18.7 Aircraft and Airline Economics

DOC and IOC

Raymer bases the Direct Operating Costs on the Air Transport Association ATA-67 method, as interpreted by Corning (Ref. 18.7.1) with some modifications. Coefficients have been updated to reflect inflation effects between 1967 and 2012 (for Raymer's 5th Edition). However, the Airline Deregulation Act of 1978 led to a gradual loosening of regulatory requirements between 1978 and 1985. Some vestiges of regulation still exist in the major air carriers in terms of work rules and benefits. Airline costs have changed radically since that time, and are constantly being driven down (with commensurate reduction in both employee benefits and services provided to the airline customers).

The following is an estimation method known as DOC+I (Direct Operating Cost plus Interest). This method is based on the work of Liebeck (Ref. 18.7.2), who was able to draw upon the operating costs of McDonnell Douglas airplanes in commercial service up until 1993. This method is therefore based on a more recent set of data which reflect airline costs in a deregulated environment. The DOC+I method takes into account the following operating expenditures: fuel, flight and cabin crew, airframe maintenance, engine maintenance, landing fees, navigation fee (for international flights), depreciation, interest and insurance. This method is also loosely based on the Air Transport Association ATA-67 method, with the addition of cabin crew costs, landing fees, navigation fees and interest. In the ATA-67 method, cabin crew costs, landing fees, and navigation fees were considered part of the indirect costs, and interest cost was excluded. The method should be used for comparing different aircraft costs only, and not for absolute operating costs.

Labor and material costs in Ref. 18.7.2 were quoted in mid-1993 dollars. Inflation has significantly increased most costs since then, but because of competitive pressures, airline labor costs per unit of productivity have not risen at all (Ref. 18.7.3). There are also some fairly wide variations in labor costs between airlines, even within the US. According to the US Department of Labor (Bureau of Labor Statistics), the Consumer Price Index (CPI) for urban consumers has risen by a factor of 1.47 from June 1993 to Feb 2009 (the most recent data available). In the following equations, material costs have been factored by 1.47 from the values in Ref. 18.7.2. Airline labor costs for flight deck, cabin and maintenance have been left unchanged from their 1993 values.

All costs in this section are costs per trip. To determine the cost per available seat mile (cost/ASM), the total cost per trip must be divided by the product of the number of available seats and trip length. The trip length may represent a typical stage length for a particular airline's route system, and will be considerably less than the design stage length. "Available seats" normally means the total number of passenger seats on the airplane, but on international flights some seats may be set aside for cabin crew, or, at the limit of the airplane range, the number of seats available may be less than the total number of seats in order not to exceed airplane gross weight limits (although this is unlikely to occur for a typical stage length).

Airplane maximum takeoff gross weight, engine weight, and fuel weight can be calculated from methods in Raymer.

Block Time

A parameter that appears in many cost equations is the block time, which is the time between removing the nosewheel blocks at the departure airport and adding the blocks at the destination airport. The procedure for calculating this time in Ref. 18.7.1, as recommended by Raymer, contains several variables which are difficult to calculate at the conceptual design stage.

A simple relationship can be established relating the block times (which are the basis for calculating flight crew pay) as listed on a major US air carrier's crew scheduling sheets with great circle distances between airports. Twenty five airport pairs were selected with distances varying from 205 to 6507 nmi. The relationship derived from this analysis is

$$T_{block} = 0.0021 \times D + 0.94 \tag{18.7.1}$$

where

T_{block} = block time [hr]

D = great circle distance [nmi].

The R^2 correlation is 0.99, which is quite adequate for these studies.

Fuel

$$Fuel\,cost = \frac{W_f}{\rho_f} \times C_f \tag{18.7.2}$$

where

W_f = mission block fuel weight (excluding reserves) [lb]

ρ_f = fuel density [lb/gal]. Use 6.7 lb/gal.

C_f = fuel cost [$/gal]. This is the great unknown. As of April 2009, the price was about $1.46/gal, and current prices may be found from the IATA website http://www.iata.org/whatwedo/economics/fuel_monitor/index.htm.

Flight Deck Crew and Cabin Crew

The flight deck crew comprises the captain, first officer, and (for older airplanes such as the B-727) the flight engineer. Long distance flights (such as those across the Pacific) may also carry an extra flight deck crew member so that pilots can take a break.

$$Flight\ deck\ crew\ cost = T_{block} \times N_{fc} \times \left(C_{fc} + 0.532 \times \frac{W_{to}}{1000} \right) \times F_i \qquad (18.7.3)$$

where

N_{fc} = number of flight deck crew (usually two, but three for older airplanes such as the B-727, and for transpacific flights).

C_{fc} = base flight deck crew cost of $440/hr.

W_{to} = Maximum takeoff gross weight [lb]

F_i = International salary premium (=1 for domestic, =1.1 for international flights)

The cabin crew are the flight attendants, whose costs are calculated as:

$$Cabin\ crew\ cost = T_{block} \times N_{cc} \times C_{cc} \qquad (18.7.4)$$

where

N_{cc} = number of cabin crew, which for airplanes above 100 seats is

$$2 + \frac{(Number\ of\ passenger\ seats) - 100}{50}$$

If the airplane has less than 100 passenger seats, refer to FAR Part 121.391(a). This is a minimum set by the FAA, and historically airlines have flown with more than the minimum, especially on international flights. Currently, airlines set the cabin staffing to the FAR minimum, or close to it.

C_{cc} = base cabin crew cost of $60/hr for domestic flights and $78/hr for international flights.

Note that these labor costs include all indirect costs, including employee benefits (pension, health care, etc), accommodation and some meals when away from home.

Total Flight Crew Cost

The total flight crew cost is the sum of the flight deck crew (Eq. (18.7.3)) and cabin crew (Eq. (18.7.4)).

Airframe Maintenance

Cost of airframe maintenance is broken down into three parts: labor, materials, and burden.

Airframe Maintenance Labor

Labor and material costs are based on an historical curve fit developed by Liebeck. Note that each cost equation consists of two parts, one a function of the trip time in block hours, and the other which is independent of the block time. The first part represents the wear and tear of the airplane in flight, and the second part represents the cost of takeoff, climb, descent and landing.

$$\begin{aligned} &\text{Airframe maintenance labor cost} \\ &= \left(\begin{aligned} &\left(1.26 + 1.774 \times \left(\frac{W_{airframe}}{10^5}\right) - 0.1071 \times \left(\frac{W_{airframe}}{10^5}\right)^2\right) \times T_{block} \\ &+ \left(1.614 + 0.7227 \times \left(\frac{W_{airframe}}{10^5}\right) + 0.1204 \times \left(\frac{W_{airframe}}{10^5}\right)^2\right) \end{aligned} \right) \times C_{ml} \end{aligned} \qquad (18.7.5)$$

where

$W_{airframe} = W_{empty}$ – (dry weight of all engines) [lb].

C_{ml} = Direct maintenance labor cost of $25/hr.

Airframe Maintenance Materials

$$Airframe\ maintenance\ material\ cost$$

$$= \left(\begin{aligned} & \left(12.39 + 29.8 \times \left(\frac{W_{airframe}}{10^5} \right) + 0.1806 \times \left(\frac{W_{airframe}}{10^5} \right)^2 \right) \times T_{block} \\ & + \left(15.2 + 97.33 \times \left(\frac{W_{airframe}}{10^5} \right) - 2.862 \times \left(\frac{W_{airframe}}{10^5} \right)^2 \right) \end{aligned} \right) \times 1.47 \qquad (18.7.6)$$

Airframe Applied Maintenance Burden

$$Applied\ Maintenance\ Burden = 2 \times Airframe\ Labor\ Cost \qquad (18.7.7)$$

This is a catchall factor that includes the indirect portion of maintenance labor costs, and the cost of taking the airplane out of service.

Total Airframe Maintenance Cost

The total airframe maintenance cost is therefore the sum of Eq. (18.7.5), (18.7.6) and (18.7.7).

Engine Maintenance

As for the airframe, engine costs are split into labor, materials, and burden.

Engine Maintenance Labor Cost

$$Engine\ maintenance\ labor\ cost = \left(0.645 + \left(\frac{0.05 \times F_n}{N_e \times 10^4} \right) \times \left(0.566 + \frac{0.434}{T_{block}} \right) \right) \times T_{block} \times N_e \times C_{ml}$$

(18.7.8)

where

F_n = Total net thrust at SLS for all engines [lb]

N_e = Number of engines

Engine Maintenance Material Cost

$$Engine\ maintenance\ material\ cost = \left(25 + \left(\frac{0.05 \times F_n}{N_e \times 10^4}\right) \times \left(0.62 + \frac{0.38}{T_{block}}\right)\right) \times T_{block} \times N_e \times 1.47$$

(18.7.9)

Engine Maintenance Burden

$$Applied\ maintenance\ burden = 2 \times Engine\ maintenance\ labor\ cost \qquad (18.7.10)$$

Total Engine Maintenance Cost

The total engine maintenance cost is the sum of Eq. (18.7.8), (18.7.9) and (18.7.10).

Landing Fee

The landing fee is based on the maximum landing weight for domestic operations, or maximum takeoff gross weight for international operations. They may vary significantly in Europe, with possible additional fees such as for NO_X emissions or community noise, which are not included in this method.

$$Domestic\ Landing\ fee = C_{land} \times \left(\frac{W_{ml}}{1000}\right) \qquad \text{or} \qquad (18.7.11)$$

$$International\ landing\ fee = C_{land} \times \left(\frac{W_{to}}{1000}\right)$$

where

C_{land} = landing fee coefficient, which is \$2.20 for domestic operations or \$6.25 for international operations.

W_{ml} = maximum landing weight.

Navigation Fee

The navigation fee is based on the first 500 nm of a trip and the maximum takeoff gross weight of the aircraft, and applies to international flights only.

$$Navigation\ fee = C_{nav} \times 500\ nm \times \sqrt{\frac{W_{to}}{1000}} \qquad (18.7.12)$$

C_{nav} = navigation fee coefficient, can be assumed to be \$0.20.

<u>Depreciation, Interest, and Insurance</u>

<u>Depreciation</u>

For all of the following equations, the total airframe and engine costs must be known. These can be found using methods in Raymer Sections 18.2 – 18.4. Alternatively, the methods in Ref. 2 may be used, with suitable correction for inflation.

$$Depreciation\ per\ year = (1-R)\times\left(\left(\frac{C_{af}}{P_{af}}\right)+S_{af}\times\left(\frac{C_{af}}{P_{af}}\right)\right)+\left(\frac{C_e}{P_e}\right)+S_e\times\left(\frac{C_e}{P_e}\right)$$

(18.7.13)

where

R = Residual fraction for airframe and airframe spares (normally 0.1)

C_{af} = Airframe cost [\$]. This may be derived from Raymer Eq. (18.9) as

$$\frac{H_E R_E + H_T R_T + H_M R_M + H_Q R_Q + C_D + C_F + C_M + C_{avionics}}{Q}$$

The variable definitions and values are given in Raymer, but labor rates must be updated from 1999 dollars to 2009 dollars by the ratio of the CPI in 2009 to that in 1999.

P_{af} = Airframe life (Liebeck assumes 15 years, but 20 to 25 years is not unusual)

S_{af} = Airframe spares (assume 0.06 × airframe cost)

C_e = Engine cost [\$] (If actual cost is not available, use C_{eng} from Raymer Eq. 18.8 multiplied by the number of engines, and factored by the ratio of the CPI in 2009 to that in 1999)

P_e = Engine life (Liebeck assumes 15 years)

S_e = Engine spares (assume 0.23 × engine cost)

The cost of depreciation per trip is

$$Depreciation\ per\ trip = \frac{Depreciation\ per\ year}{Trips\ per\ year} \quad (18.7.14)$$

Liebeck suggests values of trips per year as:

Short range aircraft = 2100 trips/year

Medium range aircraft = 625 trips/year

Long range aircraft = 480 trips/year

Interest

The average annual interest cost is approximately

$$Annual\ Interest = Interest\ rate \times Loan\ amount \quad (18.7.15)$$

Interest rate is the current interest rate for this class of loan, which is a function of underlying interest rates and the creditworthiness of the airline. A reasonable approximation is to use the 15-year mortgage rate (which can be found from a website such as www.bankrate.com) plus 2% (Ref. 18.7.3).

Loan amount is the cost of the airframe, engines, and spares which were calculated above. Airlines typically put up 15-20% in cash or equivalent towards the cost of the airplane, but for the purpose of accounting for the lost use of that cash, assume that the loan amount is 100% of the total cost.

So $$Interest\ per\ trip = \frac{Annual\ Interest\ Cost}{Trips\ per\ year} \quad (18.7.16)$$

Insurance

The annual insurance premium is calculated as

$$Annual\ Insurance = 0.0035 \times \left(Airframe\ Cost + Engine\ Cost\right) \quad (18.7.17)$$

So $$Insurance\ per\ trip = \frac{Annual\ Insurance}{Trips\ per\ year} \quad (18.7.18)$$

Total DOC+I

The total direct operating cost per trip is therefore the sum of the costs of

- Fuel cost
- Flight deck and cabin crew cost
- Total airframe maintenance cost
- Total engine maintenance cost
- Landing fee
- Navigation fee (for international flights)
- Depreciation, Interest, and Insurance

References

18.7.1 Corning, G., “Supersonic and Subsonic, CTOL and VTOL, Airplane Design”, Published by the Author, 1976.

18.7.2 Liebeck, R.H., et al., “Advanced Subsonic Airplane Design and Economic Studies”, NASA CR-195443, April 1995.

18.7.3 Zolotusky, K. (Boeing Capital Corporation), private correspondence, April 2009.