14 Design Evaluation / DOC

14.1 Costing as an Assessment Method in Aircraft Design

Just as the general assessment of an aircraft design depends on the particular perspective, so too does cost analysis depend on the respective standpoint.

14.1.1 Cost Analysis from the Perspective of the Aircraft Manufacturer

The aircraft manufacturer, as a "traditional" manufacturing enterprise, differentiates between fixed costs and variable costs.

- *Fixed costs* (non recurring costs, NRC) are the costs incurred particularly during the project, definition and development phase. They include:

  – costs incurred due to development and design: engineer's services (in-house and contracted out), equipping of development and design offices (computers);
  – costs incurred by testing departments: engineer's services, test setups (wind tunnel models, wind tunnel operation);
  – costs from cooperation with suppliers;
  – costs of analyzing reliability, maintainability, certification procedures;
  – costs of analyzing manufacturing methods;
  – costs of construction of jigs and fixtures;
  – costs of building prototypes (if necessary);
  – costs from flight testing and certification;
  – financing costs.

- *Variable costs* (recurring costs, NRC) are costs incurred particularly by Manufacturing and Product Support. They include:

  – costs of manufacturing support: services connected with rectifying errors/faults, taking into account customers' wishes, instruction manuals;
  – production costs: wage costs, cost of materials, tool costs, quality assurance costs, costs of purchased parts: auxiliary power unit (APU), landing gear; ...
  – costs incurred from flight testing with production planes and customer service,
  – financing costs.

Even for the aircraft manufacturer, **practical calculation** of these cost elements during the project phase is only possible at considerable expense and entails a large number of assumptions. Simple models for estimating the costs of the aircraft manufacturer are available in the literature (**Roskam VIII 1990**, **Nicolai 1975**, **Raymer 1992**).

An aircraft design assessment based on **cost analysis from the perspective of the aircraft manufacturer** must be viewed **critically**. Aircraft design parameters are scarcely included as input parameters in simple cost analysis models from the perspective of the aircraft manufacturer (see above). The models therefore provide little information on how costs change if the aircraft design parameters vary. Optimization of the aircraft design parameters is therefore scarcely possible with these simple models.

14.1.2 Cost Analysis from the Perspective of the Operator

There are a whole series of models for cost analysis from the perspective of the operator. These models are labeled by abbreviations such as LCC, COO, DOC, IOC, TOC, COC. The abbreviations are universally used, but should one search for detailed information on these models, one realizes that

- extensive literature research is necessary,
- different authors have very varied concepts of the same method.

Therefore, the following pages will be restricted to two purposes:

- to briefly characterize the models;
- to provide references to further reading.

Design according to **Life Cycle Costs** (LCC) is established in the military sphere, but has also been used for civil subsonic aircraft (**Johnson 1990**). LCC give the costs of the aircraft project as a whole (**Roskam VIII 1990**) or the life cycle costs of a single aircraft (**Johnson 1990**, **Raymer 1992**). **ARP 4294** states the elements of LCC. For civil operators the LCC are only of limited interest. For them, the costs of development and manufacture are simply part of the purchase price of the aircraft. Costs of scrapping the aircraft are also scarcely of interest to civil operators, because they will ultimately sell the aircraft at the end of its use and are therefore only interested in the residual value.

Cost of Ownership (COO) also constitutes an approach from the perspective of the operator. Some authors use COO to refer to the costs resulting solely from ownership of the aircraft (purchase and fixed operating costs) (**Odell 1993,** p.14), whereas others also include the variable operating costs (**Raymer 1992**, **Carubba 1992**). COO models have often also been used as marketing and selling instruments or to assess aircraft (sub-) systems (**Honeywell 1991**, **Dechow 1994**).

Direct Operating Costs (DOC) include the entire *operating costs of the aircraft*. In aircraft construction, DOC methods have become more widely accepted than any other and will therefore be examined in detail here. DOC methods of aircraft manufacturers, aircraft operators and associations (e.g. the Air Transport Association of America, ATA, and the Association of European Airlines, AEA) exist. The great success of DOC calculations started in 1967 with the method created by the Air Transport Association (**ATA 1967**). This method is now outdated, because the equations used no longer correctly reflect the current relationships between the individual cost elements (**Torenbeek 1988**, p. 387). DOC methods, by definition, only contain the *aircraft-related costs*. DOC methods have been used in practice in the past in preference to all other methods. They were used by airlines to optimally select their aircraft and by aircraft or engine manufacturers to evaluate new designs.

Cash Operating Costs (COC) (also: "Cash DOC") are DOC without depreciation. An examination of COC is of importance for operators who do not purchase their aircraft, but rather lease them. COC are also applied in academia if the (true) aircraft price is not known.

Indirect Operating Costs (IOC) complement DOC: while DOC are aircraft-related costs, IOC are *passenger-related costs* which depend on the management of the airline. An aircraft design assessment can be mainly restricted to DOC as IOC do not, by definition, depend on the aircraft. A close examination shows that the allocation of costs to DOC and IOC is not actually very clear-cut. Consequently, differing interpretations exist. The respective definitions of DOC and IOC therefore have to be looked at closely when studying the various sources. The IOC option has generally attracted less interest than DOC in the past. **Lockheed 1970** is one of the few IOC methods. It is conceived as a counterpart to the DOC method **ATA 1967** and contains costs for premises and equipment, fees and charges, cabin personnel costs, passenger service, ticket sales, advertising, luggage and cargo loading. For an airline operating scheduled flights, IOC are roughly of the same magnitude as DOC. In the case of charter flights, IOC are somewhat lower than DOC (**Fielding 1999**).

Total Operating Costs (TOC) are the sum total of DOC and IOC.

14.2 Overview of Assessment Methods

Fig. 14.1 shows an overview of the assessment methods employed in aircraft construction. The calculation of return, cash value or breakeven point makes the most sense from an economic perspective. However, for such a calculation both the revenue and expenditure always have to be known. A calculation may be made from the perspective of the aircraft manufacturer or the airline.

Applicability in practice is especially possible from the perspective of the operator with the aid of DOC methods. The method used by the *Association of European Airlines* (**AEA 1989a** and **AEA 1989b**) is presented here in full. A comparison with other DOC methods is also offered.

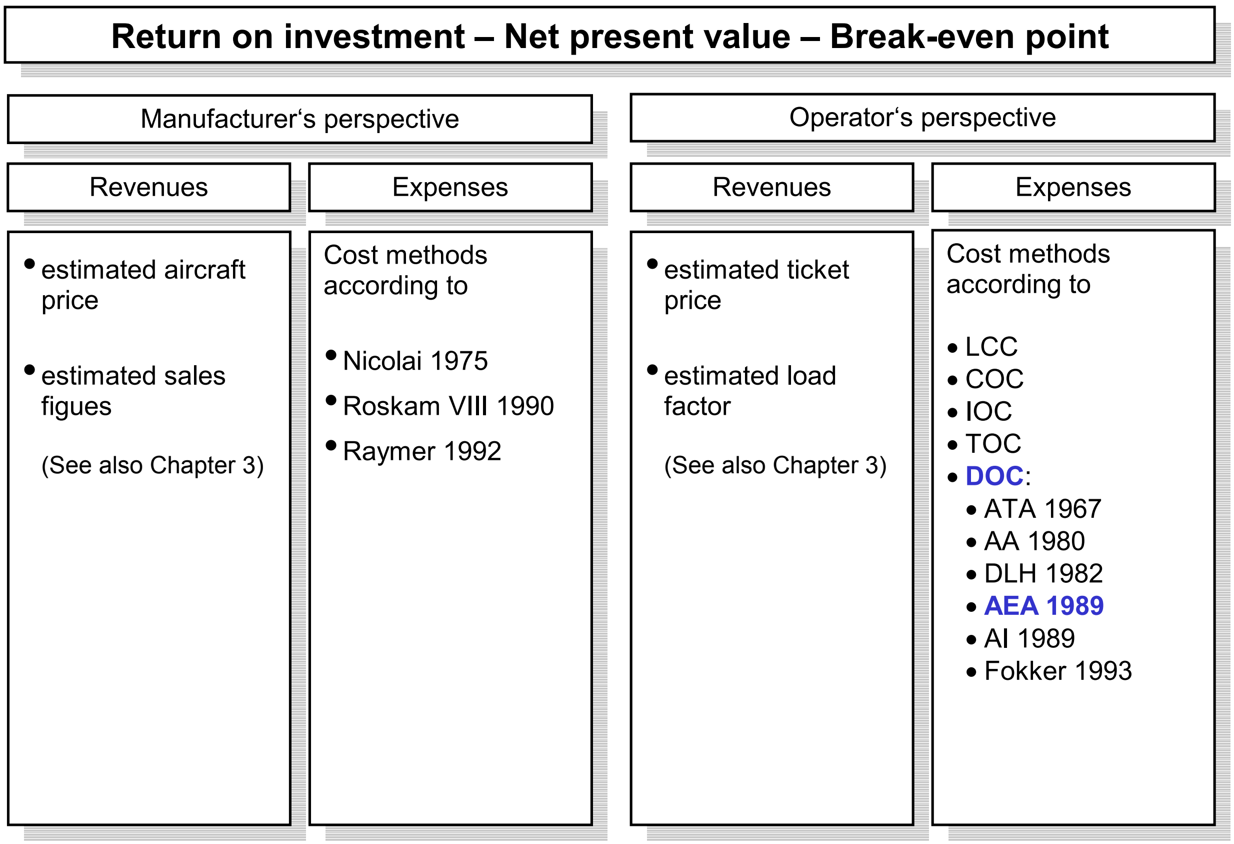

Fig. 14.1 Overview of assessment methods

14.3 Direct Operating Costs (DOC)

In this section, an attempt is to be made to summarize the various DOC methods listed in **Table 14.1**. In doing so, the DOC method applied by the *Association of European Airlines*, which is often used in Europe, will be described in full. The *Fokker* method will also be presented in full. Some of the other methods specified in Table 14.1 are very wide-ranging and are therefore not presented in full. Other DOC methods (such as the *Boeing* method) are not dealt with here.

Table 14.1 Overview of selected DOC-Methods

Organization	Comment	Year of Publication	Source
Air Transport Association of America (ATA)	Predecessors to this method are from the year: 1944, 1949, 1955 and 1960.	1967	**ATA 1967**
American Airlines (AA)	The Method is based on Large Studies sponsored by NASA. See also: **NASA 1977**.	1980	**AA 1980**
Lufthansa	The Method was continuously developed further.	1982	**DLH 1982**
Association of European Airlines (AEA)	Method for Short- and Medium Range Aircraft	1989	**AEA 1989a**
Association of European Airlines (AEA)	Method for Long Range Aircraft (a modification of the method **AEA 1999a**)	1989	**AEA 1989b**
Airbus Industries (AI)	The Method was continuously developed further.	1989	**AI 1989**
Fokker	The Method was produced to evaluate aircraft design project.	1993	**Fokker 1993**

14.3.1 Calculation of DOC

As a rule, DOC methods calculate the direct operating costs of an aircraft from the costs C incurred due to

- depreciation C_{DEP}
- interest C_{INT}
- insurance C_{INS}
- fuel C_F

- maintenance C_M, consisting of the sum of
  - airframe maintenance $C_{M,AF}$
  - power plant maintenance $C_{M,PP}$
- crew C_C, consisting of the sum of
  - cockpit crew $C_{C,CO}$
  - cabin crew $C_{C,CA}$
- fees and charges C_{FEE}, consisting of the sum of
  - landing fees $C_{FEE,LD}$
  - ATC or navigation charges $C_{FEE,NAV}$
  - ground handling charges $C_{FEE,GND}$

The DOC are then (taking into account **Table 14.2**) the sum of these cost elements.

$$C_{DOC} = C_{DEP} + C_{INT} + C_{INS} + C_F + C_M + C_C + C_{FEE} \tag{14.1}$$

Table 14.2 Included cost elements of the here mentioned DOC methods

	ATA 67	**AA 1980**	**DLH 1982**	**AEA 1989a AEA 1989b**	**AI 1989**	**Fokker 1993**
C_{DEP}						
based on A/C prize	x	x	x	x	x	x
based on spare part	x		x	x	x	x
C_{INT}			x	x	x	x
C_{INS}	x	x	x	x	x	x
C_F	x	x	x	x	x	x
$C_{M,AF}$	x	x	x	x	x	x
$C_{M,PP}$	x	x	x	x	x	x
$C_{C,CO}$	x	x	x	x	x	x
$C_{C,CA}$		x	x	x	x	x
$C_{FEE,LD}$		x	x	x	x	x
$C_{FEE,NAV}$		x	x	x	x	x
$C_{FEE,GND}$		x	x	x		x

Table 14.2 provides an overview of the cost elements included by DOC methods. **ATA 1967** does not include interest expense, costs due to cabin crew or costs due to fees and charges. The other DOC methods examined here contain virtually the same cost elements.

A closer examination of DOC methods reveals a number of other peculiarities relating to individual methods:

- **AI 1989** contains *inflation factors*. This means that the fundamental equations can be adjusted to subsequent years taking into account differing inflation rates for spare parts, wages, and fees and charges. Economic parameters of the method are adjusted to the altered circumstances at yearly intervals.
- **NASA 1977/AA 1980** contain the most wide-ranging research and equations for determining *maintenance costs*. The maintenance costs are examined and added together at the level of the individual ATA chapters.
- **DLH 1982** and **AI 1989** take into account the revenue potential from transporting *cargo* (see below).

14.3.2 Representation of DOC

The DOC can be recorded in different ways. Here, we will firstly consider DOC as the costs incurred by an aircraft (Index: *a/c*) in a fleet within one year (annual costs, Index: *a*). These are *aircraft annual costs*

$$\text{here:} \quad C_{DOC} = C_{a/c,a} \quad . \tag{14.2}$$

The analysis of DOC applied here over one year then also means that in this case all the cost elements C_{DEP}, C_{INT}, C_{INS}, C_F, C_M, C_C and C_{FEE} are calculated for one year.

DOC are calculated for a specific aircraft trip characterized by a specific range *R*, a specific flight time t_f and block time, t_b (see below for definitions). An aircraft trip for calculating DOC according to **AEA 1989b** is shown in **Fig. 14.2**. It would also be possible to calculate the DOC for such a defined flight, cycle or trip (Index: *t)* of an aircraft (Index: *a/c)*. In this way one can obtain the *aircraft trip costs*

$$C_{a/c,t} = \frac{C_{a/c,a}}{n_{t,a}} \quad . \tag{14.3}$$

Here $n_{t,a}$ is the number of flights per year that an aircraft can make on such an aircraft trip. It is also possible to relate the DOC to the *distance* flown. These are then (depending on the unit used) the *aircraft mile costs*.

$$C_{a/c,m} = \frac{C_{a/c,t}}{R} = \frac{C_{a/c,a}}{n_{t,a}\ R} \quad . \tag{14.4}$$

The DOC can also be related to the *distance* flown *and* the *number of seats* or the maximum number of passengers on the flight n_{pax}. This then gives the *seat-mile costs* (depending on the unit used)

$$C_{s,m} = \frac{C_{a/c,t}}{n_{pax}\ R} = \frac{C_{a/c,a}}{n_s\ n_{t,a}\ R} \quad . \tag{14.5}$$

The number of seats is taken from standard seat layouts, which can be arranged differently for short, medium and long haul flights. The calculation of seat-mile costs is also still purely a cost analysis. However, the revenue *potential* is already included to a certain extent because an alternative aircraft or cabin design with more seats reduces the seat-mile costs while the aircraft trip costs remain the same.

The revenue potential can also be taken into account if the DOC is related to the *distance* flown and the *payload*. If only the payload of passengers and luggage is taken into account, the *seat-ton-mile costs* (depending on the unit used) are obtained. In the case of a cargo plane the *cargo-ton-mile costs are obtained* analogously.

$$C_{pax,t,m} = \frac{C_{a/c,t}}{(m_{pax} + m_{baggage})\ R} = \frac{C_{a/c,a}}{(m_{pax} + m_{baggage})\ n_{t,a}\ R} \quad . \tag{14.6}$$

$$C_{cargo,t,m} = \frac{C_{a/c,t}}{m_{cargo}\ R} = \frac{C_{a/c,a}}{m_{cargo}\ n_{t,a}\ R} \quad . \tag{14.7}$$

If one regards the total payload $m_{PL} = m_{pax} + m_{baggage} + m_{cargo}$ as the sum total of the payload constituted by passengers, luggage and cargo, one obtains the *ton-mile costs*

$$C_{t,m} = \frac{C_{a/c,t}}{m_{PL}\ R} = \frac{C_{a/c,a}}{m_{PL}\ n_{t,a}\ R} \quad . \tag{14.8}$$

In this case the entire revenue potential can now be taken into account. However, the disadvantage is that cargo masses have just as big an influence on the relevant costs as does the "higher-value" transportation of passenger masses. In order to correct this influence, *equivalent ton-mile costs* can be calculated, in which a correction factor is applied to the cargo masses k_{cargo} (see **Table 14.3**). In doing so, a distinction can be made according to the type of cargo:

- cargo that is accommodated in **c**ontainers on the **m**ain **d**eck (such as on combi aircraft) - Index: *CMD*;
- cargo that is accommodated in **c**ontainers on the **l**ower **d**eck - Index: *CLD*;
- bulk cargo - Index: *B*.

$$C_{equiv,t,m} = \frac{C_{a/c,t}}{(m_{pax} + m_{baggage} + k_{cargo,CMD}\; m_{cargo,CMD} + k_{cargo,CLD}\; m_{cargo,CLD} + k_{cargo,B}\; m_{cargo,B})\; R} \qquad (14.9)$$

Table 14.3 Correction factors for the calculation of equivalent ton-mile costs

correction factor	type of freight	**DLH 1982**	**AI 1989**
$k_{cargo,CMD}$	**c**ontainerized, **m**ain **d**eck	1.0	-
$k_{cargo,CLD}$	**c**ontainerized, **l**ower **d**eck	0.8	$0.005 \frac{1}{\text{kg}} \cdot \frac{m_{pax} + m_{baggage}}{n_{pax}} \approx 0.5$ [a]
$k_{cargo,B}$	**b**ulk	0.5	$0.0025 \frac{1}{\text{kg}} \cdot \frac{m_{pax} + m_{baggage}}{n_{pax}} \approx 0.25$ [b]

[a] **AI 1989** assumes that 1000 kg of containerized freight generates as much revenues as 5 passengers.

[b] **AI 1989** assumes that only 50 percent of the bulk cargo transport volume will be used, but 100 percent of the container transport volume.

DOC can also be related to the **f**light time, t_f or **b**lock time, t_b

$$C_{a/c,f} = \frac{C_{a/c,t}}{t_f} = \frac{C_{a/c,a}}{n_{t,a}\; t_f} \quad , \qquad (14.10)$$

$$C_{a/c,b} = \frac{C_{a/c,t}}{t_b} = \frac{C_{a/c,a}}{n_{t,a}\; t_b} \quad . \qquad (14.11)$$

The term *flight time* is defined in **JAR 1:**

"Flight time" means the time between lift-off and touchdown.

According to **WATOG 1992,** the term *block time* essentially means:

> *Time that commences when an aircraft moves under its own power for the purpose of flight and ends when the aircraft comes to rest after landing.*

Note: According to **FAR 1** this is the definition of flight time!!!

The block time, as opposed to the flight time, also includes ground times, such as due to the push back of the aircraft, taxi prior to take-off and after landing, or waiting on the ground for clearance. **Table 14.4** contains assumed time differences $\Delta t = t_b - t_f$.

Table 14.4 Standardized assumed time difference between block time and flight time

$\Delta t = t_b - t_f$	remark	source
15 min. = 0.25 h	short and medium range	**AEA 1989a**
25 min. = 0.42 h	long range	**AEA 1989b**

14.3.3 Calculation of DOC Cost Elements - Depreciation

Depreciation C_{DEP} is the distribution of the reduction in value of an item over the useful service life (see above). The useful service life over which the item is to be depreciated n_{DEP} has to be set and the occurring reduction in value has to be determined. The value of a new item corresponds to its total purchase price P_{total} (if the value were otherwise, the purchase price would probably not have been paid). After the end of use, the item can still be sold at a price that corresponds to its residual value $P_{residual}$. The reduction in value is therefore $P_{total} - P_{residual}$ and the **depreciation**

$$C_{DEP} = \frac{P_{total} - P_{residual}}{n_{DEP}} = \frac{P_{total}\left(1 - \frac{P_{residual}}{P_{total}}\right)}{n_{DEP}} \quad . \qquad (14.12)$$

DOC methods use a similar **useful service life** n_{DEP} and a similar **relative residual value** $P_{residual} / P_{total}$. A list is shown in **Table 14.5**.

The total **purchase price of an aircraft** P_{total} comprises the delivery price $P_{delivery}$ and the price for the spares (Index: *S)* P_S purchased with each aircraft.

$$P_{total} = P_{delivery} + P_S \quad . \tag{14.13}$$

The **delivery price** $P_{delivery}$ includes:

- the *list price* for a standard configuration (manufacturers standard study price);
- from which *discounts* are deducted;
- to which *surcharges for modifications* (change orders) are added;
- the price for equipment components that the customer buys on its own responsibility (*buyer furnished equipment*, BFE); this may also include engines, which account for a considerable proportion of the total price of the aircraft;
- the interest on *construction progress payments.*

These payments can scarcely be determined due to the lack of publications. However, **estimation methods** do exist **for determining the delivery price**.

The following **estimate is provided for the maximum take-off mass** m_{MTO} at the time of this publication

$$P_{delivery} = \frac{P_{delivery}}{m_{MTO}} m_{MTO} \tag{14.14}$$

with

$$\frac{P_{delivery}}{m_{MTO}} \approx 500 \frac{\text{US\$}}{\text{kg}} \quad \text{for short and medium haul aircraft,}$$

$$\frac{P_{delivery}}{m_{MTO}} \approx 350 \frac{\text{US\$}}{\text{kg}} \quad \text{for long haul aircraft.}$$

The following **estimate** is provided **for operating empty mass** m_{OE} according to **Jenkinson 1999a**

$$P_{delivery} = \frac{P_{delivery}}{m_{OE}} m_{OE} \tag{14.15}$$

with

$$\frac{P_{delivery}}{m_{OE}} \approx 860 \frac{\text{US\$}}{\text{kg}} \quad \text{for short to long haul aircraft.}$$

When using these estimation equations it is important to bear in mind that the values only apply to aircraft of a typical construction type. If an aircraft is built to a *lighter* specification by means of complex construction, manufacture and materials, then this does not, of course, mean that it will be cheaper, as equations (14.14) and (14.16) would show, but that it will be *more expensive*!

The following **estimate of the number of seats** n_{pax} is provided at the time of this publication

$$P_{delivery} = \frac{P_{delivery}}{n_{pax}} n_{pax} \tag{14.16}$$

with

$$\frac{P_{delivery}}{n_{pax}} \approx 265000 \text{ US\$} \quad \text{for short to long haul aircraft.}$$

The price for spares (Index: *S*) P_S is calculated from a proportion $k_{S,AF}$ of the price of the airframe (Index: *AF)* P_{AF} and a proportion $k_{S,E}$ of the price of the engines (Index: *E*) $n_E\ P_E$. n_E is the number of engines. **Table 14.5** contains the proportions $k_{S,AF}$ and $k_{S,E}$.

$$P_S = k_{S,AF}\ P_{AF} + k_{S,E}\ n_E\ P_E \tag{14.17}$$

The price of the airframe is the price of the aircraft minus the price of the engines

$$P_{AF} = P_{delivery} - n_E\ P_E \quad . \tag{14.18}$$

The engine price can be obtained from the manufacturer or estimated according to the following statistical equation (based on data from **Jenkinson 1999b**). The estimate is based on the take-off thrust $T_{T/O,E}$ *of one* engine in N

$$P_E = 293\, US\$ \cdot \left(\frac{T_{T/O,E}}{\text{N}} \right)^{0.81} \quad . \tag{14.19}$$

Table 14.5 Parameters for the calculation of depreciation

Source	n_{DEP}	$\frac{P_{residual}}{P_{total}}$	$k_{S,AF}$	$k_{S,E}$
ATA 1967	12	0.00	0.10	0.10
NASA 1977			0.06	0.06
widebody [a]	16	0.10		
turbo fan [a]	14	0.02		
turbo jet [a]	10	0.05		
turbo prop [a]	10	0.15		
DLH 1982	14	0.00	calculated from necessary availability of spare parts in stock	
AEA 1989a	14	0.10	0.10	0.30
AEA 1989b	16	0.10	0.10	0.30
AI 1989	15	0.10	0.06	0.25
Fokker 1993	15	0.10	0.08	0.08

[a] Data in **NASA 1977** are quotes from the Hamurghden "Depreciation Guidelines" of the U.S. Civil Aeronautics Board (CAB).

14.3.4 Calculation of DOC Cost Elements - Interest

It is assumed that the investment for a new aircraft (price: P_{total}) is financed wholly from outside sources. Therefore $k_0 = P_{total}$. The **interest** payable to the investor C_{INT} is calculated with the aid of an average interest rate p_{av} and comes to the following per year

$$C_{INT} = p_{av}\, k_0 = p_{av}\, P_{total} \quad . \tag{14.20}$$

The average interest rate is inserted in the DOC methods as an operand for the sake of simplicity and is included in **Table 14.6**. p_{av} is lower than the interest rate p that one would expect on the capital market.

A more detailed version assumes that the outside capital will be repaid in equal installments and annual payments a at the end of the year over n_{PAY} years. After the n_{PAY} years a relative residual value k_n / k_0 of the outside capital may then remain in the company. This relative residual value of the outside capital is independent of the relative residual value of the depreciation $P_{residual} / P_{total}$ and may differ from this.

In order to calculate the average interest we take equation (14.21) from any math book on financial mathematics

$$a = \frac{k_0 \left(q^n - \frac{k_n}{k_0} \right) (q-1)}{q^n - 1} = \frac{k_0 \left(q^{n_{PAY}} - \frac{k_n}{k_0} \right) (q-1)}{q^{n_{PAY}} - 1} \quad . \tag{14.21}$$

Here, n is the number of repayment years, which we will designate as n_{PAY} to avoid confusion with the useful service life n_{DEP}.

a refers to the size of the required annual installment. Over a period of n_{PAY} years, the following is spent altogether in interest and amortization as *total payment*: $a\, n_{PAY}$. The total of the *redemption payments* is by definition $k_0 - k_n$. The total of *interest payments* is then the difference between the total payment and the redemption payments:

$$a\, n_{PAY} - (k_0 - k_n) = a\, n_{PAY} - k_0 \left(1 - \frac{k_n}{k_0} \right) \tag{14.22}$$

To calculate an average interest rate, these interest payments are spread over n_{DEP} years during which the aircraft is depreciated. Per year this comes to interest of

$$C_{INT} = \frac{a\, n_{PAY} - k_0 \left(1 - \frac{k_n}{k_0} \right)}{n_{DEP}} \quad . \tag{14.23}$$

According to the definition of the average interest rate, this is also

$$C_{INT} = p_{av}\, k_0 \tag{14.20}$$

Equation (14.32) together with (14.30) gives

$$p_{av} = \frac{a\, n_{PAY} - k_0 \left(1 - \frac{k_n}{k_0} \right)}{n_{DEP}\, k_0} \quad . \tag{14.24}$$

and finally equation (14.33) together with equation (14.31) provides the calculation equation for the average interest rate:

$$p_{av} = \frac{\dfrac{\left(q^{n_{PAY}} - \dfrac{k_n}{k_0}\right)(q-1)\, n_{PAY}}{q^{n_{PAY}} - 1} - \left(1 - \dfrac{k_n}{k_0}\right)}{n_{DEP}} \qquad (14.25)$$

The average interest rate p_{av} that the individual DOC methods assume and the parameters of equation (14.25) according to which p_{av} is calculated are contained in **Table 14.6**.

Table 14.6 Parameters for the calculation of the average interest rate p_{av}

source	p	$q = 1 + p$	n_{PAY}	$\frac{k_n}{k_0}$	n_{DEP}	p_{av}
ATA 1967	0.00	1.000	-	-	12	0.0000
NASA 1977 / AA 1980	0.00	1.000	-	-	-	0.0000
DLH 1982	0.09	1.09	14	0.0	14	0,0570
AEA 1989a	0.08	1.08	14	0.1	14	0.0529
AEA 1989b	0.08	1.08	16	0.1	16	0.0534
AI 1989	0.05	1.05	10	0.0	15	0.0197
Fokker 1993	0.08	1.08	15	0	15	0.0502

14.3.5 Calculation of DOC Cost Elements - Insurance

All the DOC methods examined here take into account the costs caused by insuring the aircraft against hull damage or even against hull loss. The insurance costs that are incurred per year C_{INS} are calculated by all methods as a percentage of the aircraft price, for the sake of simplicity

$$C_{INS} = k_{INS}\, P_{delivery} \quad . \qquad (14.26)$$

k_{INS} is listed in **Table 14.7**.

Table 14.7 Parameters for the calculation of the insurance costs

	ATA 67	**AA 1980**	**DLH 1982**	**AEA 1989a AEA 1989b**	**AI 1989**	**Fokker 1993**
k_{INS}	0.0200	0.0100	0.0056	0.005	0.005	0.004

14.3.6 Calculation of DOC Cost Elements – Fuel Costs

The fuel costs incurred per year C_F are calculated according to

$$C_F = n_{t,a} \, P_F \, m_F \tag{14.27}$$

In this equation $n_{t,a}$ is the number of flights made per year, P_F is the fuel price (in relation to a mass unit) and m_F is the mass of the fuel consumed during a flight.

The **number of flights per year** $n_{t,a}$ is dealt with in more detail below. At the moment let us assume that $n_{t,a}$ is known from the airline's statistics.

Composition of the fuel price: The price for kerosene is ascertained on a daily basis on the commodity markets. Rotterdam, for example, is an important trading center for North Western Europe. The prices negotiated in Rotterdam are referred to as spot market prices. They are specified as "free on board", or FOB for short. The FOB fuel price can be taken from published statistics. FOB means that the price includes loading for further transportation. Further transportation takes place from Rotterdam to Germany by inland waterway, for example. In this case FOB therefore means "price including loading onto the inland waterway vessel". The airlines pay a price consisting of the price FOB plus the so-called "Into-Plane-Differential". The "Into-Plane-Differential" is negotiated individually with the oil companies and specifies the difference between the spot market price and the purchase price. The "Into Plane Differential" is not made public, but comes to approximately 0.052 US$/kg in the case of a large airline.

The **fuel price** is subject to considerable fluctuations. In order to calculate the ratio of the operating cost elements to each other correctly, it is necessary to research the fuel price carefully. The fuel price is published in various statistical works and journals and can also be obtained from oil companies, airlines or airports. The DOC methods also specify a fuel price. However, these fuel prices are only of historical interest. To calculate DOC, the current fuel price has to be obtained. At the time of publication of this document $P_F = 0.22$ US$/kg is a plausible value.

In the case of a design assessment, not only the current fuel price is of interest, but rather the **fuel price** on the date **in the future** when the projected aircraft is to be operated. As this fuel price is unknown, only a parameter variation of the fuel price helps – that is the multiple calculation of DOC with the inclusion of various fuel prices. When setting the range within which the *fuel price* parameter is to be varied, it may be helpful to take a look at the price trend in the past. **Fig. 14.2** shows the fuel price trend over a period of 20 years.

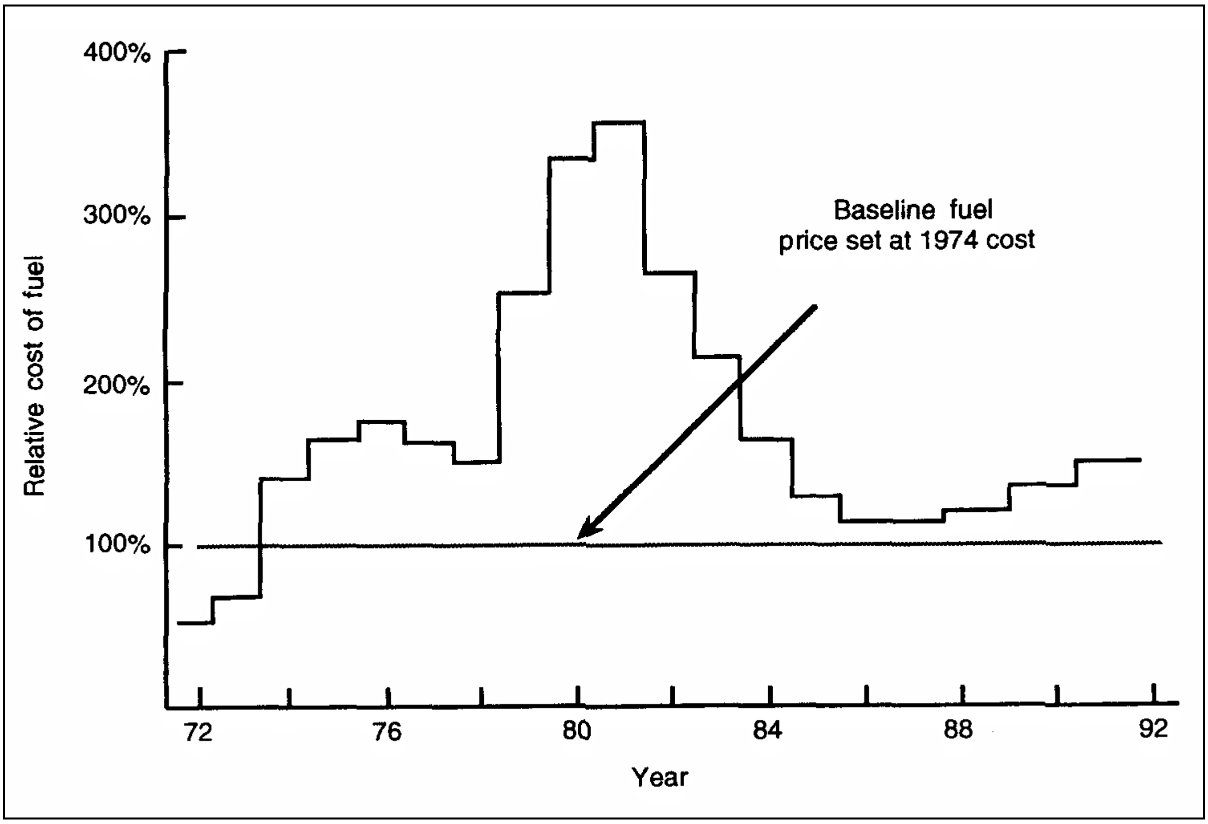

Fig. 14.2 Development of the fuel price from 1972 to 1992. Source: Publication of the American Institute of Aeronautics and Astronautics: Paper Nr.: AIAA-86-2667 quoted from **Jenkinson 1999a**

The mass of the fuel consumed during a flight – **fuel mass** m_F – is calculated according to the methods outlined in Section 5. In doing so, it is important to define the aircraft trip. The stage length, i.e. the range R between the departure and destination airport, is selected according to the probable and typical use of the aircraft. The selected stage length must be stated together with the calculated DOC, as the DOC is greatly influenced by the choice of this parameter. The DOC methods provide information on how the aircraft trip is to be perceived in detail. **Fig. 14.3** shows the definition of the aircraft trip according to **AEA 1989b**. According to **AEA 1989b** and **AEA 1989a** the aircraft is to be filled with enough fuel that

- a 5% reserve additional to the actually required fuel is included,
- in addition, an alternative airfield at a distance of 250 NM could be reached,
- in addition, the aircraft could fly for 30 minutes in a holding pattern at 1500 ft with minimal drag.

Of course only the actually consumed fuel mass is then included in the DOC calculation according to flight phases A to G from **Fig. 14.3**. The fuel reserve therefore only affects the fuel consumption due to additional aircraft weight and therefore drag and fuel consumption.

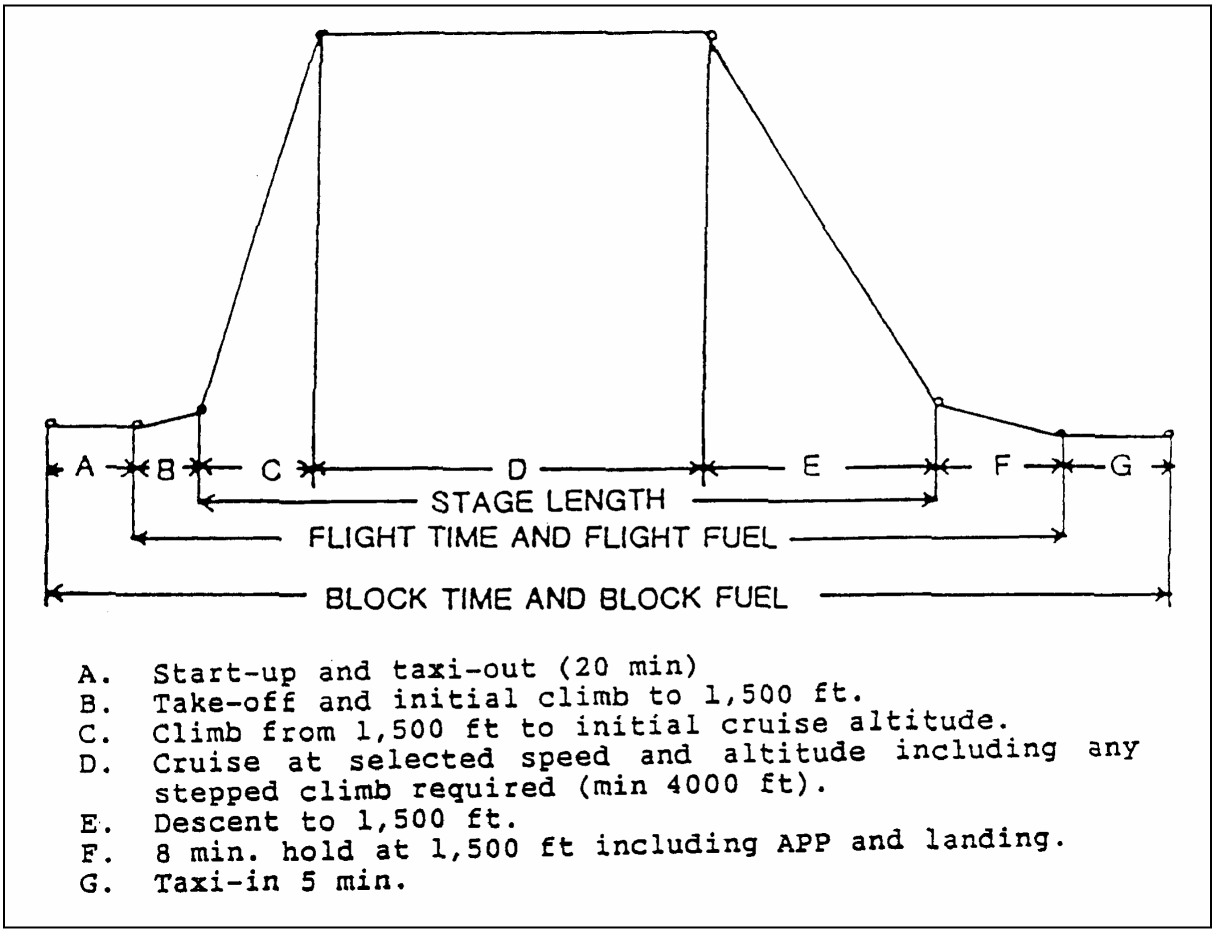

Fig. 14.3 Definition of the flight mission according to **AEA 1989b** (long range). Remark: according to **AEA 1989a** (short and medium range) for flight phase A only 10 min would have to be used

14.3.7 Calculation of DOC Cost Elements – Maintenance Costs

According to **WATOG 1992** maintenance is defined as

> *Those actions required for restoring or maintaining an item in serviceable condition, including servicing, repair, modification, overhaul, inspection and determination of condition.*

A distinction is made between the following:

- scheduled maintenance - ≈ 30% of costs;
- unscheduled maintenance - ≈ 70% of costs;

- on-aircraft maintenance - ≈ 30% of costs;
- off-aircraft maintenance - ≈70% of costs;

- time-dependent maintenance (increased costs on long flights);
- cycle-dependent maintenance (increase costs in the case of a large number of short flights as opposed to a few long flights).

Cycles are the number of flights made by an aircraft during a specific period.

The calculation of maintenance costs depends to a large extent on the figures available, which in turn depend on how maintenance costs are recorded in a maintenance organization. In addition to the classifications stated above, the following distinctions are made:

- Direct Maintenance Costs, DMC;
- Indirect Maintenance Costs, IMC.

As with the division of operating costs into DOC and IOC, the following also applies accordingly:

- DMC are the maintenance costs caused directly by the aircraft;
- IMC are the maintenance costs incurred by operation of the maintenance organization, which cannot be allocated directly to an aircraft.

IMC are incurred, for example, through training and education for the maintenance team. In the case of aircraft families with a large degree of similarity (commonality) these costs are lower. Therefore, in the case we are dealing with here even IMC can be influenced by the aircraft design. Therefore, DMC and IMC cannot always be clearly separated.

The labor rate charged for one maintenance hour on the aircraft is called

- *unburdened labor rate*: if only DMC elements are contained in the labor rate;
- *burdened labor rate*: if IMC elements are also included in the labor rate.

If the maintenance is carried out by the airline itself, then it is possible to differentiate between the *burdened* and *unburdened labor rate*. However, if the maintenance work is carried out by other organizations, the labor rate understandably also includes the IMC elements, but the maintenance expenses appear to the operator as costs caused directly by the aircraft. Therefore, it is difficult to differentiate between the *burdened* and *unburdened labor rate*. When calculating the DOC, the normal procedure is to select a labor rate that contains a specific proportion of IMC. A typical labor rate in relation to the maintenance man hour, MMH L_M is 69 US$/h in 1989-US$.

In general, maintenance costs comprise the labor costs $C_{M,L}$ and the material costs $C_{M,M}$

$$C_M = C_{M,L} + C_{M,M} \tag{14.28}$$

or, calculated from the maintenance hours t_M

$$C_M = t_M \, L_M + C_{M,M} \quad . \tag{14.29}$$

In this case this is firstly interpreted as being the costs incurred with respect to the aircraft within one year: $C_M = C_{M,a}$

$$C_M = t_{M,a} \, L_M + C_{M,M,a} \quad . \tag{14.30}$$

Maintenance costs are related to the flight time t_f , as a rule. It is then

$$C_{M,f} = t_{M,f} \, L_M + C_{M,M,f} \tag{14.31}$$

and

$$\boxed{C_M = (t_{M,f} \, L_M + C_{M,M,f}) \, t_f \, n_{t,a}} \tag{14.32}$$

The **maintenance man hours per flight hour**, MMH/FH $t_{M,f}$ increase with the size of the aircraft. **Table 14.8** contains comparative values for various types of aircraft with typical conditions of service and typical aircraft utilization. With the same type of aircraft the maintenance costs per flight hour also increase steeply with falling aircraft utilization $U_{h,f}$ (see 14.59). With the aid of values from **Nicolai 1975,** the following correlation is produced for jet transports as a guide:

$$t_{M,f} \approx \frac{1.16}{U_{h,f}} + 6 \quad . \tag{14.33}$$

Table 14.8 Required maintenance (man) hours per flight hour (MMH/FH) for typical operational conditions and utilization – comparative values

type of aircraft	$t_{M,f}$ (MMH/FH)	source
Cessna 172, Piper PA 28	≈ 1	
Cessna Citation	3.0	**Nicolai 1975**
DC-9-30	6.4	**Nicolai 1975**
DC-9 (military: C-9)	≈ 12	**Raymer 1992**
B737-200	6.6	**Nicolai 1975**
B727-100	7.9	**Nicolai 1975**
DC-10-10	10.9	**Nicolai 1975**
L1011	14.1	**Nicolai 1975**
B747-100	14.5	**Nicolai 1975**
A340	≈ 6	

Of course, it is difficult to estimate the maintenance hours and cost of materials for the aircraft as a whole in one step. For this reason, the maintenance costs for individual parts of the aircraft are calculated and then added together. In **NASA 1977**, the maintenance costs are calculated at the levels of ATA chapters. In DOC methods, it is more the norm to **differentiate between airframe** (Index: *AF)* **and engine** (Index: *E)*

$$\boxed{C_M = ((t_{M,AF,f} + t_{M,E,f})\, L_M + C_{M,M,AF,f} + C_{M,M,E,f})\, t_f \, n_{t,a} \quad . \qquad (14.34)}$$

Following **AEA 1989a** und **AEA 1989b**: L_M = 65 US$/h in 1989-US$.

For maintenance of the airframe, wage costs account for roughly 65% and the cost of materials 35%. In the case of engine maintenance the ratio is the opposite.

It is especially difficult to estimate and calculate maintenance costs within the scope of DOC methods if the **calculation equations** are to be based on simple aircraft design parameters. For this reason, the equations for calculating maintenance costs often take up the biggest space when using DOC methods. The equations for calculating maintenance costs of the *AEA*-DOC method (**AEA 1989a** and **AEA 1989b**) are presented here.

$$t_{M,AF,f} = \frac{1}{t_f}\left(9 \cdot 10^{-5}\,\frac{1}{\mathrm{kg}} \cdot m_{AF} + 6.7 - \frac{350000\,\mathrm{kg}}{m_{AF} + 75000\,\mathrm{kg}}\right)\left(0.8\,\mathrm{h} + 0.68\,t_f\right) \qquad (14.35)$$

$$C_{M,M,AF,f} = \frac{1}{t_f}(4.2 \cdot 10^{-6} + 2.2 \cdot 10^{-6}\,\frac{1}{\mathrm{h}} \cdot t_f)\, P_{AF} \qquad (14.36)$$

$$t_{M,E,f} = n_E \cdot 0.21 \cdot k_1 \cdot k_3 \cdot \left(1 + 1.02 \cdot 10^{-4} \frac{1}{\text{N}} \cdot T_{T/0,E}\right)^{0.4} \cdot \left(1 + \frac{1.3\,\text{h}}{t_f}\right) \tag{14.37}$$

$$C_{M,M,E,f} = n_E \cdot 2.56 \frac{\text{US\$}}{\text{h}} \cdot k_1\,(k_2 + k_3) \cdot \left(1 + 1.02 \cdot 10^{-4} \frac{1}{\text{N}} \cdot T_{T/O,E}\right)^{0.8} \cdot \left(1 + \frac{1.3\,\text{h}}{t_f}\right) \cdot k_{INF} \tag{14.38}$$

In equations (14.35) to (14.38):

the mass of the airframe is $m_{AF} = m_{OE} - m_{E,inst}$ (14.39a)

the mass of all engines on the aircraft is $m_{E,inst} = k_E\; k_{thr}\; n_E\; m_E$ (14.39b)

$k_E = 1.16$	for single engine piston props,
$k_E = 1.35$	for twin engine piston props,
$k_E = 1.15$	for jet transports and engines in pods,
$k_E = 1.40$	for aircraft with buried engines
$k_{thr} = 1.00$	without reverse thrust,
$k_{thr} = 1.18$	with reverse thrust,
n_E	number of engines,
m_E	mass of one engine without parts used for engine integration.

the price of the airframe is $P_{AF} = P_{delivery} - n_E\; P_E$ see above (14.18)

the take-off thrust of an engine is $T_{T/O,E}$ as calculated in the design

$$k_1 = 1.27 - 0.2 \cdot BPR^{0.2} \tag{14.40}$$

$$k_2 = 0.4 \left(\frac{OAPR}{20}\right)^{1.3} + 0.4 \tag{14.41}$$

$$k_3 = 0.032\, n_C + k_4 \tag{14.42}$$

$$k_4 = \left\langle \begin{array}{lll} 0.50 & \text{für} & n_S = 1 \\ 0.57 & \text{für} & n_S = 2 \\ 0.64 & \text{für} & n_S = 3 \end{array} \right| \tag{14.43}$$

The **engine data** contained in equations (14.40) to (14.43) can be taken from the literature or directly from the manufacturer's data. The following are required:

- the bypass ratio *BPR*;
- the overall pressure ratio *OAPR*;
- the number of compressor stages – including the fan n_C;
- the number of shafts of the engine n_S.

The engine IAE V2530-A5 (for the Airbus A321), for example, is characterized by *BPR* = 4.6 and *OAPR* = 32.5, n_C = 15 and n_S = 2.

The equations (14.35) to (14.38) always adapt to the current financial conditions if the current labor rate and the current aircraft price are used. If equations provide costs relating to the year in which the method was developed, **compensation for inflation** must be provided. This is carried out by means of an inflation factor

$$k_{INF} = (1 + p_{INF})^{n_{year} - n_{method}} \quad . \tag{14.44}$$

I have added this factor to equation (14.38) compared with the AEA original. With this factor the "old" equation is adjusted to the current financial conditions. The following are inserted in (14.44):

- the annual mean inflation rate p_{INF};
- the year for which the calculation is being made n_{year};
- the year that the method refers to n_{method}.

p_{INF} = 0.033 is a plausible value according to **AI 1989**. For equation (14.47) n_{method} = 1989 according to the publication date of the AEA method.

The DOC method of *Fokker* (**Fokker 1993**) does not provide any equations for calculating maintenance costs. In this case one has to rely on known values of comparative aircraft. Equations for calculating maintenance costs are also included in **Raymer 1992**.

According to **Jenkinson 1999a** a simple estimate of maintenance costs is possible with

$$C_M = (C_{M,AF,b} + n_E \, C_{M,P,b}) \, t_b \, n_{t,a} \quad , \tag{14.45}$$

$$C_{M,AF,b} = 175 \, \frac{\text{US\$}}{\text{h}} + 0.0041 \, \frac{\text{US\$}}{\text{h kg}} \cdot m_{OE} \quad , \tag{14.46}$$

$$C_{M,P,b} = 0.00029 \, \frac{\text{US\$}}{\text{h N}} \cdot T_{T/O} \quad . \tag{14.47}$$

In equations (14.45) to (14.47) the maintenance costs for the airframe and engine are related to the block time. The equations apply to the year 1994 and must, if necessary, be corrected with the inflation factor according to (14.44). m_{OE} is the operating empty mass, $T_{T/O}$ is the take-off thrust of *one* engine. The costs of engine maintenance apply to modern engines with a bypass ratio of approximately 5.

14.3.8 Calculation of DOC Cost Elements – Staff Costs

Many DOC methods include the costs of the cabin crew $C_{C,CA}$ in addition to the costs of the cockpit crew $C_{C,CO}$. Per year the following costs are incurred:

$$C_C = C_{C,CO} + C_{C,CA} \quad . \tag{14.48}$$

It is customary to pay the crew according to block time. Then the cockpit crew n_{CO} are paid at a mean hourly rate L_{CO} and cabin crew n_{CA} at a mean hourly rate L_{CA}

$$\boxed{C_C = (n_{CO}\ L_{CO} + n_{CA}\ L_{CA})\ t_b\ n_{t,a} \quad . \qquad (14.49)}$$

The AEA method works on the basis of one cabin crew member per 35 passengers. **Table 14.9** contrasts the hourly rates according to **AEA 1989a** and **AEA 1989b** with the current approximate hourly rates of a large German airline. The hourly rates of the over 20-year-old DOC method are somewhat higher than today's comparative figures. For DOC calculations according to the AEA method the AEA hourly rates can be used unchanged to make calculations.

Table 14.9 Comparison of flight crew costs per hour (block time)

crew	short and medium range US$/h	long range US$/h
AEA-DOC-method		
cockpit crew, average value: L_{CO}	**246.5**	**355.0**
cabin crew, average value: L_{CA}	**81.0**	**90.0**
German airline [a]		
captain	208	254
co-pilot	102	120
cockpit crew, average value: L_{CO}	155	187
cabin crew, average value: L_{CA}	53	61

[a] Conversion basis (2000): 1.) Overhead costs are accounted for with 85 percent of the gross salary, crew training costs are not included.
2.) 1 US$ = 2 DM.

14.3.9 Calculation of DOC Cost Elements - Fees and Charges

Many DOC methods include fees and charges C_{FEE} in the DOC calculation. The following fees and charges may feature in a calculation:

- landing fees $C_{FEE,LD}$ are incurred for using the airfield with its runways;
- ATC or navigation charges $C_{FEE,NAV}$ are incurred for use of the airways, radio navigation and direction by air traffic control;
- ground handling charges $C_{FEE,GND}$ may include:
  - ground service: services connected with passengers, luggage, cargo and post; landing, unloading, provisioning and cleaning; pulling, parking and starting the aircraft; information and documentation services;
  - technical services: refuelling (these fees and charges are already included in the "Into Plane Differential" as a rule (see above)), filling up with other fluids, de-icing and maintenance (rectification of small defects);
  - flight advisory services.

  The costs incurred due to ground handling have to be assigned to IOC according to general opinion (and according to **Lockheed 1970**) unless they are affected by specific design parameters of the aircraft. We note that some DOC methods also include the ground handing charges for simplicity's sake and with little differentiation.

The following costs are incurred per year

$$C_{FEE} = C_{FEE,LD} + C_{FEE,NAV} + C_{FEE,GND} \quad . \tag{14.50}$$

The cost elements of fees and charges are often calculated according to the following fundamental equations:

$$C_{FEE,LD} = k_{LD}\ m_{MTO}\ n_{t,a}\ k_{INF} \quad . \tag{14.51}$$

$$C_{FEE,NAV} = k_{NAV}\ R\ \sqrt{m_{MTO}}\ \ n_{t,a}\ k_{INF} \quad . \tag{14.52}$$

$$C_{FEE,GND} = k_{GND}\ m_{PL}\ n_{t,a}\ k_{INF} \quad . \tag{14.53}$$

Equations (14.51) to (14.53) have been created by first calculating the fees and charges for the individual flight. Multiplied by the number of flights per year $n_{t,a}$, this gives the annually incurred fees and charges. As fixed costs are calculated in US\$ in this case and the fees and charges have increased sharply over the years, it is necessary to make an adjustment to the current cost level with the inflation factor (14.44). An inflation rate for the fees and charges of 6.5% is a plausible value (**AI 1989**: 3.3%, **DLH 1982**: 8%, value from 1998: 7.2%).
In the case of the simplified study carried out here:

- the landing fees depend on the maximum take-off mass;
- the ATC or navigation charges depend on the flight distance and the maximum take-off mass;
- the ground handling charges depend on the payload.

There are DOC methods that use other correlations for individual types of fees and charges. The correlations shown here are, however, very widespread. Thus, the handling charges according to **Fokker 1993**, for example, are calculated with

$$C_{FEE,GND} = 182\ \text{US\$} + 6.6\text{US\$} \cdot n_{PAX}\ n_{t,a}\ k_{INF} \quad . \tag{14.54}$$

The other parameters of equations (14.51) to (14.53) are contained in **Table 14.10**.

Table 14.10 Parameters for the calculation of fees and taxes

source	k_{LD} US$/kg	k_{NAV} $\frac{\text{US\$}}{\text{nm}\sqrt{\text{kg}}}$	k_{GND} US$/kg	p_{INF}
AA 1980	$0.0022\, m_{MTO} / m_L$	different context	different context	-
DLH 1982	different context		different context	0,080
Germany		0.00706		
Europe		0.00547		
long range		0.00141		
AEA 1989a	0.0078	0.00414	0.10	-
AEA 1989b	0.0059	0.00166	0.11	-
AI 1989	0.0025	0.00180	not a DOC - component	0.033
Fokker 1993	0.0090	0.00716	see (14.54)	-

14.3.10 Calculation of Aircraft Utilization

The equations for calculating DOC contain one further parameter that has been tacitly assumed to be known so far, namely the number of flights per year $n_{t,a}$. This parameter is of great importance in practice and indicates the efficiency of an airline's operation.

If a large number of flights are carried out each year with an aircraft, then the fixed costs (depreciation, interest, insurance) are distributed over more flights, so that the individual flight is burdened with fewer costs. The question is how many flights per year can be managed – or to be more precise, how many flight hours can be carried out with an aircraft in a year. The number of flight hours carried out in a defined period is called flight utilization *U*. There is a fixed correlation, via the flight time, between the number of flights per year and the aircraft utilization.

The number of flight hours (FH, Index: *f)* flown annually (Index: *a)* gives the annual aircraft utilization $U_{a,f}$, calculated by

$$U_{a,f} = t_f \; n_{t,a} \quad . \tag{14.55}$$

t_f is the flight time already defined above.

With the number of flights per year $n_{t,a}$ we can also calculate the number of flights during a different period:

Trips (Index: *t)* daily (Index: *d)* $n_{t,d} = n_{t,a} / 365$, (14.56)

Trips (Index: *t)* hourly (Index: *h)* $n_{t,h} = n_{t,d} / 24 = n_{t,a} /(365 \cdot 24)$ (14.57)

and also the aircraft use in relation to the flight time, Index: *f* t_f :

daily utilization (Index: *d*) $U_{d,f} = t_f \; n_{t,d}$, (14.58)

hourly utilization (Index: *h*) $U_{h,f} = t_f \; n_{t,h}$ (14.59)

The number of block hours (BH, Index: *b*) flown annually (Index: *a)* gives the annual aircraft utilization $U_{a,b}$, calculated with

$$U_{a,b} = t_b \; n_{t,a} \quad . \tag{14.60}$$

The number of flights during another period can also be calculated here:

daily utilization (Index: *d)* $U_{d,b} = t_b \; n_{t,d}$, (14.61)

hourly utilization (Index: *h)* $U_{h,b} = t_b \; n_{t,h}$. (14.62)

Annual aircraft utilization (unit: hours per year) and daily utilization (unit: hours per day) are common parameters in practice. Calculations can be made especially easily with the dimensionless hourly aircraft utilization – relative aircraft utilization.

Some DOC methods provide calculation equations for aircraft utilization and therefore make it possible to make a conclusive DOC comparison between different aircraft and aircraft trips. All these calculation equations for annual aircraft utilization have the same structure:

$$U_{a,f} = t_f \, \frac{k_{U1}}{t_f + k_{U2}} \tag{14.63}$$

The only difference between the calculation equations are the parameters k_{U1} and k_{U2}. These parameters are stated in **Table 14.11**.

Table 14.11 Parameters for the calculation of the aircraft utilization according to equation (14.64)

source		k_{U1} h	k_{U2} h
AA 1980 / NASA 77		3205	0.327
AEA 1989a		3750	0.750
AEA 1989b		4800	0.420
AI 1989 [a]			
R < 1000 nm	(1)	3994	0.754
1000 nm ≤ R ≤ 2000 nm	(2)	5158	1.650
2000 < R nm	(3)	6566	3.302

[a] 1.) **AI 1989** gives an equation for calculating $U_{a,b}$.

$U_{a,f}$ was calculated in this case assuming $t_b - t_f$ = 0.25 h

2.) R is the distance flown in the flight time t_f

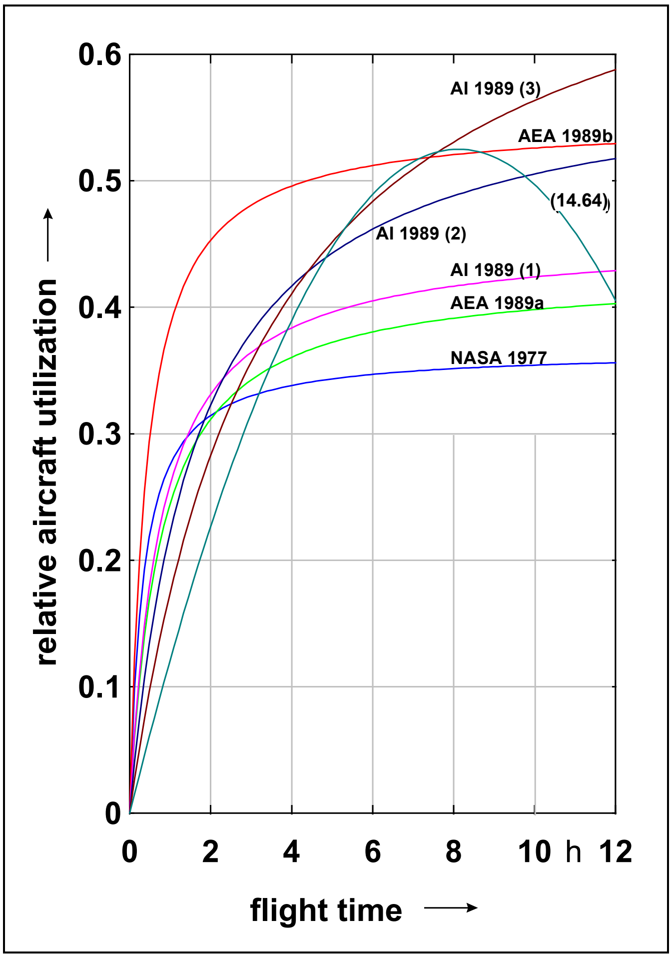

Fig. 14.4
Relative aircraft utilization $U_{h,f}$ calculated according to equation (14.64) and parameters taken from Table 14.11 and equation (14.64)

The relative flight utilization $U_{h,f}$ calculated with the aid of the parameters from **Table 14.11** is shown in **Fig. 14.4**. According to this, aircraft utilization increases with increasing flight time. This corresponds to experience in practice: a large number of short flights cause more ground times than a few long flights. Therefore, *more flight hours can be flown with fewer but longer flights.*

After the introduction of the new **long haul aircraft**, such as the Airbus A340, it became clear that this simple view of things no longer applied. After a flight of 8 hours, it is still possible to schedule an additional flight within 24 hours. With longer flight times this becomes difficult, with the result that the aircraft may only be able to embark on another long haul flight the next day. As a result of this enforced waiting time caused by planning the rosters, it may therefore be the case *that the aircraft utilization falls again with extremely long flight times*. This correlation evaluated on the basis of data from **Airbus 1996** leads to an alternative equation structure for calculating aircraft utilization

$$U_{h,f} = k_{U,A} \, (t_f - k_{U,B})^2 + k_{U,C} \tag{14.64}$$

with

$$k_{U,A} = - 0.00796 \text{ 1/h}^2$$
$$k_{U,B} = 8.124 \text{ h}$$
$$k_{U,C} = 0.525 \; .$$

This correlation is also shown in **Fig. 14.4**.

14.3.11 DOC Model Data

Fig. 14.5 contains DOC expressed in US$ per block hour. The data have been taken from **Friend 1992** and are average values of selected American airlines from the years 1986 and 1988. If DOC of various aircraft are compared, a chart as shown in Fig. 14.5 provides a good overview. The results of an individual DOC calculation are normally illustrated in a pie chart, as is the case in **Fig. 14.6**.

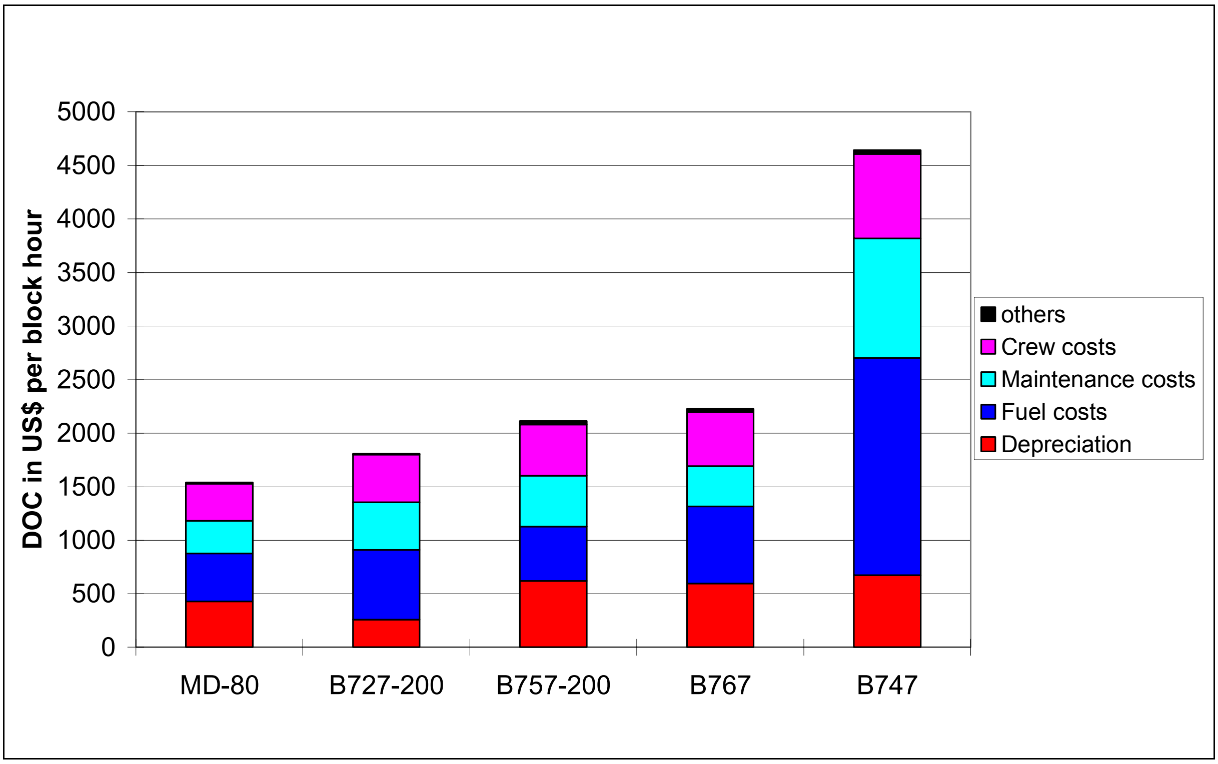

Fig. 14.5 Direct Operating Costs, DOC: Average values of selected American airlines from 1986 and 1988. Data taken from **Friend 1992**

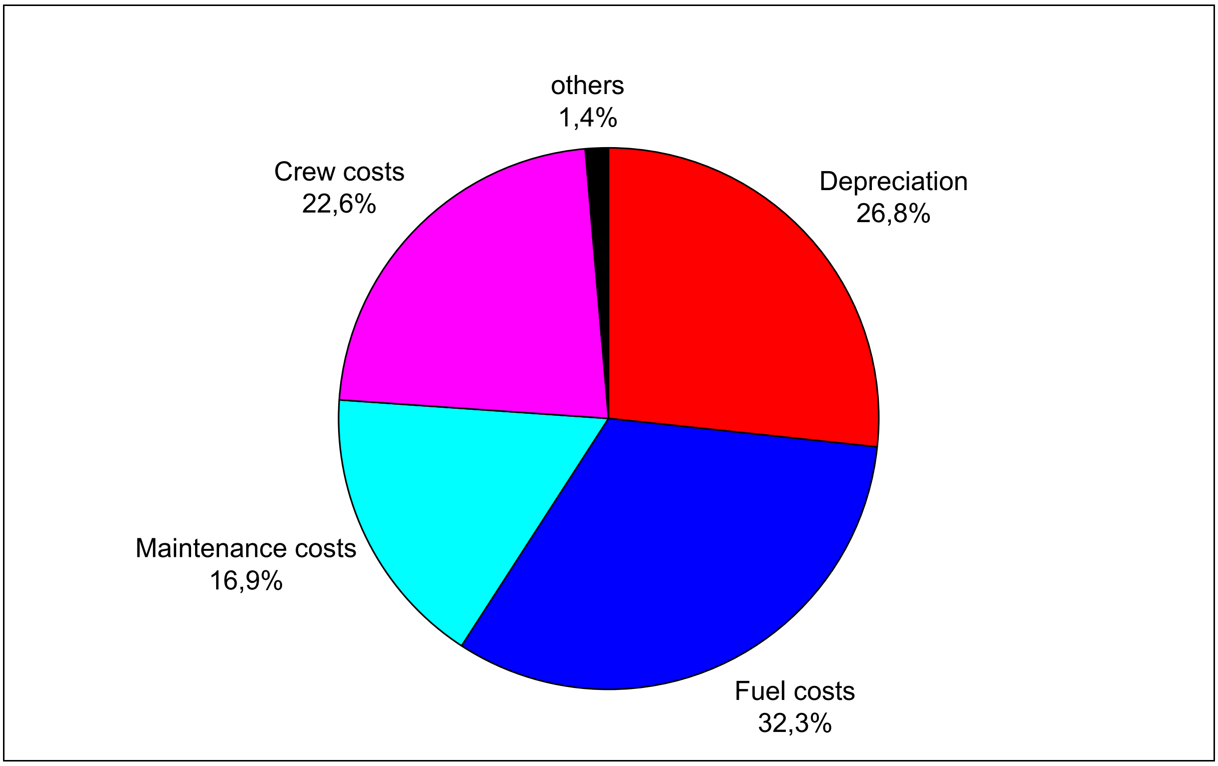

Fig. 14.6 Direct Operating Costs (DOC) of the Boeing 767 from Fig. 14.5. A common way of presentation of DOC is the pie chart

14.4 Final Comments

This section of the Aircraft Design lecture notes has tried to give an insight into aircraft assessment. The aim was to describe the **correlations** relevant in practice and to provide **equations for actual calculations**. Many correlations cannot be proven in the physical sense and demand a certain degree of intuition when applied. I have compiled comparative values from various sources in order to demonstrate the range of variation of the parameters. In practice you will endeavor to obtain the most up-to-date and meaningful parameters from your organization.

Actual **aircraft assessments** are carried out at the university **with** a **DOC method**. With the information given from these lecture notes, the method from **the Association of European Airlines** (AEA) will be used. In a first step the annual DOC are calculated. The conversion of these DOC to **equivalent ton-mile costs** increases the informative value of the results.