



# Rolls-Royce

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

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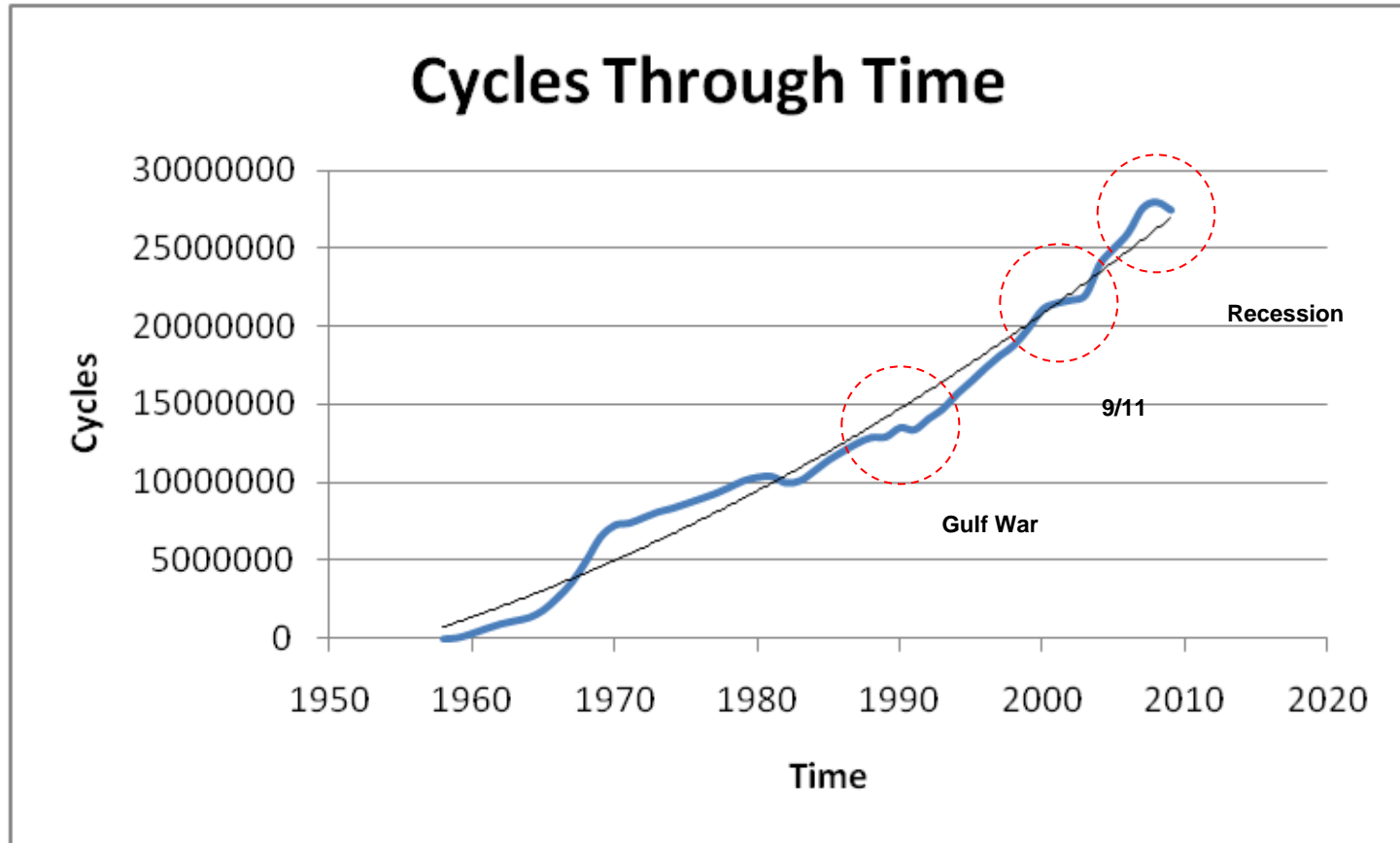
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# Overview

- **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**

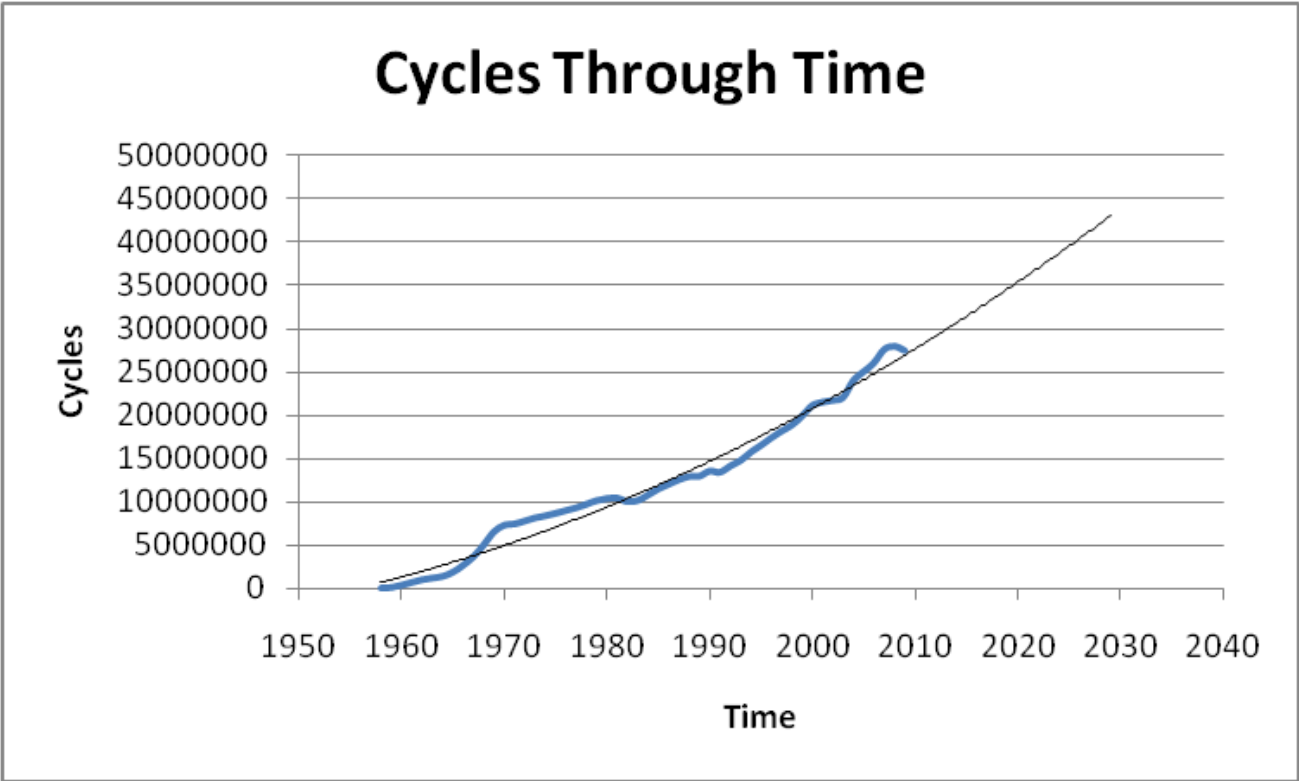
# Fleet Aircraft Cycles Per Year

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



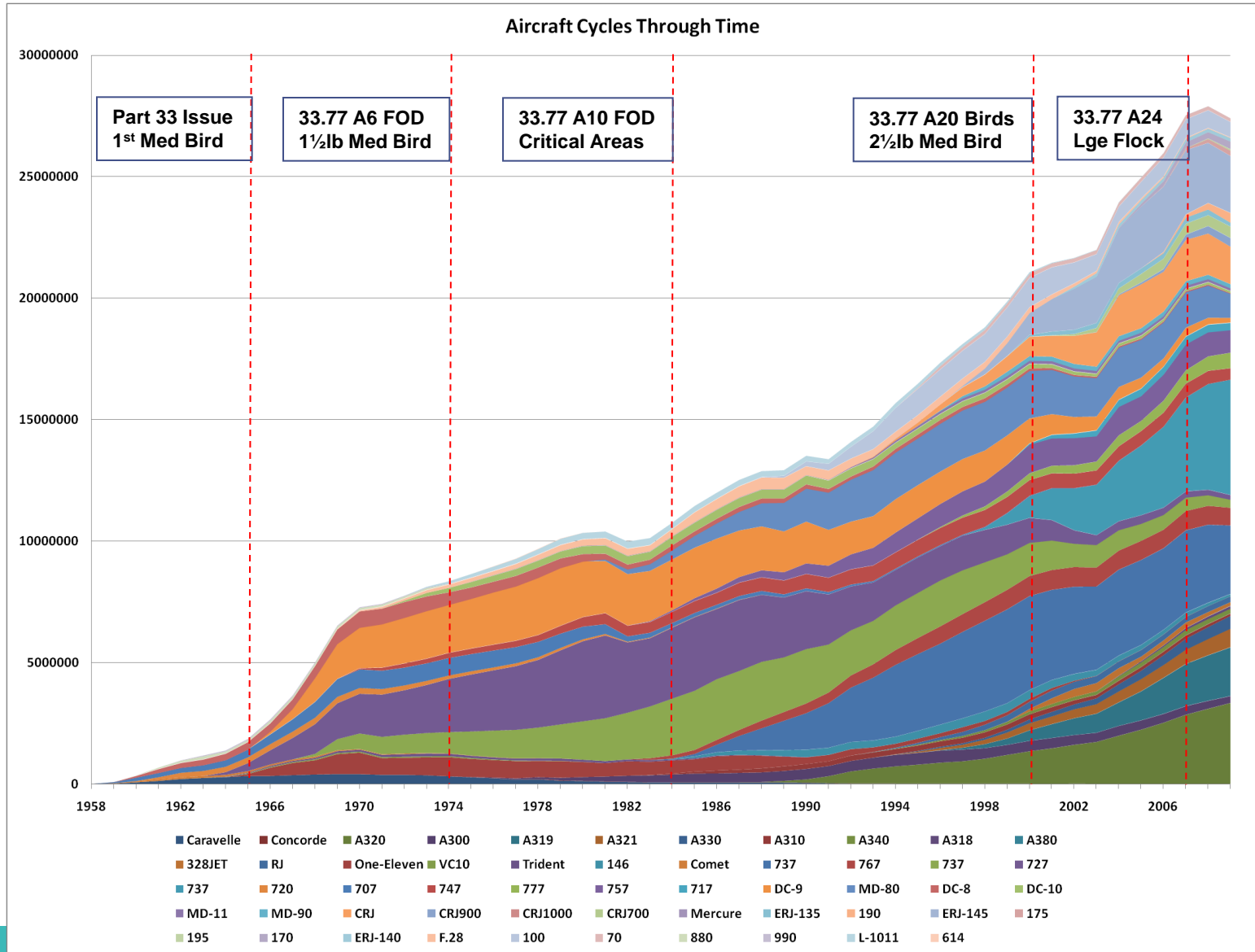
# Fleet Cycles Per Year – Looking Forward

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



- But what lies behind the curve?

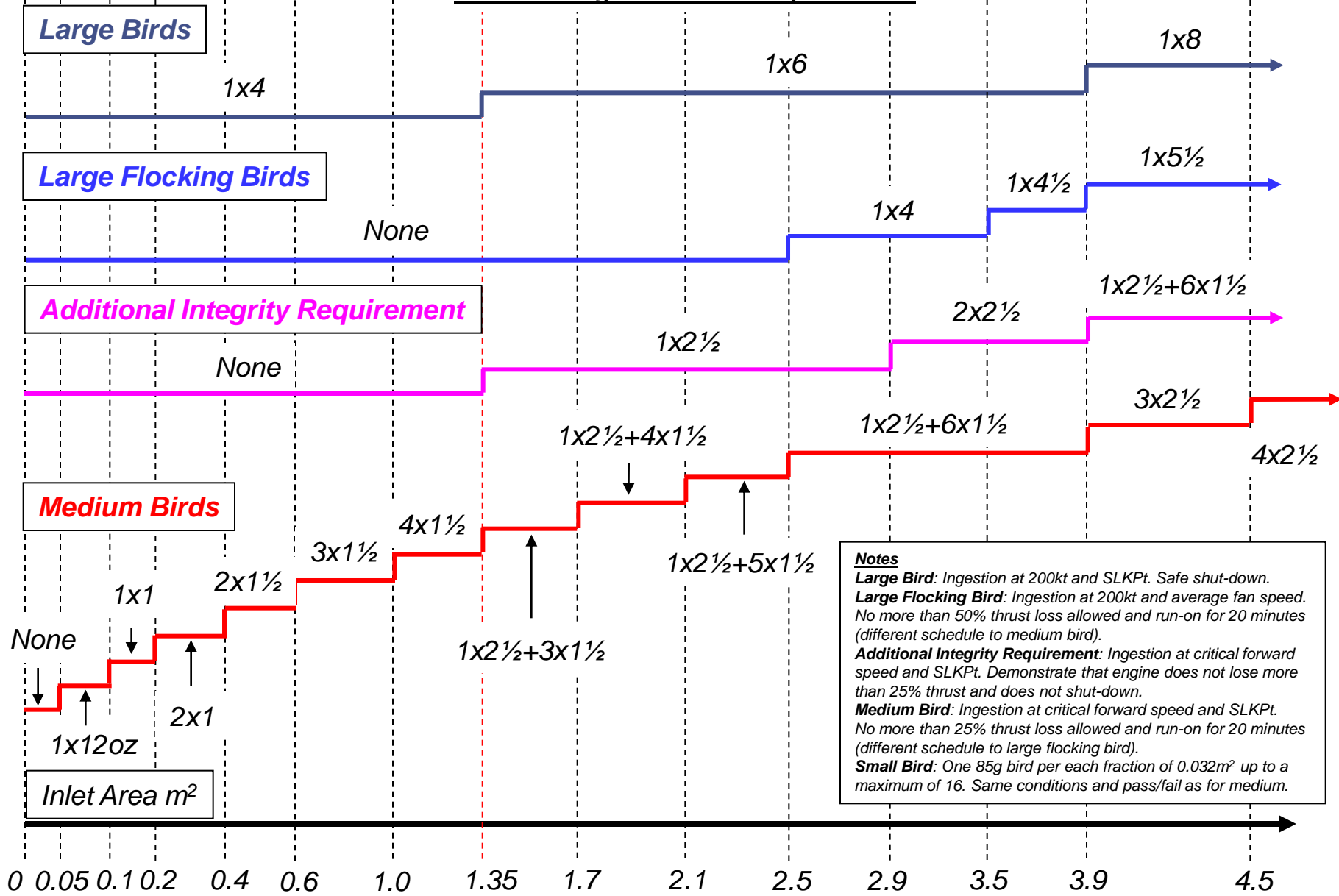
# Fleet Cycles Makeup – Data from ASCEND



# 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

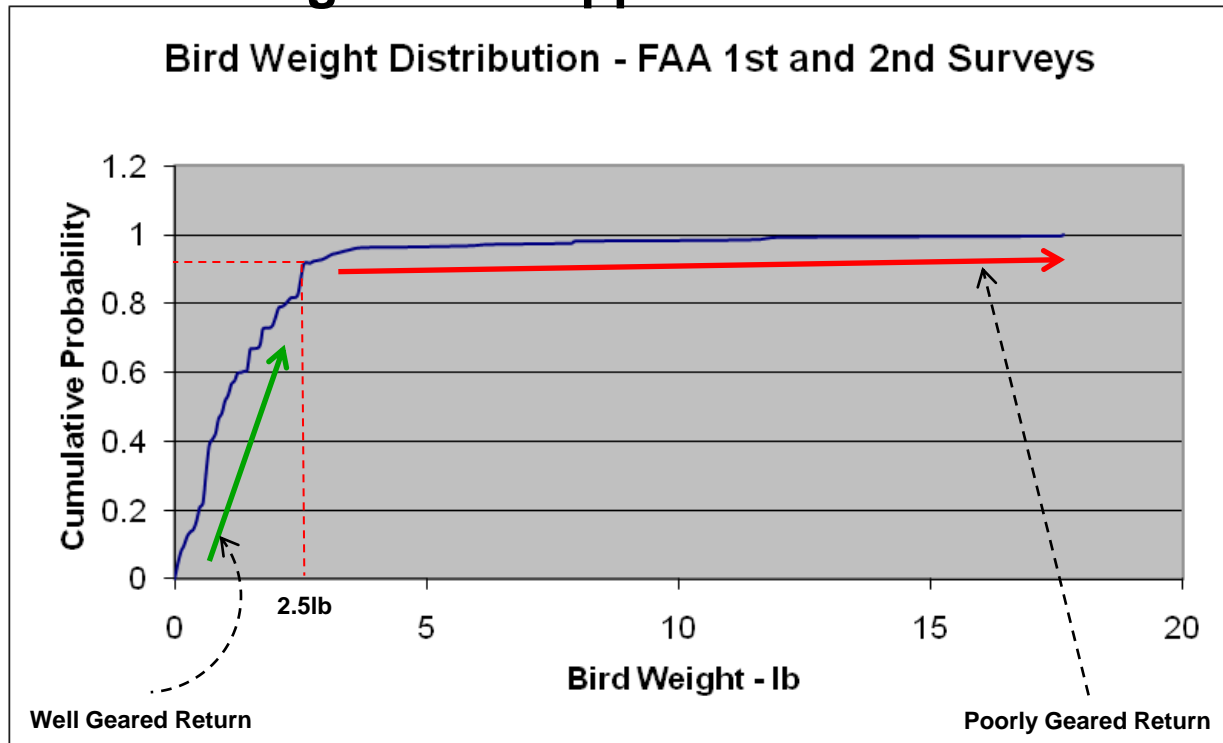


**Notes**  
**Large Bird:** Ingestion at 200kt and SLKPt. Safe shut-down.  
**Large Flocking Bird:** Ingestion at 200kt and average fan speed. No more than 50% thrust loss allowed and run-on for 20 minutes (different schedule to medium bird).  
**Additional Integrity Requirement:** Ingestion at critical 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.



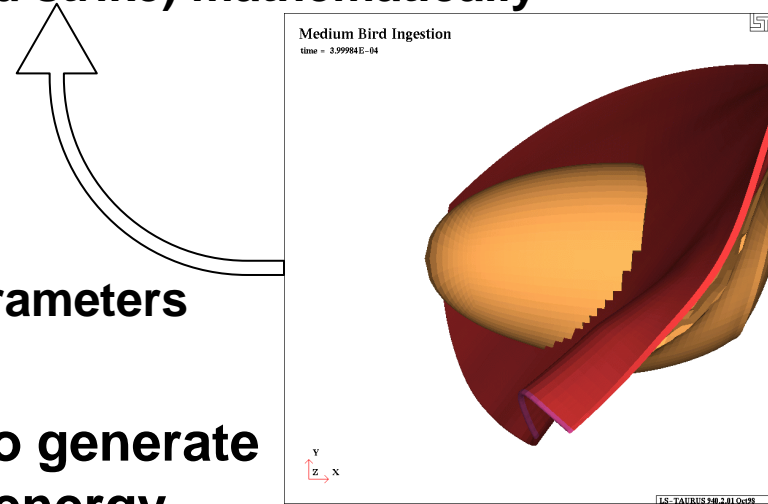
# Bird Population Considerations

- 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 <sup>2</sup> ) ▶					
		<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	<b>0.042</b>	0.040	0.062	0.027

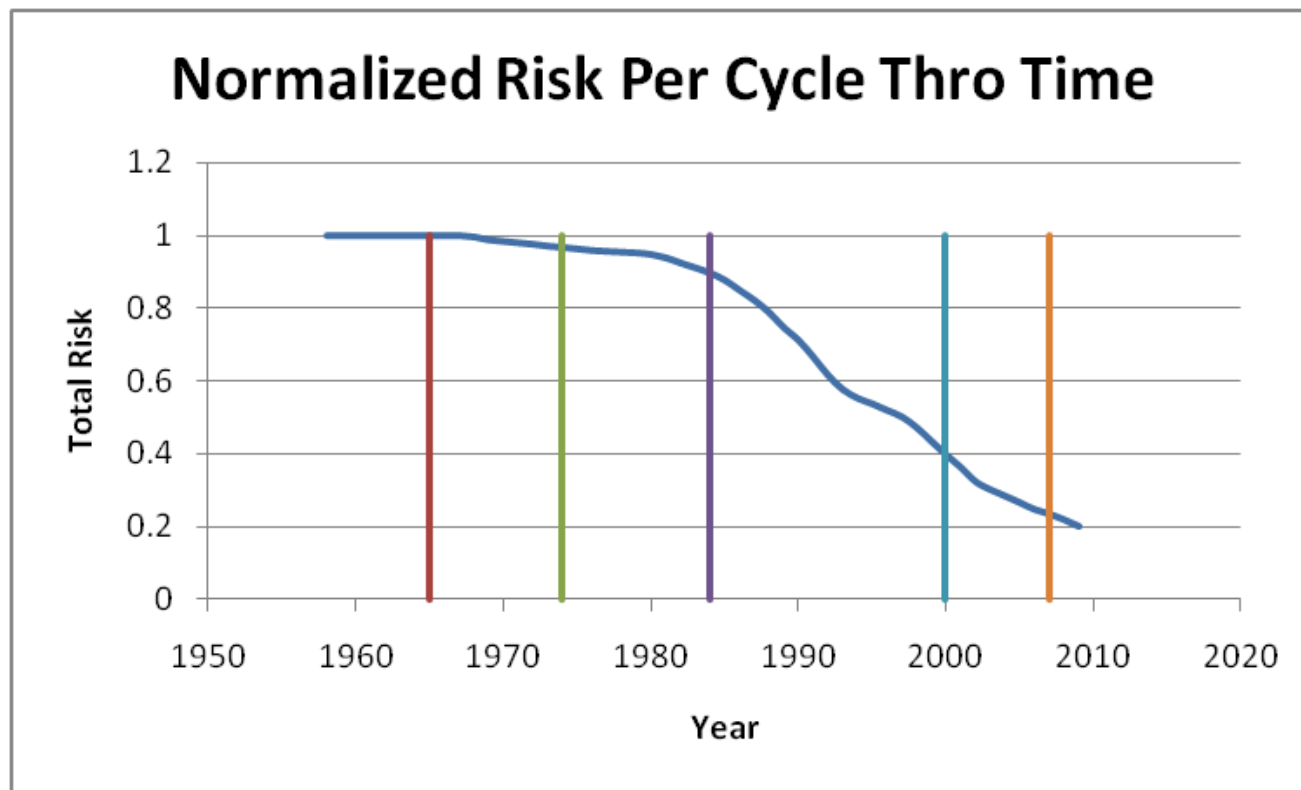
- Note improvement in situation particularly after 2001
- These factors used with fleet cycle data to calculate risk
- Red denotes NTSB area of interest after Hudson River

# 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

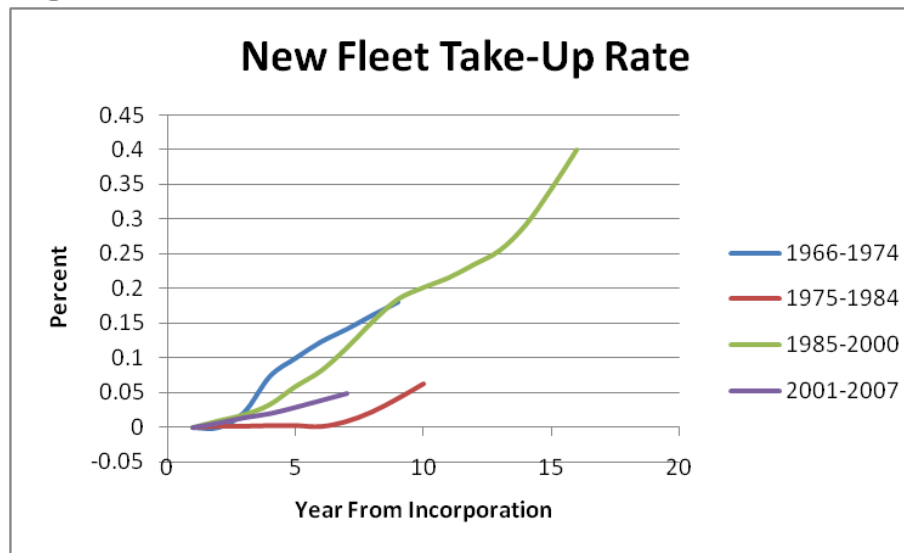


# Observations

- **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

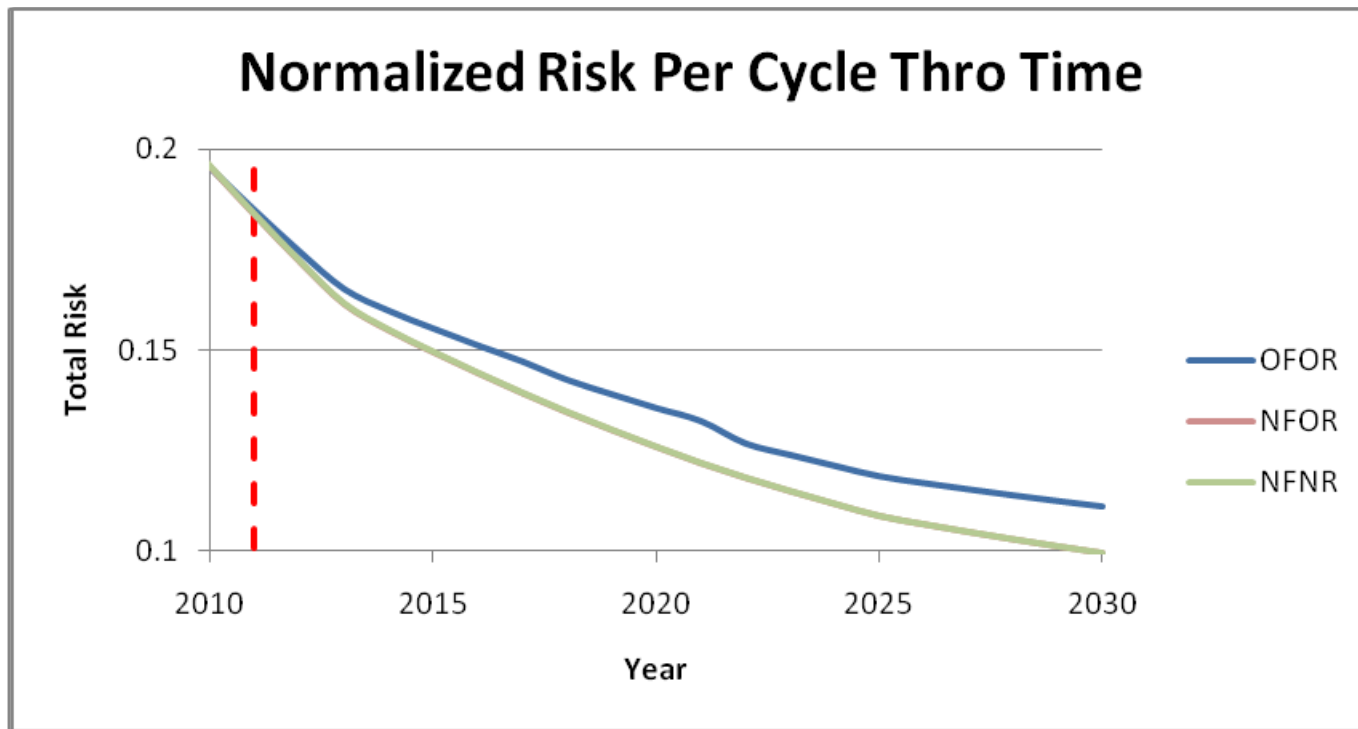
- In order to assess future trends, need three pieces of information
  - | Rate at which new aircraft are introduced
  - | Which aircraft are likely to be retired
  - | Which engine sizes will be required for replacement aircraft



- 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 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**