DOCsys - The Method Summarized

- This help file provides a summary of the method on which DOCsys is based. DOCsys calculates Direct Operating Cost of aircraft systems.

- DOCsys and its method has been presented in a couple of publications as listed here.

- The text of this help file is based on:
  SCHOLZ, D. : *DOCsys - A Method to Evaluate Aircraft Systems.* (Workshop: DGLR Fachausschuß S2 - Luftfahrtsysteme, Bewertung von Flugzeugen; München, 26./27. Oktober 1998), Bonn : Deutsche Gesellschaft für Luft- und Raumfahrt, 1998
  Bezug: `http://www.fh-hamburg.de/pers/Scholz/paper/DOCsysPaper.pdf`

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DOCsys: Calculating Direct Operating Costs for Aircraft Systems

Although it is heavily debated which cost elements do belong to Direct Operating Costs and which don't, it is generally accepted that DOC include those cost elements which depend on the aircraft itself. Indirect Operating Costs (IOC), in contrast, depend on the way an airline is run.

The "mother" of DOC methods, [ATA 1967], considers as aircraft-dependent and hence part of DOC:

- cockpit crew costs,
- fuel costs,
- maintenance costs,
- depreciation,
- insurance (against hull loss).

DOCsys are considered to be a part of total aircraft DOC. Cockpit crew cost can be fully allocated to that part of aircraft DOC which are not DOCsys. This approach is valid as long as the number of members in the cockpit crew is not changed due to the system configuration in question.

Training costs for the crew or maintenance personnel traditionally do not belong to DOC. Hence, they are also not included in DOCsys.

Costs for insurance of an aircraft depend on the aircraft price and hence also on the price of aircraft systems. However, insurance policies are quite complicated and diverse. For simplicity and clarity of the DOCsys - method, insurance costs have been neglected. Insurance costs per aircraft and per year account for about 0.5% to 3% of the aircraft price. If desired, these percentages can also be considered for an insurance cost estimate for aircraft systems. In that case, the percentages have to be based on the aircraft system price.

Following from this discussion on DOCsys cost elements, we obtain the fundamental DOCsys from

$$DOC_{SYS} = Depr_{SYS} + Fuel_{SYS} + DMC_{SYS}$$

```
Depr_sys   depreciation of the system,
Fuel_sys   fuel costs caused by the system,
DMC_sys    Direct Maintenance Costs caused by the system.
```

Airline practice revealed also an interest in further cost elements, especially when dealing with aircraft systems:

- delay and cancellation costs caused by aircraft systems,
- capital costs caused by necessary spare parts on stock.

Extended DOCsys - called DOCsys,ext - take these additional cost elements into account:

$$DOC_{SYS,ext} = Depr_{SYS} + Fuel_{SYS} + DMC_{SYS} + Delay_{SYS} + SHC_{SYS}$$

```
Delay_sys   delay and cancellation costs caused by the system,
SHC_sys     capital costs caused by necessary spare parts on stock (Spare Holding Costs).
```

DOCsys will be calculated per aircraft and per year. A conversion of DOCsys-figures in any other unit common to DOC is possible.

See also:
Depreciation
Fuel Costs
Direct Maintenance Costs
Capital Costs Caused by Spare Parts on Stock
Delay and Cancellation Costs

Depreciation

Technical depreciation is considered here as a time dependent depreciation (this is the same approach as followed in aircraft DOC)

$$Depr_{SYS} = \frac{Price - Residual}{N} = \frac{Price \cdot \left(1 - \frac{Residual}{Price}\right)}{N}$$

```
Price          price of considered aircraft system, subsystem, or single part,
Residual       value of the aircraft system after N years
               (mostly chosen to be 15% of the aircraft system price),
N              depreciation period (mostly chosen to be 15 years).
```

See also:
DOCsys: Calculating Direct Operating Costs for Aircraft Systems
Fuel Costs
Direct Maintenance Costs

Fuel Costs

Fuel costs are differentiated by means of their physical origin. This approach helps to pinpoint the origin of fuel costs and allows to effectively find measures to reduce fuel consumption. Causes of fuel consumption due to aircraft systems, subsystems, or single parts are:

```
Fuel_mf     fuel costs due to transportation of fixed mass
            (mass that does not vary in flight),
Fuel_mv     fuel costs due to transportation of variable mass
            (mass that does vary in flight: e.g. water drained during flight),
Fuel_P      fuel costs due to mechanical power off-takes from the engines
            (e.g. by electrical generators additionally loaded for pipe heating elements),
Fuel_B      fuel costs due to bleed air off-takes,
Fuel_R      fuel costs due to ram air off-takes,
Fuel_D      fuel costs due to additional drag caused by the presents of aircraft systems,
            subsystems, or single parts (e.g. due to drain masts).
```

$$Fuel_{SYS} = Fuel_{mf} + Fuel_{mv} + Fuel_P + Fuel_B + Fuel_R + Fuel_D$$

The fuel costs for each cause of fuel consumption X are calculated from

$$Fuel_X = m_{fuel,X} \cdot FuelPrice \cdot NFY$$

```
m_fuel,X       mass of fuel consumed due to cause X during the whole flight,
FuelPrice      fuel price,
NFY            number of flights per year.
```

See also:
DOCsys: Calculating Direct Operating Costs for Aircraft Systems
Depreciation
Direct Maintenance Costs

Calculating the Mass of Fuel Consumed

The fuel consumption is calculated for 7 flight phases i:

- i = 1, engine start,
- i = 2, taxi,
- i = 3, take-off,
- i = 4, climb,
- i = 5, cruise,
- i = 6, descent,
- i = 7, landing, taxi, engine shut down.

The total amount of fuel consumed for a physical cause X is

$$m_{fuel,X} = \sum_{i=1}^{7} m_{fuel,i,X}$$

For flight phases i = 1, 2, 3, 7, the fuel consumption is estimated from mass fractions.

$$m_{fuel,i,X} = m_{i,X} \left(\frac{m_{(i-1),X}}{m_{i,X}} - 1 \right)$$

flight phase	1	2	3	7
m_i / m_{i-1}	1	1	0.995	0.996

For flight phases i = 4, 5, 6 the fuel consumption is calculated from special equation as presented here:

See also:
Fuel Consumption due to Fixed Mass
Fuel Consumption due to Variable Mass
Fuel Consumption due to Mechanical Power Off-Takes from the Engines
Fuel Consumption due to Additional Drag
Fuel Consumption due to Bleed Air Off-Takes
Fuel Consumption due to Ram Air Off-Takes

Fuel Consumption due to Fixed Mass

The fuel consumption due to fixed mass during flight phase *i* is

$$m_{fuel,i,X,m} = m_{i,X} \cdot \left(e^{t_i \cdot k_{E,i}} - 1\right)$$

This equation is just another form of the well known Breguet Range Equation. The form presented here is a general form, considering not just cruise flight but also climb and descent.

```
t_i       duration of flight phase i ,
m_i,X     mass at the end of flight phase i due to physical cause X ,
```

$$k_{E,i} = SFC_i \cdot g \cdot \left(\frac{\cos \gamma_i}{L / D_i} + \sin \gamma_i \right)$$

```
SFC       thrust specific fuel consumption,
g         earth acceleration,
gamma     flight path angle,
L/D       lift to drag ratio.
```

See also:
Fuel Costs
Calculating the Mass of Fuel Consumed

Fuel Consumption due to Variable Mass

The mass flow rate $\dot{m}_{i,mv}$ is considered positive if mass is leaving the aircraft. It is assumed that the mass flow rate is constant during each flight phase. The water-/waste system is an example where mass leaves the aircraft: Gray water from the sinks in the lavatories and from the galleys leaves the aircraft via drain masts. Finally the fuel consumed due to the physical cause "variable mass" during flight phase *i* is

$$m_{fuel,i,mv,f} = \frac{\dot{m}_{i,mv}}{k_{E,i}}\left(e^{t_i \cdot k_{E,i}} - 1\right) - \dot{m}_{i,mv} \cdot t_i$$

See also:
Fuel Costs
Calculating the Mass of Fuel Consumed

Fuel Consumption due to Mechanical Power Off-Takes from the Engines

Mechanical power is taken off the engine as shaft power from the accessory gear box when driving generators or hydraulic pumps. The fuel flow due to shaft power off-takes during flight phase *i* is

$$m_{fuel,i,P,f} = \frac{P_i \cdot k_p \cdot m_{A/C}}{n \cdot T_{T/O}} \left(e^{t_i \cdot k_{E,i}} - 1 \right)$$

```
k_p = 0,0094 N/W

P_i         power taken off the engines,
n           number of engines,
T_T/O       take-off thrust,
m_A/C       average mass of the airplane during flight.
```

See also:
Fuel Costs
Calculating the Mass of Fuel Consumed

Fuel Consumption due to Additional Drag

Aircraft systems can cause additional drag. In this context, drag is considered "additional" if it is not due to e.g. the wings and the fuselage but due to excrescencies as antennas, drain masts and air data sensors. Fuel Consumption due to Additional Drag *D* during flight phase *i* is

$$m_{fuel,i,D,f} = \frac{SFC_i \cdot D_i}{k_{E,i}}\left(e^{t_i \cdot k_{E,i}} - 1\right)$$

See also:
Fuel Costs
Calculating the Mass of Fuel Consumed

Fuel Consumption due to Bleed Air Off-Takes

If bleed air is taken off the engines, the fuel flow can be estimated which is required to maintain constant thrust during flight phase *i*:

$$m_{fuel,i,B,f} = \frac{k_B \cdot T_{tb} \cdot \dot{m}_B}{k_{E,i}} \left(e^{t_i \cdot k_{E,i}} - 1 \right)$$

$$k_B = 3.015 \cdot 10^{-5}\ 1/K$$

$\dot{m}_B$ `bleed air flow,`

`T_tb      turbine inlet temperature.`

See also:
Fuel Costs
Calculating the Mass of Fuel Consumed

Fuel Consumption due to Ram Air Off-Takes

It is assumed that the air being taken in is decelerated down to a velocity of zero with respect to an aircraft fixed coordinate system. To overcome drag resulting from this deceleration of surrounding air. Fuel consumed due to this physical cause in a flight phase *i* is

$$m_{fuel,i,R,f} = \frac{SFC_i \cdot \rho_i \cdot Q_i \cdot v_i}{k_{E,i}} \cdot \left(e^{t_i \cdot k_{E,i}} - 1\right)$$

`Q_i  is the required air flow rate.`

See also:
Fuel Costs
Calculating the Mass of Fuel Consumed

Direct Maintenance Costs

The calculation of Direct Maintenance Costs is based on fundamental input parameters from the maintenance department.

$$DMC_{SYS} = \left(MMH_{on} + MMH_{off} \right) \cdot LR + MC$$

```
MMH_on      Maintenance Man Hours On Aircraft,
MMH_off     Maintenance Man Hours Off Aircraft,
LR          Labor Rate,
MC          Material Costs.
```

If such information is not available, a comparison method can be applied. Airbus Industrie uses the "Airbus Industrie Comparison Method", AICM

See also:
DOCsys: Calculating Direct Operating Costs for Aircraft Systems
Fuel Costs
Depreciation

Capital Costs Caused by Spare Parts on Stock

Spare Holding Costs, *SHC,* defined here as the interest paid on bound capital of spare parts on stock, can reach considerable sums of money. By definition, total stock keeping costs belong to Indirect Operating Costs, IOC and not to DOC. Nevertheless, especially the capital costs of the spares on stock depend on parameters which are primarily aircraft dependent. For this reason, these Spare Holding Costs will be included into extended Direct Operating Costs of Aircraft Systems, DOCsys.

$$SHC_{SYS} = \frac{SPF \cdot SPR}{RED} \cdot Price \cdot \frac{RQS_{req}}{FS} \cdot r$$

SPF	Spare Part Factor: Spare part price divided by initial purchase price,
SPR	Spare Part Ratio: Portion of costs of spare parts in total amount of parts for the aircraft system, or subsystem,
RED	average redundancy level (resulting in equal parts) in the system or subsystem,
RQS_req	required amount of spare parts (depends on the "on average" required amount of spare parts and the required probability of having a required spare part on stock),
FS	fleet size,
r	interest rate.

$$RQS_{req} = RQS_{av} + z \cdot \sqrt{RQS_{av}}$$

RQSav	"on average" required amount of spare parts,
z	availability factor.

$$RQS_{av} = RED \cdot TATR \cdot FS \cdot \frac{FT \cdot NFY}{MTBUR}$$

TATR	Turn Around Time Ratio, ratio of repair time and considered time interval (here, the considered time interval is one year),
FT	Flight Time, airborne time,
NFY	Number of Flights per Year,
MTBUR	Mean Time Between Unscheduled Removals.

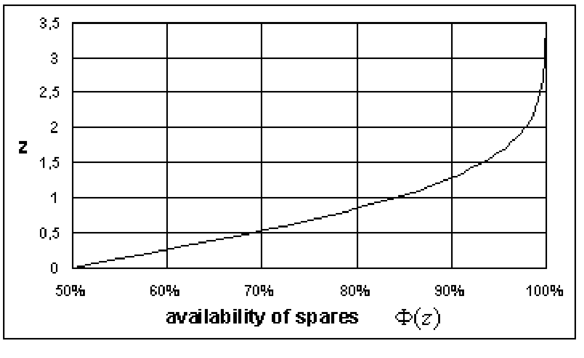
$$MTBUR = FTRR \cdot MTBF$$

FTRR	Failure To Removal Ratio,
MTBF	Mean Time Between Failure.

The availability factor *z* depends on the required availability of spares on stock. *z* is the inverse function of the cumulative Gaussian normal distribution

$$\Phi(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} e^{\frac{-x^2}{2}} dx$$

The inverse function z can not be derived analytically, however, the inverse function exist in tabulated or graphical form as given below.



$\Phi(z)$	0.900	0.950	0.975	0.990	0.999
z	1.282	1.645	1.960	2.326	3.090

See also:
DOCsys: Calculating Direct Operating Costs for Aircraft Systems

Delay and Cancellation Costs

$$Delay_{SYS} = \left(D_I \cdot C_I + D_{II} \cdot C_{II} + D_{III} \cdot C_{III} + D_C \cdot C_C \right) \cdot NFY$$

Delay and cancellation costs, , are calculated here based on three delay categories (taking account of different lengths of delays) and one category for cancellations:

```
D_1     probability for a delay of up to 29 min.,
D_2     probability for a delay between 30 min. and  59 min.,
D_3     probability for a delay of equal or more than 60 min.,
D_C     probability for a cancellation,
C_1     cost of a delay of up to 29 min.,
C_2     cost of a delay between 30 min. and  59 min.,
C_3     cost of a delay of equal or more than 60 min.,
C_C     cost of a cancellation.
```

The probability of delays and cancellations depends on the aircraft system considered. Statistical evaluations by American Airlines and Lufthansa for ATA-Chapters 21 to 49 are given in [NASA 1977] and [SCHOLZ 1997a] respectively.

See also:
DOCsys: Calculating Direct Operating Costs for Aircraft Systems

Other Cost Elements

Other cost elements depend very much on the respective aircraft system in question. E.g. in case of water/waste systems, such other cost elements could be:

- water costs for filling the potable water tanks,
- costs for precharging the waste tanks with special fluid for disinfection.

A decision has to be made in which way (if at all) such additional cost elements shall be included in the calculation.

See also:
DOCsys: Calculating Direct Operating Costs for Aircraft Systems

Literature

Publications related to DOCsys:

Scholz 1995
SCHOLZ, D. : Betriebskostenschätzung von Flugzeugsystemen als Beitrag zur Entwurfsoptimierung, (Deutscher Luft- und Raumfahrtkongreß, Bonn, 26. - 29. September 1995). In: BüRGENER, G. (Hrsg.): *Jahrbuch 1995*, Bonn : Deutsche Gesellschaft für Luft- und Raumfahrt, 1995, S. 50 - 61. - Paper: DGLR-JT95-016

Scholz 1997a
SCHOLZ, D. : *Entwicklung eines CAE- Werkzeuges zum Entwurf von Flugsteuerungs- und Hydrauliksystemen*. Fortschritt-Berichte VDI, Reihe 20, Nr. 262, Düsseldorf : VDI, 1997

Scholz 1997b
WESTPHAL, R.; SCHOLZ, D. : A Method for Predicting Operating Costs During Aircraft System Design. In: *Cost Engineering*, Morgantown : American Association of Cost Engineers, 1997, Bd. 39, Nr. 6, S. 35 - 39

Scholz 1998
SCHOLZ, D. : *DOCsys - A Method to Evaluate Aircraft Systems*. (Workshop: DGLR Fachausschuß S2 - Luftfahrtsysteme, Bewertung von Flugzeugen; München, 26./27. Oktober 1998), Bonn : Deutsche Gesellschaft für Luft- und Raumfahrt, 1998

Some Publications related to DOC in general:

ATA 1967
AIR TRANSPORT ASSOCIATION OF AMERICA: *Standard Method of Estimating Comparative Direct Operating Costs of Turbine Powered Transport Airplanes*. Washington D.C. : ATA, 1967

COPPEE 1989
COPPEE, R.: *Airbus Project DOC Method*. Blagnac : Airbus Industrie, 1989

NASA 1977
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (ED.): *A New Method for Estimating Current and Future Transport Aircraft Operating Economics* / American Airlines. New York. Washington D.C. : NASA, 1977 (NASA CR-145190)