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Accelerated Mission Testing of Gas Turbine Engines

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Commercial and military aircraft engines are designed to meet specific usage requirements. In the past, verification of these designs was based on the successful completion of a "model" endurance test. The "model" test was a yardstick-type test and was not specifically designed to simulate actual usage. Flight experience has shown that this type of qualification testing is not representative of real usage. Today, new development engines are being tested to accelerated mission test cycles. These test cycles are designed to include all significant engine excursions and time at high power conditions in a representative fashion. The philosophy and methodology of mission-related testing of gas turbine engines are presented.

Introduction

THE renewed emphasis in lowering life cycle cost of both current and upcoming Air Force systems has prompted a more in-depth look into engine development, i.e., design, test, and usage. The approach taken in integrating these three facets of engine development resulted in the formulation of a mission-related test. This test could then be used throughout the development cycle for substantiation and verification of the structural durability of engine components. The transition from past to present philosophy in relationship to engine development can best be portrayed through the history of the Air Force's weapon systems.

Background

In the past, gas turbine engine qualification consisted primarily of the successful completion of either a 150- or 300-h qualification or "model" test, similar to that shown in Fig. 1. Upon demonstrating the capability to adequately complete this test, the engine would be certified for the mission—be it fighter, bomber, or cargo—regardless of differences which exist among the missions. The limitations of this kind of endurance testing were noted by the inability to relate test results directly to field usage. Also, structurally related problems were encountered in the field which had not been observed in the factory testing.

The shortcomings of this "model" testing approach to engine qualification prompted the development of a test which would not only provide good correlation to operational usage but would also reveal potential field problems on the test stand before they became serious problems in operation. Thus, this led to the development of Accelerated Mission Testing (AMT) as we know it today.

Philosophy

Various interpretations of AMT exist. However, the formal definition as defined by the Air Force is "An engine test conducted in a ground test facility in which the test profile bears a direct relationship to mission usage. The profile accounts for all significant throttle excursions and time at high power that would typically be seen in a composite operational mission."

The key points which should be emphasized are 1) that AMT directly relates to field usage and 2) that it accounts for the major throttle excursions and time at high power. Since AMT is primarily a structural durability oriented test, the need for maintaining a direct relationship to field usage is essential. The major throttle excursions drive the low cycle and thermal fatigue failure modes. Engine power excursions provide the failure inducing agents in the fluctuating loads produced by the centrifugal and thermal transients. The engine high power or "hot" time contributes to the creep, stress rupture, and erosion-type failure phenomenon. In this case, the failure inducing agent is a combination of the temperature and stress imposed by the high power condition. These mechanisms or modes constitute some of the major failures encountered in gas turbine engines today.

Therefore, AMT can be considered a useful tool in addressing three major areas of concern. First, the AMT program addresses safety so that potential field problems are recognized and corrected on the test stand before they manifest themselves in the operational fleet. Next, AMT reduces costs, since attention can be directed to areas requiring redesign early in the testing stage, often negating the need to retrofit the fleet. Thirdly, AMT addresses system readiness as problems are solved early in the engine development cycle. It seems clear that through the use of AMT, a very useful as well as a more effective system is possible.

Methodology

It is first necessary to explain the underlying concepts and stages of development associated with accelerated mission testing. The major intent of AMT is to reveal potential field problems/distress on a representative mission basis. Therefore, knowledge of how the system is to be used is of paramount importance to the development of a successful AMT test plan. The test cycle can be no better than the information used in its generation. User projections, usage surveys, or actual flight-recorded data are used to analyze the particular system usage. This constitutes the first stage of AMT development. Consideration has to be given to all aspects of engine usage, i.e., flight, test cell, trim, and ground operation. The flight sector of the total planned usage should be examined in terms of individual missions. The effects of inlet conditions for various operating points on engine structural hardware has to be factored into each mission

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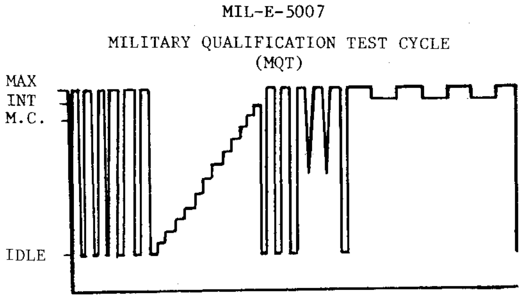

Fig. 1 Gas turbine engine substantiation test.

segment. The second stage of AMT development involves the combination of these distinct usage bands or profiles utilizing the mission mix and trim/test cell records. The result is a composite mission or set of missions, representing average mission usage. The third, and probably most important, stage of cycle development consists of eliminating the nondamaging or insignificant portions of the composite mission profile resulting in an accelerated mission test on total operating time. The part power dwell or hold times and the minor power excursions represent the insignificant parts of the test. The relative damages of these portions of the test are typically determined through analysis. Rather than treating each occurrence separately, the rate of occurrence of the minor damaging conditions are included in the analysis for an understanding of the total damage induced. Certain operating conditions influencing the damage may require simulation. This can be accomplished by either running the engine in an altitude facility or by modifying the engine's power extractions to approximate more closely the operating conditions required. Figure 2 graphically represents the three steps of development as described.

Benefits and Limitations of AMT

Accelerated Mission Testing addresses both a large portion of the total failures (Fig. 3) as they relate to engine structural durability and a significant portion of the gas turbine engine structural components. Some of the simulated primary failure modes through AMT are low cycle fatigue, erosion, creep, stress rupture, thermal shock, and some types of wear related distress. Figure 4 shows the regions of the engine (encircled) that AMT adequately addresses.

There are certain areas which AMT does not completely address. One such area is high cycle fatigue (HCF). In deriving the accelerated mission tests, part power dwell times which contribute to HCF related problems are eliminated. Both the Air Force's TF34-100 and F100 engine testing programs have incorporated a stairstep or linear deceleration at the end of their test cycles in order to "run out" any HCF related phenomenon. Thus, HCF can be adequately addressed with the slight penalty of a small increment of additional test time. Another area which AMT cannot totally simulate is bearing and accessory component damage. The component lives are primarily a function of total operating time. Due to the nature of this type of test, i.e., that of accelerating on total operating time, adequate simulation of the damage cannot be expected. It should be noted that bearing distress is also a function of maneuver loads encountered in flight, which cannot be simulated through a ground test. Elaborate techniques[1] have been employed to account for the loads induced in actual operation. In addition, separate tests (i.e., bench tests) are commonly required for accessory and control component verifications.

The question of whether or not sufficient benefit can be derived from running a one-to-one (real-time) test to simulate mission usage is often posed.[2] From the points previously discussed, little additional benefits would be expected from running a real-time test as compared to an accelerated mission test. Component distress relating only to total operating time at a particular part power setting would be simulated by real-time testing. It warrants mentioning that real-time testing would induce the additional damage of the minor power excursions eliminated from AMT. Whether these benefits outweigh the additional test time and cost associated with real-time testing is questionable judging from the results[3] thus far obtained in AMT.

Table 1 Accelerated mission test status

System	Engine	Accelerated mission test	Acceleration factor (equiv oper time/test time)
A-10	TF34-100	Simulated Service Test (SST IIA)	2.
A-7	TF-41	Simulated Accelerated Flight Endurance (SAFE)	2.
F-15	F100	AMT II	3.1
F-16	F100	AMT III	2.9
F-5E	J85-21	LCF Endurance Test	2.0
B-1	F101	AMT	10.
F-111	TF30	AMT	2.3

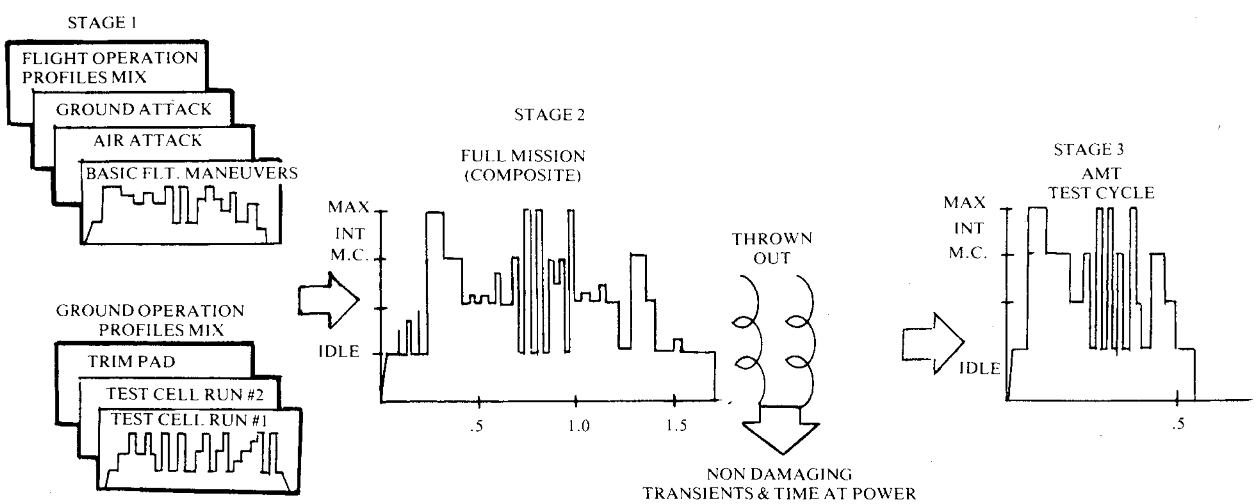

Fig. 2 Three stages of AMT cycle derivation.

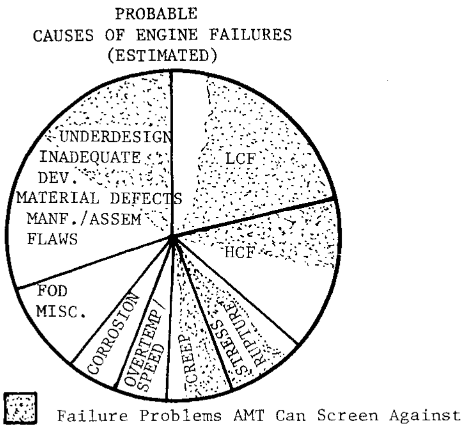

Fig. 3 Engine component failure modes.

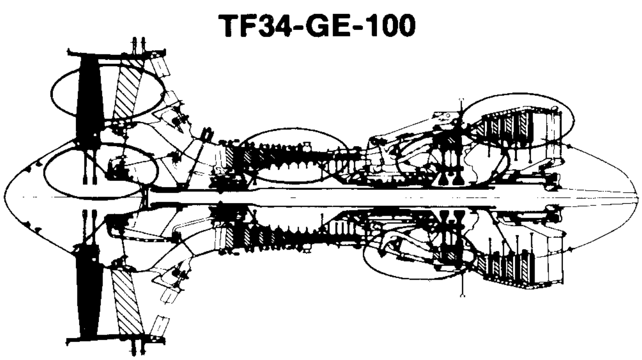

Fig. 4 Areas of engine that AMT addresses.

AMT Program Status

Although a brief reference was made to two Air Force systems utilizing an AMT approach to gas turbine engine structural durability qualification/verification, they are by no means the only such systems. Table 1 summarizes the rather impressive list of current Air Force systems employing some type of AMT. As noted, the various systems have acronyms associated with their respective accelerated test cycles. The standardization of the terminology for these tests has resulted in all accelerated operational tests being referred to as AMT.

Summary

The major intent of this paper has been to present the rationale for using AMT rather than a "model" or real-time test in engine development today. The major justification for the use of AMT is that it does provide good correlation to field usage related distress. Potential field problem areas have been identified and fixes defined early in program development through the use of AMT. AMT has been shown to be an effective tool for design substantiation as it relates to structural durability. This approach to testing has also proven useful in substantiating or verifying redesign components for areas revealed as requiring improvement. AMT is currently being used to establish and update overhaul limits for both field and depot level maintenance. There are limitations associated with this type of testing. The data sample is small, thus, engine-to-engine variability cannot be adequately addressed. AMT cannot completely address performance degradation. Also, AMT does not provide a total answer to engine structural durability due to the stochastic nature of engine component life and the synergistic effects between the simulatable and nonsimulatable damage mechanisms. In addition, all real-time environmental effects are not duplicated by AMT. As a result of the inability to simulate/duplicate all operational conditions, a definite requirement exists for maintaining a "lead the force" program. Additional tests and analyses should also serve to supplement the AMT and fleet leader programs. Finally, AMT needs to be updated continually. Changes in the mission mix or the way in which a particular mission is flown can dramatically affect the life of an engine's components.

References

[1]Swain, R.L. and Mitchell, J.G., "Simulation of Turbine Engine Operational Loads," *Journal of Aircraft*, Vol. 15, June 1978, pp. 381-382.

[2]Cote, S., "Propulsion System Duty Cycle: The Navy's New Look," AIAA Paper 77-883, AIAA/SAE 13th Propulsion Conference, Orlando, Fla., July 11-13, 1977.

[3]Sammons, J. and Ogg, J.S., "Using Accelerated Mission Testing as a Tool Within the F100 Engine CIP Program," AIAA Paper 78-1085, AIAA/SAE 14th Joint Propulsion Conference, Las Vegas, Nev., July 25-27, 1978.