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TU Berlin DOC Method

A simplified DOC Model
JAVA DOC Applet

The method with remarks in red by Dieter Scholz

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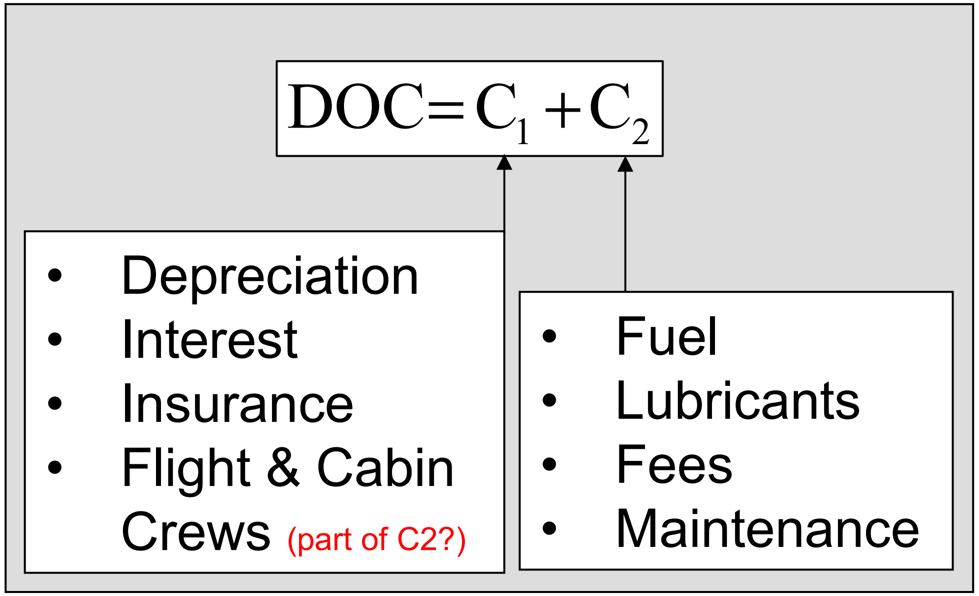
http://SCAD.AircraftDesign.org

A simplified DOC Model

- Two elements are required for the most simple DOC model :
  - C1: Route independent (fixed) Cost
  - C2: Route dependent (variable) Cost



$$DOC = C_1 + C_2$$

- Depreciation
- Interest
- Insurance
- Flight & Cabin Crews (part of C2?)

- Fuel
- Lubricants
- Fees
- Maintenance

- COC = DOC without capital cost (depreciation, interest, insurance)
- How does a typical cost scenario look like?
- Which parameters do we need to know in order to use that formula?
- Which parameters have to be assessed from statistical data?

A simplified DOC Model

- Simplifications:
- All **route independent cost** are primarily based on the aircraft size and its respective operational empty weight (OEW)
- The major element is the **capital cost** which can be assumed to be a linear function of the OEW (if the aircraft market influence is considered negligible) and thus

$$C_{CAP} = \left[P_{OEW} \cdot \left(OEW - W_{Eng} \cdot N_{Eng}\right) + W_{Eng} \cdot N_{Eng} \cdot P_{Eng}\right] \cdot \left(a + f_{Ins}\right)$$

$$\text{with} \quad a = IR \cdot \frac{1 - f_{RV} \cdot \left(\frac{1}{1+IR}\right)^{DP}}{1 - \left(\frac{1}{1+IR}\right)^{DP}}$$

with a: Annuity factor

P_{OEW}: Price per kg OEW (Structure/Systems/Equipment, 1150 €/kg)

P_{Eng}: Price per Engine Weight (2500 €/kg)

IR: Interest rate (5%)

DP: Depreciation period (14 years), also mortgage payback period

f_{RV}: Residual value factor (Residual value / aircraft price, 10%)

f_{Ins}: Insurance rate (0,5%)

N_{Eng}: Number of Engines

W_{Eng}: Weight per Engine

A simplified DOC Model

- That annuity formula, which is based on a modified mortgage equation, addresses both yearly depreciation and interest
- The reason for the a.m. modification is to include the residual aircraft value at the end of the depreciation period into the capital cost, which is occasionally meaningful
- That does assume that an operator is buying an aircraft at a constant price per kg and spends the corresponding capital cost constantly per year all over the depreciation period
- Insurance cost are also proportional to the aircraft price

A simplified DOC Model

- **Personnel cost** are assumed to be route independent because an airline has to provide a sufficient number of crews to ensure flight operations over the entire service time and therefore are proportional to the payload
- 50 passengers per Flight attendant (certification requirement) and 100 kg per passenger are assumed
- Flight crew cost are considered constant per year and result from the sum of the average of a commander and a first officer salary and thus

$$C_{Crew} = CC \cdot \left(S_{FA} \cdot \frac{MPL}{5000} + S_{FC} \right)$$

or:

$$C_{Crew} = CC \cdot (S_{FA} \cdot n_{FA} + S_{FC})$$

$$n_{FA} : \text{one for each 50 pax}$$

with n_{PAX}: Maximum number of passengers; MPL: max. payload
S_{FA}: Average yearly salary of a flight attendant (60.000 €/year)
S_{FC}= Average yearly salary of a cockpit crew (300.000 €/year for 2 pilots)
CC: Crew Complement (Number of crews per Aircraft, 5) (independent of utilization?)

- The **route independent cost** per year therefore sum up to

$$\mathrm{C_1 = C_{CAP} + C_{Crew}}$$

A simplified DOC Model

- Within the **route dependent cost** lubrication cost can be assumed to be of minor order of magnitude compared to the **fuel cost** and can be addressed by a minor correction of the fuel price
- The fees are comprising payload dependent **handling fees** and maximum take-off weight (MTOW) dependent **ATC fees** and **landing fees**
- The **route dependent yearly cost** thus be calculated by

$$C_2 = FC \cdot \left(P_F \cdot TF + P_{PL} \cdot PL + P_L \cdot MTOW + f(R) \cdot R \cdot \sqrt{\frac{MTOW[to]}{50}} + MC \right)$$

with P_F: Fuel price [0,5 €/kg] (see p. 13)

TF: Trip fuel [kg]

PL: Payload [kg]

FH: Yearly flight time

P_L: Landing fees [0,01 €/kg]

P_{PL}: Handling fees [0,1 €/kg]

FC: Yearly flight cycles

R: Range [km]

MC: Maintenance cost per flight cycle

f(R): Range dependent ATC price factor (1,0 for domestic Europe, 0,7 for transatlantic flights, 0,6 for far east flights (only half of landings at European airports)

A simplified DOC Model

- **Fuel cost** are based on the trip fuel (e.g. from payload range diagram)
- The fourth term represents the EUROCONTROL formula for **ATC-fees**. The price factor considers the fact that the price scenarios are varying strongly for each continent (or even region)
- **Landing fees** are charged on basis of aircraft MTOW and **Handling fees** on Payload whereas **ATC fees** are based on both the secured flight distance (Range) and the discounted (square root!) MTOW
- **Maintenance cost split into**
  - **flight cycle dependent cost**, reflecting primarily structural fatigue and overhaul burden,
  - **flight hour dependent cost**, which take into account primarily wear and the associated line maintenance work and
  - **calendar time dependent cost**, which is a constant share reflecting for example the rectification of corrosion during overhaul, the latter being route independent and thus considered as constant

A simplified DOC Model

- The following method is an approximation for maintenance cost per flight cycle is given by the sum of three parts:
  - $MC_{AF,MAT}$:Airframe material maintenance cost (repair and replacement)
  - $MC_{AF,PER}$: Airframe personnel maintenance cost (inspection and repair)
  - MC_{ENG}: Engine total maintenance cost

$$MC_{AF,MAT} = OEW[to] \cdot (0{,}21 \cdot FT + 13{,}7) + 57{,}5$$

$$MC_{AF,PER} = LR \cdot (1 + Burden) \cdot \{(0{,}655 + 0{,}01 \cdot OEW[to]) \cdot FT + 0{,}254 + 0{,}01 \cdot OEW[to]\}$$

$$MC_{ENG} = N_{ENG}(1{,}5 \cdot SLST[to] + 30{,}5 \cdot FT + 10{,}6)$$

$$MC = MC_{AF,MAT} + MC_{AF,PER} + MC_{ENG}$$

- with

  Burden: Cost burden (2)

  FT: Flight time

  LR: Labor rate (50 €/h)

  N_{ENG}: Number of engines

  SLST: Sea level static thrust of one engine [to]

  OEW: Operating empty weight

- These empirical formulae include time dependent constant shares as well as burden reflecting fixed maintenance cost and administrative overhead

A simplified DOC Model

- A basic structure of a generic **utilization** formula is

$$FC = \frac{OT_{p.a.}}{(FT + BT)} = \frac{OT_{p.a.}}{\left(\frac{R}{v} + BT\right)} \qquad \text{with} \qquad OT_{p.a.} = POT_{p.a.} - DT_{p.a.}$$

with $OT_{p.a.}$: Yearly operation Time

$POT_{p.a.}$: Potential yearly operation time (365 · 24h = 8760 h)

$DT_{p.a.}$: Yearly forced downtime (2748,8 hours) consisting of

C-Checks (3,2 days p.a., 4 days per 15 month)
D-Checks (5,6 days p.a., 4 weeks per 5 years)
Repairs (2,6 days p.a., statistical average)
Night Curfew (7 days p.a., from 11:00 p.m. until 6:00 a.m. at operation days)

FT: Flight time

BT: Block time supplement per flight (1,83 hours (too high ?), statist. average)

R: Average stage length

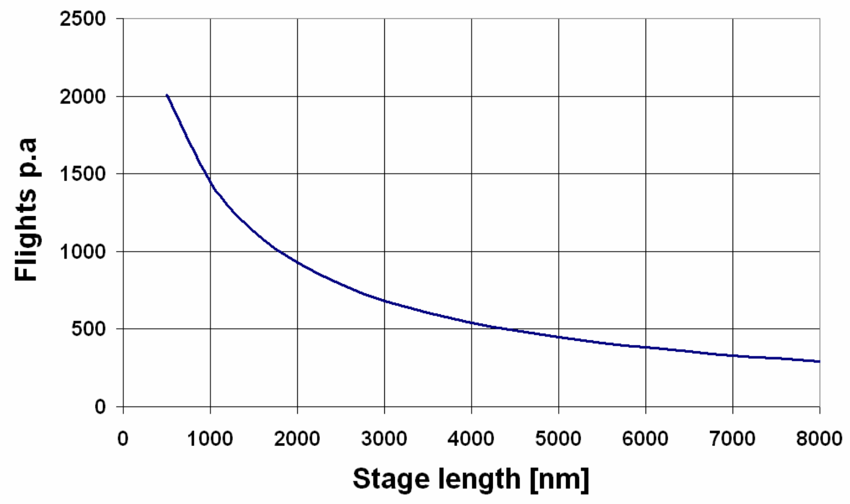
v: Cruise speed

- Note: It is hereby assumed, that the flight is performed with constant speed, which is not the actual case (ref. climb/descent/approach segments)

A simplified DOC Model

- Statistical values for large airlines operating in the European scenario are
  - Average operation time: 6011,2 hours (Maintenance, night curfews)
  - Average block time increment: 1,83 hours
- With that the Utilization formula can be written

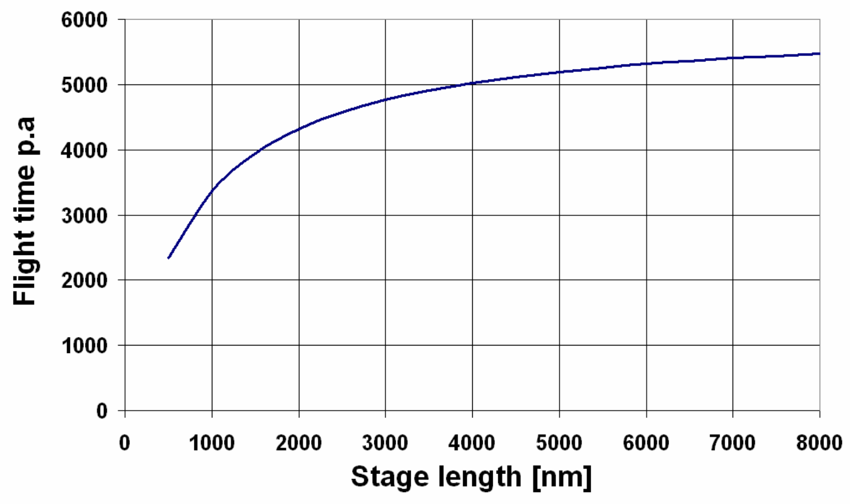
$$FC = \frac{6011{,}2}{\left(\frac{R}{v} + 1{,}83\right)}$$



- The yearly flight time yields

$$FH_{p.a.} = FC \cdot FT$$

$$= \frac{6011{,}2}{1 + v \cdot \frac{1{,}83}{R}}$$



A simplified DOC Model

- Only a limited number of parameters are necessary to calculate DOC
  - **Financial parameters** (Interest rates, depreciation period, residual value)
  - **Operational parameters** (Yearly flight cycles & downtime, block time supplement, crew salaries, crew complement, specific maintenance cost)
  - **Aircraft design weights** (MTOW, OEW, PL)
- Whereas financial and operational parameters can be obtained from statistical investigations, the aircraft weights have a flight physical origin
- For comparison purposes, the operational scenario described by the above figures can be set relatively arbitrary, however, within reasonable limits
- In order to adopt the method to a known result, the most uncertain parameters can easily be calculated by applying a non-linear optimization algorithm (e.g. EXCEL-SOLVER) to a least squares formulation of the error sum

A simplified DOC Model

- Consideration of additional cargo
  - Method of freight equivalent passenger seats
    - Cargo revenue from residual cargo payload at MZFW ($PL_{Max} - PL$)

$$E_{CARGO} = FR \cdot \left(G_{N,max} - G_{PAX}\right)$$

    - Equivalent seat revenue

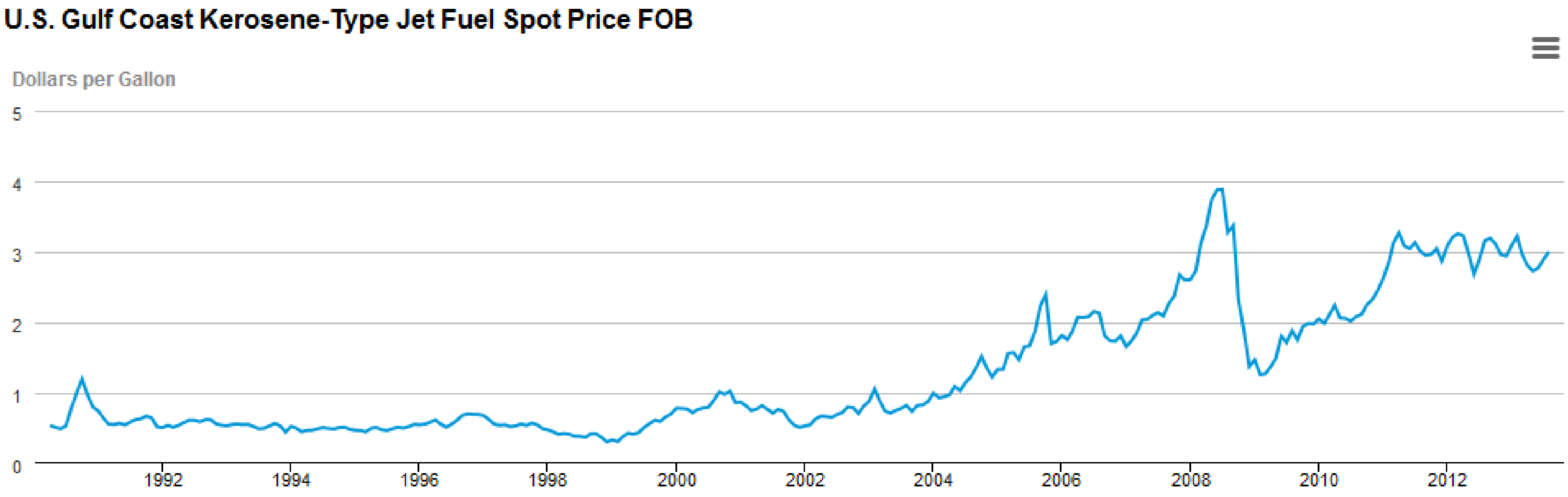
$$n_{PAX,Cargo} = \frac{E_{CARGO}}{E_{PAX}} \cdot R$$

      - E_{Pax}: Revenue per seat and flight [€], 370 € (constant ?)
      - FR: Revenue per freight-km [€/to·km], 0,07 €
    - DOC correction

$$\left(\frac{DOC}{SKO}\right)_{kor} = \left(\frac{DOC}{SKO}\right) \cdot \frac{n_{PAX}}{n_{PAX} + n_{PAX,Cargo}}$$

Kerosine Price

- Current kerosene price is about constant since 2011



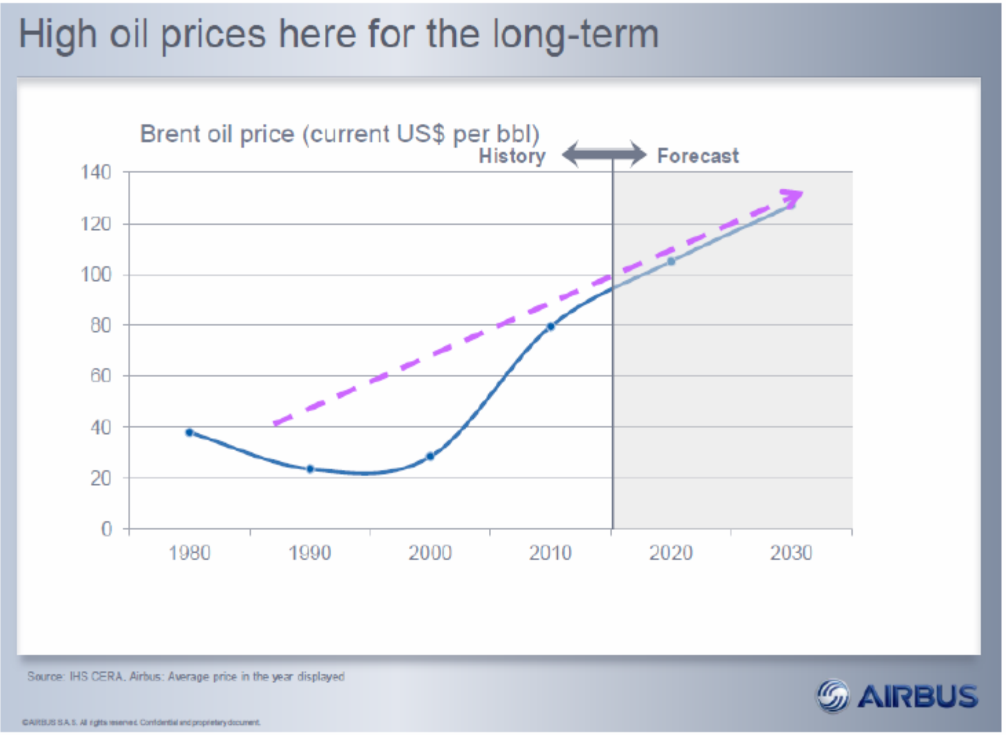
Independent Statistics & Analysis
U.S. Energy Information Administration

Current fuel price: 0.80 €/kg

- 3,7854 l/USgal; 0,8 kg/l; 1,3 US$/€; “Into Plane Differential”: 0,05 US$/kg
- The fuel price is higher than the fuel price on page 6

Price Increase of Kerosene

- The increase of kerosene price in the future is predicted by Airbus to be linear: 2 US$/bbl/year
- Barrel: 1bbl (US) = 159 l; 1,3 US$/€; 0,8 kg/l
- Future fuel price: current fuel price (2013: 0,53 €/kg) plus price increase



High oil prices here for the long-term

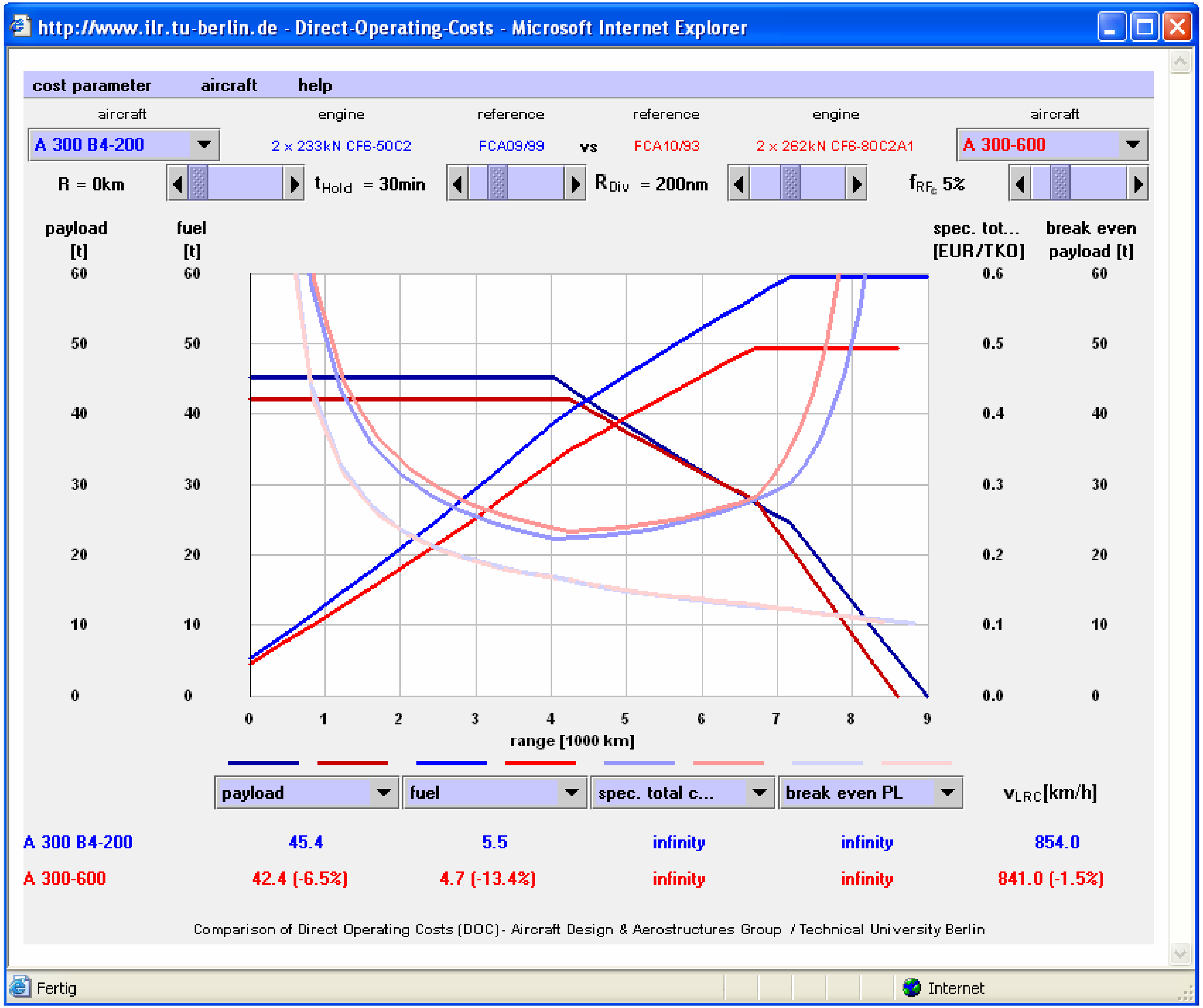
Source: IHS CERA, Airbus; Average price in the year displayed

0.012 €/kg/year

J. LEAHY. *Navigating the Future.* Global Market Forecast 2012-2031. Airbus, 2012

D. Scholz

JAVA DOC Applet



http://www.ilr.tu-berlin.de - Direct-Operating-Costs - Microsoft Internet Explorer

aircraft	engine	reference		reference	engine	aircraft
A 300 B4-200	2 x 233kN CF6-50C2	FCA09/99	vs	FCA10/93	2 x 262kN CF6-80C2A1	A 300-600

R = 0km
t_{Hold} = 30min
R_{Div} = 200nm
f_{RF_c} 5%

	payload	fuel	spec. total c...	break even PL	v_{LRC}[km/h]
A 300 B4-200	45.4	5.5	infinity	infinity	854.0
A 300-600	42.4 (-6.5%)	4.7 (-13.4%)	infinity	infinity	841.0 (-1.5%)

Comparison of Direct Operating Costs (DOC) - Aircraft Design & Aerostructures Group / Technical University Berlin

JAVA DOC Applet

- The applet provides the following functions
  - Selection of two comparison aircraft out of an integrated aircraft data base
  - Defining a new aircraft by its design characteristics
  - Altering the DOC assumptions
  - Comparing the influence of a parameter change for a selected aircraft
  - Graphical representation of up to four of the following selectable parameters over the range axis:
    - Absolute DOC of components and resulting total
    - Relative DOC on TKO, Paxkm and km basis of components and resulting total
    - Payload
    - Break even Payload
    - Trip and reserve fuel
    - Flight time
    - Take of weight
    - Average mission weight
    - Productivity (per flight & p.a.)
    - Utilization (flight hours & flight cycles p.a.)
    - Payload factor

JAVA DOC Applet

- For a proper comparative assessment of aircraft it is helpful to calculate and display also the break even payload BEPL
- For a given revenue rate (RR) in terms of €/TK the comparison of cost (DOC) and revenue leads directly to the break even payload (BEPL) because for break even the condition must be

$$\text{Revenue} = DOC \;\Rightarrow\; RR \cdot BEPL = SMC \cdot PL \;\Rightarrow\; BEPL = \frac{SMC \cdot PL}{RR}$$

- The area between the BEPL and PL line in the payload range diagram indicates the profitable domain of operations
- Below BEPL the operation is prone to financial losses
- The best result is achieved, if the aircraft is operated with maximum payload in the domain close to design range
- For testing of the a.m. formulae, a java applet has been supplied, which can be accessed via the internet under

https://web.archive.org/web/20130625041829/http://www.luftbau.tu-berlin.de/menue/studium_und_lehre/java_applets/doc/