BALANCING TECHNOLOGICAL OPPORTUNITIES VS. OPERATIONAL REQUIREMENTS: AN AFML CHALLENGE

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ABSTRACT

The mission of the NDE Branch of the Air Force Materials Laboratory is twofold: first, to support the overhaul and maintenance functions, and second, to provide new technology to allow the development of more durable and higher performance equipment. The lack of a mature NDE technology base, coupled with identifiable future needs, necessitates a long term commitment to providing generic capabilities. However, the severity of present day problems and the high payoff which would result from their solution, creates a strong demand for programs aimed at short term results. The attempt by the Materials Laboratory to balance these competing demands will be discussed. In addition, a potential application of quantitative NDE to an Air Force problem will be discussed in terms of the NDE requirements and possible benefits. This will illustrate the necessity of maintaining the effort to develop the technology base.

I would like to welcome you to this meeting on behalf of the Air Force Materials Laboratory. This is the fourth annual review of this program and I must say that the progress which has been made over the last four years has been dramatic. I attended the first meeting back in '74 as a member of the University research community who was just beginning work in the Nondestructive Evaluation (NDE) field. My major impression from that meeting was that NDE was a field with many horrendous practical problems and very little in the way of a scientific foundation for the techniques used.

During the four years of the ARPA/AFML program's existence, significant progress has been made in constructing a science base. Beyond the technical advances, the assembly of a multidisciplinary research group from the university and industrial communities devoted to the development of the NDE science base has been a major achievement. This is in contrast to the research along disciplinary lines which was the norm prior to the inception of this program.

As an example on the technical side, we have progressed from attempting to quantitatively predict scattering from individual model defects to the point where we are now addressing the inverse problem, i.e. the description of the source geometry from a limited knowledge of the scattered ultrasonic fields. The next step is to integrate these results into new component life management concepts in an effort to obtain greater reliability and longer service life for aircraft components.

In this talk, I would like to briefly touch on the changes which will have to be made for this program to remain as the core of the effort to develop the NDE science base. In addition, I will try to show how the program fits into the overall AFML NDE program and lastly, I will discuss in some detail a possible application for the quantitative NDE capability we are developing.

For this program to serve as a base for future advances in NDE, it is essential that the core be maintained and preferably expanded. The Air Force Materials Laboratory has committed itself to maintaining its support at least at the present level for the next several years. For an expansion to occur, other agencies, such as the Army and Navy, will have to be brought into a coordinated effort. At the present time, a subpanel of the Joint Directors of Laboratories Council has been chartered to look into the needs of the Department of Defense in the NDE field. It is possible that the recommendations of this subpanel may result in expanded programs in both the fundamental and application areas.

In terms of the overall Air Force Materials Laboratory NDE program, this program is a major part, but not the largest. The Laboratory is a mission oriented organization with the job of transitioning technology into field use as well as developing it. As such, a large number of our programs are applications oriented, designed to answer short term needs and transition technology into the field. The lack of a mature NDE technology base, however, required the commitment to a long term fundamental research effort, such as this one, which the Laboratory has made. The competition between long and short term needs and the ever present limits on available financial resources produced the overall program focus on the development of ultrasonic and electromagnetic techniques which may be applied to our most pressing problems. The largest portion of AFML NDE funds is concentrated in the Manufacturing Technology area which represents the final step in the process of transitioning the technology.

The technical goals of the applications efforts are primarily to improve the reliability of detection in present inspection procedures, among which are ultrasonics and eddy current. This improvement is needed to insure the present safety of our aircraft and to allow the implementation of the quantitative NDE techniques in conjunction with life extension programs in the future. Without the defined reliability that flaws larger than a given critical size can be found, it makes little sense to implement sophisticated quantitative techniques, since the present safety margin in the allowed service life is large enough to take into account the high probability of missing the small defects which must be detected and measured in most life management programs. A second requirement for improved reliability is the need to reduce the number of parts which are rejected when, in fact, they have no flaws present. While errors in this case do not affect safety, in many instances the economic cost becomes prohibitive.

I would like to take a more detailed look at a potential application area where a quantitative NDE capability is essential to the success of the proposed program. The effort is referred to as Retirement for Cause. It's primary goal is to extend the service life of engine components, such as disks, which are now retired after a fixed number of fatigue cycles, independent of any detection of a rejectable flaw, at a point where the probability of failure is 0.02%. This number of fatigue cycles is derived from design life calculations which assume the largest flaw likely to go undetected is actually present in the part. Figure 1 shows how the service life of the part can be extended if reliable, quantitative NDE is available. If all detectable cracks have length less than A_0 at each inspection, and there is confidence that no cracks of length greater than A_0 have not been detected, the part can be returned to service with confidence that the remaining life should be at least equal to the original design life. As techniques improve, it may even be possible at some point to put parts back into service with cracks just slightly smaller than A* with the confidence that these cracks will not reach the critical size, A_c before the next inspection.

The simple relationship between the crack surface length and the component lifetime implied by Fig. 1 is valid only for those cases where the aspect ratio ($^a/_{2c}$ = crack depth/surface length) is a constant. In the real world of the alloys found in engines, the aspect ratio is a variable which must be taken into account. This is illustrated in Fig. 2 where the crack growth as a function of number of flights is plotted for bolt hole cracks in the third stage turbine disk in the TF-33 engine. From this figure one immediately comes to the conclusion that crack depth must be accurately measured as well as surface length.

At first glance it might appear that we have identified all the parameters which must be measured by our quantitative NDE techniques; however this is not the case. Figures 1 and 2 are idealizations in the sense that they are valid for elliptical cracks. While real cracks may be elliptical, in many cases they have rather ragged boundaries. This is especially true in coarse grained materials where relatively large cracks can form as a result of the link-up of many small ones. As our NDE techniques improve, it is anticipated that through an iterative procedure with developments in fracture mechanics the essential details of crack geometery needed for remaining life calculations may be identified and the needed techniques developed.

Now let us take a look at how NDE fits into the overall Retirement for Cause strategy. This is illustrated in Fig. 3 where the current and proposed maintenance flow charts are shown. As was mentioned before, the present system retires the disk after one design life even if no flaws are detected in the part. It has been estimated that at least 85% of the disks in one of our newest engines could go for more than 10 design lifetimes without failure. For the retirement for cause program to succeed, the required NDE and analytical techniques which are necessary to separate this long life 85% from the 15% which would fail earlier must be developed.

In the proposed program, NDE comes into the

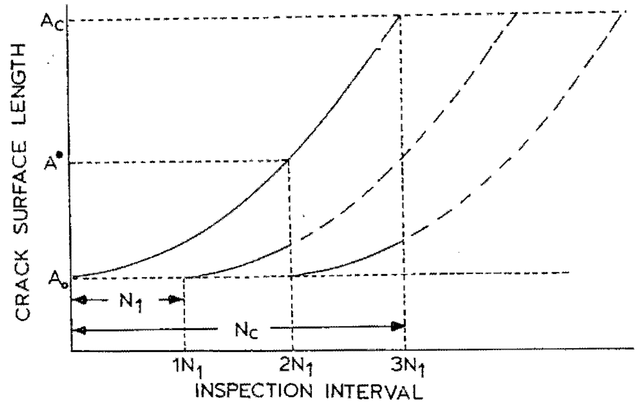

Fig. 1. Crack growth - NDE relationship for Retirement for Cause program.

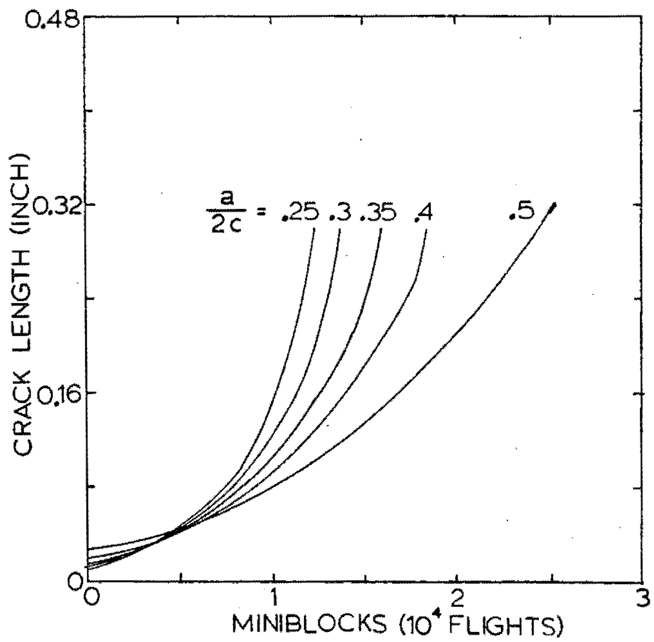

Fig. 2. Crack growth as a function of aspect ratio for 3rd stage turbine disk in the TF-33 engine.

disk evaluation process in two very important places. The first is the initial evaluation of the disk at one design lifetime. Here, the disk is examined for the presence of cracks. If no flaws (cracks, changes in microstructure, etc) are found, it may be put back into service for an additional lifetime. I should mention at this point that it may be necessary to also inspect for nondiscrete defects such as abnormal residual stresses in the part, which may also cause premature failure. Unfortunately, present residual stress measurement techniques are extremely poor except for near surface stress measurements. A great deal of progress would be necessary in this area before we could say we had an acceptable method for measuring bulk stresses.

In the case where a crack is found, accept/reject criteria for the part must be developed. For cracks above a certain size, the disk will have to be rejected, for very small cracks it could be

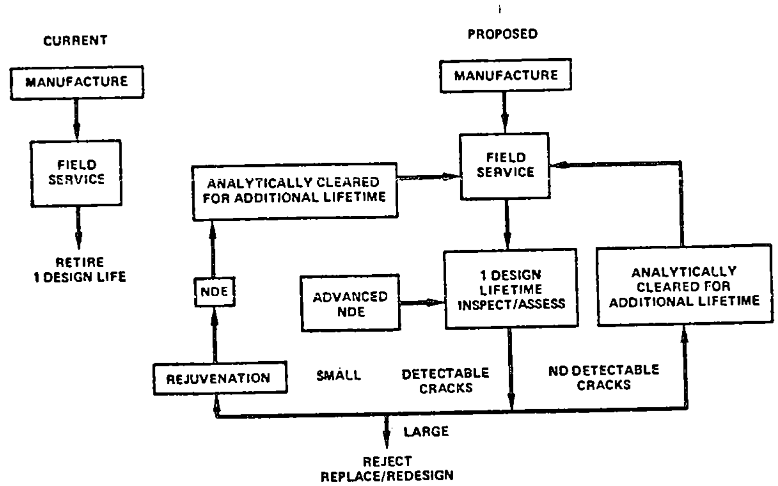

Fig. 3. Disk Retirement for Cause Strategy.

put back into service with no attempt at repair. In the intermediate range, if the techniques are sufficiently developed, the part could be repaired or rejuvenated. After this stage NDE must again be used to determine if the rejuvenation has been successful and no additional damage has been introduced.

In summary, the Retirement for Cause program depends in a critical way on the development of a reliable quantitative NDE capability. It will be a very expensive program due to the large amount of testing needed to provide the statistics, but the potential payoff is so great that it may make the difference between a sufficiently large and reliable Air Force and a severely limited one due to the high cost of maintenance. I have tried in this description of our Retirement for Cause program to give some feeling of the need for a quantitative NDE capability. The research papers to be presented in this conference will bring us up to date on our progress toward this goal. I hope you will find them interesting and leave with the feeling that a great deal of progress has been made and that our goal appears to be achievable.