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

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Overview

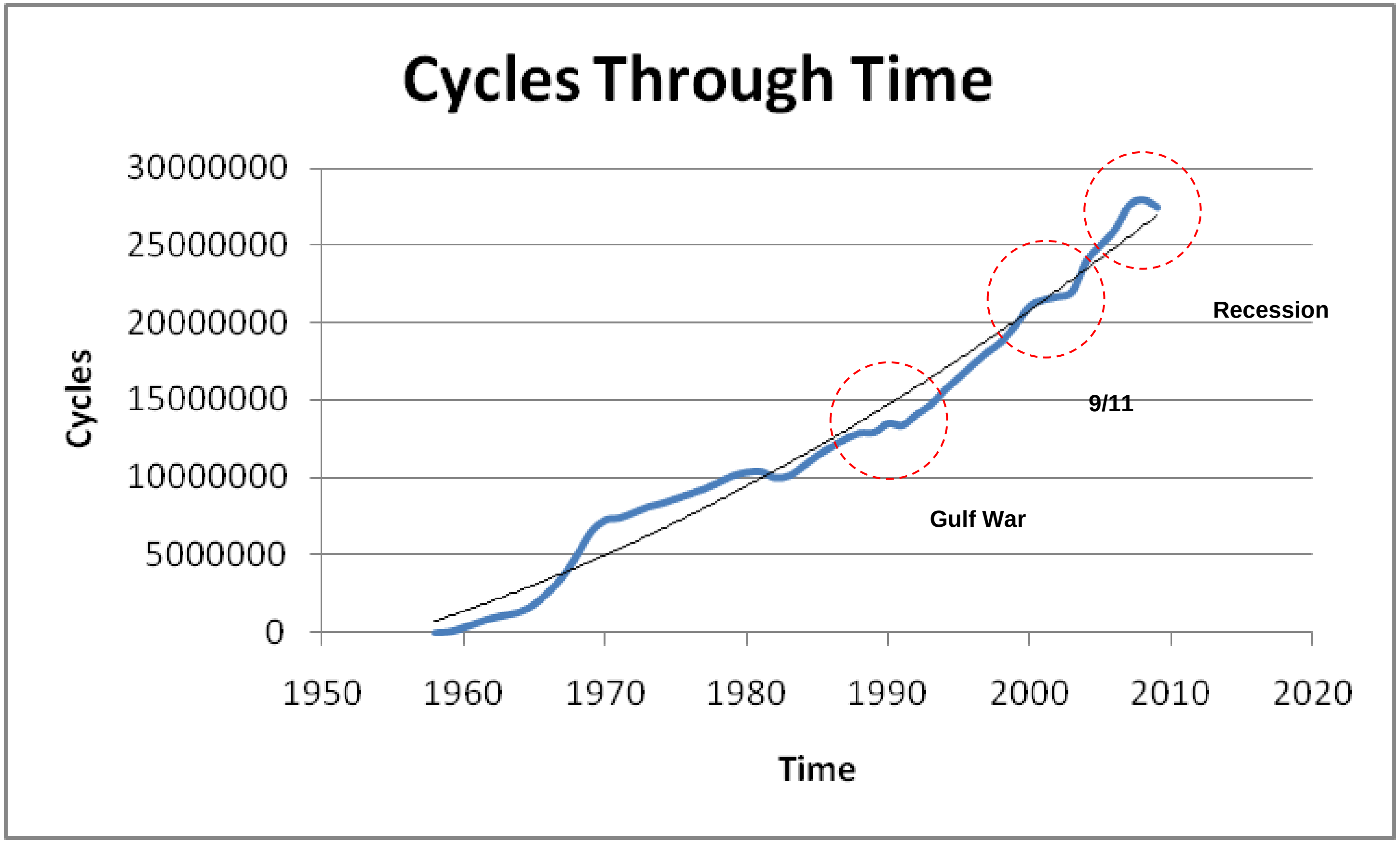
- Aim: to develop a means of assessing potential benefit of engine certification rule changes

- 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

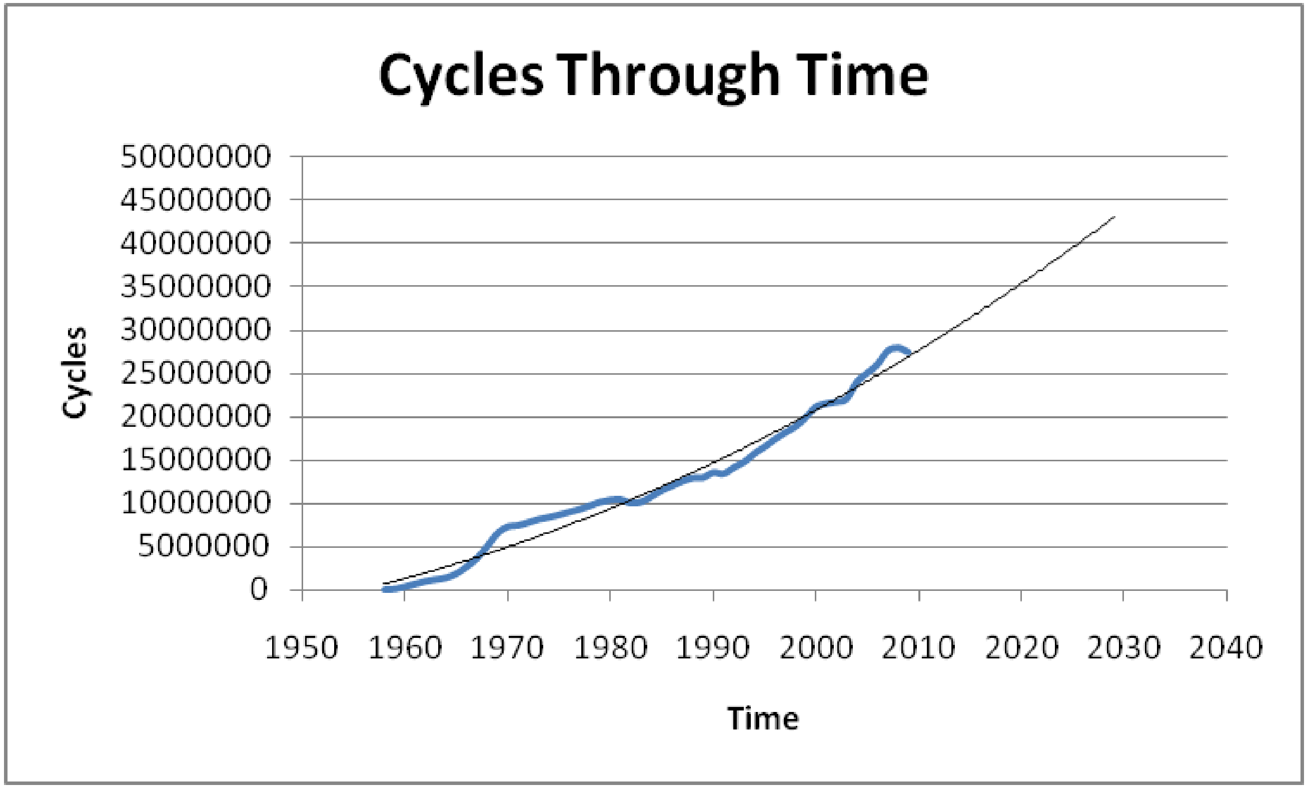
Fleet Aircraft Cycles Per Year

- Increase is sustained through time and predictable
- Trend seems to recover from major setbacks



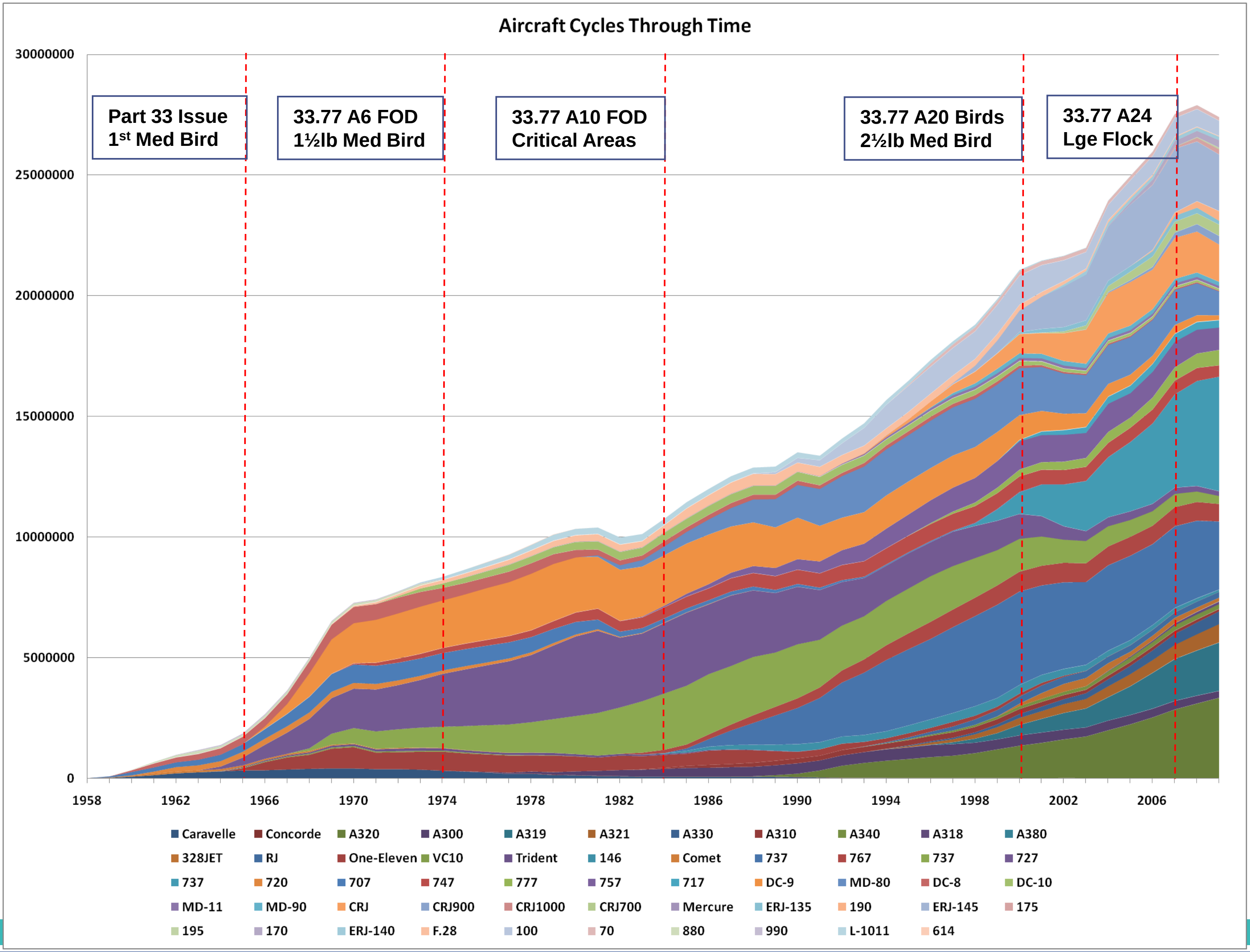
Fleet Cycles Per Year – Looking Forward

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



- **But what lies behind the curve?**

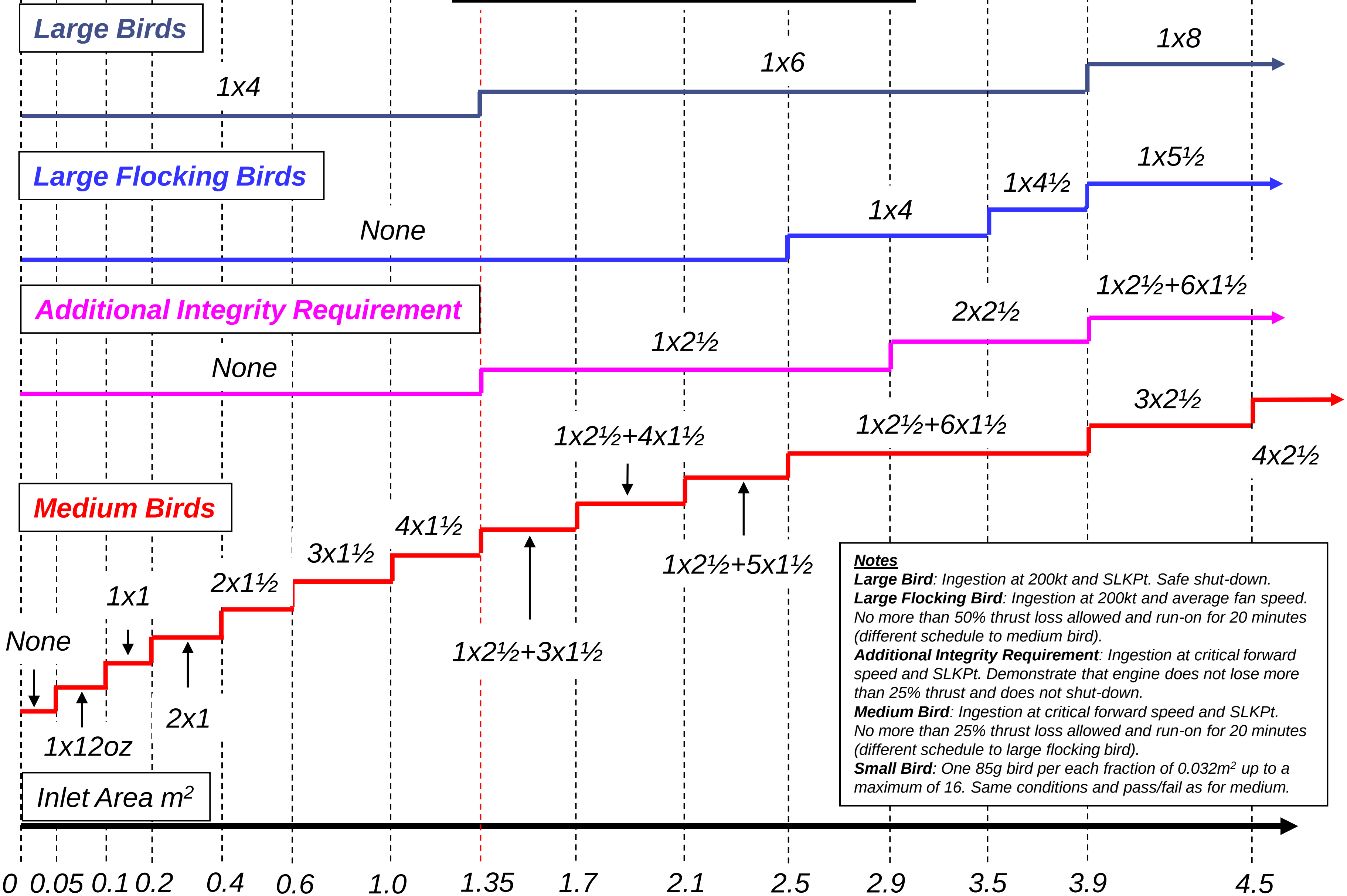
Fleet Cycles Makeup – Data from ASCEND



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**

2011 Bird Regulation Summary Chart – lb

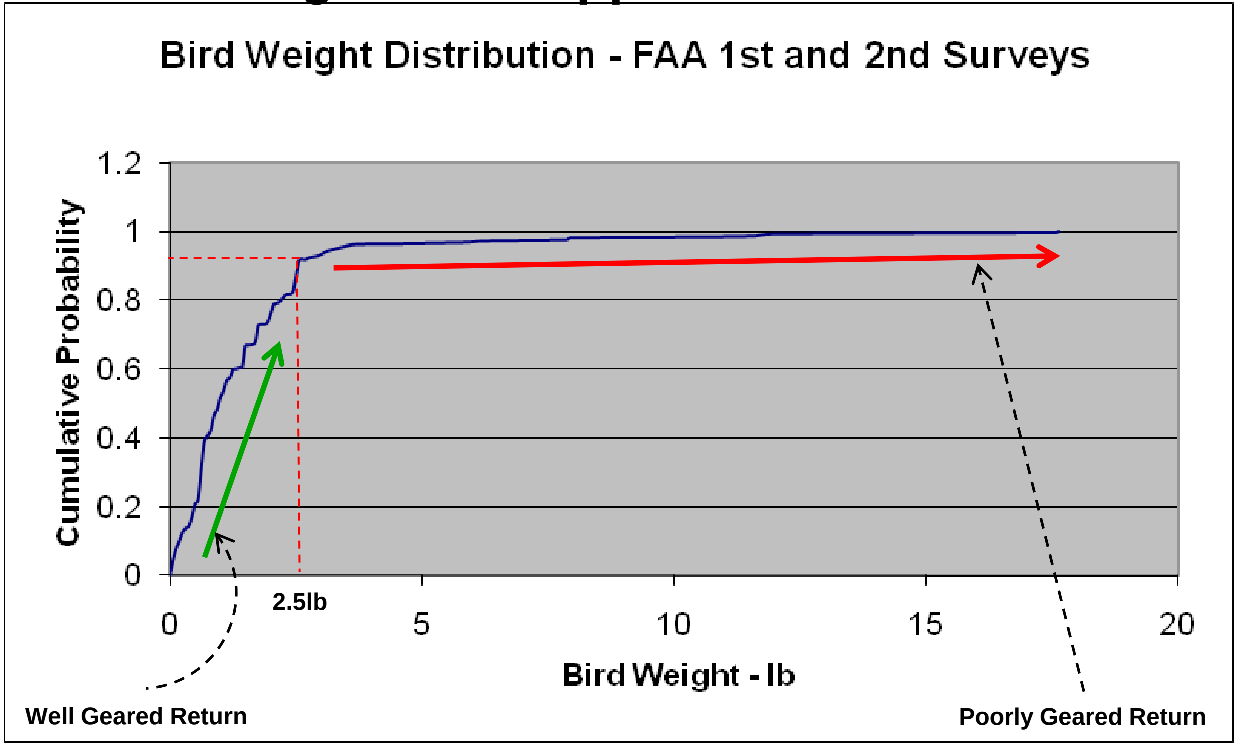


Notes

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.*

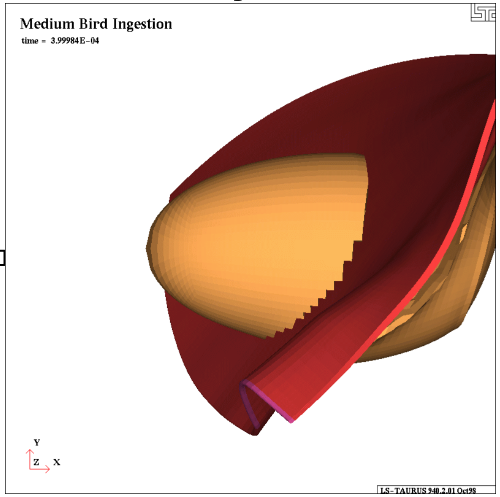
Bird Population Considerations

- **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 →2.9lb – 16% increase in energy**
- **Law of diminishing returns applies here**



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**

		Inlet Area (m^2) ▶					
		<1.0	1.0-1.35	1.35-2.5	2.5-3.5	3.5-3.9	>3.9
Rule Year ▼	1958-1964	1.000	1.000				
	1965-1974	0.840	0.840			0.855	0.656
	1975-1984	0.387	0.387	0.224	0.224	0.429	0.332
	1985-2000	0.214	0.214	0.082	0.082	0.272	0.170
	2001-2007	0.112	0.112	0.042	0.042	0.077	0.037
	2007-2011	0.112	0.112	0.042	0.040	0.062	0.027
	2011-????	0.112	0.112	**0.042**	0.040	0.062	0.027

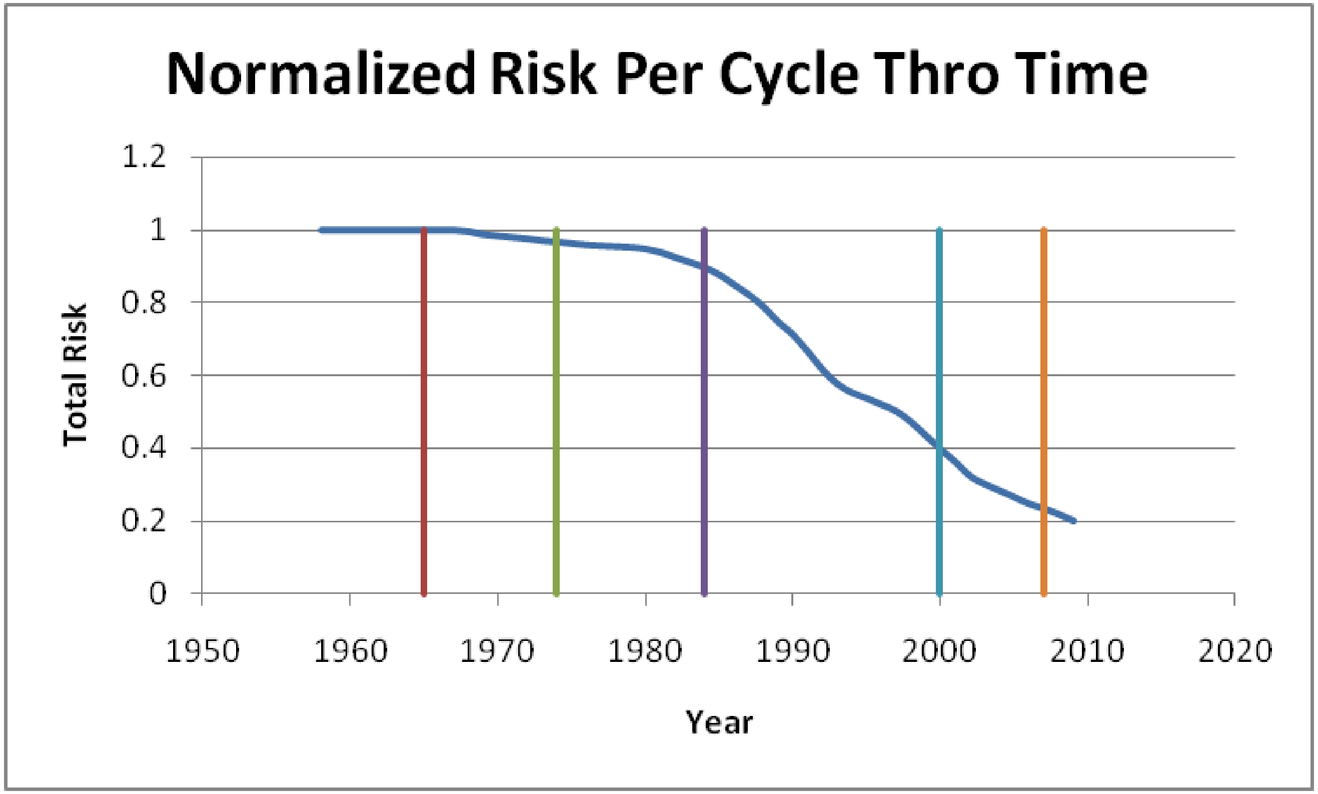
- **Note improvement in situation particularly after 2001**
- **These factors used with fleet cycle data to calculate risk**
- **Red denotes NTSB area of interest after Hudson River**

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

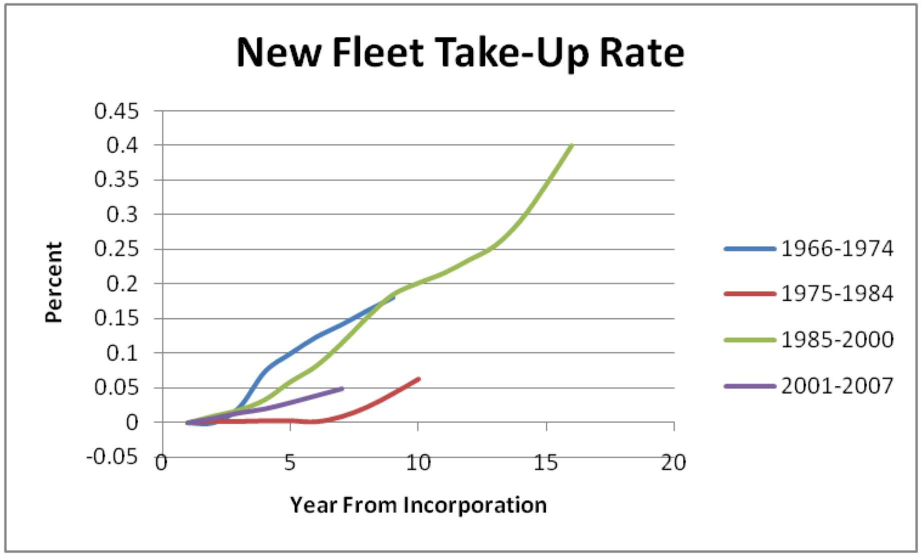


Observations

- 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

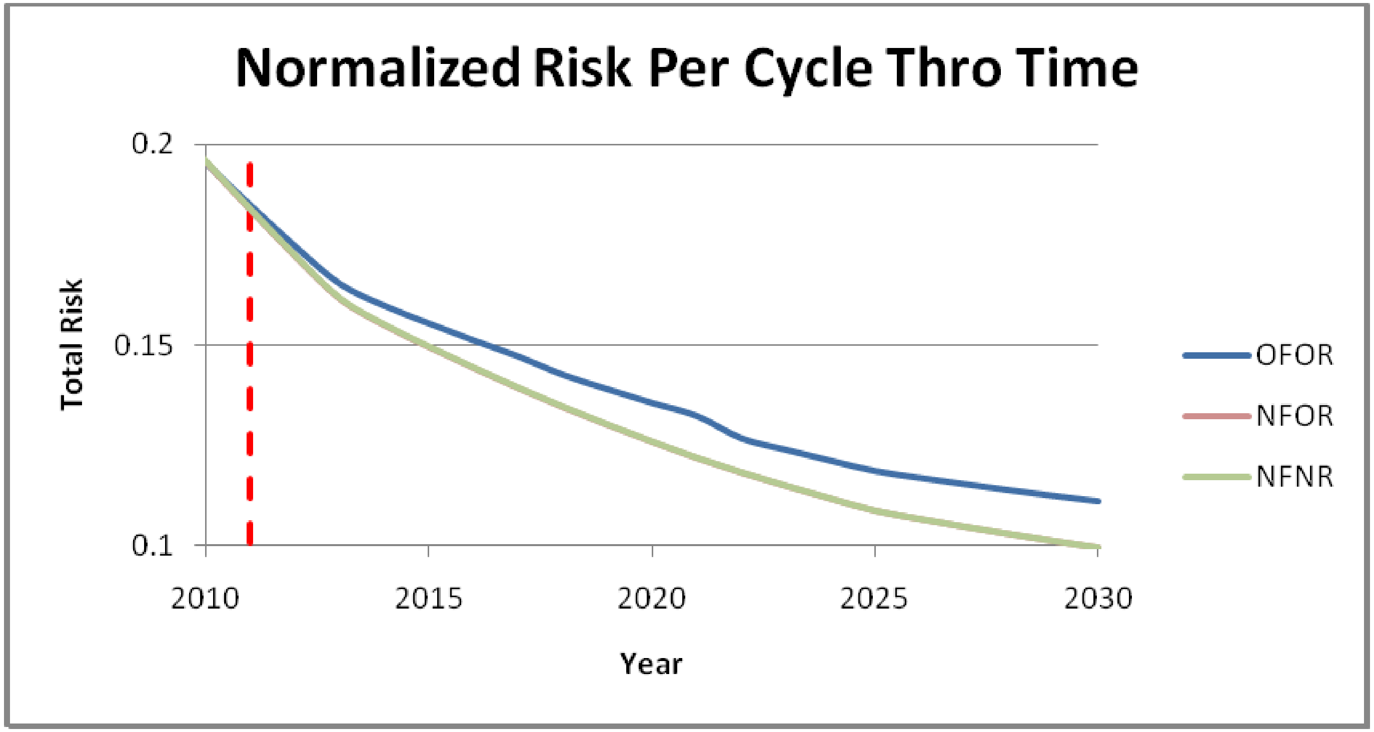
- **In order to assess future trends, need three pieces of information**
  - **Rate at which new aircraft are introduced**
  - **Which aircraft are likely to be retired**
  - **Which engine sizes will be required for replacement aircraft**



- **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 assymptote
- 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**