{ kgf}$. This configuration gives $P_s = 9.1 \text{ m/s}$,

$s_{TO} = 181 \text{ m}$ and $t_a = 47 \text{ s}$. Note s_{TO} requirement is not satisfied.

Subsequent studies are carried out with $W/S = 50 \text{ lbs / ft}^2$ (2394 N / m^2),

60 lbs / ft^2 (2783 N / m^2) and 70 lbs/ft^2 (3352 N/m^2)

and $T/W = 0.9, 1.0$ and 1.1 .

Analysis of the results pointed out that an airplane with $W/S = 2560 \text{ N/m}^2$,

$T/W = 0.98$ and $W_0 = 20400 \text{ kgf}$ would satisfy all the requirement and have the lowest weight.

Sections 23.2 and 23.3 of Ref.1.18 give examples of design and parametric studies for single seat acrobatic and light weight fighter respectively.

(2) Reference 1.15, in Addendum 5 gives outlines of the design of (a) aerobatic trainer (b) turboprop feeder liner (c) uninhabited high altitude reconnaissance airplane and (d) supersonic combat airplane.

(3) Reference 1.24 in chapter 6 obtains optimum tail arm, for a horizontal tail, from the considerations of minimising the skin friction drag of the tail cone and the horizontal tail as a combination. It may be recalled that as the tail arm increases, the area of h.tail decreases but the wetted area of the tail cone of the fuselage increases.

10.6 Multidisciplinary optimization (MDO)

The earlier practice in aerodynamic design was to optimize the airplane configuration separately from aerodynamic, propulsion, structural, manufacturing and other considerations. However, with the availability of computing power and packages for aerodynamic, structural and other analyses, it is now possible to arrive at a configuration which is simultaneously optimum from multiple considerations. This procedure is referred to as multidisciplinary optimization. Some remarks based on Wikipedia are given below.

Multidisciplinary design optimization (MDO) is a field of engineering that uses optimization methods to solve design problems incorporating a number of disciplines. It is also known as multidisciplinary optimization and multidisciplinary system design optimization (MSDO).

MDO allows designers to incorporate all relevant disciplines simultaneously. The optimum of the simultaneous problem is superior to the design found by optimizing each discipline sequentially, since it can exploit the interactions between the disciplines. However, including all disciplines simultaneously significantly increases the complexity of the problem.

For example, the proposed Boeing blended wing body (BWB) aircraft concept has used MDO extensively in the conceptual and preliminary design stages. The

disciplines considered in the BWB design are aerodynamics, structural analysis, propulsion, control theory, and economics.

NASA Langley researchers have developed a new shape parameterization technique that enables rapid and automatic multidisciplinary sensitivity analysis with respect to wing planform, twist, dihedral, thickness and camber variations. There is also considerable ongoing effort to make computational aeroelasticity as part of vehicle MDO in conceptual and preliminary design.

Every year the December issues of the magazine “Aerospace America” contains reviews of latest developments in various Aerospace fields. The article on developments in MDO be consulted for latest information on this topic.

10.7 Concurrent Engineering

The traditional way of design and production of a product involved first the design, then manufacturing and then removing deficiencies. With the availability of computing power and CAD/CAM packages, the current practice is to use concurrent engineering.

According to Ref.1.2 in concurrent engineering the considerations of market, design, manufacture (and tooling), test, service, cost and quality are taken into account from the outset.

This type of engineering allows different stages of development to go on at the same time, allowing for any modifications to be made along the way. It adopts a problem prevention method as compared to the problem solving and re-designing in the traditional engineering method.

Acknowledgements

The major part of the lecture material has been prepared when the author was an AICTE Emeritus fellow at IIT Madras. Support of AICTE and IIT Madras is gratefully acknowledged. Thanks are due to Prof.K.Mangal Sunder, coordinator NPTEL and Prof.Job Kurian, Prof.P.Sriram and Prof.K.Bhaskar, Heads of Aerospace Engineering Department, IIT Madras for providing infrastructure to carry out the work.

The notes on Airplane design (Aerodynamic) in power point form were reviewed by Prof.C.V.R Murti, formerly of IIT Kanpur and now at Institute of Aeronautical Engineering near Hyderabad, Prof.B.S.M.Augustine, Sathyabama University, Prof.K.Elangovan, Dept. of Aeronautical Engineering, M.I.T., Chennai and Prof.R.Rajasekhar, Park college of Engineering & Technology, Coimbatore. The author is indebted to them for their comments which helped in considerably improving the text. Prof.C.V.R. Murthi made detailed comments and special thanks are due to him. The notes in the running matter form have been reviewed by Prof.S.Santhakumar, Dept. of Aerospace Engineering I.I.T Madras. The author is grateful to him for constructive comments.

The help of Mr.S.R. Hiravennavar, Mr.G.Trinath and Mr.S.Ananth former M.Tech/dual degree/B.Tech students, Mr.Sandip chhajed Project Associate, Aerospace department and Ms.K.Sujatha project Associate CCE, IIT Madras, in preparing the slides in power point format and preparing figures needs special mention.

The author would like to record appreciation of Mr.G.Manikandasivam of NPTEL Web studio, IIT Madras for painstakingly keying in several revisions of the lecture material and also for preparing figures suitable for conversion to PDF format.

Appendix – 10.1 (for self study)

TERM PAPER TOPICS

Though a large number of topics has been covered in the present course material, the design of an actual airplane would involve many more aspects. However, with the background covered in the course, the student should be able to study the literature on his own and enrich his knowledge. To gain some experience in this, he is advised to prepare a term paper on one of the topics given below. The report on the topic chosen could consist of about 10 pages, and the student should be able to make a presentation of about 20 minutes duration.

Suggested Topics

(1) From the websites obtain information about the following items installed on some airplanes.

(i) Navigation system (ii) Fuel system (iii) Electrical system (iv) Air-conditioning system (v) Avionics (vi) Instruments (vii) Auto pilot (viii) Fly-by-wire (ix) High lift devices (x) De-icing System (xi) Hydraulic system (xii) Fire suppression system (xiii) Noise Suppression System (xiv) Evacuation system (xv) Pneumatic system (xvi) Landing gear (xvii) Braking system (xviii) Auxiliary power unit (APU) (xix) Eject seat and (xx) Lightening prevention system.

(2) Design features for specific airplane from the case studies brought out by AIAA, for example

(a) Gossamer candor-human powered aircraft

(b) C-5 galaxy,

(c) X-29.

(3) The book entitled “Aircraft design projects” by L.R. Jenkinson and J.F.Marchman (Ref.1.16) contains studies on the following aircraft.

(a) Long range business jet

(b) Electric – powered vehicle

(c) Dual – mode (air/road)vehicle

(d) Deep interdiction aircraft

(e) High altitude long-range uninhabited aerial surveillance vehicle

(f) Amphibian aircraft etc.

Study these cases and note the special features of each design.

(4) The book entitled “Introduction to aircraft design” by J.P.Fielding (Ref.1.13) in chapter 11 describes what went wrong with some airplane projects which failed. Study these cases and note what should be avoided.

(5) From past issue of journals mentioned in chapter 1, obtain the features of successful designs.

Sample question paper and hints for answers* (for self study)

B.E./B.Tech. Degree examination,

Anna university

November/December 2007.

AE 043 – Aircraft Design

*Hints are given in bold letters.

Time : Three Hours

Maximum : 100 marks

Part A – (10 x 2 = 20 marks)

1. What are the different phases of airplane design?

[For answer see section 1.2 “Stages in airplane design”].

2. List out some of the missions for which various categories of airplane are designed.

[For answer see section 1.4 “classification of airplanes according to function”, subsection 1.4.1 and the remark following it].

3. What is the effect of aspect ratio on the drag of an airplane?

[For answer see subsection 5.3.1 for effect of aspect ratio on slope of lift curve and induced drag].

4. What is the importance of data collection in airplane design?

[For answer see sections 2.1 and 2.2].

5. How is the total weight of an airplane subdivided for weight estimation?

[For answer see section 3.3 and remarks following it].

6. For a passenger airplanes with design Mach number of 0.85, which engine would be the best choice? Give reasons.

[For answer see sections 4.12, 4.15.2 and 4.17].

7. What are the advantages of tractor configuration?

[For answer see subsection 6.41 and remarks in it.]

8. What is the design load factor?

[For answer recapitulate discussion on V-n diagram in subsection 9.4.3 in Ref.3.3. The design load factor is the value of load factor ($n = L/W$) which the structure should withstand without yielding.]

9. Sketch a multi-bogey tricycle landing gear arrangement.

[Subsection 6.6.1 deals with tricycle landing and refers to pictures of multi-bogey landing gear. Draw a three view drawing of the airplane and show landing gear in side view and front view].

10. Forward swept wings are not preferred because of high structural weight penalty. Comment on this.

[For answer see subsection 5.3.2 of “Choice of sweep” and subsection 5.3.7 on forward swept wing].

Part B – (5 x 16 = 80 marks)

11(a) Discuss briefly various steps involved in the conceptual design of an airplane.

[For answer see section 1.2 “Stages in airplane design”].

(ii) Discuss the advantages and disadvantages of pusher configuration.

[For answer see subsection 6.4.1 and remark after it].

(iii) What is “lofting” in airplane design?

[For answer see section 7.1].

Or

(b) (i) Sketch a typical configuration layout of a passenger airplane.

[For answer see section 6.2.7 and example 8.2].

(ii) Discuss briefly the methodology of obtaining an estimate of the cost of manufacturing based on conceptual design of airplane.

[For answer see section 10.4 “Cost analysis”].

12(a) Discuss in detail various types and estimation of drag of an airplane and appropriate methods of minimizing the drag.

[For answer see portion on drag polar estimation in section 4.4.1. The important types of drag are (a) parasite drag (b) induced drag and (c) wave drag at high speeds. Parasite drag is reduced by smooth surface, low thickness ratio for wings and high fineness ratio for fuselage. The induced drag is reduced by high aspect ratio. The wave drag is reduced when low thickness ratio airfoil and swept wing are used].

Or

(b) Write short notes on :

(i) Airfoil and flap.

[For answer see section 5.2. on “Airfoil selection“ and subsection 4.2.3 on flaps]

(ii) Aerodynamics considerations in supersonic airplane design.

[For answer see section 7.2. The wing will have low aspect ratio, high sweep and airfoil with low thickness ratio. The fuselage would have pointed nose and high fineness ratio]

13.(a) Discuss in detail the effect of wing loading on the performance of an airplane during various stages of flight.

[For answer see section 3.2 and subsections 3.2.1 to 3.2.7].

Or

(b) Discuss in detail the selection and location of power plants for an airplane with suitable diagrams.

[For answer regarding types of engines used on airplanes and the range of flight speeds they are used, see sections 4.12, 4.13, 4.15.2 and 4.17. For engine location see section 6.4.].

14.(a) (i) Discuss various types of landing gear arrangements.

[For answer see section 6.6 “Landing gear”].

(ii) Explain the steps involved in preliminary landing gear design.

[Answer : Landing gear design is a specialized topic involving the following.

(a) Selection of the type of landing gear viz. nose wheel, tail wheel or bicycle type.

(b) Selection of retractable or non-retractable configuration

(c) After the type of landing gear is chosen, the details like wheel arrangement, tyre size, shock absorbers and retraction mechanism are designed during structural design.

In the preliminary design(aerodynamic) the type of landing gear and wheel base and wheel track are decided.

The tail wheel type of landing gear is used on low subsonic speed general aviation aircraft. Nose wheel type of landing gear is used in other types of airplanes. The non-retractable type is used on airplanes flying at speeds lower than about 250 kmph. At higher speeds the drag of landing gear becomes excessive and retractable landing gear is the choice.

The location of landing gear is such that the main wheels take 85% of the weight. This consideration decides the wheel base. The wheel tread depends on the location of wheel wells for retraction of main wheels. The tread is small if the wheels are retracted in pods on fuselage. It is large if the wheels are retracted in wings or in nacelles mounted on wings.]

Or

(b)(i) classify aircrafts with respect to load factor giving suitable examples.

[Answer:An airplane is designed to withstand certain permissible load factor (n). Higher the permissible load factor, heavier will be the weight of airplane structure. Hence, for actual airplanes the manoeuvre load factor is limited depending on its intended use. Federal Aviation Administration (FAA) in USA and similar agencies elsewhere, prescribe values of permissible manoeuvre load factors (n_{positive} and n_{negative}).

Typical values are as follows.

Type of airplane	n_{positive}	n_{negative}
General aviation – non-aerobatic	2.5 to 3.8	-1
Transport	3 to 4	-1
Fighter	6 to 9	-3

(ii) Discuss V-n diagram considering gust loads.

[For answer recapitulate discussion on V-n diagram in subsection 9.4.3 in Ref.3.3].

(iii) Discuss briefly the different common tail arrangements.

[For answer see section 6.3].

15(a) write short notes on :

Elements of wing design

[For answer see section 5.1].

(ii) Role of CAD in aircraft design.

[For answer see subsection 1.2.3].