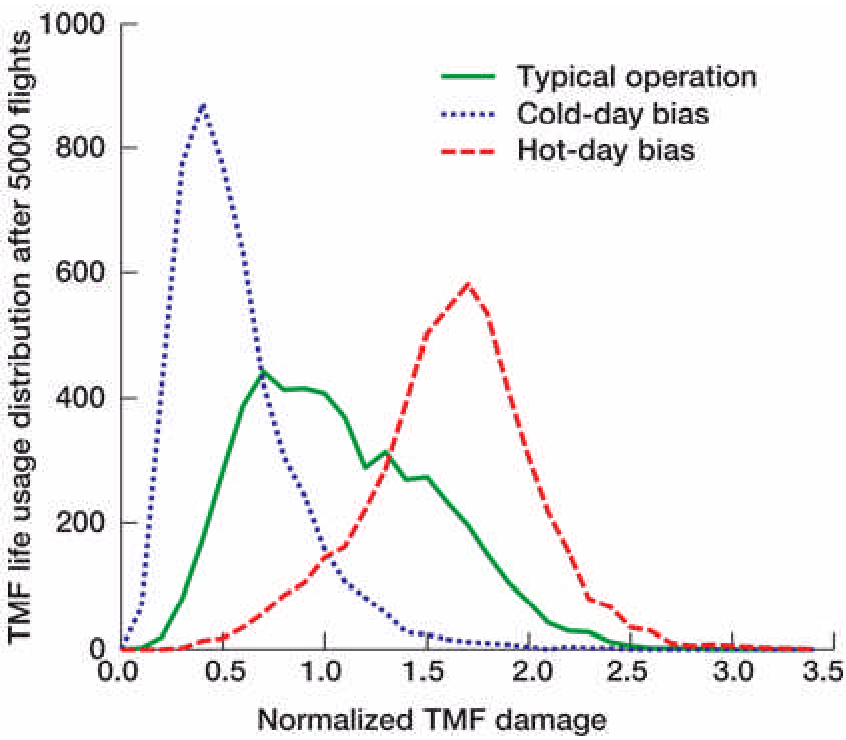
Probabilistic Study Conducted on Sensor-Based Engine Life Calculation

Turbine engine life management is a very complicated process to ensure the safe operation of an engine subjected to complex usage. The challenge of life management is to find a reasonable compromise between the safe operation and the maximum usage of critical parts to reduce maintenance costs. The commonly used "cycle count" approach does not take the engine operation conditions into account, and it oversimplifies the calculation of the life usage. Because of the shortcomings, many engine components are regularly pulled for maintenance before their usable life is over. And, if an engine has been running regularly under more severe conditions, components might not be taken out of service before they exceed their designed risk of failure.

The NASA Glenn Research Center and its industrial and academic partners have been using measurable parameters to improve engine life estimation. This study was based on the Monte Carlo simulation of 5000 typical flights under various operating conditions. First a closed-loop engine model was developed to simulate the engine operation across the mission profile and a thermomechanical fatigue (TMF) damage model was used to calculate the actual damage during takeoff, where the maximum TMF accumulates. Next, a Weibull distribution was used to estimate the implied probability of failure for a given accumulated cycle count. Monte Carlo simulations were then employed to find the profiles of the TMF damage under different operating assumptions including parameter uncertainties. Finally, probabilities of failure for different operating conditions were analyzed to demonstrate the importance of a sensor-based damage calculation in order to better manage the risk of failure and on-wing life.

		ENGINE OPERATING CONDITIONS			
Case	**System parameter uncertainties**	**Change from ambient temperature (standard deviation), °F**	**Airport elevation, ft**	**Number of equivalent standard flights after 500 flights**	**Probability of failure after 5000 flights, percent**
Deposit point	None	0	0	5000	0.01
Normal operation	Yes	Normal (30)	Uniform, 0 to 1000	5501	.0148
Hot-day-biased	Yes	Bias = 30 (20)	Uniform, 0 to 1000	7892	.062
Cold-day-biased	Yes	Bias = -30 (20)	Uniform, 0 to 1000	3172	.0016

The table compares the different study cases. In the typical usage study, where system uncer-tainties, as well as different ambient temperatures and altitudes, were considered, the average risk of failure was 48-percent higher than the design point. In the hot-day-biased case, the ambient temperatures were consistently higher than for the standard condition. The 5000 simulated flights were actually equivalent to 7892 standard flights. This has a corresponding risk of failure of 0.062 percent, or 6.2 times the original value. An engine operated under these extreme conditions should be taken out of service much sooner than the nominal 5000 cycles if the same risk of failure is to be maintained. On the other hand, in the cold-day-biased case, much less engine life was consumed, and the risk of failure at the 5000 flight point was only a fraction of the original designed value. An engine operated at this condition could be allowed to extend its on-wing service life without any safety concerns. The graph shows the TMF life usage distribution of 5000 flights based on the Monte Carlo simulation for normal, hot-day, and cold-day operation. In conclusion, this study clearly shows the necessity of sensor-based life monitoring in order to avoid the high risk of failure when an engine is operated under severe conditions, or to do unnecessary maintenance on the engine when the engine is still safe statistically.



TMF damage distribution for different operating conditions.

This TMF damage histogram for normal operation has a roughly normal distributed curve centered at 1, and most data points fall between 0.3 and 2.4. During hot-day-biased operation, the curve shifted to the right and centered at about 1.7, and most data points fell between 0.4 and 2.7. During cold-day-biased operation, the curve shifted to the left and peaked at 0.4, and most data points fell between 0.1 and 1.7.

Bibliography

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