

# Introduction

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Fatigue is one of the most common of the failure mechanisms of gas turbine engine components. Both the cool parts and hot parts are susceptible to this mode of failure, and the origin may be either mechanical or thermal.

The importance of fatigue as a limiting factor in jet engine reliability was brought out clearly in a study conducted some time ago by the NACA (the forerunner of the NASA). This study was made in the middle 1950's (Ref 1) on military jet engines, using statistics obtained from Air Force overhaul bases as a framework for the analysis. All the major components studied—bearings, compressor blades, combustors, turbine nozzle vanes and buckets, and turbine disks were, to a serious extent, life limited, because of fatigue problems. Some of the problems encountered were due to the high performance demanded of the engines by the military requirements; others were due to the fact that the jet engine was then in its early formative years and experience was limited. However, the major reason for the prevalence of the fatigue problem relates to the very nature of the service to which jet engine components are subjected. High fluctuating loads, high temperatures and temperature gradients, frequent starts and stops, stress concentrations resulting from complex geometrical shapes and from surface discontinuities produced by service conditions—all contribute to making the components fatigue-prone. Add to this the fact that light weight and high performance provide the strongest of motivations in gas turbine design and service, and it becomes clear that fatigue will continue to be an important limitation in the life of gas turbine engines.

The NACA study (Ref 1), it is true, related to gas turbine engines of early design in which information now available could not be incorporated. Also, in military engines, performance comes first; cost of overhaul and frequent part replacement is accepted as an appropriate price to pay for the high performance sought. It might be properly asked whether the picture has not changed in the intervening years, and whether trade-offs between performance and life cannot be suitably made in commercial gas turbines for both stationary and aircraft use. To a limited extent the answer to both of these questions is affirmative. Much research has been conducted in the intervening years since the NACA study was made, and this information can be well used to increase fatigue life of com-

<sup>1</sup> National Aeronautics and Space Administration Lewis Center Staff, "Factors that Affect Operational Reliability of Turbojet Engines," NASA TR R-54, 1960.

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ponent parts. Furthermore, the trade-off constants are reasonably well known; increase in life for a reduction in temperature can be reasonably determined. But performance is still a magic incentive, and engines for high-speed flight count more than ever on high temperature and operating efficiency. Furthermore, turbines are becoming more complex; cooled turbine buckets require intricate passages that produce stress concentration while still requiring the material to operate at the limit of its capability in regard to both temperature and temperature gradient. There seems little likelihood that fatigue, as an important failure mechanism, will go away on account of reduction in severity of service or the availability of better materials.

If fatigue is really to be combatted, it must be met forthrightly and dealt with thorough knowledge. The mechanisms involved must be understood, and these mechanisms must then provide the guidance for methods of avoidance or mitigation. The survey contained in this Special Technical Publication has been prepared with such an objective in mind. Following an expression of urgent need expressed by members of the Joint Committee on the Effect of Temperature on the Properties of Metals, it was decided to prepare a "state-of-the-art" survey on fatigue of gas turbine components. Such a survey could well serve as a framework for future research on this subject. It seemed appropriate to include the following:

### 1. *Basic Mechanisms of Fatigue in the Sub-Creep Range*

Since many components of gas turbines operate at moderately low temperatures, the mechanism of fatigue in this temperature range must be defined. Furthermore, the mechanisms at the lower temperatures would act as a baseline for superimposing further effects needed to understand the fatigue mechanisms at higher temperatures.

### 2. *Basic Mechanisms of Fatigue in the Creep-Range*

Many components, such as nozzle guide vanes, turbine buckets, and combustion liners operate at temperatures wherein creep becomes an important, if not the dominating, mechanism. It is conventional to define the temperature at which creep starts to become important as half the absolute melting temperature. At this temperature, and above, new mechanisms can affect the fatigue life. Thus, it is important to define these mechanisms and show their relation to fatigue life.

### 3. *Detection of Fatigue Damage*

Fatigue manifests itself as damage in many ways, ranging from minor misorientation of atoms to gross cracking. An extensive literature already exists on fatigue damage detection wherein the part or specimen involved must be metal-

lurgically sectioned or in some way invalidated for further useful service. Nondestructive techniques have recently been greatly expanded and improved for fatigue detection after the damage has proceeded to a considerable extent. Nondestructive techniques also have been developed for observing flaws, such as inclusions, that are likely to become nuclei for fatigue failure. The most advanced and successful of these techniques should be collated and evaluated.

#### *4. Study of Field Practices for Repair of Fatigue Damage*

Only an actual field survey can reveal the nature of fatigue damage as encountered in field service and to discover the extent of present practices used in the field to repair such fatigue damage. The NACA study made use of reports issued by the military overhaul bases, together with actual field visits, in order to obtain pertinent information. To bring the information up to date it appeared desirable to arrange visits to overhaul centers of the commercial airlines. Such visits, if made by personnel from an engine producer, could serve to coordinate the aspects that relate to initial design with those that relate to service operation.

#### *5. Avoidance, Control, and Repair of Fatigue Damage*

Avoiding fatigue, or repairing it once it has been nucleated, is an extremely broad subject. However, even in a preliminary survey, such as undertaken in the present study, much useful information can be crystallized into a single compendium. Drawing on an understanding of the mechanism of fatigue provides the most useful approach. The most important single guiding principle is recognizing that the avoidance of fatigue is the joint domain of the designer, the fabricator, the service staff, and the maintenance staff. If he does not fulfill his role properly, any one of these participants can destroy the most meticulous efforts of the others. Thus, it is important to outline not only approaches that are in current use, but also to draw on possible opportunities that have not yet been fully exploited.

With the foregoing outline as a framework, each section was assigned to an individual or group of individuals who were equipped by training, interest, and experience to provide a useful document in their specialty. It was recognized that exhaustiveness of treatment would not be possible because of time and space limitations, and because the state of the art is still rapidly unfolding. However, it was felt that a useful purpose would be served by describing the progress that has been made, and directing attention to gaps in understanding that needed to be filled.

While the emphasis in these chapters has been application to aircraft gas turbines, much of the information is applicable not only to stationary gas turbines but also to machines other than gas turbines in which fatigue plays an

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important role in governing life. It is hoped that this volume will serve all who are interested in the subject of metal fatigue.

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