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Maintenance Costs Calculated from DOC Methods of Passenger Aircraft with Different Numbers of Engines

Aircraft with four engines are expensive for airlines. One reason: Engine maintenance costs are higher.

When designing passenger aircraft, the required thrust is determined, which is distributed among a selected number of engines. Certification under EASA CS-25 requires for safety at least two engines. Only 2, 3, or 4 engines are discussed in CS-25. Today, we see that designs with 3 or 4 engines hardly stand a chance on the market. Why is that? This is a holistic aircraft design question involving many facts (specific fuel consumption, drag of the engine nacelles, engine mass, etc.). Engine maintenance costs are highlighted as primary reason for the trend towards two engines, as these costs are said to be higher with multiple small engines than with two large engines. Two approaches: 1.) DOC methods contain simple formulas for estimating engine maintenance costs and can be analyzed. The DOC methods are known by the abbreviation of the publishing organization and the year of publication: ATA 1967, DLH 1982, AEA 1989, AI 1989. Additionally, the methods developed by Jenkinson (Loughborough University) and Thorbeck (TU Berlin) are available. Beyond the student's results: 2.) Public engine maintenance costs are evaluated.

PURPOSE

Why are aircraft with three or four engines rarely sold today? One hypothesis is that aircraft with a larger number of engines may have higher maintenance costs. To answer this question, six different methods for calculating Direct Operating Costs (DOC) of passenger aircraft are used, which also estimate the costs of engine maintenance, among other things. Four of these DOC methods were developed by aviation organizations. Two DOC methods were developed at universities (see above).

METHODOLOGY

The equations for calculating engine maintenance costs for all six methods are presented and explained. The methods vary significantly in their complexity. Since the methods refer to different years, the costs are converted to 2017 using an inflation factor, thereby making them comparable. To calculate engine maintenance costs, four medium-range aircraft of comparable size were selected: B737-800, A318 (two engines), Yak-42 (three engines), BAE 146-300 (four engines). Additionally, four long-haul aircraft of comparable size were selected: A330-300 (two engines), MD11-ER, TriStar (three engines), A340-300 (four engines). The A330 and A340 are particularly suitable for comparison since their technology, age, and dimensions are very similar.

FINDINGS

The DOC results showed that the distribution of maintenance costs between the airframe and the engines is inconsistent. In comparison, the AI method yields engine costs that are far too high. The AI method was disregarded. The other methods yielded similar results. For a final comparison, one aircraft was included for each engine count for both medium- and long-haul routes (Figure 1 & 2). The student's DOC results got contrasted with a regression of published engine maintenance costs (Figure 3 & 4).

$$C_{M,E,f} = t_{M,E,f}\, L_R + C_{M,E,M,f}$$

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

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

Figure 1: **AEA 1989 method gives engine maintenance (per aircraft) in \$/FH from maintenance time, $t_{m,E,f}$ in MMH/FH and labor rate, L_R in \$/MMH and material costs, $C_{M,E,M,f}$ in \$/FH. This value can be inflated to the current year with k_{inf}.**

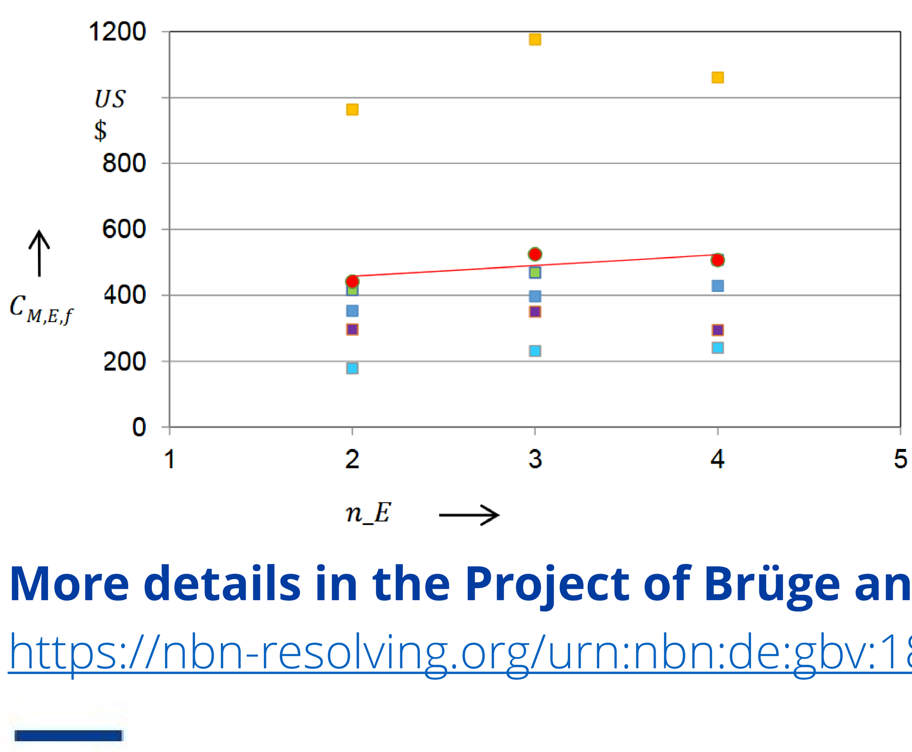


Figure 2: **Engine maintenance costs in \$/FH for 2, 3, 4 engines: A330-300, TriStar, A340-300.**

- AEA 1989 method
- Jenkinson method
- TU Berlin method
- ATA1967
- DLH method
- average value

More details in the Project of Brüge and Kranich (2018):
https://nbn-resolving.org/urn:nbn:de:gbv:18302-aero2018-04-30.011

PRACTICAL IMPLICATIONS

With this adjusted selection of aircraft and methods, a slight decrease in engine maintenance costs was observed for medium-haul flights of only 6.10 \$ per flight hour per engine. For long-haul flights, there was a slight increase in engine maintenance costs with the number of engines of only \$32.50 per flight hour per engine (Figure 2). Thus, the initial hypothesis of an increase in engine maintenance costs with the number of engines could only be partially confirmed. The analysis showed that engine maintenance costs depend on many parameters; the number of engines is just one of many. Even similar aircraft with the same number of engines yield engine DOC maintenance costs that vary significantly, making the dependence on the number of engines less apparent. Suggestions are made regarding other methodological approaches that could remedy this situation (Figure 3 & 4, AI-assisted).

ORIGINALITY

No other work was found to compare DOC methods on engine maintenance costs.

$$C_{\mathrm{maint,2025}} = \begin{cases} -184.59 + 11.627T + \dfrac{234.83}{L}, & 23\ \mathrm{klbf} \lesssim T \lesssim 45\ \mathrm{klbf} \\ -247.29 + 6.514T + \dfrac{950.34}{L}, & 45\ \mathrm{klbf} < T \lesssim 115\ \mathrm{klbf} \end{cases}$$

$T \le 45$: $R^2 = 0.642$, $RMSE = 41.1$ \$/EFH

$T > 45$: $R^2 = 0.860$, $RMSE = 73.7$ \$/EFH

$1 \lesssim L \lesssim 10$

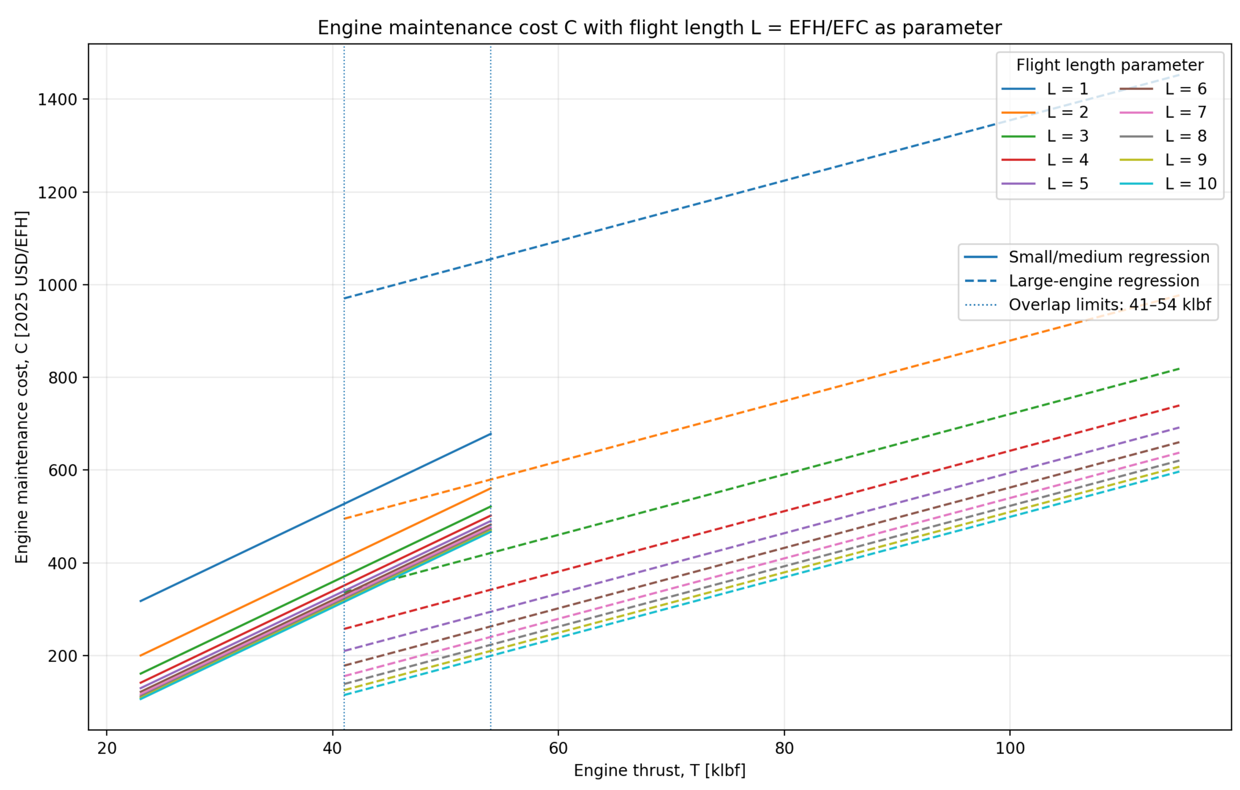
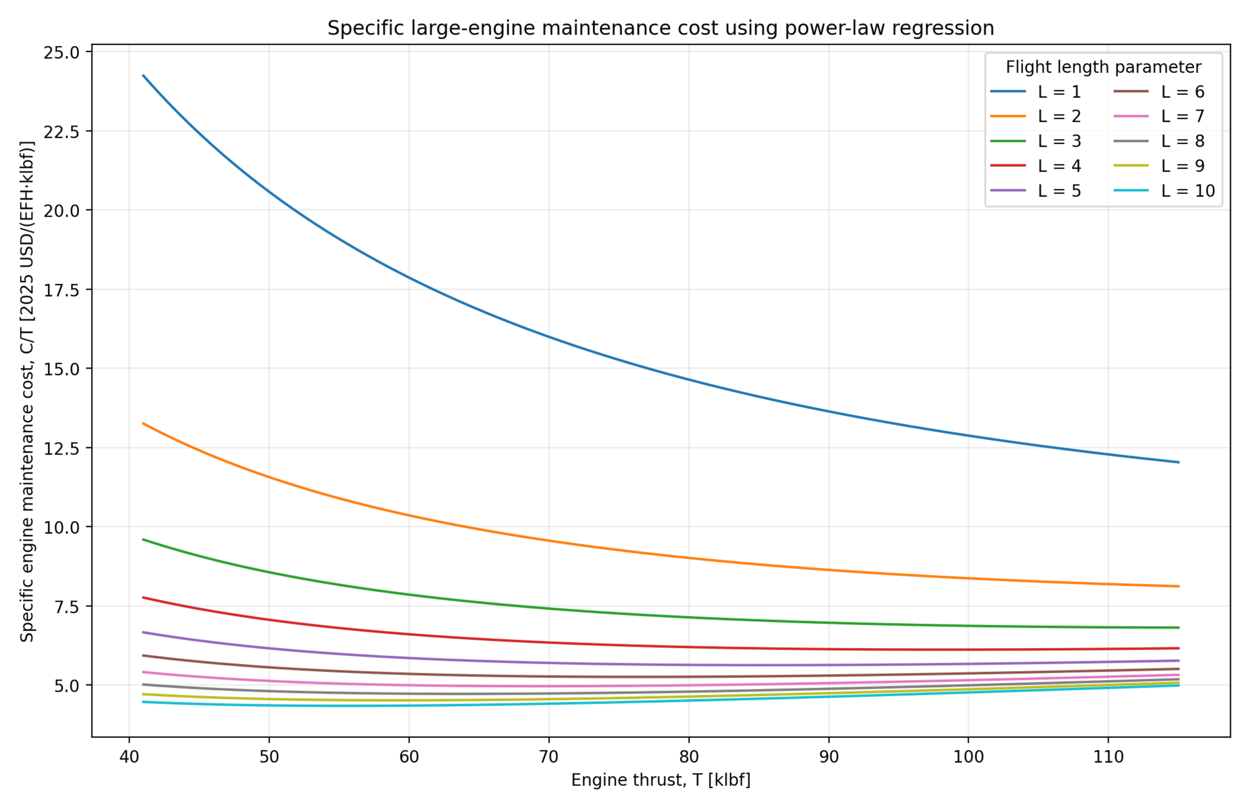


Figure 3:
Regression of engine maintenance costs determined from published data:
a) small/medium engines (n=10),
b) large engines (n=25).

Cost drivers are:
- **shop visits**
- **engine size (thrust in klbf)**
- **cycles (L = EFH/EFC)**

EFH: engine flight hours
EFC: engine flight cyles
L = EFH/EFC: flight time/cycle



$$\frac{C}{T} = 0.2459\, T^{0.598} + \frac{900.82}{L\,T}$$

$$R^2 = 0.839,$$
$$RMSE = 79.0\ \$/EFH$$

Figure 4:
A different regression on the same data, this time for large engine maintenance costs with a power law. Plotting of maintenance costs per flight hour and per thrust, C/T in \$/(FH · klbf)

Associated research data (Harvard Dataverse):
https://doi.org/10.7910/DVN/5O7CSB

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