



# Air Force Research Laboratory | AFRL

*Science and Technology for Tomorrow's Air and Space Force*

## **Materials and Manufacturing Directorate**

2977 Hobson Way

• Wright-Patterson Air Force Base, Ohio

• 45433-7746

### **High-Cycle Fatigue**

High-Cycle Fatigue has been identified as a leading cause of turbine engine failures, excessive maintenance costs, and source of responsibility for numerous standdowns affecting operational readiness over the past decade. High-Cycle Fatigue (HCF) is fatigue that occurs at relatively large numbers of cycles and is caused by high frequency vibrations in both static and rotating hardware. The distinction between high-cycle fatigue and low-cycle fatigue is made by determining whether the dominant component of the strain imposed during cyclic loading is elastic (high cycle) or plastic (low cycle), which in turn depends on the properties of the material and on the magnitude of the stress.

This program is focused on the capability of materials to withstand HCF after being subjected to initial and service induced damage and modeling of the fatigue behavior associated with the onset of high-cycle fatigue failure in titanium and nickel-base alloys for propulsion systems. Studies are aimed at three principal areas of material HCF capability under damage states, namely high cycle/low cycle fatigue (HCF/LCF) interactions, the role of notches and foreign object damage and fretting fatigue. The approach involves combining new experimental techniques for imaging microstructural damage with detailed micro-mechanical characterization and modeling of the salient micro-mechanisms to facilitate the prediction of the effects of such damage on HCF lifetimes. The results of these studies are being transitioned into design and analysis tools used by both the military and commercial engine industries.

The High Cycle Fatigue Program is part of a national effort to help eliminate HCF as a major cause of engine failures, and supports the Integrated High Performance Turbine Engine Technology (IHPTET) Program, and one of its major goals – to reduce engine maintenance cost. In the past, failures of titanium fan and compressor blades due to foreign object damage (FOD) caused by ice and hard objects ingested into the engine would sometimes damage or destroy the rest of the engine. It was estimated that one to two engines would be lost per year from this type of damage.

Scientists and engineers at ML have dramatically improved the HCF performance of turbine engines by increasing their resistance to FOD. A Laser Shock Peening technology was developed and transferred, which improves the resistance of aircraft turbine engine blades significantly. Stronger engine blades result in less foreign object damage to engines, and less risk to aircraft and pilots. This technology has avoided over \$59 million in costs

through reduced blade replacement costs, reduced secondary damage engine repair costs, and cost avoidance through airfoil failures. By avoiding 42 catastrophic failures over the life of the B-1B program, another \$40 million cost avoidance will be realized. If this impact is calculated over all the engines in the Air Force fleet, the potential savings could easily approach one billion dollars!

The ML program in fretting fatigue has developed new analytical tools to assess the stresses in the contact region between a blade and a disk. At present, numerous disks and blades

are retired from service because of fretting fatigue damage. The damage results from vibration induced stresses which could not be calculated in the original design because of lack of computational tools. The newly developed tools have been adopted by the engine manufacturers and are being used for new engine designs for the JSF and for redesigns of existing hardware. Analyses which took days to conduct in the past can now be done in seconds. The reduction in fretting fatigue related maintenance costs is estimated to save the Air Force tens of millions of dollars over the next decade.

Finally, the HCF program conducted by ML is producing results and understanding which is being incorporated into the design guidelines for Air Force engines, namely the Engine Structural Integrity Program (ENSIP) document. Such design guidelines will lead to the development of more durable engines in the future providing less risk of HCF failures and lower maintenance costs. Current estimates of a cost of \$400M/yr for unscheduled maintenance due to HCF are anticipated to be reduced by more than a factor of two due to better and more robust design.



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