Cost (and Other Issues)
W. H. Mason

- The Business Conduct of Engineering
- Basic Considerations for Cost Estimation

Engineering Is In Fact a Business

- Your contribution will be judged in an economic context
  - Somebody pays your salary
    - It is likely you will fill out a time card
- You have to add value to the product
- There is an economic aspect to all engineering decisions
Business Considerations

• You have to account for every cent
• You have to get approval to spend money
• You must use purchase orders
• Make sure your bosses know what you are doing

A Brief Overview of Aircraft Cost Estimation

• Military and Commercial Aircraft
  – differ in some of the details
• We will follow Roskam, Vol. VIII
Definition of Cost, Price and Profit

follow Roskam, Vol. VIII:
COST: amount of expenditures needed to manufacture the airplane
PRICE: amount paid for the airplane by the customer
PROFIT: PRICE - COST

Airplane Life Cycle: time for the 6 phases of an airplane program
LIFE CYCLE COST - total cost of an airplane during the airplane life cycle

Note: manufacturer, commercial and personal or corporate owners, and the public all have different viewpoints.

Cost Perspectives: Commercial Aircraft

MINIMUM ACCEPTABLE

MANUFACTURER PERSPECTIVE

ROI
Number of Aircraft

AIRLINE PERSPECTIVE

PROFIT

TRAVELING PUBLIC’S PERCEPTION

In a competitive market, margins approach

Performance

Manufacturing

DOC + I

60% DOC + I Decrease = 30% Ticket Price Decrease

From a NASA briefing
Phases of an Airplane Program

1. Planning and Conceptual Design
2. Preliminary Design and System Integration
3. Detail Design and Development
4. Manufacturing and Acquisition
5. Operation and Support
6. Disposal

Preliminary Cost Definitions

Costs:
- CRDTE: Research, development, test and evaluation
- CACQ: Acquisition cost (CMAN + CPRO)
  - CMAN: manufacturing cost
  - CPRO: manufacturer’s profit
- COPS: Operating cost
- CDISP: Disposal Cost

Life Cycle Cost:

\[ \text{LCC} = \text{CRDTE} + \text{CACQ} + \text{COPS} + \text{CDISP} \]

COPS >> CACQ >> CRDTE

But: Phase 1 and 2 lock in LCC!!
Viewpoints on Important Cost

Military:
claims to use Life Cycle Cost
- but Congress often minimizes initial cost,
at expense of LCC

Commercial:
often uses operating cost,
- made up of direct (DOC)
  and indirect (IOC) pieces

Commercial Airplanes
Boeing Cost Method

Total Operating Cost (TOC) =

Indirect Operating Costs (IOC) +

Direct Operating Costs (DOC)

Example: 1000 nm domestic trip
60% load factor (1985)

<table>
<thead>
<tr>
<th>IOC</th>
<th>737-200ADV</th>
<th>747-100B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airplane Related</td>
<td>16%</td>
<td>14%</td>
</tr>
<tr>
<td>Passenger Related</td>
<td>26%</td>
<td>29%</td>
</tr>
<tr>
<td>Cargo Related</td>
<td>2%</td>
<td>6%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>44%</strong></td>
<td><strong>49%</strong></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>DOC</th>
<th>737-200ADV</th>
<th>747-100B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>8%</td>
<td>7%</td>
</tr>
<tr>
<td>Fuel</td>
<td>17%</td>
<td>16%</td>
</tr>
<tr>
<td>Crew</td>
<td>12%</td>
<td>5%</td>
</tr>
<tr>
<td>Interest</td>
<td>8%</td>
<td>10%</td>
</tr>
<tr>
<td>Insurance</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Depreciation</td>
<td>10%</td>
<td>12%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>56%</strong></td>
<td><strong>51%</strong></td>
</tr>
</tbody>
</table>
### Indirect Operating Costs

**As defined by Boeing:**

<table>
<thead>
<tr>
<th>Airplane Related</th>
<th>Passenger Related</th>
<th>Cargo Related</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Property &amp; Equipment</td>
<td>Passenger Food</td>
<td>Cargo Handling &amp; Ins.</td>
</tr>
<tr>
<td>Maintenance &amp; Burden</td>
<td>Passenger Liability Insurance</td>
<td>Cargo Res. &amp; Sales</td>
</tr>
<tr>
<td>Ground Property &amp; Equipment</td>
<td>Passenger Handling</td>
<td>Cargo Commissions</td>
</tr>
<tr>
<td>Depreciation &amp; Amortization</td>
<td>Passenger Baggage Handling</td>
<td>Cargo Advert. &amp; Pub.</td>
</tr>
<tr>
<td>Cabin Crew</td>
<td>Passenger Reservations &amp; Sales</td>
<td>General &amp; Admin.</td>
</tr>
<tr>
<td>Control &amp; Communications</td>
<td>Passenger Commissions</td>
<td></td>
</tr>
<tr>
<td>Aircraft Handling</td>
<td>Passenger Advertising &amp; Publicity</td>
<td></td>
</tr>
<tr>
<td>APU Fuel (Ground Power)</td>
<td>General &amp; Administrative</td>
<td></td>
</tr>
<tr>
<td>Landing Fees</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General &amp; Administrative</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Some Details

1. **Ways to quote DOC**
   - DOC: US dollars per block hour
   - DOC: dollars per statute mile
   - DOC: cents per ASM (Available Seat Mile)

2. **Leasing:** Leasing is now a popular approach, and alters the “typical” cost breakdown distribution

3. **Inflation:** Comparing data from different years, you must include inflation factor adjustment to get an “apples-to-apples” comparison, and consider fuel cost variations also.

4. **Military Aircraft Pricing:** Military procurement cost studies have been done by the Rand Corporation, and they have produced the methods used for military aircraft estimates
Connecting DOCs

- 2 class seating
- 1,000 nmi
- 1989 U.S. domestic majors

DOC, cents per ASM

DOC, dollars per statute mile

from John Steiner, "Jet Aviation Development: One Company’s Perspective" A Boeing Report

Another Boeing Cost Breakdown

<table>
<thead>
<tr>
<th>Cash cost (DOC) &quot;out of pocket&quot;</th>
<th>Operating Cost (DOC) (including ownership)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Maintenance, 13%</td>
<td>Engine Maintenance, 6%</td>
</tr>
<tr>
<td>Airframe Maintenance, 17%</td>
<td>Airframe Maintenance, 8%</td>
</tr>
<tr>
<td>Flightcrew, 31%</td>
<td>Flightcrew, 14%</td>
</tr>
<tr>
<td>Fuel, 39%</td>
<td>Fuel, 18%</td>
</tr>
<tr>
<td></td>
<td>Ownership, 54%</td>
</tr>
<tr>
<td></td>
<td>- Depreciation</td>
</tr>
<tr>
<td></td>
<td>- Financing</td>
</tr>
<tr>
<td></td>
<td>- Insurance</td>
</tr>
</tbody>
</table>

Note: New airplane in 1989 dollars, 1000nm trip

from John Steiner, "Jet Aviation Development: One Company’s Perspective" A Boeing Report
What can the designer do to reduce DOC?

- Reduce fuel use
  - Examine the Brequet Range Eqn.
    > $L/D$
    > $sfc$
    > $TOGW$
- Reduce purchase price of the plane
  - Reduce $TOGW$
  - Reduce manufacturing cost (complexity)
### Some Fuel Efficiency Trends of Boeing Aircraft

![Graph showing fuel efficiency trends of Boeing Aircraft](slide)

from John Steiner, “Jet Aviation Development: One Company’s Perspective” A Boeing Report

### Examples of Airline Economics

<table>
<thead>
<tr>
<th>Airline</th>
<th>Fleet</th>
<th>Pass. Rev. (Miles)</th>
<th>Yield per RPM</th>
<th>Operating Cost per ASM</th>
</tr>
</thead>
<tbody>
<tr>
<td>United</td>
<td>554</td>
<td>108,016</td>
<td>11.23</td>
<td>8.48</td>
</tr>
<tr>
<td>American</td>
<td>566</td>
<td>98,736</td>
<td>12.98</td>
<td>9.16</td>
</tr>
<tr>
<td>Delta</td>
<td>543</td>
<td>86,298</td>
<td>13.00</td>
<td>9.53</td>
</tr>
<tr>
<td>Northwest</td>
<td>382</td>
<td>57,851</td>
<td>13.36</td>
<td>9.41</td>
</tr>
<tr>
<td>British Airways</td>
<td>230</td>
<td>53,583</td>
<td>16.08</td>
<td>12.17</td>
</tr>
<tr>
<td>Japan Airlines</td>
<td>119</td>
<td>39,108</td>
<td>19.93</td>
<td>16.23</td>
</tr>
<tr>
<td>US Air</td>
<td>441</td>
<td>37,940</td>
<td>15.61</td>
<td>11.32</td>
</tr>
<tr>
<td>Continental</td>
<td>311</td>
<td>37,510</td>
<td>11.26</td>
<td>7.91</td>
</tr>
<tr>
<td>TWA</td>
<td>194</td>
<td>24,901</td>
<td>11.32</td>
<td>8.62</td>
</tr>
<tr>
<td>Southwest</td>
<td>199</td>
<td>19,789</td>
<td>11.65</td>
<td>7.14</td>
</tr>
<tr>
<td>Air Canada</td>
<td>107</td>
<td>14,152</td>
<td>14.33</td>
<td>9.19</td>
</tr>
<tr>
<td>America West</td>
<td>86</td>
<td>12,199</td>
<td>10.76</td>
<td>7.03</td>
</tr>
</tbody>
</table>

source: Aviation Week, Jan. 8, 1996
A Comment on Hub & Spoke

- Invented by Federal Express for Freight
  - excellent for overnight delivery

- Widely applied to passenger operations
  - does not “scale up,” airlines don’t get economy of scale
  - personnel & equipment to handle peak demand leads to very inefficient use of equipment and people on an average basis


From a previous VPI design study: 1993 data

the Miser design team, John Pierson leader
1993-1994 (3rd place in AIAA Competition
see also: Vincent Press, cost analyst,
AVIATS Aviation, Inc. Reston, VA
From a previous VPI design study: DOC Sensitivity to Design Parameters

The Miser design team, John Pierson leader, 1993-1994 (3rd place in AIAA Competition.

Source: Aviation Daily (Mar 30, 1994 & Nov. 8, 1993)
**Cost Estimating**

Roskam’s Volume VIII presents a method to estimate each cost

- Use as a guide
- Adjust Roskam’s method to reflect what you know about your design

Finally, Roskam gives:

- 88 Design Guidelines for Low Cost (page 246-254)
- 17 Lessons Learned from past airplane programs (page 280-284)

**Some Other References**

*Commercial*


*Military*

Help Making the Calculation?

*Roskam’s Company*, DARcorporation  
http://www.darcorp.com

COST for Windows, Version 1.0  
($49.96 or $25 with purchase of text)

*Raymer*:  http://www.aircraftdesign.com  
his software contains some type of cost module

*In the past,*  
students have coded the algorithms themselves  
I have one code (by Scott Dyer - military cost)

Is All This Important?

Check the RFP, ask your customer.
Phil Condit, 1996 Wright Brothers Lectureship

“Today, technology is only one component in the design of an airplane. More and more, our airline customers describe their needs in terms of economics. Their number one priority is for airplanes that are less expensive to own and operate. As a result, our industry is now applying the same kind of creativity and ingenuity to reducing the cost of designing and building airplanes as we do to developing the technology that goes into them.”

Important - And Not Addressed Here Yet: Risk

Companies commit to the product before building it!

You bet your company

Key Decisions:
- Level of Technology Used
  - Use of Technology without validation:
    > cost overrun
    > even a “show stopper”
    > has happened over and over again
- Plan for future versions/product derivatives
Finally:

In defense programs, congress often feels that there are two phases to a program:

1. It’s too early to tell

2. It’s too late to do anything about it