Who are we?

*TBE international Limited ("TBE")* is a boutique Hong Kong based consulting and contracting company incorporated in February 2007, specialising in Aviation and Aviation associated management and advisory services.

Our People

- Airline Executives
- Airline Senior Managers
- Six Sigma Black Belts
- Professional Engineers
- Accountants
- Licensed Engineers

Our Services

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>✔ Lease Mgt</td>
<td>✔ Maintenance Management</td>
<td>✔ Start-up Planning and implementation</td>
<td>✔ Structured knowledge transfer</td>
</tr>
<tr>
<td>✔ Asset ‘Health Check’ Services</td>
<td>✔ PBH Agreement Negotiation</td>
<td>✔ Economic Analysis</td>
<td>✔ Project based learning</td>
</tr>
<tr>
<td>✔ Lease/Sale/Purchase Services</td>
<td>✔ Lease Return</td>
<td>✔ Business Improvement</td>
<td>✔ lean/6-sigma mentoring</td>
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<tr>
<td>✔ Asset Valuations</td>
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<td>✔ IT system implementation</td>
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Areas technology change affecting cost

Aircraft Related

Materials
- Composites
- Refined alloys

Engineering
- CAD
- Computer modelling
- Manufacturing techniques

Interior Products:
- IFE
- Seats v ‘suites’
- Galley facilities

On-Aircraft Monitoring Systems
- Performance Monitoring
- Health Monitoring

Maintenance Related

Inspection Techniques
- NDT

Remote diagnostics

Logistics

Things Not Changed

Labour (people)

Infra structure
- Hangers
- Non specialised tooling

Coatings/Sealants
- High temperature
- Anti corrosion

Commercial arrangements
PBH
Component Pooling
Fleet Technical Management
So have Aircraft adopted technology?

What do the OEMs say…..

**AIRBUS** .... on the A350

“Key design features driving this improvement in economic efficiency are the **extensive use of lightweight composite materials for lower weight and maintenance costs**; the implementation of **simple, efficient and proven systems**, including integrated modular avionics; the application of state-of-the-art aerodynamics; and the use of **latest-generation engines** with the lowest fuel consumption and reduced emissions.

**Composites, titanium and advanced aluminium-alloys** are applied extensively throughout the A350 XWB’s fuselage, with their use tailored to the best characteristics of these materials. The 53 per cent of composites utilised in the fuselage and wing **reduces the need for fatigue-related inspections** required on more traditional aluminium jetliners. The composites and titanium also diminish the requirement for corrosion-related maintenance checks on the A350 XWB. **These two factors reduce the new aircraft's overall fatigue and corrosion maintenance tasks by 60 per cent.**

Construction of the A350 XWB’s fuselage sections is made by assembling four-skin panel sections – two lateral side panels, one at the crown, and another for the belly – onto carbon fibre frames. In contrast to other composite aircraft, this construction technique allows for a tailoring of composite layup thickness to each panel, based on calculations of local fuselage stresses and loads.”

So have Aircraft adopted technology?

What do the OEMs say…..

BOEING

…. on the 787

“Advanced Technology
The key to the exceptional performance of the 787 Dreamliner is its suite of new technologies and its revolutionary design. Composite materials make up 50 percent of the primary structure of the 787, including the fuselage and wing.

At the heart of the 787 design is a modern systems architecture that is simpler, more functional and more efficient than that of other airplanes. For example, onboard health-monitoring systems allow the airplane to self-monitor and report systems maintenance requirements to ground-based computer systems.

Advances in engine technology are the biggest contributor to overall fuel efficiency improvements on the Dreamliner. The 787 features new engines from General Electric and Rolls-Royce that represent nearly a two-generation jump in technology.

The design and build process of the 787 has added further efficiency gains. Boeing and its supplier partners developed new technologies and processes to enhance efficiency. For example, manufacturing the 787 fuselage as one-piece sections eliminated 1,500 aluminum sheets and 40,000 - 50,000 fasteners per section.”

Source: www.boeing.com, …/787family/, “About the 787 Family”, 25-Aug-2014
So have Aircraft adopted technology?

ANSWER:
..... Undoubtedly…. YES!

• But does the incorporation of Technology reduce maintenance costs?

• From and Airbus perspective on the A350:
  o “…[use of composites] reduces the need for fatigue-related inspections
  o “…composites and titanium also diminish the requirement for corrosion-related maintenance checks”
  o “These two factors reduce the new aircraft’s overall fatigue and corrosion maintenance tasks by 60 per cent”

• Boeing on the B787 uses a significant amount of composites:
  o “Composite materials make up 50 percent of the primary structure”

• Focus on Base Maintenance Labour for this presentation:
  o This is where ‘structural’ tasks are likely to be completed
  o Other items such as engines or components and cost categories such as material should also be included for a complete review.
How to measure Base Maintenance Cost

1. Frequency of Maintenance Checks
   - Check intervals

<table>
<thead>
<tr>
<th>Aircraft Age (Years)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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<tbody>
<tr>
<td>A/C Type 1</td>
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<td>C</td>
<td>C</td>
<td>C = 8 Chks / 10 Yrs</td>
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</tr>
<tr>
<td>A/C Type 2</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C = 5 Chks / 10 Yrs</td>
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</tr>
</tbody>
</table>
   
Higher check intervals are better

2. Size of Checks
   - Labour (manhour) content
     - Routine/Non Routine/Mods
   - Material expenditure
   - Subcontract
   - Ground time
     - Critical path rather than manpower limitations

Lower manhour (cost) checks are better
How to measure Base Maintenance Cost, cont

It is possible to gain a single measurement

- Total Maintenance Cost = f(Check intervals, Event Cost)
- Plot the cumulative maintenance cost for a particular aircraft over time.
  - This normalises the effect of different check intervals and check size (cost)
What would be expect?

We would expect to see 2 trends:

1. For the same aircraft type, a decrease in maintenance cost for later production hulls due to:
   - Maintenance Interval Escalation
   - Modification Incorporation:
     - Safety
     - Reliability
     - Product
   - MRO efficiency

2. A step change in maintenance costs for ‘new/next generation’ aircraft due to the incorporation of new technology, (composites, simpler, ‘smarter’ systems etc)
Consider a fleet of B744 aircraft all operating with the same airline.

- The airline has taken delivery of its aircraft at regular intervals but the fleet can be split into 2 distinct delivery periods:
  - Subfleet 1: Aircraft delivered between 1989 and 1991
  - Subfleet 2: Aircraft delivered between 2000 and 2003

- By the time Subfleet 2 is delivered Subfleet 1 is between 9-14 years old, ie: 9-14 years of improvement in:
  - Maintenance Intervals
  - Modification Incorporation
  - MRO efficiency

- Plot the cumulative Routine and Non Routine manhhours expended on each aircraft versus the age of the aircraft
  - This neutralises the effect of different labour rates over time
Case Study 1: B744, Cont

- Restrict Routine and Non Routine to age 10 years to cover overlap period

To look at effect of check escalation split Subfleet 1 into pre and post escalation
Case Study 1: B744, Cont

- Split Subfleet 1 into Pre (Subfleet 1a) and Post (Subfleet 1b) check escalation

Increase in check interval appears to increase maintenance cost, i.e.: latest delivery is the most expensive

Very similar trends to first D Check

Take a closer look at Routine and Non Routine drivers separately to understand trend
Case Study 1: B744, Cont

- Consider the Cumulative Routine Manhours

Subfleet 2 has a higher Routine Manhour component before and after first D check

Subfleet 1a and 1b have similar Routine manhour components before and after first D check

This is counter intuitive – we would expect Subfleet 1b and 2 to have lower Routine
Case Study 1: B744, Cont

- Consider the Cumulative Non Routine Manhours

The increase in check intervals appear to increase non routine findings AND Aircraft EIS seems to have little bearing on cost

Similar trends for all Subfleets to first D Check

This is counter intuitive – we would expect Subfleet 1b and 2 to have lower NR
Case Study 1: B744, Cont

- Consider the amount of Non Routine manhours generated by each Routine manhour

Subfleets 1a and 1b have a converging trend but Subfleet 1b has higher variability

After first D check Subfleets 1a and 2 converge, but Subfleet 1b has slightly higher NR/R ratio due to higher variability

Subfleet 2 has a much lower NR/R ratio up to its first D check

Mixed results – expect Subfleet 1b to have same NR/R and 2 to have lower NR/R
### Case Study 1: B744, Conclusion

<table>
<thead>
<tr>
<th></th>
<th>Subfleet 1a</th>
<th>Subfleet 1b</th>
<th>Subfleet 2</th>
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<tbody>
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<td>(Old EIS,</td>
<td>(Old EIS,</td>
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<tr>
<td></td>
<td>no Chk Escal)</td>
<td>with Chk Escal)</td>
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<td></td>
<td>Expectation</td>
<td>Actual</td>
<td>Expectation</td>
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<tr>
<td></td>
<td>Actual</td>
<td>Expectation</td>
<td></td>
</tr>
<tr>
<td>Cumulative Routine</td>
<td>Pre-deck</td>
<td>Baseline</td>
<td>Lower</td>
</tr>
<tr>
<td>Manhours</td>
<td>Post D Check</td>
<td>Baseline</td>
<td>Lower</td>
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<td></td>
<td></td>
<td>Lower</td>
<td>Same</td>
</tr>
<tr>
<td>Cumulative Non</td>
<td>Pre-deck</td>
<td>Baseline</td>
<td>Lower</td>
</tr>
<tr>
<td>Routine Manhours</td>
<td>Post D Check</td>
<td>Baseline</td>
<td>Lower</td>
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<td></td>
<td></td>
<td>Lower</td>
<td>Same</td>
</tr>
<tr>
<td>NR/R Ratio</td>
<td>Pre-deck</td>
<td>Baseline</td>
<td>Same</td>
</tr>
<tr>
<td></td>
<td>Post D Check</td>
<td>Baseline</td>
<td>Same</td>
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<td></td>
<td></td>
<td>Same</td>
<td>Higher</td>
</tr>
</tbody>
</table>

- Matched expectations

- Didn’t match expectations

Trends indicate build practices and in-built modifications reduce maintenance cost.

Trends indicate a poorly implemented escalation programme.
What about “Next Generation” Aircraft

- Recall Expectation 2: **Step change** in maintenance cost between ‘old/current generation’ aircraft and ‘new/next generation’ aircraft.

There are the same 2 drivers:
- Check frequency (intervals)
- Check cost (manhour content etc)

First look at the maintenance intervals of ‘New/Next Generation’ Aircraft
Composites are being marketed as enabling maintenance cost reductions, so how has this changed over the years.

Look at the maintenance intervals of the A330 and B787.
### Case Study 2: A330 v B787 Maintenance Intervals

<table>
<thead>
<tr>
<th></th>
<th>A330</th>
<th>B787*</th>
<th>Technology Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Check:</td>
<td>800 FH</td>
<td>1000 FH</td>
<td>✓</td>
</tr>
<tr>
<td>C / BM Check:</td>
<td>24 Mths or 10000 FH</td>
<td>24 Mths or 12000 FH</td>
<td>✓/✗</td>
</tr>
<tr>
<td>Structural Check:</td>
<td>6 / 12 Years</td>
<td>6 / 12 Years</td>
<td>✗</td>
</tr>
</tbody>
</table>

Source: A330 MPD Revision 20, Issue 00, Sep 01/13
Source: B787, D011Z009-03, Jul 28/2014

* Boeing have adopted the ‘no letter check style’ MPD which allows an airline to easily customise its maintenance program to its operation. Intervals shown are an example of a particular B787 operators AMS

- **However**, to make a fair comparison the manhour content should also be considered

This is snapshot today - B787 intervals are likely to escalate beyond the A330 as service experience increases
Maintenance Cost and Step Change in ‘Technology’

- It would be nice to compare the B787 / A350 versus a ‘current generation’ aircraft, however Base Maintenance experience on the B787 is limited and is non existent on the A350

‘Step’ change in incorporation of composite technology

Source: Boeing Data = Boeing, Airbus Data = Airbus

Lets look at the A380 v B744 comparison
- Aircraft are different sizes so total manhour expenditure may vary
Case Study 3: B744 v A380

Consider a fleet of A380 aircraft in addition to the B744 fleet.

• Introduce an A380 fleet into the B744 graphs previously shown:
  o **B744 Subfleet 1a:** Aircraft delivered between 1989 and 1991 (no chk escalation)
  o **B744 Subfleet 1b:** Aircraft delivered between 1989 and 1991 (with chk escalation)
  o **B744 Subfleet 2:** Aircraft delivered between 2000 and 2003 (with chk escalation)
  o **A380:** New fleet delivered

• Plot the cumulative Routine and Non Routine manhours expended on each aircraft versus the age of the aircraft
  o This neutralises the effect of different labour rates over time
Case Study 3: B744 v A380, Cont

• Look at Cumulative Routine and Non Routine Manhours for A380

A380 manhours are ~20-25% higher than early B744s at D/C3-4 check

A380 has a similar trend to B744 but pre D/C3-4 check manhours are ~10-15% higher than early B744s

Take a closer look at Routine and Non Routine drivers separately to understand trend
Case Study 3: B744 vs A380, Cont

- Consider A380 Cumulative Routine Manhours

A380 has a similar trend to B744 but pre D/C3-4 check routine manhours are ~30% higher than early B744s.

A380 Routine manhours are ~15-20% higher than early B744s at D/C3-4 check.

We would expect smaller structural check ‘bump’ due to use of composites.
• Consider the Cumulative Non Routine Manhours

A380 Non Routine manhours are ~10-15% higher than early B744s at D/C3-4 check
A380 has a similar trend to B744 but pre D/C3-4 check Non Routine manhours are ~15% lower than early B744s

We would expect lower structural check ‘bump’ due to use of composites
Case Study 3: B744 v A380, Cont

- Consider the amount of Non Routine manhours generated by each Routine manhour

As expected, NR/R ratio for A380 is lower than B744

A380 exhibits a lower NR/R ratio up to D/C3-4 check

A380 exhibits trend similar (but lower) to late EIS B744s at D/C3-4 check

Cumulative NR/R Ratio

Aircraft Age (Years)
### Case Study 3: B744 v A380 Conclusion

<table>
<thead>
<tr>
<th>Subfleet 1a (Old EIS, no Chk Escal)</th>
<th><strong>A380</strong></th>
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</thead>
<tbody>
<tr>
<td><strong>Cumulative Routine Manhours</strong></td>
<td></td>
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<tr>
<td>Pre-deck</td>
<td>Baseline</td>
<td>?</td>
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<tr>
<td>Post D/C3-4 Check</td>
<td>Baseline</td>
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<tr>
<td><strong>Cumulative Non Routine Manhours</strong></td>
<td></td>
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<tr>
<td>Pre-deck</td>
<td>Baseline</td>
<td>Lower</td>
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<tr>
<td>Post D/C3-4 Check</td>
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<td>Lower</td>
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<tr>
<td><strong>NR/R Ratio</strong></td>
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<tr>
<td>Pre-deck</td>
<td>Baseline</td>
<td>Lower</td>
</tr>
<tr>
<td>Post D/3-4 Check</td>
<td>Baseline</td>
<td>Lower</td>
</tr>
</tbody>
</table>

- **Matched expectations**
  - NR/R trends appear to indicate that composite technology has reduced maintenance costs

- **Other Observations**
  - Routine inspections are more manpower consuming. This is largely due to access and complexity of cabin

- **Didn’t match expectations**
  - NR/R is lower but overall NR manhours are higher, again this is generally due to cabin complexity
Summary

So has technology reduced Base Maintenance Costs? ....YES.....

but.....

• Early delivery ‘new/next generation’ aircraft don’t necessarily have higher check intervals than ‘old/current generation’ aircraft
  o ‘new/next generation’ aircraft also rely the check escalation process to increase maintenance intervals
  o ‘new/next generation’ aircraft have more potential for further check escalation
  o Any benefits can be quickly reversed due to poor check content management during the check escalation process.....BEWARE!

• Improved build practices and incorporation of mods at manufacture appear to reduce Non Routine findings
  o Be careful if introducing late model aircraft into an existing older fleet – manage check content!

• Use of composites and other exotic materials appear to reduce the Non Routine findings (at least up to first structural check)
  o Routine inspections appear to take more time and/or require new (costly) equipment to complete
Some words of caution....

1. These findings may not be ‘global’
   • Results may vary between aircraft types and between airlines
     o Maintenance programme management is a key aspect of extracting ‘savings’

2. We have only looked at part of the maintenance cost picture
   • This study only looked at Airframe Base Maintenance Manpower, to complete a full analysis the following costs should also be considered:
     o Line Maintenance
     o Base Maintenance material/subcontract
     o Engine Maintenance
     o Component Maintenance
     o Spares Inventory and Tooling
     o Engineering Support
     o Ground time and dispatch reliability associated

3. Maintenance Cost is only part of the operating cost build up

Use with Caution!!
Thank You!

TBE...Capability through people...
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