12

Aircraft cost estimations

Objectives

Aircraft design decisions have significant influence on the first cost and operating expenses of the aircraft. It is therefore important to understand the cost implications of aircraft manufacture and operation and to take these into account when deciding the aircraft configuration and performance.

Consideration of cost aspects is especially significant in the preliminary design phase of aircraft projects as fundamental decisions are taken which will be influential in the overall cost of the project. Such decisions affect the cost of manufacturing and equipping the basic aircraft and the subsequent cost of operating it over the route structure of an airline. It is therefore essential to understand the cost estimation methods to be used by the customer when comparing competitive aircraft, in order to make sensible design choices.

This chapter introduces the methods by which aircraft operating costs are estimated. These methods are used in the preliminary project phase to allow comparisons to be made between different aircraft configurations and to assess the best choice of values for all the aircraft parameters.

Indirect costs (those not directly related to the aircraft parameters, for example those associated with marketing and sales expenses) are only briefly covered, whereas direct costs are described in enough detail to allow estimating methods to be incorporated into the aircraft design process. The principal cost functions are described and typical values given.

The chapter concludes with a specimen calculation and some reference data to be used in student project work.

After completing this chapter you should understand the main characteristics of cost estimation and be able to predict direct operating cost (DOC) on projected aircraft designs.

Introduction

The main financial criterion on which the aircraft design should be judged is the return on investment (ROI) to the company. The difficulty of using this parameter

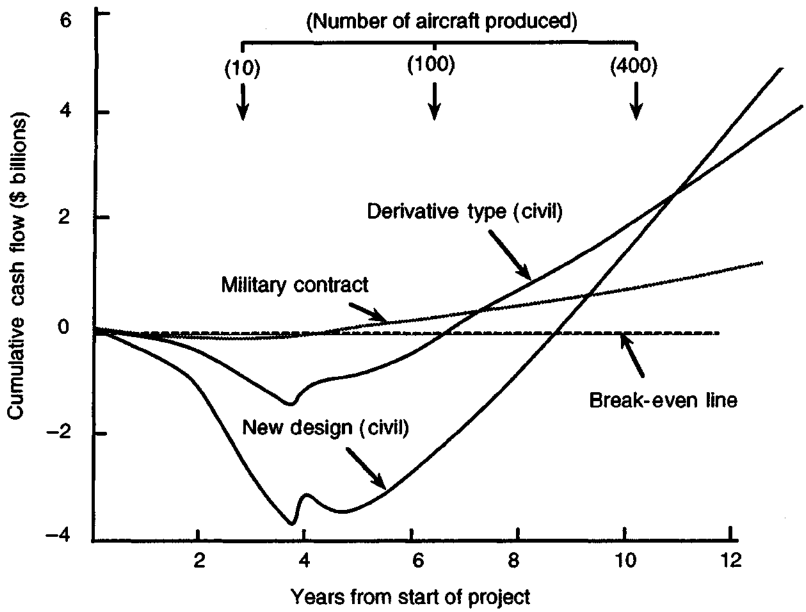

Fig. 12.1 Project cash flow 150 seat aircraft ($1995) (source AIAA-86-2667).

lies in the inherent variability in the nature of aircraft manufacture and operations and the associated substantial initial investment (i.e. prior to the inflow of revenue from sales of aircraft). The delay in recovering expenditure will result in negative cost flow in the early years of production. During this time customers (airlines) make only a small payment to the manufacturers, to reserve a position in the aircraft production schedule; this is called an option. From a project design study of a 150 seat regional aircraft conducted by McDonnell–Douglas (MD) some years ago, the cash flow history was forecast. This is shown in Fig. 12.1 together with cash flow histories for a developed (stretched) existing civil aircraft and a military project.

The 'return' as measured in the ROI parameter will depend on the terms and conditions of the investment loans and not solely on the aircraft technical and operational performance. Nevertheless, the overall financial balance sheet for the project must provide sufficient confidence to investors for the project to be externally financed. The degree of confidence held by the investors will be conditioned by many factors. Such factors will include the technical analysis of the aircraft performance in comparison with competing designs and the expectation of the total world market for the aircraft. The design team will be expected to provide such analysis.

A major difficulty in assessing the financial success of a project is the long timescales involved in aircraft design and development. The factors which influence financial viability are often considered over shorter time cycles than those associated with typical aircraft developments. Within this environment it is not surprising that funding is sometimes difficult to find for new projects. Such reluctance leads to national/governmental involvement in aircraft projects. This further complicates a pure financial analysis as political issues may be have to be considered.

Although aircraft manufacturers are in business to exploit advances in technology the financial restrictions mentioned above make them somewhat conservative in the development of new designs. If a revolutionary innovation ran into technical/operational difficulties it could ruin the company. A lot of technical effort needs to be put into building confidence in new methods before they are accepted for production.

The difficulties of using ROI as the design criterion have led to the adoption of life-cycle cost analysis. This involves the summation of all the cost elements associated with purchasing, operating and supporting the aircraft throughout the operational life. Although this parameter can be used for both military and civil projects, the components in the total cost equation differ for each sector. For civil aircraft a lot of data is available from past aircraft and operations, on which to base such analysis.

Each airline has developed its own methods for estimating operating expenses related to their particular type of operation, flight patterns, aircraft fleet and accounting procedures. The aircraft manufacturer will have to subject the projected aircraft, in competition with others, to the particular cost method of potential customer airlines. Since these methods vary widely between different operators it is necessary for the design team to use a standardised method for cost analysis, especially in the early stages of the design. Such methods are used to provide guidance in the choice of values for the fundamental operational and design parameters.

It is difficult to rationalise the design of the aircraft to different cost methods so a choice has to be made. Whichever method is chosen it can be used only to show the relative cost variation between different designs. The method will not predict actual costs as these vary so widely over different operational practices.

There are several different standardised methods available but they all trace their origin to the 'Standard Method of Estimating Comparative Direct Operating Costs of Turbine Powered Transport Airplanes' (Air Transport Association of America, Dec. 1967). Most standard cost methods only estimate the direct operating costs of the aircraft. The total cost of owning and operating an aircraft is the sum of indirect operating costs (IOC) and DOC. Although both costs may be influenced by the type of aircraft under consideration (e.g. fleet mix) it is common practice to consider the two cost components separately.

In an inflationary economic climate, values for costs are highly time-dependent; therefore some effort must be made to secure current prices for the various elements that make up the total operating cost. Alternatively, old prices must be 'factored' to account for changes since publication. This factoring requires the use of an inflation index. Traditionally such an index is difficult to determine but as the cost method used in aircraft design is employed only to estimate relative costs the exact evaluation of the index may be less significant than for absolute cost predictions. Cost values are however 'date sensitive' and any published data must show the year to which costs refer. American airlines are compelled to submit cost information to the government and this is collated and published annually in

'Aircraft Operating Costs and Performance Report' CAB Report (this data is used in *Aviation Week* quarterly/annual reports). These reports are useful sources of cost updating information. Although in project studies only relative costs are considered care must be taken to ensure that the influence of individual variables is truly represented in the cost equation.

Indirect operating cost (IOC)

IOC estimation methods deal with those costs not directly attributable to a particular aircraft type or the flying costs of a particular operation. It may include some or all of the following expenses:

- facility purchase cost and facility depreciation
- facility leasing cost
- facility maintenance cost
- ground equipment depreciation
- ground equipment maintenance costs
- maintenance overheads
- headquarters overheads
- administration and technical services
- advertising, promotion and sales expenses
- public relations cost expenses
- booking, ticket sales and commission
- customer services
- training

In order to classify the above parameters for particular airlines the American Civil Aeronautics Board (CAB) requires American airlines to report indirect costs associated within the following headings: aircraft and traffic servicing, promotion and sales, passenger services, general and administrative overhead, ground property and equipment maintenance and depreciation expenses.

Indirect operating costs obviously vary over a wide range depending on the type of operation and activity of the airline. Standard methods of estimating these costs are available (e.g. 'Boeing Operating Cost Ground Rules') and data are published on airline actual expenses (e.g. the USA CAB annually publishes statistics and data in journals such as the *Flight International* and *Aviation Week* annual reviews). Although aircraft design may have significant influence on indirect costs, for example by requiring new maintenance facilities and the introduction of new skills for advances in technology, it is difficult to quantify the exact cost of the interrelationship. Airline management and operational aspects are predominant factors in the indirect costs and these are outside the control of the aircraft designer. It is therefore usual to ignore the effects of indirect cost on the selection of aircraft design parameters. As the variation in direct operating costs of competing aircraft and airlines narrows, the influence of IOC will become much more significant and aircraft sales teams will use reductions in the indirect costs to show their product to advantage over competitors (e.g. through savings in fleet commonality).

Indirect operating costs are not insignificant; they can account for between 15 and 50% of the total operating expenses (i.e. up to the same cost as the direct operational expenses).

Direct operating costs (DOC)

Under the DOC category all the costs associated with flying and direct maintenance must be considered. Figure 12.2 shows a typical breakdown of these costs.

Some standardised DOC methods do not include all the factors shown in Fig. 12.2. The cost components may be considered under four broad headings:

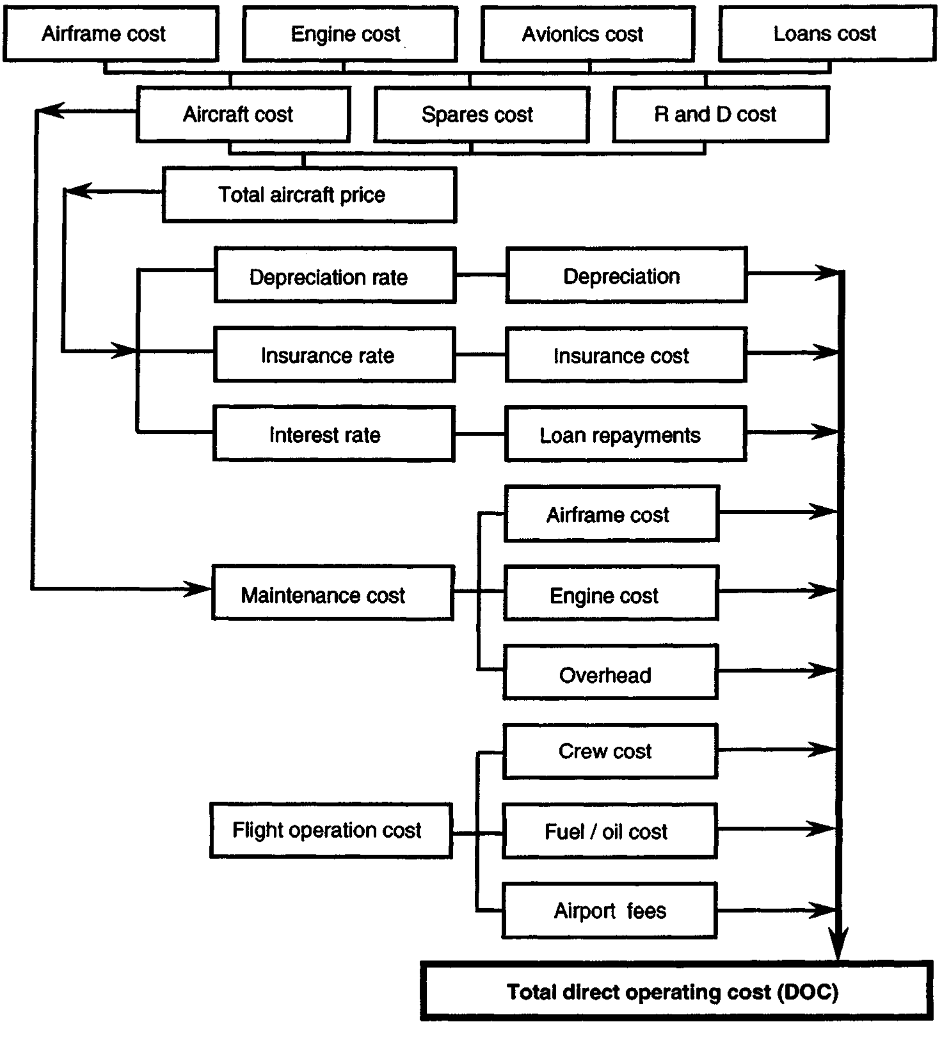

Fig. 12.2 Direct operating cost components.

- standing charges
- flight costs
- maintenance costs
- cost parameters

A description of each of these headings is given below.

Standing charges

These are the proportion of the costs that are not directly linked to the aircraft flight but may be regarded as the 'overhead' on the flight. Such costs, in order of importance, include:

1. depreciation of the capital investment
2. interest charges on capital employed
3. aircraft insurance

Depreciation and interest charges are sometimes quoted as an item and referred to as 'ownership' costs. Items 2 and 3 are ignored in some cost methods as they are small components compared to the cost of depreciation; however, these items will be discussed first.

Insurance cost

This is directly related to the risks involved and the potential for claims following loss. The airworthiness authorities oversee the observance of the safety standard; therefore the risk of accident is well established. For the insurance companies the associated technical risk is relatively easy to estimate as it is associated directly with the probability of failure of the total aircraft system. Above this baseline risk is the possibility of losing aircraft due to non-technical occurrence (e.g. terrorism) and the subsequent potential for personal claims. Such risks are difficult to determine in advance due to the sometimes transient nature of the problem. Insurance companies will therefore vary their fee in relation to the nature of the operation (e.g. geographical areas of flights) and the level of airline security. The annual premiums for aircraft insurance vary between 1 and 3% of the aircraft price. If insurance is to be included in the cost method a value of 1.5% is considered typical.

Interest charges

Interest charges are impossible to quantify in a general analysis as the banks and government agencies will charge various fees to different customers. Such charges will be dependent on the world economic climate, local exchange rates, the credit standing of the purchaser and the export encouragement given by the national government of the airline or manufacturer. Further complications may arise due to 'off-set' agreements made between the two trading partners (manufacturer and airline). For all these reasons, and because most of these factors are outside the influence of the aircraft manufacturer, many cost estimation methods ignore this cost component but it is necessary to include the interest costs in any business plan. Current national base interest rates should be determined and used for such analysis.

Depreciation

Depreciation will be dependent on many factors including the capital involved, the airline purchasing policies, the accounting practices of the financial loan companies, the competition for capital and the overall world economic conditions at the time the aircraft is purchased. As the aircraft is always maintained to a fully airworthy condition throughout its life, it will have an identifiable value when sold (known as the residual value). As with any capital item, the residual value will reduce as the aircraft ages. The depreciation period will be dependent on the accountancy policy of the airline and the expected development of the routes for which the aircraft is bought to service. Typically, an aircraft may be considered to be at the end of its useful life after 15–20 years with zero residual value. With civil aircraft design methods reaching a mature technology state the useful life of aircraft is progressively extending with 20–30 years likely to become more common in the next decade. The choice of depreciation period and the estimation of residual value is made by the purchasing airline (* e.g. 12 years depreciation to 15% residual value).

The main parameter in the evaluation of depreciation is the total price of the aircraft. The initial aircraft price used in the evaluation of depreciation will include an allowance for the capital required to provide for spares holding (typically 10–15% of the aircraft initial price). Therefore

$$\text{aircraft initial price} = \text{factory cost of the aircraft} + \text{spares cost}$$

The percentage of the first cost of the aircraft to be depreciated per year can be determined as:

$$[(\text{initial price} - \text{residual value})/\text{initial price}]/(\text{depreciation period}/100)$$

For example in the case above * the equation will give:

$$[(P - 0.15P)/P]/[12/100] = 7.08\%$$

where P = aircraft manufacturer's price (including airframe, engines, systems and online equipment).

The estimation of aircraft price is complicated by many non-engineering factors (e.g. market conditions, competition, politics, off-set trade agreements, international collaboration on manufacture, etc.). The president of one of the largest aircraft manufacturers once said, 'The price of an airplane . . . has little direct relationship to the design and production costs of the vehicle.' Nevertheless the price of an aircraft must be sufficiently high to allow a reasonable return on investment for the manufacturer and sufficiently low to allow an adequate return on the purchase investment made by the operator.

A cynical view of this process is to state that the initial price of the aircraft (and engine) is set at what the customer will pay and not related to the technical manufacturing factors. This may not be exactly true but it is known that the initial sales prices of a new aircraft type are always set low to enable the manufacturer to gain market penetration. Also, when the aircraft type is old the manufacturer will quote low prices against competing new aircraft, in the knowledge that the development costs for his aircraft have been recovered. The airline will order airframe and engines by separate contract and will bargain for the best price for

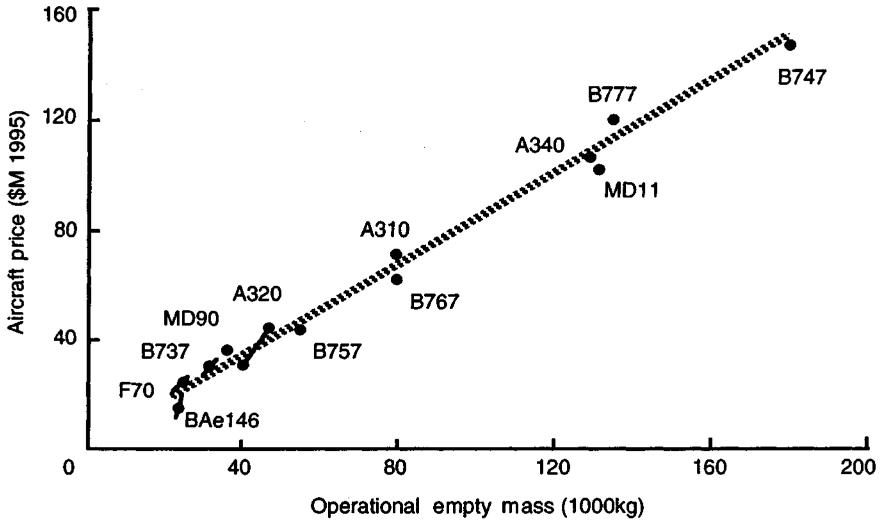

Fig. 12.3 Aircraft purchase price against OEM (1995) (data source Avmark).

each from different suppliers. The price of aircraft (airframe plus engines) is quoted in annual surveys in the aeronautical press. These data identify the current market price for the aircraft and not the cost of manufacturing the aircraft. However, the data can be used to determine aircraft price in the project design phase, as shown in Fig. 12.3.

With the complexity and uncertainty of factors associated with the market price for aircraft it is surprising that there is not more variability in the price of aircraft per pound of aircraft empty mass (OEM). Such a crude plot should not be used for particular aircraft analysis as the range of aircraft size covered is too extensive (100–500 passengers). A more detailed analysis should be made around the size of aircraft under consideration (e.g. if only aircraft less than 200 000 lb were analysed on the data above a different average-line would have been drawn). There is a strong argument in favour of using aircraft parameters other than OEM for determining aircraft price (e.g. maximum take-off mass, aircraft speed, number of passengers, etc.). Each design study should consider which parameter is most appropriate.

There are several data sources available from which aircraft price information can be obtained (e.g. The *Avmark Aviation Economist* database of jet airliner values). These should be used to build a database for the particular design. Care must be taken when using price data to normalise the values to account for inflation and the devaluation of currencies. In some cost evaluation methods there is an option to allow for leasing of aircraft to be substituted for purchasing.

There are several methods available for determining aircraft manufacturing costs from the configuration and system details (e.g. J Burns, SAWE Paper No 2228, 1994). The total cost can be considered as the sum of the design costs (which is a function of the technical complexity of the design), the overhead cost of development (which is a non-recurring cost independent of the number of aircraft produced) and the production cost (which is directly related to the number of aircraft produced, the complexity of the design and the number of co-operating manufacturing companies). The design and overhead costs occur in the early years of the design and manufacture cycle. In the early years these costs will be a large component of the sales cost, but as the design matures and sales increase the design and development cost will be repaid and eventually form a relatively small element in the sale price. For a constant production volume, the manufacturing cost will start low (because some of the early production cost will be regarded as development) but quickly stabilise to a constant value. The capital requirements for each cost will depend on the type of aircraft, the complexity of the design and the method of manufacture. A new aircraft design will involve more design and development capital than a derivative (e.g. stretched) aircraft. The MD study for a 150 seat regional jet mentioned earlier showed the estimated total programme cost for a new and derived design as shown in Fig. 12.4.

The overhead cost may be regarded as a small part of the total cost only if sufficient numbers of aircraft can be produced (and sold). Dividing the total cost associated with the design, development and manufacturing cost, by the number produced gives the unit cost (aircraft break-even price) as shown in Fig. 12.5.

This analysis determines the average cost of producing each aircraft, evaluated at the end of the productive life of the design. The problem for the manufacturers is that they do not know at the start of the project how many aircraft will be produced so the average price study is not used as a basis for fixing the initial aircraft price. Setting a constant price for a new aircraft sale (\$57M and \$50M on the above figure) allows a break-even production quantity to be predicted (i.e. about 250 and 350 aircraft respectively). One aircraft manufacturing company president commented that the break-even production value for an aircraft type was always about 100 more than your current sales!

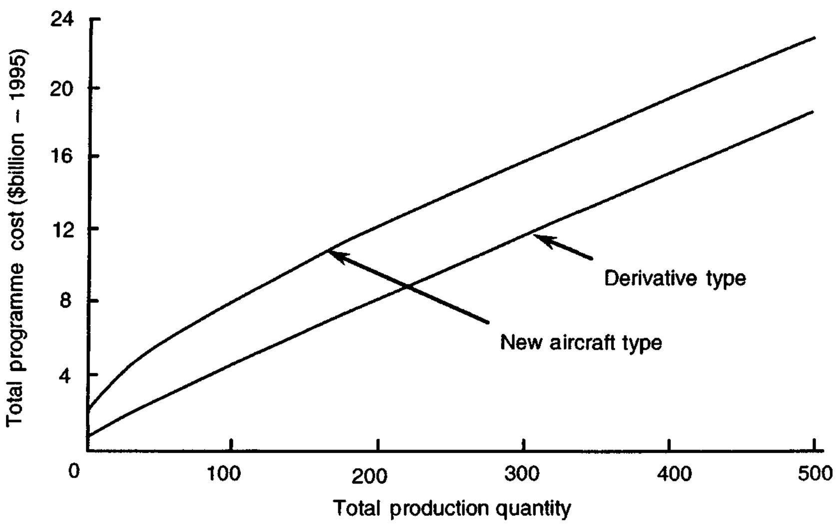

Fig. 12.4 Total programme cost (data AIAA-86-2667).

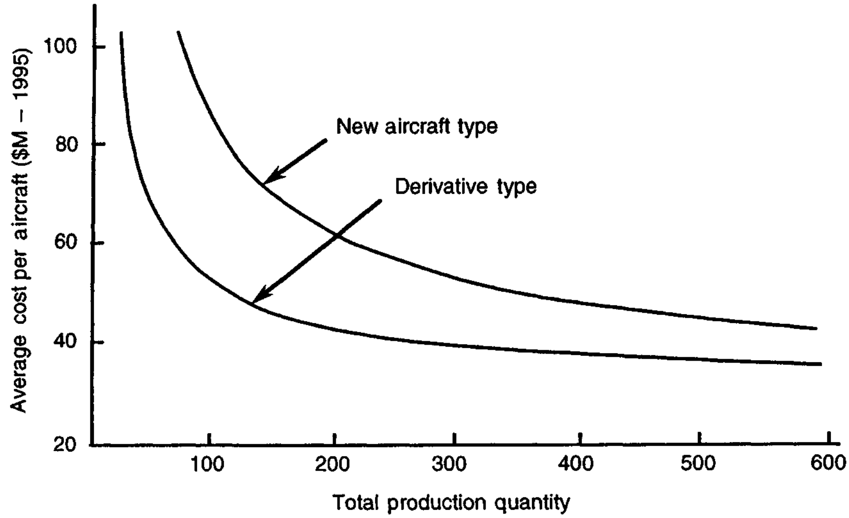

Fig. 12.5 Effect of production quantity on aircraft price (data AIAA-86-2667).

The break-even values are used to draw the programme cash flow diagrams shown in Fig. 12.1. The discontinuity in the curves in the third year arises from the receipt of deposits for future sales options. A customer will be asked to pay a small deposit to secure an option position (date) on the production line. About two years ahead of delivery the manufacturer will ask for progressive stage payments up to about one third of the sale price. These cash inputs help with the manufacturers' cash flow and show goodwill from the customer.

Note, in the above analysis the manufacturer's cash flow break-even point lies between six and nine years from the start of the project. The variability is caused by the uncertainty in the number of aircraft produced. A stabilised production volume will only arise after about six years from the start of the production process.

The differences between new and derived designs in the above analysis illustrates the variability in the assessment of aircraft production cost. Although constant sales price was assumed in the analysis, experience shows this is not the normal market practice.

As mentioned earlier, the average price will be discounted at the start and towards the end of the production run. The only rule that seems to apply to the price of aircraft is that it is set to suit the market and not as a calculation from the design and production cost. However, on average, the manufacturer needs to make a profit from the sales to stay in business and the airline must make a profit from the purchase.

In some studies it is desirable to include the engine cost as a separate item from the aircraft price. In this way the optimum aircraft design (from an aircraft DOC standpoint) can be determined. Engine price is largely dependent on the take-off thrust with a small overhead to account for non-thrust dependent cost components. In Chapter 9 the following relationship was introduced for the cost of the

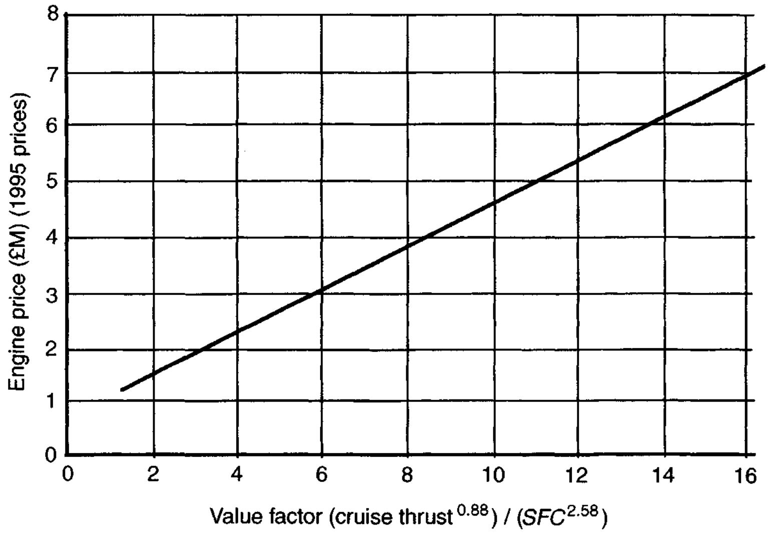

Fig. 12.6 Engine price estimation.

engine: The value factor based on 1995 market prices below is used in the trade-off graph (Fig. 12.6) which is reproduced here.

$$\text{value factor} = \frac{(\text{cruise thrust})^{0.88}}{(SFC)^{2.58}}$$

Both thrust and SFC are at the maximum cruise rating at $M = 0.8$ at 35 000 ft.

Leasing

For accountancy purposes, sometimes related to local taxation policies, some airlines lease their aircraft from a third party in preference to outright purchase. The cost method reflects this option by eliminating the standing charge element and then calling the DOC value a 'Cash DOC'.

Maintenance costs

Prediction of maintenance costs is complicated by the lack of definition for items to be included under this heading. Setting up a maintenance facility is an expensive outlay for the airline. Some such facilities run as a separate business. The capital cost of buildings, the administration costs and the cost of special equipment may be regarded as an indirect cost on the total maintenance operation and included in the IOC evaluation. This suits the aircraft manufacturer as the evaluation of DOC would be proportionately reduced. The attribution of the maintenance overhead burden forms the biggest variability in the different standard methods for estimating DOC. Some airlines contract-out their aircraft and engine maintenance to other airlines or specialised maintenance companies. In these cases the total charge for maintenance will be automatically set against DOC as the cost will be directly attributable to a specific aircraft.

Maintenance charges include labour and material costs associated with routine inspections, servicing and overhaul (for airframe, engines, avionics, systems, accessories, etc.). There will also be some non-revenue flying involved and this will be charged to the maintenance account.

Generalised estimation of the total costs involved has always presented difficulties due to the variability of maintenance tasks for different aircraft and the variations in the types of operation. All the standard DOC methods include procedures for estimating maintenance costs but care must be taken when adapting these standardised methods to particular designs.

It is common practice to divide the maintenance tasks into airframe and engine components giving:

$$\begin{aligned}\text{total maintenance cost} = {} & \text{cost of airframe maintenance} + \text{cost of engine} \\ & \text{maintenance} + \text{maintenance burden (overhead cost)}\end{aligned}$$

The airframe and engine maintenance costs are further sub-divided into labour and material components, for example:

$$\text{airframe maintenance cost} = \text{cost of labour} + \text{cost of materials}$$

Furthermore, each component cost is considered to be the sum of a cost per flight (flight overhead) and the cost per flying hour (recurrent charge). For example the cost of airframe labour maintenance is defined as:

$$\begin{aligned}\text{airframe labour cost} = {} & (\text{labour cost per stage} + \text{labour cost per flying hour} \\ & \times \text{stage time}) \times \text{labour rate}\end{aligned}$$

The total maintenance burden is often based on a standing charge to cover the overhead cost of providing the maintenance service plus an hourly cost, as shown below:

$$\text{maintenance burden} = \text{standing cost} + \text{hourly charge} \times \text{block time/stage}$$

Hence the components of the maintenance cost are:

1. airframe maintenance labour cost per stage
2. airframe maintenance labour cost per flying hour
3. airframe maintenance material cost per stage
4. airframe maintenance cost per flying hour
5. engine maintenance labour cost per stage
6. engine maintenance labour cost per flying hour
7. engine maintenance material cost per stage
8. engine maintenance material cost per flying hour
9. maintenance burden standing charge
10. maintenance burden hourly (flying) charge

Items 5–8 are sometimes reduced to a simple maintenance cost per flying hour obtained from the engine supplier.

Flight costs

This cost element comprises all the costs which are directly associated with the flight. The following items are summed to give the total flying costs per hour:

1. crew cost
2. fuel and oil usage
3. landing and navigational charges

Crew costs

These include the salaries for the flight and cabin staff. Crew productivity has increased over the last ten years with the increased acceptance of two-pilot operation. The number of crew is dictated by airworthiness standards and labour union agreements. Typically there will be two flight crew for smaller aircraft travelling shorter stages, three for heavier aircraft and for long-range flights it is sometimes necessary to have more than one set of flight crew on the flight. The number of cabin staff is associated with the number of passengers (30–50 passengers per cabin attendant is typical). Annual utilisation of crew varies depending on staff contracts. Eight hundred hours a year is typical for a medium size regional jet aircraft operation. Wage rates differ between airlines and between aircraft type so it is difficult to generally assess crew costs. The following relationship can be used:

$$\begin{aligned}\text{crew costs} = {} & (\text{annual cost of flight crew member} \times \text{number of flight crew} \\ & + \text{annual cost of cabin staff member} \times \text{number of cabin staff}) \\ & \times (\text{flight block hour})/(\text{crew utilisation per year})\end{aligned}$$

Note, flight and cabin staff utilisation is likely to be different, cabin staff having a higher utilisation.

Crew cost will include overheads for enforced stop-overs on long-range schedules. These expenses are sometimes treated as a general operating cost and therefore considered as indirect costs.

Fuel and oil

The cost of fuel and oil is relatively easy to estimate providing the price of fuel can be accurately predicted. Next to depreciation, fuel cost represents the most significant cost parameter in the design. A historical survey of fuel price over a 20-year period shows the difficulty of making this prediction. Figure 12.7 shows how the price of fuel has varied between 50 and 350% of the baseline value in only a 20-year period (due mainly to the imposition of cartel trading by the oil suppliers in the late 1970s). With such variability it is difficult to confidently predict fuel price in the future.

Cost parameters

All the preceding costs are calculated on an hourly (flight) basis. They are all summed to produce the direct operating cost of the aircraft per flight hour. The

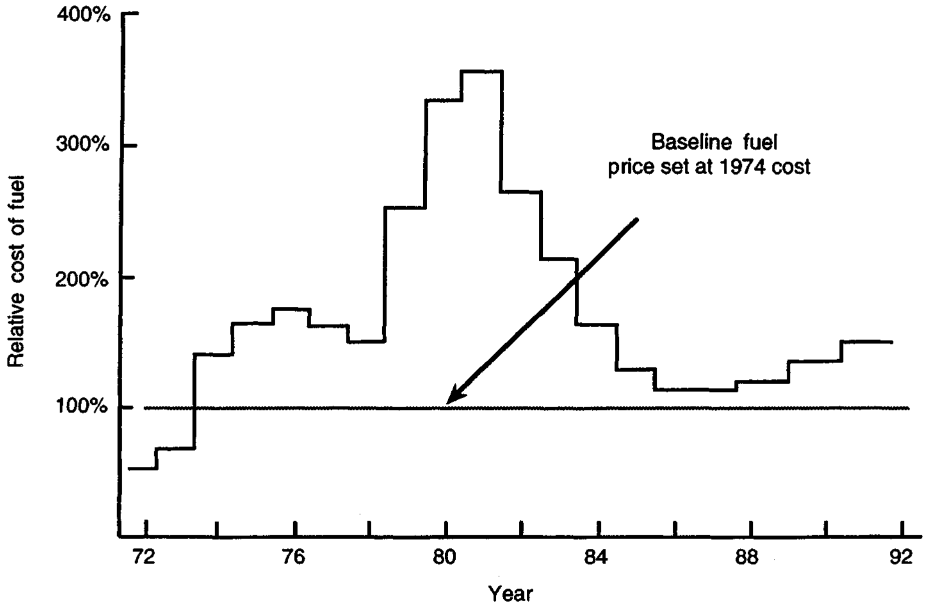

Fig. 12.7 Fuel price variability (data source AIAA-86-2667).

cost of flying a particular route (known as the **stage cost**) is found by multiplying the hourly DOC by the block time (hours). The stage cost can be divided by the block distance to show the **mile cost**. The mile cost can be divided by the maximum number of seats flown on the stage (note not the number of seats occupied as this will vary with airline schedules) to provide the **seat mile cost**.

Some manufacturers quote all the above cost parameters on a **cash** basis, by which they mean that the aircraft standing charge is not included in the total cost. Their reasoning for doing this (apart from making the DOC figure much lower) is that it is becoming common practice for airlines to lease their aircraft on an annual basis and therefore this cost becomes a different part of the company balance sheet. Be careful when using quoted DOC figures from manufacturers or the aeronautical press to understand if the **total** or **cash** method of calculating the values has been used.

Design influence

Aircraft project designers are seen to influence costs directly by the basic configuration of the aircraft (system complexity, aircraft size, engine size, etc.) and the selected performance (cruise speed, range, etc.). All these aspects will have a substantial input to the cost model through the standing charges, the fuel used and the maintenance required. The designers also influence cost indirectly through airline economics (market size, ticket price, aircraft performance, passenger appeal). These indirect factors feed into the cost analysis through revenue potential, the demand for the aircraft type, market development and ultimately to commonality and type derivations. It is important for the designers to recognise these influences in the early stage of the aircraft project so that the design can meet the market potential and thereby maximise success of the project.

It will be necessary to conduct several parametric trade-off studies to fully understand the various competing aspects of the design. It is unusual for the design team to consider the aircraft as a 'point-design' aimed exclusively at one market sector. The initial design will be slightly compromised to allow for future stretch (increased payload and/or range) to extend the market for the aircraft type.

Example

To illustrate how the direct costs are calculated consider an aircraft with the following details:

number of seats	300
range at maximum payload	7200 nm
cruise speed	M0.825
(at a representative altitude this equates to a speed of 243 m/s)	
aircraft maximum take-off mass	243 200 kg
engine take-off thrust (two engines)	370 kN (each engine)
cruise *SFC*	0.55
fuel consumption	5500 kg/hr (each engine)
aircraft utilisation	4200 hr/year
engine maintenance	\$190/hr/engine
airframe maintenance	\$660/hr (labour) and \$218/hr (materials)

Estimating the standing charges

We shall first estimate the 'standing charge' element in the DOC calculation. From a graph similar to Fig. 12.2, drawn for aircraft of similar size (weight) to the proposed design, we can determine the aircraft price. Using the *MTOM* quoted above and assuming an empty weight fraction of 58% (typical of this size aircraft) we estimate the empty weight and then the aircraft price:

$$OEM = 0.58 \times MTOM = 0.58 \times 243\,200 = 141\,100\,\text{kg}$$

From the cost graph (Fig. 12.3) at this weight:

$$\text{total aircraft price} = \$\text{M}118$$

Using the quoted engine *SFC* and derating the take-off thrust to the cruise condition allows an estimate of the engine price to be made using the value function shown in Chapter 9:

$$\text{value function} = (\text{cruise thrust})^{0.88}(SFC)^{-2.58}$$

The graph of current engine prices gives a value of \$M9.8 per engine. There are two engines; therefore cost of engines = \$M19.6, making the cost of airframe = \$M98.4 and giving:

$$\text{total aircraft factory price} = \$\text{M}118$$

Assuming the cost of aircraft spares is 10% of the airframe price and the cost of engine spares is 30% of the engine price we can determine the total spares cost:

$$\text{spares cost} = (0.1 \times 98.4) + (0.3 \times 19.6) = \$\text{M}15.7$$

Adding the spares cost to the total aircraft factory price gives:

$$\text{total investment cost} = 118 + 15.7 = \$M133.7$$

Assuming that this cost is depreciated to 10% over a 16-year operational life gives an annual cost of:

$$\text{depreciation costs/year} = 0.9 \times 133.7/16 = \$M7.52$$

Assuming interest on investment cost is set at 5.4% per year, the annual cost will be increased by:

$$\text{interest/year} = 0.054 \times 133.7 = \$M7.22$$

Assume insurance is charged at 0.5% of aircraft cost:

$$\text{insurance/year} = 0.005 \times 118 = \$M0.59$$

Hence the total annual standing charge is:

$$\text{total standing charge/year} = 7.52 + 7.22 + 0.59 = \$M15.33$$

Dividing this by the quoted aircraft utilisation per year of 4200 hours gives:

$$\text{standing charge/flying hour} = \$3650$$

Estimating the flying costs

Assume two flight crew at \$360 per hour and nine cabin crew at \$90 per hour are used:

$$\text{crew costs/hr} = (2 \times 360) + (9 \times 90) = \$1530$$

Assume landing fees are charged at \$6 per ton (of aircraft MTO):

$$\text{landing charge} = 0.006 \times 243\,200 = \$1459$$

Assume navigational charges of \$5640 per flight for this type of aircraft.
Assume ground handling charges of \$11 per passenger per flight.
For a 300-passenger aircraft this gives:

$$\text{ground handling} = 11 \times 300 = \$3300$$

Therefore airport charges are:

$$\begin{aligned}\text{total airport charge} &= 1459 + 5640 + 3300 \\ &= \$10\,399 \text{ per flight}\end{aligned}$$

In order to relate this cost to the aircraft flying hours it is necessary to determine the block time of the flight. For the cruise phase of 7200 nm and with the aircraft travelling at M0.825 (a cruise speed of 473 kt) the time taken is:

$$\text{cruise time} = 7200/473 = 15.22\,\text{hr}$$

To this must be added the time for climb and descent and the time on the ground. As part of the 7200 nm stage distance will be covered in the climb and descent phases and the aircraft speed will be reasonably high in these parts of the flight profile, assume 10 minutes lost time. Assume 20 minutes for start-up, taxi-out and take-off, eight minutes for hold prior to landing and five minutes for landing and taxi to stop:

$$\text{total extra time on flight} = 10 + 20 + 8 + 5 = 43\,\text{min}\ (= 0.72\,\text{hr})$$

Hence:

$$\text{block time} = 15.22 + 0.72 = 15.94\,\text{hr}$$

The above airport charges can now be related to flying hours:

$$= 10\,399/15.94 = \$669/\text{hr}$$

The fuel consumption is quoted as 5500 kg/hr per engine at cruise. During the non-cruise phases the fuel consumption would be higher than this but on this long-range design it will be sufficiently accurate to ignore these increases.

Converting the fuel consumption to US gallons using the conversion factors and fuel density quoted in Data E, gives:

typical jet fuel density = 800 kg/m^3
volume of fuel used = 5500/800 (per engine) = 6.875 m^3 = 6875 litres
(conversion: 1 US gallon = 3.785 litres)
volume of fuel = 1816 US gallons
With two engines, the aircraft will burn (2 × 18 116) = 3632 gallons/hr.
The cost of fuel is assumed to be 70c/US gallon. Therefore:

$$\text{Fuel cost} = 3632 \times 0.7 = \$2542/\text{hr}$$

Maintenance costs

These are relatively difficult to estimate in the initial project stage so values are used that are representative of the aircraft and engine types:

engine (labour + materials)	\$190/hr/engine
airframe (labour)	\$660/hr
airframe (materials)	\$218/hr

$$\text{total maintenance cost} = (2 \times 190) + 660 + 218 = \$1258/\text{hr}$$

Total direct operating cost

(a) Total DOC per flying hour. This is the sum of all the above component costs:

standing charge	= \$3192	(35% total)
crew cost	= \$1530	(17%)
airport charge	= \$669	(7%)
fuel cost	= \$2542	(27%)
maintenance cost	= \$1258	(14%)
total cost	**\$9191**	

Total stage cost = 9191 × 15.94 = \$146 500

Mile costs = 146 500/7200 = \$20.35

Seat mile cost = 20.35/300 = 6.78c

(b) Total cash direct operating cost/hour. For those operators that lease their aircraft the 'standing charge' estimated above may not form part of the direct operating cost analysis as the leasing contract may be accounted as an annual charge unrelated to the aircraft operation. In such cases the DOC calculation is termed the 'Cash DOC' and will have values as shown below for our specimen aircraft:

crew cost	\$1530	(26% total)
airport charge	\$669	(11)
fuel cost	\$2542	(42)
maintenance cost	\$1258	(21)
total cost	**\$5999**	

Total stage cost = 5999 × 15.94 = \$95 624

Mile cost = \$95 624/7200 = \$13.28

Seat mile cost = \$13.28/300 = 4.43c

Note how the significance of crew and fuel cost increases in the cash DOC compared to the normal DOC. In this type of analysis the fuel cost becomes nearly half the total operating cost. Manufacturers will want to quote this figure if their aircraft is more aerodynamically efficient than their competitors, particularly if their aircraft is newer and more expensive to buy than the competition!

Reference data

Typical values for parameters used in modern direct cost estimation models are given below.

1. Flight profile (at ISA conditions)

1. Start-up and taxi-out = 20 minutes (10 minutes for short-haul operations).
2. Take-off and climb up to 1500 ft*.
3. Climb from 1500 ft* to initial cruise altitude.
4. Cruise at specified speed to include any stepped climb manoeuvre+.
5. Descent to 1500 ft*.
6. Hold (eight minutes) at 1500 ft.
7. Landing and taxi-in = five minutes
   (* note maximum speed below 10 000 ft is 250 kt in US airspace)
   (+ only possible with minimum rate of climb of 500 ft/min or more).

2. Reserves

1. Diversion = 200 nm (after hold).

2. Hold = 30 minutes at 1500 ft at minimum drag speed (clean).
3. Contingency = 5% of stage fuel.

3. Payload

Either (a) fuselage volume limit or (b) zero fuel weight limit.

4. Block time

Flight time plus 25 minutes long-haul, 15 minutes short-haul).

5. Utilisation

(a) Long-range (6500 nm is typical) = 4800 hours/year.
(b) Medium/short-range = 3750 hours/year.

6. Investment

The sum of:

(a) aircraft price (A) = manufacturer's price (M) + buyer's equipment (B) + modification costs* + capitalised interest on stage payments**
where: * = 6% of $M + B$, ** = 2.5% of M
(b) airframe spares = 10% of (A less engine cost)
(c) engine spares = 30% of total installed engine cost

7. Depreciation

(a) Useful life = 14–20 years for new designs.
(b) 10% residual value.

8. Interest

5% of total investment (approximately 11% on 100% financing).

9. Insurance (values vary between 0.35 and 0.85)

0.5% of aircraft price (A).

10. Crew costs (1989 cost value, ref. AEA)

(a) Flight = \$710 long-haul (493 short-haul)/flying hours (minimum two crew).
(b) Cabin = \$90/operating hours (1 per 35 passengers).

11. Landing fees (1989 cost value, ref. AEA)

\$6 per metric ton.

12. Navigation changes (1989 cost value, ref. AEA)

$$(\text{Stage length}/5) \times (MTOM/50)^{0.5}$$

where: stage length is in km and $MTOM$ is in metric tonnes.

13. Ground handling charges (1989 cost value, ref. AEA)

110 × payload (metric tonnes).

14. Fuel price

Use current price (e.g. \$0.22/kg, i.e. between 65 and 80c per US gal).

15. Maintenance

Maintenance costs are dependent on the way aircraft are used (e.g. route structure), the maintenance practices adopted by the airline and the age of the equipment (airframe and engines). Evaluation of the costs involves a detailed knowledge of factors which are unlikely to be available in the early design stages. Standardised methods for calculating maintenance costs are published (e.g. AEA, Boeing) and these should be used as soon as sufficient data is available (e.g. typical operating profiles). Until this time values from aircraft of a similar size and performance can be used or the simplified formulae below.

(a) Airframe direct cost (US\$/block hour) (1994):

$$C_{\mathrm{AM}} = 175 + 4.1\, M_{\mathrm{OET}}$$

where M_{OET} = aircraft operational empty mass in metric tonnes.

Typical values range from 300 for small regional jets to over 1000 for the B747–400.

(b) Engine direct cost per engine (US\$/block hour) (1994):

$$C_{\mathrm{EM}} = 0.29\, T$$

where T = engine thrust (kN).

The engine maintenance cost is a function of several engine parameters. The above calculation is appropriate to modern medium bypass (typically five) engines.

(c) Total aircraft maintenance cost is

$$C_{\mathrm{AM}} + C_{\mathrm{EM}} \cdot N_{\mathrm{E}}$$

where N_{E} = number of engines.

The maintenance costs above include all costs associated with the facility (e.g. overhead/burden).

Some comments on the above data

Absolute values for costs are time-dependent due to the effects of inflation in world economies. The figures above should be increased in line with inflation indices (typically between 3 and 6% per annum).

The data above is given as guidance to be used when better information is not available. It is appropriate to aircraft of conventional layout and materials. It does not include costs associated with specialised equipment such as thrust reversers, nacelle noise alleviation structures, freight doors and cargo equipment, extra passenger services and sophisticated aircraft instruments and avionics. Cost estimation is regarded as a 'black art'. Each airline and manufacturer will have developed methods and parameters appropriate to their own operations. In preliminary aircraft design it is necessary to show the trade-offs that are possible in the assumptions above. This will allow significant variations from the standard values to be assessed and allowances made to the aircraft specification if appropriate.

Miscellaneous definitions for airline DOC calculations

1. Utilisation

Aircraft utilisation is used for the calculation of depreciation and maintenance costs. It is defined as:

> Revenue hours is that time associated with the block time calculation below and does not include training, positioning for schedule, or any other non-revenue flying. Utilisation depends on the type of flight operation, time-round time, stand-down time, maintenance time, etc. Utilisation will obviously vary from one airline to another and for difference aircraft types. Increasing utilisation directly reduces costs and reflects an increased efficiency; therefore much effort has been put into raising utilisation.

Disregarding airline operational aspects the most significant factor affecting utilisation is block time. Long duration schedules without the non-revenue time stops associated with shorter flights show highest utilisation (as in the previous example calculation).

2. Block time (T_b) (hours)

This includes the total time spent from starting engines to engines 'off'. It includes the following components:

$$T_b = T_{gm} + T_{cl} + T_d + T_{cr} + T_{am}$$

where: T_{gm} = ground manoeuvre time including one minute for take-off
= 0.25 hr
T_{cl} = time to climb including acceleration from take-off speed to climb speed
T_d = time to descend including deceleration to manual approach speeds
T_{am} = time for air manoeuvres (no credit for distance) = 0.1 hr
T_{cr} = time at cruise altitude (including traffic allowance)

This is evaluated by:

$$T_{cr} = [D + (K_a + 20) - (D_c + D_d)]/V_{cr}$$

where: D = trip distance (i.e. stage length) CAB (statute rules)
D_c = distance to climb (statute miles) including distance to accelerate from TO speed to climb speed
D_d = distance to descend (statute miles) including distance to decelerate to normal approach speed
V_{cr} = average true airspeed in cruise (mph)
K_a = airway distance increment
= $(7 + 0.015\,D)$ for $D < 1400$ statute miles
= $0.02\,D$ for $D > 1400$ statute miles

These values should be estimated within the following conditions:

- climb and descent rates shall be such that 300 ft/min cabin pressurisation rate is not exceeded;
- in transition from cruise to descent the cabin floor angle shall not change by more than 4° nose down;
- the true airspeed used should be the average speed attained during the cruising portion of the flight including the effects of step climbs, if used;
- zero wind speed and standard temperature shall be used for all performances.

3. Block speed (V_b)

This is defined as:

$$V_b = D/T_b$$

4. Flight time (T_f) hours

This is defined as:

$$T_f = T_b - T_{gm}$$

5. Unit costs

It is common practice to quote aircraft costs in ways other than the aircraft hourly cost. The following costs are often used.

1. *Cost per aircraft mile* (usually quoted in cents/mile or pence/mile)

$$C_{am} = C_{ah}/V_b \times 100$$

2. *Cost per short-ton mile*

$$C_{st} = C_{am}/(\text{payload in short tons})$$

(Note: 1 short-ton = 2000 lb)

3. *Cost per seat mile* (or alternatively defined as cost per passenger mile)

$$C_{sm} = (C_{st} \times \text{passenger unit weight})/2000$$

(Passenger unit weight can be assumed to be 205 lb, the 2000 converts the short ton unit to pounds.)

Note cost estimates 2. and 3. assume 100% load factor. If lower load factors are to be assumed it is necessary to make more detailed modifications to the earlier cost analysis (e.g. fuel costs) to account for reduced aircraft weight.

6. Weights

To establish a constant method of cost estimation it is necessary to precisely define various weight terms.

1. *Payload* Within the limitations of the volumetric payload capacity and the structural payload capacity, the payload is equal to:

   aircraft take-off weight − (operating weight + weight of fuel)

2. *Volumetric payload capacity* is equal to:

   (no. of passenger seats × weight of the passenger plus food) × (gross volume of all freight and baggage holds × density of freight and baggage)

3. *Structural payload capacity* Two limits to payload may frequently be imposed by structural strength considerations:

   (a) maximum zero fuel weight
   (b) maximum landing weight

   In the latter case the take-off weight must be such that the following total does not exceed the maximum landing weight:

   $$\text{operating weight} + \text{payload} + \text{reserve fuel and oil}$$

   The reserve fuel = (fuel carried + ground burn fuel consumed).

4. *Operating weight* The operating weight is the weight of the aircraft fully equipped and ready for operation, including flight and cabin crew and their baggage, but less fuel, oil, and payload. It includes expendable items such as anti-icing fluid, humidification, drinking, washing and galley water, and passenger amenities associated with the role of the aircraft.
   If the fuel required for anti-icing, cabin heating, auxiliary power units, etc. is drawn from the main tanks or if their operation affects engine consumption, a suitable allowance must be added to the fuel carried.

5. *Weight of crew members* The weights of male crew members and of stewardesses shall be taken as 165 lb (75 kg) and 143 lb (65 kg) respectively plus baggage allowances of 44 lb (20 kg) each for services involving overnight stops away from base. It is to be assumed that the weight of the crew's food, when carried, is covered within the total allowance for passengers' food.

6. *Passenger weight* The inclusive weight of a passenger, baggage and food, termed the 'passenger-unit weight', is to be taken as 205 lb (93 kg). This figure, which is specified for general purpose calculations of passenger mile cost, is a weighted mean of loads realised in operation and is based on medium-range services; it is made up of 156 lb passenger weight, 44 lb baggage weight and 5 lb food.

Table 12.1

Service category	Baggage	Amenities, including food		
Short service (local)	33 lb (15 kg)	4 lb (1.8 kg) for all seats		
		Economy	Tourist	1st class
Continental and feeder-line (duration less than 6 hours)	44 lb (20 kg)	7 lb (3.2 kg)	12 lb (5.5 kg)	25 lb (10.4 kg)
Intercontinental services (duration greater than 6 hours)	66 lb (30 kg)	9 lb (4.1 kg)	16 lb (7.3 kg)	32 lb (14.6 kg)

7. *Density of freight and baggage* The density of freight and baggage is to be taken as 10 lb/cu ft (160 kg/m^3) on the gross volume of the freight and baggage holds. For use in more specific calculations the values in Table 12.1 may be regarded as fairly typical.

8. *Unit weights of fuel and oil* The following unit weights of one Imperial gallon (note, 1 US gallon = 0.8 Imperial gallon) of fuel and oil are to be employed for the cost methods.

Turbine Fuel	8 lb	(3.63 kg)
Lubricating Oil	8.9 lb	(4.04 kg)
Methanol-water	9.1 lb	(4.13 kg)