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

May 22, 2017

MATERIALS LABORATORY STUDY REPORT Report No. 17-034S

A. ACCIDENT INFORMATION

Place	:	Chicago, Illinois
Date	:	October 28, 2016
Vehicle	:	Boeing 767-300, N345AN
NTSB No.	:	DCA17FA021
Investigator	:	Lorenda Ward, AS-10

B. COMPONENTS EXAMINED

Three (3) pieces of a fractured GE CF6-80C2B6 stage 2 high-pressure turbine disk (P/N: 9362M43P04, S/N: MUNBB592).

C. DETAILS OF THE STUDY

Materials Laboratory Factual Report 17-034 documented the presence of multiple fatigue cracks that initiated at an internal material anomaly (a discreet dirty white spot), in the forward bore region of the stage 2 high-pressure turbine disk. The cracks exhibited striated features consistent with low cycle fatigue (LCF). A series of scanning electron microscope images was taken for each crack along the path of crack progression up to the transition to cyclic tensile behavior and striation densities were measured on those images. The images and the measurement data can be found in Materials Laboratory Factual Report 17-034. The purpose of this study is to use that data to estimate the number of flight cycles that elapsed in each LCF region.

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 for IN 718 plate 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).

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 disk are at their highest, drove 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 (the discreet dirty white spot). 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 chosen to be the edge of the anomaly and was defined as 0 inch. The upper limit was determined for each case as the point at which striations could no longer be resolved on the fracture surface (the transition to cyclic tensile growth). The upper limits were 0.219 inch, 0.314 inch, and 0.210 inch for cracks 1, 2, and 6, respectively.

The plots of the striation data are shown in figures 2 through 4 for cracks 1, 2, and 6 respectively. The resulting power law equations were as follows:

Crack number	Power law equation
1	$Striation\ Density = 18709 * Distance\ from\ origin^{-0.128}$
2	$Striation\ Density = 5775.3 * Distance\ from\ origin^{-0.455}$
6	$Striation\ Density = 6264 * Distance\ from\ origin^{-0.372}$

The integrated equations were as follows:

Crack number	Integrated equation
1	$Striations = 21577 * (Upper\ Limit^{0.872} - Lower\ Limit^{0.872})$
2	$Striations = 10597 * (Upper\ Limit^{0.545} - Lower\ Limit^{0.545})$
6	$Striations = 9974.5 * (Upper\ Limit^{0.628} - Lower\ Limit^{0.628})$

The calculations estimated that the cracks **1**, **2**, and **6** progressed by LCF for approximately **5,700 cycles**, **5,600 cycles**, and **3,700 cycles** respectively.

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.

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

Donald Kramer, Ph.D.
Sr. Materials Engineer

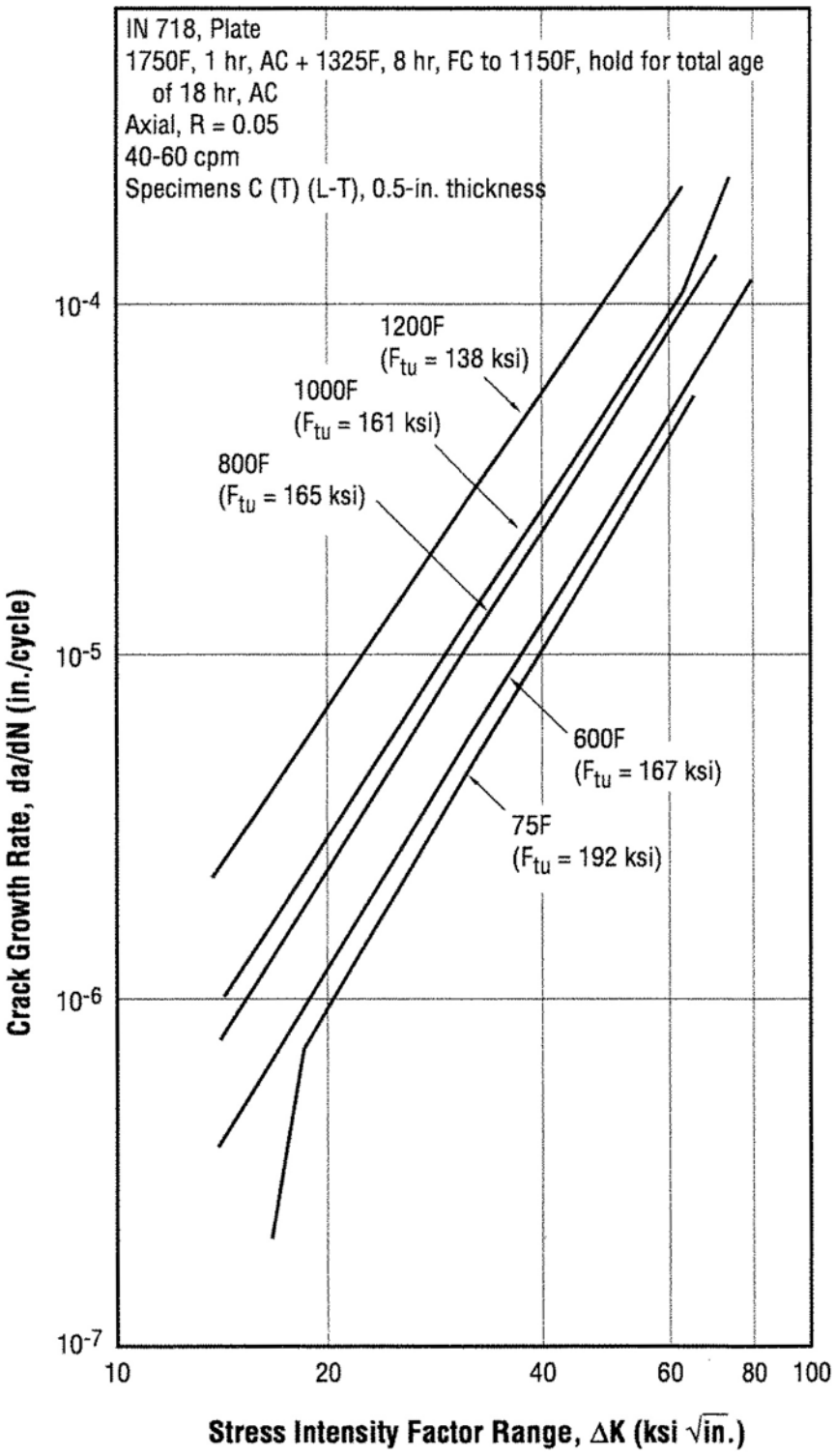

Figure 1: Correlation between stress intensity range (ΔK) and crack growth rate (striation spacing) for IN 718 nickel-based superalloy.

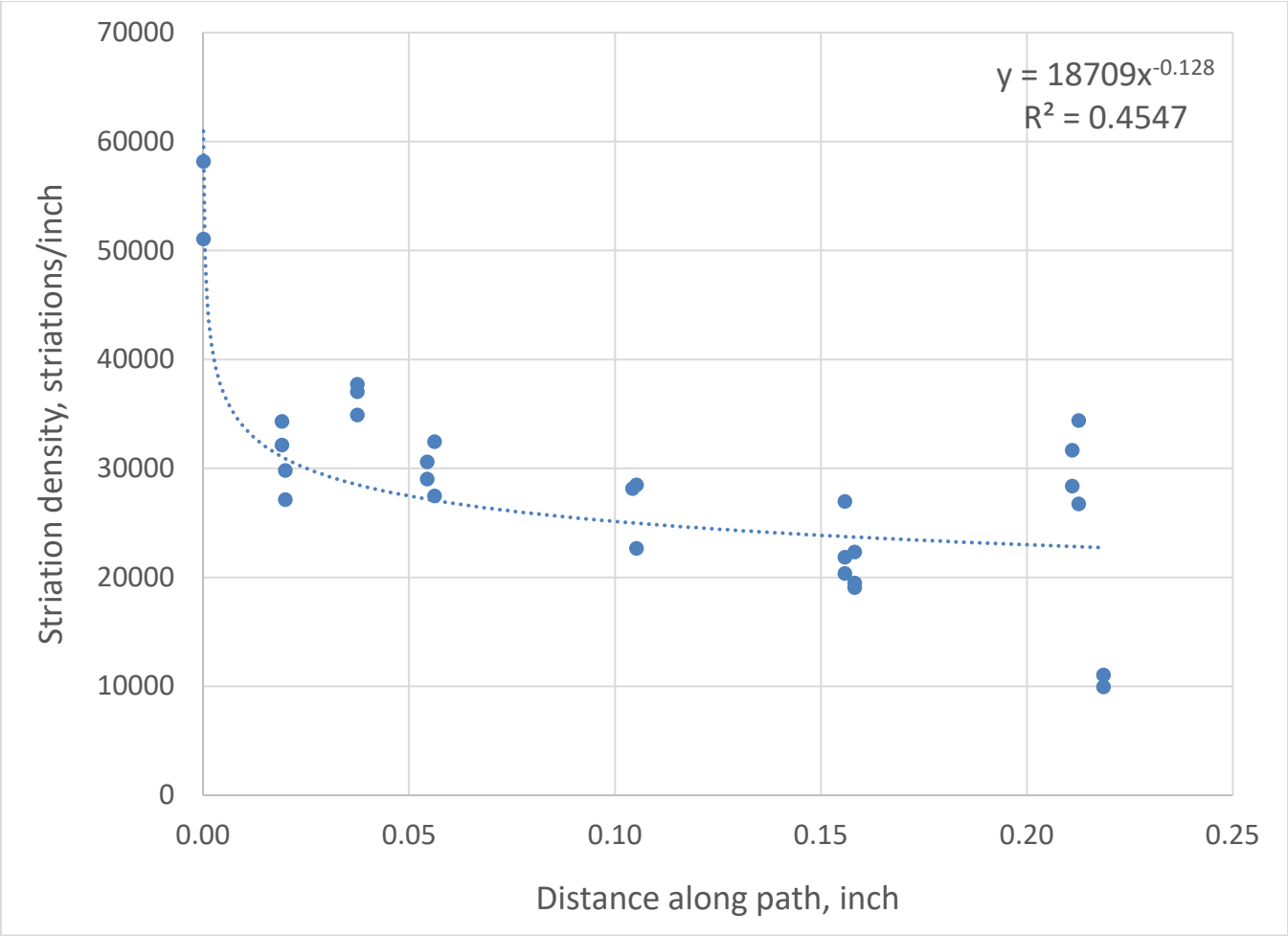

Figure 2: Crack number 1 - plot of striation density as a function of distance along the path of crack propagation.

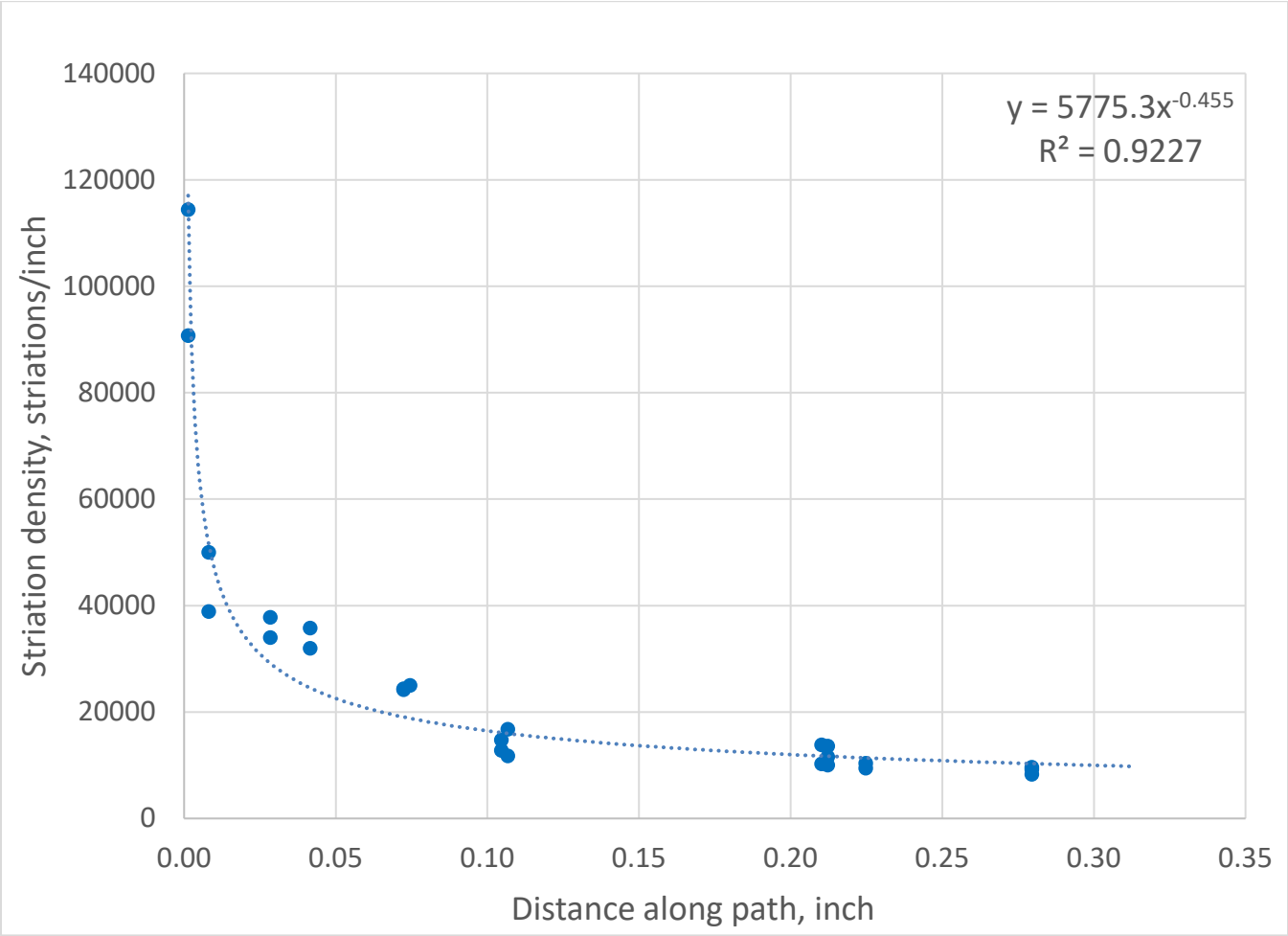

Figure 3: Crack number 2 - plot of striation density as a function of distance along the path of crack propagation.

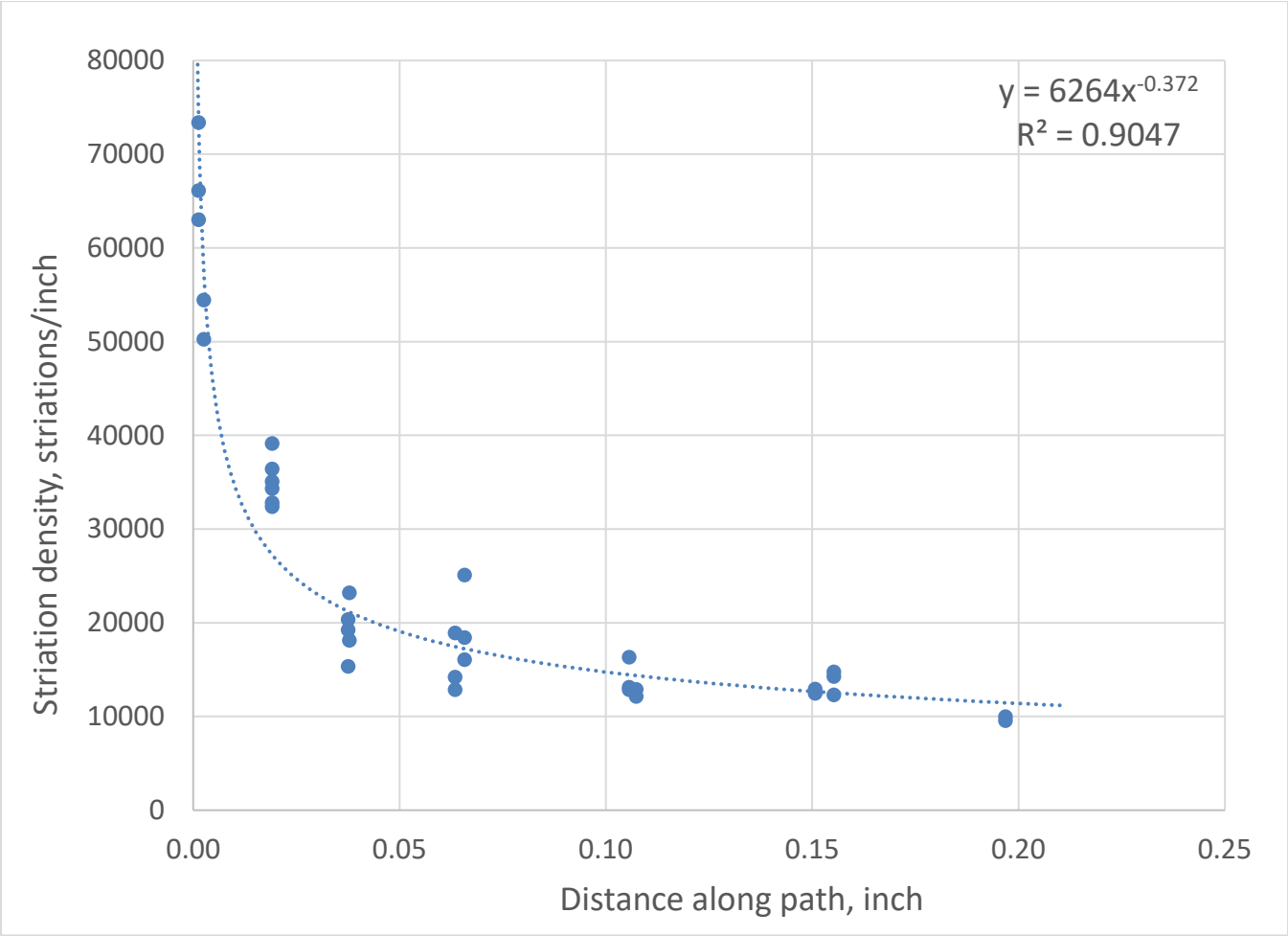

Figure 4: Crack number 6 - plot of striation density as a function of distance along the path of crack propagation.