AN INVESTIGATION OF LIFE EXTENDING CONTROL TECHNIQUES FOR GAS TURBINE ENGINES

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Abstract

The consumption of engine life characterized by low EGT margin, expended life-limited parts, and slow engine accelerations is the principal cause of aircraft engine removal. Life extending control results from a conscious effort on the part of control system designers to extend the life of an engine by modifying control logic or control hardware to influence one or more of these life-consuming factors.

General Electric Aircraft Engines and NASA Glenn Research Center are currently engaged in a collaborative research program to investigate control technologies applicable to extending on-wing life of aircraft engines. A trade study of potential schemes that may have a positive impact on engine life has been performed, and the results of this study are used to narrow the focus of further research under this program.

1 Introduction

The principal cause of aircraft engine removal is consumption of engine life characterized by low EGT margin, expended life-limited parts (LLP) due to low cycle fatigue (LCF), and slow engine accelerations. EGT margin loss is due primarily to hot section deterioration, while the primary contributors to engine LLP life consumption are high rotor speeds, high peak temperatures, and extended time at temperature (exposure). Slow engine accels can be the result of various deterioration effects. Life extending control (LEC) results from a conscious effort on the part of control system designers to extend the life of an engine by modifying control logic or control hardware to influence one or more of these life-consuming factors. General Electric Aircraft Engines (GEAE) and NASA Glenn Research Center are currently engaged in a collaborative research program to investigate control technologies applicable to extending on-wing life of aircraft engines.

The joint NASA-GEAE Life Extending Control effort has the overall goal of extending the on-wing life of aircraft engines using advanced control techniques. The Phase I program, covered in this paper, was a trade study of various control schemes that may have a positive impact on engine life. Phase I was not a search for solutions; rather, it was desired to establish a framework for investigating life extending control techniques and to narrow the scope of further investigation under a Phase II program.

2 Quality Function Deployment

A quality function deployment (QFD) process is a tool for distilling expert opinion into a quantitative ranking system. Several possible activities or processes may be considered for their perceived impact on multiple evaluation factors. The QFD method accommodates complex or qualitative evaluations in addition to any available quantitative appraisals. It is used to identify means for achievement (potential LEC schemes) based on means of measurement (metrics), and it highlights trades between conflicting properties.

A cross-functional discussion resulted in a list of potential technologies and the metrics for evaluating those technologies, presented in Table 1.

Table 1. LEC Technologies and Metrics

Technologies	<u>Metrics</u>
Smart Accel/Decel Logic Modulated Cooling/Heating Modulated Bleed	Blade Life Rotor Life Implementation Cost Maturity Technology Gap Payoff – Extended Time on Wing Payoff – SFC Payoff – Thrust-to-Weight
Active Clearance Control Pattern Factor Control Control Schedule Optimization	

Smart accel/decel logic was the highest-ranked purely software technology, and improved active clearance control was the highest ranked software/hardware technology.

While many technologies were studied under this program, this paper will focus on the accel/decel studies and the improved active clearance control studies, due to their high QFD ranking and the interest by NASA and GEAE.

3 Smart Accel/Decel Studies

Studies were conducted to assess the impact of control schedule modifications on LCF engine life. Engine life is limited in part by material fatigue that is caused by the normal, cyclic operation of the engine. Stresses that are inflicted by rotational and thermal effects limit the life of rotating parts, and individual locations are evaluated to determine impact of engine usage on those locations. This study was motivated by the idea that modifying the control

scheme (i.e., reshaping acceleration and deceleration profiles, etc.) might have an impact on the mechanical and thermal stresses in the rotating parts, favorably impacting LCF life.

A large commercial engine model was selected for this study, and GEAE's high-fidelity engine simulation environment, the cycle workstation (CWS), was used to generate engine parameters needed for life evaluation. In this environment, it is possible to edit the FADEC control algorithms and demonstrate modified engine behavior for a user-specified flight profile. The flight profile can include realistic throttle movements and altitude, Mach number, and temperature variations. The CWS model is used to compute the response of the engine to these changing conditions. The output of CWS is then sent to a life management tool to compute the thermal and mechanical stresses at various locations on the rotating parts. The computed stresses and temperatures are then used to calculate the cyclic life values at the individual locations for that particular mission.

The nominal control was evaluated for a standard mission flight profile, then multiple alternate control modes were evaluated. One alternate control mode imposed a severe limit on the rate-of-change of core speed during the engine acceleration. An example of engine behavior while under this control mode is shown in Figure 1. Another alternate control mode imposed an upper limit on the rate-of-change of EGT for temperatures above a set value. This had the effect of changing the engine characteristics only at higher power settings.

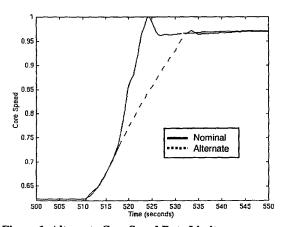


Figure 1. Alternate Core Speed Rate Limiter

In both cases mentioned above, the impact of the alternate control modes on LCF life at life-limiting locations (those with the lowest LCF life values) was not significant. It should also be noted that these example control modifications are extreme cases; such substantial increases in accel and decel times would not be tolerated in actual engine operation.

4 Enhanced Active Clearance Control

Active clearance control (ACC) systems² have become an integral part of modern commercial gas turbine aircraft engines. They are used to improve performance and lower SFC, thereby lowering turbine operating temperatures and extending engine life accordingly. The spacing, or clearance, between the blade tips on a rotating component and the case or shroud encircling the component directly affects gas turbine performance and efficiency. Engine clearances change during operation of the engine and over the life of the engine, and vary depending on rotor speeds. temperatures, and deterioration. Active clearance control (ACC) is an attempt to improve engine efficiency (thereby improving SFC, reducing temperatures, extending life, etc.) by manipulating the transient and steady state clearances during operation.

Improving the ACC system may allow for benefit by compensating for deterioration or by improving nominal control with increased control authority. Both cases are considered below. Blade tips and shrouds wear over time due mainly to rubs when clearances are too tight. As the engine thus deteriorates, EGT increases, which accelerates the gas path deterioration process. New engines are shipped with a certain amount of cold clearance, and as the engine is used, this cold clearance may increase substantially before the first overhaul. It is suspected that the majority of this wear occurs early in the engine life and that it is due to a series of discrete events (severe takeoffs and rotations, hard landings, etc.). A rule-of-thumb equates 1 mil of clearance to 1°C takeoff EGT margin. 10 mils of clearance (or 10°C EGT), for example, can be worth a significant amount in terms of on-wing life. This represents the potential improvement in life (in terms of takeoff EGT margin) if the deterioration could be compensated for by the ACC system. There is a further economic benefit as well. At cruise, 1 mil of clearance is worth as much as .1% SFC, so 10 mils of reduced clearance is worth approximately 1% SFC.

5 Conclusions

Trade studies have been conducted to assess the potential impact of various controls technologies on gas turbine engine life, and the results of these studies are being used to focus future LEC research activities. A Phase II GEAE/NASA program in the area of enhanced active clearance control is currently being planned.

References

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- Beitler, R.S., et al. <u>Fuel Conservation through Active Control</u> of Rotor Clearances. AIAA-80-1087. 1980.