Generating Cost Efficiency Charts: A Comparison between B737, A319 and A321

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Abstract

With a help of a local airline, the aim of this paper is to construct a cost efficiency charts, for three given aircraft to operate in three independent sectors. These chart are generated by an Excel code, the efficiency charts would be useful for airlines and fleet planners in their decision making process.

Keywords: Cost efficiency charts; Fleet planning; Direct operation cost

Introduction

The intent of this paper is to calculate the cost efficiency for three aircraft namely B737-500, A319, and A320 for prescribed sectors. The cost efficiency is to be calculated using the flight data provided by an airline and the output was assessed for two possible flight scenarios. The cost efficiency charts would be useful for airlines and fleet planners in the discussion making, and in-depth rout analysis. The two routes considered here are Jeddah to Medina (JED to MED) and Jeddah to Riyadh (JED to RUH). All trips would be assumed as round trip flights.

Table 1 shows the selected engine type for the study

Methodology

The first step in all scenarios was to determine the flight utilization. This was done by stating values for the time to climb and descend, and the associated climb and descent speed, along with various associated distances.

The take-off weight of each of the aircraft is calculated by the weight fraction method as identified in Figure 1, [1]. Since the empty weight was known for each aircraft, the total weight and fuel weight is easily determined.

The first step would be to calculate the payload weight \( W_{pl} \) from equation 1

\[
W_{pl} = \text{number of passengers} \times (174 + 40) \tag{1}
\]

The second step would be to calculate the fuel weight \( W_f \) from equation 2

\[
W_f = (1 - M_{ff}) W_{to} W_{fuel\,res} \tag{2}
\]

Where \( M_{ff} \) if the fuel fraction calculated, the fuel fraction ware calculated in each phase of flight, startup, taxi, take off, climb, decent and landing

The \( W_{to} \) is the assumed takeoff weight for the aircraft at this flight, while the fuel fraction in cruise is calculated from equation 3

\[
R_c = \frac{V_{cr}}{C_l} \left( \frac{L}{D} \right) h \left( \frac{W_4}{W_5} \right) \tag{3}
\]

Where

\[
\left( \frac{L}{D} \right) \text{Lift to drag ratio}
\]

\( C_l \) specific fuel concumtion in lb/lb/hr

\( V_{cr} \) aircraft crusing speed in kts

\( R_c \) cruise range in n.m

The thread step would be to calculate the operating weight empty \( W_{oe} \) equation 4

\[
W_{oe} = W_{to} + W_f + W_{pl} \tag{4}
\]

The forth step would be to calculated the empty weight from equation 5

\[
W_{ent} = W_{oe} + W_{to} + W_{crew} \tag{5}
\]

Where

\( W_{crew} \) from mission specification

\( W_{to} \) trapped fuel and oil

\( W_{to} = 5\% W_{to} \)

The empty weight then is compared from the empty weight allowable from Ref1 equation 6

\[
W_{e} = \text{inv}\cdot\text{Log} \left( \frac{\text{Log} W_{to} - A}{B} \right) \tag{6}
\]

Where A, and B are constant from page 47, [1], [Table 2]

If the error between \( W_{ent} \) calculated and \( W_{e} \) is less than 5% then the \( W_{ent} \) is acceptable and \( W_{f} \) and \( W_{to} \) are acceptable if not change the \( W_{to} \)

Note: all dimensions are in Ib

Figure 1 summarize the process in which all weights are calculated.

Table 1: Aircrafts specification

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>Engine Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>B737-500</td>
<td>CFM56-3B1R</td>
</tr>
<tr>
<td>A 319</td>
<td>CFM56-5A4</td>
</tr>
<tr>
<td>A320</td>
<td>CFM56-5B4/P</td>
</tr>
</tbody>
</table>

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Received December 18, 2015; Accepted January 20, 2016; Published January 22, 2016


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Step 1. From mission specification

\[ W_{pl} = \text{PAX Number} \times (175+40) = \ldots \ldots \text{lb} \]

Step 2. \( W_{to} \) guess from similar airplanes

<table>
<thead>
<tr>
<th>A/C</th>
<th>( W_{pl} )</th>
<th>( W_{to} )</th>
<th>( V_{cr} )</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>(lb)</td>
<td>(lb)</td>
<td>(kts)</td>
<td>(n.m.)</td>
</tr>
</tbody>
</table>

Step 3. Determine \( W_{f} \)

\[
M_{ff} = \frac{W_{1}}{W_{to}} \sum\left(\frac{W_{i+1}}{W_{i}}\right)
\]

\[
M_{ff} = \frac{W_{9}}{W_{8}} \frac{W_{8}}{W_{7}} \frac{W_{7}}{W_{6}} \frac{W_{6}}{W_{5}} \frac{W_{5}}{W_{4}} \left(\frac{W_{4}}{W_{3}}\right) \frac{W_{3}}{W_{2}} \frac{W_{2}}{W_{1}} \frac{W_{1}}{W_{to}}
\]

\[
W_{fused} = (1-M_{ff})W_{to}
\]

\[
W_{f} = (1-M_{ff})W_{to} + W_{f \text{ res \ phase 1}}
\]

Step 4. Calculate Airplane Operating Weight

\[
W_{oe} = W_{to} - W_{f} - W_{pl}
\]

Step 5. Calculate \( W_{t} \)

\[
W_{t \text{ ent}} = W_{oe} - W_{t\text{f - W crew}}
\]

\[
W_{t\text{f - W crew}}\text{ from mission specification}
\]

\[
W_{t\text{f - W crew}}\text{ trapped unusable fuel and oil}
\]

\[
W_{t\text{f - W crew}} = 0.005 \times W_{to}
\]

Step 6. Allowable value for \( W_{t} \)

from figure 2.9 or from eq. 2.16

\[
W_{t} = \text{inv} \cdot \text{Log} \left( \frac{\text{Log} W_{to} - A}{B} \right)
\]

\[
A = 0.0833 \text{ from page 47 table 2.15}
\]

\[
B = 1.0393 \text{ from page 47 table 2.15}
\]

Figure 1: Calculating the fuel and takeoff weight through the weight fraction method Ref [1].
Next the actual Direct Operating Cost DOC, components is calculated. The DOC is calculated by using the method used in [2], starting with the DOC of flight. Within the DOC of flight the cost of the crew, fuel and oil, and insurance all can be directly determined. All values for the crew cost were assumed based on the values from the local airline and [3]. As were the input values for the fuel and oil cost and insurance. [Table 2].

\[
\text{DOC} = \text{DOC}_{\text{fly}} + \text{DOC}_{\text{maint}} + \text{DOC}_{\text{depr}} + \text{DOC}_{\text{lnr}} + \text{DOC}_{\text{fin}} \quad (7)
\]

Where:

\[
\text{DOC}_{\text{fly}} \text{ is the direct operating cost of flying in } \$/\text{n.m.}
\]

\[
\text{DOC}_{\text{maint}} \text{ is the direct operating cost of maintenance in } \$/\text{n.m.}
\]

\[
\text{DOC}_{\text{depr}} \text{ is the direct operating cost of depreciation in } \$/\text{n.m.}
\]

\[
\text{DOC}_{\text{lnr}} \text{ is the direct operating cost of landing fees, navigation fees, and taxes in } \$/\text{n.m.}
\]

\[
\text{DOC}_{\text{fin}} \text{ is the direct operating cost of finance in } \$/\text{n.m.}
\]

The DOCfly is given by

\[
\text{DOC}_{\text{fly}} = \text{C}_{\text{crew}} + \text{C}_{\text{pol}} + \text{C}_{\text{ins}} \quad (8)
\]

Where

\[
\text{C}_{\text{crew}} \text{ is crew cost given by}
\]

\[
\text{C}_{\text{crew}} = \sum (n_c j) \left[ \left( 1 + K_j \right) / V_{\text{bl}} \right] \left( \text{SAL}_j / \text{AH}_j \right) + \left( \text{TEF}_j / V_{\text{bl}} \right) \quad (9)
\]

\[
\text{nc}_j \text{ is the number of crew member of each type (i.e. captain, and co-pilot)}
\]

\[
V_{\text{bl}} \text{ is the airplane block speed in n.m/hr.}
\]

\[
\text{SAL}_j \text{ is the annual salary paid to crew members of each type}
\]

\[
\text{AH}_j \text{ is the number of flight hours per year of each type}
\]

\[
\text{TEF}_j \text{ is the travel expense factor}
\]

\[
K_j \text{ factor which accounts for items such as vacation pay, cost of training}
\]

\[
\text{C}_{\text{pol}} \text{ is the fuel and oil cost per nautical mile given by}
\]

\[
\text{C}_{\text{pol}} = 1.05 \left( W_f / R \right) \left( \text{FP} / \text{FD} \right) \quad (10)
\]

\[
W_f \text{ is the fuel weight in lb}
\]

\[
R \text{ range in n.m}
\]

\[
\text{FP} \text{ is the price of fuel in } \$/\text{gallon}
\]

\[
\text{FD} \text{ is the fuel density in lbs/gallon}
\]

\[
\text{C}_{\text{ins}} \text{ is the airframe insurance cost in } \$/\text{n.m given by}
\]

\[
\text{C}_{\text{ins}} = \left( \text{fins} \right) \left( \text{AMP} / \left( \text{Uann} \right) \left( V_{\text{bl}} \right) \right) \quad (11)
\]

\[
\text{fins} \text{ is the annual hull insurance rate in } \$/\text{year}
\]

\[
\text{AMP} \text{ is the airplane market price}
\]

\[
\text{Uann} \text{ is the annual hour utilization}
\]

\[
\text{The DOCmaint is given by}
\]

\[
\text{DOC}_{\text{maint}} = \text{Clab/ap} + \text{Clap/eng} + \text{Cmat/ap} + \text{Cmat/eng} + \text{Camb} \quad (12)
\]

Where

\[
\text{Clab/ap} \text{ is the labour cost of airframe and systems in } \$/\text{n.m}
\]

\[
\text{Clab/ap} = 1.03 \left( \text{MHRA} \right) \left( R / V_{\text{bl}} \right) \quad (13)
\]

\[
\text{MHRA} \text{ is number of airframe and systems maintenance}
\]

\[
\text{hours needed per block hours}
\]

\[
\text{Clap/eng} \text{ is the labour cost of engines in } \$/\text{n.m}
\]

\[
\text{Clap/eng} = 1.03 \left( 1.3 \right) \text{ Ne} \left( \text{MHRE} \right) \left( R / V_{\text{bl}} \right) \quad (14)
\]

\[
\text{Ne} \text{ number of engines}
\]

\[
\text{MHRE} \text{ is the number of engines maintenance hours needed per block hours}
\]

\[
\text{Cmat/ap} \text{ is the cost of maintenance materials for the airframe and systems } \$/\text{n.m}
\]

\[
\text{Cmat/eng} \text{ is the cost of maintenance materials for the engines } \$/\text{n.m}
\]

\[
\text{Camb} \text{ is the applied maintenance burden in } \$/\text{n.m.}
\]

\[
\text{The DOCdepr is given by}
\]

\[
\text{DOC}_{\text{depr}} = \text{Cdap} + \text{Cdeng} + \text{Cdav} + \text{Cdasp} + \text{Cdengsp} \quad (15)
\]

Where

\[
\text{Cdap} \text{ is the cost of airplane depreciation without engines in } \$/\text{n.m}
\]

\[
\text{Cdeng} \text{ is the cost of engine depreciation in } \$/\text{n.m}
\]

\[
\text{Cdav} \text{ is the cost of depreciation of avionics systems in } \$/\text{n.m}
\]

\[
\text{Cdasp} \text{ is the cost of the depreciation of airplane spare part in } \$/\text{n.m}
\]

\[
\text{Cdengsp} \text{ is the cost of the depreciation of engine spare part in } \$/\text{n.m}
\]

\[
\text{The DOClnr is given by}
\]

\[
\text{DOC}_{\text{lnr}} = \text{Clf} + \text{C nf} + \text{Crf} \quad (16)
\]

Where

\[
\text{Clf} \text{ the direct operating cost due to landing fees in } (\$/\text{n.m}) \text{ are calculated by}
\]

\[
\text{Clf} = \left( \text{Caplf} \right) / \left( \left( V_{\text{bl}} \right) \left( t \right) \right) \quad (17)
\]

Where

\[
\text{Caplf} \text{ is the landing fees per landing given by}
\]

\[
\text{Caplf} = 0.002 W_t \text{ to } \$/\text{lbs} \quad (18)
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual salary paid for one pilot [$/year]</td>
<td>100000</td>
</tr>
<tr>
<td>Annual salary paid for one co-pilot [$/year]</td>
<td>80000</td>
</tr>
<tr>
<td>Cost of maintenance materials for airplane [$/n.m]</td>
<td>404</td>
</tr>
<tr>
<td>Cost of maintenance materials for engine [$/n.m]</td>
<td>217</td>
</tr>
<tr>
<td>Annual hull insurance rate [$/year]</td>
<td>0.015</td>
</tr>
<tr>
<td>Maintenance manhours per flight hours / year</td>
<td>5.86</td>
</tr>
<tr>
<td>Number of flight hours / year</td>
<td>750</td>
</tr>
<tr>
<td>Fuel densityFD [lbs/gallon]</td>
<td>8</td>
</tr>
<tr>
<td>Fuel price FP [$/gallon]</td>
<td>1.4</td>
</tr>
<tr>
<td>L / D</td>
<td>15</td>
</tr>
<tr>
<td>engine maintenance labor rate [$/hr]</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 2: Some data given Ref [3].
$W_{to}$ is the airplane takeoff weight in lbs

$C_{nf}$ the navigation fees in $/n.m$

\[ C_{nf} = \frac{C_{amnf}}{(V_{bl})(t)} \quad (19) \]

Where

$C_{amnf}$ is the navigation fees charged per airplane per flight

$C_{rt}$ is the direct cost of registry taxes in $($/n.m) are calculated by

\[ C_{rt} = (f_{rt}) \cdot DOC \quad (20) \]

Where $f_{rt}$ is a factor suggested from [3]

\[ f_{rt} = 0.00 + (10^{-6}) \cdot W_{to} \quad (21) \]

Where

$W_{to}$ takeoff weight in lbs

$DOC_{fin}$ is given by

\[ DOC_{fin} = 0.07 \cdot DOC \quad (22) \]

In order to calculate the cost per aircraft per trip and the cost per seat mile, it is calculated as follows

Cost per aircraft per trip = $DOC \cdot [$/n.m] \times \text{Distance [n.m]} \quad (23)

Cost per seat mile = $DOC \cdot [$/n.m] \div \text{Number of seats} \quad (24)

More details are available in [2].

The DOC of maintenance was calculated, mostly based on the values from a local airline and values founded in [2]. This was also true for the DOC of the depreciation, as well as the DOC of the landing and navigation fees. Once all of these components were calculated, the total direct operation cost could be calculated by just adding these values together, for each of the flight scenarios. The unite of DOC is dollars per nautical miles.

After calculating DOC, and with the known distance and the seats for each aircraft at each sector, the cost efficiency chart could be generated and determined (Table 3).

### Results

Figures 2 and 3 show the efficiency of each aircraft at a given sector. Different aircraft types are not only compared with their trip cost but also with their seat mile cost, the lower the two parameters for the given aircraft the better, the aircraft is said to be more efficient if both parameters are low.

Figure 2, shows the cost efficiency chart results for the sector Jeddah to Riyadh, Figure 3 shows the cost efficiency chart results for the sector Jeddah to Medina.

### Conclusion

- In the cost efficiency chart the best-performed aircraft in this sector would be the lowest seat mile cost and the lowest aircraft trip cost.
  - B737-500 has the highest seat mile cost but the lowest trip cost for each sector.
  - A321 has the lowest seat mile cost but has the highest trip cost.
  - Since it is preferential to have the lowest seat mile cost and the lowest trip cost the A319 performed better than the B737-500 and A321.

### References

3. Local Airline

Table 3: Direct operating cost in $ per n.m.

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>JED - MED</th>
<th>JED - RUH</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 737-500</td>
<td>15.3</td>
<td>15.0</td>
</tr>
<tr>
<td>A 319</td>
<td>16.6</td>
<td>16.3</td>
</tr>
<tr>
<td>A 321</td>
<td>21.0</td>
<td>20.5</td>
</tr>
</tbody>
</table>