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Statistical Assessment of Changes in Bird Certification Rules for Aero-Engines Through Time

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Statistical Assessment of Changes in Bird Certification Rules for Aero-Engines Through Time

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Overview

- Aim: to develop a means of assessing potential benefit of engine certification rule changes

- Fleet cycles past and future
- Bird rule changes through time
- Bird strike distribution considerations
- Monte-Carlo method → engine capability for different rules
- Fleet risk through time
- Rate of introduction of new products
- Fleet risk in the future
- Conclusions and recommendations

- Note: predictions made regarding future fleet mix are solely the judgement of the author
Increase is sustained through time and predictable
Trend seems to recover from major setbacks

Fleet Aircraft Cycles Per Year

Cycles Through Time

<table>
<thead>
<tr>
<th>Time (Years)</th>
<th>Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>0</td>
</tr>
<tr>
<td>1960</td>
<td>5000000</td>
</tr>
<tr>
<td>1970</td>
<td>10000000</td>
</tr>
<tr>
<td>1980</td>
<td>15000000</td>
</tr>
<tr>
<td>1990</td>
<td>20000000</td>
</tr>
<tr>
<td>2000</td>
<td>25000000</td>
</tr>
<tr>
<td>2010</td>
<td>30000000</td>
</tr>
<tr>
<td>2020</td>
<td>35000000</td>
</tr>
</tbody>
</table>

Events:
- 9/11: 2001
- Gulf War: 1990
- Recession: 2000
Fleet Cycles Per Year – Looking Forward

- 40 million flights per year by 2030
- Will have doubled since start of century

But what lies behind the curve?
Bird Ingestion Certification Rule History

- **Section 33.13/19** – Feb 1965
  - Original Rule
  - Small, medium, large birds defined

- **Section 33.77 A6** – Oct 1974
  - Concept of critical areas on engine introduced for large bird
  - Run-on after ingestion mandated

- **Section 33.77 A10** – Mar 1984
  - Critical areas expanded to all bird sizes

- **Section 33.76 A20** – Dec 2000
  - Medium bird increased to 2½lb
  - Ingestion at critical conditions
  - Very significant increase in capability

- **Section 33.76 A24** – Nov 2007
  - Large Flocking Bird added to address Goose population growth
**Large Birds**

- 1x4

**Large Flocking Birds**

- None

**Additional Integrity Requirement**

- None

**Medium Birds**

- 1x1
- 2x1½
- 3x1½
- 4x1½
- 1x2½+3x1½
- 1x2½+5x1½

**Inlet Area m²**

- 1x12oz
- 2x1

**Notes**

- **Large Bird**: Ingestion at 200kt and SLKPt. Safe shut-down.
- **Large Flocking Bird**: Ingestion at 200kt and average fan speed. No more than 50% thrust loss allowed and run-on for 20 minutes (different schedule to medium bird).
- **Additional Integrity Requirement**: Ingestion at critical forward speed and SLKPt. Demonstrate that engine does not lose more than 25% thrust and does not shut-down.
- **Medium Bird**: Ingestion at critical forward speed and SLKPt. No more than 25% thrust loss allowed and run-on for 20 minutes (different schedule to large flocking bird).
- **Small Bird**: One 85g bird per each fraction of 0.032m² up to a maximum of 16. Same conditions and pass/fail as for medium.
Bird Population Considerations

- 1.5lb medium bird test accounts for ~67% of bird population
- 2.5lb medium bird test accounts for ~92% of bird population
- To gain a further 1% of bird population (1.1% increase in capability) test mass \( \rightarrow \) 2.9lb – 16% increase in energy
- Law of diminishing returns applies here

![Bird Weight Distribution - FAA 1st and 2nd Surveys](image)
Monte-Carlo Technique Summary

- The Monte-Carlo technique depends on several things:
  - Description of a process (such as bird strike) mathematically
    - Weight of bird
    - Location
    - Speeds
    - Geometry of engine etc
  - Distributions describing the input parameters
  - A random number generator

- These parameters can be combined to generate in the case of Rolls-Royce an impact energy

- Repeating the process many times gives a picture of the range of impact energies that an engine is likely to see as it continues to ingest birds

- Comparing the energies to a test standard enables assessment of single/multiple engine power loss rates
Monte-Carlo Technique Output

- Table contains normalized single engine power-loss rates for categories of interest – may be used as probabilities

<table>
<thead>
<tr>
<th>Rule Year</th>
<th>Inlet Area (m^2)</th>
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<tbody>
<tr>
<td></td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>1958-1964</td>
<td>1.000</td>
</tr>
<tr>
<td>1965-1974</td>
<td>0.840</td>
</tr>
<tr>
<td>1975-1984</td>
<td>0.387</td>
</tr>
<tr>
<td>1985-2000</td>
<td>0.214</td>
</tr>
<tr>
<td>2001-2007</td>
<td>0.112</td>
</tr>
<tr>
<td>2007-2011</td>
<td>0.112</td>
</tr>
<tr>
<td>2011-????</td>
<td>0.112</td>
</tr>
</tbody>
</table>

- Note improvement in situation particularly after 2001
- These factors used with fleet cycle data to calculate risk
- Red denotes NTSB area of interest after Hudson River
Calculation Process

- The fleet historical cycles data is maintained in a spreadsheet:
  - For each aircraft/engine combination inlet size is known, 1→6
  - For each aircraft/engine combination EIS date is known, 1→7
- A standard ingestion rate of 1/5000 aircraft cycles is assumed
- A look-up table for inlet size and EIS date is used to return the appropriate engine shut-down (ESD) probability
- Thus for each aircraft/engine combination for each month the number of ESD is calculated
- Data is then summed across the entire fleet for each year to provide a total risk
- Data is then divided by number of flights per year to obtain the ‘per cycle’ evaluation
Results

- Risk calculated using the fleet cycle data in conjunction with the Monte-Carlo generated power-loss rates
- Rule change dates annotated at date of incorporation
Observations

- As of 2011 the general trend in risk is downward
  - Due in part to much older engines being retired
  - Due in part to engines designed to more recent rules being introduced

- This means that we are yet to see full benefit for rule changes already made
  - i.e. it takes many years for the full benefit of rules to be seen
  - New products are not introduced immediately there is a rule change

- Introducing new rules does not introduce step changes in risk level
  - i.e. the curve is smoothly transitioning
Looking Forward

- In order to assess future trends, need three pieces of information
  - Rate at which new aircraft are introduced
  - Which aircraft are likely to be retired
  - Which engine sizes will be required for replacement aircraft

- Assumed 25% of fleet will have been replaced by 2030; of which, 5% very large, 10% corporate, 10% regional
Risk Prediction for Next Two Decades

- Prediction performed for 3 main cases:
  1. Old aircraft retire; replaced with existing fleet mix
  2. Old aircraft retire; replaced with 2007 certificated products
  3. Old aircraft retire; replaced with 2011 certificated products
Observations

- Over the next 20 years the risk curve begins to asymptote.
- This is a function of:
  - Increased number of fleet cycles year on year
  - A greater proportion of the fleet being certificated to the same rule standard
- The degree of improvement for a rule change is very small:
  - This effect will be more marked as yearly fleet cycles increase i.e. it becomes more difficult to achieve a significant fleet percentage for new products
- The effect of any rule change is not seen for ~20 years after it is made:
  - This effect will be more marked as yearly fleet cycles increase as above
Conclusions

- A method has been developed to enable numerate assessment of risk for different scenarios.

- The results show that a change in engine certification bird rules will not deliver a significant risk reduction in the short to medium term.
  - More timely measures must therefore take priority.

- Risk is a product of engine robustness and number of strikes per aircraft cycle – engine robustness is clearly levelling out.
  - The more effective risk reducer must be to reduce the number of strikes.

- Product safety remains the number 1 priority within Rolls-Royce; the rule assessment process is properly supported.