NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

January 15, 2016

MATERIALS LABORATORY STUDY REPORT Report No. 15-131S

A. ACCIDENT INFORMATION

Place	:	Las Vegas, Nevada
Date	:	September 8, 2015
Vehicle	:	Boeing 777-200, G-VIIO
NTSB No.	:	DCA15FA185
Investigator	:	Lorenda Ward, AS-10

B. COMPONENTS EXAMINED

Multiple fragments from a GE90-85B-G11 high pressure compressor stage 8-10 spool (P/N: 1694M80G04, S/N: GWNHA236).

C. DETAILS OF THE STUDY

Materials Laboratory Factual Report 15-131 documented the progression of a fracture that initiated on the aft face of the web of the high-pressure compressor (HPC) stage 8 disk, part of the HPC stage 8-10 spool. The crack initially exhibited an intergranular morphology but at approximately 0.010 inch from the origin gradually transitioned to a transgranular morphology with striated features consistent with low cycle fatigue (LCF). A series of scanning electron microscope images were taken in the LCF regime and striation density measurements were made on those images. The images and the data can be found in Materials Laboratory Factual Report 15-131. The purpose of this study is to use that data to estimate the number of flight cycles that elapsed between the point of detectable crack initiation (FAA, 2009) and the end of the LCF region.[1]

Cracks that propagate by cyclic fatigue often leave striations on the fracture surface as a result of the opening, advancing, and closing of the crack during each stress cycle (Hertzberg, 1989). The striation spacing (da/dN) is correlated with the amplitude of the stress cycle and the length of the crack through the stress intensity range (ΔK), as shown in figure 1 (Brown, Mindlin, and Ho, 1995). If the stress amplitude is constant, the spacing of consecutive striations should be nominally uniform (i.e. within the field of view of a scanning electron microscope image).

[1] Detectable crack initiation is a measure of the size of a crack that can be detected using a non-destructive inspection method. In FAA AC33.70-1, that depth is defined as 0.015 inch. The cycle count does not include the cycles that were accumulated in the intergranular region or transgranular region up to the 0.015 inch crack depth.

For the purpose of the study, it was assumed that one striation correlated with one flight cycle and that the forces during takeoff, when the stresses on the web are at their highest, were driving the advancement of the crack.

The striation data were plotted as the number of striations per unit distance as a function of distance from the origin. A power curve was then fit to the data and the resulting equation integrated by hand. The integrated equation was then evaluated between two limits. The lower limit was determined starting with the crack depth associated with a detectable crack initiation as defined in FAA Advisory Circular AC33.70-1 (0.015 inch) (FAA, 2009). The 0.003 inch of post separation impact damage along the aft web face at the origin was then subtracted from that depth, resulting in a lower limit of 0.012 inch (0.305 mm). The upper limit was 0.111 inch (2.82 mm) and was determined by subtracting a small cyclic tensile region of approximately 0.004 inch and the impact damage of 0.003 inch from 0.118 inch, the thickness of the web.

The plot of the striation data is shown in figure 2. The resulting power curve was:

$$Striation\ Density = 2437.7 * Distance\ from\ origin^{-0.774}$$

The integrated equation was:

$$Striations = \frac{2437.7}{0.226} * (Upper\ Limit^{0.226} - Lower\ Limit^{0.226})$$

The calculation estimated that the fatigue crack progressed by LCF for approximately **5,400 cycles** beyond the point of detectable crack initiation.

D. REFERENCES

Brown, W.F., Jr., Mindlin, H. and Ho, C.Y. (Eds.). (1995). *Aerospace Structural Metals Handbook.* CINDAS/USAF CRDA Handbooks Operation, Purdue University: West Lafayette, IN.

FAA. (2009). *FAA Advisory Circular 33.70-1: Guidance Material for Aircraft Engine Life-Limited Parts Requirements, July 31, 2009*, Federal Aviation Administration, Washington, DC.

Hertzberg, Richard W. (1989). *Deformation and Fracture Mechanics of Engineering Materials (3rd Ed.).* John Wiley & Sons: New York.

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Sr. Materials Engineer

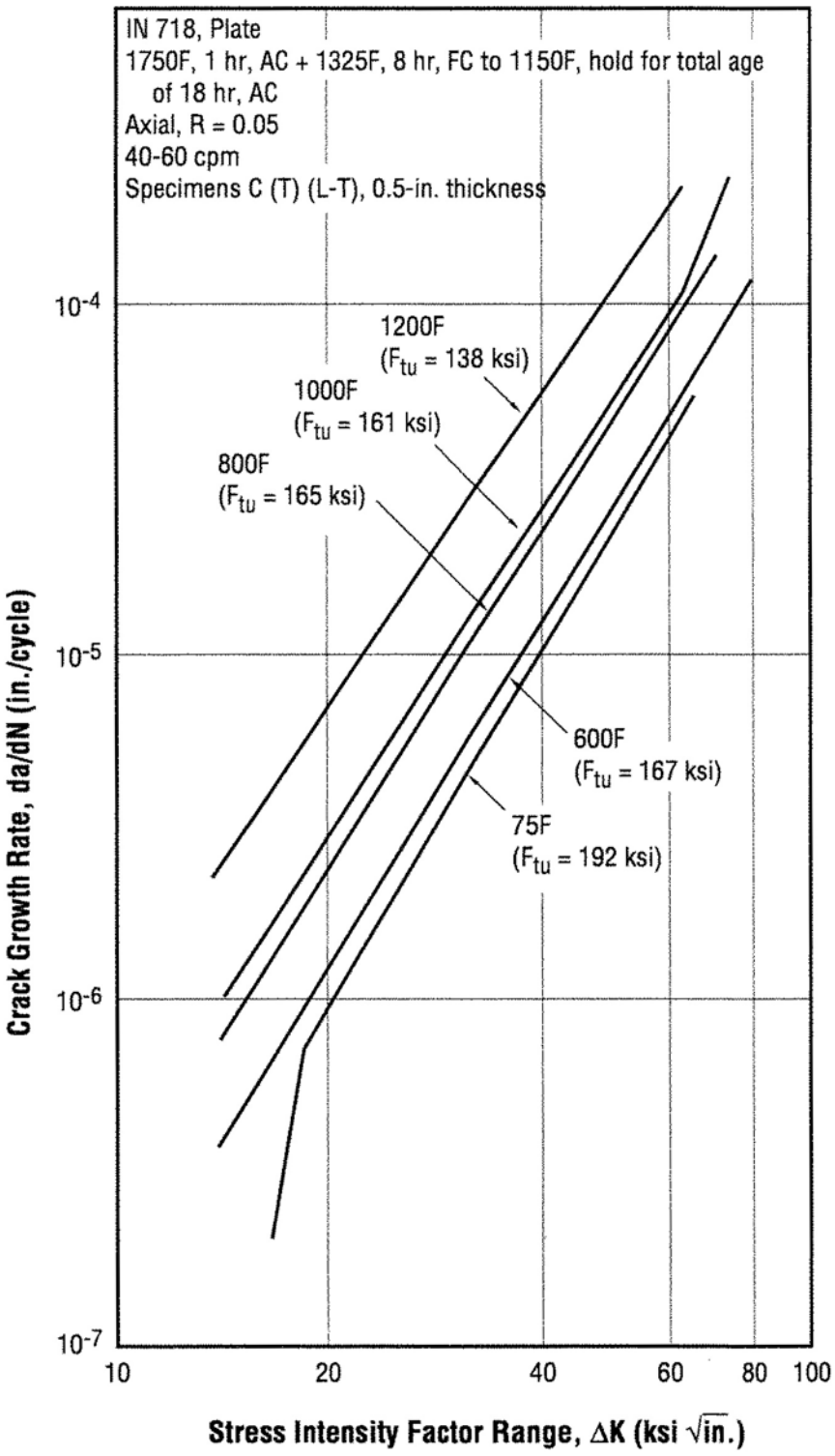

Figure 1: Correlation between stress intensity range (ΔK) and crack growth rate (striation spacing) for IN 718 nickel-based superalloy.

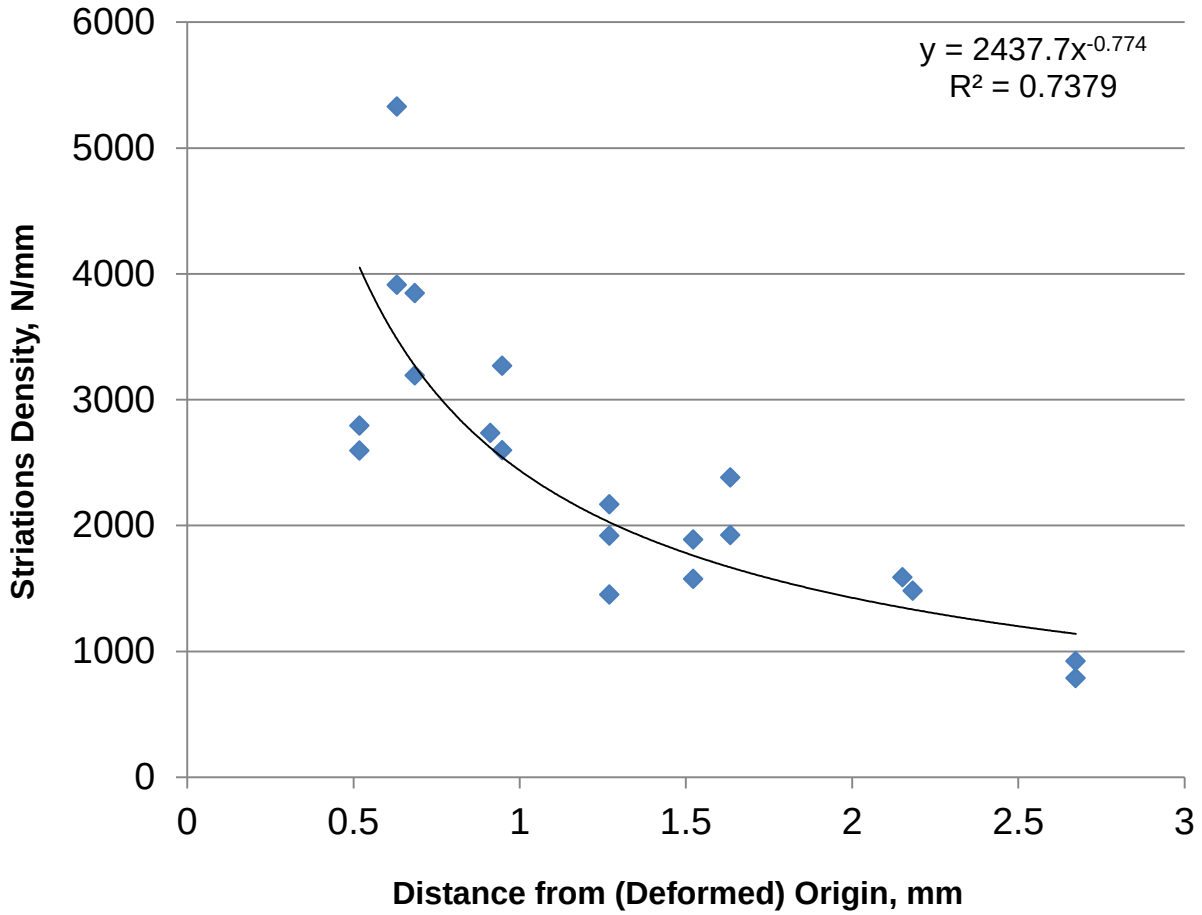

Figure 2: Plot of striation density as a function of distance from the deformed origin. As a result of the deformation, the origin was displaced forward by approximately 0.003 inch (0.076 mm).