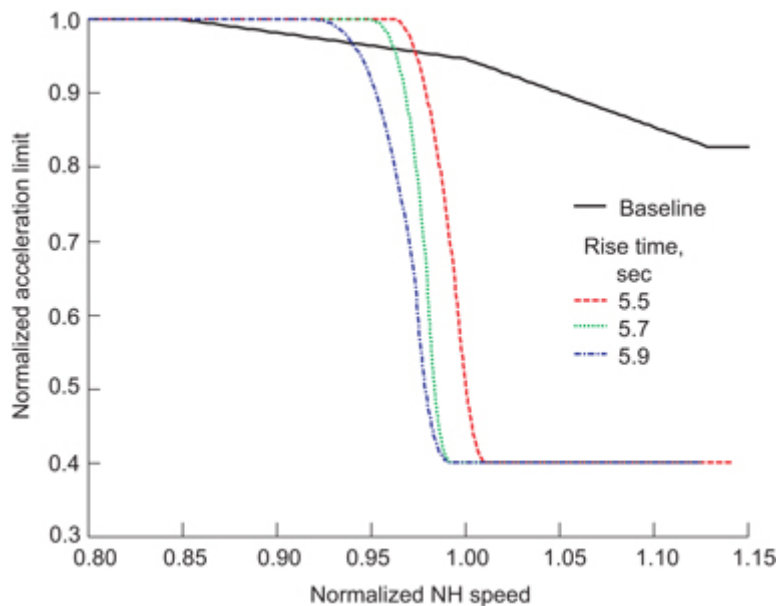


Intelligent Life-Extending Controls for Aircraft Engines Studied

Current aircraft engine controllers are designed and operated to provide desired performance and stability margins. Except for the hard limits for extreme conditions, engine controllers do not usually take engine component life into consideration during the controller design and operation. The end result is that aircraft pilots regularly operate engines under unnecessarily harsh conditions to strive for optimum performance. The NASA Glenn Research Center and its industrial and academic partners have been working together toward an intelligent control concept that will include engine life as part of the controller design criteria. This research includes the study of the relationship between control action and engine component life as well as the design of an intelligent control algorithm to provide proper tradeoffs between performance and engine life. This approach is expected to maintain operating safety while minimizing overall operating costs.

In this study, the thermomechanical fatigue (TMF) of a critical component was selected to demonstrate how an intelligent engine control algorithm can significantly extend engine life with only a very small sacrifice in performance. An intelligent engine control scheme based on modifying the high-pressure spool speed (NH) was proposed to reduce TMF damage from ground idle to takeoff. The NH acceleration schedule was optimized to minimize the TMF damage for a given rise-time constraint, which represents the performance requirement. The intelligent engine control scheme was used to simulate a commercial short-haul aircraft engine.

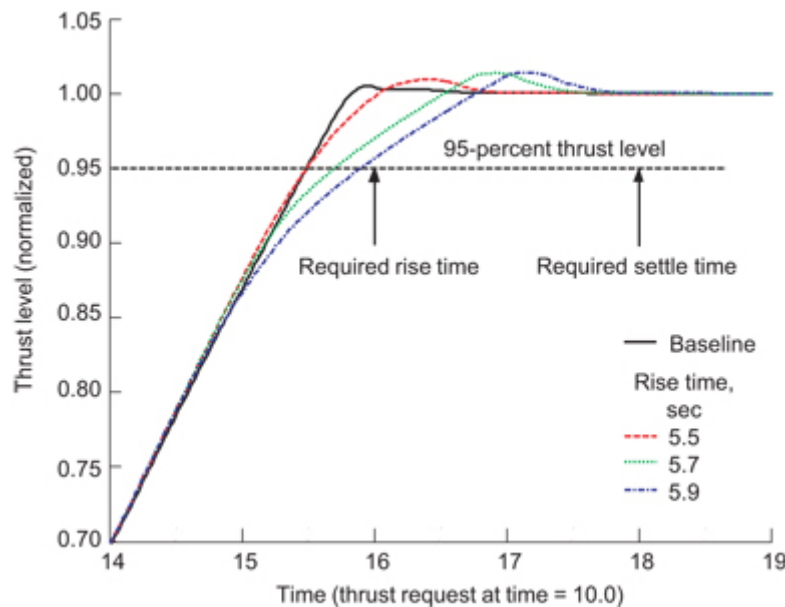


Optimized acceleration schedule (normalized).

Long description of figure Graph of the normalized acceleration limit versus the normalized NH speed, comparing the three optimum schedules for rise times of 5.5, 5.7, and 5.9 seconds, respectively, and the original schedule.

The preceding graph compares the optimum schedules for rise times of 5.5, 5.7, and 5.9 sec with the original schedule. These acceleration schedules provide the best results in minimizing the TMF damage for specified rise time requirements. They suggest that the controller should continue the maximum acceleration of NH beyond the designed 85 percent, and take a sharper cut in the acceleration to reduce the maximum strain at the peak temperature. This acceleration schedule strategy will keep the rise time relatively constant while reducing the maximum temperature difference (ΔT) between the airfoil and the stator endwall.

The following graph shows the thrust response curves of the selected optimized acceleration schedules during the takeoff acceleration process. It can be seen that the optimized thrust curves are kept at a slower acceleration rate when the full power level is being approached. Although the overshoots are about the same in all cases, the maximum metal temperatures are all reduced in the optimized cases in comparison to the baseline. The slow acceleration helps to reduce the maximum temperature difference between the stator airfoil and the endwall.



Response curves for different optimized schedules.

Long description of figure Graph of the normalized thrust level versus time, showing thrust response curves of the selected optimized acceleration schedules during the takeoff acceleration process.

The table shows the simulation results of the optimized schedule in terms of its impact on engine life. The results show that the new control schedules can reduce the maximum metal temperature as well as the difference in temperature between the airfoil and endwall of the cooled stator. In comparison to the baseline case, an optimized acceleration schedule can reduce the TMF damage of the selected component by 34

percent for standard flight conditions while keeping the rise time unchanged. This translates to about 52 percent more flights before the removal of the component from service.

The table shows that the TMF damage can be reduced even more if the engine is allowed to incur a small delay in thrust rise time. The tradeoffs between rise time and TMF damage can be significant. By allowing the rise time to increase from 5.5 to 5.9 sec, the usable engine life can be more than doubled with the optimized schedule over that with the nominal schedule. This result is important for engine controller design philosophy because it may prompt the reevaluation of engine performance requirements to account for overall operating costs.

| OPTIMIZED THERMOMECHANICAL FATIGUE DAMAGE VERSUS RISE TIME | | | | |
|---|--|---|-------------------------------|-------------------------------|
| Rise time | Maximum metal temperature (difference from baseline), T_{metal}, °F | Maximum change in temperature (difference from baseline), ΔT_{max}, °F | TMF reduction, percent | Life extension percent |
| 5.50 | Baseline | Baseline | ---- | ---- |
| 5.50 | -16 | -30 | 34 | 52 |
| 5.60 | -16 | -44 | 46 | 85 |
| 5.70 | -16 | -50 | 51 | 104 |
| 5.80 | -16 | -59 | 56 | 127 |
| 5.90 | -16 | -65 | 58 | 138 |

The research results depend heavily on the fidelity of the engine operation model, thermal model, and life model. Further research in these areas is important for successful transition of the intelligent life-extending control approach to operating aircraft engines.

Bibliography

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Find out more about this research at <http://www.grc.nasa.gov/WWW/cdtb/>

Glenn contact: Dr. Ten-Huei Guo, 216-433-3734, Ten-Huei.Guo-1@nasa.gov

Author: Dr. Ten-Huei Guo

Headquarters program office: Aeronautics Research
Programs/Projects: CICT