TURBINE DISK RETIREMENT-FOR-CAUSE: MEASUREMENT OF INSPECTION UNCERTAINTY FOR DISK EDDY CURRENT INSPECTIONS

C. A. Rau, Jr., S. W. Hopkins, J. W. Eischen and D. E. Allison
Failure Analysis Associates
Palo Alto, California 94304

ABSTRACT

Major cost savings are possible through life extension of high-cost jet engine components until damage develops. Retirement-for-cause (RFC) decisions will be based upon both non-destructive inspection (NDI) to detect and size defects, and engineering analysis to assess defect severity under future usage. Failure Analysis Associates is performing a three-year program for ARPA/AFML to define and verify an optimum RFC strategy for jet engine disks. In depth, quantitative characterization of NDI performance is a major part of this project. This presentation summarizes the quantitative evaluation of inspection (NDI) uncertainty for four independent inspections - two state-of-the-art eddy current inspections of disk bolt holes, one with conventional hardware but improved signal processing, and one higher resolution eddy current inspection system assembled for this project.

Separate inspections of the same 490 bolt holes in 49, 3rd stage disks retired from service in TF33 engines were performed with each of the four NDI techniques. Inspection results were compared with each other and with the actual cracks measured by surface plastic replicas and selected destructive metallography. The variation of detection probability and sizing errors with flaw size and indication level is defined in a form suitable for the probabilistic reliability analysis and RFC strategy formulation. Progress in the other project tasks, especially the stress and fracture mechanics analysis to define the conditional failure probability if a flaw of specified size were present will also be summarized.

# #

SUMMARY DISCUSSION
(C. Rau)

Robb Harris (Pratt & Whitney): When you showed that the inspection probability deteriorated for finding positions accurately, would one possiblly infer from that that the things you found weren't really cracks - you found something else, and it happened to correlate with the one you found in the same hole?

Charles Rau: I think that's part of the problem. I don't know that that's all of the problem. In our destructive sectioning, which is under way now, we're going to be answering just that kind of question. I think we have to infer that, because some of the misses are way off, they found a defect up at the top of the hole and it spiraled down and 25 turns later you receive a signal. That's obviously not the same defect. If anything, they found a defect that somebody else missed. But the inspection reliability for that defect is not in fact as high as we think it is.

Al Morton (Los Alamos Scientific Lab): Are these new or used disks?

Charles Rau: These disks are used disks. They were actually removed from service in C-140's, C-141's and they had a various number of cycles on them. They were rejected by the field depot inspections. Of course, they had been rejected for one bolt hole. We were inspecting all the bolt holes. We were characterizing not just the biggest cracks, but the whole range of cracks--much smaller than with which they were concerned. But they were used. I'd like to amplify this point. An advantage of this program is that we're producing a demonstration program of the retirement-for-cause strategy on actual, used hardware which has been exposed to actual engineering environments, realistic statistical variations and duty cycles, and all the other problems that go along with the real world as opposed to the laboratory. Further, we will be verifying the strategies we developed through a laboratory testing program where we actually make bolt hole specimens and fly them in the laboratory where the inspectors won't know what the duty cycle is, and we will basically inspect many accept-reject decisions and continue running them to see what breaks. Appropriate economic factors will be ascribed onto relative to the consequences of breakage or nonbreakage, and the entire procedure that produces a total payoff will be verified.

Bill Sturrock (Northrop): Did you repeat any of the eddy current inspections after electropolish?

Charles Rau: No. We wanted to simulate the real world inspection. Sure, we were likely to see different results. We saw some of the cracks weren't surface-connected. We noticed that on these high-frequency probes we obviously interrogated a very local region. I'm sure we could have improved the resolution by opening up some of the defects at the surface, but that wasn't what we were really looking for.

Bob Addison (Science Center): I was curious about the micrographs that you showed. Were those micrographs of the plastic piece, or were they actual photos of the hole?

Charles Rau: Bob, they were both there. There were replicas which were, in fact, the surface of the bolt holes. We scanned the surface first to detect the surface length. Then we took others at cross sections through the bolt holes. You also saw those planes. We used those to determine the crack depth at various positions along the surface level. So, both were involved there. I'm sorry I was running through them pretty quick and didn't tell you which was which.

Mike Buckley (ARPA): Is your optimism for a retirement-for-cause strategy on these disks based on the fact that the crack growth rate is very slow and, therefore, you can tolerate a fairly large crack?

Charles Rau: My optimism is not based on the fact that the crack propagation is slow, although obviously it has to be slow enough to have some margin. The optimism is based on the fact that, first of all, there is a lot of money being thrown away. Secondly, we can establish inspection intervals so that we can miss a crack one time and still catch it at another interval. We can improve our total reliability by redundant inspections without the probability of failure being very high. Further, we have ten bolt holes in a disk. The fact that we're going

(continued)

to reject a disk for any one of them adds additional conservatism to the whole R.F.C. strategy. You put all of these things together probabilistically, and your probabilities of failure come out to be quite low. And you multiply those by cost of failure, and it's still a small number compared to the cost of throwing away the whole fleet of disks.

Warren Berger (RADCOM): We have recognized the three elements in a probability of failure, although not in as formal a manner as you have presented today. Our problems are significantly different, I think, in that we have one-shot devices. We have to screen the entire production to try to isolate, quantify, and reject those elements that will be failures in functioning. Our biggest problem currently is getting a handle on the reliability of our inspection in terms of removing from stockpile or preventing from getting into stockpile those metal parts that contain critical cracks, whatever that might be.

Charles Rau: Just a comment. We have looked at the problem, also, of nonsubcritical crack growth. I think you can handle it by many of the same procedures, and I think it's amenable to the same kind of calculations. I think you are right: the inspection reliability is one of the key inputs. But the preinspection, the probabilities of flaws being there, is equally important. The probability of failure, instead of involving fatigue or subcritical growth, is just a probabilistic overlap of the strength distribution and the stress distribution, but methodologically it's very similar except for that difference.

Robb Thomson: Any other questions?

John Duke (Virginia Tech): You indicated you have some very complex crack shapes, and I tend to agree, after looking at those pictures. I was wondering if you feel that your classification by means of length is sufficient to indicate the significance of what you're monitoring with your eddy current? Do you think that using a different classification scheme based more on the performance that results from that particular type of a crack would be a better means of characterizing your inspection?

Charles Rau: There is no question about that--particularly with these complex geometries. I hope when we get done with our destructive work we will be able to identify additional parameters. For example, the opening of the crack at the surface or the integrated opening over the crack depth may turn out to be a lot more important than the length of the crack. But at this point in time we are already three or four orders of magnitude more sophisticated in our comparisons than most people have been able to do with theirs.

# #