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COST/RISK ANALYSIS FOR DISK RETIREMENT
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19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*
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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*
As the replacement cost for jet engine components increases and the average age of the fleet starts to approach the "traditional" design life, major life cycle cost savings can potentially be accrued from a "Retirement for Cause" (RFC) approach to component retirement. This approach takes advantage of the ability of most members of a population (or "fleet") of engine components to perform safely for several lifetimes longer than the traditional design life. This report presents details of the development and evaluation of an RFC methodology.

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Failure Analysis Associates (FaAA) was supplied with 49 randomly selected retired TF-33 third stage turbine disks for this project. Each disk had 10 bolt holes which were susceptible to fatigue damage. Each bolt hole was inspected by up to five separate inspectors using both conventional and high-resolution eddy current nondestructive inspection (NDI) equipment.

Following the NDI inspections, each bolt hole was mechanically and electrically polished before replication. Each replica was then examined under a microscope. In total, over 1000 replicas were made and examined in order to locate and measure the surface crack lengths in each of the 490 bolt holes inspected. The replicas revealed 847 surface-connected cracks in 280 bolt holes. In the remaining 210 bolt holes, no surface-connected cracks were found; only four of the 49 disks inspected were not cracked. After replication, 28 bolt holes were metalographically sectioned to measure the depth of 56 surface crack indications. The sectioning results of the 56 surface cracks provided the crack shape information necessary to convert surface crack lengths measured on each replica into crack depth. Inspection reliability for both radially inward (RI) and outward (RO) bolt hole surfaces were then calculated separately for each of the three independent inspections that could distinguish the difference between RI and RO indications.

In a parallel effort, various RFC analytical procedures were developed and tested using Monte Carlo simulation. RFC Procedure No. 1 was deterministic and totally uncalibrated against field experience. RFC Procedure No. 2 calibrated each disk by selecting a stress that would have been required to cause the measured crack size at the reported number of cycles. However, RFC No. 2 was also without memory and therefore could not react to the overall fleet experience. RFC Procedure No. 3 was not calibrated for each individual disk according to its measured crack size, but it did use all past field performance knowledge to adjust the allowable cyclic life extension. Thus, the inspection and analysis team had both the memory and the ability to react and improve the RFC procedure on an ongoing basis. RFC Procedure No. 4 combined the improvements of RFC Procedure Nos. 2 and 3. Each disk was calibrated to account for (1) the stress that would have been required from the measured crack size, and (2) the overall performance of the fleet. This calibration allowed for continuous updating and improvement to the RFC procedure. Through computer simulation each RFC procedure was evaluated against changes in allowable cycle-based safety factor (inspection interval), inspection reliability, maximum allowable inspection interval, maximum allowable crack size, and cycle counting errors.

The final task in this project was an RFC specimen verification task in which 32 bolt hole specimens were fatigue-cycled to failure. Periodically during the life of each specimen they were inspected using the high-resolution eddy current probe system, whose reliability had been evaluated. Three cyclic stress levels and reasonable cycle counting errors were incorporated. The analyst was only given the measured crack size and the indicated cycles from which to determine the next inspection interval. The exact cyclic stress and real number of cycles were known only to the test engineer. Various RFC procedures were evaluated using this laboratory data. The results indicated that (1) RFC Procedure No. 4 does result in a significant cost savings by extending the useful life of the specimen and (2) a fleet of only 32 specimens is not sufficient to determine the optimal RFC procedure.

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1.0 SUMMARY

As the replacement cost for jet engine components increases and the average age of the fleet starts to approach the "traditional" design life, major life cycle cost savings can potentially be accrued from a "Retirement for Cause" (RFC) approach to component retirement. This approach takes advantage of the ability of most members of a population (or "fleet") of engine components to perform safely for several lifetimes longer than the traditional design life. The traditional design life limit is intended to ensure adequate fatigue performance of an entire fleet of new components without the benefit of in-service inspections. The RFC approach is to retire components only when unacceptable cracking is detected by inspection and to allow the remaining components to stay in service until periodic inspection identifies an unacceptable crack size. The RFC approach in general is applicable to any failure mode that can be forestalled effectively with periodic inspections.

The retired TF-33 third stage turbine disks presented to both the Air Force and the Defense Advanced Research Project Agency (DARPA) a unique opportunity to develop an RFC approach using disks that had developed in-service fatigue cracks. Failure Analysis Associates (FaAA) was supplied with 49 randomly selected retired turbine disks for this project. Each disk had 10 bolt holes which were susceptible to fatigue damage. As will be discussed later, each bolt hole had two locations where high cyclic stresses caused fatigue crack initiation: radially inward (RI) toward the bore of the disk and radially outward (RO) toward the rim of the disk. Each bolt hole was inspected by up to five separate inspectors using both conventional and high-resolution eddy current nondestructive inspection (NDI) equipment.

Following the NDI inspections, each bolt hole was mechanically and electrically polished before replication. Each replica was then examined under a microscope. In total, over 1000 replicas were made and examined in order to locate and measure the surface crack lengths in each of the 490 bolt holes inspected. The replicas revealed 847 surface-connected cracks in 280 bolt holes. In the remaining 210 bolt holes, no surface-connected cracks were found; only four of the 49 disks inspected were not cracked. After replication, 28 bolt holes were metalographically sectioned to measure the depth of 56 surface crack indications. The sectioning results of the 56 surface cracks provided the crack shape information necessary to convert surface crack lengths measured on each replica into crack depth. Inspection reliability for both radially inward and outward bolt hole surfaces were then calculated separately for each of the three independent inspections that could distinguish the difference between RI and RO indications.

In a parallel effort, various RFC analytical procedures were developed and tested using Monte Carlo simulation. RFC Procedure No. 1 was deterministic and totally uncalibrated against field experience. RFC Procedure No. 2 calibrated each disk by selecting a stress that would have been required to cause the measured crack size at the reported number of cycles. However, RFC No. 2 was also without memory and therefore could not react to the overall fleet experience. RFC Procedure No. 3 was not calibrated for each individual disk according to its measured crack size, but it did use all past field performance knowledge to adjust the allowable cyclic life extension. Thus, the inspection and analysis team had both the memory and the ability to react and improve the RFC procedure on an ongoing basis. RFC Procedure No. 4 combined

the improvements of RFC Procedure Nos. 2 and 3. Each disk was calibrated to account for (1) the stress that would have been required from the measured crack size, and (2) the overall performance of the fleet. This calibration allowed for continuous updating and improvement to the RFC procedure. Through computer simulation each RFC procedure was evaluated against changes in allowable cycle-based safety factor (inspection interval), inspection reliability, maximum allowable inspection interval, maximum allowable crack size, and cycle counting errors.

The final task in this project was an RFC specimen verification task in which 32 bolt hole specimens were fatigue-cycled to failure. Periodically during the life of each specimen they were inspected using the high-resolution eddy current probe system, whose reliability had been evaluated. Three cyclic stress levels and reasonable cycle counting errors were incorporated. The analyst was only given the measured crack size and the indicated cycles from which to determine the next inspection interval. The exact cyclic stress and real number of cycles were known only to the test engineer. Various RFC procedures were evaluated using this laboratory data. The results indicated that (1) RFC Procedure No. 4 does result in a significant cost savings by extending the useful life of the specimen and (2) a fleet of only 32 specimens is not sufficient to determine the optimal RFC procedure.

This project has shown that RFC of inspectable components is very cost effective. Even under actual service conditions and considering actual uncertainties in design, manufacture, usage and maintenance if the optimal RFC parameters have not been selected initially, an experienced-based RFC procedure (RFC No. 4) will tolerate initial estimate uncertainties and improve with time.

2.0 INTRODUCTION AND OBJECTIVES

Major life cycle cost savings can accrue from optimum application of nondestructive inspection (NDI). However, the cost effectiveness of NDI is strongly dependent upon many diverse factors beyond the specific inspection process and its uncertainty, sensitivity, and costs. Specifically, these factors include the loads and environment experienced by the component; the consequences and costs associated with component failure; the quality of the material; the response of the material to imperfections; the consequences and costs associated with rejection of a component; the manufacturing, maintenance, logistics, and failure sequence; and the presence of other failure control procedures and constraints. The importance of many of these factors has been recognized for some time; however, only recently have these diverse factors been quantified and integrated into a methodology for predicting the overall cost effectiveness of the inspection process. This methodology can be used to optimize failure control programs like RFC and to establish meaningful goals for nondestructive inspection and fracture mechanics development programs.

FaAA has developed a general methodology for probabilistic assessment of inspection performance, fracture mechanics, and RFC. Major goals of this project were to convincingly demonstrate the technical feasibility and cost effectiveness of alternative RFC approaches and to evaluate the impact of uncertainty in input data likely to be encountered with actual engine disk life extension. It was felt by the Air Force and ARPA that it was important to refine and apply this new methodology under ARPA funding to develop and verify effective RFC strategies. Furthermore, the retired third stage turbine

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disk from the TF-33 represents a unique opportunity to utilize parts cracked in engine service to verify the basic technologies necessary for RFC.

The specific objectives of this program were:

1. To estimate the state-of-the-art capability to nondestructively detect and evaluate fatigue damage in turbine disks

2. To verify techniques for estimating preinspection material quality from nondestructive observations

3. To establish effective RFC strategies for gas turbine disk life extension

4. To establish the sensitivity of these RFC strategies to uncertainty in inspection performance, materials performance, disk stresses and usage

5. To demonstrate in a laboratory simulation with bolt hole specimens the effectiveness of the RFC strategy

3.0   FATIGUE DAMAGE DETECTION CAPABILITY

FaAA had five independent eddy current inspections performed on the bolt holes of 49 retired TF-33 third stage turbine disks, Figure 3-1. Once the eddy current inspections had been completed, the actual surface length of each crack was determined in the laboratory along with the crack depth for a variety of different surface lengths. The inspection reliability was then obtained for each inspection using the actual laboratory crack sizes.

3.1   Eddy Current Inspection

Five independent eddy current inspections of 490 bolt holes have been performed. Two inspections used the conventional field probe and instrumentation. Two of the inspections utilized conventional state-of-the-art (SOA) eddy current probes and instrumentation, and the last inspection utilized a high-resolution probe and better instrumentation.

All of the eddy current inspections used the same basic procedure. The sensing element is located at a point on the outside diameter of the probe. The probe is then rotated as it screws down through the bolt hole. The speed at which the probe rotates and the axial advancement of the probe per rotation may vary from one inspection to the next. The amount of probe advancement per probe rotation is related to the sensing area. As the magnetic field becomes more concentrated, and reduces the sensing area, the probe advancement is reduced to ensure 100% inspection of the hole. For all of the laboratory inspections, the directions of the probe's sensing element was also known as the probe advanced. This additional feature allowed a distinction between cracks propagating RI and RO.
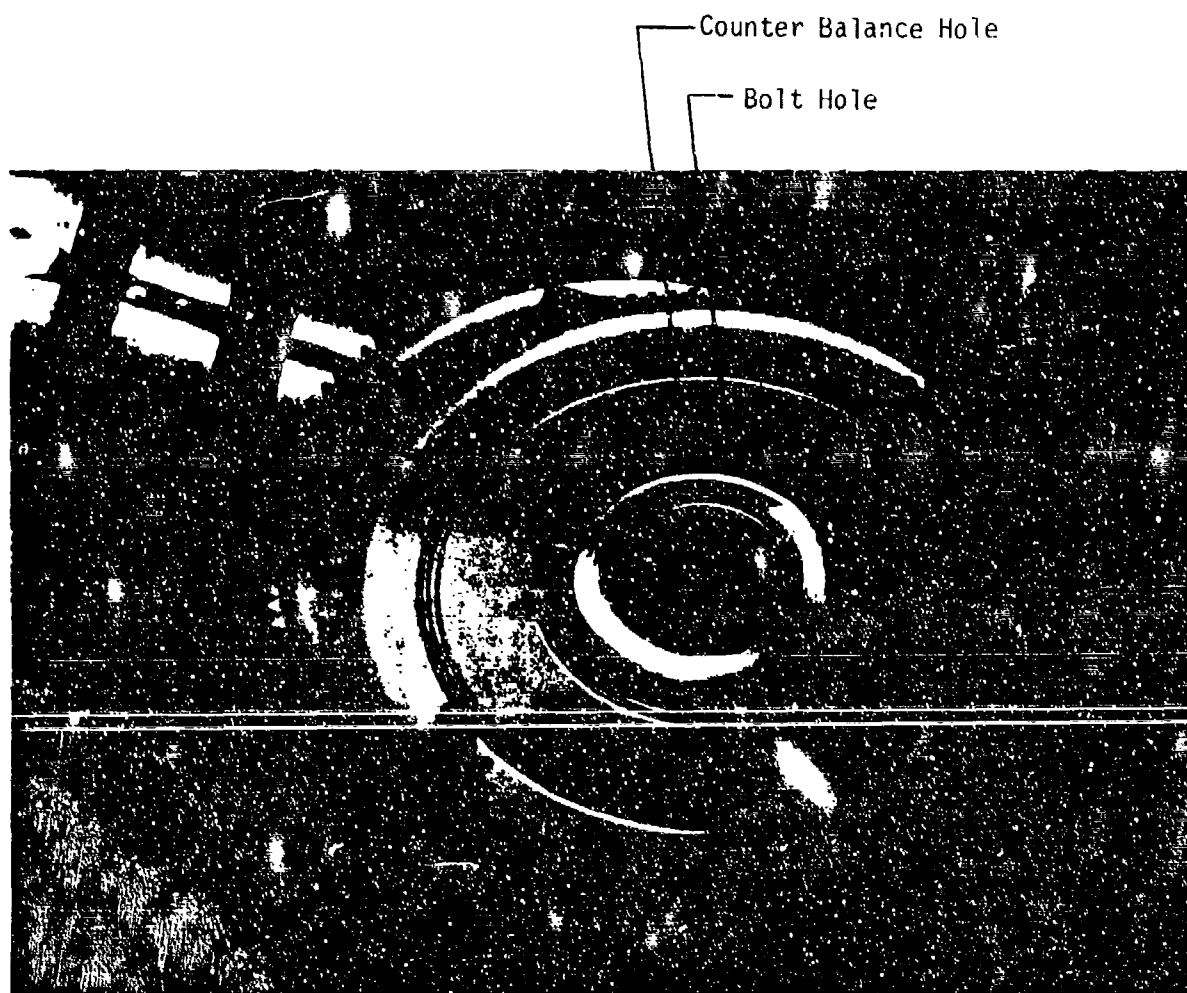
Figure 3-1 - Front View of a Typical TF-33 Third Stage Turbine Disk Showing the Ten (10) Bolt Holes, Each of Which is Separated by a Counter Balance Hole.

The two conventional field inspections were performed at Tinker Air Force Base using Gulton FD-100 inspection units. The first inspection was done using depot personnel on all 50 disks. The second inspection was conducted by Tinker AFB laboratory personnel using only one set of the same equipment. During this second field inspection, 36 disks were inspected and the results were recorded on magnetic tape. Data reduction for the first field inspection was conducted by the depot personnel and data reduction for the second field inspection was performed by FaAA.

The outside laboratory inspections utilizing conventional SOA eddy current equipment actually inspected each bolt hole at each of four frequencies (50, 100, 500, and 1000 KHz) using the NDT-15 instrumentation. These inspections will be identified as outside laboratory results elsewhere in this report. However, only the results of the 500 and 1000 KHz frequencies were selected for complete analysis. FaAA personnel performed the data reduction and analysis of these inspections.

The last inspection using a high-resolution (HR) Reluxtrol 700-29 CREG^{tm} eddy current inspection system. This probe was constructed specifically for this project and operated at 5000 KHz frequency. The crack position, crack length, and crack signal amplitude data reduction was performed by Reluxtrol.

In performing these eddy current inspections, a standard is required for comparison and equipment setup. Bolt hole A of Disk 5T7431 was selected and used as the standard throughout this study. The only exception to use of this standard is the Tinker AFB data. All other inspection data were scaled around the crack within this hole.

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As a crude comparison of inspection results before the real crack sizes were available, the percentage of bolt holes cracked was used. The depot inspection performed at and called by the Tinker AFB personnel indicated that 40.8% (200/490) of the bolt holes have indications. The second depot inspection performed by laboratory personnel at Tinker AFB and called by FaAA indicated that 44.4% (151/340) of the bolt holes have indications. The outside laboratory inspection performed at 1000 KHz for 41 disks and 2000 KHz for the remaining eight disks and called by FaAA indicates that 38.2% (187/489) of the bolt holes have indications. The high-resolution system laboratory inspection performed at 5000 KHz frequency indicated that 55.5% (201/362) of the inspected bolt holes have indications. The high-resolution system results showed the highest percentage of bolt holes which had indications. Both depot inspections and the outside laboratory inspection at 1000 KHz resulted in about the same percentage of crack bolt holes.

3.2   Replication and Destructive Sectioning Results

The fatigue cracks that were detected within the bolt holes from the various eddy current inspections were tightly closed and extremely difficult to detect using plastic replicas. For this reason, a procedure was developed to enhance the detectability of these cracks. The details of this procedure are described below.

Following all of the eddy current inspections, the bolt holes were first optically inspected and measured. The holes were then mechanically polished with 240 grit paper. The 240 grit paper was attached to a rotating arbor that translated up and down while turning at 1725 RPM. Typically the

hole diameter increased by 0.0005 inch during the mechanical polishing. The bolt holes were then electropolished in a 90% methanol and 10% sulfuric acid electrolytic solution. The temperature of the electrolyte was maintained at 5°C and each hole was electropolished for five minutes. This electropolishing procedure removed between 0.0005 and 0.001 inch of the diameter, bringing the total material removed from the surface preparation to less than 0.001 inch, or less than 0.002 inch increase in diameter.

Once the bolt holes' surfaces had been electropolished, a series of scribe lines were added to aid in determining the crack locations. Because each hole has a chamfer on both the front and rear faces of the disk, it was difficult on the replica to exactly locate either the front or rear edge of the bolt hole. For this reason, two circular scribes were placed inside each hole, 0.1 inch from the front and rear faces of the hole, as shown in Figure 3-2. These scribe lines would then be visible on the replica and would act as depth indicators along the axis of the bolt holes. In addit.on to the circular scribe line, scribe lines parallel to the bolt hole center line were added. At the 0° angular position (radially inward) a single scribe line was added, as shown in view AA of Figure 3-2, and at the 180° angular position (radially outward) two parallel scribe lines were added, as shown in view BB of Figure 3-2. These parallel scribe lines are intended to accurately locate the 0° and 180° positions on each replica.

The next step was to make two plastic replicas of each bolt hole, one at the 0° position and one for the 180° position. The replica was then mounted on a glass slide for handling and viewing under the microscope. All replicas were scanned for cracks at a magnification of 100X, and higher magnifications were used to examine suspect areas and to separate artifacts from surface cracks on the replicas.

Bore ← → Rim

View A-A   0° Location

View B-B   180° Location
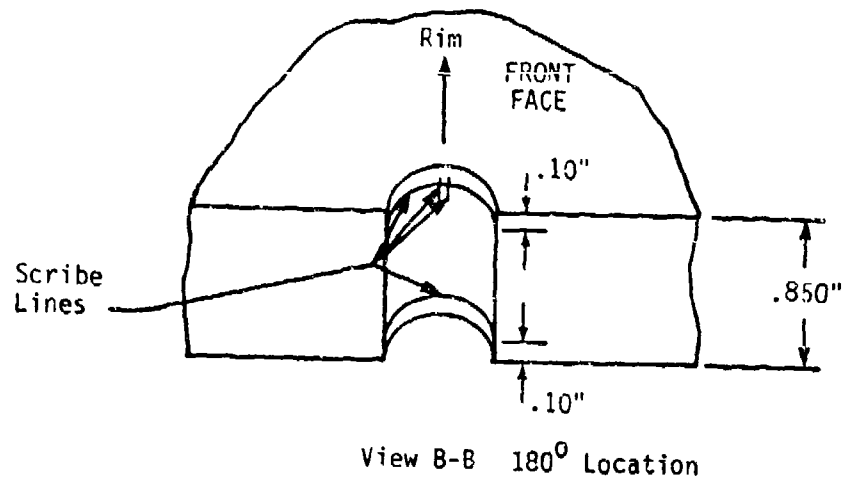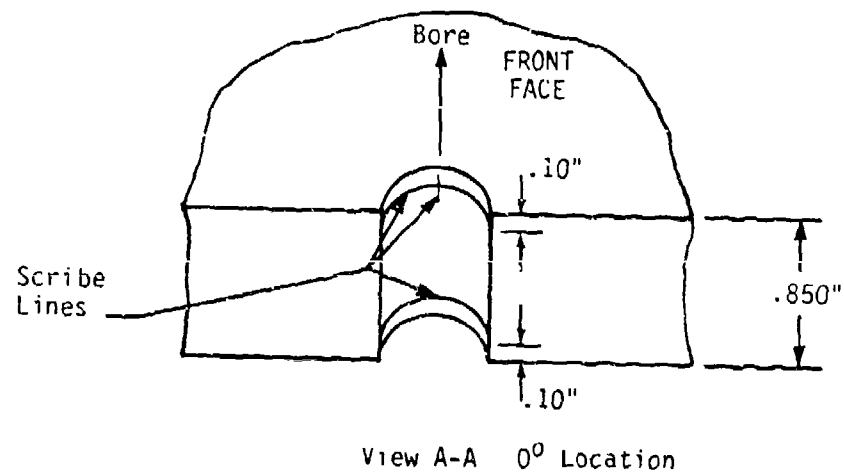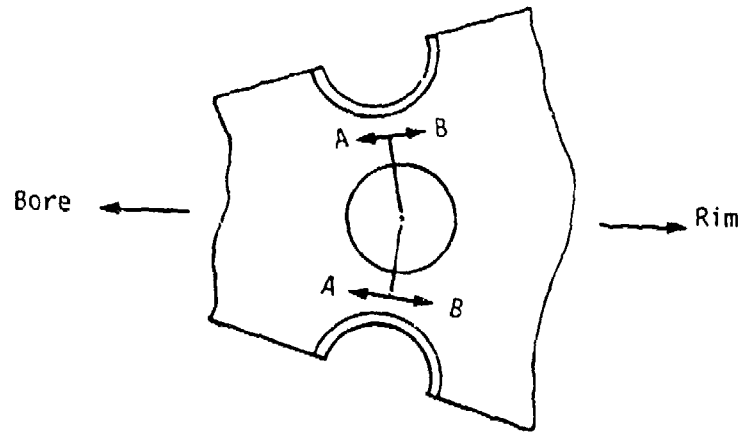
Figure 3-2 – Position of Scribe Lines Placed Inside
Each Bolt Hole for Accurate Angular and
Axial Reference Marks which are Needed
to Record Crack Locations.

The large cracks were easy to identify after this surface preparation. Figure 3-3 shows an example of a 0.025-inch-long RO surface crack at a 100X magnification. Figure 3-4 shows a large indication. Prior to the introduction of electropolishing, even these large indications were difficult to find on the replicas. The number of crack indications found on the replicas as a function of crack surface length is shown graphically in Figure 3-5. As can be seen from this bar graph, over 87% (738/847) of the cracks found were between 0.0 and 0.100 inch. A distribution of crack length within the 0.0- to 0.100-inch range is shown in Figure 3-6. Figure 3-6 shows the 738 cracks less than 0.1 inch long, of which 585 were less than 0.020 inch long.

The dotted line in Figures 3-5 and 3-6 represents a revised population of crack lengths that was determined after reviewing the destructive sectioning results which will be discussed next. Through destructive sectioning, we found that most surface cracks separated by less than 0.040 inch axially on the bolt hole surface were connected on some subsurface plane. One example of this is hole G of Disk 4, in which the replica identified two cracks of 0.007 and 0.018 inch in length, separated by 0.040 inch. The destructive sectioning revealed that these two cracks were connected. It was also observed that when the separation distance was greater than 0.040 inch, cracks were usually not connected below the surface. Hence, the revised crack distribution considered cracks within 0.040 inch of each other on the surface as one crack. This modification reduced the number of cracks to 620. The dotted lines in Figures 3-5 and 3-6 show the revised distributions, and indicate that a large number of small cracks less than 0.020 inch in length were combined to form longer cracks during this data processing.

Figure 3-3 - Example of a 0.025 Inch Long Surface Crack Length
Which was Easily Detected After Electropolishing.
Magnification = 100X.

Figure 3-4 - Large Crack Indication in a Bolt Hole Which Was
Very Easy to Find on the Replica, and Extends
Beyond the Photograph in Both Directions.
Magnification = 100X.
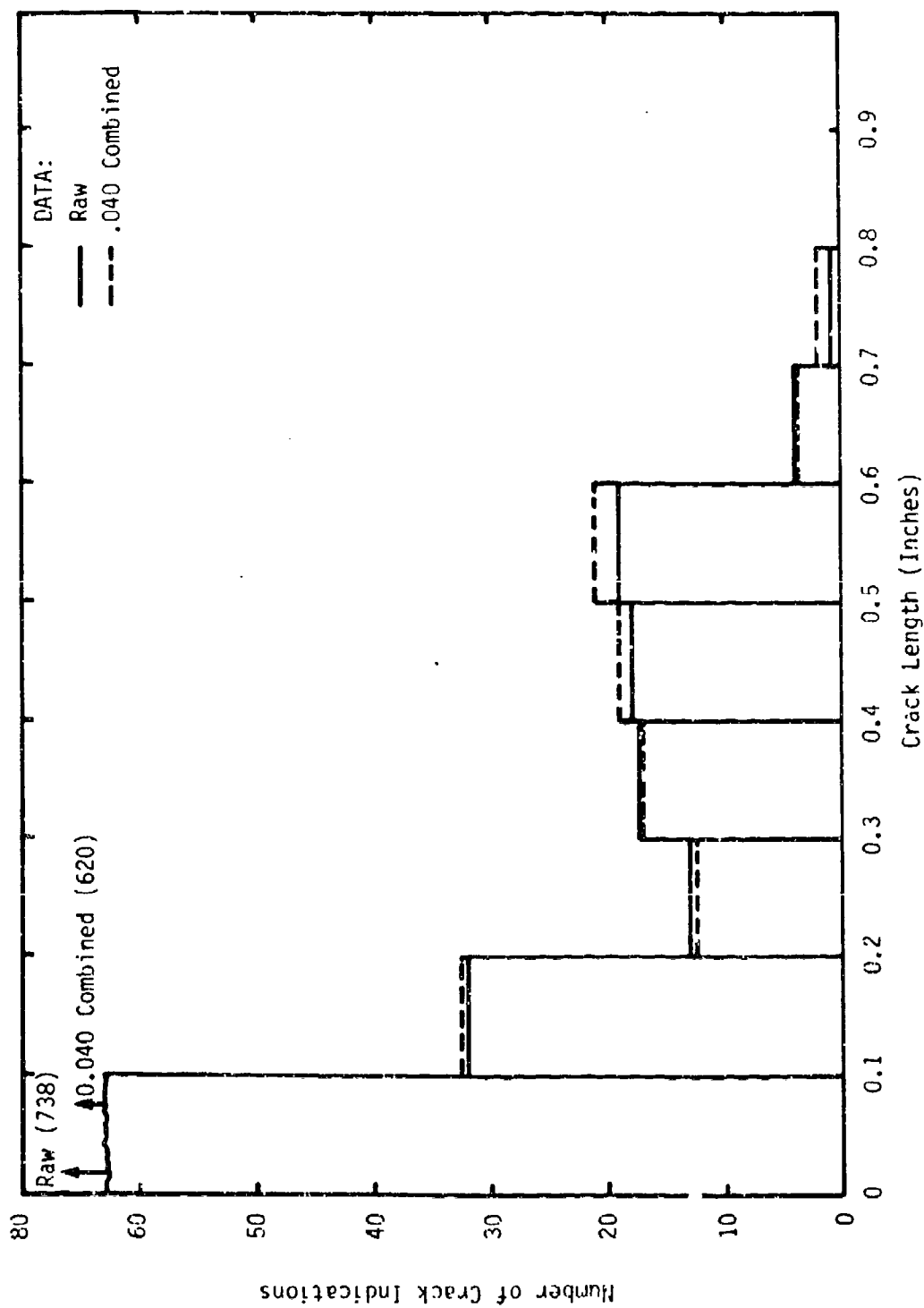
Figure 3-5 – Surface Crack Length Distribution of All Cracks Found in TF-33 Turbine Disks.
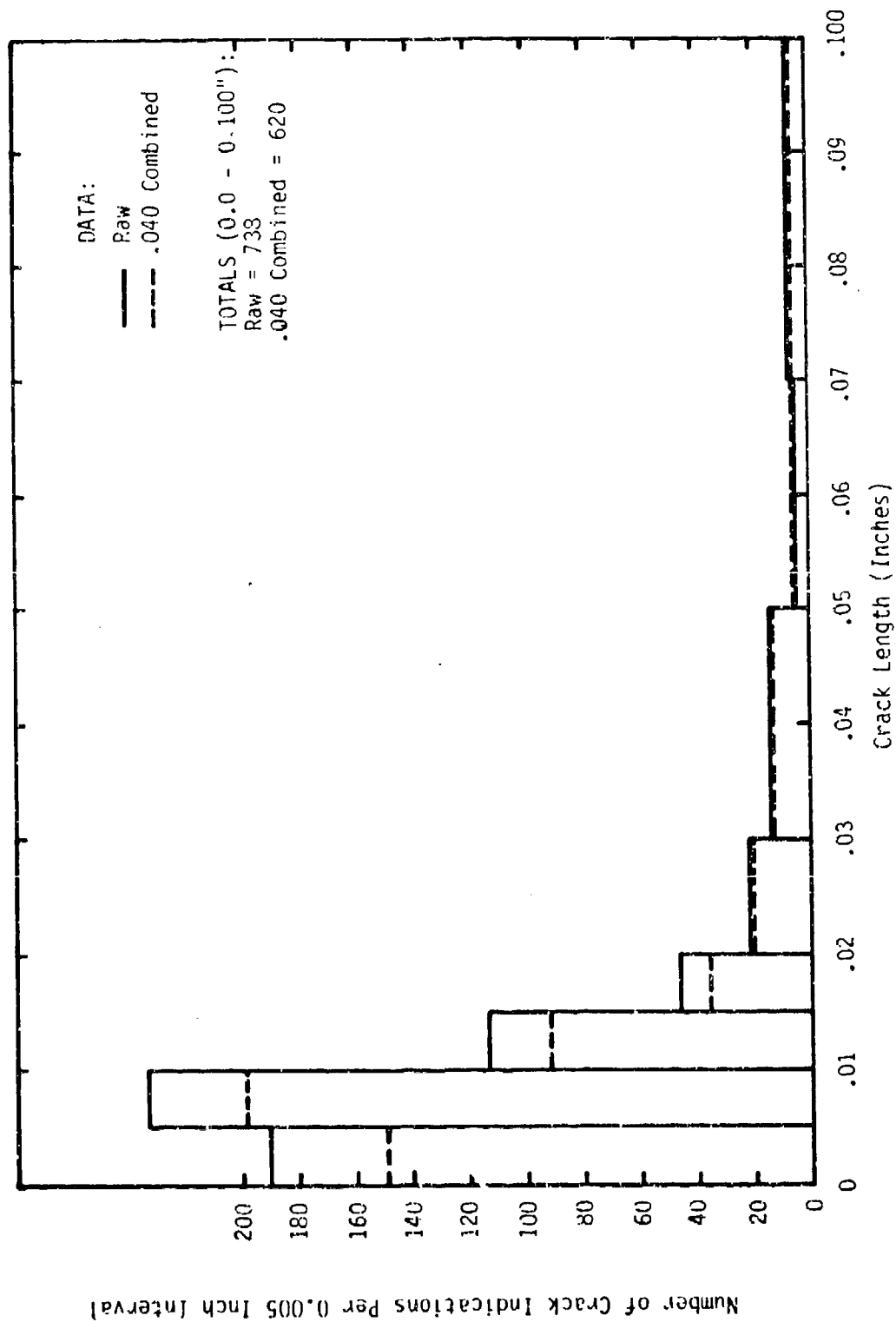
Figure 3-6 - Surface Crack Length Distribution in TF-33 Turbine Disks for Cracks of Length 0.00 - 0.10 Inch.

3-11

Following the replication of all the bolt holes to obtain surface crack lengths, a number of bolt holes were sectioned to obtain the specific crack depth. Some 56 surface indications found in 28 bolt holes were sectioned to obtain the crack aspect ratio for all sizes of surface crack lengths. Sections were taken through the bolt hole parallel to the front face of the disk and at right angles to the center line of the bolt hole. The axial position along the bolt hole center was determined from the replica. If the surface crack was located some distance from either free surface of the disk, the first step was to cut with an abrasive cut-off wheel about 0.030 inch from where the crack first appears on the surface. After the cut, the section was rough polished to the location of interest before final polishing. The final polishing step was with 0.05 micron aluminum oxide powder suspended in water. The section was then inspected under the microscope and any and all crack information was recorded. To locate the crack in the circumferential position, the position of the two longitudinal scribe marks were also recorded.

Once the section plane had been fully documented, the mount was repolished to remove between .002 and .020 inch, depending upon the surface length of the crack as defined by the replica. The crack information at each plaie was recorded, and this procedure was continued until sufficient information was determined for establishing the crack shape (aspect ratic).

For example, the RI location of hole G in Disk 25 has a 0.028-inch-long surface crack as revealed by the replica. Figure 3-7 shows the correlation between the surface crack and the crack depth as revealed through sectioning at various levels. The first crack was found 0.564 inch from the

3-12
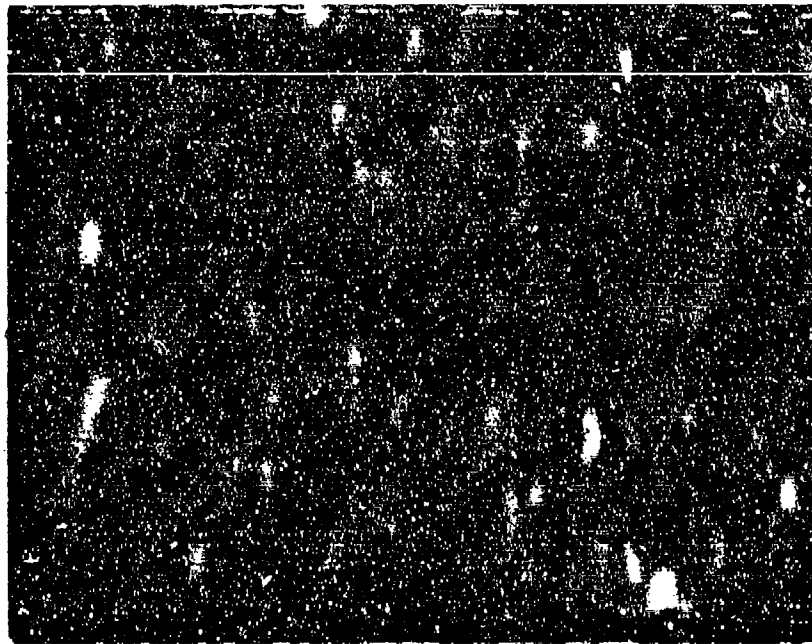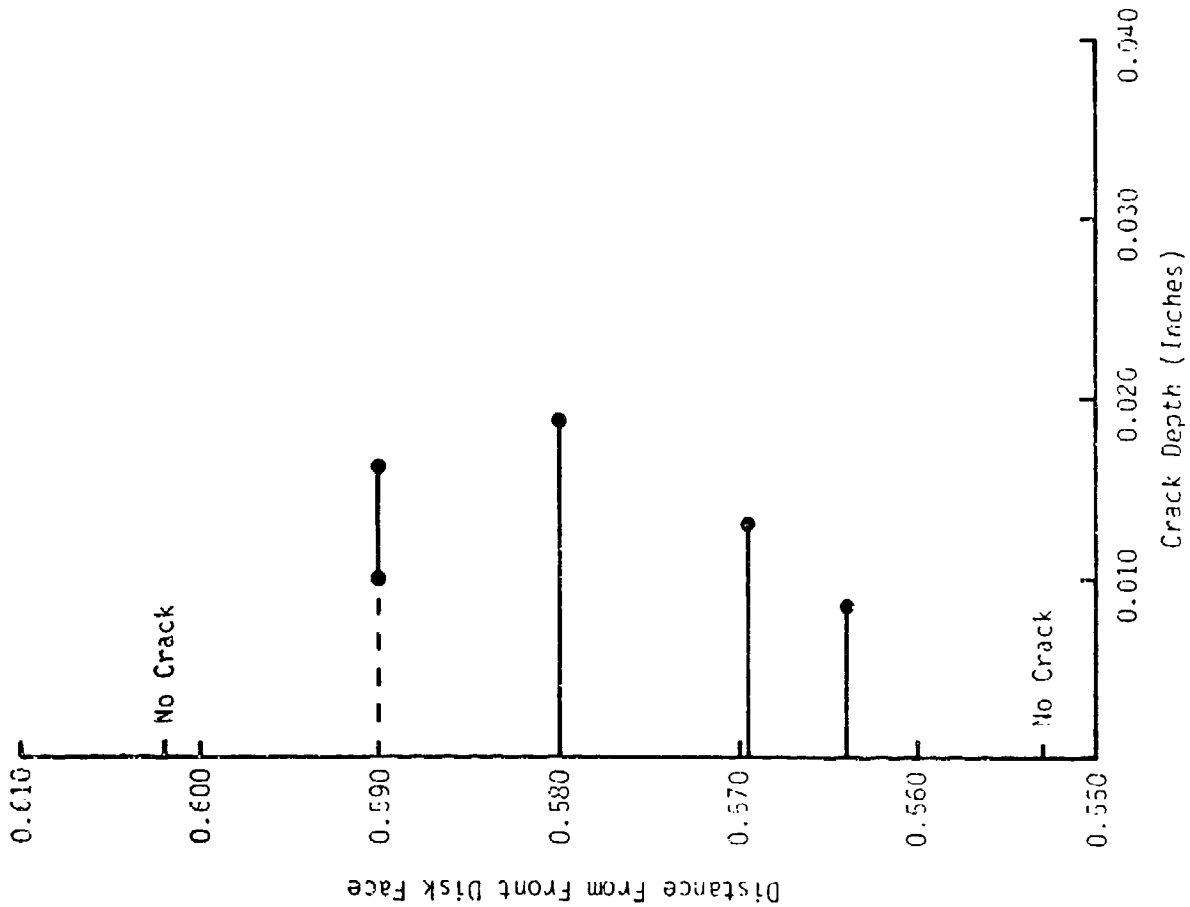
Figure 3-7 - Disk 25, Hole G - Radially Inward Location, Surface Replica vs. Destructive Sectioning Results.

front face of the disk and was 0.009 inch deep. The next section examined was 0.569 inch from the front face of the disk where the crack depth was (0.005 inch from the first level) 0.014 inch. Three additional planes were examined, as indicated in Figure 3-7. The maximum crack depth was 0.018 inch at 0.580 inch from the front face of the disk. Pictures of the cracks found on the four planes are shown in Figures 3-8 and 3-9. Figure 3-8a shows the crack at 0.564 inch; Figure 3-8b shows the crack at 0.569 inch; Figure 3-9a shows the crack at 0.580 inch; and Figure 3-9b shows the subsurface crack at 0.590 inch from the front face of the disk.

The replica of hole E on Disk 4 revealed a surface connected crack 0.030 inch long. Sectioning of this hole indicated a crack longer than 0.060 inch, as shown in Figure 3-10, and shows the extent of subsurface cracking and how the depth of these cracks changes significantly. For example, at the 0.622-inch plane, the crack starts at 0.016 inch and stops 0.024 inch from the bolt hole surface. The next plane was examined at 0.628 inch from the front face of the disk where the crack starts at 0.040 inch and stops 0.057 inch from the bolt hole surface.

Some 28 bolt holes were sectioned to characterize 56 surface crack indications. Destructive sections were chosen to investigate the entire range of surface crack lengths found with the replicas. In addition, a limited number of bolt holes were selected where the replica showed no surface cracks, but which were identified to be cracked by eddy current inspection. In these bolt holes where destructive sections were identified using the eddy current results, about 50% of the signals were confirmed as cracks and 50% were unconfirmed.

a.

0.564 Inches From
Front Disk Face
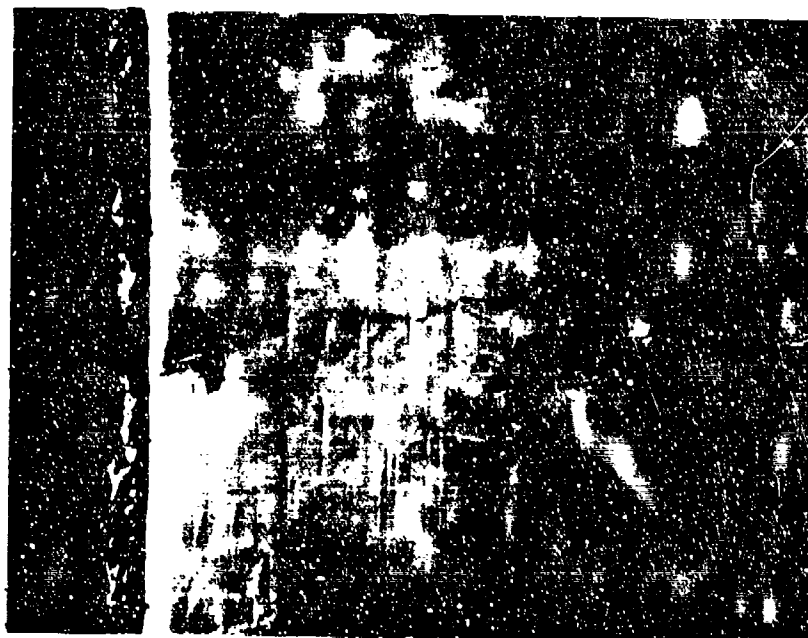
b.

0.569 Inches From
Front Disk Face
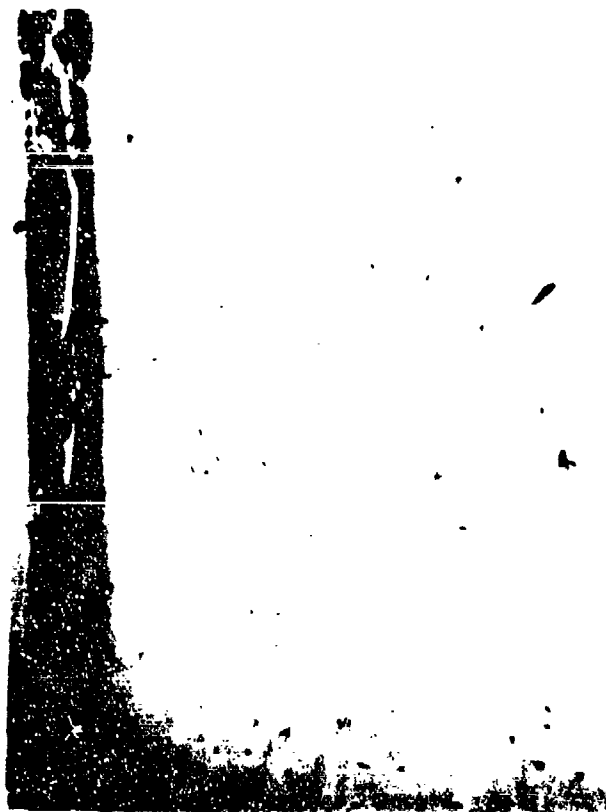
Figure 3-8 - Disk 25, Hole G - Radially Inward Location, Destructive
Sectioning Results. (Front Disk Face is the Inlet Side of
Disk.) Magnification - 200X

a.

0.580 Inches From
    Front Disk Face

b.

0.590 Inches From
    Front Disk Face
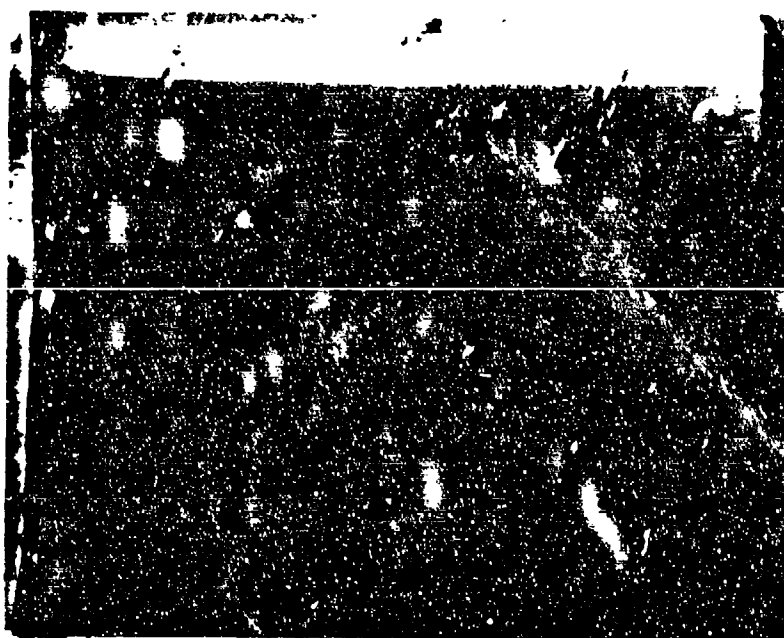
Figure 3-9 - Disk 25, Hole G - Radially Inward Location, Destructive Sectioning
            Results. (Front Disk Face is the Inlet Side of Disk.)
            Magnification - 100X

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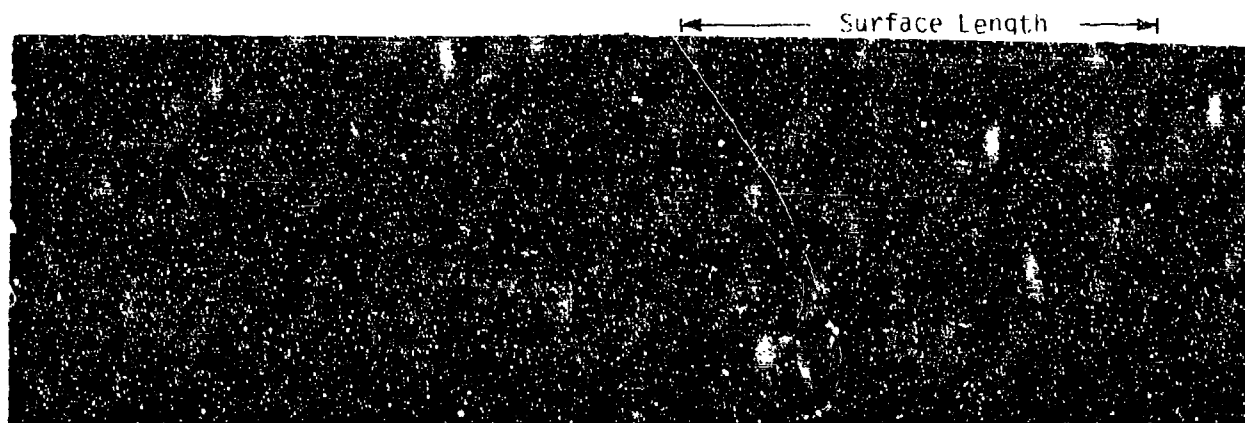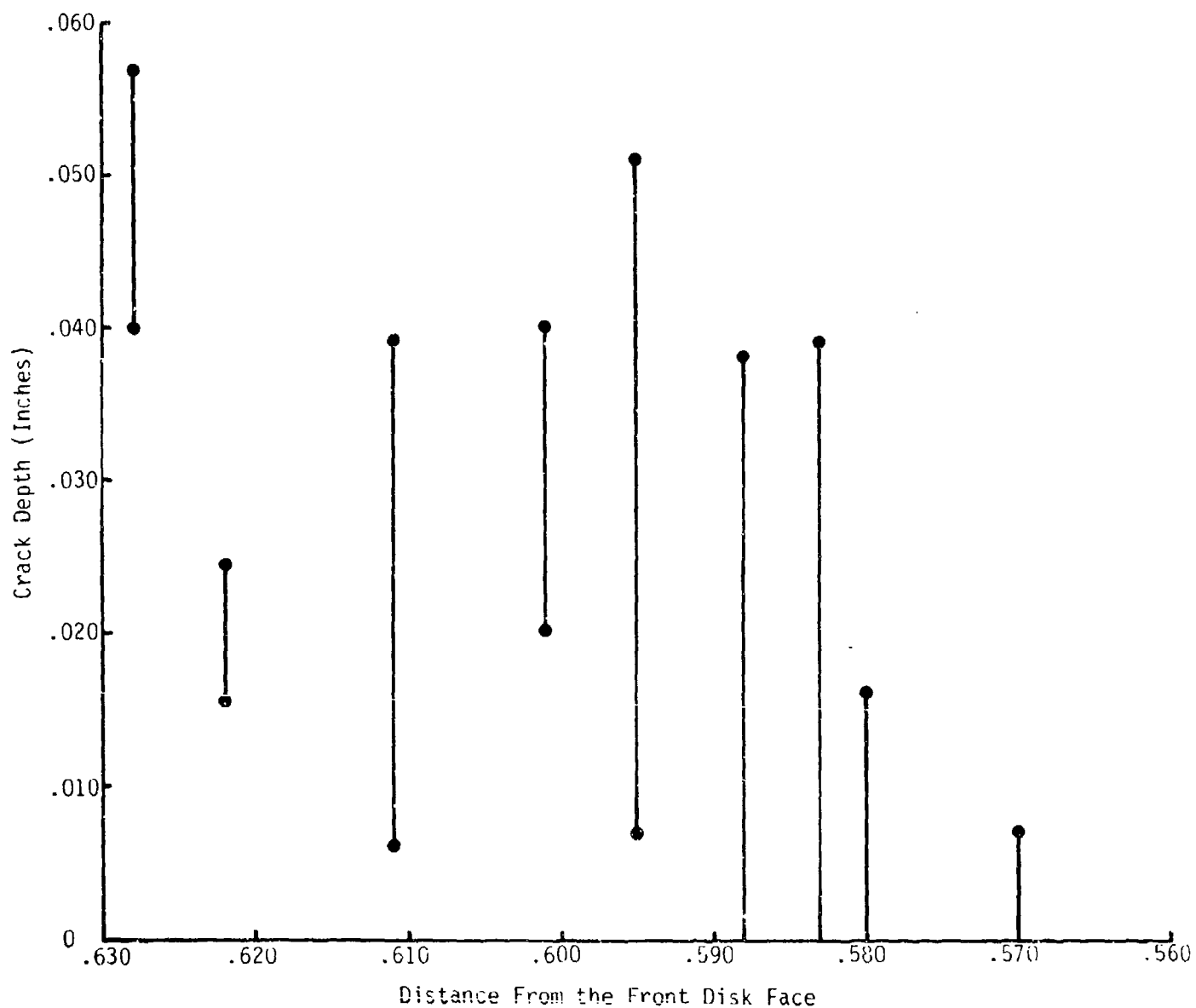
Figure 3-10 - Disk 4, Hole E - Radially Inward Location, Surface Replica vs. Destructive Sectioning Results. Sectioning Shows an Extensive Amount of Sub-surface Cracks. Magnification - 100X

The results of the 725 destructive sectioning planes taken for the 56 surface crack indications are summarized in Figures 3-11 and 3-12. Figure 3-11 shows the real crack length versus the maximum crack depth, where the real crack length includes both surface and subsurface length along the bolt hole axis. In Figure 3-12, the real crack length has been replaced with the surface crack length, where this surface crack length incorporates the separation distance criterion of 0.040 inch for combining cracks. The results of Figure 3-12 were used to estimate crack depth given surface crack length. The straight line shown in both Figures 3-11 and 3-12 represents a constant crack aspect ratio (a/c=0.35), which was used by R. J. Hill [2] for his analysis of spin pit crack growth.

3.3   Conventional Inspection Reliability

In order to make crack length comparisons between the replica results and the eddy current results, a conversion was needed. By knowing the approximate sensing area (i.e., spot size) for both the high-resolution probe and the outside laboratory probe, a conversion was made from the number of consecutive probe turns of eddy current information to crack length for the various eddy current inspections. Table 3-1 shows this conversion for the first eight consecutive turns of the probe and the conversion continues in the same format beyond this point. The table shows only the three inspection results used in the investigation. As was mentioned earlier, the other inspection data could not distinguish between RI and RO cracks within the bolt hole. By distinguishing between these two locations, the number of $1/2$ bolt hole volumes was effectively doubled.

3-18
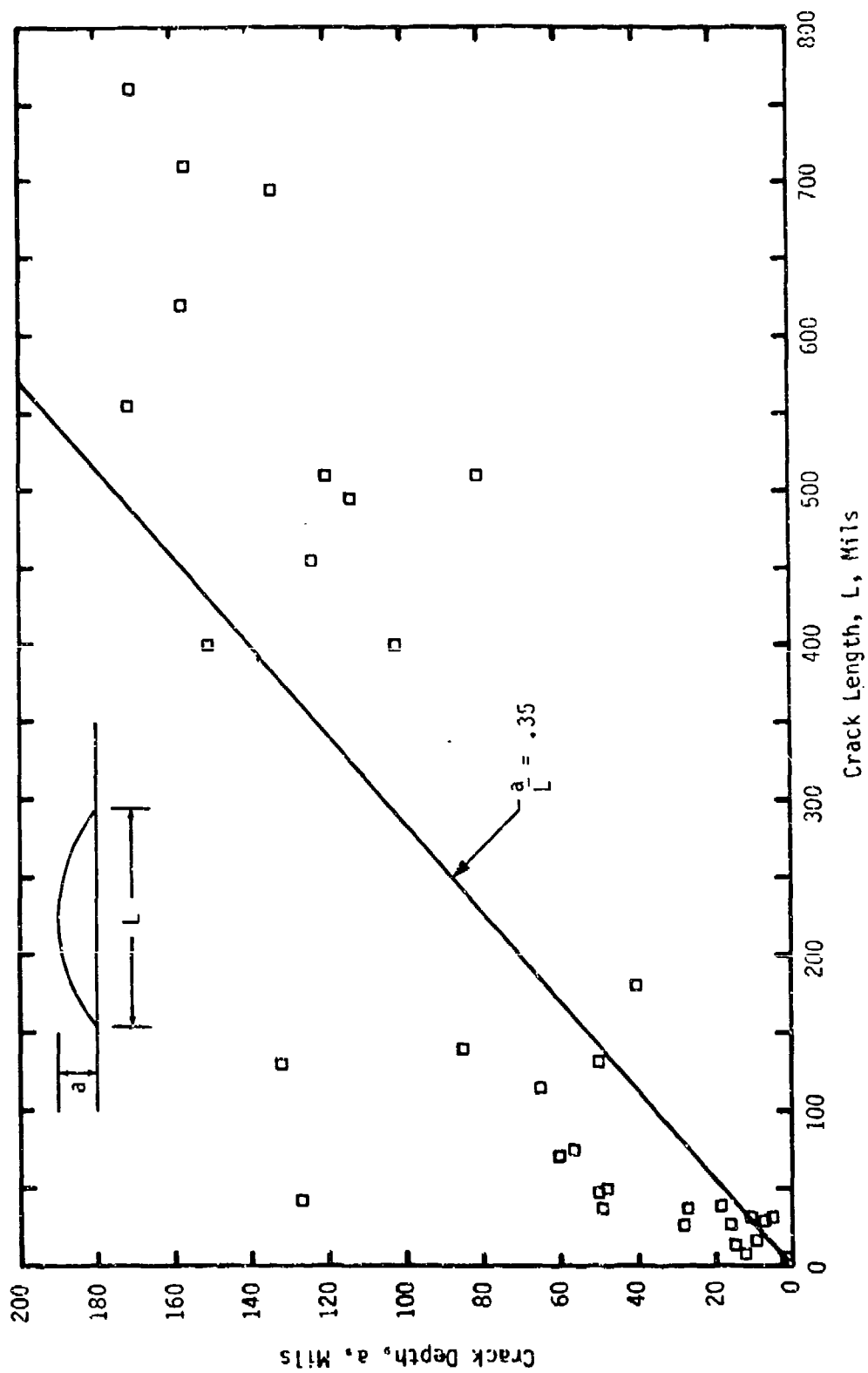
Figure 3-11 - Crack Depth vs. Crack Length for ARPA Bolt Hole Cut-Ups Based On Real Crack Lengths.
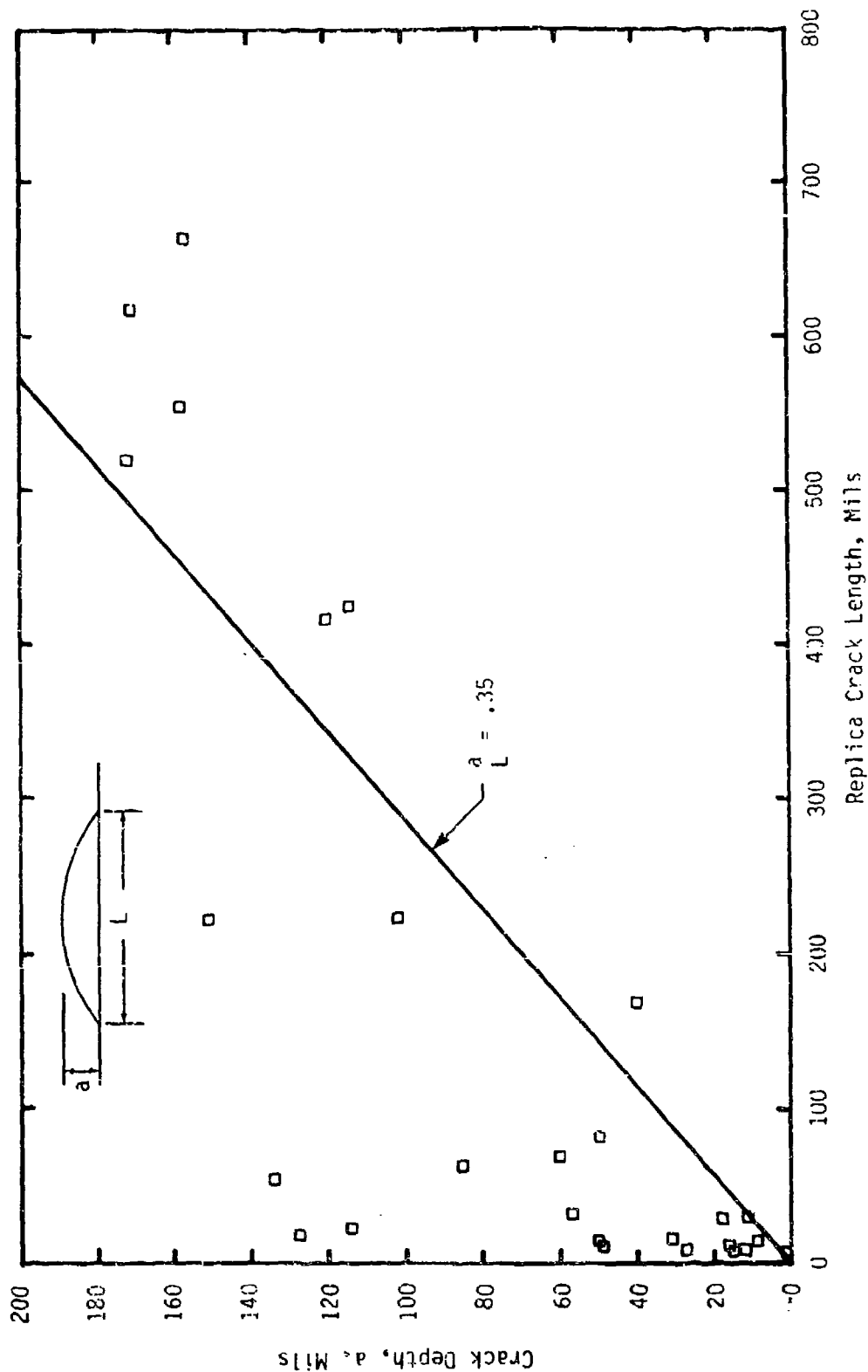
Figure 3-12 - Crack Depth vs. Replica Surface Crack Length for ARPA Bolt Hole Cut-Ups Using the 0.040 Surface Crack Combining Criterion.

NUMBER OF CONSECUTIVE TURNS

CRACK LENGTH IN INCHES (MINIMUM/MAXIMUM)

	2	3	4	5	6	7	8
HIGH RESOLUTION (0.0184"/TURN)	0.0 / 0.0152	0.0 / 0.036	0.0152 / 0.052	0.0336 / 0.0704	0.052 / 0.0888	0.0704 / 0.1072	0.0888 / 0.1256
OUTSIDE LAB (1 MHZ) (0.025"/TURN)	0.0 / 0.0	0.0 / 0.0	0.0 / 0.025	0.0 / 0.050	0.025 / 0.075	0.050 / 0.100	0.075 / 0.125
OUTSIDE LAB (500 KHZ) (0.025"/TURN)	0.0 / 0.0	0.0 / 0.0	0.0 / 0.025	0.0 / 0.050	0.025 / 0.075	0.050 / 0.100	0.075 / 0.125

Table 3-1 - Eddy Current Signal to Crack Length Conversion.

The conventional detection/nondetection counting analysis was conducted using various agreement criteria which are listed below:

Indication agreement: Eddy current (EC) inspector called an indication within the bolt hole.

Location agreement: EC inspector called the correct radially inward (RI) or outward (RO) location within the bolt hole.

Length agreement: EC inspection satisfied the crack location agreement and sized the correct crack length within two times the replica crack length and one-half the replica crack length.

Position agreement: EC inspector's call satisfied the crack length agreement and called the correct axial crack position within $\pm^1/_8$ (± 0.106) inch of the bolt hole height (disk thickness).

As previously discussed, a "0.040-inch combining criterion" was used to obtain the total crack lengths, confirmed by destructive sectioning from multiple nearby crack lengths measured by surface replication. This combining criterion was used prior to constructing the population of maximum crack lengths in $^1/_2$ bolt hole volumes that had been used to generate the inspection reliability values shown in Figures 3-13, 3-14, and 3-15 for each of the three inspection teams. These figures represent the inspection reliability as a function of the precision of the agreement criteria (indication, indication + location, indication + location + length, indication + location + length + position) for selected surface crack length intervals. The general trends of increasing reliability for increasing crack sizes and decreasing reliability for more stringent agreement criteria are present for all three inspections. The high-resolution inspection appears to have a higher reliability than the outside laboratory inspections for all crack length ranges.

3-22
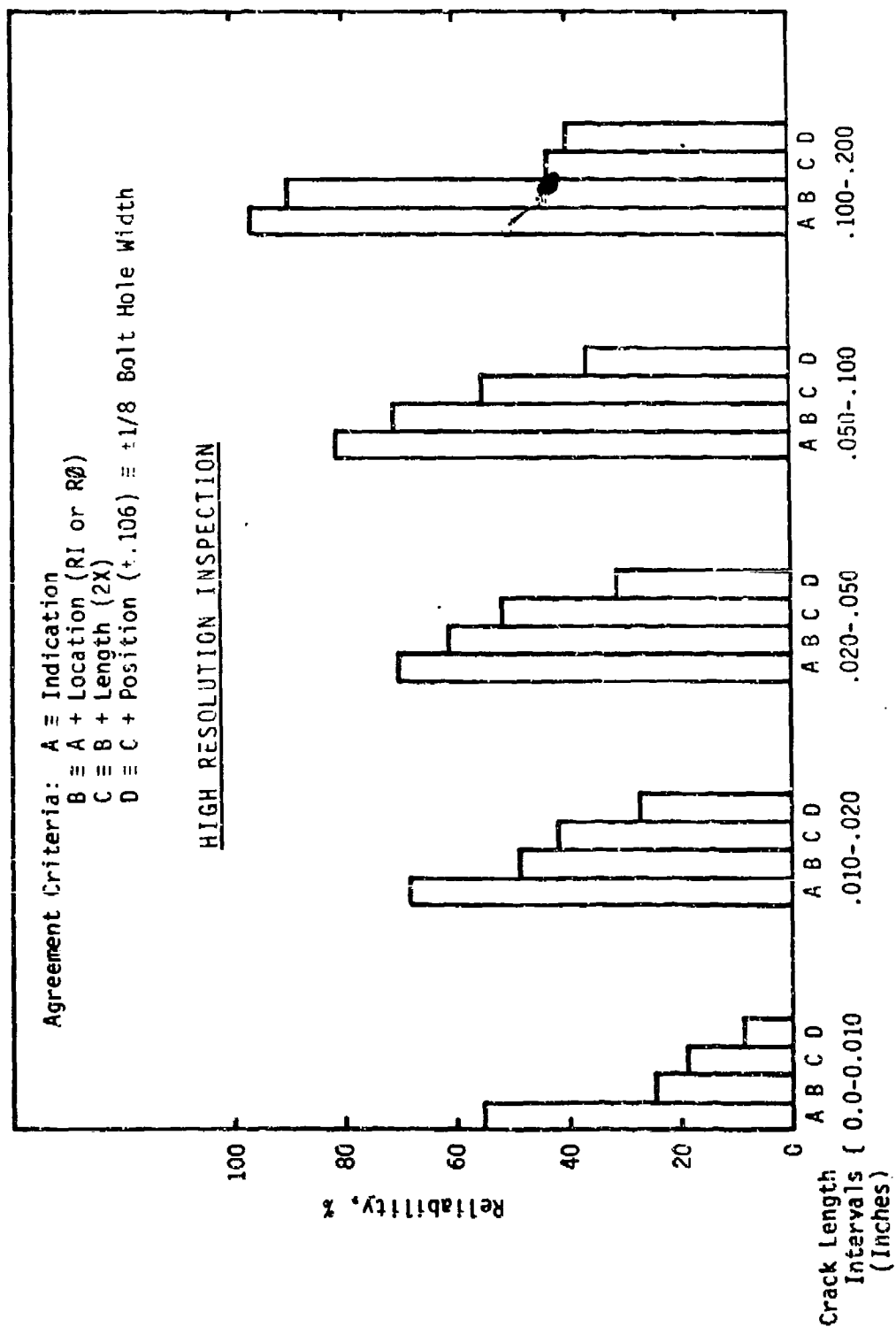
Figure 3-13 - Inspection Reliability For a Maximum Crack Within a 1/2 Bolt Hole Population For High Resolution Inspection As a Function of Various Agreement Criteria. Selected Surface Crack Length Intervals Are Indicated.
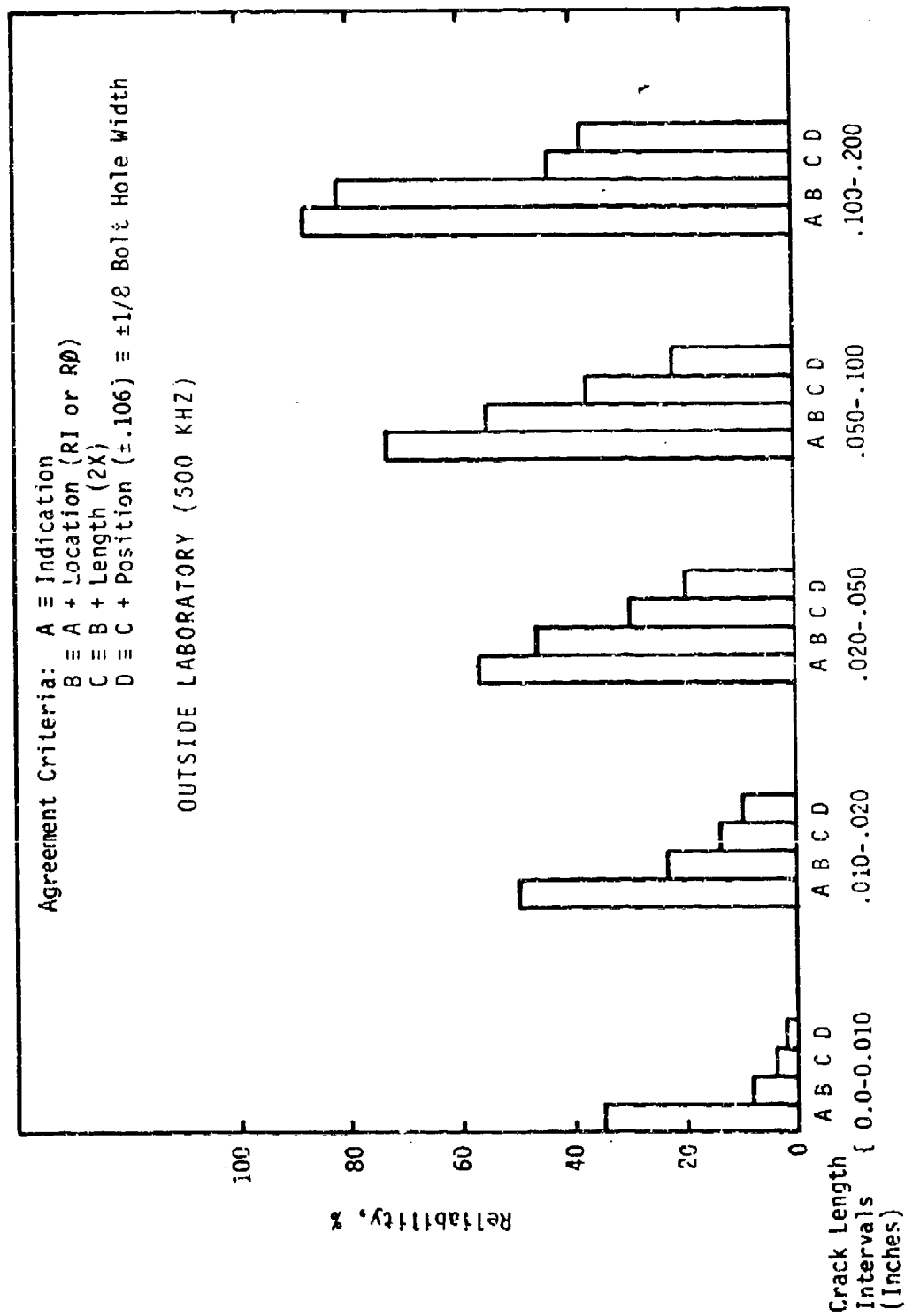
Figure 3-14 – Inspection Reliability For a Maximum Crack Within a 1/2 Bolt Hole Population For Outside Lab (500 KHZ) Inspection As a Function of Agreement Criteria. Selected Surface Crack Length Intervals Are Indicated.
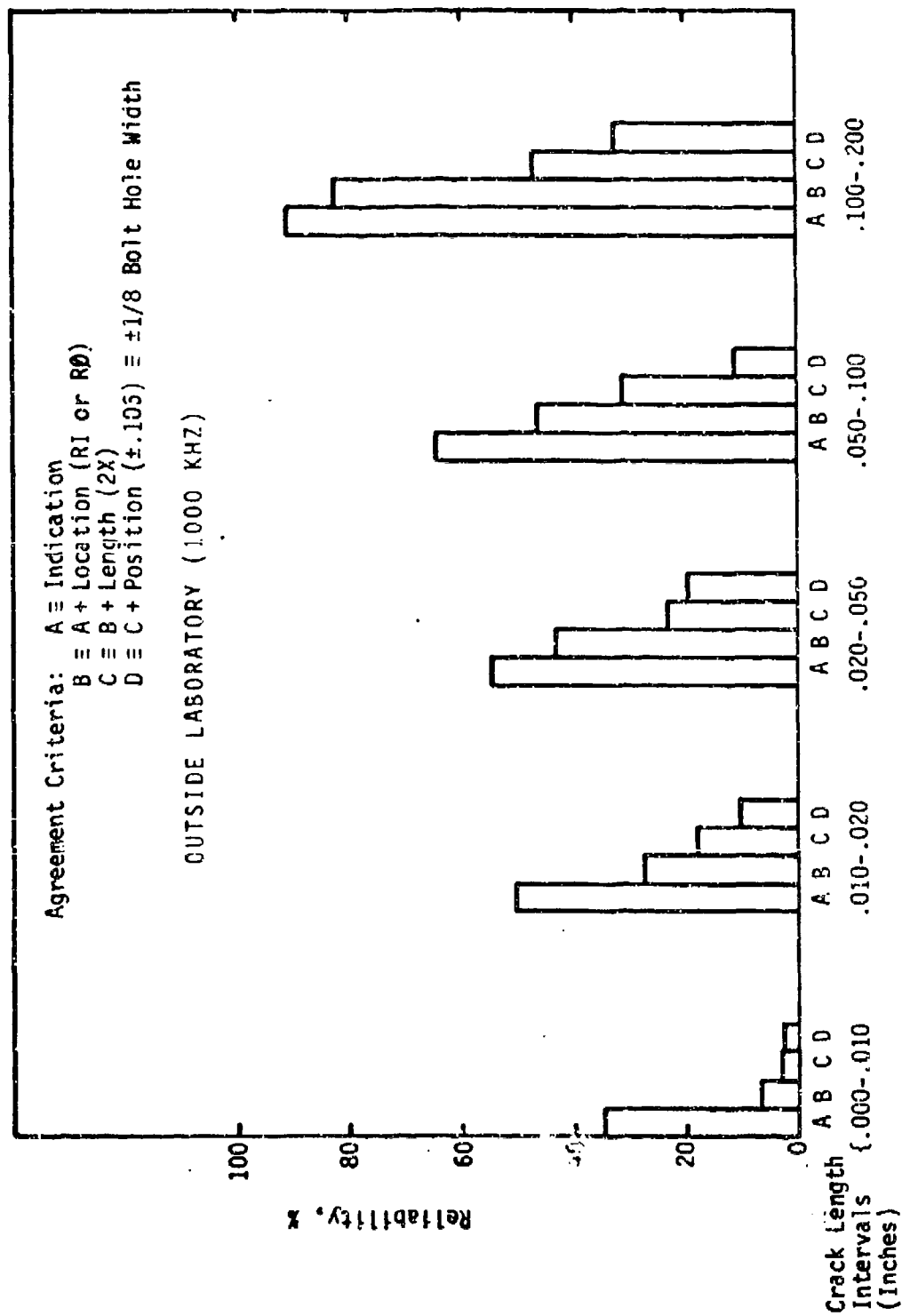
Figure 3-15 - Inspection Reliability For a Maximum Crack Within a 1/2 Bolt Hole Population For Outside Lab (1000 KHZ) Inspection As a Function of Agreement Criteria. Selected Surface Crack Length Intervals Are Indicated.

The inspection reliability values shown in Figures 3-13 through 3-15 are a result of using the conventional detection/nondetection counting analysis with the further requirements of crack length and position agreement. In this type of analysis, the eddy current signal is counted as a crack indication if it exceeds a predetermined signal value and is not counted if it is less than the predetermined value. This counting analysis was used to generate the reliability numbers labeled indication in Figures 3-13, 3-14, and 3-15. Note that no consideration is given to probabilistic aspect of the distribution of probe signals for a given crack size in the conventional analysis. This distribution of maximum eddy current signals for a given maximum real crack size within a $1/2$ bolt hole volume is, however, included in the inspection uncertainty analysis $P(\hat{a}\backslash a)$ which is discussed later within this report.

Eddy current inspection reliability decreases if the inspector specifies the location, length, and position of the crack within the bolt hole volume. This decrease can be attributed to the inspector's inability to correctly size the crack. As was discussed earlier, most cracked bolt holes have numerous cracks; therefore it is impossible to know which crack (if any) the EC inspector is identifying without more specific agreement criteria. For example, it is not very restrictive to ask the EC inspector to identify whether the crack is RI or RO. However, this restriction reduces the high-resolution inspection reliability from 58% to 25% for cracks less than 0.010 inch long and from 82% to 71% for cracks between 0.050 and 0.100 inch long. The same trend is true for the outside laboratory inspection (1000 KHz). The 1000 KHz inspection reliability is reduced from 35% to 10% for cracks less than 0.010 inch long and from 65% to 46% for cracks between 0.050 and 0.100 inch long.

The length agreement criteria is more stringent and for this analysis was based upon Table 3-1. Using Table 3-1 and the acceptance factor of 2 ($^1/_2$ to 2) for crack length, the inspection reliability decreases from 25% to 20% for cracks less than 0.010 inch for the high-resolution inspection, and decrease from 10% to 5% for the outside laboratory (1000 KHz) inspection.

The position agreement criterion is even more stringent and depends upon the inspector's ability to know when the eddy current probe initially enters the bolt hole. However, a positioning error of $\pm^1/_8$ (±0.106) inch of the bolt hole means a tolerance of ±6 probe turns for the high-resolution inspection and ±4 probe turns for both of the outside laboratory inspections to accurately locate the center of the crack.

In the next section of this report, an alternative approach will be discussed to establish the inspection reliability when multiple cracks are present within each $^1/_2$ bolt hole. This approach uses only the maximum replica crack and maximum eddy current signal for each $^1/_2$ bolt hole (1 volume) for comparison, rather than the multiple cracks and multiple eddy current signal that was used in the above analysis.

4.0 INSPECTION UNCERTAINTY ANALYSIS

Inspection uncertainty analysis is a statistical procedure used to express the reliability of an inspection system in a useful manner. The method of analysis accounts for the uncertainty in the inspection signal by establishing the distribution of maximum eddy current crack length, $\hat{a}$, for the maximum real crack length, a, in a $^1/_2$ bolt hole volume, which in turn is used in the following equation for the inspection reliability:

$$P(R\backslash a) = P(D\backslash a)\ P(\hat{a} \geqslant a_{rej} \backslash (a,D))* \qquad (4\text{-}1)$$

where

$P(R\backslash a)$	=	probability of rejecting a $^1/_2$ bolt hole volume given that a crack of length a exists in the volume.
$P(D\backslash a)$	=	probability that inspection system detects a crack of length a.
$P(\hat{a} \geqslant a_{rej}\backslash(a,D))$	=	probability that the apparent crack length determined from eddy current signals is greater than or equal to the rejection crack size given that a crack of length a exists and has been detected.

As can be seen from equation (4-1), $P(\hat{a} \geqslant a_{rej}\backslash(a,D))$ describes the distribution of eddy current signals for a given crack size after detection has occurred. The probability of rejection given a maximum crack of length a is composed of

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* See Appendix D for a discussion of probability notation.

detection and sizing events. Through our data manipulation, the detection and sizing events have been combined and presented as cne event which can be represented by $P(\frac{\hat{a}}{a} > x \backslash a)$ and can be restated as $P(\hat{a} > a_{rej} \backslash a)$. Although a_{rej} is not specified, the inspection uncertainty function $P(\hat{a} \backslash a)$ had been determined for all three inspections, and it can be used to develop $P(\hat{a} > a_{rej} \backslash a)$ for any specified inspection-rejection level, a_{rej}.

4.1 Conversion of Eddy Current Signals to Crack Length (inch)

Prior to establishing $P(\hat{a} \backslash a)$, the eddy current crack length in inch, $\hat{a}$, has to be defined in terms of the inspection signal outputs of number of probe turns and voltage amplitude (percent calibration scale). To this end, a non-linear regression analysis was used to correlate the maximum real crack length found by replication within a $1/2$ bolt hole volume to both the number of probe turns and voltage amplitude for the maximum eddy current signal recorded within in the corresponding bolt hole. For the high-resolution inspection results and real surface crack lengths below 0.100 inch, there appeared to be a stronger correlation between crack length and voltage amplitude than between crack length and number of probe turns. This stronger correlation was analytically confirmed by the nonlinear regression analysis. For both outside laboratory inspection results, the nonlinear regression analysis resulted in neither turns nor voltage amplitude as being preferred for small crack sizes. The number of turns was therefore chosen in the nonlinear regression analysis to compute $\hat{a}$.

The following best fit equations represent the strongest correlation to convert the inspection results to surface crack length:

Outside Laboratory (500 KHz) Inspection

$$\hat{a} = 4.68 \times 10^{-3} \text{ (Turns)}^{1.466} + 7.89 \times 10^{-3}, \text{ for Turns} > 3 \quad (4\text{-}2)$$

Outside Laboratory (1000 KHz) Inspection

$$\hat{a} = 6.64 \times 10^{-3} \text{ (Turns)}^{1.342} + 8.07 \times 10^{-3}, \text{ for Turns} > 3 \quad (4\text{-}3)$$

High-Resolution Inspection

$$\hat{a} = \left[1 - e^{\frac{-\text{Turns}}{5.85}}\right]\left[2.38 \times 10^{2} \text{ (Turns)}^{0.851} + 3.5 \times 10^{2}\right] +$$

$$\left[e^{\frac{-\text{Turns}}{5.85}}\right]\left[2.48 \times 10^{-4} \text{ (AMP)}^{1.187} + 6.59 \times 10^{-3}\right], \text{ Turns} > 1 \quad (4\text{-}4)$$

Note that for the high-resolution inspection, the bracketed expression involving amplitude will dominate for eddy current signals with a low number of turns (<5.85 turns) whereas the bracketed expression involving turns will dominate for eddy current signals with a larger number of turns (>5.85 turns). The $e^{\frac{-\text{Turns}}{5.85}}$ terms provide for a smooth curve fit in the vicinity of 5.85 turns. Examination of equation (4-4) at the point where no eddy current signal was observed (Turns=0, Amp=0) results in a crack length of 0.0066 inch instead of zero. This value is a result of the extrapolation performed by the regression analysis and it does not imply that 0.0066-inch cracks were assumed present with no inspection indication. In fact, when Turn < 1 the apparent crack size was assumed zero. The same is true for both outside laboratory results. Equation (4-2) for the outside laboratory (500 KHz) results indicate $\hat{a}$ = 0.0079 inch when turns = 0 and for the outside laboratory (1000 KHz) results, equation (4-3), indicates $\hat{a}$ = .0081 inch when Turns = 0. In both cases when the number of Turns was less than 3, the apparent crack size was assumed zero.

4-3

In the next step of the analysis, equations (4-2), (4-3), and (4-4) were used to generate the apparent crack size $\hat{a}$. This apparent crack size was obtained by substituting the measured signal responses of probe turns and/or voltage amplitude into the appropriate equation. Figures 4-1, 4-2, and 4-3 show the results of this substitution and indicate apparent crack size, $\hat{a}$, versus real crack length, a, for the high-resolution, outside laboratory (500 KHz) and outside laboratory (1000 KHz) inspections, respectively. In each of these figures a line labeled exact correlation is shown which represents a one-to-one correspondence to observed eddy current crack lengths and replicated crack lengths. A generally expected trend, which can be seen in Figures 4-1, 4-2, and 4-3, is that less scatter (in terms of percent error in estimating a) is observed in $\hat{a}$ as a approaches larger crack sizes. This trend is a result of the nonlinear analysis because the regression was minimized on crack length differences. It could also have been minimized on percent error instead, however, for the TF33 RFC analysis, sizing of large cracks is more important than sizing small cracks.

After establishing $\hat{a}$ versus a for the 3 different inspectors, the frequency function $P(\hat{a}\backslash a)$ was established by taking selected real crack length intervals and establishing the distribution of $\hat{a}$ within the intervals.

4.2 Establishing $P(\hat{a}\backslash a)$

The distribution of maximum apparent crack size, $\hat{a}$, given a maximum real crack of length, a, in a $1/2$ bolt hole volume was established from the results shown in Figures 4-1, 4-2, and 4-3. Vertical slices which represented

4-4
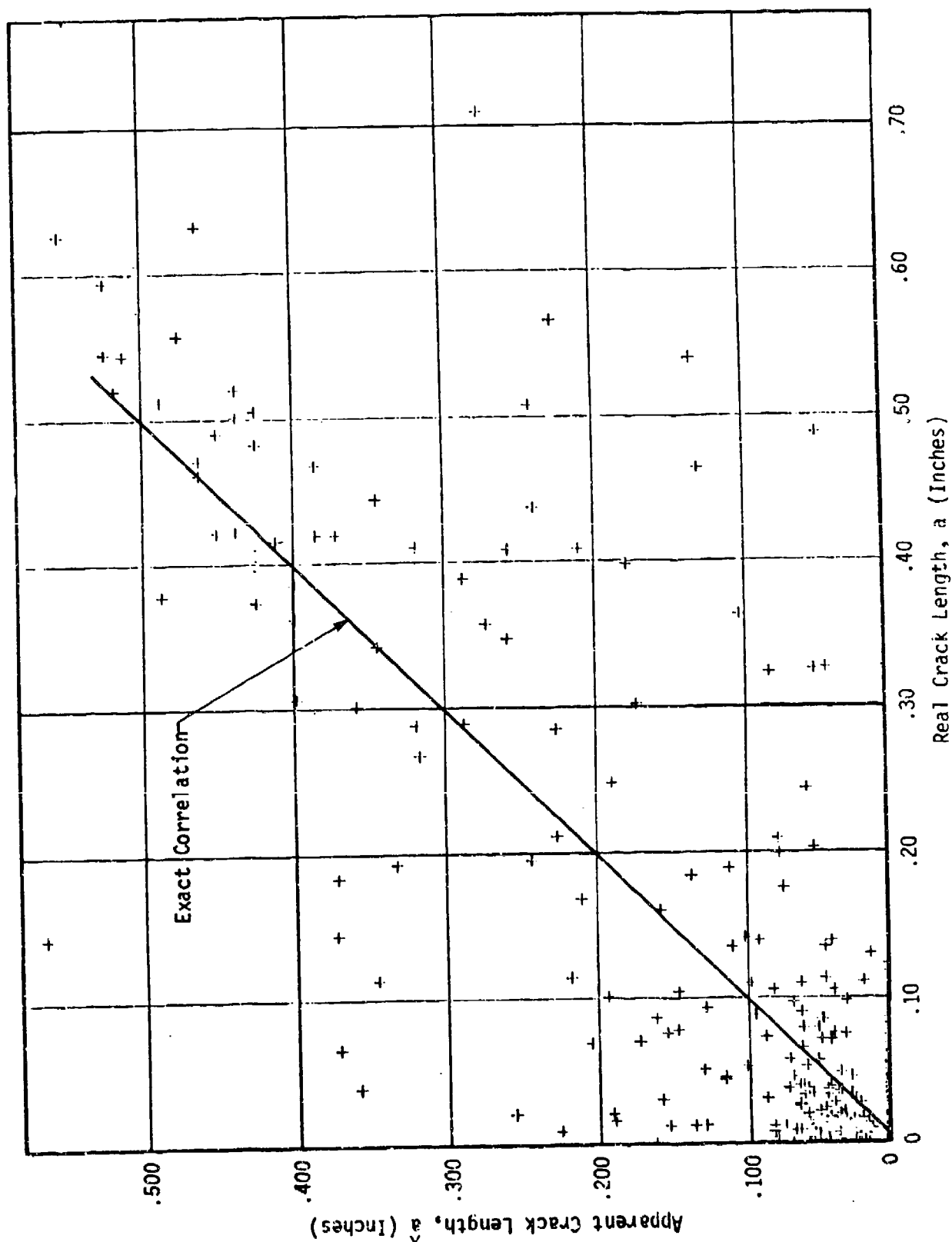
Figure 4-1 - Apparent Crack Length from High Resolution Inspection Signals Versus Real Crack Length Measured by Replication. Equation 4-4 was Used to Convert Eddy Current Inspection Results to Apparent Crack Length.
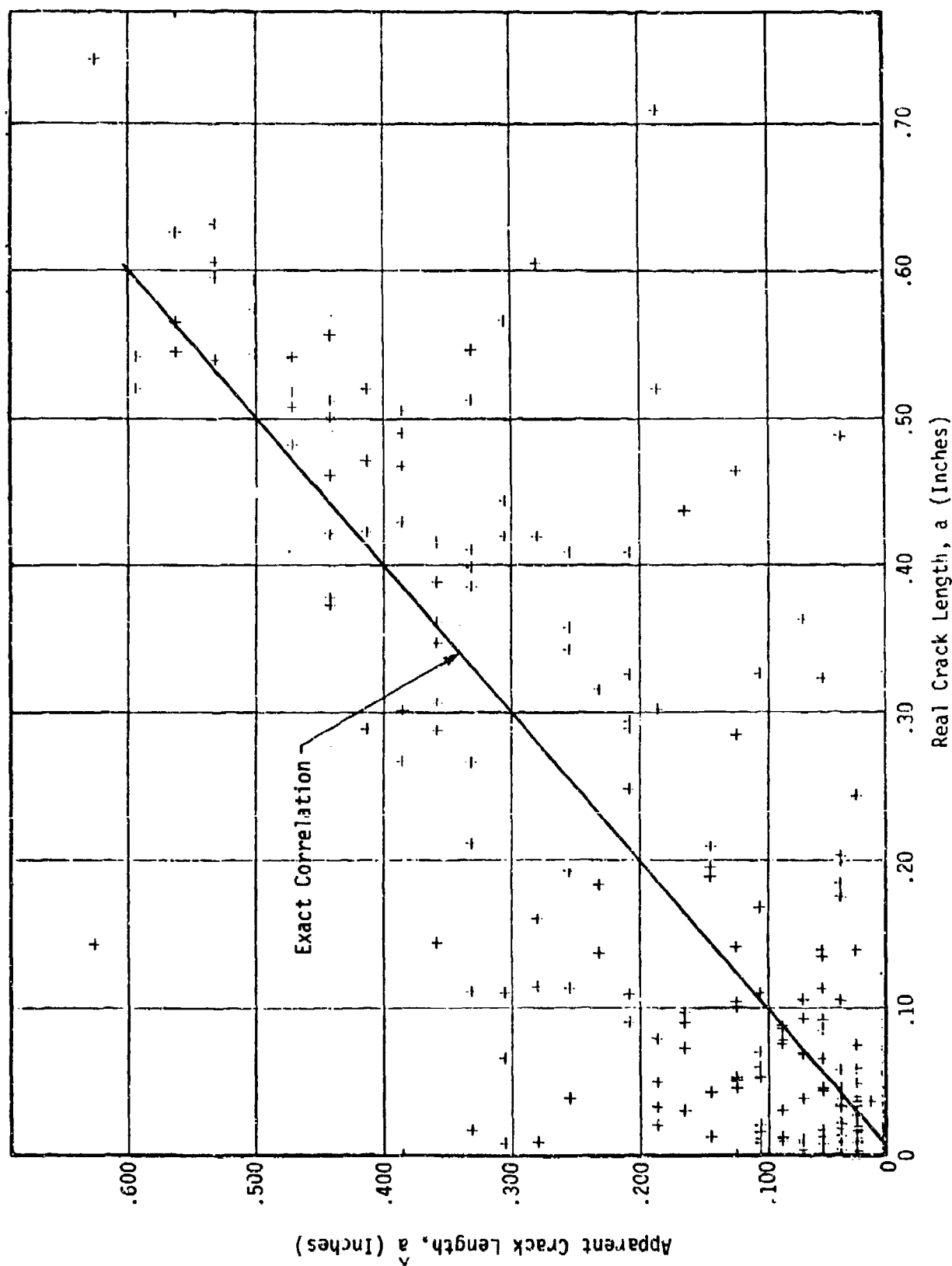
Figure 4-2 - Apparent Crack Length from Outside Lab (500 KHZ) Inspection Signals Versus Real Crack Length Measured by Replication. Equation 4-2 was Used to Convert Eddy Current Inspection Results to Apparent Crack Length.

4-6
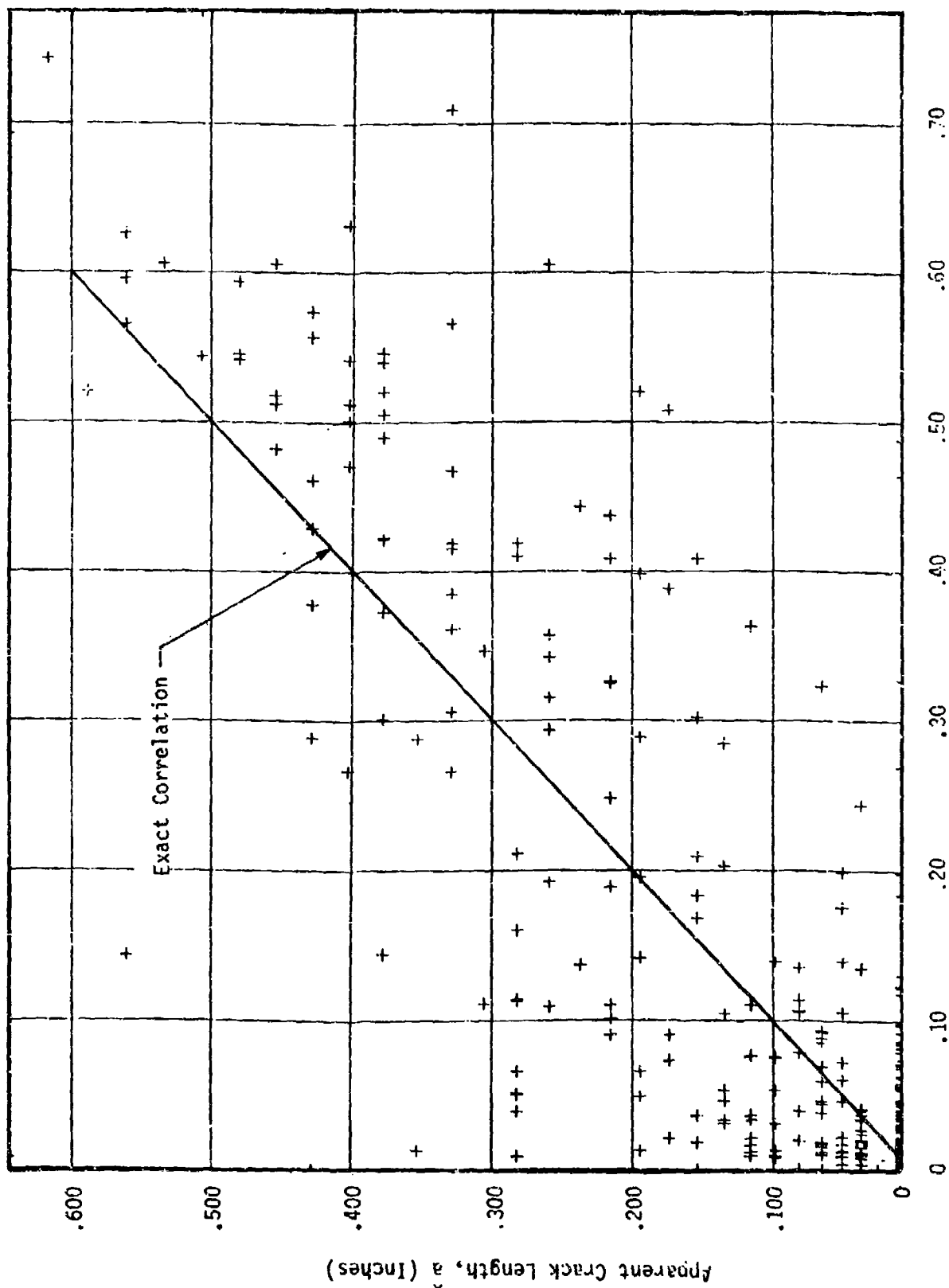
Figure 4-3 – Apparent Crack Length for Outside Lab. (1000 KHZ) Inspection Signals Versus Real Crack Length Measured by Replication. Equation 4-3 was Used to Convert Eddy Current Inspection Results to Apparent Crack Length.

4-7

real crack length intervals were selected, and the cumulative frequency distribution of the ratio of $\hat{a}$ to a was tabulated and plotted on Weibull probability paper. Figures 4-4, 4-5, and 4-6 are representative plots of the cumulative distribution, $P(\hat{a}\backslash a)$, for the real crack intervals of 0.001 to 0.010, 0.040 to 0.060, and 0.100 to 0.200 inch, respectively, for the high-resolution inspection. A few items must be mentioned to help interpret these figures. Taking Figure 4-5 as an example, an abscissa value of $\hat{a}/a=2$ implies that given a real crack of length 0.050 inch (i.e., which lies in the interval 0.040<a<0.060 inch), the apparent crack length observed by the eddy current inspection would be less than twice that (or 0.100 inch) 82% of the time. The circled data points on these figures indicate cracks within the $1/2$ bolt hole volumes which went undetected ($\hat{a}=0$) by the high-resolution eddy current inspection. Although nondetection points are plotted according to equations (4-2), (4-3), and (4-4) with $\hat{a}=0.0066$, the nondetection points will be input as $\hat{a}=0$ in the RFC procedure. In Figure 4-4, the detected and nondetected crack sizes overlap while in Figures 4-5 and 4-6 there is a sharp delineation between detection and nondetection. For example in Figure 4-5, the probability of not detecting a crack in this interval is about 50%, and in the 0.100- to 0.200-inch crack length interval summarized by Figure 4-6, the nondetection probability is about 10%. Given an actual crack length of between 0.040 and 0.060 inch, 90% of the time the apparent crack size will be less than 2.5 times the real crack size, i.e., $\hat{a}/a<2.5$. Similar results have been generated for both of the outside laboratory inspections.

Several trends can be seen for the high-resolution inspection uncertainty by comparing Figures 4-4, 4-5, and 4-6, which is similar for the other

4-8

Figure 4-4 - Cumulative Frequency Distribution of Apparent Crack Length to Real Crack Length for High Resolution Inspection. For Clarity Not All Points Have Been Plotted, Only a Representative Sample. Real Crack Length Range: 0.001 - 0.010 Inch.
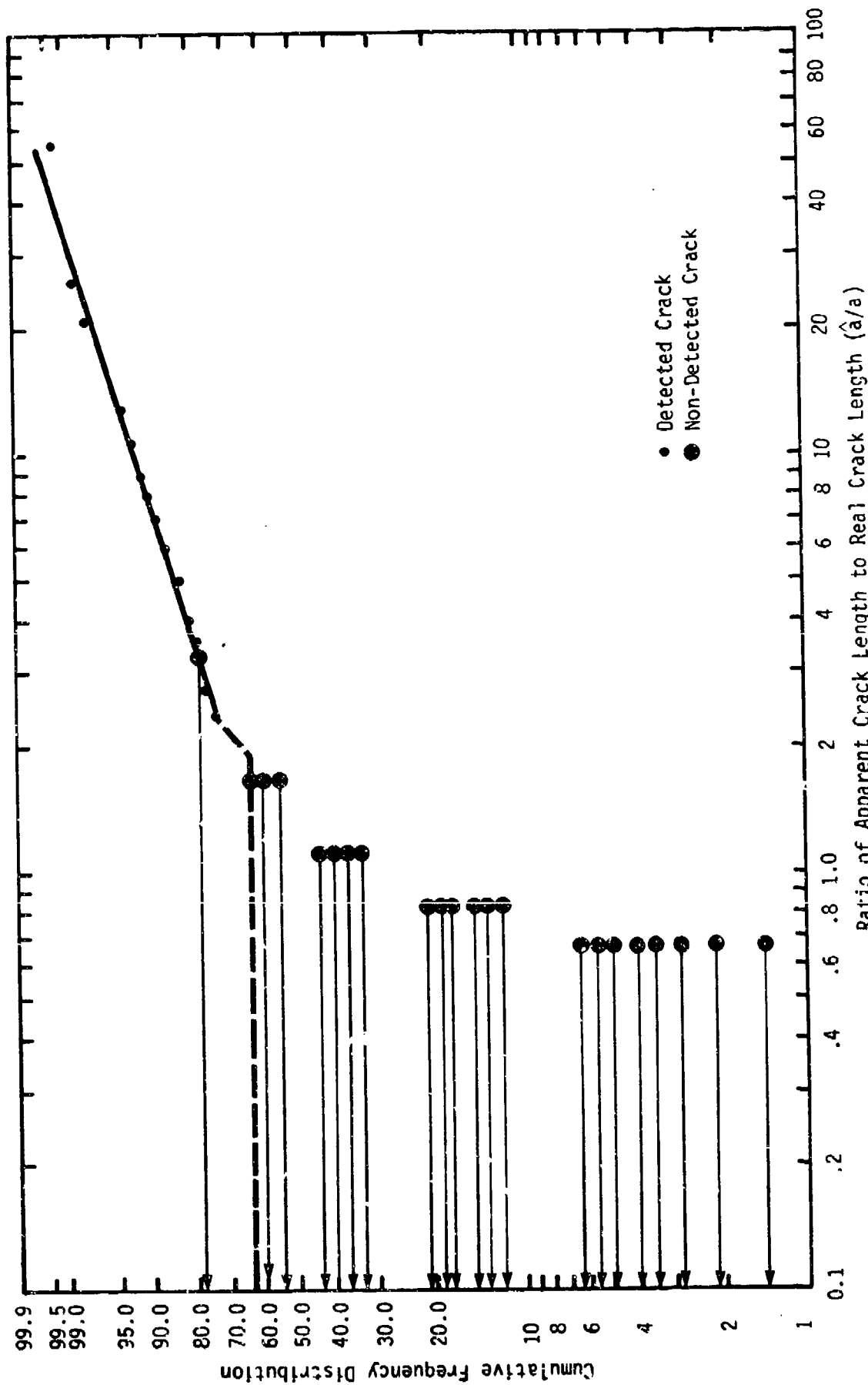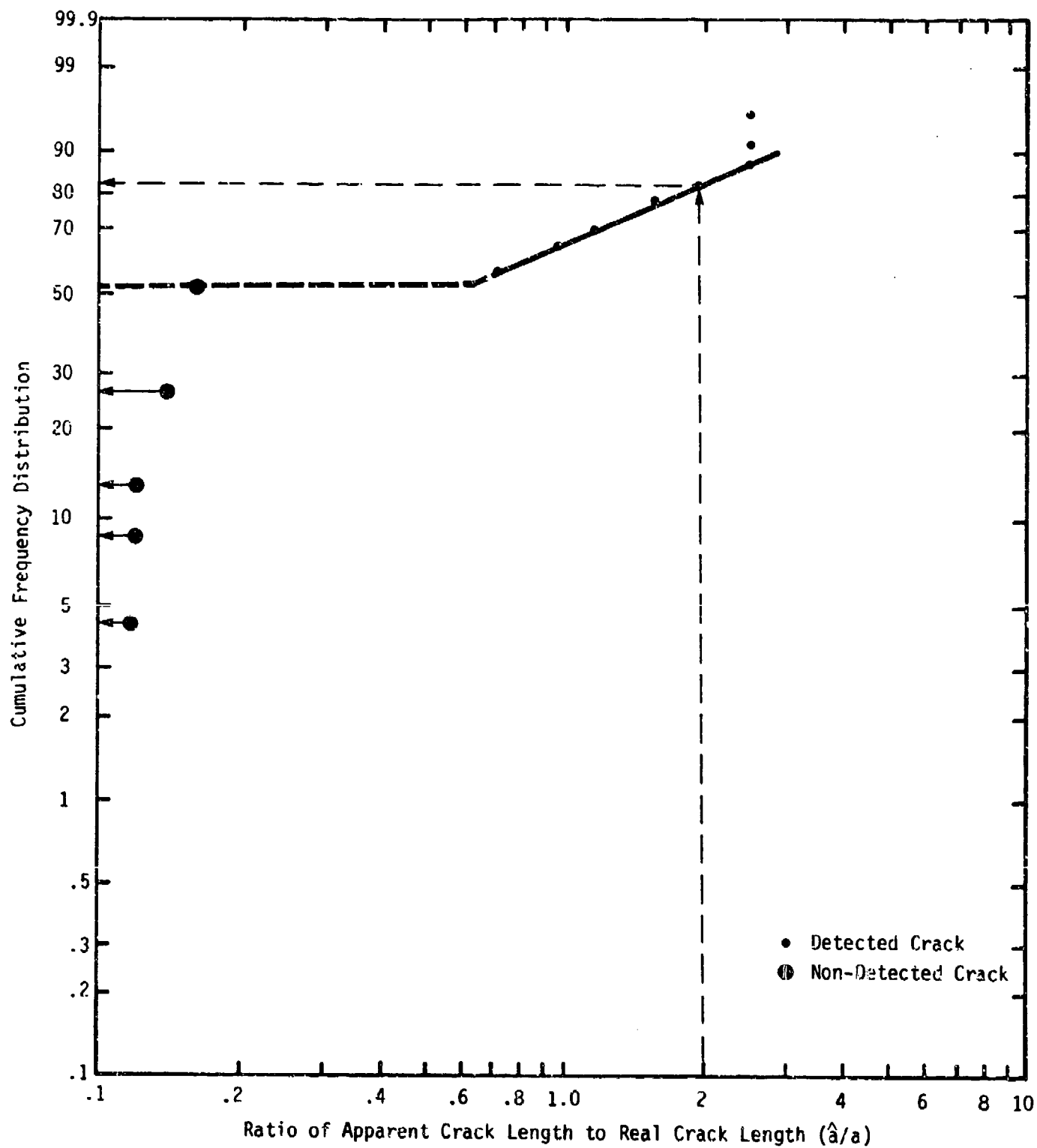
Figure 4-5 – Cumulative Frequency Distribution of Apparent Crack Length to Real Crack Length for High Resolution Inspection. Real Crack Length Range: 0.040 – 0.060 Inch.
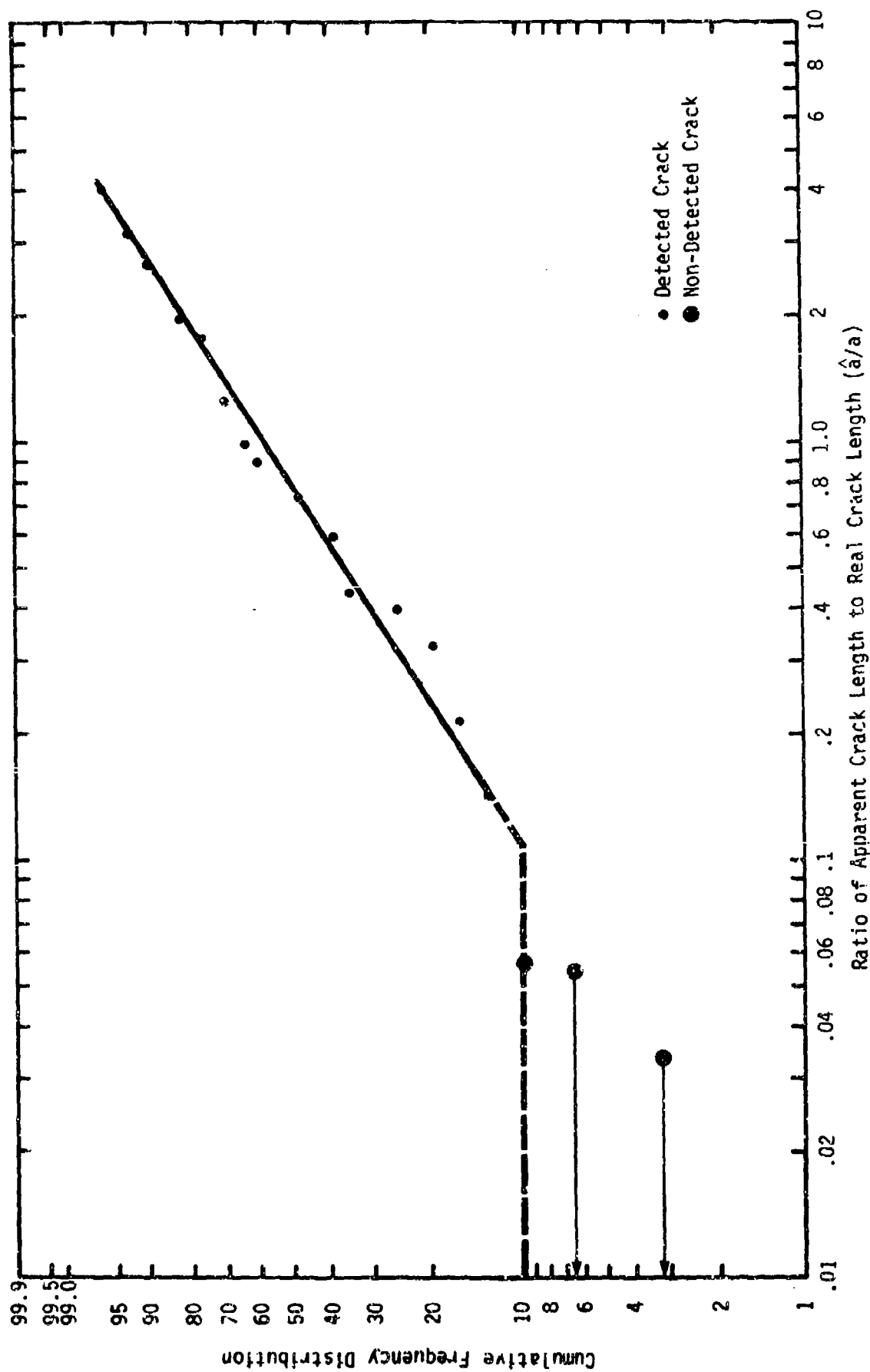
Figure 4-6 – Cumulative Frequency Distribution of Apparent Crack Length to Real Crack Length for High Resolution Inspection. Real Crack Length Range: 0.100 – 0.200 Inch.

two inspections. First, the probability of detection increases as the real crack size increases. Second, the distribution of apparent to actual crack sizes, $\hat{a}/a$, is tighter as the cracks become larger. Furthermore, for small crack lengths (0.001 to 0.010 inch), the eddy current signal tends to oversize the real crack length more so than for larger real crack lengths on a percentage basis. This may in part be due to the regression analysis used to establish the eddy current crack length, $\hat{a}$.

5.0 PRE-INSPECTION MATERIAL QUALITY

The pre-inspection material quality has been determined from the distribution of eddy current signals for each inspected $1/2$ bolt hole volume. This probable number distribution of apparent crack lengths is denoted as $pn(\hat{a})$ and is used directly to obtain the real crack length (probable number) distribution, $pn(a)$, by deconvolution (solving for the integrand) of the following integral equation:

$$PN(\hat{a}) = \int_0^\infty pn(a)\ P(D\backslash a)pd(\hat{a}\backslash D,a)\ da \qquad (5\text{-}1)$$

$$Pd(a\backslash\hat{a}) = Pd(\hat{a}\backslash a)\ \left[\frac{PN(a)}{PN(a)}\right] \qquad (5\text{-}1A)$$

where

$pn(\hat{a})$	= distribution of apparent crack lengths
$pn(a)$	= distribution of real crack lengths
$P(D\backslash a)$	= probability of detection given a crack of length a
$pd(\hat{a}\backslash D,a)$	= probability of the apparent crack size, $\hat{a}$, being a certain size given that a crack of length a exists and has been detected.

$P(D\backslash a)$* and $pd(\hat{a}\backslash(D,a))$* have been determined for the three laboratory inspection by the method discussed in Section 4.2. These two distributions, along with the apparent crack distribution, $pn(\hat{a})$* will be used to predict the pre-inspection flaw frequency for the TF33 disk bolt holes. This methodology for

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* These formulations are actually expressed in terms of cumulative frequency functions. The various distribution functions can be related through $pd(x) = pN(x)/\int_0^\infty pN(x)dx = d(PD(x))/dx$.

estimating the defect distributions will be verified by comparing the predicted defect distribution with the actual defect distributions measured from replication and destructive sectioning.

5.1 Pre-inspection Material Quality From Bolt Hole Replication

The actual pre-inspection material quality defect distribution has been determined from the results of the destructive sectioning and surface replication. The defect distribution for the $1/2$ bolt hole volumes inspected by the high-resolution system (744 total $1/2$ bolt hole volumes) is shown by histogram in Figure 5-1. RI and RO cracks are represented by solid and dashed lines, respectively. Note that there were significantly fewer uncracked RI bolt holes (126) than uncracked RO bolt holes (219). Figure 5-2 is a cumulative frequency plot of $pD(a)$, the data in Figure 5-1. This cumulative plot shows that 90% of the RO cracks are less than 0.020 inch in length, 90% of all RI cracks are less than 0.400 inch, and 50% of all RI cracks are less than 0.010 inch.

A similar cumulative frequency plot of $pD(a)$, obtained from destructive sectioning and replication results of the $1/2$ bolt hole volumes inspected by the outside laboratories (978 total $1/2$ bolt hole volumes) is shown in Figure 5-3. In comparing Figures 5-2 and 5-3, the only significant difference in defect population occurs at the smaller crack sizes.
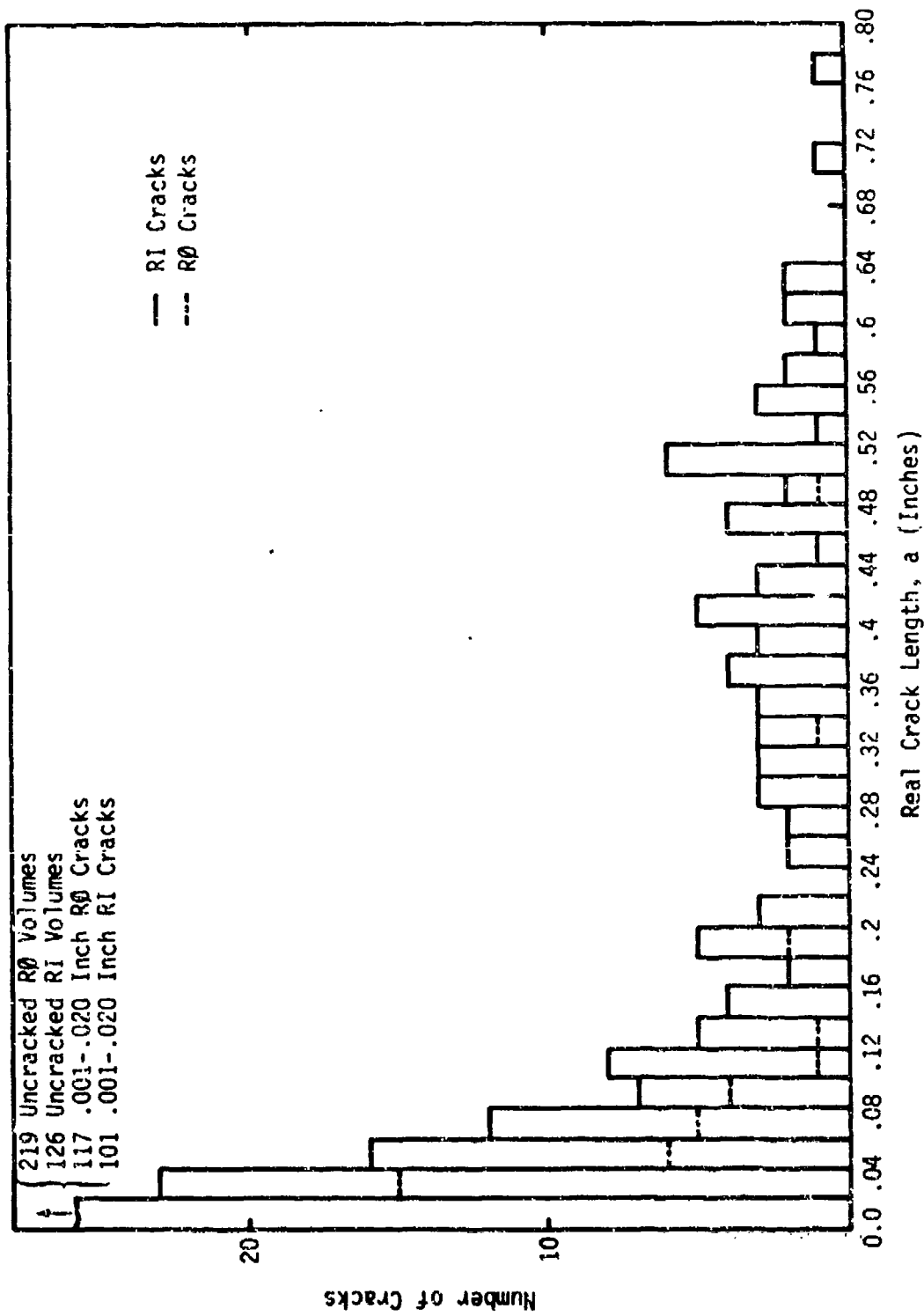
Figure 5-1 - Frequency Distribution of Real Crack Lengths (a) Determined From Surface Replication For the 1/2 Bolt Hole Volumes Inspected by the High Resolution Eddy Current System.
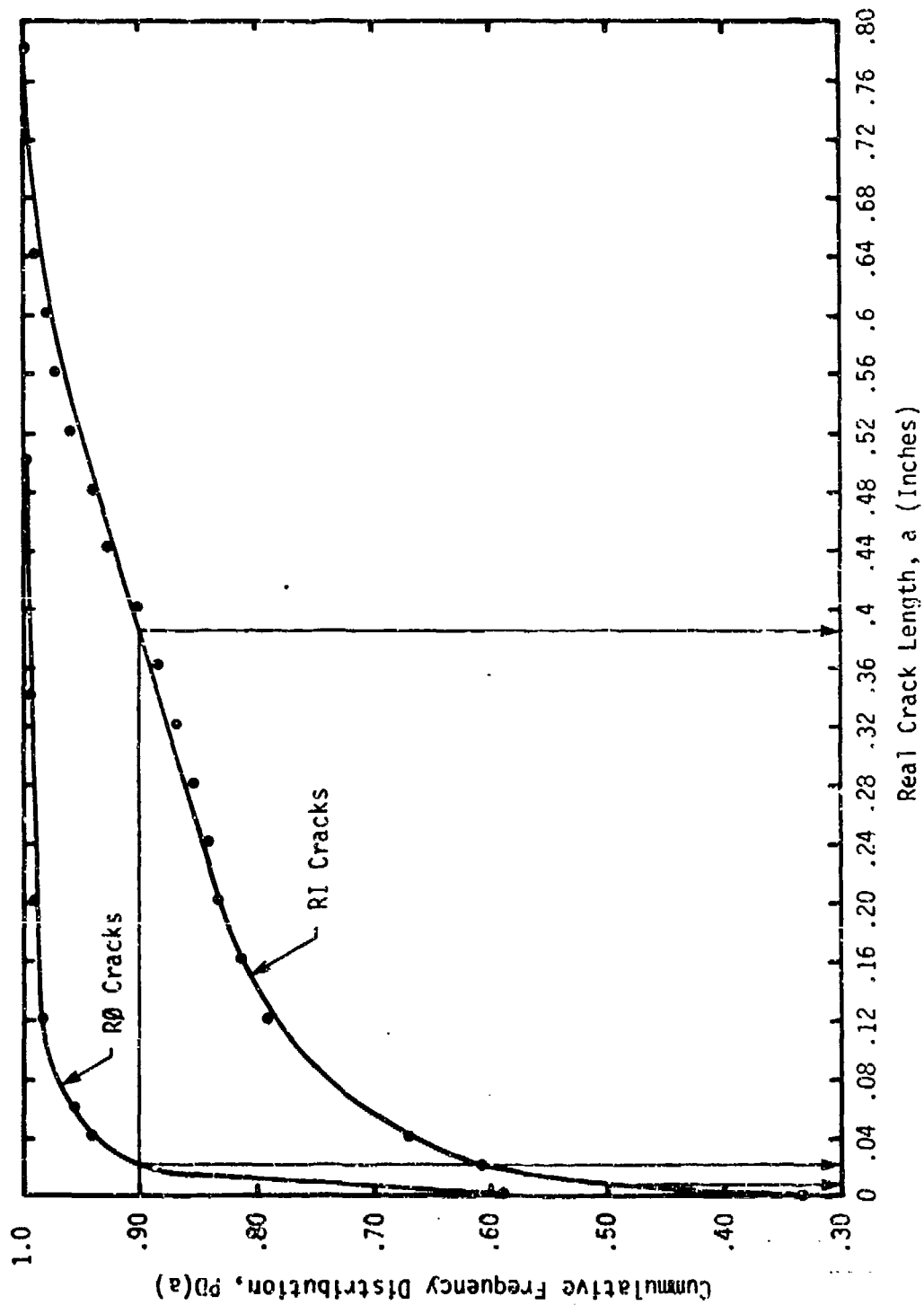
Figure 5-2 - Cumulative Frequency Distribution of Real Crack Lengths (a) Determined From Surface Replication For the 1/2 Bolt Hole Volumes Inspected by the High Resolution Eddy Current System.
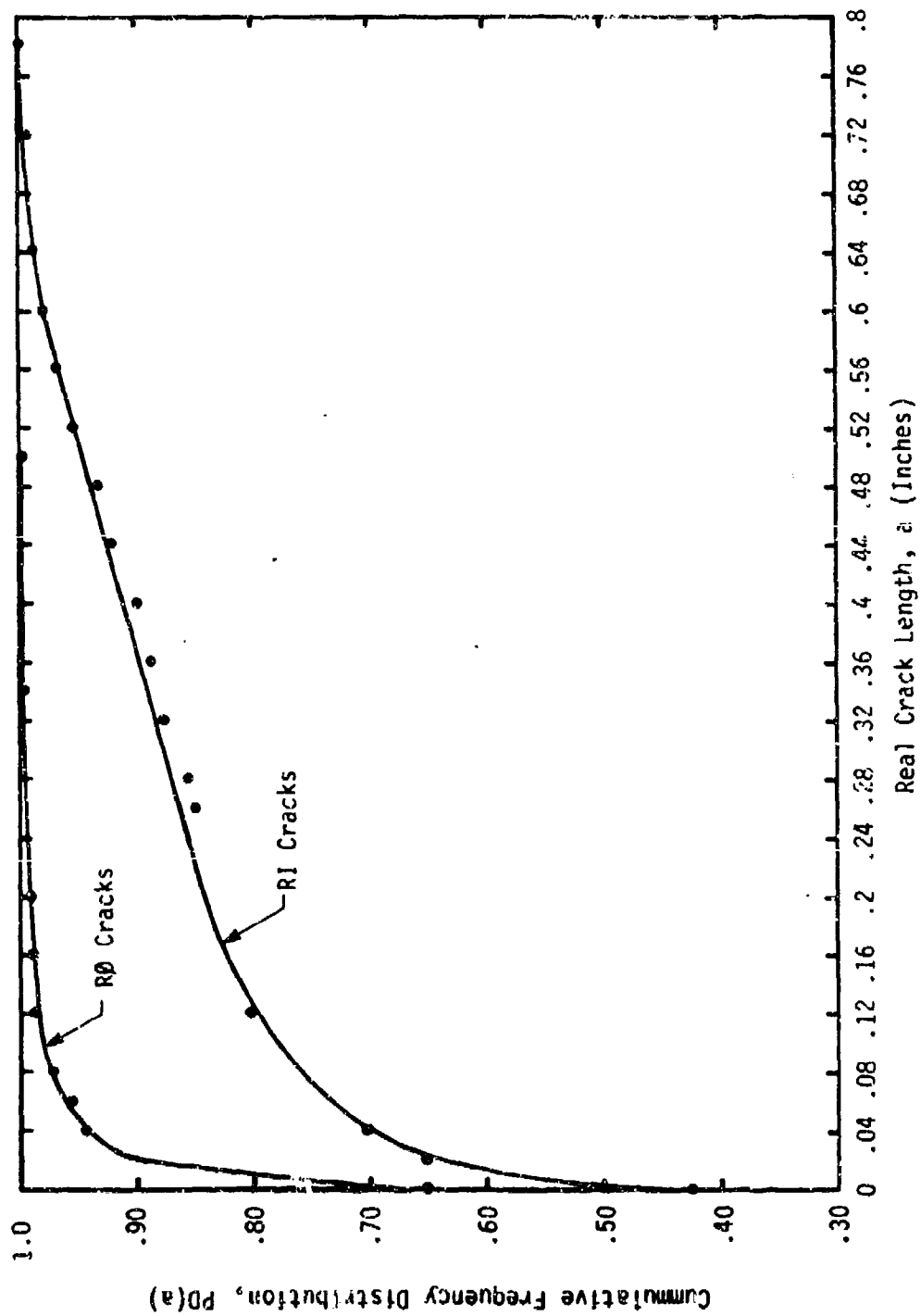
Figure 5-3 - Cumulative Frequency Distribution of Real Crack Lengths (a) Determined From Surface Replication For the 1/2 Bolt Hole Volumes Inspected by the Outside Lab (1 MHZ and 500 KHZ) Eddy Current Systems.

5.2   Apparent Crack Distribution, PD($\hat{a}$)

The cumulative distribution of apparent crack size, PD($\hat{a}$), has also been determined for the high-resolution and the two outside laboratory inspections. As mentioned previously, $\hat{a}$ values were generated by a regression analysis on eddy current signals. The results of cumulative frequency distribution for Pd($\hat{a}$) for the high-resolution and outside laboratory (500 KHz) inspections are shown in Figures 5-4 and 5-5. By comparing these two figures, it is seen that the high-resolution inspection identified a smaller percentage of the bolt holes uncracked than did the outside laboratory inspections. For the RI location, the high-resolution inspection identified 48% as being uncracked, whereas the outside laboratory (500 KHz) inspection identified 63% as being uncracked. For the RO location, the high-resolution inspection identified 86% as being uncracked, whereas the outside laboratory (500 KHz) inspection identified 95% as being uncracked.

The cumulative frequency distribution for PD(a) and PD($\hat{a}$) for the various inspections can be compared using Figures 5-2 and 5-4 for the high-resolution inspection, and Figures 5-3 and Figure 5-5 for the outside laboratory (500 KHz) inspection.
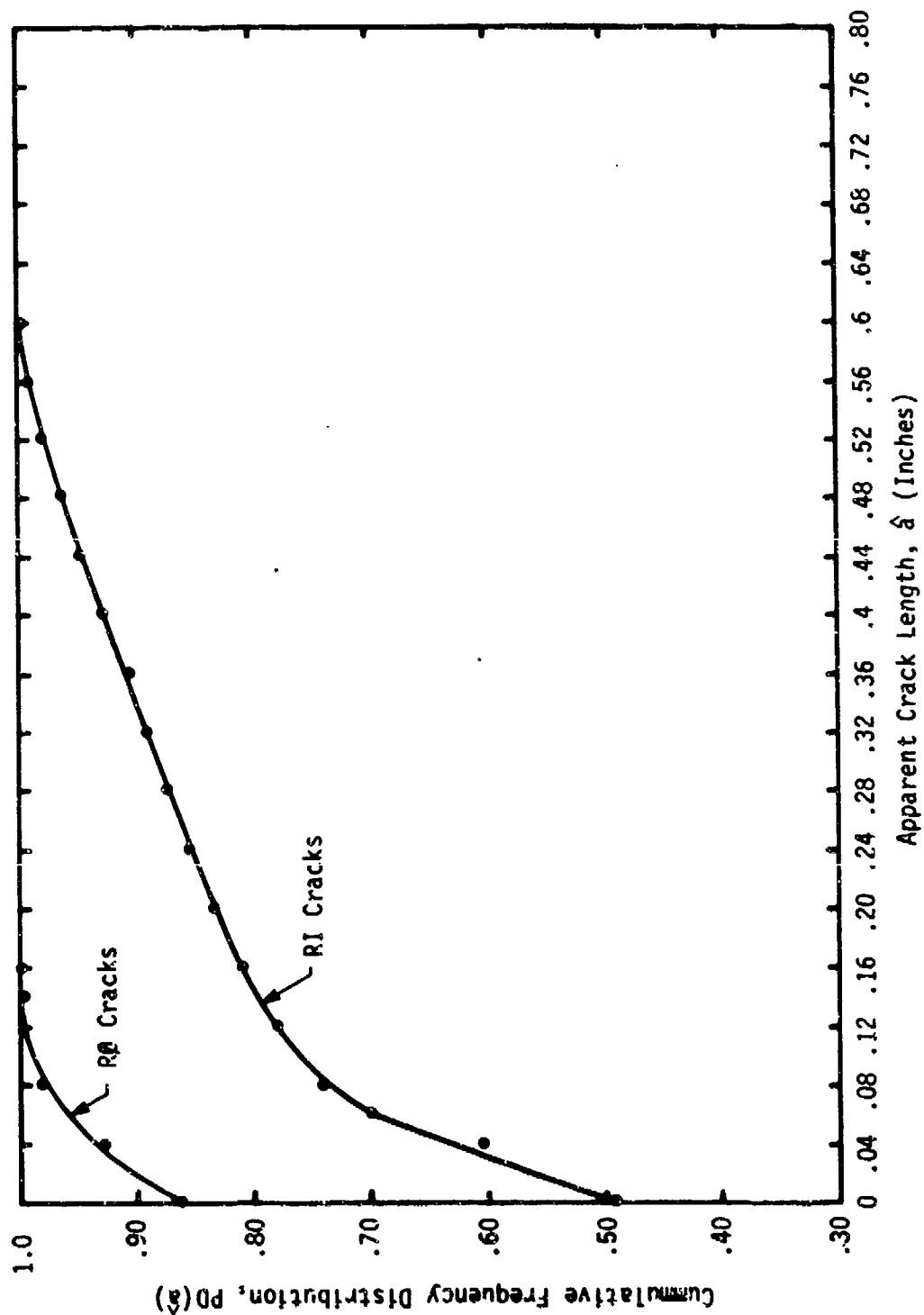
Figure 5-4 - Cumulative Frequency Distribution of Apparent Crack Lengths (â) Reduced Using Equation 4-4 and Eddy Current Signals Recorded by High Resolution Inspection for 1/2 Bolt Hole Volumes.
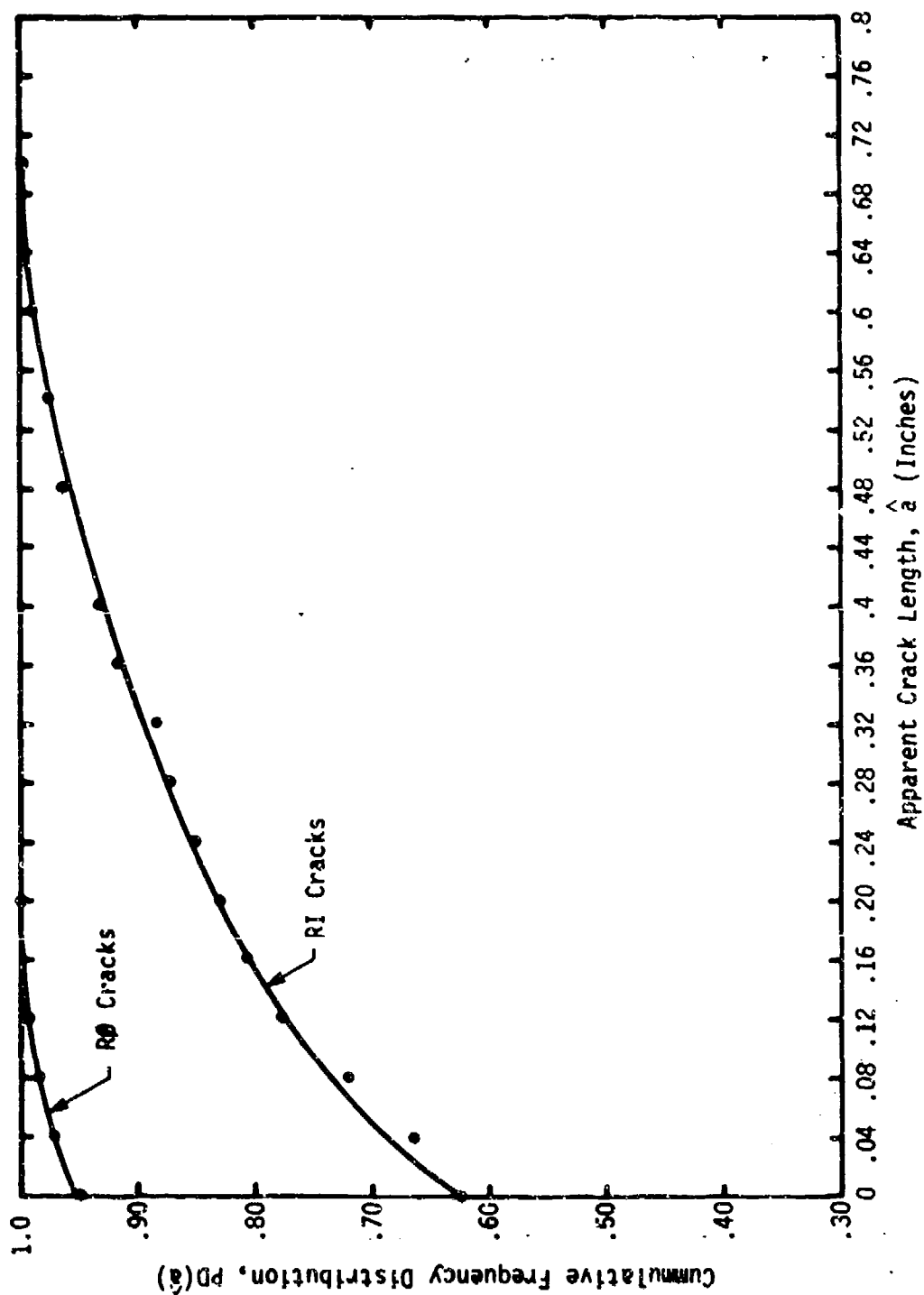
Figure 5-5 - Cumulative Frequency Distribution of Apparent Crack Lengths (â) Reduced Using Equation 4-2 and Eddy Current Signals Recorded by Outside Lab (500 KHz) Inspection of 1/2 Bolt Hole Volumes.

6.0 ECONOMIC EQUATION DEVELOPMENT

The costs associated with various decisions is an important aspect in evaluating which RFC procedure is best. It is the relative cost that is most important, not the absolute cost. For this investigation, FaAA collected cost information on disk inspection, disk replacement, and disk failure in service. The cost to inspect this third stage TF-33 disk was established at $200, and disk replacement cost was established at $7,500. The design life of this disk was established at 750 cycles, therefore for every extra cycle obtained from a disk, a cost benefit of $10 was assigned (i.e., $7500 per additional design life). There was no defined cost information on TF-33 disk failures available from the Air Force. FaAA has used $2,000,000 as an average failure cost. This cost assumes that most disk failures destroy one complete engine but some few could cause loss of the aircraft (since engine replacement cost is $750,000).

As was mentioned above, it is the relative costs which are the most important. A disk failure costs 267 times more than a disk replacement; a disk inspection cost is only 3% of a disk replacement. Based on these costs, inspections can be analytically performed relatively inexpensively and disk failures should be avoided. These cost estimates were used in all RFC procedures to evaluate the economic impact of the different procedures. During the RFC verification task of this program, these costs were reduced to encourage a higher failure rate. Reducing the cost of failure permits worst-case tails of the probability distributions to be evaluated with a small number of specimens. The actual costs used are discussed in the verification section of this report.

6-1

7.0   TASK V - RETIREMENT-FOR-CAUSE STRATEGY OPTIMIZATION

Analytical development and evaluation of alternative RFC strategies was accomplished using inspection reliability data generated within this project. The following accomplishments were completed:

1. The fatigue crack initiation and growth behavior observed in the 49 disks inspected in this program was analyzed.

2. The observed variability in fatigue cracking of the 49 disk population, or "fleet," was represented and simulated on the computer using Monte Carlo simulation software (see Appendixes A and B).

3) The reliability of the three actual inspection procedures, discussed previously, and a fourth hypothetical procedure far superior to the three real ones, were also represented and simulated on the computer in a form that allows great generality in simulating inspection uncertainty.

4) The RFC procedure was greatly improved and recoded into simulation software.

5) A comprehensive RFC program was developed to quantitatively evaluate alternative RFC procedures when applied with the actual variations and uncertainties demonstrated by the data generated in this program. The computer code has been named PERFCT, Probabilistic Engineering Retirement For Cause Tester. PERFCT is documented in Appendix B and meets all major objectives of the computer program REFRECH.

6) PERFCT was run extensively to produce a broad parametric study of the alternative RFC procedures. It identifies the strengths, benefits, and weaknesses when applied to actual service conditions.

This study addressed the RI bolt hole cracks that control the life of the TF-33 disk. More complex RFC procedures might consider simultaneously more than one type of failure location within the disk. However, the RFC methods optimized here, which consider only one failure mode at a time, is applicable to many of the engine components that are candidates for RFC.

7.1 Analysis of the Forty-Nine Disk Fleet Inspected

The fatigue life prediction model for these TF-33 third stage disks was first developed deterministically and is presented in Section 7.1.1. The spin pit results reported by Hill (2) were compared with our fatigue crack growth model. This model is then extended to include crack initiation; the final deterministic life model is then compared with the field disk data in Figure 7-3. Our extension of the deterministic model to a probabilistic model, which is again compared to the field data in Figure 7-4 is given in Section 7.1.2. The fatigue parameters which were used to simulate probabilistically the field data are discussed in Section 7.1.3, and the probability distributions for cycle counting errors are presented in Section 7.1.4. Methods for simulating the impact of the cycle counting errors on fatigue crack growth predictions are given in Section 7.1.5; the eddy current inspection performance simulation in terms of inspection uncertainty is discussed in Section 7.1.6.

7-2

7.1.1 Deterministic Analysis

In order to analyze the disks, formulation of a fatigue model that would describe the key aspects of crack propagation and crack initiation was necessary. Figures 7-1 and 7-2 represent the results of our crack propagation analysis and demonstrate the agreement between this analysis and a spin pit experiment(2). To minimize computing costs, these analytical results (Figures 7-1 and 7-2) were subjected to a regression analysis to produce closed-form equations that can be utilized in the RFC computer program. One regression equation which provides an accurate fit to the data is

$$N_p = \frac{C_p}{\sigma^{3.04}} (1.50 + \log a_c)^{.585} \qquad (7\text{-}1)$$

where

N_p = life in cycles to propagate a crack from size (length) a_i=0.031 inch*

C_p = 12,000 cycles, a constant

σ = dimensionless ratio of the "actual" bolt hole nominal stress to the nominal stress experienced by a bolt hole in the spin pit experiment (Figure 7-1) reported by Hill (2)

a_c = critical crack length (inches)**

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* Because of roundoff, the size is actually $10^{-1.5}$=.0316"=a_i

** Assumed to equal the crack depth d times 2.857 (i.e., 1/aspect ratio). This "aspect ratio," 0.35, was assumed to be constant during all stages of crack growth - an assumption whose modification to account for variations in aspect ratio in accordance with our sectioning results did not substantially change the analysis.

NOTE: SPS Means Computed Spin Pit Stresses.

100% SPS

70% SPS

120% SPS

140% SPS

Crack Depth, d(in)

1.0

0.5

0

N(d) = Cycles Required to Grow a Crack from Depth .0182" to Depth, d

2000 · 4000 · 6000 · 8000 · 10,000 · 12,000 · 14,000
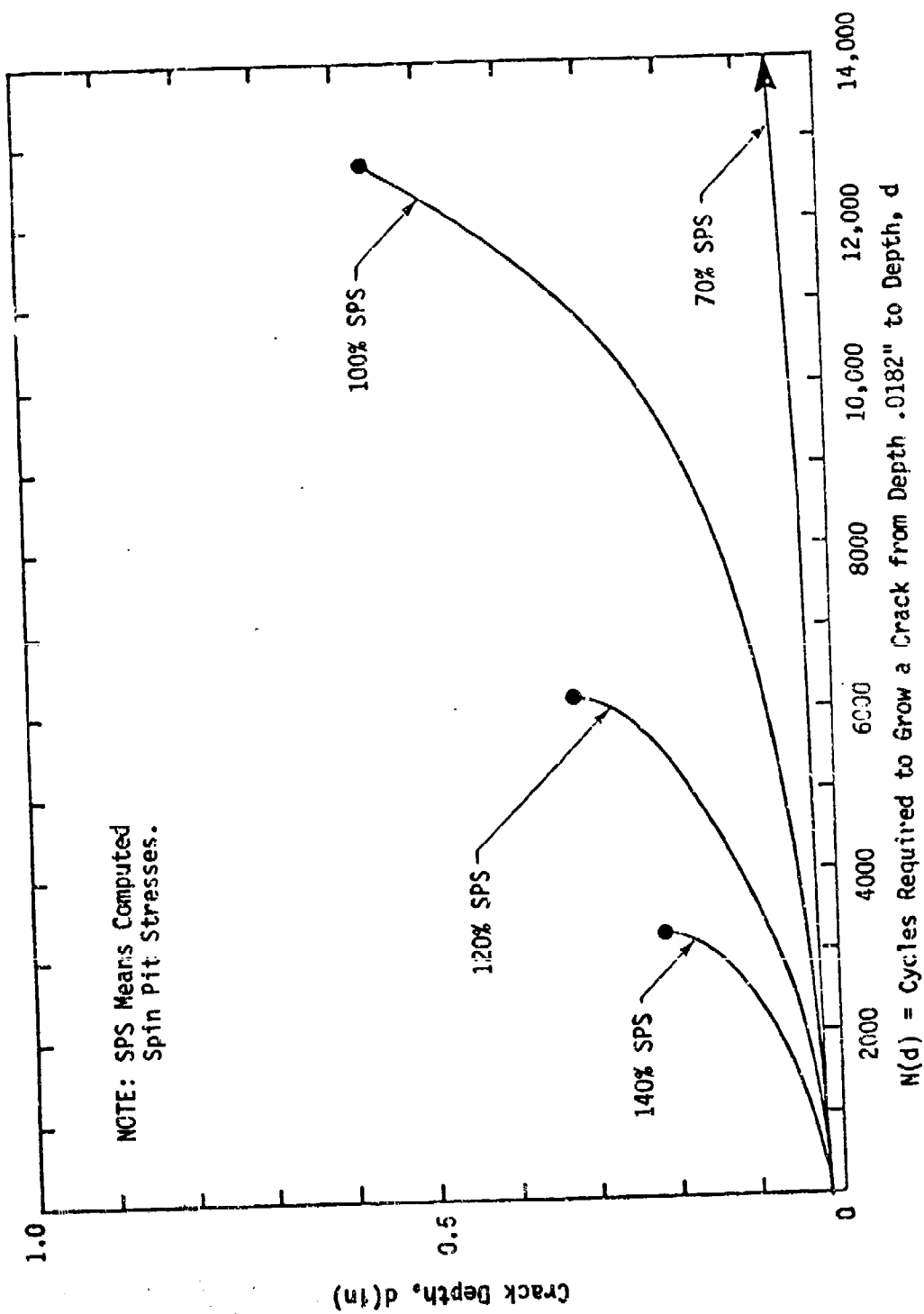
Figure 7-1 - Results of Inboard Bolt Hole Fatigue Crack Growth Analysis.

O Bolt Hole #1 Data
△ Bolt Hole #2 Data

$K_{crit} = 110$ ksi $\sqrt{in}$

Failure

$N(d) = $ Cycles Required to Grow a Crack from Depth .0182" to Depth, d

Crack Depth, d (in)
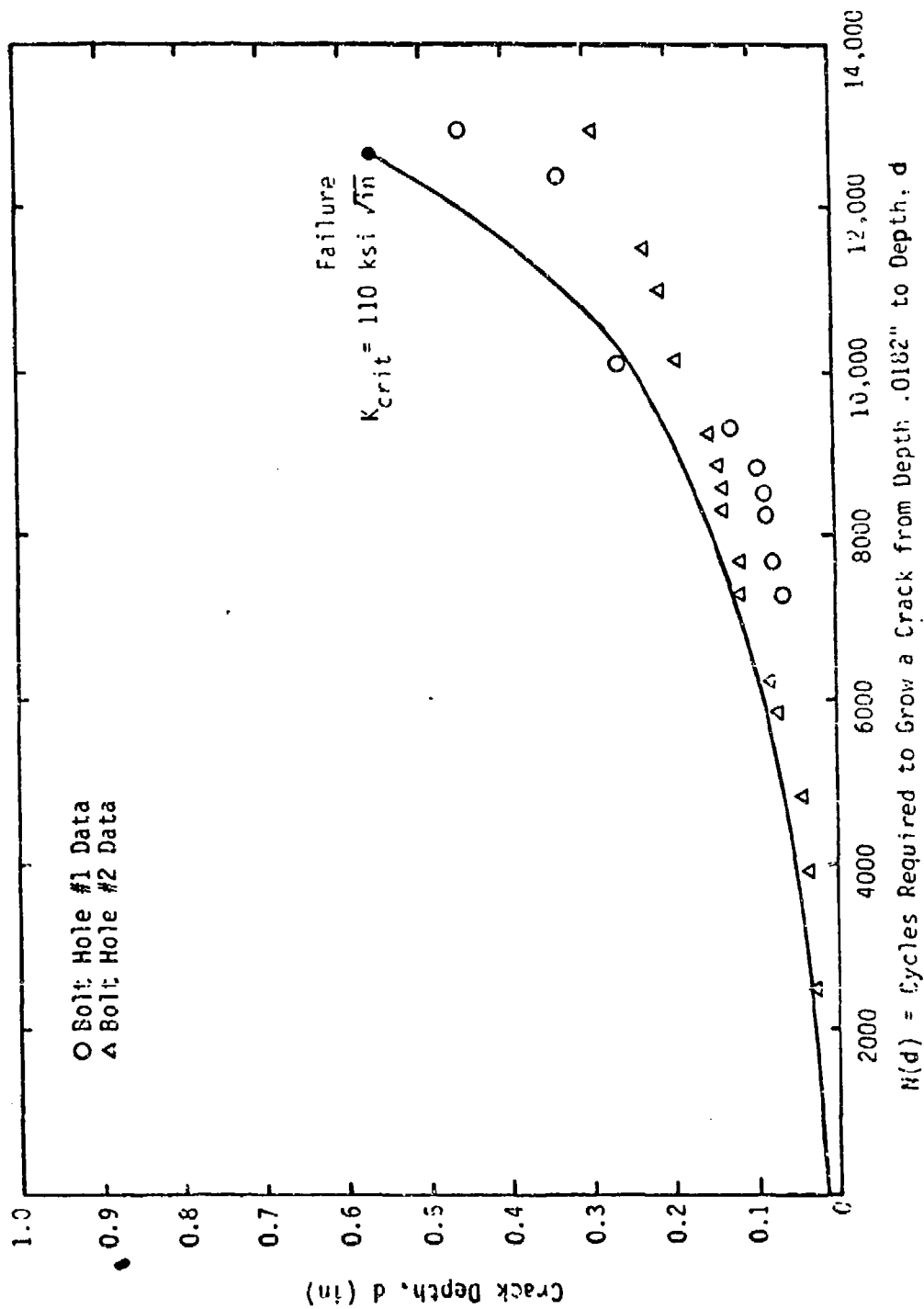
Figure 7-2 - Comparison of Inboard Bolt Hole Fatigue Crack Growth Analysis with Experimental Data Points from Spin-Pit Testing Reported by Hill (2).

7-5

The critical crack length (a_c) relationships derived from our using BIGIF (3) fatigue crack growth analysis were also subjected to regression analysis to obtain

$$a_c \approx 1.4 \ (K_c/K_{cu}/\sigma)^{2.64} \ \text{inches} \tag{7-2}$$

for the range $0.125 < a_c < 3$ inches
where

$\quad K_c$ = the critical stress intensity factor fracture toughness for the bolt hole in $ksi\sqrt{in.}$

$\quad K_{cu}$ = 110 ksi $\sqrt{in.}$ the value of K_c used in the BIGIF analysis.

The exponent 2.64 in equation (7-2) differs from the exponent 2, which corresponds to uniform stress because of the radial stress gradient in hoop stress caused by both the bolt hole stress concentration and the increasing nominal stress as the bore is approached.

We have less definitive basis for selecting the equation to reflect fatigue crack initiation of a crack 0.031 inch long. However, as a basic reflection of the 4000-to-6500 cycle range for the manufacturer's original design life, and from our own experience of the dependence of fatigue initiation life N_i upon stress at operational temperatures less than 700°F, for wrought nickel alloys, we have used

$$N_i = \frac{C_i}{\sigma^6} \tag{7-3}$$

where

$\quad C_i$ = 4000 cycles

Clearly, analysis of additional fatigue initiation data would improve this initiation prediction; however, the results that follow show that the precise form of the equation used to simulate the initial occurrence of cracks is not critical to evaluation of the RFC procedure.

The crack initiation and propagation equations (7-1) to (7-3) can be combined into a single equation for total fatigue life.

$$N_f = N_i + N_p = \frac{4000}{\sigma^6} + \frac{12000}{\sigma^{3.04}} \left[1.50 + \log \left\{ 1.4(K_c/110\sigma)^{2.64} \right\} \right]^{.585} \quad (7-4)$$

where N_f = total number of cycles to failure.

Furthermore, the number of cycles, N, required to cause a crack of any size, a, greater than 0.031 inch is

$$N(a) = N = \frac{4000}{\sigma^6} + \frac{12000}{\sigma^{3.04}} \left[1.50 + \log a \right]^{.585} \quad (7-5)$$

Finally, Equation (7-5) solved for a as a function of the number of cycles $(N > C_1/\sigma^6)$

$$a \equiv 10^{\log a}$$

where

$$\log a = \left\{ \frac{\sigma^{3.04}}{C_p} \left[N - C_1/\sigma^6 \right] \right\}^{1/.585} - 1.50 \quad (7.6)$$

Equation (7-6) is plotted in Figure 7-3. Clearly, this equation predicts lives that are far longer than the majority of the 49 disks. The fleet is subject to high scatter and extreme lack of correlation between reported life cycles and crack sizes, as previously described. Because many of the 49 disks were characterized previously as rejections and have large cracks at relatively low numbers of cycles, they are undoubtedly not representative of the entire TF-33 fleet, which is supposed to produce few (if any) cracks of 0.031 inch or larger within the design life of 4000 to 6500 cycles. Therefore, we reduced the numerical coefficients in equation (7-6) to C_i = 2500 cycles and C_p = 9590 cycles to provide a slightly better mean-life fit to the data (Figure 7-3). Since the life of a disk is governed by the shortest-lived of the 10 bolt holes, the dashed curve in Figure 7-3 is included to represent the expected performance of a typical disk. The scatter about this (dashed) mean-life regression line is still, of course, enormous and can't be used to support any mean trendline. This demonstrates the importance, while simulating a highly variable fleet of disks, of selecting appropriate probability distributions of key input parameters. The selection of these probability distributions is discussed in detail below.

7.1.2   Probabilistic Analysis

In order to express the data in Figure 7-3 in a form suitable for simulation by the Monte Carlo method, it was useful to calculate an "inferred" number of cycles to failure for each disk. The inferred life-to-failure calculation is complex but is equivalent to adjusting the coefficients C_p and C_i so that an equation of the form of equation (7-4) goes through the data point $(a, \hat{N})$ on Figure 7-3. Table 7-1 shows the raw data for the RI cracks

7-8
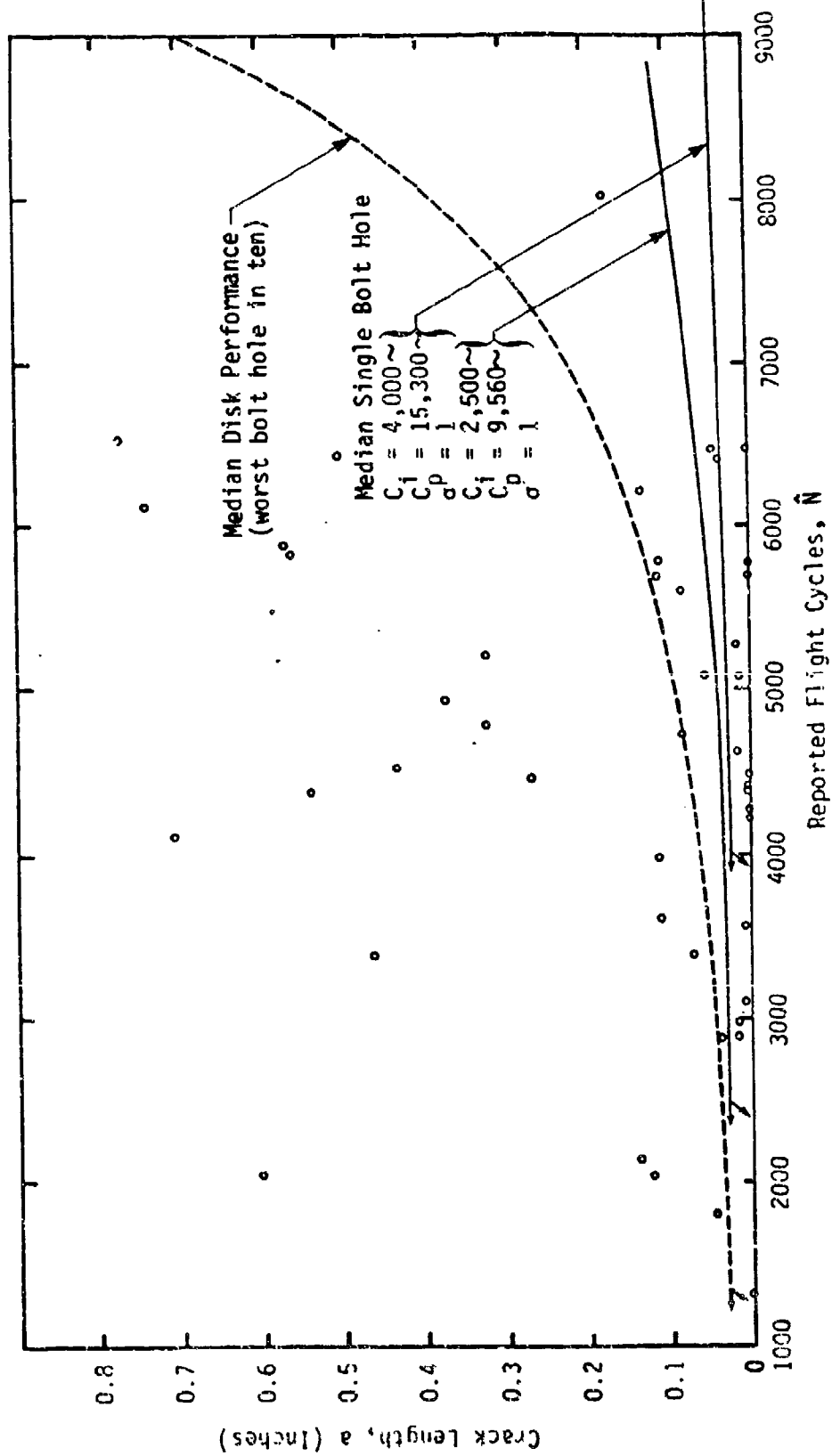
Figure 7-3 - Comparison of the Calculated and Measured Maximum Radially-Inward Crack Length in a TF-33 Disk as a Function of Reported Flight Cycles.

and the resulting inferred life calculation for the 49 fleet disks. Figure 7-4 is a plot of the cumulative probability distribution of this inferred-life data (the curve in Figure 7-4 will be explained further in Section 7.1.3 below). As can be seen in Table 7-1, the inferred lives-to-failure have enormous scatter ranging from 2174 cycles for Disk 26 to cycles in excess of 30,000 for disks in which no cracks were found or cracks less than 0.031 inch were found (e.g., Disk 47).

There are many sources which can contribute to producing these observed statistical variations. Major possible sources are:

1. Stress variations from disk to disk. This was rejected as the major source of variation although a significant amount of stress variability is simulated as discussed below.

2. Error in measuring the real crack size a due to difficulties of replication and the necessity of sectioning bolt holes that showed significant amount of subsurface cracking. Thus, errors in the effective crack size listed in Table 7-1 could easily be contributing to the variation in the resulting inferred-time-to-failure distribution of Figure 7-4.

3. The observed variation in our fleet of 49 rejected disks could be greater than expected or than represented by the total fleet of TF-33 disks because of both inadvertent and intentional methods of disk selection for this program. It seems clear from the majority of the disks examined that some of the parts belong to the worst of the TF-33 reject population, especially Disk 26 with its 0.6-inch crack

7-10

Table 7-1

SALIENT DETAILS OF SIMULATED FLEET OF DISKS

Disk ID #	Serial #	Perceived Cycles (N)	Maximum Radially Inward Crack Length in Ten Bolt Holes, a (inches)	Inferred Number of Perceived Cycles-to-Failure ($\hat{N}_f$)
1	0N0382	2135	.139	3361
2	0N0471	6471	.044	19545
3	0N0479	3995	.114	6936
4	0N0487	5814	.566	6695
5	0V0036	4366	.542	4998
6	0V0041	4111	.709	4448
7	0V0386	4758	.325	6097
8	0V0401	4461	0.000	>26338
9	0V0403	6205	.135	10229
10	0V1078	5600	.086	10983
11	0V1101	4451	.270	5942
12	1R2846	4724	.085	9308
13	1R2874	5215	.326	6700
14	1R2900	8034	.175	12281
15	1S2830	5789	.113	10147
16	1T2951	6524	.775	7146
17	2R2418	3611	.110	6339
18	2S3780	3383	.071	7302
19	2S3789	4415	0.000	>26066
20	3M0757	5065	.017	>29410
21	4G5001	1303	0.000	>9233
22	4P8343	5094	.012	>29579
23	4S4933	3551	.006	>21684
24	4S5220	5690	.118	9817
25	4Y9881	6404	.039	22234
26	5T7431	2049	.605	2174
27	5T7457	6116	.743	6719
28	5Y9177	3095	.007	>19225
29	6P5450	5785	0.000	>33042
30*	6P6124	2807		N/A
31	6P6127	5083	.055	12848
32	6R4839	6442	.505	7629
33	6S7835	2875	.017	>18168
34	6S8257	5273	.018	>30618
35	6S8291	6039	.626	5844
36	6S8342	4939	.378	6127
37	6S8355	5875	.574	6761
38	8K1505	2037	.122	3363
39	8K1515	2972	.015	>18620
40	8M7647	4374	.002	>26041
41	8M7648	2875	.036	12142
42	8P5147	3939	0.000	>23650
43	8P5548	4617	.016	>27259
44	8P6229	4286	0.000	>25517
45	8X3910	4226	0.000	>25160
46	9J5092	5720	.003	>32671
47	9J5144	6478	0.000	>36401
48	9R2857	3370	.464	3916
49	9S0788	4517	.437	5411
50	9S1148	1800	.046	5469

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*   Disk #30 was not inspected and has been excluded from the simulated "fleet".
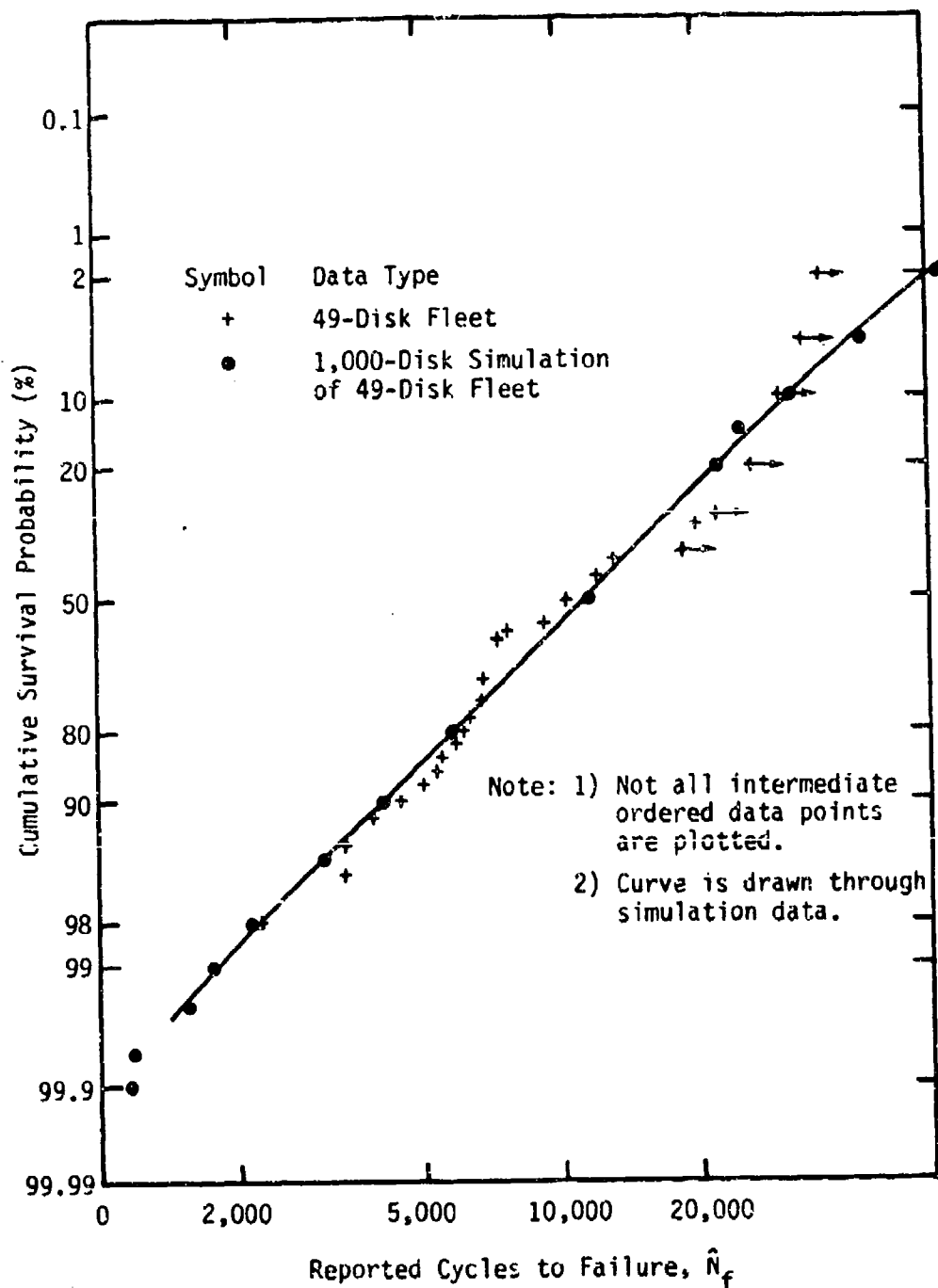
Figure 7-4 - Probabilistic Comparison of Real and Simulated
Reported Cycles to Failure.

length at only 2049 reported cycles. Although we suspect that most of the disks were rejects, clearly some disks could be from the typical or even the superior part of the TF-33 population, such as Disk 47 which shows no evidence of cracking at 6478 reported cycles. This heterogeneous mixture of disk cracks is very useful for evaluating the inspection reliability for many crack sizes. However, disk selection to provide enormous variety for the inspection evaluation will obviously overstate the fatigue scatter expected in the entire TF-33 fleet of over 1000 engines.

4. The last significant source of uncertainty could be systematic or random errors associated with estimating (with $\hat{N}$) the number of fatigue cycles, N, experienced by disks in the fleet. In informal discussions with Air Force personnel, we learned that very rough rules of thumb have been applied to estimating cycles such as (1) the multiplication of the number of training hours by 3 to estimate training mission cycles and (2) the multiplication of the number of operational hours by 1/3 to obtain an appropriate estimate of disk cycles during normal operation. This factor-of-nine variation in estimated cycles per mission and the lack of more specific criteria for counting cycles suggest that relatively large errors can be made in counting cycles. In describing this type of error, we define N as the actual number of cycles and $\hat{N}$ as the estimated number of cycles and consider the ratios of $\hat{N}/N$. We believe that this cycle-counting error may be the largest source of variable, and we use it below as a curve-fitting parameter to simulate the actual fatigue performance variability shown in Figure 7-4.

7.1.3 Simulation of Fatigue Performance of the Forty-Nine Disk Fleet

All numerical probabilistic work in this report was accomplished using the Monte Carlo method (Appendix A). The Monte Carlo method is used to select values of input random variables from their respective probability distributions and to insert those values into an equation for computation of time-to-failure, crack size, or any other value of a needed dependent random variable. Each computed value is called a trial. In general, each trial is different because the Monte Carlo procedure selects different input values from the probability distribution. With enough trials, the probability distribution of the dependent variable can be computed accurately.

The input random variables used are: (1) C_i, C_p, K_c, and $\hat{a}/a$ each of which vary randomly for each of the 10 bolt holes in the disk and (2) σ and $\hat{N}/N$, which vary randomly from disk to disk.

The curve in Figure 7-4 shows the result of a successful Monte Carlo probabilistic regression of the disk time-to-failure. The predicted distribution of time to failure is in excellent agreement with the actual disk service experience, especially up to the 70th percentile of the reported time-to-failure distribution. Although a better fit could have been obtained above the 70th percentile (30% cumulative survival probability) by using input distributions with discontinuous frequency functions, this was not considered to be necessary to produce simulated populations which behave like the 49 disks. None of the RFC-simulation fleet failures come from above the 70th percentile, and the simulated values of life, which are all greater than 20,000 cycles, are large enough to represent disks that could be used for the entire useful life of the engine.

The life equation has been given before but is repeated below for convenience:

$$N_f = \frac{C_i}{\sigma^6} + \frac{C_p}{\sigma^{3.04}}\left[1.5 + \log a_c\right]^{.585} \tag{7-7}$$

The variability in the fatigue initiation "constant" C_i is represented by

$$C_i = \text{LGAU} \ (4000, \ 0.35) \tag{7-8}$$

or

$$\log C_i = \text{GAU} \ (3.602, \ 0.35) \tag{7-9}$$

where both equations are our shorthand notation for the statement "$\log C_i$ is a random variable from the Gaussian or normal distribution with median 3.602 (log 4000) and standard deviation 0.35 inch. Appendix A explains how the C_i, or any other, probability distribution is simulated within the Monte Carlo method by selecting, at random, a value of the variable from its probability distribution. The 0.35 scatter parameter represents a 7.9-fold average difference in the time to initiate a 0.031-inch crack between the earliest and latest crack in a 10-hole disk. As learned from the detailed simulation results, this degree of scatter translates into a similar order-of-magnitude difference in crack sizes between the bolt hole with the smallest RI crack length and that with the largest RI crack in the disk. Such crack length variation has been observed for typical disks in which all holes are cracked.

Thus, the 0.35 value in equations (7-8) and (7-9) above* can be said to represent the observed hole-to-hole variation of crack size actually experienced in most of the 49 disks. Furthermore, the 0.35 value is not inconsistent with that which the authors and others (e.g., (4)) have encountered in previous probabilistic investigations of crack initiation scatter in nickel-based and steel alloys.

The variation of two fracture-mechanics-related parameters has been simulated. First, the crack propagation constant, C_p, is modeled with the log normal distribution given below:

$$\log C_p = GAU (\log 9560, 0.12) \tag{7-10}$$

This 0.12 value is entirely consistent with extensive unpublished Pratt and Whitney Aircraft (P&WA) studies, done by an author on Incoloy 901 and similar materials, of crack growth variations in bolt hole specimens. Figure 7-5 contrasts the assumed variability for time to crack initiation with that of crack propagation.

Disk-to-disk stress variation is simulated with the normal distribution:

$$\sigma = GAU (1.0, 0.1), \tag{7-11}$$

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* The propagation rate scatter of C_p also influences the hole-to-hole variation in crack size but, because a crack has to initiate before it can grow to any size, not as much as does the larger C_i scatter.
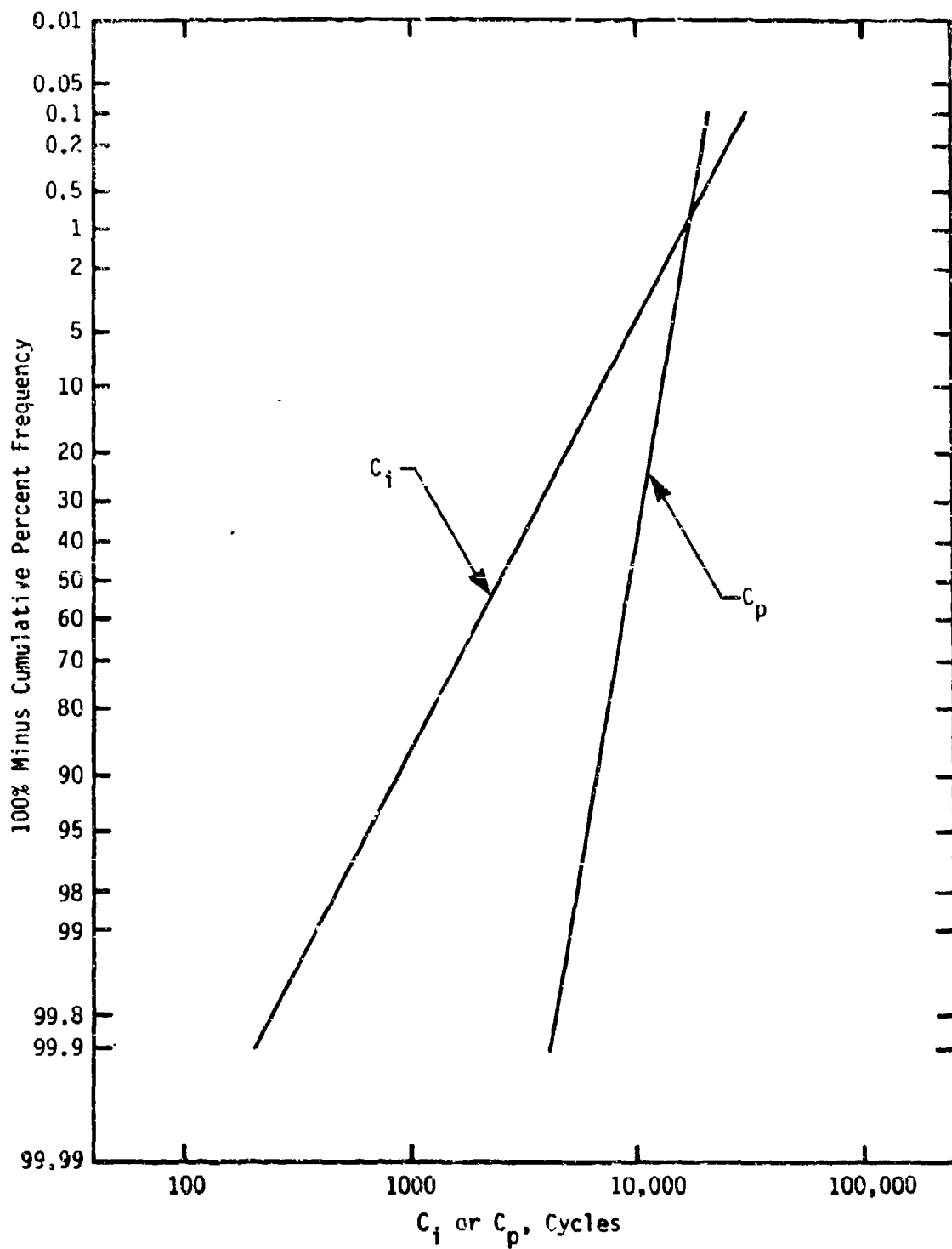
Figure 7-5 - Probability Distributions Used to Simulate Crack Initiation (C_i) and Propagation (C_p) Life Scatter.

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which translates to a 10% "coefficient of variation," a degree of stress variability that is reasonably large.

The critical stress intensity factor or fracture toughness, K_c, is simulated with the probability distribution

$$K_c = GAU \ (110 \ ksi \ \sqrt{in}, \ 16.5 \ ksi \ \sqrt{in}) \tag{7-12}$$

The implied 15% coefficient of variation is considered to be realistic-to-large based on our previous experience for data far from the transition temperature. This value can be improved and updated if toughness and critical crack size information becomes available. The 110 ksi $\sqrt{in}$ value is probably low as a mean toughness but has been chosen to reflect the rapid increase of stress intensity factor during transition from a partial- to a through-thickness crack. This increase was not explicitly modeled in the BIGIF runs. The most important overall effect of the combination of two conservative values in equation (7-12) and the coefficient of variation used in equation (7-11) is to produce very occasional critical crack lengths of only 200 to 250 mils, which may be compared with a thickness of 850 mils. This range corresponds to critical crack depths of only 57 to 71 mils. It is not surprising that many of the failures encountered in the simulation had critical crack sizes in these ranges. While these ranges are believed to be unrealistically low, they were not altered in order to test the RFC procedure more stringently. Thus, in the studies described below, it is believed that two worrisome effects have been at least partly accounted for implicitly: (1) a rare high-stress maneuver and (2) an occasionally brittle material heat such

as might be characteristic of the higher-strength alloys used in the F-100 engine.

7.1.4 Simulation of Usage Estimation Errors

After a series of trial-and-error Monte Carlo runs devoted to curve-fitting the data in Figure 7-4, the probability distribution chosen to simulate errors in cycle counting was calculated to be

$$\log (\hat{N}/N) = GAU (0., 0.30) \tag{7-13}$$

By coincidence, this distribution, necessary to match the fatigue performance of the 49 disks, is identical to that used in (1) to simulate large cycle counting errors.

Although the data input to the simulation represents our best current knowledge, the sources of data and degree of confidence in each specific probability distribution vary markedly. However, the important point is that all the probability distributions, when combined into a disk life simulator, reproduce accurately the observed performance of the fleet, as shown in Figure 7-4.

While it is possible that equally good fits could have been obtained with other combinations of specific probability distributions, it can be demonstrated that RFC effectiveness and the evaluation of the RFC procedures is primarily a function of the time-to-rejectable crack size and time-to-failure probability distributions used to simulate the fleet and not the exact statistical character of any one individual parameter (such as the scatter of fracture toughness or stress).

Although the 49 disks analyzed show far more scatter than does the full TF-33 fleet, we have simulated the highly variable behavior of the 49 disk fleet in order to test the RFC procedure under the most difficult conditions justified by data acquired in this program.

7.1.5 Specific Simulation of Crack Growth

So far, we have presented all information needed and used to compute the times to failure for the simulated disk population. However, one additional item should be discussed to complete the description of the fleet fatigue performance simulation. That item is the capability to simulate the real crack size, a, at any given $\hat{N}$, where $\hat{N}$ is the perceived amount of cyclic exposure at the time of inspection. Simulation of "a" is accomplished by the following:

1. For a given inspection time at a perceived number of cycles $\hat{N}$, select a value of $\hat{N}/N$ from the appropriate probability distribution (Equation (7-13)) in order to simulate the actual number of cycles N. The $\hat{N}/N$ "cycle-counting uncertainty" has been characterized in three ways:

   a) Select a different $\hat{N}/N$ for each inspection which would simulate the case of a disk taken from one engine and placed in another at random (type 1 error).

   b) Select a single $f = \hat{N}/N$ for the first inspection and multiply it by a new N/N for each subsequent inspection (type 2 error).

   c) Use the same $\hat{N}/N$ ratio for all inspections-simulating a constant error factor during the entire RFC process (type 3 error).

2. Knowing N and the other relevant random variables (C_i, C_p, and σ), compute, a, from equation (7-6).

3.   Repeat step "2" for each of the 10 bolt holes in the disk.

These three steps simulate real crack sizes in each bolt hole. The next step is to simulate the inspection uncertainty in detecting and sizing each of these cracks.

7.1.6   Simulation of Uncertainty of Four Inspection Procedures

The performance of three inspection procedures (high resolution probe, outside lab (500 KHz) and outside lab (1000 KHz)) have been characterized by means of general, empirical* probability distributions of the ratio $\hat{a}/a$ for various ranges of, a. In addition to the three real sets of inspection uncertainty data, a fourth artificial set, representing a hypothetical dramatic improvement in inspection reliability, was also examined.

7.2   RFC Procedure Development and Implementation

The general RFC philosophy which directed the development of the four RFC procedures is presented in Section 7.2.1, and the analytical details of the four RFC procedures are presented in Section 7.2.2. Most of the analytical details are common to all RFC procedures as discussed below in Section 7.2.1.1. Following this, the differences among RFC procedures are summarized (Section 7.2.1.2) and detailed (Section 7.2.2). Finally, four recommended improvements are identified at the end of Section 7.2.2.

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* A piecewise-Weibull characterization of the inspection uncertainty is used to obtain full generality. For details, see Figures 4-4 through 4-6, Section 4.2, and subroutine DAHAT in Appendix B herein.

7.2.1 Developed RFC Procedures

7.2.1.1 Details Common to All Investigated RFC Procedures

The RFC procedures considered and developed in this project have several commonalities. First, they assume that the fleet's engines are produced and released to service as a series of "subfleets." All components (engines) in a subfleet are introduced at essentially the same (calendar) time. Although only one critical component, in this case a disk, is simulated per engine, that component can have several nominally identical structural details which are sites for cracking, inspection, and failure. For most of the study, it is assumed that the engine life is seven times the "design life" of the critical component being considered and that inspection can occur only at integer multiples of the design life. In other words, each engine will have a disk inspected, and possibly replaced, between one and six times. This means that, by definition, without RFC six replacement parts will be required over the life of each engine. The goal of RFC is to decrease the large number of replacements with a minimum of cost and of failures.

7.2.1.2 Differences Among Investigated RFC Procedures

Four general types of RFC procedures developed and evaluated in this study are given in Table 7-2. The key differences among the procedures are the use or lack of use of two sources of "feedback" or "updates" from in-service inspections and historical data. As seen in Table 7-2, the two sources of feedback considered are (1) use of measured crack sizes to revise

Table 7-2

Four Developed and Evaluated RFC Procedures

Stress Estimation Method	Allowable-Life-Extension Estimation Method	
	Use Analyst's a vs N equation with a life-extension-based safety factor, SF. No adjustments allowed	Use statistical update of in-service component performance data. Continually adjust and compute life-extension with a maximum allowable conditional failure probability, F_{cmax}.
Based on prior stress analysis only. No adjustments allowed	RFC PROCEDURE No. 1 [Input IDIN = 0 and ISTRES = 2 in Program PERFCT]	RFC PROCEDURE No. 3 [Input IDIN = 1 and ISTRES = 2 in Program PERFCT]
Inspection-Based. The stress used is that "required" to produce the largest measured crack $\hat{a}$ in the perceived cycles $\hat{N}$ for each disk	RFC PROCEDURE No. 2 [Input IDIN = 0 and ISTRES = 1 in Program PERFCT]	RFC PROCEDURE No. 4 [Input IDIN = 1 and ISTRES = 1 in Program PERFCT]

All procedures:

① Base life extension on the largest crack measured $\hat{a}$ from the disk's several nominally identical failure sites.

② Always extend a disk with $\hat{a}$ < 1/32"; always retire a disk with $\hat{a}$ > $\hat{e}_{max}$.

③ Make use of an equation predicting fatigue performance and subject to systematic errors.

④ Honor the constraints on minimum ($\Delta\hat{N}_{min}$), maximum ($\Delta\hat{N}_{max}$), and descretized (integer multiples of $\Delta\hat{N}_{min}$) inspection intervals.

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the estimates of stress for each individual disk in a deterministic manner and (2) periodic statistical analyses of the "actual/predicted" time-to-failure probability distribution demonstrated by the global fleet of engines. Major features of the four procedures are summarized in Table 7-2 and the steps followed in each procedure are detailed below.

7.2.2 Simulation of Four Alternative RFC Procedures

1. Simulate each inspection process for each of 10 holes in each simulated disk by computing the inspection's uncertainty (represented by the ratio $(\hat{a}/a)$ from the appropriate piecewise Weibull distribution for the actual crack size, a, present in each hole. This hole-by-hole simulation allows great generality in reflecting such real scenarios as the lack of detection of a crack in one hole that would have failed the disk in a few cycles but rejection of the disk due to a much smaller crack that was oversized in another hole. A less fortunate scenario would be to undersize the two leading cracks in the disk and size any other cracks in the disk in such a manner that the disk is marginally acceptable. The simulated RFC procedure and fleet performance could then allow the disk to be put back into service where a failure could take place. The use of the multiplicity of potential failure sites (in this case of the 10 RI crack origins) is a major improvement made upon the work in (1).

2. Upon inspecting each hole in the disk, the inspector and the analyst base their decision on the disposition of the disk on the largest $\hat{a}$ measured. To simulate other realistic constraints, we make two

further requirements. If $\hat{a}$ is undetected (or found to be less than 0.031 inch, where this value corresponds to the inspection size separating "may-accept" from "accept"), the new disk life prediction is unchanged and the disk is placed back into service. Furthermore, if $\hat{a}$ is larger than some maximum value, $\hat{a}_{max}$ (values between .125" and ∞ are used in this report with most of the study focused on the value $\hat{a}_{max}$ = .250"), the disk is retired without analysis or consideration for further usage. Thus $\hat{a}_{max}$ corresponds to the inspection size separating "may-reject" from "reject." Repair is not simulated within the context of the RFC procedures.

3. If $\hat{a}$ is less than $\hat{a}_{max}$, the value is substituted into the equation

$$\hat{N} = F(\hat{a}, \hat{\sigma}, etc) \qquad (7\text{-}14)$$

where F represents the best estimate of the (a versus N) behavior by the simulated analyst of the RFC procedure. In this study, we used

$$N = \frac{\hat{C}_1}{\hat{\sigma}^n} + \frac{\hat{C}_2}{\hat{\sigma}^m} (1.50 + \log \hat{a})^{\hat{P}} \qquad (7\text{-}15)$$

where the ^ symbol refers to the analyst's estimate of the parameter. Stress estimation is the first point of difference among the four RFC procedures in Table 7-2. The "prior-analysis-based" stress method simply uses the s ne initial $\hat{\sigma}$ estimate (e.g. design calculation) for all disks. Howevei, in the "inspection-based" stress method (see Ref. (1)), we "infer" $\hat{\sigma}$ for each disk from $\hat{N}$ and $\hat{a}$ by solving equation (7-15) implicitly for $\hat{\sigma}$.

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4. Substitute* $\hat{\sigma}$ into the time-to-failure prediction equation

$$\hat{N}_f = F (\hat{a}_c, \hat{\sigma}, etc) \tag{7-16}$$

5. To obtain the allowable cyclic life extension, $\hat{N}_{allow}$, two methods are used depending on the RFC procedure. For the nonprobabilistic, constant-safety-factor technique, we apply a safety factor SF to compute

$$\hat{N}_{allow} = \hat{N} + (\hat{N}_f - \hat{N})/SF \tag{7-17a}$$

For the probabilistic/statistical update, conditional-failure-probability technique, we perform a periodic statistical analysis of the in-service fleet failures and successes. Figure 7-6 is a schematic representation of the procedure in which a maximum allowable conditional failure probability is defined, F_{cmax}. Using this safety/economic criteria constraint, along with the two parameters (α, β) representing the time-to-failure Weibull probability distribution, the allowable cyclic life extension is

$$\hat{N}_{allow} = F (\hat{N}, F_{cmax}, \hat{\alpha}, \hat{\beta}) \tag{7-17b}$$

---

* In the inspection-based method, $\hat{\sigma}$ is merely a curve fitting parameter which "makes up" or "calibrates" for errors of all sorts, including the dominant cycle-counting errors discussed before. We could have used other methods of calibration; for example, use the original stress estimate and "adjust" the cycle count. In general, the parameters subject to the highest-impact errors could be r luced to "calibrators."
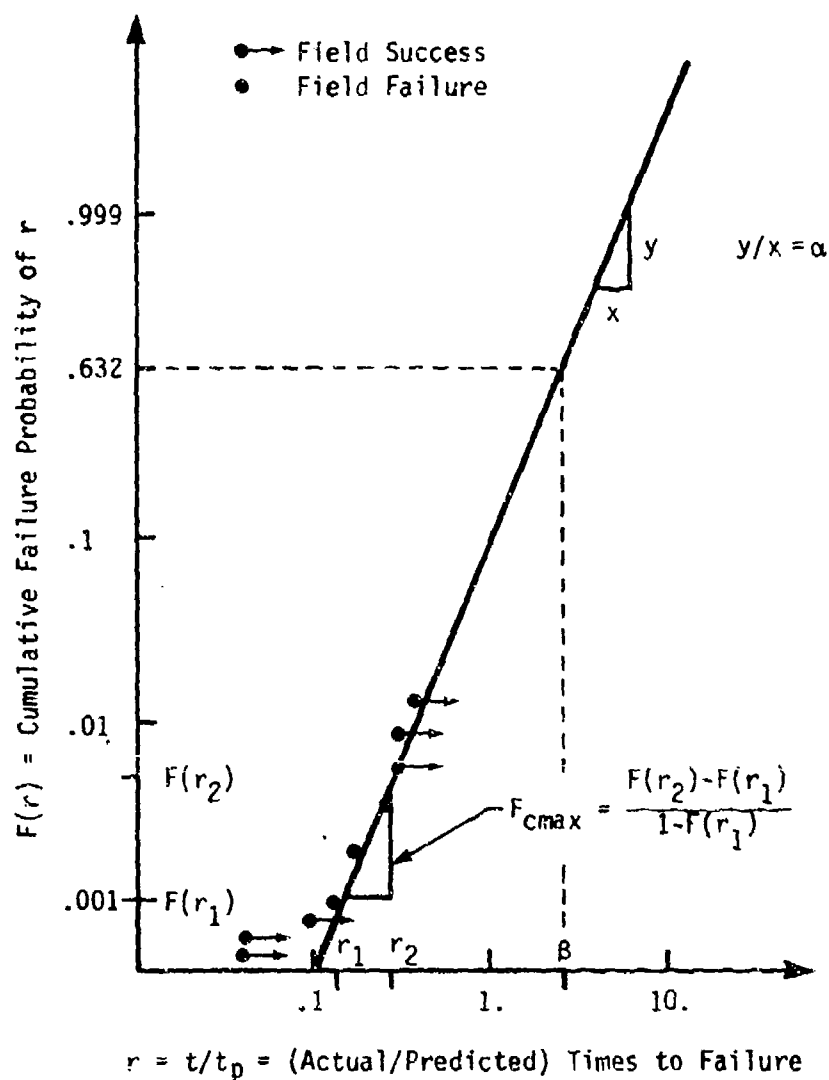
Figure 7-6 – Procedure for Setting Maximum Time (t_2) to Next RFC Inspection. Past Experience, Field Failures, and Successes are Used to Estimate α and β and to Continually Update These Estimates. Then, at any Given Time, with Known α, β, t_1, t_p, and Maximum Allowable Failure Probability F_{cmax}, we can Calculate (r_2, t_2) Graphically as Above, or from Eqs. (7-17b) or (C-8).

The lengthy derivation of the precise form used for equation (7-17b) is given in Appendix C. The most important points are that equation (7-17b) represents the utilization of all knowledge regarding the fleet and the fatigue phenomenon to arrive at a near-optimum allowable life extension. Even the pre-fleet statistical and historical knowledge of the phenomenon (such as the estimation of pn(a)*, the changing probability distribution of real crack sizes), can be used to estimate initial values of α and β (Fortran variables AL and BET). Thus, the statistical update capability allows us to take advantage of actual past fleet performance to improve the RFC procedure for subsequently introduced and exposed parts. As will be seen in the probabilistic RFC evaluation discussions to follow, the update capability is quite important to optimizing the RFC procedure. In fact, the study indicates that our decision to statistically analyze the fleet at every minimum inspection interval (to be defined below) is not optimum. The Monte Carlo simulations indicate that the update frequency should be increased to, at the very least, update the fleet statistical analyses directly after any failure.

6. The next inspection point $\hat{N}_e$ is computed to account for the realistic constraints on minimum and maximum inspection interval $\hat{N}_{min}$ and $\Delta \hat{N}_{max}$, through

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* In our original plans, we regarded the prior estimation of pn(a) as an important part of an optimum RFC procedure. When faced with the need to fully define, develop, and evaluate specific procedures, this prior goal led to significant problems. These problems, details of our progress, and our specific approach to evaluation of pn(a) are described in Appendix D.

$$\hat{N}_{el} = \hat{N} + AMIN1 \left[\Delta\hat{N}_{max}, \; (\hat{N}_{allow} - \hat{N}) \right] \qquad (7\text{-}18)$$

and

$$\hat{N}_{e} = FIX \; (\hat{N}_{el}/\Delta\hat{N}_{min}) \qquad (7\text{-}19)$$

where the FIX function* rounds its argument down to the nearest low integer, and the AMIN1 function* chooses the least of the two quantities in the bracket. The disk is then reinspected at $\hat{N}_e$ cycles, new $\hat{a}$, $\hat{\sigma}$, and $\hat{N}_e$ values are calculated and another life extension is computed. If the calculation predicts that the disk life cannot be extended to at least the next scheduled inspection, the disk is retired at the pre.ent inspection. Thus, if a large enough minimum inspection interval were chosen or forced by logistics, all disks would be retired after the first inspection and no RFC would be possible.

Throughout most of this study we use $\Delta\hat{N}_{min}$ = 750 cycles and either $\Delta\hat{N}_{max}$ = 750 cycles or =, where 750 cycles is taken as the "design life" of our simulated sub TF-33 disk fleet. No disk or engine is allowed to remain in service for more than seven disk

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* To avoid ambiguities in comparing similar quantities, such as three different types of estimates of a statistical parameter, use is made of both Fortran functions and variable names which are occasionally intermixed with algebraic symbols. Fortran variables are all defined in Appendix B.

design lives (5250* cycles); a value which might represent the life of the engine or the obsoletion of the aircraft. Because the performance of the simulated fleet is worse than that expected for the TF-33 third stage turbine disk's total fleet, these specific cyclic values are about one-fourth as large as might be expected. Since everything is "scaled-down" by this one-fourth factor, the per-cycle numerical economic results of RFC would have been proportionately better for the actual TF-33, third turbine disk.

As can be seen from Table 7-2, the RFC Procedure No. 1 is deterministic and totally uncalibrated against field experience. It is a primitive unrealistic procedure in the sense that it assumes that the inspection and analysis teams are automotons without memories. Specifically, the inspector and the analyst are assumed not to learn from their previous experience not to use the results of a previous inspection to compare with that of the current inspection. Furthermore, they are powerless to change any aspect of the RFC procedure, safety factors, or analytical tools in response to actual events, such as a number of unexpected field failures.

RFC Procedure No. 2 analyzes and calibrates each individual disk by asking the question: "What stress level ($\hat{\sigma}$) must have been present to cause the crack to grow to the measured size $\hat{a}$ in $\hat{N}$ cycles?" It is expected that, with a minimum inspection reliability, such an adjustment of $\hat{\sigma}$ should re   e

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* The actual input engine life was rounded down to 5200 cycles to make sure PERFCT did not schedule a 7th inspection a few cycles before engine retirement.

the impact of a variety of errors. However, RFC Procedure No. 2 also assumes the use of inspectors without memories; there is no reaction to the overall experience of the fleet.

RFC Procedure No. 3 doesn't calibrate each individual disk according to its measured crack sizes but does use all past field performance knowledge to adjust the allowable cyclic life extension and subsequent inspection points $\hat{N}_e$ of all disks. Thus, the inspection and analysis teams have both memories and the ability to react and improve the RFC procedure on an ongoing basis.

RFC Procedure No. 4 combines the two improvements described above for RFC Procedure Nos. 2 and 3. Each disk is calibrated (with $\hat{\sigma}$) to the fatigue crack initiation/propagation model according to its largest measured crack size and the overall performance of the fleet is accounted for with updates of the statistical analysis of the fleet. Procedure No. 4 is at present our best fully developed procedure. The major capabilities and limitations of the procedure and accompanying software are described in the comment cards of the computer program PERFCT (Appendix B). Although RFC Procedure No. 4 could be improved, it is considered to be an opt...um tradeoff between capabilities and enough simplicity to allow full analytical development, software development, and analytical evaluation within the limits of this project. The only major improvement we would strongly recommend is that the statistical update analysis be performed more often than every $\Delta\hat{N}_{min}$ cycles. Other possible improvements are:

1. The software should be expanded to handle more than one part type per engine and crack-site type per part.

2. Statistical updates would be provided for each failure mode and, in fact, could be expanded to differentiate between old and young subsets of a given component population, where advisable.

3. Statistical updates could also be expanded to account for data obtained from destructive examination of retired disks.

4. Account for the possible reduction of new-part "infant mortality-type" failures through the reduced use, by RFC, of replacement parts. More discussion of this infant-mortality aspect is given later in this section.

It is noted that a conservative appraisal of RFC benefits is made for all four procedures based upon the very large scatter observed from the 49 disks inspected.

7.3   Cost Details of RFC Evaluation

The costs associated with inspection, replacement, and failure used in this investigation are given in Section 7.3.1. Safety criteria which are not associated with cost are discussed in Section 7.3.2. The method for computing RFC savings is described in Section 7.3.3, and Section 7.3.4 discusses the impact of pre-design life failures observed in the simulations.

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7.3.1 RFC Gains and Costs Simulated by PERFCT

The RFC procedures described above were programmed into the Monte Carlo simulation program, PERFCT. The program simulates any number of randomly selected "grand fleets," each containing (1) up to 50 subfleets, (2) up to 1500 single-component "engines" and (3) up to 10,600 new and replacement components. The program does the following for each engine: (1) generates "in-service" fatigue data for the component (disk) at the appropriate calendar time, TE, at which the subfleet is introduced; (2) performs a chosen RFC procedure on each engine at the appropriate time and makes (random) errors based upon the input error-simulation probability distributions described above; (3) makes RFC decisions of inspection intervals and disk replacements (each replacement disk requires generation of new in-service fatigue performance data); and (4) checks for failure of any disk which is replaced. Costs are assigned to the various outcomes of the RFC procedure for the jth engine.

Each time the engine disk is inspected, a negative dollar gain (cost) of

$$G_{ji} = -200 \text{ dollars} \tag{7-20}$$

is incurred. Each time the life of the disk is extended, a gain of

$$G_{je} = 10\hat{N}'_e \text{ dollars} \tag{7-21}$$

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(i.e. $7500 per forestalled replacement of a disk with design life, DL = 750 cycles) is assigned, and $\hat{N}'_e$ is the perceived amount of cyclic life extension beyond DL until either the next inspection, retirement, or failure, whichever applies. Should a failure occur before the rotor is retired, a negative gain (cost) of

$$G_{jf} = -2,000,000 \text{ dollars} \tag{7-22}$$

is assigned.

7.3.2 Safety Aspects of Part Failure

Clearly, the estimation of the expected cost of failure G_f is finite because the failure probability is never zero (even without RFC). To insist otherwise is unrealistic and impractical for RFC as well as for the initial life limits. Our specification of a $2 million average cost of failure is equivalent to assuming that most failures damage one engine while some failures could lead to aircraft loss (since complete engine replacement cost is $750,000).

In dealing with high impact safety and economic considerations regarding structural failure modes, we have developed a simple way of performing rational economic analysis without limiting the flexibility to maintain safety criteria. The procedure is to define G_f clearly as the economic impact of failure only. It should be noted that G_f is a dollar cost only and has no connection with safety criteria or constraints.

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Having decided that G_f is not a safety criterion, the choice of criterion is totally flexible and either traditional or new methods can be used. Once the independent safety criterion is specified, the selection of RFC parameters is based upon whichever one limits, and it becomes an exercise in mathematics rather than politics. Specifically, the goal is to maximize the RFC cost savings without violating the safety criterion. This is a straightforward optimization problem in which the safety criterion serves as a constraint. Another recommended goal might be to minimize the probability that total RFC gain is less than some desired minimum, again subject to safety and other constraints.

We studied two types of safety criteria. In the first, a maximum allowable failure probability, F_{cmax}, is specified and built into the statistical-update RFC procedure constraints. This failure probability could be specified and justified by using several comparative criteria. For example, the failure probability may be acceptable if it is less than the in-service failure probabilities demonstrated during the initial design life of similar equipment. A second safety criterion with a long history of use is the safety factor. In this report, a life-based safety factor, SF, representing the ratio of estimated-to-allowable life extension after an RFC inspection, is used in conjunction with deterministic RFC procedures. Further, safety factors and failure probabilities are related and can be computed from each other.

Alternative or additional safety constraints might also be imposed. Two such additional safety constraints evaluated in this report are a maximum crack size beyond which a part will never be placed back into

7-35

service ($\hat{a}_{max}$) and a maximum inspection interval ($\Delta\hat{N}_{max}$). For this study, $\Delta\hat{N}_{max}$ has been set equal to its extremes; namely, either to (1) the minimum inspection interval, to produce a single, constant inspection interval (see equations 7-18 and 7-19) or (2) infini y, representing no maximum inspection interval. The $\hat{a}_{max}$ value has been set at 0.250-inch for the majority of this study and varies from 0.125-inch to ∞ for a sensitivity study.

7.3.3 Total RFC Savings Estimation and Sampling Error

The total RFC cost savings for each engine is given by summing all the costs times the number of times each is incurred,

$$G_j = f_i G_{ji} + f_e G_{je} + f_f G_{jf} \quad \text{(Repeated indices do not denote summation)} \quad (7\text{-}23)$$

where f_i, f_e, f_f represent the number of incidents for each type of cost or gain for the jth engine.

The expected average dollar gain per engine of the RFC procedure is then estimated from

$$\bar{G} = \sum_{j=1}^{IDN} G_j / IDN \quad (7\text{-}24)$$

where IDN is the number of engines simulated (between 800 and 1500 in this case). $\bar{G}$ is computed for alternative F_{cmax} or SF to evaluate the RFC performance for specific RFC procedures and parameters. The rms error of the $\bar{G}$ estimate (i.e., the sampling tolerance or standard deviation of $\bar{G}$) due

to the use of a finite number of engine simulations (which represent 1100 - 10,000 disk simulations) is estimated to be less than $4000 near the optimum safety factor, where the simulated failure probability is of the order of .001 to .005.

7.3.4 Pre-Design Life Failures

Due to the atypically large scatter of the simulated fleet, it was not possible to eliminate pre-design life failures (which are not chargeable to RFC) without reducing the design life (DL) to an even more unrealistic value than 750 cycles. In fact, assuming a design life of 1000 cycles produced 8 to 10 failures during the initial 1000 hours of each of the 1500 engine fleets simulated. The 750-cycle design life produced 1-3 failures in the initial 750 cycles. On average, 10,000 new disks will suffer twice the pre-design-life number of failures than will 5000 new disks. Since, as will be shown below, the better RFC procedures resulted in 0, 1, or 2 post-design life failures, while authorizing a reasonably small number of replacements, it is clear that the RFC procedure has the potential to reduce the total number of failures of a high-scatter fleet.

The best way to understand this concept is through reference to the schematic in Figure 7-7. Illustrated is the classic "bathtub curve" showing the component failure rate variation with time. Normally we think of fatigue as a wear-out process and of disks as components in which the wear-in portion of the curve is negligible. However, given a significant amount of wear-in, RFC can actually reduce the number of failures below that which would be experienced in the non-RFC situation. While mechanical engineers often

7-37
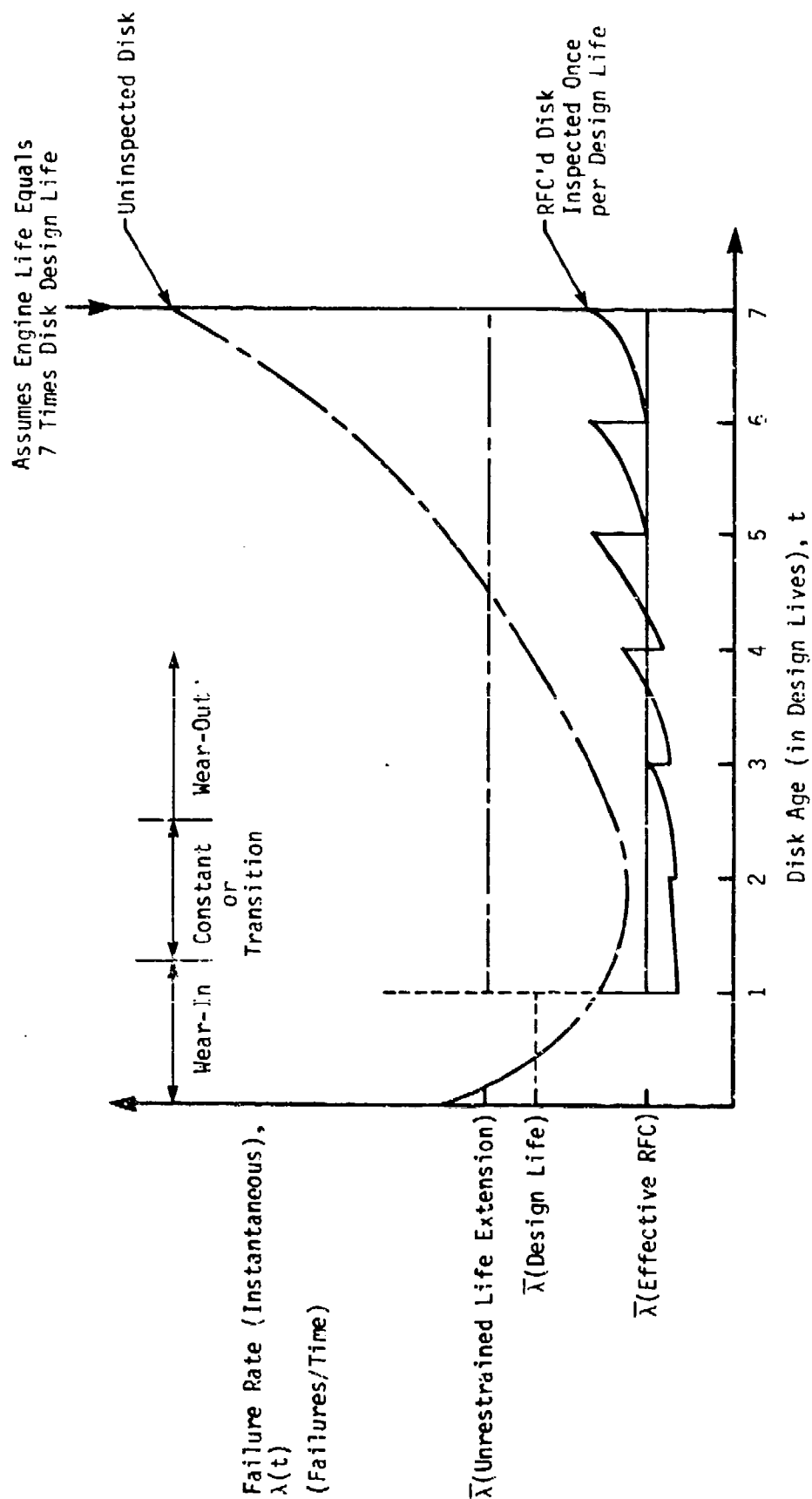
Figure 7-7 - Schematic Illustrating the Overall Effect on Failure Rate of RFC and the Additional RFC Benefits Gained by Partially Defeating a Significant "Wear-In" or "Infant Mortality" Failure Mode for New Disks. The Post-Design-Life Average Failure Rate $\overline{\lambda}$ (Unrestrained Life Extension) is Reduced by Effective RFC to a Level $\overline{\lambda}$ (Effective RFC) Lower Than the Pre-Design-Life Level for New Disks, $\overline{\lambda}$ (Design Life). Thus, Each Avoided Needless Replacement Lowers the Overall Effective Failure Rate. Wear-In Can Also be Reduced by Process and Quality Control (e.g., Inspect New Disks) and Changes in Design Life.

associate wear-in failure modes with electronic components, structural failures also show wear-in. These might be due to a source of unusually large scatter such as for the 49-disk population examined at FaAA. More likely causes of wear-in failures are such identifiable physical phenomena as a rare-but-possible, initial, large, crack-like defect located at the point of highest stress concentration in the fatigue-critical notch. This latter problem would be compounded for a structure with a lower ratio of propagation-to-total part life than that exhibited by this TF-33 component. Several RFC-candidate components of the F-100 engine exhibit potentially a lower ratio than this TF-33 component. Thus this potential "extra credit" of RFC should be carefully studied in the F-100 application.

No extra credit was given RFC in this evaluation for the reduction of pre-design life failures. In fact, for the case of the statistical update RFC procedures, no provision was made to use the pre-design life failure information in the statistical algorithm so, again, the cost effectiveness of RFC could be further improved.

7.4   Simulated Analyst/Inspection Teams

Five analysts and four inspectors are considered to obtain various analyst/inspector (A/I) teams. Five of these teams are used in Section 8 to investigate the effect of analysis and inspection errors on RFC performance.

7.4.1   Five Analysts

Analyst 1 uses a <u>deterministic</u> equation to model the fatigue process that, on average, will <u>overpredict the median</u> failure life by a factor of

three. Such an error could be due, for example, to the use of inappropriate temperatures for laboratory fatigue tests. (An Analyst "1a" is also considered who uses the correct model with an underestimate of stress to produce a factor-of-three overprediction of life.)

Analyst 2 uses an equation to model the fatigue process which under-predicts median life by a factor of three. (An Analyst "2a" is also considered who uses the correct model but overestimates the stress to produce a factor-of-three underprediction of life).

The third analyst develops a perfect deterministic model of the fatigue process that corresponds to the median life calculated from equation (7-4)*.

It has been assumed that the analysts have included all relevant failure modes in their assessments. For example, the effect of a larger-than-anticipated vibratory stress in the rim could cause the disk life to be limited by a combination of low and high cycle fatigue near the rim rather than low cycle fatigue and brittle fracture for the bolt hole cracks.

7.4.2 Four Inspectors

The sensitivity of the RFC program dollar gains to inspection procedure is simulated by using three different "real" inspectors, the performance of which has been measured, and one "hypothetical" inspector to inspect each engine disk. Inspector A uses the high resolution probe, Inspection B uses

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* With constants of C_i = 2500 and C_p = 9560 cycles.

the outside lab technique with a 500 KHz frequency and Inspector C uses the outside lab technique with a 1000 KHz frequency. Inspector D uses a hypothetically improved version of the high-resolution probe which reduces the crack sizing error substantially.

7.5   Combination of Software Into the Computer Code

The individual software items mentioned above for simulation of (1) fleet, (2) fatigue, (3) analysis, (4) inspection, (5) constraints, (6) RFC procedure implementation, and (7) economic results were combined into the computer program PERFCT. The program is internally documented with comment cards listed in Appendix B and has been thoroughly checked out by comparing its output with detailed hand computations based on both deterministic and probabilistic calculations.

8.0 RFC PROCEDURE EVALUATION BY MEANS OF SENSITIVITY STUDIES

8.1 Graphical and Tabular Presentation of Results

Major RFC evaluation results of the most informative cases that have been examined in this project are presented in Figures 8-1 through 8-14a. The primary result of each case is a curve showing the relationship between the average dollar gain per disk, $\bar{G}$, which is a measure of the effectiveness of the RFC procedure, and either (a) safety factor SF or (b) maximum allowable failure probability F_{cmax}. In most of the figures, the perfect deterministic analysis was used as a baseline or "standard curve" in conjunction with (1) the high-resolution probe inspection-uncertainty data and (2) the factor-of-two, "type 3" cycle counting error (see Section 7.1.5). Other details of the baseline curve are summarized in Figure 8-1. Thus, the baseline curve appears with other curves which represent important parametric variations used in the RFC evaluation sensitivity study. The same solid circular symbol "●" is used for both the $\bar{G}(SF)$ and $\bar{G}(F_{cmax})$ baseline curves.

Note from the baseline (Figure 8-1) and most other curves a general "hump" shape corresponding to a tradeoff between excessive premature failures and excessive premature retirements. The optimum safety factor represents the best balance between these two competing effects and corresponds to simulated failure rates of the order of 0.25 to 3 failures per 1500 engines, depending on the circumstances. The sometimes sharp drop in the $\bar{G}$ curves on the low SF (high F_{cmax}) end corresponds to too many failures. The usually gradual drop in the $\bar{G}$ curves on the high SF (low F_{cmax}) end represents the cost of an increasing number of premature disk retirements.
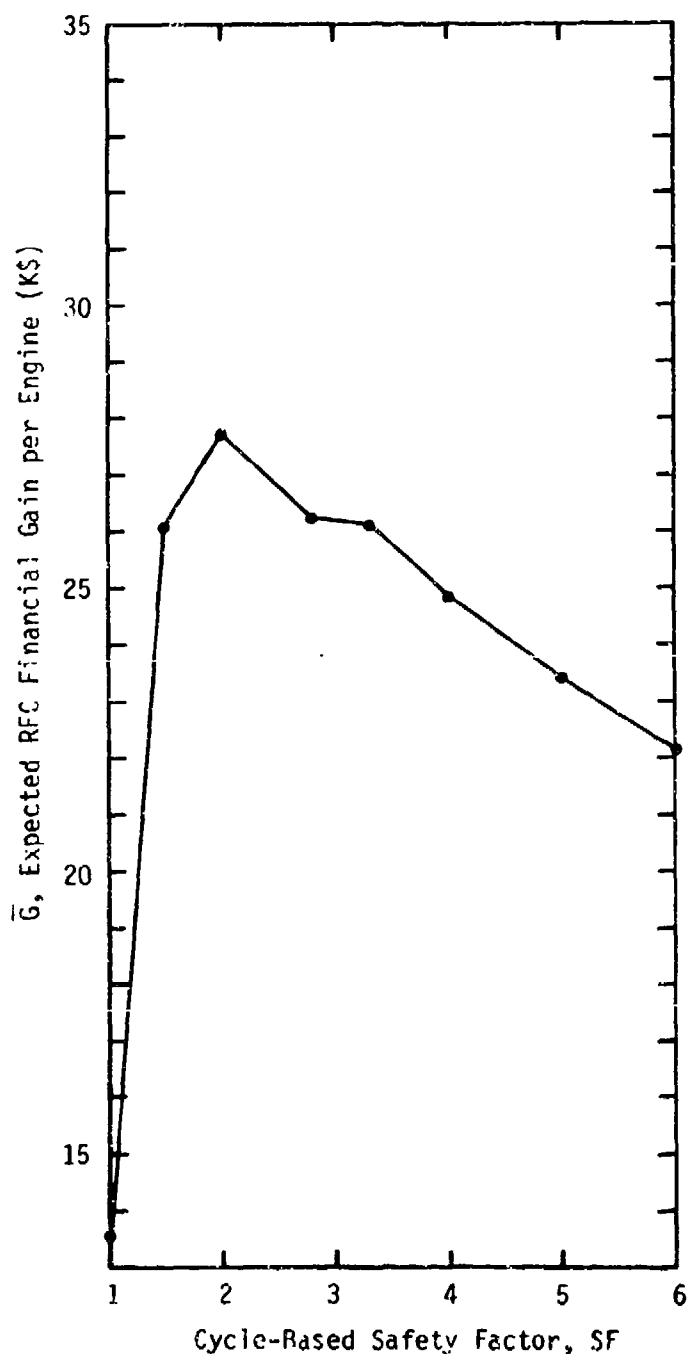
BASELINE CASE PARAMETERS:

1) Perfec. Deterministic a vs. N Analysis

2) Perfect Estimate of Average Disk Stress

3) High Resolution Probe Inspection Uncertainty Data

4) "Factor-of-Two, Uniform (Type 3)" Cycle Counting Error

5) Constant Safety Factor and Infer Stress from Crack Measurement (RFC Procedure #2)

6) Inspect Every 750 Cycles

7) Always Return to Service if $\hat{a}$ is Less Than 1/32"

8) Always Replace if $\hat{a}$ is Greater Than 1/4"

9) For $\hat{a}$ Values Between 1/32" and 1/4", Replace Only if Dictated by the Analysis and Safety Factor

10) Ten Nominally Identical Cracking Sites per Disk

● Baseline $\bar{G}$ (SF) {E-1 through E-8}

Figure 8-1 - Effect of Safety Factor on RFC Benefits for the Baseline or Standard Case. {Bracketed Information Lists Table Numbers in Appendix E Which Correspond to the Displayed Data Points.}

Occasionally, one or more of the RFC procedural constraints, such as the use of a very short maximum inspection interval such as $\Delta\hat{N}_{max} = 750$ cycles, nearly or totally governs the RFC decision procedure, so as to reduce the effect of changing the safety factor or maximum failure probability. In these cases, the curves become nearly horizontal lines rather than humps. In discussing the RFC evaluation results, those constraints that cause unusual behavior of the curve will be pointed out.

Each plotted point in Figures 8-1 through 8-14a is supported by a table in Appendix E that summarizes, for each subfleet, the frequency of all operation, inspection, replacement, and failure events that when combined resulted in the data point for RFC economic gain. While each table in the voluminous Appendix E is referenced in a figure and/or table in this section, only the baseline and the most interesting results are discussed in any detail.

8.2   Discussion of Baseline Curve

Table 8-1, summarizes results from Tables E-1 through E-10 for the baseline RFC procedure. For the range of safety factors considered, the economic gain of the baseline RFC procedure ranges from $13,610 to $27,784 per engine. The poorest RFC performance corresponds to a safety factor of 1, for which 1770 disk replacements out of a possible 9000 (6 x 1500) prevented all but 16 disk failures. The safety factor value, 2, produced the optimum economic result by requiring 2668 replacements and preventing all but two failures, which resulted in a $27,784 gain per engine. While the tabulated dollar gains are based on accurate cycle-by-cycle prorations computed by

8-3

Table 8-1

Comparison of RFC Benefits of Baseline Constant Safety Factor
Procedure (#2) with the Extremes: (1) Unattainably Perfect
RFC, (2) Pure Negligence, and (3) No RFC at all.

PFC Procedure	Appendix E Table # for Summary	Safety Factor	Fleet Replacements	Fleet Failures	RFC Dollar Gain per Engine
Baseline	E-1	1.0	1776	16	13610
"	E-3	2.0 (optimum)	2668	2	27784
"	E-5	3.3	3532	0	26127
"	E-8	6.0	4319	0	22187
(1) Unattainably Perfect	E-9	Variable and Perfect	311	0	43163
(2) Negligent, never replace a Disk throughout Engine Life in spite of Failures	E-10	N/A	308 (failed disks must be replaced)	308	-367760
(3) No RFC	N/A	N/A	9000	zero	zero (no account of pre-design-life failures)

PERFCT, the equations below demonstrate that the economic gains can be essentially reproduced with simple hand calculations.

$$G = 45,000 - \left[200 \ F_i + 7500 \ F_r + 2,000,000 \ F_f \right] / 1500 \qquad (8-1)$$

where F_i, F_r, and F_f are the total numbers of inspections, replacements, and failures in the 1500-engine fleet as output in the tables of Appendix E.

The reason that the safety factor value of 1.0 does not result in more than 16 failures is the presence of two synergistic, conservative factors listed as items 6 and 10 in Figure 8-1. These factors are the frequent (750-cycle) inspections combined with the multiplicity of inspection sites that allow every disk inspection ten opportunities to reject the disk. In effect, these powerful factors are optimally balanced by the choice of a generally low safety factor of 2.

The "no RFC" condition serves as a reference of zero dollar gain per engine, and corresponds to 9000 fleet replacements with no failures (as explained in Section 7, no credit is being given to RFC for preventing pre-design-life failures) and no inspections. The maximum cost savings is $45,000 per engine (6 replacements per engine times $7500 per replacement). However, since the undisturbed simulated fleet will produce many failures (in fact, Table 8-1 notes 308 failures) in the 5200 cycle engine life, $45,000 per engine is not an achievable upper bound for the analyzed situation. Rather, as noted in Table 8-1 no less than 311 perfectly timed and accurate inspections and replacements are necessary to avoid all failures. The reason that 311 rather than 308 replacements are required is that the PERFCT program

assumes that any engine suffering a failure is down until the next scheduled inspection. Therefore, the "unattainably perfect" RFC procedure involves slightly more disk time than the "negligent" RFC procedure. Thus, the upper bound of RFC gain is shown in Table 8-1 as $43,163, racher than $45,000 per engine, when the 3:1 necessary replacements are included.

The "negligent" case involves a test program-like situation in which neither replacements nor inspections are permitted through the 5200-cycle engine life. Since the resulting 308 failures correspond to a 17% cumulative failure probability (308/1,808), it is clear from this "do-nothing" analysis that any RFC procedure would be severely tested using the high-scatter, high-failure rate fleet represented by the 49 inspected disks.

The baseline RFC simulation is considered to be very encouraging in comparison to the extreme cases of perfection, absurd negligence, and no RFC. The potential (for example, with SF = 3.3) for avoiding well over half the 9,000 replacements with no failures and a gain of over $25,000 per engine is impressive. The $25,000 value is also impressive considering the absolute extreme results of approximately $43,000 for an unattainably perfect situation. However, the baseline case involved perfect deterministic fracture mechanics and stress analyses and fairly conservative constraints and inspection practices. Most of the remainder of Section 8 is devoted to exploring the impact of different assumptions, inspection procedures, constraints, and introduction of several types of possible errors.

8.3   Effect on RFC Benefits of Inspection Equipment and Procedures

8.3.1   Effects of Inspection Uncertainty and Intervals Between Inspections

Figure 8-2 shows the effect of changing the inspection procedure from the baseline high-resolution-probe inspection on RFC benefits. We have also characterized the uncertainties of two other inspection procedures; namely, the "outside" lab procedure for frequencies of 500 KI and 1000 KHz. As seen from Figure 8-2, there is little to choose among the economic benefits gained from the three inspection procedures for safety factors between two and four. However, for safety factors greater than 4, the outside lab inspection using a 500 KHz frequency leads to the highest benefit of the three inspections. Table 8-2 gives some idea as to why the 500 KHz inspection is superior for adequate-to-high safety factors in this application. Basically, the 500 KHz inspection revealed less propensity to oversize cracks, especially by large amounts such as the factor "4" addressed in Table 8-2.

The high resolution probe is clearly superior for detecting small cracks (below 0.03"), but, in the context of the simulated TF-33 RFC program, this extra detection capability has almost no effect upon the RFC gain. The two major reasons for this lack of effect, as learned from examining the details of the premature failures and retirements that occurred in the simulated results, are (1) it is the intermediate-to-large crack sizes that are important (e.g., 0.05 inch to 0.2 inch) for most RFC decisions and (2) given an adequately large safety factor and many chances to detect cracks (e.g., frequent inspections and multiple crack sites), the superior RFC procedure will be the one with least propensity to greatly oversize the crack. Again, as seen in Table 8-2, the 500 KHz inspection has demonstrated the least

8-7
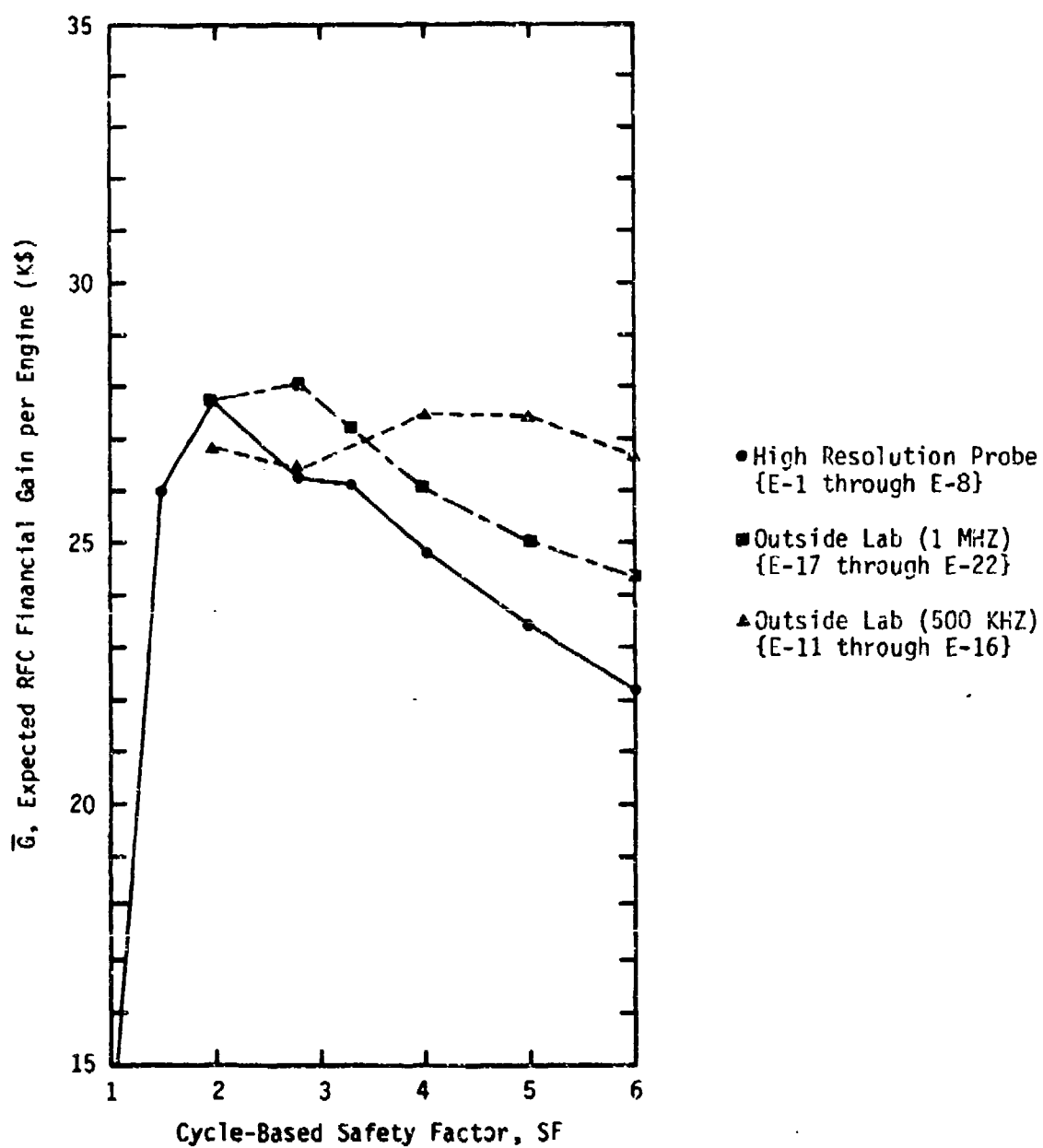
Figure 8-2 - Effect of Inspection Procedure on RFC Benefits.

Table 8-2

Comparison Of The Probability Of Overestimating

Crack Sizes Using Three Inspection Procedures

Actual Crack Size a (inches)	Probability of Overestimating Crack Size by any Amount			Probability of Overestimating "a" by more than 4 times		
	High Resolution Probe	Outside Lab (500 KHZ)	Outside Lab (1 MHZ)	High Resolution Probe	Outside Lab (500 KHZ)	Outside Lab (1 MHZ)
.003	.25	.10	.10	.18	.08	.09
.015	.53	.25	.30	.12	.12	.15
.025	.60	.30	.30	.20	.12	.14
.035	.50	.32	.45	.10	.09	.12
.05	.50	.39	.43	.06	.035	.08
.08	.34	.32	.34	.06	.04	.03
.15	.40	.40	.43	.03	.03	.03

tendency of the three inspection procedures to oversize the crack. A key reason why crack detection probability, per se, does not dramatically influence the optimum RFC benefits is that the multiplicity of inspection and failure sites (in this case, ten bolt holes which can produce RI cracks) introduces ample opportunity to detect at least one crack if multiple bolt holes are cracked. For example, if the probability of detection for a given crack size present in each bolt hole is independent of the other nine holes and is only 0.5, the probability of detecting at least one of these 10 cracks would be greater than 0.999.

Figure 8-3 is included to show possible upside benefits for a hypothetical dramatic improvement in the high-resolution probe inspection. While detection probabilities for given cracks were not changed, the sizing was dramatically improved by inserting a square root function "operator" into the inspection simulation subroutine (DAHAT; Appendix B). The square root operator was used to reduce inspection uncertainty and to produce $\hat{a}/a$ ratios closer to unity, the perfect value. For example, if a random selection from the probability distributions of uncertainty for the high resolution probe produced an $\hat{a}/a$ of 4, the square root function transformed this ratio to 2, and for an $\hat{a}/a$ of 1/9, the square root operator artificially changed this value to 1/3, etc. As might be expected, this dramatic reduction in crack sizing uncertainty produces an across-the-board increase in RFC gain for realistic values of safety factor.* However, the increases are not dramatic and the optimum benefits of the actual high-resolution probe inspection ($28,000 per

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* If the effective safety factor is too low, a better inspection can increase the number of failures. By comparing Tables E-1 and E-23, note that at SF = 1, the superior inspection increased failures from 16 to 19 but produced economic benefit by reducing replacements from 1770 to 645.

The chart axes:
- Y-axis: $\bar{G}$, Expected RFC Financial Gain per Engine (K$)
- X-axis: Cycle-Based Safety Factor, SF

•Actual High Resolution
 Probe Data
 {E-1 through E-8}

■Hypothetical-Improvement
 Inspection in which the
 square root function was
 used to reduce inspection
 uncertainty of the High
 Resolution Probe â/a data.
 (i.e. an â/a of 4 was
 transformed to 2, an â/a
 of 1/9 was changed to 1/3,
 etc.)
 {E-23 through E-30}

Figure 8-3 · Effect of a Dramatic Reduction of Inspection Uncertainty on
RFC Benefits.

engine; short of perfection by $15,000) are increased approximately $5000 per engine to $33,000 per engine (short of perfection by $10,000). The presence of the many other variables and constraints limits the impact of improved inspection.

Figure 8-4 demonstrates the effect of removing the maximum-inspection-interval constraint. Removing this constraint produces a slightly higher optimum benefit of over $29,000 per engine along with a dramatic shift in optimum safety factor from 2 to 4. Again, the optimum SF is associated with two failures (see Table E-36). Thus Figure 8-4 shows clearly the underlying conservatism inherent in the use of very frequent inspections. Because of the multiplicity of inspection sites, there is a much higher probability of over-predicting the magnitude of the largest crack in the disk than underpredicting it. Therefore, the multiplicity of inspection sites and high inspection frequency lead to optimum results at a low safety factor. When the constraint on maximum inspection interval is removed, the optimum safety factor takes on a value (SF = 4), which is much more intuitively pleasing considering the scatter in the fleet under study. Note the unexpected modest increase in the number of failures from 2 to 17 (Tables E-25 through E-31) and decrease in cost (Figure 8-4) for the large reduction of the safety factor from 4 to 2 for the unconstrained-maximum inspection interval case. This "safety net" is due primarily to the multiplicity of inspection sites and the 0.25-inch limit on maximum measured crack size for return to service.

In Figure 8-4a, the effect of a limit on the maximum time between inspection is examined in conjunction with the probabilistic-update RFC benefit (Procedure No. 4). For the baseline case, the maximum economic benefit is gained by specifying a maximum allowable failure probability at the very high
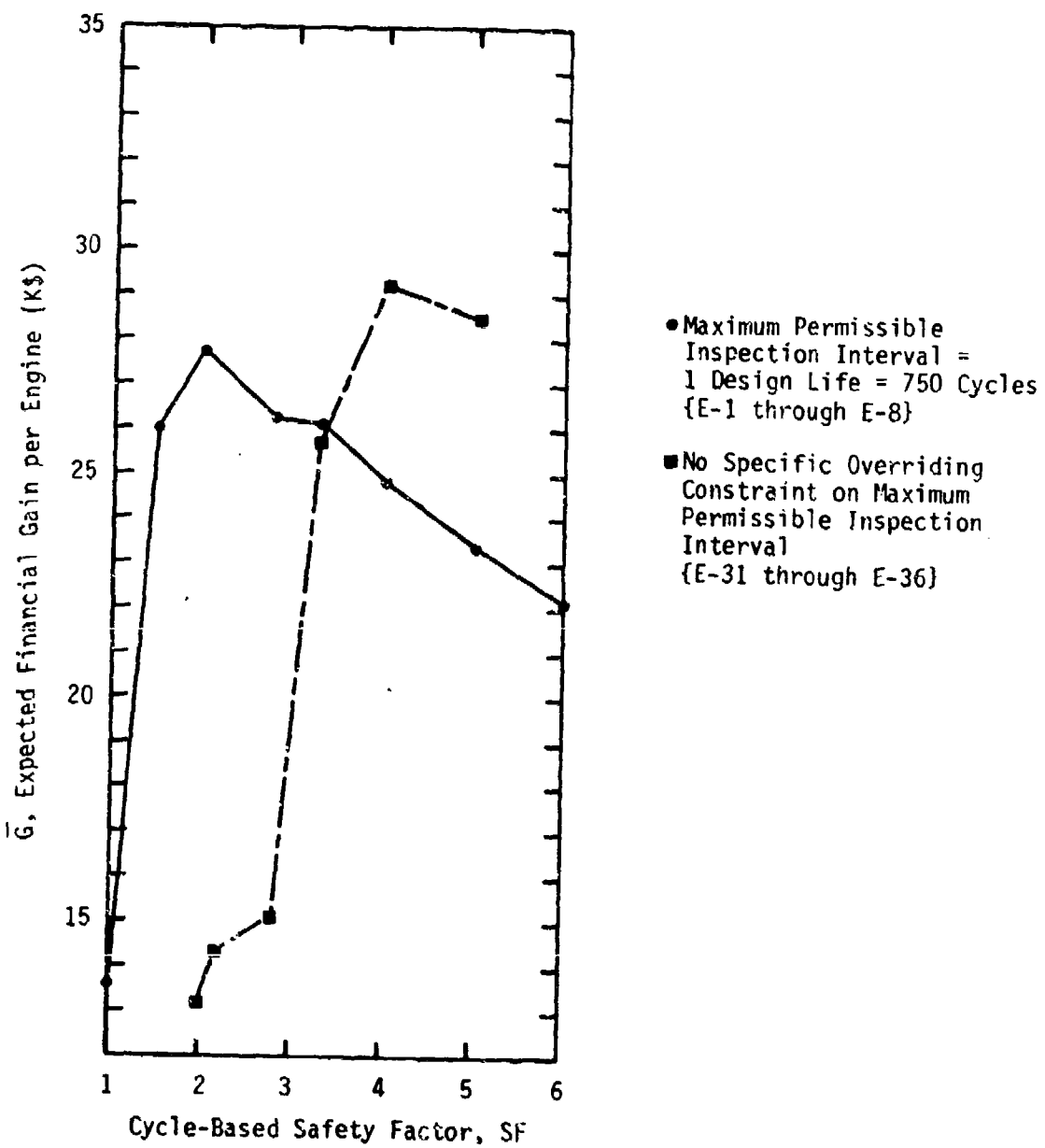
Figure 8-4 - Effect of Removing the Overriding Constraint of Maximum
Permissible Inspection Interval.
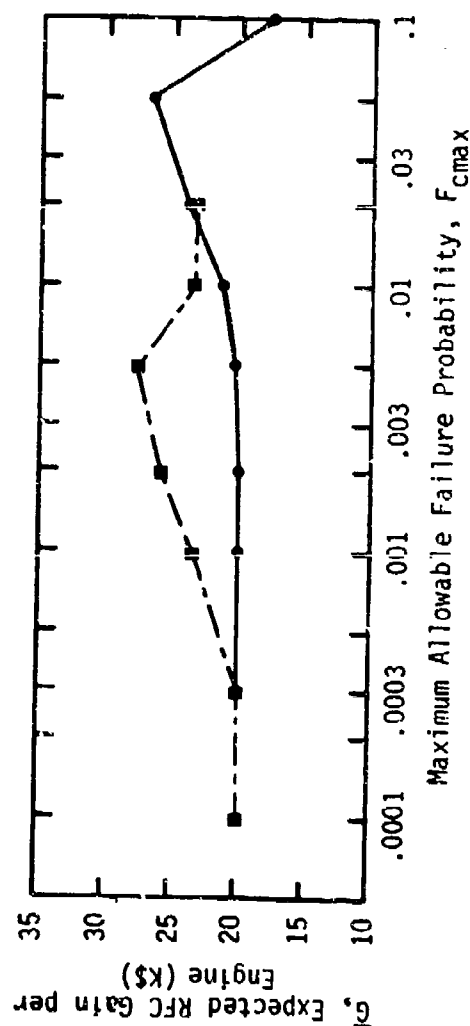
● Baseline or Standard Case (see text), Maximum Time Between Inspections = 750 Cycles {E-37 through E-44}

■ Same as Standard Except Maximum Time Between Inspections is Unlimited {E-45 through E-51}

Maximum Allowable Failure Probability, F_{cmax}

$\bar{G}$, Expected RFC Gain per Engine (k$)

Figure 8-4a - Effect of Limit on Maximum Time Between Inspections on Probabilistic RFC Benefit. Note that, Other Than the Lack of a Constant Safety Factor, the Baseline Probabilistic RFC Procedure has the Same Parameters Described in Figure 8-1, Items 1-10 for the Baseline Deterministic Procedure. In Addition, the Baseline Probabilistic Case: (a) Uses a Specified Allowable Failure Probability F_{cmax}, (b) Assumes Initial Probability Distribution Parameters (Appendix C) $\alpha = 4$ and $\beta = 1$, (c) and Operates on Four Subfleets Introduced at 0, 750, 1500, and 2250 Fleet-Leader Engine Cycles.

value, 0.05. Again, the conservatism embodied in the multiplicity of inspection sites and frequent inspections must be offset by an unreasonably large failure probability specification to produce an optimum economic return. The curve for the baseline case also demonstrates that the economic penalty associated with using much lower values of maximum allowable failure probability (F_{cmax}) is not exorbitant. In fact, because of the liberal constraint that all disks with maximum measured crack sizes less than 0.031 inch be returned to service unconditionally, the curve reaches an asymptote of approximately $20,000 per engine for specified failure probability values less than 0.001.

The dashed curve in Figure 8-4a corresponds to the removal of constraints upon maximum inspection intervals. As with Figure 8-4, the disk is inspected at integer multiples of the minimum inspection interval. The integers are determined by the fracture mechanics, stress, and safety analyses. Upon removing the constraint on $\Delta \hat{N}_{max}$, the economic benefits peak at a much more reasonable value of specified failure probability of 0.005. Note that if the conservative and liberal aspects of the RFC procedure were to exactly balance each other, the optimum failure probability specification could be computed directly from the costs. This optimum value would, at least to a first order, simply be the ratio of replacement and failure costs which would result in $F_{cmax} = 0.00375$ ($7500/$2,000,000). Thus, the removal of the constraint on maximum inspection interval acts to balance and modestly improve the RFC procedure if the fracture mechanics, stress, and other errors are not overwhelming. Results discussed later in this section will show how important the use of frequent inspections is when analysis and cycle counting errors become more extreme.

In comparing Figures 8-4 and 8-4a, it should be noted that the optimum return for the probabilistic update procedure is somewhat less than that of the constant safety factor procedure but that the downside risk of the probabilistic-update RFC procedure appears to be somewhat less. This trend will continue for most of the results to be described below. The major reasons why the employed probabilistic-update procedure results in slightly lower optimum economic benefits are: (1) the use of non-optimum initial values of the input statistical parameters $\alpha = 4$ and $\beta = 1$ (see Appendix C) and (2) the failure to apply the statistical update more often than once every 750 cycles (a major improvement in the optimum would result just by adding the condition that the fleet be reanalyzed immediately upon any failure). While the reduction of downside risk through statistical updates is not dramatic in comparing Figures 8-4 and 8-4a much greater reductions will be illustrated below for cases in which significant analytical and other errors are simulated. Thus, the major benefit of field feedback in specifying allowable life extension is to avoid major costs or risk associated with improper choice of SF. More frequent updates are required than used herein to raise or maintain the optimum levels associated with the fortunate choice of an optimum constant safety factor.

8.3.2 Effect of Maximum Allowable Measured Crack Size

Figure 8-5 indicates the minor influence of the value specified for maximum allowable crack size ($\hat{a}_{max}$) for the present study. The economic results of the RFC procedure are so constrained by other specifications, mainly the use of very frequent inspections, that this "must reject" crack size value has relatively little impact. If the constraint on maximum inspec-
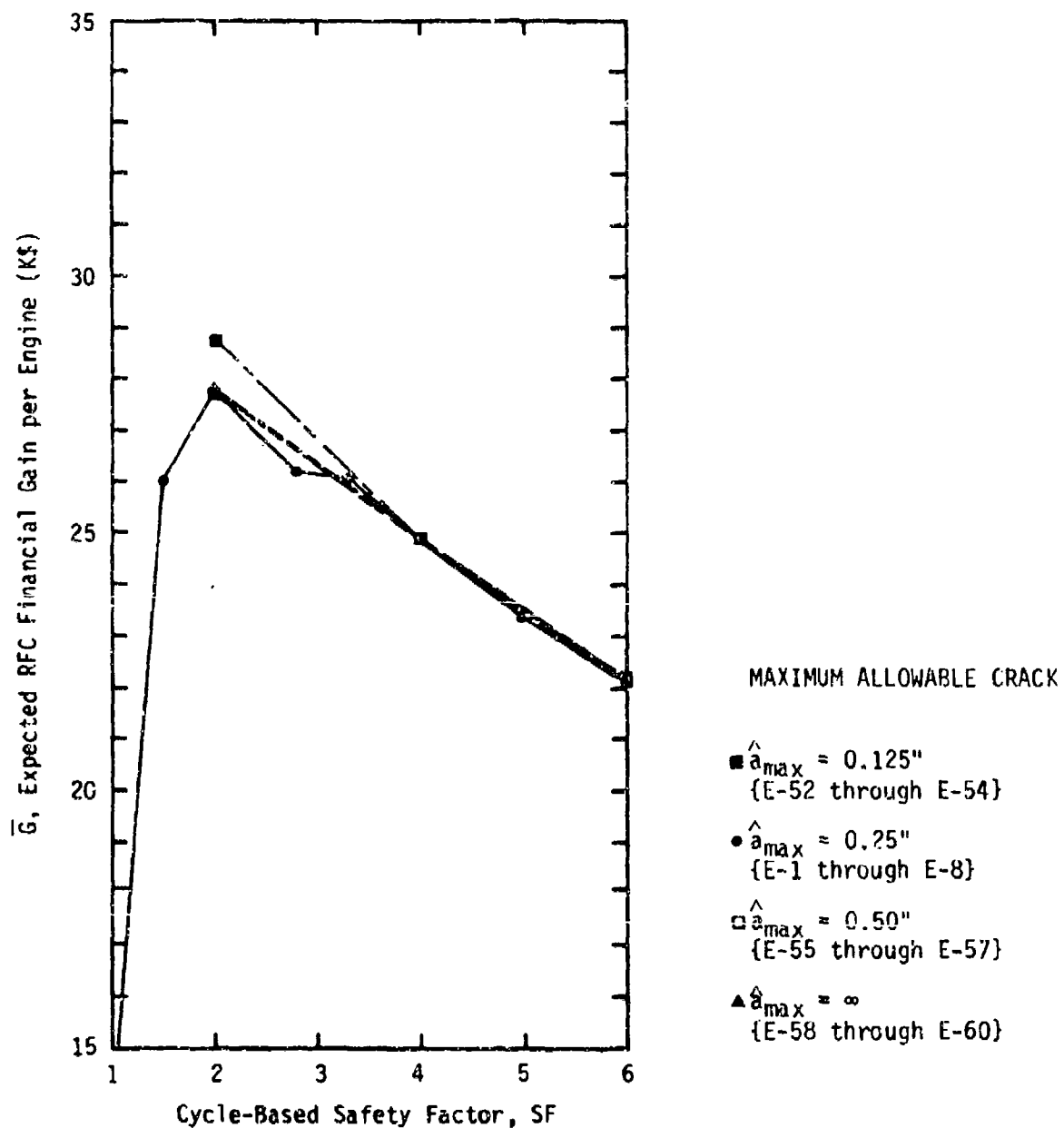
Figure 8-5 - Effect of Maximum Allowable Apparent Crack ($\hat{a}_{max}$) on RFC Benefits.

tion interval had been removed, the downside risks of removing $\hat{a}_{max}$ would be enormous, which was pointed out for a more primitive analysis earlier in this project.

8.3.3 Effect of Number of Crack/Inspection/Failure Sites

Figures 8-6 and 8-7 demonstrate the dramatic effects of changing the number of inspection sites from 10 to 1. A first order approach to the problem might conclude that reduction of failure sites by a factor of 10 should reduce the number of failures by this same factor and result in a more successful RFC program. However, this first-order approach ignores the "multiple-crack safety net" on crack detection when inspection variations are primarily site-to-site (rather than inspector-to-inspector, time-to-time, etc.). Many failures are prevented in the simulated results when the most dangerous and largest cracks in the disks are undetected or undersized while a smaller crack (or even a false call with no crack present at all) produces a rejectable value of $\hat{a}$. For the case of one inspection site per disk, this safety net is completely removed.

An initial comparison of Figures 8-6 and 8-7 seems to reveal an inconsistency in that the disks with 2 or 5 crack sites appear to produce at least as much economic benefit as the disks with 10 crack sites while also producing more failures. However, the study of Tables E-1 through E-8 and E-61 through E-68 in Appendix E resolves this apparent anomaly. The number of disk replacements is dramatically reduced when the number of crack sites is reduced, for any given constant safety factor.
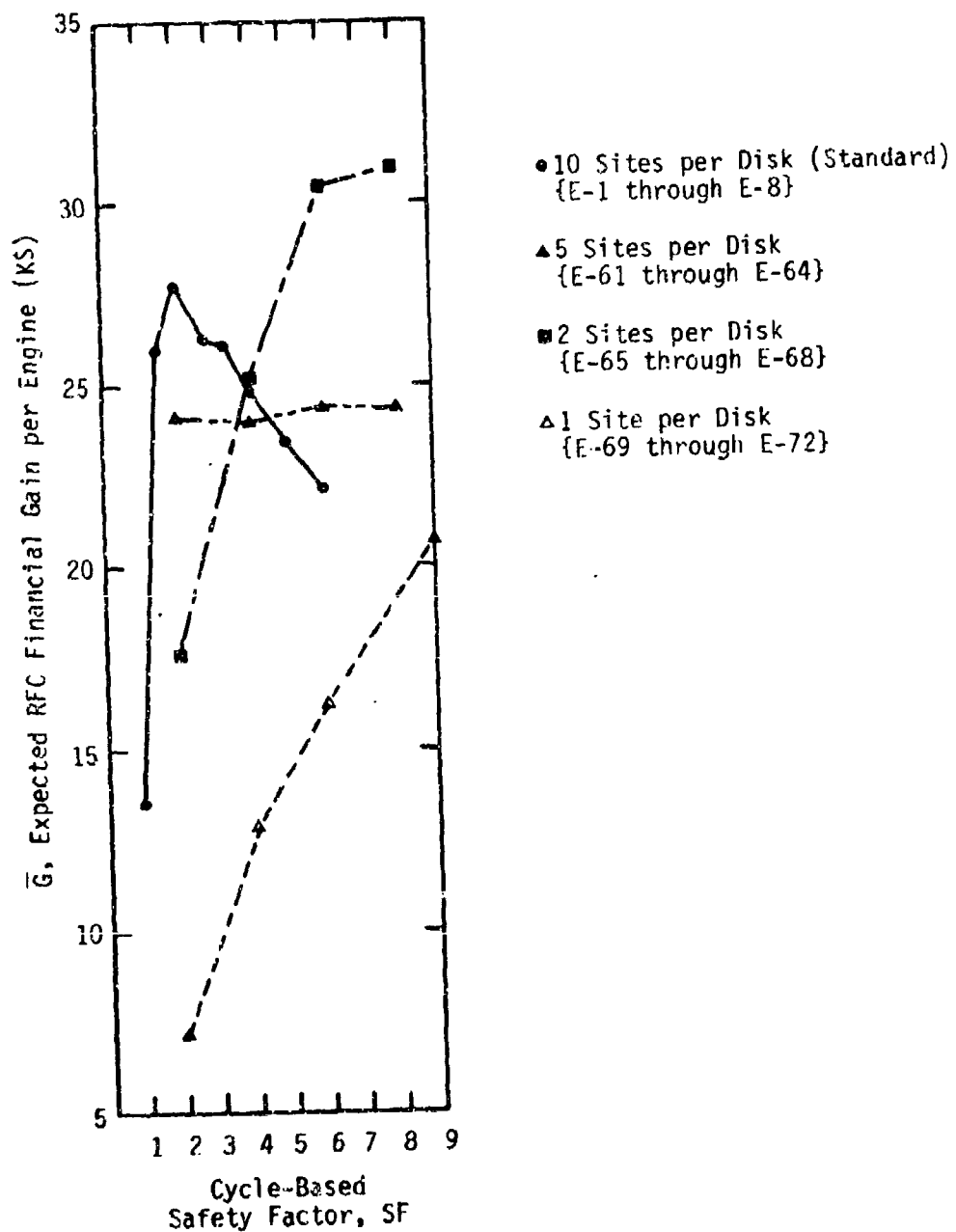
Figure 8-6 - Effect of the Number of Nominally Identical Crack/
Inspection Sites per Disk on RFC Benefits.
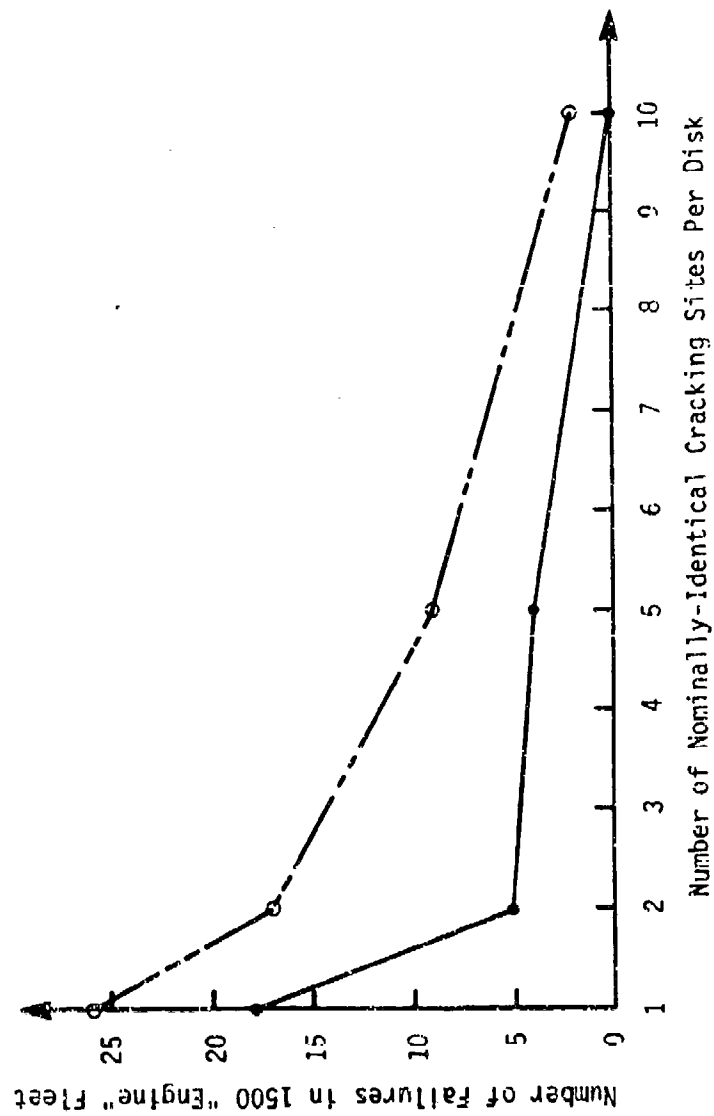
Figure 8-7 . Effect of Number of Cracking Sites on Number of Fleet Failures Encountered While Employing Two RFC Procedures.

8-20

Two effects could reduce the safety net associated with more crack sites. The first is if the physics of the inspection process and cracking are such that factors causing the lack of detection of the crack in one disk failure site are also very likely to be present at other failure sites of that disk. Then the inspection reliability of the failure sites would not be independent in a given disk, and missing one large crack could imply an unacceptably high probability of missing an equally large crack at some other disk location. The second effect would be a combination of higher mean and scatter of times to crack initiation than simulated here. Such a situation, especially if compounded by a non-negligible probability of significant fabrication cracks at the critical location, could cause the poor performing disks to have only one large crack just prior to failure.

The downside risk-reduction power of the probabilistic update procedure is amply demonstrated in Figure 8-8 which shows that for reasonable specified allowable failure probabilities, say less than 0.01, the effective feedback of field data provides an immediate and effective substitute for the removal of the multiple-inspection-site safety net. Specifically, when compared to the constant safety factor procedure, the number of failures (see Tables E-76 through E-81) are markedly reduced for the disks with one or two cracking sites without a cost-compensating increase in the number of replacements required. Basically, the probabilistic update procedure reacts to the initial "surprise" failures, decides something is wrong and quickly adjusts the allowable life extensions to maintain a failure probability less than 0.01.
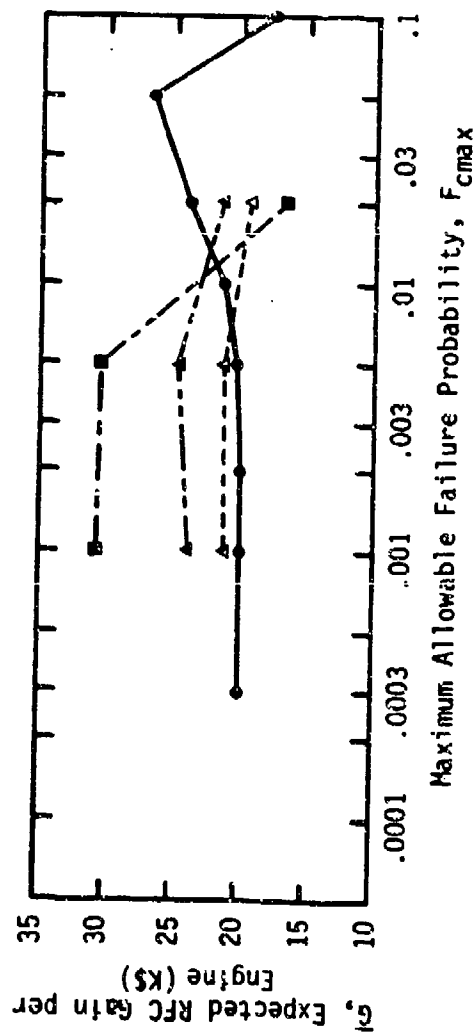
● Standard Case (Ten Cracking Sites Which Can Cause Rejection) {E-37 through E-44}

▲ Same as Standard Except Five Cracking Sites {E-73 through E-75}

■ Same as Standard Except Two Cracking Sites {E-76 through E-78}

△ Same as Standard Except One Cracking Site {E-79 through E-81}

Figure 8-8 - Effect of Number of Nominally Identical Cracking Sites on Probabilistic RFC Benefits.

8.4 Effect of Fracture Mechanics and Stress Analysis Errors on RFC Economics

8.4.1 Fracture Mechanics Analysis Errors

In Figure 8-9 are shown some effects of fracture mechanics analysis errors on RFC benefits. For this Figure, the high resolution probe inspection uncertainty data was used in combination with three deterministic analysis procedures described in detail in Section 7. The perfect deterministic curve is the baseline discussed previously. The other two curves on Figure 8-9 represent algorithms which underestimate and overestimate failure cycles by a factor of 3 for a given stress. Stress analysis errors are not simulated directly in Figure 8-9. The results demonstrate that there are enough constraints in the procedure to easily absorb such life prediction errors. Two key reasons that errors have so little effect on the baseline (RFC Procedure No. 2) case are 1) the high frequency of inspections and 2) the ability to use stress as an adjustable parameter to fit the observed crack sizes and compensate for other errors.

The ability of the baseline RFC procedure to handle large life prediction errors is somewhat surprising considering the devastating results of a factor-of-three overestimate of failure cycles on the similar, if more primitive, RFC procedure evaluated earlier in this project. In order to explore this dramatic difference in sensitivity to analysis errors, some of the aspects of the earlier RFC evaluation are reproduced in Figure 8-10. The major differences in the past and present RFC procedures evaluated are the use of a 15,000 cycle engine life and no limit on the maximum permissible inspection interval. It should be noted that the combination of a 750-cycle disk design life and 15,000 engine cycles implies the need for up to 19 (rather
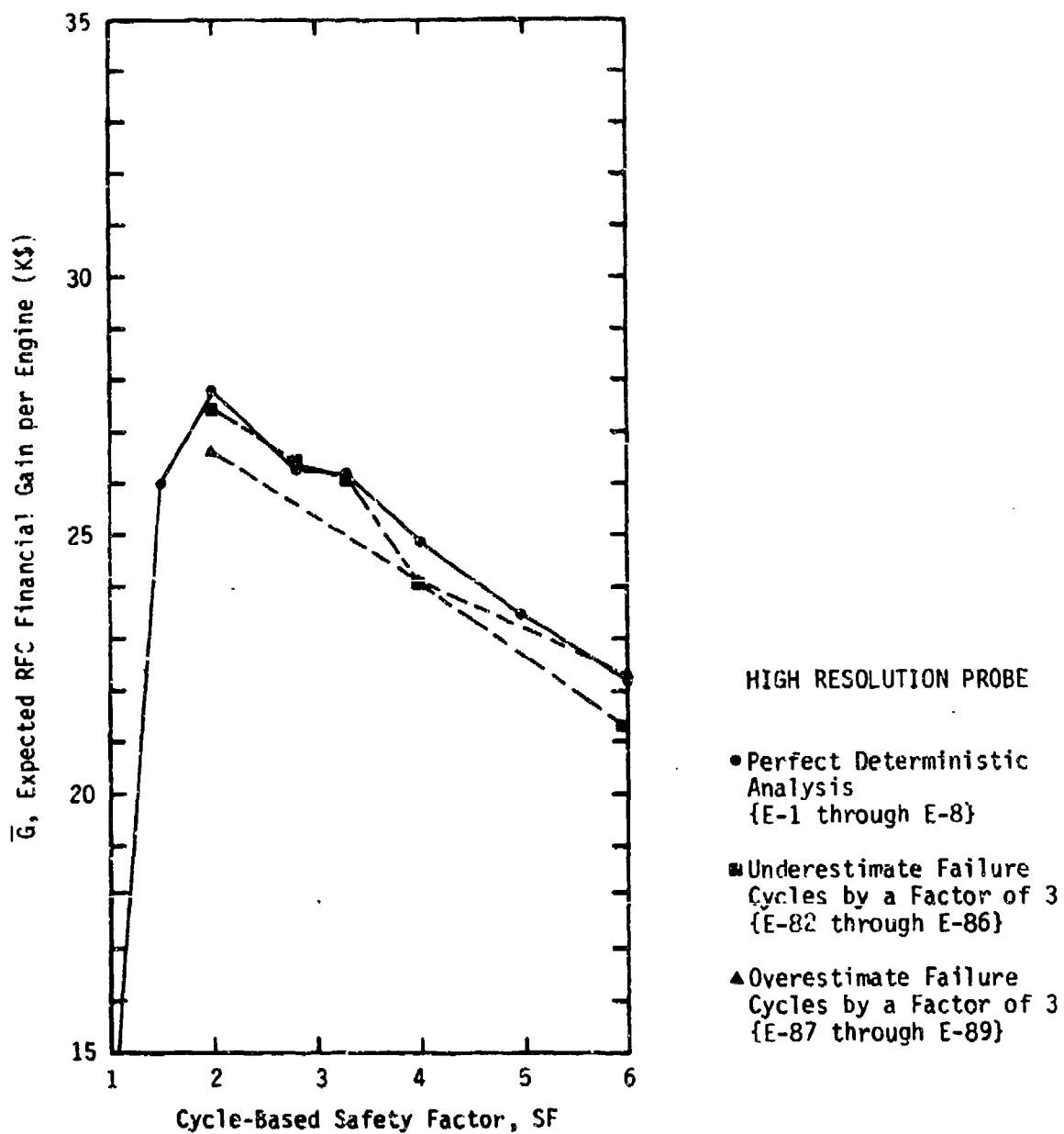
Figure 8-9 - Effect of Deterministic Analysis Errors on RFC Benefits.

HIGH RESOLUTION PROBE

● Perfect Deterministic
Analysis
{E-1 through E-8}

■ Underestimate Failure
Cycles by a Factor of 3
{E-82 through E-86}

▲ Overestimate Failure
Cycles by a Factor of 3
{E-87 through E-89}
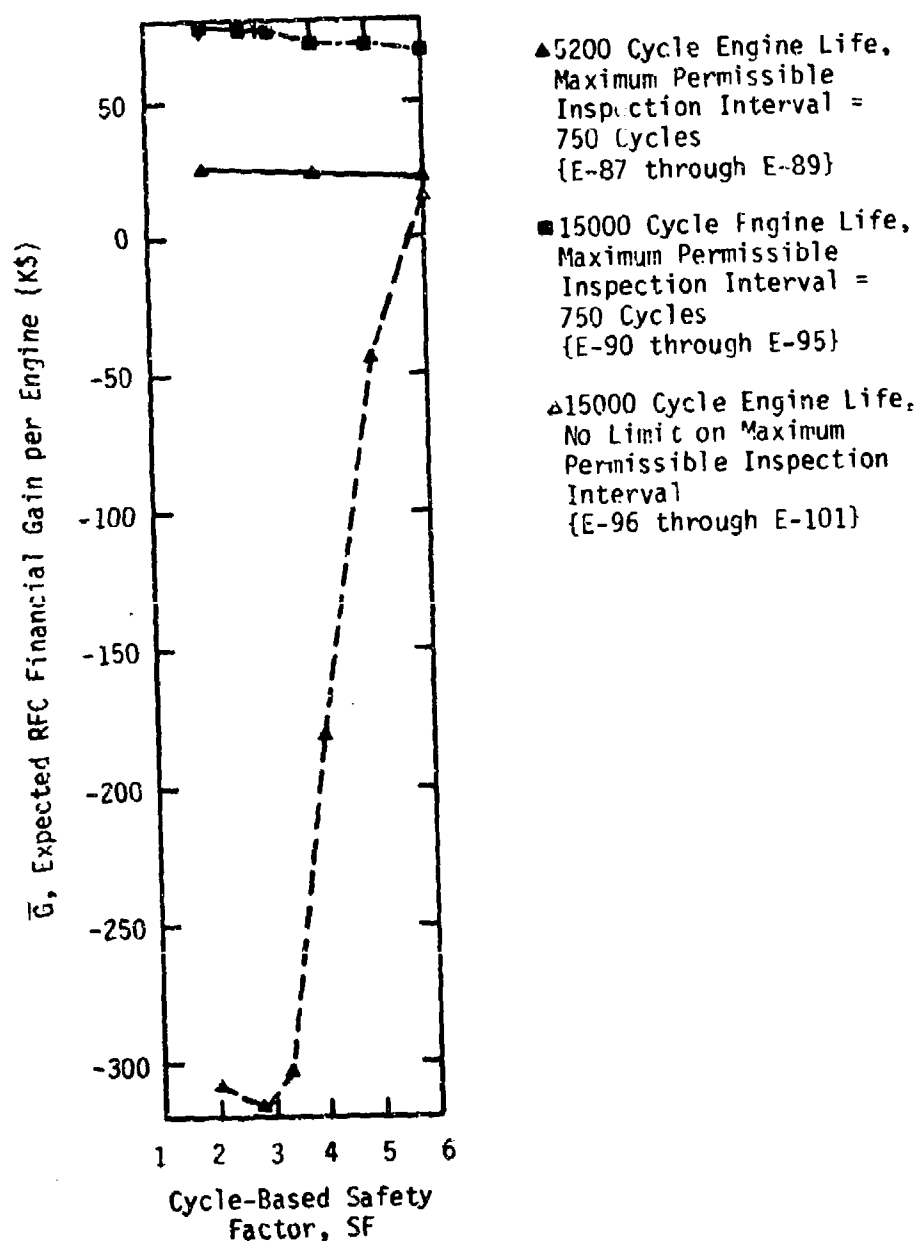
Figure 8-10 - Effect of Some Specific Changes in Specified Lives and Inspection Interval Constraints Upon RFC Benefits When Life Prediction Algorithm (Anti-conservatively) Overpredicts Life by Factor of Three.

than 6) disk replacements and potential RFC savings of more than $100,000 per engine. The middle curve in Figure 8-10 is a reproduction of the solid triangle data points in Figure 8-9 which represent a factor-of-three overestimate of life. This curve provides a reference for comparison with the baseline 5,200-cycle-engine life case. The lower curve demonstrates the devastating impact of the factor-of-three overestimate of life for the 15,000-cycle engine with no constraint on maximum inspection interval, ΔN_{max}. The upper curve in Figure 8-10 shows the dramatic effect of restricting all inspection intervals to the 750-cycle design life value. Obviously, the requirement for reasonably frequent inspections can eliminate an enormous amount of downside risk of RFC.

In Figure 8-10a, the simulations of Figure 8-10 are repeated exactly with the single exception that the probabilistic-update procedure (No. 4) is used rather than the constant-safety-factor procedure (No. 2). Again, the downside risk associated with unlimited maximum inspection intervals and a large anti-conservative life prediction error is easily absorbed with the introduction of effective feedback from the field. Especially encouraging is the near-zero impact of maximum permissible inspection interval at reasonable failure probability specifications less than 0.005.

Figure 8-10b shows the same three cases as Figure 8-10 but includes no fracture mechanics analysis errors. Comparison of Figures 8-10 and 8-10b demonstrates the synergism of the detrimental effects of (1) factor-of-three life prediction error and (2) the failure to specify a maximum inspection interval. Elimination of either effect eliminates the tremendous number of field failures resulting from both effects occurring together.

The y-axis is labeled "Ḡ, Expected RFC Gain per Engine (K$)" with values 50, 25, 0, -25.

The x-axis is labeled "Maximum Allowable Failure Probability, F_{cmax}" with values .0001, .001, .01, .1.

Legend:
■15000 Cycle Engine Life, Maximum Permissible Inspection Interval = 500 Cycles {E-102 through E-104}

▲15000 Cycle Engine Life, No Limit on Maximum Permissible Inspection Interval {E-105 through E-108}

Figure 8-10a - Effect of Some Specific Changes in Specified Lives and Inspection Interval Constraints Upon Probabilistic-Update RFC Benefits When Life Prediction Algorithm (Anti-conservatively) Overpredicts Life by Factor of Three.

8-27
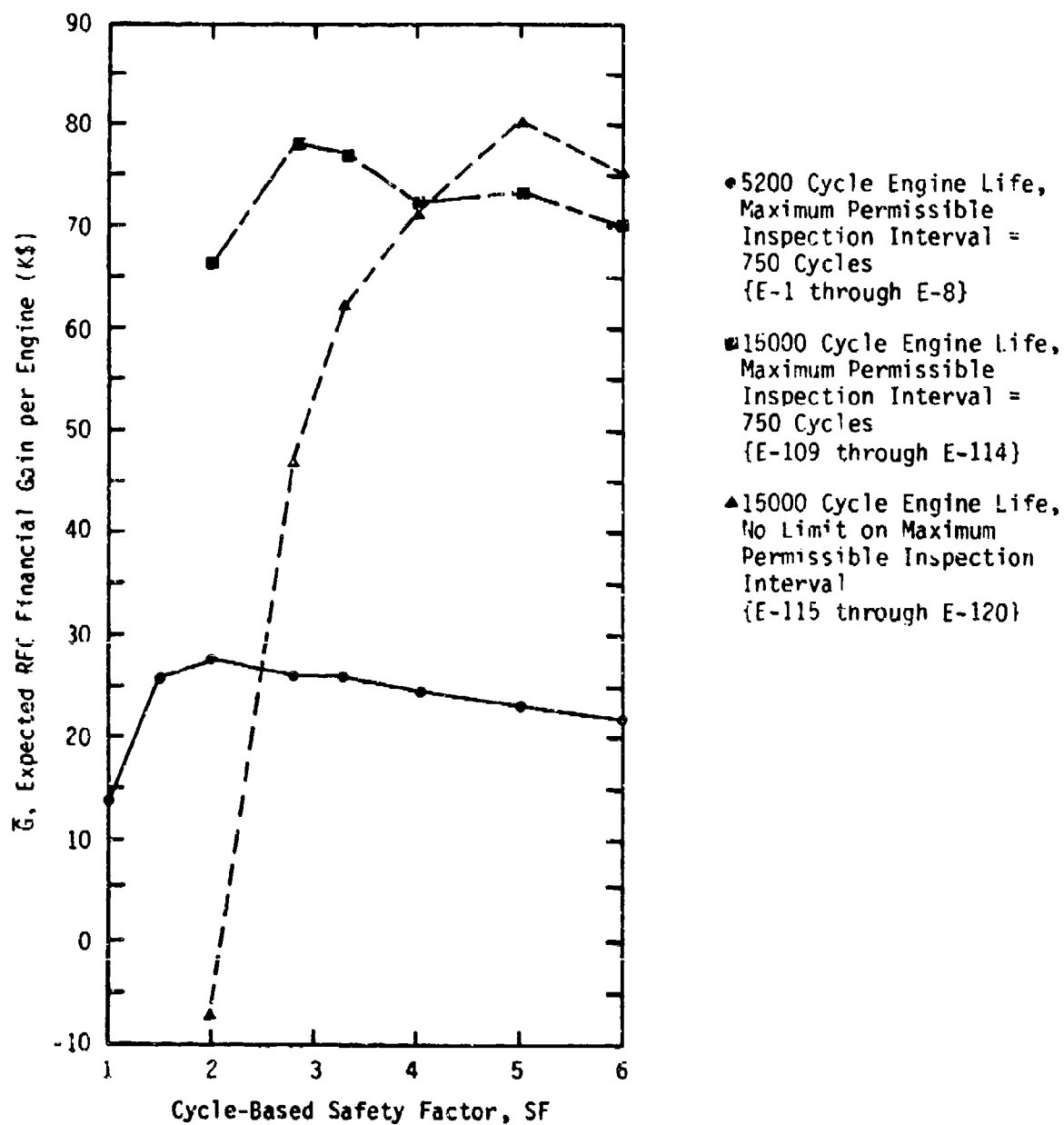
Figure 8-10b - Effect of Some Specific Changes in Specified Lives and Inspection Interval Constraints Upon RFC Benefits **When No Errors Are Made In the Life Prediction Algorithm.**

8.4.2   The Effect of Stress Analysis Errors and Estimation Technique

In Figure 8-11 is shown the effect of severe initial stress analysis errors, in an otherwise perfect fracture mechanics model, on the probabilistic update procedure's economic return. The stress analysis errors simulated correspond approximately to factor-of-three overestimates or underestimates of life, so as to be comparable to the fracture mechanics analysis errors simulated previously. As seen, the errors have virtually no impact upon the RFC economics for the investigated RFC Procedure No. 4 in Figure 8-11. While not shown, similar results were obtained for the constant-safety-factor RFC Procedure No. 2. The key factors that reduce the impact of stress analysis errors are the use of frequent inspections and the estimation of stress from measured crack size rather than prior design analysis. Apparently, the inspection procedures investigated have sufficient accuracy to permit economic gains through calibration of a key parameter such as stress.

In Figure 8-12 the impact is explored of using prior stress estimates not subject to modification. Initially, the results are surprising until detailed investigation is accomplished. The two upper curves are (1) the baseline case, representing stress estimates based on inspection results and (2) the use of an unmodified prior estimate of average fleet stress 33% larger than the true value. The reason the stress overestimate produces far better gains than the perfect but unmodified estimate of stress (middle curve with open triangles) is that the conservative overestimate of stress balances the other errors occurring in the RFC procedure; most notably, the large cycle-counting errors. The use of a perfect stress estimate which is unmodified to compensate the cycle counting errors results in a very poor performance unless safety factors much larger than normal happen to have been chosen. Of
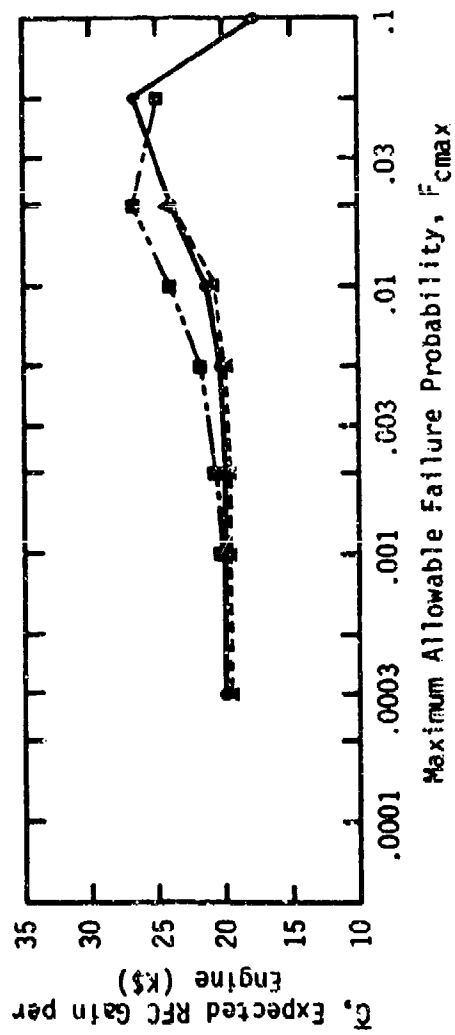
- No Initial Error in Analysis of (Average) Cyclic Disk Stress {E-37 through E-44}

- Severe (+33%) Overestimate of Average Disk Stress {E-121 through E-126}

- Severe (-25%) Underestimate of Average Disk Stress {E-127 through E-132}

Figure 8-11 - Effect of Severe Initial Stress Analysis Errors on Probabilistic-Update RFC Economic Benefits.
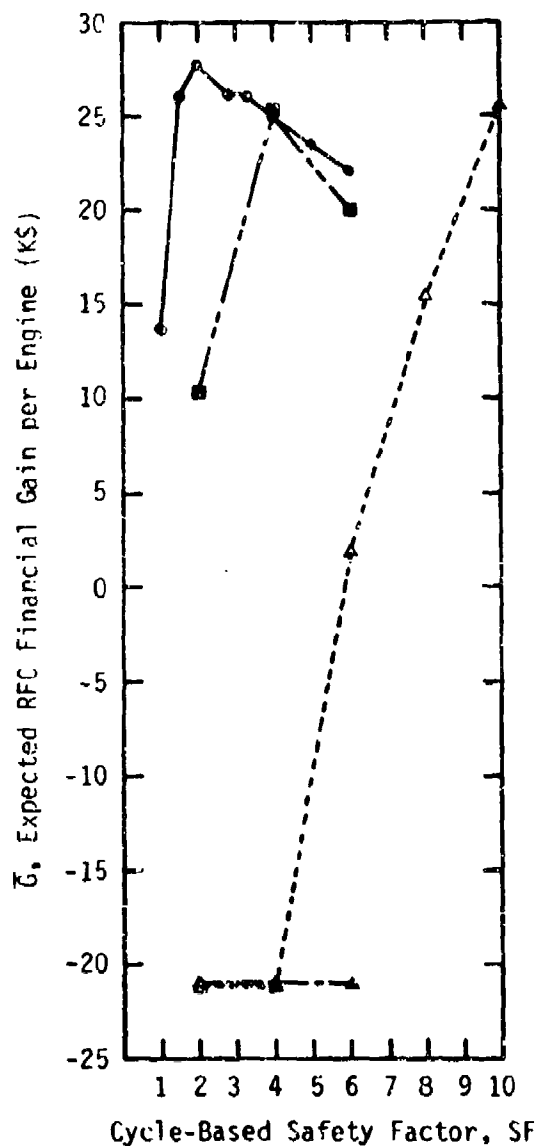
Figure 8-12 - Effect of Stress Estimation Method on RFC Benefits.

The figure's legend reads:

• Standard Case - Perfect Initial
Estimate of Average Fleet
Stress Subject to Modification
[ISTRES = 1] for Each Disk
Based Upon Inspection Results
{E-1 through E-8}

△Perfect Initial Estimate of
Average Fleet Stress Not Subject
[ISTRES = 2] to Individual-Disk,
Inspection-Based Modifications
{E-133 through E-137}

▲Severe (25%) Underestimate of
Average Fleet Stress Not Subject
[ISTRES = 2] to Inspection-Based
Modifications
{E-138 through E-140}

■Severe (33%) Overestimate of
Average Fleet Stress Not Subject
[ISTRES = 2] to Inspection-Based
Modifications
{E-141 through E-143}

The plot axes are labeled: vertical axis "$\bar{G}$, Expected RFC Financial Gain per Engine (K$)" ranging from -25 to 30; horizontal axis "Cycle-Based Safety Factor, SF" ranging from 1 to 10.

course, the underestimation of stress compounds the problem. The reason the underestimation curve is horizontal (solid triangles, lowest curve) in Figure 9-11, is the fact that it leads to no restraint on RFC for safety factors between 2 and 6. The only reason the losses are held to approximately $21,000 per engine are the frequent inspections and requirement that all disks with cracks measured greater than 0.25 inch be immediately replaced.

In Figure 8-12a, the simulations of Figure 8-12 are repeated exactly for the probabilistic-update procedure. The results are again encouraging although the failure to adjust stress estimates to reflect inservice inspection results still reduces the benefits of RFC.

Another interesting effect is summarized in Figure 8-12a and is detailed in the results of Tables E-148 through E-150 and E-153 through E-155. This is a "lead-the-fleet" effect in which the introduction times of new engines into service are altered to gauge the effect upon the updating scheme. The upper ("lead-the-fleet" Tables E-149 and E-154) points represent complete usage of a subfleet before the next subfleet is introduced and allow the probabilistic update more time to produce optimum results. The lower points in the brackets correspond to all four subfleets being introduced simultaneously; hence the "no-fleet-leader" designation in Tables E-150 and E-155. Some updating is performed as all engines age together, but there is no lead the fleet benefit in which data from old engines are fed back to produce greater RFC returns for younger engines. The results also indicate that the lead-the-fleet effect is most pronounced when it is most needed. That is, when the RFC returns are already near optimum, the addition of more information cannot help or hurt very much. However, for the case of severe under-

8-32

● Standard Case - Perfect Initial Estimate of Average Fleet Stress Subject to Modification [ISTRES = 1] for Each Disk Based Upon Inspection Results {E-37 through E-44}

△ Perfect Initial Estimate of Average Fleet Stress Not to Subject [ISTRES = 2] to Individual-Disk, Inspection Modifications {E-144 through E-147}

▲ Severe (25%) Underestimate of Average Fleet Stress Not to Subject [ISTRES = 2] to Inspection-Based Modifications {E-148 through E-152}

■ Severe (33%) Overestimate of Average Fleet Stress Not to Subject [ISTRES = 2] to Inspection-Based Modifications {E-153 through E-157}
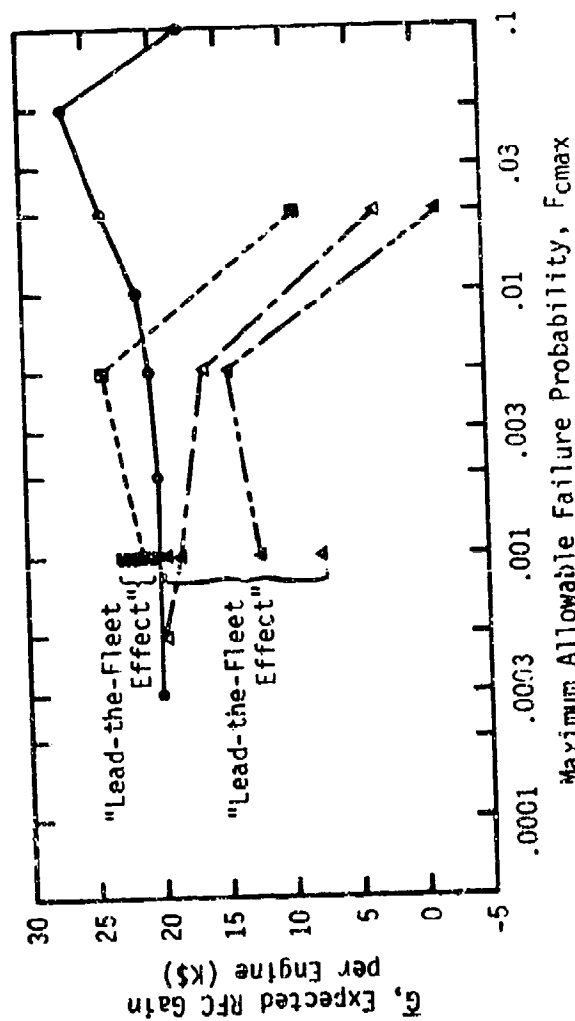
Figure 8-12a - Effect of Stress Estimation Method and "Lead-the-Fleet" on Probabilistic-Update RFC Benefits.

estimation of stress, where the RFC returns are lower, the lead-the-fleet effect is more important.

8.5   Effect of Usage Estimation Errors

In Figure 8-13, we investigate the effect of the magnitude and type of cycle-counting errors ($\hat{N}$ versus N) on RFC benefits are investigated. As shown in Figure 8-13, all investigated serious errors in cycle counting can be tolerated in conjunction with the baseline RFC procedure. The most serious type of error is the "Type 1" error that allows random changes in cycle-counting errors from inspection-to-inspection. The most obvious and serious sequence of such errors would be (1) an overestimate of past usage of an inspected disk, leading to false confidence regarding the lack of measured cracks in a "seasoned" disk, followed by (2) an underestimate of future usage leading to additional false confidence regarding the future rate of crack growth. As seen in Figure 8-13, even Type 1 errors cannot eliminate most of the RFC economic benefits.

As mentioned previously, the baseline situation involves Type 3 errors in which the usage estimation error is constant over the entire life of the part. The simulated Type 2 errors in Figure 8-13 are the most realistic in that they include an initial systematic constant usage estimation error that applies for the life of the disk and a smaller inspection-to-inspection usage estimation error. Surprisingly, the smaller Type 2 error simulated led to slightly lower economic returns than the larger Type 2 error. This apparent anomaly (which, detailed checking has shown, is not due to any analysis error or program "bugs") is believed to be due to the complex interaction of the
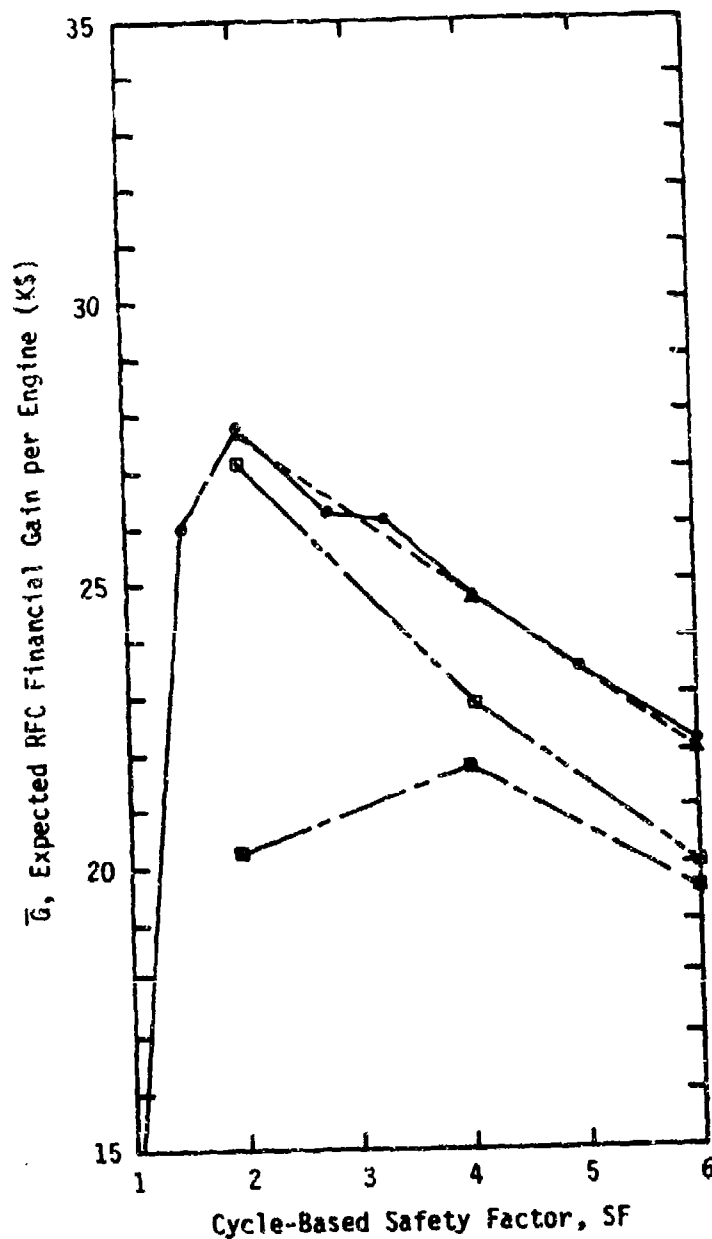
CYCLE-COUNTING ERROR

- Type 3 (random factor-of-2.0 error before first inspection and identical constant error factor for all subsequent inspections) {E-1 through E-8}

- Type 1 (random factor-of-2.0 error that changes before each new scheduled inspection) {E-158 through E-160}

- Larger Type 2 Error (random factor-of-2.0 error, f_i, before first inspection; random factor-of-1.41 error, f, that changes each subsequent inspection and multiplies f_i. That is, the total error factor is $f_i f$ where f changes every inspection) {E-161 through E-163}

- Smaller Type 2 Error (random factor-of-1.41 error, f_i, before first inspection; subsequent random and changing factor-of-1.19 error, f, for additional inspections) {E-164 through E-166}

Figure 8-13 - Effect of Magnitude and Type of Cycle-Counting Error ($\hat{N}$ vs. N) on RFC Benefits. Error Factors are Defined in Terms of Log Averages. Specifically, a Factor of Two Error would Mean that $Log(\hat{N}/N) = GAU(0, Log\ 2)$.

8-35

aggregately anticonservative usage estimation errors with the highly conservative constraints of the RFC procedure.

In Figure 8-14, the very severe Type 1 usage estimation error is examined in the context of the 15,000-cycle, rather than 5,200-cycle, engine. This study was conducted to verify that the high frequency of inspections was the prime reason that the baseline RFC system could tolerate these extremely severe cycle-counting errors. The more primitive simulation conducted earlier in this project, which involved no constraint upon the maximum inspection interval, produced a dramatic loss of RFC benefit due to the Type 1, factor-of-two, cycle-counting errors. In Figure 8-14 this devastating effect upon RFC benefits is again demonstrated where even the upper curve is significantly lower than the baseline curve of Figure 8-1C which uses the Type 3 cycle-counting error. Thus, with no statistical updating, the Type 1 cycle-counting error produces an out-of-control failure rate if inspection intervals are too infrequent and if engine life is much greater than disk design life.

The probabilistic-update procedure was also simulated for this huge cycle-counting error in Figure 8-14a. Although the probabilistic-update procedure certainly and dramatically reduces the downside risk of such severe errors, it is not immune to large, random inconsistencies in usage estimation. By updating more frequently, the tolerance to such errors could be further increased, but the results suggest that large usage-estimation errors should be eliminated. At the usually optimum specification of 0.005 maximum allowable failure probability, the combined poor estimation of usage and lack of constraint on maximum inspection interval eliminate most of the benefits of RFC. However, it is encouraging to note that for the more probable and conservative use of a 0.001 (or lower) maximum allowable failure probability, the

8-36
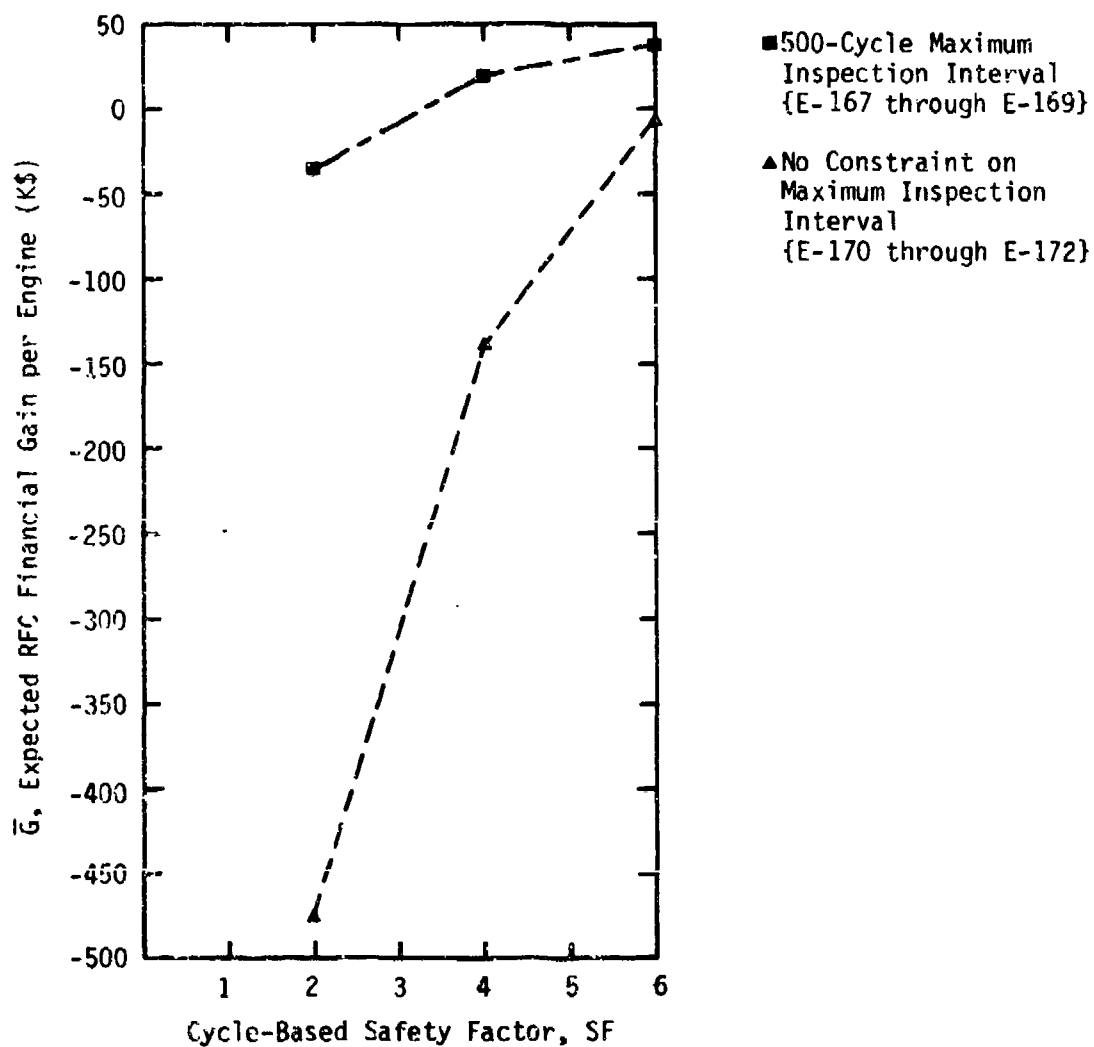
Figure 8-19 – Effect on Maximum Inspection Interval Length on RFC Benefits for a 15000-Cycle (Rather Than a 5200-Cycle) Engine Subject to the Most Severe Usage Estimation Errors Considered (i.e., Type 1, Factor-of-Two, Cycle Counting Errors).

■500-Cycle Maximum Inspection Inverval {E-173 through E-175}

▲No Constraint on Maximum Inspection Interval {E-176 through E-178}
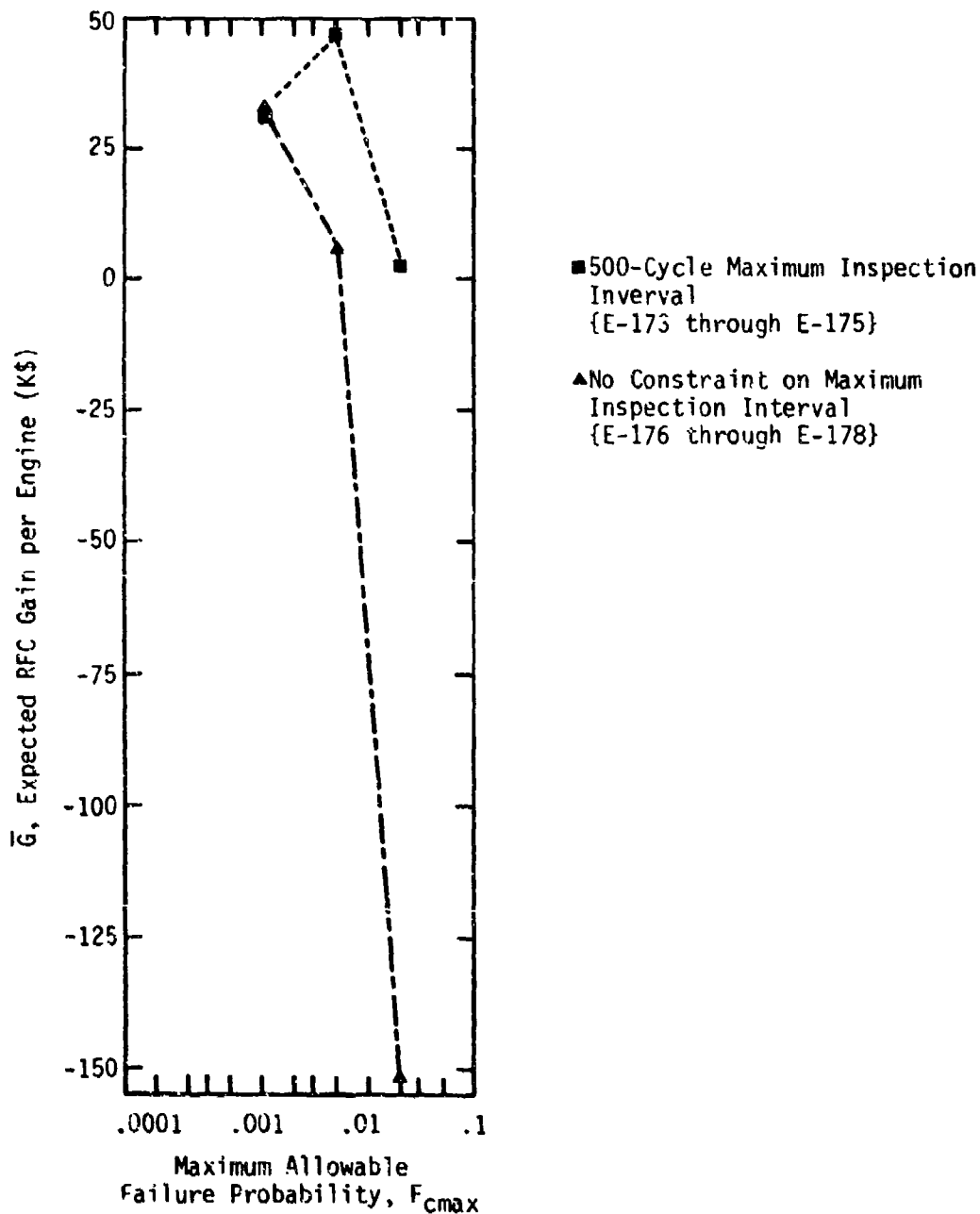
Figure 8-14a – Effect on Maximum Inspection Interval Length on Probabilistic-Update RFC Benefits for a 15000-Cycle (Rather than a 5200-Cycle) Engine Subject to the Most Severe Usage Estimation Errors Considered (i.e., Type 1, Factor-of-Two, Cycle Counting Errors).

probabilistic-update procedure is able to cope with the lack of specific external constraint on maximum inspection interval. The reason for this is quite simple, the low failure probability specification acts as an implicit constraint to reduce the inspection intervals to either 750 or 1500 cycles, and it avoids the high failure rates associated with specifications of F_{cmax} = 0.005 or greater.

9.0 DEVELOPMENT OF A TEST PLAN FOR EXPERIMENTAL RFC VERIFICATION

The objective of this task was twofold: the first was to set general goals and requirements that any RFC specimen verification program (SVP) with unlimited funds should meet, and the second was to identify through simulation the number of specimens that would be required. Using the results of this task, the specific SVP for the project was designed and carried out. The details of the specific SVP for this project are described.

9.1 General Goals and Requirements of RFC Specimen Verification Program

An SVP should test RFC for a particular component; specifically, in this program the bolt hole of the TF-33 third turbine disk. It should, to the extent practical, realistically model the important factors affecting RFC for that component. Where this is impractical, the factors should be bounded such that the SVP will tend to underestimate the dollar gain from RFC (preferably only a small underestimation). Given below is a list of factors that affect the viability of RFC and that are important to duplicate in a specimen verification program of the subject bolt hole location.

(a) The ratio of mean number of cycles for an initiated crack to propagate to failure, to the number of cycles for the minimum inspection interval (N_{prop}/N_{insp});

(b) Scatter in number of cycles for an initiated crack to propagate to failure $s(N_{prop})$;

(c) The probability of finding a crack of given size by inspection $[PD (a\backslash a)]$;

(d) The ratio of number of cycles for propagation to number of cycles for initiation (N_{prop}/N_{init});

(e) The scatter in number of cycles for initiation $s(N_{init})$;

9-1

(f) N_{prop} mean value;

(g) N_{init} mean value.

Major testing parameters which affect the above factors are listed below:

1. <u>Specimen geometry and stress gradient.</u> These are of primary importance. The geometry of the initiating sites and the stress gradient around them should be accurately modeled. However, the specimen thickness need not necessarily be the same as for the actual component, although this would probably be most desirable.

2. <u>Number of specimens.</u> As a minimum, the analyst needs sufficient specimens to distinguish between RFC and non-RFC by testing statistically the hypothesis that RFC benefits are positive. Furthermore, there should be sufficient specimens such that the verification program will apply to field conditions, given reasonable assumptions on the shape of the probability distributions of key input variables. Monte Carlo computer calculations are needed to determine the number of specimens required and some preliminary results are described in Section 9.2.

3. <u>Load history/distribution.</u> It should be practical to include load history and distribution variables in the SVP, provided adequate information relevant to service conditions can be obtained. Cycle-counting errors could be simulated here.

4. Inspection reliability/multiple initiation sites. The SVP can be used to obtain data on inspection reliability. The program should be designed to represent field crack characteristics and inspection parameters and conditions as far as is practical. The effect of multiple potential initiation sites in reducing the importance of random inspection errors could be modeled through the gang rigging of several single-hole specimens, the use of multiple holes in some specimens, and the computer.

5. Initial flaws and inhomogeneities. The presence of these may have an impact on the scatter in cycles to initiation. They should be included in the SVP as far as is practical; e.g., through worst-case notches or surface preparation.

6. Dwell times. For the third stage disk bolt holes, it was not necessary to include dwell times in the tests. Short dwell times could be included for certain components; a judgement must be made on the trade-off between dwell time and numbers of specimens tested for a given component. It may be advisable to apply a factor to stress levels and/or massage the experimental data in order to allow for realistic dwell time effects.

7. Temperature/environment effects. It may be important to include service temperatures and temperature variations in the SVP. Aside from a more faithful reproduction of fatigue performance, use of

service temperatures might be needed to adequately simulate the cracks' inspectability.

8. <u>Gross blunders.</u> Aside from the worst-case notches being considered for Item 5 above, blunders should not be included directly in the SVP. The probability of failure arising from gross blunders might simply be estimated, simulated on the computer, and added into the results of the SVP at the end.

9.2   Required Number of Specimens for SVP

The need to simulate adequately a fleet of engines and the worst-case tails of the probability distributions of key variables dictates that per-specimen costs for the SVP be minimized. This requirement clearly rules out engine testing, spin pit testing, and ferris-wheel testing for the majority of an SVP.

For the component under study, specimens with one or more holes meeting the requirements of Section 9.1 are assumed. The number of specimens required depends on how far down the tails of the input probability distributions the SVP intends to evaluate and on the results of the computer simulation runs. As a minimum, the program should have enough specimens to distinguish between RFC and non-RFC economic consequences. This is equivalent to testing the statistical hypothesis that the economic gains of RFC be greater than zero, or some defined minimum level to make RFC "worth the trouble."

If RFC is to work, then the portion of failures occurring in real life will be very small, less than one in a thousand. With only a few score, or at

most, a few hundred "disks" in the SVP, it is unlikely to see any "failures" if field failure rates are specified. Artificially low failure consequences can be set, so as to get some "failure" in the SVP. However, this may be a source of unrealism because the test results will not be controlled by the far ends of the tails of the distributions, and it is these far ends which will control failure rates in actual service. One way around this problem would be to test more specimens. Specimens representing 50,000 disks would be a good number, but impracticably expensive. A second way around this problem is to attempt, through extensive analysis and simulation, to construct scenarios where RFC might "pass" a limited-specimen SVP but "fail" a field application. Steps can then be taken to eliminate or rule out these negative scenarios with a better SVP. A key contribution to the SVP would then be to evaluate, by Monte Carlo simulation, how many specimens are required so that the verification program applies to field conditions, given reasonable assumptions on the shapes of the input probability distributions.

In Figures 9-1 through 9-3 (and Tables E-179 through E-182) the first step is taken to perform this analytical simulation support for the test program. The PERFCT simulations summarized by these figures and tables have the following modifications relative to the baseline cases discussed in detail in Section 8:

1. The cost of failure has been specified as only $150,000. This low level would produce a near-optimum economic return at specified and actual failure probabilities of 5%. Thus, this new test program ground rule could produce a very successful economic result with, for example, one failure in 20 specimens or 5 failures in 100 specimens.

9-5
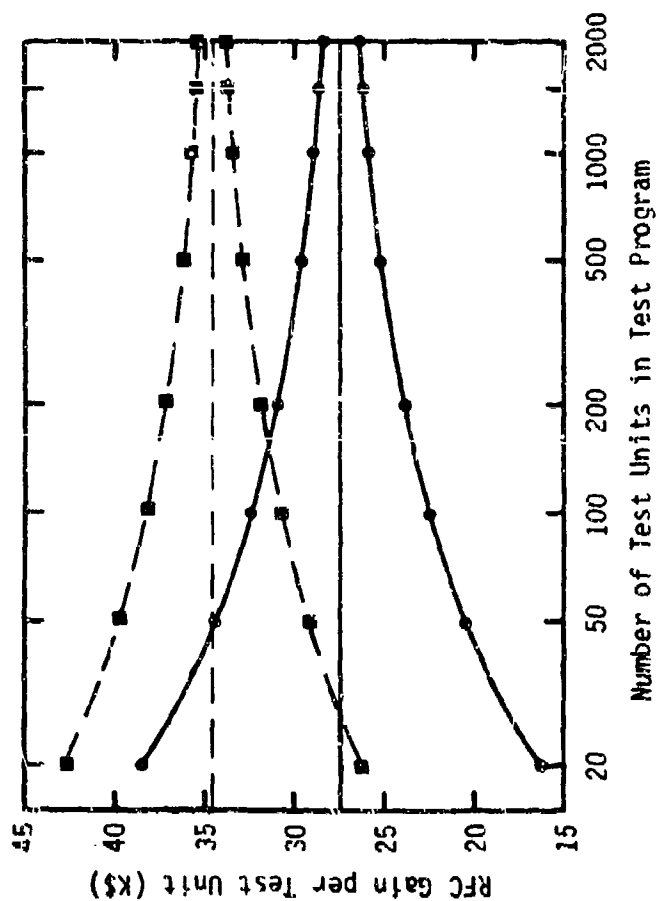
NOTE: One Test Unit is equivalent to 1.14 to 1.19 specimens (refer to text).

● Safety Factor = 4; 10% underestimate of average stress with no adjustment of stress based on inspection. (E-179)

■ Safety Factor = 4; perfect estimate of average stress with no adjustment of stress based on inspection. (E-180)

Number of Test Units in Test Program

RFC Gain per Test Unit (K$)

Figure 9-1 - The Effect of Test Program Size Upon Accuracy of Economic Estimates for Two RFC Procedures.

9-6
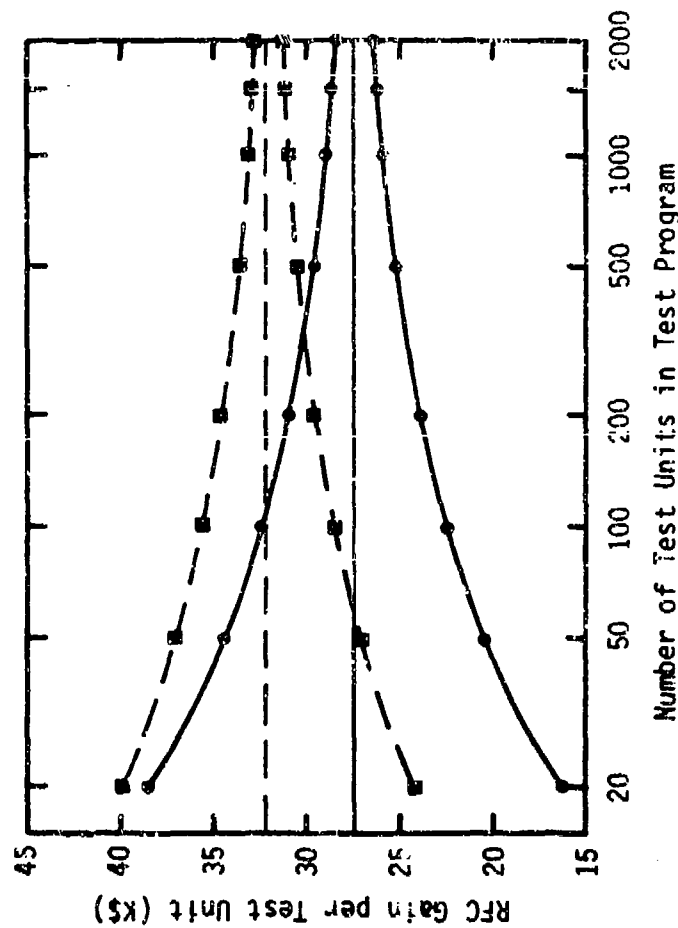
NOTE: One Test Unit is equivalent to 1.14 to 1.62 specimens (refer to text).

● Safety Factor = 4; 10% underestimate of average stress with no adjustment of stress based on inspection. {E-179}

■ Maximum Allowable Failure Probability = 0.05 (with probabilistic update); 10% underestimate of average stress with no adjustment of stress based on inspection. {E-181}

Figure 9-2 - The Effect of Test Program Size Upon Accuracy of Economic Estimates for Two RFC Procedures.
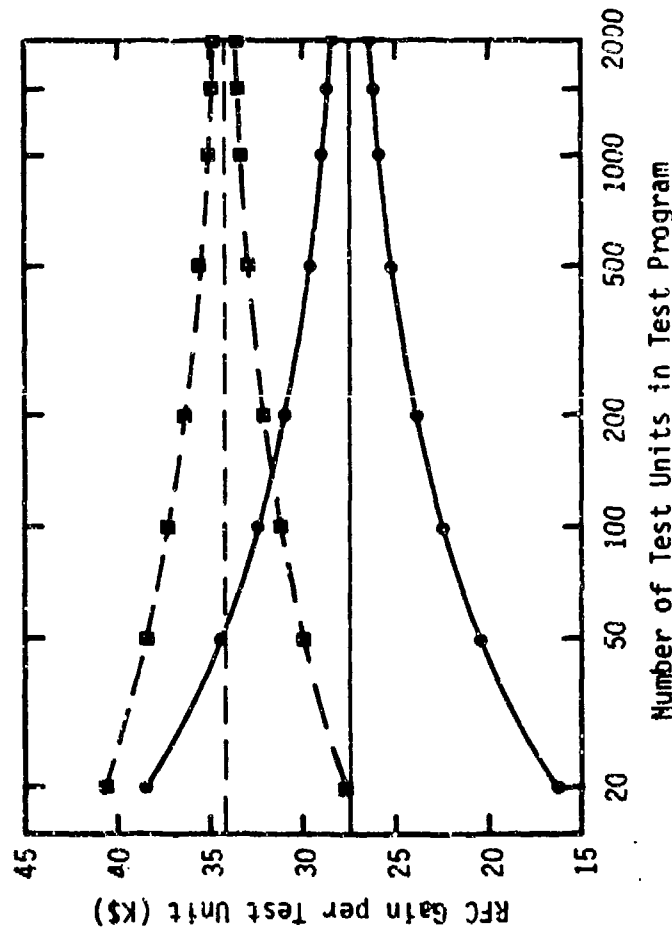
NOTE: One Test Unit is equivalent to 1.14 to 1.65 specimens (refer to text).

• Safety Factor = 4; 10% underestimate of average stress with no adjustment of stress based on inspection. (E-179)

■ Maximum Allowable Failure Probability = 0.05 (with probabilistic update); perfect estimate of average stress with no adjustment of stress based on inspection. (E-182)

Figure 9-3 – The Effect of Test Program Size Upon Accuracy of Economic Estimates for Two RFC Procedures.

2. No constraint has been placed upon maximum inspection interval; the applied inspection interval is to be computed purely from the specified safety factor or allowable failure probability and with no upper limit.

3. No constraint has been placed upon the value of $\hat{a}_{max}$, the crack size at which a specimen __must__ be retired.

4. In all cases, 1500 single bolt hole specimen test units are simulated. A test unit consists of the (random) number of replacement specimens required to complete the 5200 cycle "engine" life. Since it is assumed that both sides of the hole are nominally identical, the variable NHOLE is set equal to 2 in the program PERFCT.

Two of the RFC procedures described in Table 7-2 were each applied with two different specifications of optimum safety factor or maximum allowable failure probability to produce the study summarized in Figures 9-1 through 9-3. The RFC gains, $\bar{G}$, detailed in Tables E-179 through E-182, are summarized in Table 9-1.

One of the output parameters of PERFCT is E_{1500}, an estimate of the sampling error associated with the 1500-test unit simulation. The use of the +/- symbol in Table 9-1 denotes that E_{1500} is the +/- one-standard deviation range of $\bar{G}$. Clearly, the error bands associated with a 1500 unit test program which duplicates the simulations would be adequately small for showing

Table 9-1

SUMMARY OF TEST-PROGRAM SIMULATION RESULTS

Table/ Figure Nos.	Safety Criterion	RFC Procedure No.	Stress Error	Number of Replacements	Number of Failures	RFC Gain (K$), G	Sampling Error (K$), E_{1500}
E-179/ 9-1 to 9-3	SF = 4	2	10% Under-Estimate	215	160	27.4	±1.29
E-180/ 9-1	SF = 4	2	No Error	288	84	34.5	±0.95
E-181/ 9-2	$F_{cmax} = 0.05$	4	10% Under-Estimate	928	76	32.1	±0.90
E-182/ 9-3	$F_{cmax} = 0.05$	4	No Error	979	53	34.1	±0.75

that all four RFC procedures produce a positive test-program* gain, even for +/- three standard deviations. However, for a smaller number of specimens (n) in the test program, one can estimate the sampling standard deviation (E_n) from the above table with the equation

$$E_n = E_{1500} \sqrt{1500/n} \qquad\qquad (9\text{-}1)$$

The upper and lower bounds associated with Equation 9-1 are plotted in Figures 9-1 through 9-3. They indicate that as few as 20 units (i.e., 20 or 30 single hole specimens) would probably be adequate for correctly demonstrating a positive gain on any of the considered RFC procedures.

To a first order, one might also estimate the number of specimen test units required to distinguish the optimum among RFC procedures as the abscissa point where the lower bound of the more economical procedure intersects with the upper bound of the less economical procedure. Such an estimate would require 170, 400, and 150 test units to distinguish between the RFC procedure pairs in Figures 9-1, 9-2, and 9-3, respectively. This is a very crude statistical estimation of the required sample size since it neither estimates the probabilities of an incorrect conclusion regarding the comparative RFC results nor accounts for the fact that all RFC procedures are applied to the same group of specimens.

A more appropriate technique would be to simulate for a test program, for example, a group of 50 specimens subjected to each of two RFC procedures

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* A recommended more thorough study would compare the simulation results of the test program with corresponding results for inservice simulation.

(e.g., Procedures A and B). The same simulation would then be applied to a second group of 50 simulated specimens. The applications would be repeated for each of, say, 100 or more groups of 50 specimens and the result (i.e., Procedure A is better, B is better, or A and B are essentially identical) could be counted. In this manner, the probability of reaching an incorrect conclusion due to an insufficient number of test specimens could be calculated as a function of the number of specimens.

10.0   VERIFICATION TESTING PROGRAM FOR RETIREMENT FOR CAUSE

An experimental RFC verification testing program has been conducted to determine whether or not RFC will "work" in a practical situation. The overall effort was divided into two categories which are (1) design and execution of the fatigue testing and (2) analysis of test data for various RFC procedures.

10.1   Fatigue Experiments

Our fatigue testing for RFC evaluation and verification consisted of six tasks:

1. Specimen design,

2. Selection of parameters for each test specimen,

3. Inspection procedure design and repeated execution during the testing of each specimen,

4. Execution of the tests,

5. Reduction of the inspection results so as to estimate crack sizes $(\hat{a})$ for analysis, and

6. Reduction of fatigue performance and inspection data for RFC analysis and verification.

10.1.1 Specimen Design

While it would have been desirable to duplicate all of the TF33 third-stage disk bolt hole geometry, this could not be accomplished, given the limitations of the disk geometry from which the specimens were cut and the load capacity of FaAA's testing equipment. From the point of view of both

10-1

fatigue and inspection performance, the most important difference between the specimen and third stage disk bolt hole configurations is the ratio of thickness to hole diameter which is 1.37 for the disk and 0.32 for the laboratory specimen. Aside from specific effects on the fatigue performance, as measured by the (a versus N) curve, the major qualitative effect of this thickness change is to initiate fatigue cracks from the corners of the specimen bolt hole more often than from the midthickness location. This change in crack origin is primarily due to the reduction in the plane strain conditions and triaxial constraint at the midthickness of the disk. Figure 10-1 provides all specimen dimensions and details. Because of the thin web in these disks, FaAA could not maintain a plane strain field around the bolt hole of the laboratory specimens and with the same bolt hole diameter. The decision was therefore made to maintain the same bolt hole diameter in an attempt to keep the same inspection reliability for the laboratory tests as previously established for the high-resolution inspection on the disks. As a result of this decision, most of the laboratory cracks, initiated at the corners of the bolt holes. This crack initiation location did not dramatically effect the inspection results because, for this verification program, the detection of large cracks was more important than the detection of small cracks.

10.1.2 Testing Parameters

Three different cyclic stress levels were employed to simulate the verification in the mission cycle that might be encountered in the field. The nominal gross section alternating stress levels used were 97.8 ksi, 105.9 ksi, and 119.4 ksi. The frequency was 20 Hz and the R-ratio ($R = q_{min}/q_{max}$) was 0.06 for the entire test program. These bolt holes typically operate at 450°F
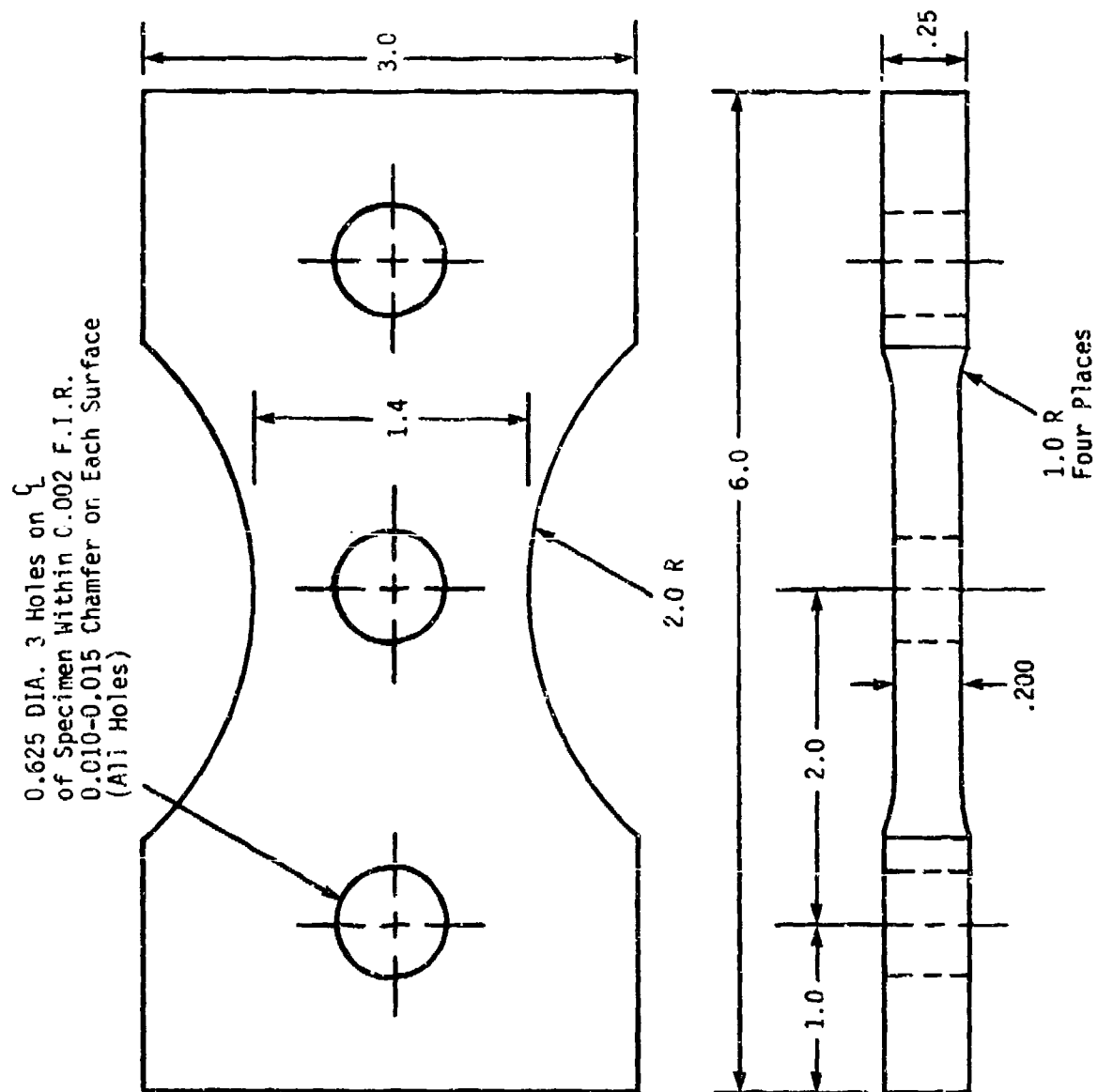
Figure 10-1 - Geometry of the Bolt Hole Fatigue Specimen
(all dimensions are in inches)

in the engine which is well below the creep region for this material. In fact, the observed fatigue cracks found in the disk bolt holes were all transgranular. FaAA duplicated the transgranular cracking mode in the laboratory at room temperature and therefore chose to perform the entire verification program at room temperature.

Three specimens were ganged in series for each mechanical test group. When one specimen failed, the loading train was shortened and testing continued. All specimens were periodically removed from the fatigue machine and inspected using the eddy current inspection system. In addition to the eddy current system for inspection, surface replicas were taken on some specimens as a means of confirming that the inspection reliability of the eddy current system used for this verification program was the same as that previously measured.

10.1.3 Inspection

Inspections were performed on each fatigue test specimen. Calibration of the system was routinely performed using several specimens that were partially cracked during the preliminary stages of this task. The inspection system contained a Reluxtrol CREG 201 eddy current sensing element, a Nortec NDT-15 Eddyscope, and a Hewlett-Packard dual pen strip chart recorder for obtaining permanent inspection records. A probe frequency of 5 MHz was used during the inspection procedures. A high gain of 40 and high sensitivity output levels were used to obtain maximum overall sensitivity. Indications that were greater than 5% of the standard calibration signal were reported as fatigue crack indications.

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The probe was fixed in the test stand, and the specimen was simultaneously rotated and advanced past the sensing element. This is opposite to the field and laboratory testing that was performed earlier in this program on actual disks. The current system is simpler for laboratory fatigue specimens and also results in less electrical noise on the inspection signal. The rate of specimen advancement was 0.025 inch per revolution. In addition to the crack indication signal, the specific side and location of the flaw were also recorded. A photograph of the test fixture and accompanying electrical equipment is shown in Figure 10-2.

Replication of the test hole surface was made in conjunction with the eddy current inspection for a small number of initial specimens. This permitted an accurate calibration between inspection signal and crack length along the hole surface. A least-squares regression analysis was performed upon these data, as illustrated in Figure 10-3, to obtain the relationship between signal amplitude and real crack size. This curve has the identical functional form as that previously reported for high-resolution inspections of actual disk bolt holes. Note, Figure 10-3 (i.e., specimens 19I, 26I, or 28G), the tendency for a given specimen to give signals that are either consistently below, above, or on the mean trend signal-versus-crack-size curve, over its entire life duration. This data could be analyzed in greater detail at a later date to separate the effects of (1) crack growth and (2) specimen-to-specimen variation on signal size. Having established through data regression the best-fit relationship between signal, s, and inspection size, $\hat{a}$, this $\hat{a}(s)$ equation was utilized to report the inspection results for each specimen.

Figure 10-2 - Bolt Hole Eddy Current Inspection
Equipment.
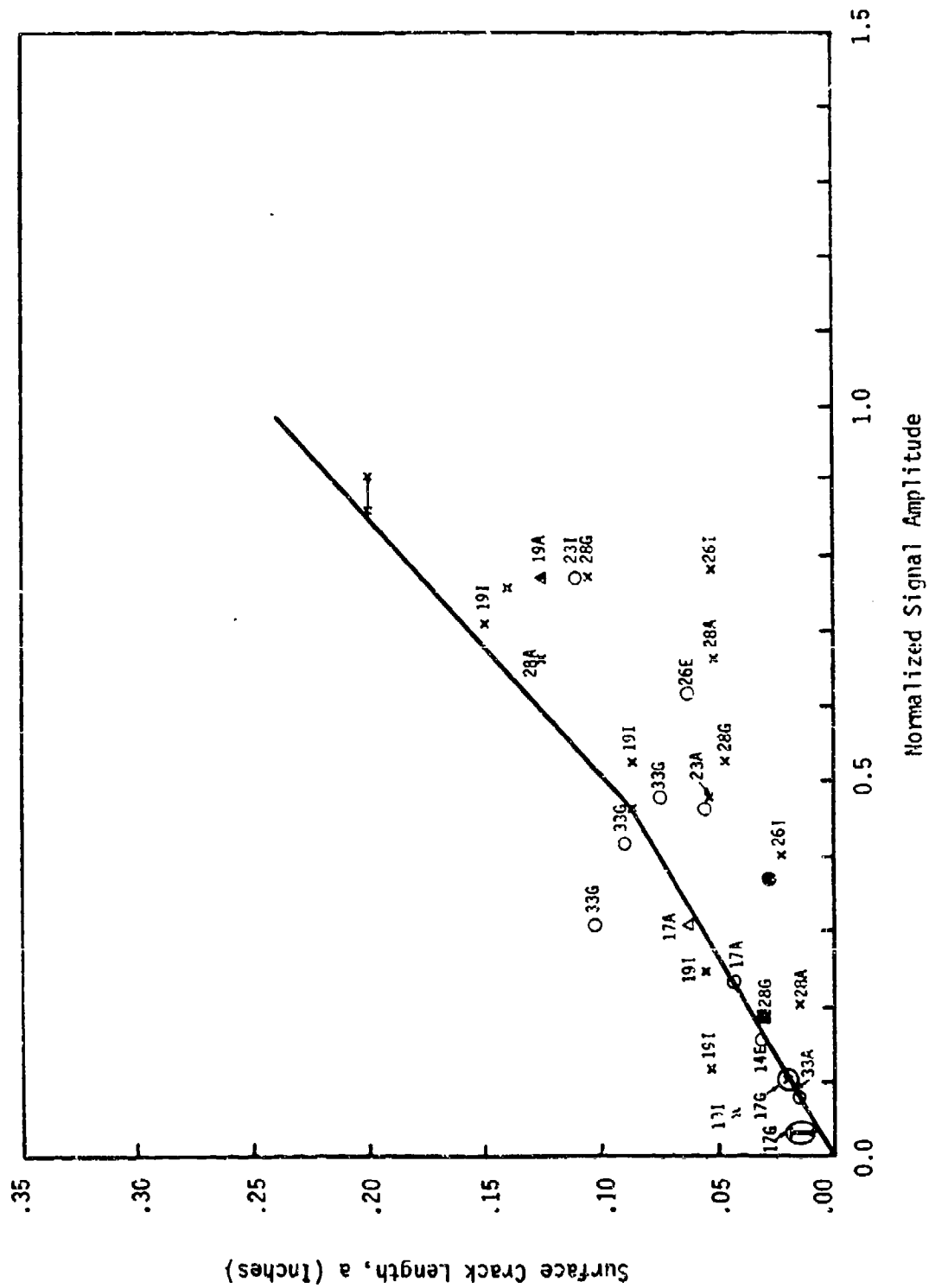
Figure 10-3 - Bolt Hole Surface Crack Length as a Function of the Normalized Eddy Current Signal (indication amplitude). The Solid Line Represents the Relationship Between Crack Size and the Observed Inspection Signal for the Previous High Resolution Inspections of Actual Disks.

It would have been possible to work without the explicit inspection crack size concept and simply to base all RFC procedures upon allowable signal size, s_a. However, since the developed RFC procedures use crack size estimates, $\hat{a}$, the regression relationship was used. Use of implicit s, rather than explicit $\hat{a}$, would have produced few differences in the results to be reported in Section 10.2. Replication data points, a, (presumably more accurate than the inspection amplitude $\hat{a}(s)$ in characterizing crack size) were not used as input to the RFC procedures, or for any other purpose besides the inspection-characterization regression in Figure 10-3.

10.1.4 Execution of the Fatigue Experiments

All specimens were cycled on the MTS machine at one of the three stress levels cited in Section 10.1.2. Inspections were performed on all specimens at intervals based on both the stress level employed and the results of previous inspections. While 5 to 11 inspections were typically accomplished on a specimen, some specimens experienced fairly rapid failures and as a result were inspected only two or three times. The interval of these actual inspections has no connection with the method for simulating RFC inspection intervals to be described in Section 10.2.

10.1.5 Fatigue Specimen Test Results

The results from the 32 fatigue specimens is given in Table 10-1. The table lists the actual time of each inspection, N, and the crack length, ℓ, for both the left and right side of the specimen calculated from the

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THE NUMBER OF RFC SPECIMENS IS 32.

FOR SPEC # 1, WITH 12 TIME PTS, THE NHAT/N RATIO IS 1.74764, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES   MEASURED LEFT CRACK   MEASURED RIGHT CRACK

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
4000.	0.0080	0.0	
5000.	0.0225	0.0	
5500.	0.0390	0.0	
6000.	0.0550	0.0150	
6500.	0.0650	0.0225	
7000.	0.0675	0.0300	
7500.	0.0700	0.0400	
8000.	0.1225	0.0500	
8500.	0.1225	0.0550	
9000.	0.1275	0.0725	
9500.	0.2725	0.2075	
9550. FAILURE POINT:	N/A	N/A	XNS= 16690.

FOR SPEC # 2, WITH 9 TIME PTS, THE NHAT/N RATIO IS 1.13798, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
14000.	0.0	0.0055	
15000.	0.0	0.0075	
16500.	0.0085	0.0200	
18000.	0.0200	0.0225	
20000.	0.0315	0.0300	
22000.	0.0425	0.1050	
24000.	0.0525	0.1560	
26000.	0.1550	0.2025	
26310. FAILURE POINT:	N/A	N/A	XNS= 29940.

FOR SPEC # 3, WITH 6 TIME PTS, THE NHAT/N RATIO IS 0.99331, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
4000.	0.0	0.0088	
4500.	0.0073	0.0147	
5000.	0.0235	0.0294	
5500.	0.0646	0.0588	
6000.	0.2184	0.1967	
6030. FAILURE POINT:	N/A	N/A	XNS= 5990.

FOR SPEC # 4, WITH 4 TIME PTS, THE NHAT/N RATIO IS 0.93238, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
25000.	0.0176	0.0235	
30000.	0.0588	0.0274	
35000.	0.1099	0.1836	
36200. FAILURE POINT:	N/A	N/A	XNS= 35617.

Table 10-1 - Complete Results of Fatigue Experiments Specimen Inspections.

FOR SPEC # 5, WITH 8 TIME PTS, THE NHAT/N RATIO IS 0.99299, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES MEASURED LEFT CRACK MEASURED RIGHT CRACK

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
10000.	0.0029	0.0088	
15000.	0.0088	0.0088	
15460.	0.0102	0.0088	
16510.	0.0117	0.0088	
17500.	0.0352	0.0132	
20000.	0.1706	0.0823	
22500.	0.2184	0.1967	
22750. FAILURE POINT:	N/A	N/A	XNS= 22591.

FOR SPEC # 6, WITH 7 TIME PTS, THE NHAT/N RATIO IS 1.15961, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
25000.	0.0	0.0088	
27500.	0.0	0.0764	
30000.	0.0	0.1316	
32500.	0.0	0.1793	
35000.	0.0132	0.2314	
37500.	0.0411	0.2531	
39600. FAILURE POINT:	N/A	N/A	XNS= 45921.

FOR SPEC # 7, WITH 5 TIME PTS, THE NHAT/N RATIO IS 1.34178, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
20000.	0.0411	0.0073	
21030.	0.0646	0.0147	
22500.	0.0882	0.0294	
25000.	0.2140	0.0646	
25360. FAILURE POINT:	N/A	N/A	XNS= 34028.

FOR SPEC # 8, WITH 6 TIME PTS, THE NHAT/N RATIO IS 1.17492, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
5500.	0.0	0.0117	
6000.	0.0	0.0294	
6500.	0.0073	0.0617	
7000.	0.0176	0.1099	
7500.	0.0294	0.1489	
7790. FAILURE POINT:	N/A	N/A	XNS= 9153.

FOR SPEC # 9, WITH 10 TIME PTS, THE NHAT/N RATIO IS 0.43243, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
17500.	0.0029	0.0029	
20000.	0.0044	0.0044	
22500.	0.0044	0.0044	
25000.	0.0044	0.0044	
27500.	0.0161	0.0088	
30000.	0.0338	0.0558	
32500.	0.0558	0.1229	
35000.	0.1055	0.2053	
37500.	0.1860	0.2791	
37520. FAILURE POINT:	N/A	N/A	XNS= 16225.

Table 10-1 - (continued)

FOR SPEC # 10, WITH 5 TIME PTS, THE NHAT/N RATIO IS 1.33714, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES		MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
7500.		0.0441	0.0	
10000.		0.0705	0.0	
12500.		0.1185	9.0	
15600.		0.1706	0.0264	
17090.	FAILURE POINT:	N/A	N/A	XNS= 22652.

FOR SPEC # 11, WITH 4 TIME PTS, THE NHAT/N RATIO IS 0.76408, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES		MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
4000.		0.0	0.0235	
4500.		0.0	0.0411	
5000.		0.0073	0.0793	
5530.	FAILURE POINT:	N/A	N/A	XNS= 4073.

FOR SPEC # 12, WITH 4 TIME PTS, THE NHAT/N RATIO IS 0.70552, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES		MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
9600.		0.0098	0.0205	
10000.		0.0117	0.0646	
11000.		0.0705	0.1055	
11700.	FAILURE POINT:	N/A	N/A	XNS= 8255.

FOR SPEC # 13, WITH 4 TIME PTS, THE NHAT/N RATIO IS 1.67725, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES		MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
4000.		0.0	0.0411	
5000.		0.0235	0.0968	
5300.		0.0441	0.1446	
5910.	FAILURE POINT:	N/A	N/A	XNS= 9929.

FOR SPEC # 14, WITH 4 TIME PTS, THE NHAT/N RATIO IS 1.04789, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES		MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
10000.		0.0073	0.0352	
12500.		0.0132	0.0538	
15000.		0.0294	0.1316	
17450.	FAILURE POINT:	N/A	N/A	XNS= 18204.

FOR SPEC # 15, WITH 5 TIME PTS, THE NHAT/N RATIO IS 0.32692, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES		MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
17500.		0.0925	0.0	
20000.		0.1533	0.0323	
22500.		0.2083	0.0852	
25000.		0.2083	0.1619	
26040.	FAILURE POINT:	N/A	N/A	XNS= 8490.

Table 10-1 - (continued)

FOR SPEC # 16, WITH 13 TIME PTS, THE NHAT/N RATIO IS 0.81076, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES   MEASURED LEFT CRACK   MEASURED RIGHT CRACK

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
9000.	0.0	0.0117	
9500.	0.0	0.0205	
10000.	0.0	0.0382	
10500.	0.0	0.0529	
11000.	0.0	0.0617	
11500.	0.0	0.0705	
12000.	0.0117	0.0925	
12500.	0.0191	0.1185	
13000.	0.0205	0.1402	
13500.	0.0235	0.1750	
14000.	0.0323	0.1967	
14500.	0.0588	0.2314	
14790.	FAILURE POINT: N/A	N/A	XNS= 11991.

FOR SPEC # 17, WITH 4 TIME PTS, THE NHAT/N RATIO IS 1.69272, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
17500.	0.0	0.0793	
20000.	0.0	0.0968	
22500.	0.0294	0.2401	
24110.	FAILURE POINT: N/A	N/A	XNS= 40811.

FOR SPEC # 18, WITH 7 TIME PTS, THE NHAT/N RATIO IS 1.61053, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
8000.	0.0	0.0176	
8500.	0.0	0.0470	
9000.	0.0	0.0793	
9500.	0.0	0.1012	
10000.	0.0073	0.1750	
10500.	0.0352	0.2097	
10990.	FAILURE POINT: N/A	N/A	XNS= 17700.

FOR SPEC # 19, WITH 9 TIME PTS, THE NHAT/N RATIO IS 3.02453, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
5000.	0.0	0.0058	
5500.	0.0	0.0058	
6000.	0.0	0.0088	
6500.	0.0	0.0176	
7000.	0.0117	0.0323	
7500.	0.0264	0.0529	
8000.	0.0676	0.0882	
8500.	0.1923	0.2053	
8710.	FAILURE POINT: N/A	N/A	XNS= 26344.

FOR SPEC # 20, WITH 4 TIME PTS, THE NHAT/N RATIO IS 2.23401, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
15000.	0.0470	0.0176	
17500.	0.1012	0.0705	
20000.	0.1229	0.1967	
22070.	FAILURE POINT: N/A	N/A	XNS= 49305.

Table 10-1 - (continued)

FOR SPEC # 21, WITH 8 TIME PTS, THE NHAT/N RATIO IS 1.37682, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
5000.	0.0056	0.0	
5500.	0.0147	0.0	
6000.	0.0235	0.0176	
6500.	0.0499	0.0176	
7000.	0.0793	0.0264	
7500.	0.1185	0.0470	
8000.	0.1576	0.0617	
8390. FAILURE POINT: N/A		N/A	XNS= 11552.

FOR SPEC # 22, WITH 5 TIME PTS, THE NHAT/N RATIO IS 1.59592, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
20000.	0.0176	0.0073	
22500.	0.0646	0.0147	
25000.	0.1359	0.0588	
27500.	0.2006	0.2006	
27870. FAILURE POINT: N/A		N/A	XNS= 44478.

FOR SPEC # 23, WITH 2 TIME PTS, THE NHAT/N RATIO IS 2.16755, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
7500.	0.0058	0.0823	
9860. FAILURE POINT: N/A		N/A	XNS= 21372.

FOR SPEC # 24, WITH 4 TIME PTS, THE NHAT/N RATIO IS 2.43308, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
15000.	0.0132	0.0117	
17500.	0.0382	0.0176	
20000.	0.1099	0.0793	
22000. FAILURE POINT: N/A		N/A	XNS= 53578.

FOR SPEC # 25, WITH 8 TIME PTS, THE NHAT/N RATIO IS 0.70285, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
8000.	0.0005	0.0	
8500.	0.0132	0.0	
9000.	0.0529	0.0	
9500.	0.0558	0.0	
10000.	0.0676	0.0	
10500.	0.1012	0.0	
11000.	0.2018	0.0	
11350. FAILURE POINT: N/A		N/A	XNS= 7977.

FOR SPEC # 26, WITH 5 TIME PTS, THE NHAT/N RATIO IS 1.61030, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES	MEASURED LEFT CRACK	MEASURED RIGHT CRACK	
12500.	0.0	0.0029	
15000.	0.0	0.0235	
17500.	0.0	0.0558	
20000.	0.0	0.1663	
21930. FAILURE POINT: N/A		N/A	XNS= 33869.

Table 10-1 - (continued)

FOR SPEC # 27; WITH 3 TIME PTS, THE NHAT/N RATIO IS 0.69602, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES   MEASURED LEFT CRACK   MEASURED RIGHT CRACK

10000.	0.0396	0.0
15000.	0.2184	0.0382
15460. FAILURE POINT:	N/A	N/A

XNS= 10760.

FOR SPEC # 28, WITH 6 TIME PTS, THE NHAT/N RATIO IS 0.95790, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES   MEASURED LEFT CRACK   MEASURED RIGHT CRACK

5000.	0.0	0.0235
5500.	0.0	0.0411
6000.	0.0	0.0588
6500.	0.0	0.1316
7000.	0.0264	0.1489
7270. FAILURE POINT:	N/A	N/A

XNS= 6964.

FOR SPEC # 29, WITH 5 TIME PTS, THE NHAT/N RATIO IS 1.04550, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES   MEASURED LEFT CRACK   MEASURED RIGHT CRACK

15000.	0.0	0.0044
17500.	0.0205	0.0044
20000.	0.1099	0.0147
22500.	0.1921	0.0529
24600. FAILURE POINT:	N/A	N/A

XNS= 25719.

FOR SPEC # 30, WITH 3 TIME PTS, THE NHAT/N RATIO IS 0.94184, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES   MEASURED LEFT CRACK   MEASURED RIGHT CRACK

7500.	0.0056	0.0793
10000.	0.1316	0.1619
10500. FAILURE POINT:	N/A	N/A

XNS= 9880.

FOR SPEC # 31, WITH 4 TIME PTS, THE NHAT/N RATIO IS 0.71117, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES   MEASURED LEFT CRACK   MEASURED RIGHT CRACK

10000.	0.0056	0.0352
15000.	0.1446	0.1706
15460.	0.1576	0.1830
16510. FAILURE POINT:	N/A	N/A

XNS= 11741.

FOR SPEC # 32, WITH 4 TIME PTS, THE NHAT/N RATIO IS 0.92242, AND THE INSPECTION & FAILURE HISTORY IS:

INSPECTION OR FAILURE CYCLES   MEASURED LEFT CRACK   MEASURED RIGHT CRACK

10000.	0.0	0.1055
12500.	0.0	0.1750
15000.	0.0	0.2357
16150. FAILURE POINT:	N/A	N/A

XNS= 14897.

Figure 10-1 - (continued)

inspection signal and the regression curve in Figure 10-3. In addition, the actual number of cycles to specimen separation is given.

Since the inspection focused on the crack length projected on the inner diameter of the bolt hole, failure for the analytical phase of this verification program has been defined as a crack across the entire 0.2-inch specimen thickness; i.e., a = 0.2 inch denotes a failure. The N_f values given in Table 10-1 represent complete rupture of the specimen. However, this inconsistency in the failure point definition is negligible since, on average, the time to rupture was equal to 1.06 of the time for the crack to reach 0.2 inch and, at most, the time to rupture was 1.16 of the time to produce a = 0.2 inch.

In order to simulate cycle-counting errors similar to those investigated in the TF-33 fleet analysis, the actual number of specimen fatigue cycles as multiplied by a number which could vary between 0.32602 and 3.02453. The specific number for each of the 32 specimens is given in Table 10-1 as the NHAT/N ratio. The procedure was to choose values randomly between these two limits and to maintain this $\hat{N}/N$ ratio for the life of the specimen. The perceived time to rupture for each specimen, $\hat{N}_f$ = XNS, is also given within Table 10-1. It was verified that the probability distribution of the $\hat{N}_f$ values, which ranged from a low of 4032 cycles for specimen number 7 to a high of 53,274 cycles for specimen 16, reproduced the probability distribution previously determined for the TF-33 disk population we inspected. It should be noted that reasonable agreement between investigated PD($\hat{N}$) distributions is somewhat fortuitous due to the small sample of specimens subjected to this cycle-counting simulation procedure. Thus, the program PERFCT was used to

simulate a much larger fleet of specimens, namely 1000, to insure that the overall scatter of $PD(\hat{N})$ is in fact in agreement with the TF-33 probability distribution. The $\hat{N}$ values are used for the specimens throughout the simulation study which follows in Section 10.2, with the exception of one series of computer runs in which actual N data was input into the RFC procedure to determine the effect of cycle-counting errors for the small 32-specimen population.

10.2 Analysis Of Fatigue Experiments For RFC Verification

Two major tasks were performed to test and analytically evaluate several RFC procedures for the specimen data generated in Section 10.1. The first task was the creation of software to execute the various RFC procedures using real fatigue data, instead of Monte Carlo simulated data as with the PERFCT program. The second part of the effort was to actually execute the analysis using the various RFC procedures with the new software.

10.2.1 Software Development

In order to take advantage of the many improvements to computer program PERFCT developed on a related FaAA project [4], the computer program PERFCT.VER2 was used as a starting point. All software changes to produce PERFCT.VER2 from PERFCT.VER1 are documented in Reference 4. The major reason for using PERFCT.VER2 is the improved ability to characterize any crack propagation behavior or prediction through tabular input of the (a versus N) curve or data.

The procedure actually used to input a life prediction to all RFC procedures is shown in Figure 10-4. Curve A was based upon the first specimen tested which was used to simulate a laboratory test program that might be conducted before hardware was introduced to service. Plotted as a dashed line on the same figure, curve B, is the average of several specimens that were tested at the median alternating stress level, $\Delta\sigma = 105.9$ ksi. As one can see, the curve employed for most of the RFC evaluation was, by chance, too optimistic, such that it adds an anti-conservative element to the RFC procedure. Curve C, to the left, represents the poorest fatigue performance of the specimens tested at $\Delta\sigma = 105.9$ or 119.4 ksi. It was employed in a limited sensitivity study to determine the impact of using a different life prediction on the RFC procedure results. The two solid curves in Figure 10-4 were accurately input in tabular form to PERFCT.VER2 by discretizing them into many piecewise linear segments. This RFC verification software program is called PERVERT (probabilistic engineering retirement f cause verification tester).

In addition to the four procedures outlined in Table 7-2 and repeated in this section for convenience, as shown in Table 10-2, a more primitive RFC procedure reflecting an unalterable maximum allowable flaw size criterion is employed. Specifically, inspection intervals are set at a constant value, in this case XNMIN equals 1000 cycles and if a perceived flaw size $\hat{a}$ greater than the allowable of $\hat{a}_a$ the specimen is rejected by the RFC procedure. Otherwise, the specimen is accepted. There is no limit on the maximum allowable crack size used for procedures RFC 1 through RFC 4 (the primitive procedure is numbered RFC 0). There is no provision for replacing specimens as there is for replacing disks within an engine. Each specimen is run until it is rejected or fails. As will be seen below, the RFC procedure is given credit

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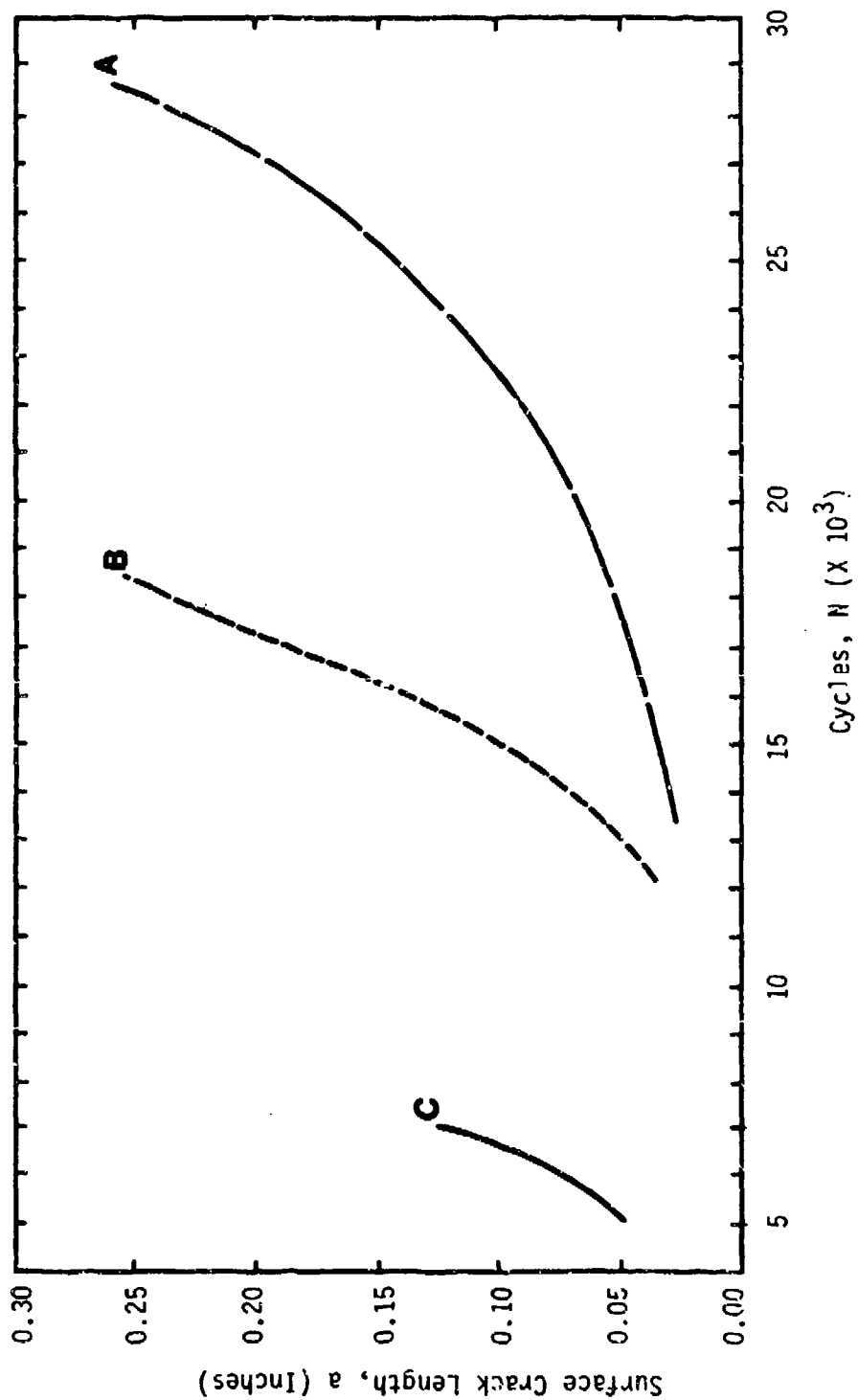
Figure 10-4 – Bolt Hole Surface Crack Length Versus Number of Fatigue Cycles for Several Test Specimens. Curve A represents the Initial Crack Extension Data Used by the RFC Model. Curve B is the Average Extension Data at the Median Cyclic Load Level, and Curve C Represents the Poorest Crack Extension Behavior Measured in this Verification Program.

Table 10-2

Four Developed and Evaluated RFC Procedures

	Allowable-Life-Extension Estimation Method	
Stress Estimation Method	Use Analyst's a vs N equation with a life-extension-based safety factor, SF. No adjustments allowed	Use statistical update of in-service component performance data. Continually adjust and compute life-extension with a maximum allowable conditional failure probability, F_{cmax}.
Based on prior stress analysis only. No adjustments allowed	RFC PROCEDURE No. 1 [Input IDIN = 0 and ISTRES = 2 in Program PERFCT]	RFC PROCEDURE No. 3 [Input IDIN = 1 and ISTRES = 2 in Program PERFCT]
Inspection-Based. The stress used is that "required" to produce the largest measured crack $\hat{a}$ in the perceived cycles $\hat{N}$ for each disk	RFC PROCEDURE No. 2 [Input IDIN = 0 and ISTRES = 1 in Program PERFCT]	RFC PROCEDURE NO. 4 [Input IDIN = 1 and ISTRES = 1 in Program PERFCT]

All procedures:

① Base life extension on the largest crack measured $\hat{a}$ from the disk's several nominally identical failure sites.

② Always extend a disk with $\hat{a} < 1/32"$; always retire a disk with $\hat{a} > \hat{a}_{max}$.

③ Make use of an equation predicting fatigue performance and subject to systematic errors.

④ Honor the constraints on minimum ($\Delta \hat{N}_{min}$), maximum ($\Delta \hat{N}_{max}$), and descretized (integer multiples of $\Delta \hat{N}_{min}$) inspection intervals.

for using as much of the life of the specimen as is possible without causing a failure; failure is defined as a crack all the way across the thickness at the inner diameter of the hole, a = 0.2 inches.

The complex cost algorithms used to evaluate TF-33 and F-100 procedures have been replaced with a much simpler algorithm. This simple algorithm reflects the fact that there is no specimen replacement or repair simulated so that the only two costs are inspection and average failure cost. The cost to inspect a specimen was set at $1000 and the average specimen failure cost was set at $100,000. As discussed in Section 9, the failure cost has been set artificially low in order to encourage RFC procedures which can result in failure rates on the order of 1 or 2 in the 32-specimen population.

The last item was to set the maximum useful life of the specimens and the design life of the specimens. For this RFC verification testing, the specimen design life (DL) was set at 2000 cycles and the maximum useful life (Q) was set at 55,000 cycles. This latter value is effectively infinite in that it exceeds the maximum actual life of every specimen. Therefore, no RFC procedure was able to retire a specimen on the basis that its life had been used up.

As was done previously for the fleet simulation, these 32 specimens were divided into 4 groups of 8. The starting time for each specimen group was then staggered to permit the program PERVERT to learn from the past fleet's performance. The first group was started at time 0, the second group was started at 4000 cycles, the third group was started at 8000 cycles, and the fourth group was started at 12,000 cycles.

10.2.2 RFC Procedure Results and Verifications

The raw experimental data or Table 10-1 were input to the program PERVERT to test the five RFC Procedures, 0 through 4. Major results of these simulations are tabulated in the remainder of this section.

Primitive RFC Procedure (No. 0). Table 10-3 shows the effect of changing the allowable flaw size as part of the primitive RFC Procedure 0. The table shows that more than half of the total available RFC cycles are obtained from the specimen population, before the first failure is encountered. Note that since this primitive RFC procedure involves only a maximum allowable flaw size criterion, the over-estimation of the crack growth life associated with the curves in Figure 10-4 plays no direct part. Thus, the table simply reflects that specification of an allowable flaw size somewhere between 20 and 50 mils would result in optimum performance for the small RFC verification specimen population.

RFC Procedure No. 1: Constant Safety Factor and Crack Growth Rate Prediction. Results of applying RFC Procedure No. 1 with an overly optimistic and unadjustable crack growth rate prediction are summarized in Table 10-4. Failures are encountered even with a life-base safety factor of 10. An unrealistically high life-base safety factor of 7 is required to optimize RFC costs-per-cycle, under the assumed ratio of inspection and failure costs. For safety factors of 4 and 5, which are usually quite reasonable, 6 and 5 failures were suffered, respectively, of the 32-specimen population; this clearly shows the effect of the unalterable anti-conservative life predictions used in RFC Procedure No. 1.

Table 10-3
Evaluation of RFC AG Procedure

Max. Allowable Crack Size for Return to Service a_{allow} (in.)	XMMIN (cycles)	XMMAX (cycles)	Number of Inspections	Number of Failures	Number of RFC Cycles	Percent Population Usage (%)	Dollar Cost per Cycle
0.005	1,000	1,000	240	0	216,000	35	$1.15
0.01	1,000	1,000	310	0	293,000	49	1.10
0.02	1,000	1,000	405	0	373,000	60	1.09
0.05	1,000	1,000	495	1	454,590	72	1.29
0.10	1,000	1,000	550	3	525,931	84	1.63

Notes:

1) XMMIN and XMMAX are the minimum and maximum return-to-service intervals, respectively.

2) Numbers of Inspections, Failures, and RFC Cycles are for the aggregate 32-specimen population.

3) The first 2,000 cycles of each specimen are not counted as "RFC Cycles" since they occur before the original design life and first RFC inspection.

4) If all specimens were allowed to fail, 622,935 RFC cycles would be "achieved." Thus, "percent population usage" is computed by dividing RFC cycles x 100% by 522,935.

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Table 10-4
Evaluation of RFC #1 Procedure

Safety Factor	XMMIN (cycles)	XMMAX (cycles)	Number of Inspections	Number of Failures	Number of RFC Cycles	Percent Population Usage (%)	RFC Cost per Cycle
10.0	1,000	*	395	1	447,990	72	$1.10
7.0	1,000	*	30	2	489,967	79	1.03
5.0	1,000	*	231	5	517,259	83	1.41
4.0	1,000	*	197	6	537,411	86	1.48
3.0	1,000	*	159	7	554,739	89	1.55
2.5	1,000	*	137	10	564,944	91	2.01
2.0	1,000	*	105	16	575,031	92	2.97

Notes:

1) XMMIN and XMMAX are the minimum and maximum return-to-service intervals, respectively.
2) Numbers of Inspections, Failures, and RFC Cycles are for the aggregate 32-specimen population.
3) The first 2,000 cycles of each specimen are not counted as "RFC Cycles" since they occur before the original design life and first RFC inspection.
4) If all specimens were allowed to fail, 622,935 RFC cycles would be "achieved." Thus, "percent population usage" is computed by dividing RFC cycles x 100% by 622,935.

RFC Procedure No. 2:   Constant Safety Factor with Adjustable Life
Prediction. Dramatic improvement occurred using RFC Procedure No. 2 to alter
the life prediction, on a specimen-by-specimen basis, according to the per-
ceived inspection site, $\hat{a}$ is shown in Table 10-5. While unreasonably high
safety factors of 7 to 10 are required to eliminate failures and optimize the
RFC procedure costs, the safety factors of 4 and 5 result in much better per-
formance than with RFC Procedure No. 1. Under the assumed cost constraints,
the 0.79 cent per cycle result for this RFC procedure has turned out to be the
best result obtained for any RFC procedure and parametric specification
employed in this study. The attainment of 77% of the maximum possible life of
the specimen population, while encountering only a single failure, appears to
be a very impressive performance. Equally impressive is the result under a
safety factor of 10 in which 71% of the total available life of the specimen
population was obtained without failure.

RFC Procedure No. 3:   Constant Life Prediction with Probabilistic
Update on Return-to-Service Intervals. Improvement of incorporating proba-
bilistic update procedures into the RFC Procedure No. 1 is indicated in Table
10-6. Specified maximum allowable failure probabilities of 0.01 to 0.02
represent optimum performance although the overall levels achieved appear to
be inferior to those due to the deterministic adjustment to the life predic-
tion algorithm shown in Table 10-5. While no definitive conclusions can be
made because of the small RFC verification specimen population, a proba-
bilistic update procedure could be improved well beyond the current level
achieved by reducing the overprediction of residual life that results under
low failure costs and high failure rates on the order of 0.01 for a return to
service interval are tolerable.

Table 10-5
Evaluation of RFC #2 Procedure

Safety Factor	XMMIN (cycles)	XPMAX (cycles)	Number of Inspections	Number of Failures	Number of RFC Cycles	Percent Population Usage (%)	RFC Cost per Cycle
10.0	1,000	-	350	0	442,000	71	$0.79
7.0	1,000	-	269	1	477,990	77	0.79
5.0	1,000	-	210	2	513,062	82	0.80
4.0	1,000	-	178	3	532,026	85	0.90
3.0	1,000	-	145	5	546,255	88	1.18
2.5	1,000	-	117	12	572,253	92	2.30
2.0	1,000	-	92	17	583,154	94	3.07

Notes:

1) XMMIN and XPMAX are the minimum and maximum return-to-service intervals, respectively.
2) Numbers of Inspections, Failures, and RFC Cycles are for the aggregate 32-specimen population.
3) The first 2,000 cycles of each specimen are not counted as "RFC Cycles" since they occur before the original design life and first RFC inspection.
4) If all specimens were allowed to fail, 622,935 RFC cycles would be "achieved." Thus, "percent population usage" is computed by dividing RFC cycles x 100% by 622,935.

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Table 10-6
Evaluation of RFC #3 Procedure

Max. Allowable Return-to-Service Probability of Failure	XNMIN (cycles)	XNMAX (cycles)	Number of Inspections	Number of Failures	Number of RFC Cycles	Percent Population Usage (%)	RFC Cost per Cycle
0.01	1,000	-	255	0	322,000	52	$0.92
0.02	1,000	-	334	1	365,990	59	1.19
0.05	1,000	-	284	4	514,459	83	1.33
0.10	1,000	-	235	15	597,435	96	2.90
0.20	1,000	-	155	27	618,180	99	4.62

Notes:

1) XNMIN and XNMAX are the minimum and maximum return-to-service intervals, respectively.
2) Numbers of Inspections, Failures, and RFC Cycles are for the aggregate 32-specimen population.
3) The first 2,000 cycles of each specimen are not counted as "RFC Cycles" since they occur before the original design life and first RFC inspection.
4) If all specimens were allowed to fail, 622,935 RFC cycles would be "achieved." Thus, "percent population usage" is computed by dividing RFC cycles x 100% by 622,935.

RFC Procedure No. 4: Adjustable Life Prediction and Probabilistic Update Both Included. Results of employing what is nominally the most advanced RFC procedure are documented in Table 10-7. There are essentially no significant differences between the results of Tables 10-6 and 10-7 which indicates that the two positive updating benefits of altering the life prediction on a specimen-by-specimen and probabilistic updates of fleet performance as a whole are not synergistic in the current application. Recall from the TF-33 study that much more synergism was apparent in that RFC Procedure No. 4 was capable of resisting very large life predictions and cycle counting errors. Again, the lack of synergism in the verification population is believed due to the current probabilistic update procedure and the presence of small fleets with high failure rates.

Effect of Eliminating Cycle Counting Errors with RFC Procedure No. 4. In comparing Tables 10-7 and 10-8, we note little or no improvement associated with removing the cycle counting errors. Based upon the extensive investigation showing large effects of cycle counting errors on the TF-33 large fleets with low failure rates, it is clear that the RFC verification population was too small to bring out the worst features of large cycle counting errors.

Limiting the Maximum Allowable Return to Service Interval.   In Tables 10-9 and 10-10, RFC Procedure No. 4 is investigated for finite values of XNMAX, the maximum allowable return to service interval. In comparing Tables 10-9 with 10-7, the imposition of XNMAX = 1000 cycles is restrictive enough to produce slightly higher optimum costs. However, the lack of failures for all values of F_a less than or equal to 0.05, indicates that this

Table 10-7
Evaluation of RFC #4 Procedure

Max. Allowable Return-to-Service Probability of Failure	XMIN (cycles)	XMAX (cycles)	Number of Inspections	Number of Failures	Number of RFC Cycles	Percent Population Usage (%)	RFC Cost per Cycle
0.002	1,000	*	340	0	308,000	49	$1.10
0.005	1,000	*	312	0	309,000	49	1.01
0.01	1,000	*	313	0	339,000	54	0.92
0.012	1,000	*	342	1	350,073	56	1.26
0.015	1,000	*	335	1	374,073	60	1.16
0.02	1,000	*	357	1	397,990	64	1.15
0.05	1,000	*	259	4	500,459	80	1.32
0.10	1,000	*	216	14	576,352	93	2.80
0.20	1,000	*	134	27	619,150	99	4.58

Notes:

1) XMIN and XMAX are the minimum and maximum return-to-service intervals, respectively.
2) Numbers of Inspections, Failures, and RFC Cycles are for the aggregate 32-specimen population.
3) The first 2,000 cycles of each specimen are not counted as "RFC Cycles" since they occur before the original design life and first RFC inspection.
4) If all specimens were allowed to fail, 622,935 RFC cycles would be "achieved." Thus, "percent population usage" is computed by dividing RFC cycles x 100% by 622,935.

Table 10-8
Evaluation of PFC #4 Procedure
With No Cycle-Counting Errors

Max. Allowable Return-to-Service Probability to Failure	XMIN (cycles)	XMMAX (cycles)	Number of Inspections	Number of Failures	Number of RFC Cycles	Percent Population Usage (%)	RFC Cost per Cycle
0.01	1,000	•	232	0	259,000	51	$0.90
0.02	1,000	•	238	2	275,250	54	1.59
0.05	1,000	•	218	2	360,820	71	1.16
0.10	1,000	•	213	13	450,680	89	3.36
0.20	1,000	•	151	29	501,700	99	6.08

Notes:

1) XMIN and XMMAX are the minimum and maximum return-to-service intervals, respectively.
2) Numbers of Inspections, Failures, and RFC Cycles are for the aggregate 32-specimen population.
3) The first 2,000 cycles of each specimen are not counted as "RFC Cycles" since they occur before the original design life and first RFC inspection.
4) If all specimens were allowed to fail, 505,311 RFC cycles would be "achieved." Thus, "percent population usage" is computed by dividing RFC cycles x 100% by 505,311.

Table 10-9
Evaluation of RFC #4 Procedure
With 1000- Cycle Return-to-Service Intervals

Max. Allowable Return-to-Service Probability to Failure	XMMIN (cycles)	XMMAX (cycles)	Number of Inspections	Number of Failures	Number of RFC Cycles	Percent Population Usage (%)	RFC Cost per Cycle
0.01	1,000	1,000	369	0	337,000	54	$1.09
0.02	1,000	1,000	440	0	408,000	65	1.08
0.05	1,000	1,000	529	0	497,000	80	1.06
0.10	1,000	1,000	590	6	562,834	90	2.11
0.20	1,000	1,000	629	16	607,904	98	3.67
0.999	1,000	1,000	635	32	622,935	100	6.16

Notes:

1) XMMIN and XMMAX are the minimum and maximum return-to-service intervals, respectively.
2) Numbers of Inspections, Failures, and RFC Cycles are for the aggregate 32-specimen population.
3) The first 2,000 cycles of each specimen are not counted as "RFC Cycles" since they occur before the original design life and first RFC inspection.
4) If all specimens were allowed to fail, 622,935 RFC cycles would be "achieved." Thus, "percent population usage" is computed by dividing RFC cycles x 100% by 622,935.

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Table 10-10
Evaluation of RFC #4 Procedure
With 2000-Cycle Return-to-Service Intervals

Max. Allowable Return-to-Service Probability to Failure	XMMIN (cycles)	XMMAX (cycles)	Number of Inspections	Number of Failures	Number of RFC Cycles	Percent Population Usage (%)	RFC Cost per Cycle
0.01	2,000	2,000	194	1	325,990	52	$0.90
0.02	2,000	2,000	205	1	347,990	56	0.88
0.05	2,000	2,000	245	1	427,990	69	0.81
0.10	2,000	2,000	281	2	501,518	81	0.96
0.20	2,000	2,000	312	8	573,008	92	1.94
0.999	2,000	2,000	325	32	622,935	100	5.66

Notes:

1) XMMIN and XMMAX are the minimum and maximum return-to-service intervals, respectively.
2) Numbers of Inspections, Failures, and RFC Cycles are for the aggregate 32-specimen population.
3) The first 2,000 cycles of each specimen are not counted as "RFC Cycles" since they occur before the original design life and first RFC inspection.
4) If all specimens were allowed to fail, 622,935 RFC cycles would be "achieved." Thus, "percent population usage" is computed by dividing RFC cycles x 100% by 622,935.

imposition results in a more forgiving RFC procedure and a "flatter curve" of RFC costs versus F_a.

Table 10-10, with its maximum inspection interval of 2000 cycles, appears to improve the RFC Procedure No. 4. This can be seen by comparing the RFC costs per cycle in Tables 10-10 and 10-7. Since an optimum probabilistic update procedure should utilize maximum flexibility, the fact that restrictions of the inspection interval improved performance indicates that the probabilistic update RFC procedures used herein can be improved.

10.2.3 Discussion of Results

The comparisons made in Section 10.2.2 indicate that, especially under such unfavorable conditions as an overly optimistic initial life prediction, deterministic or probabilistic update, combined with enough flexibility in the RFC procedure to respond to field problems, can have a marked improvement on the performance of the RFC system. The fact that the probabilistic procedure did not out perform the deterministic update procedure is not considered significant, but rather is an artifact of employing a procedure designed for large, low failure rate fleets to a small high failure rate specimen population. Some further studies have verified this belief by indicating that the population size of 32 was not enough to permit substantial improvement of the probabilistic update results with either more (1) lead-the-fleet cycles, or (2) accuracy in the initial life prediction (a versus N) curve.

It is verified by the RFC verification tests that RFC, with some reasonable feedback and updating flexibility, can be successful for making return-to-service decisions for components similar to the TF-33 third stage

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turbine disk. This RFC verification test evaluation indicates that the probabilistic update procedures developed herein can be further improved; it is also clear that such improvements cannot be accurately verified using small specimen populations, but will require simulation of large fleets and actual field experience to truly evaluate optimized RFC systems designed for large, low-failure rate fleets.

11.0 CONCLUSIONS

- The inspection reliabilty of three eddy current inspections has been determined and found to be adequate for an RFC procedure whose critical crack size is similar to the bolt holes in the TF-33 third stage disk.

- The preinspection material quality can be determined through analysis of non destructive inspection results.

- Large potential cost savings have been demonstrated through RFC simulation and verified by laboratory testing.

- Four RFC procedures have been developed, tested using Monte Carlo simulation, and shown to result in cost savings.

- Sensitivity analyses with Monte Carlo simulations show that the optimum RFC procedure should include both a specific component feedback and rejection decision update capability.

- The laboratory verification test program has demonstrated that a variety of RFC procedures are very cost effective.

11-1

12.0 REFERENCES

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APPENDIX A

A BRIEF INTRODUCTION TO
MONTE CARLO SIMULATION

Monte Carlo simulation is a method for solving complicated technical probability problems, such as the evaluation of a Retirement-For-Cause procedure in the face of systematic errors and random variation and uncertainties of processed data, which cannot be solved directly without questionable approximations. In a Monte Carlo solution, the given problem is replaced by a mathematical or engineering model $y = f(x_i; a_i)$ which can be solved numerically. This engineering model is called a simulation, the x_i are variables and the a_i are constants. Many of the engineering parameters of the problem are random variables. In the simulation, the random variables X are represented not by single-point typical or worst-case values but by specific cumulative distributions $F_X(x)$. Then a value is specified for each variable by choosing a number at random from its corresponding distribution. Figure A-1 shows the procedure for selecting each X_i at random. Each set of values, when substituted into $y = f(x_i; a_i)$ determines an answer Y (one data point) used to help estimate F(y), the desired probability distribution of the dependent variable. This single data point constitutes one trial. Accurate calculation of F(y) can be obtained by performing a large number of trials with the aid of a computer. In summary, Monte Carlo simulation is an artificial generation of a statistical sample of Y, which in this case represents, first, failure times or ages of a disk population and, second, the outcome of events and financial losses and gains of the RFC procedure under investigation. In order to calculate these RFC gains, it is necessary to embed software to simulate all aspects of actual and estimated fatigue perfor-
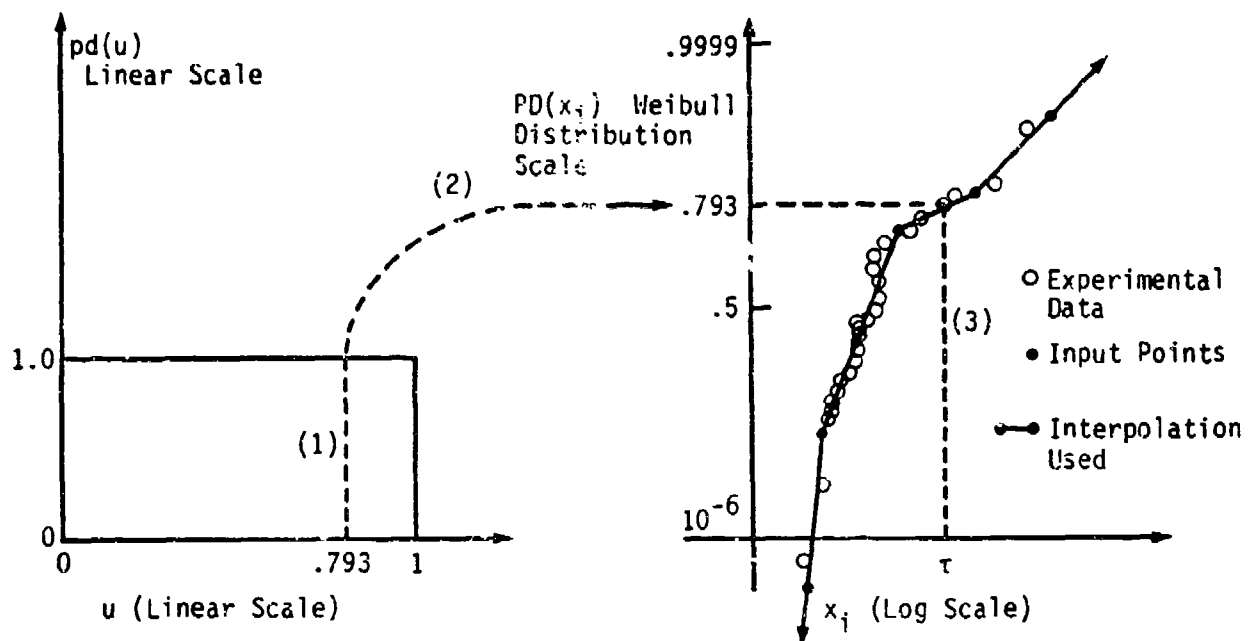
1. Use uniform distribution random-number generator to select a value of "u" (e.g., u = 0.793)

2. Enter cumulative distribution scale at u where $u = PD(x_i(u))$

3. Using the piecewise Weibull interpolation, calculate τ, where $\tau = x_i(u)$

For the example shown above, $P(x_i < \tau) = 0.793$. In general,

$$P(x_i < \tau) = P(x_i < x_i(u)) = PD(x_i(u)) = u$$

Figure A-1 – Monte Carlo Simulation Procedure Used to Select a Value of One of the Input Random Variables, x_i.

mance of each hole in each disk within the Monte Carlo simulation computer program. Each trial yields an RFC gain or loss; enough trials yield a probability distribution, with the desired scope and accuracy, of the average RFC gain, $\bar{G}$.

The Monte Carlo method is a brute force numerical approach which has essentially no limitations with regard to the complexity and scope of the problems it can attack. The method's major drawback is that an extremely large amount of computer programming and execution time and cost may be necessary to generate enough samples of Y to obtain the desired accuracy at the upper and lower portions (tails) of the probability distributions. To summarize with a reasonable analogy, the Monte Carlo method is to probabilistic analysis what the Finite Element method is to stress analysis.

APPENDIX C
DETAILS OF THE PROBABILISTIC- OR
STATISTICAL-UPDATE ANALYSIS OF THE FLEET

It is anticipated that for most components, the design and RFC analyses will be accurate enough to be used throughout the life of the fleet and not require major changes. However, given the complexity of the physical phenomena involved (such as fatigue crack growth and initiation) and the procedures themselves (with varying degrees of inspection uncertainty and complex constraints), occasional surprises will occur. To prepare for these inevitable problems (and also, for trouble-free components, to allow for gradual relaxation of the usually conservative procedures as field data become available) a nearly-continuous statistical update of the RFC procedure, based on field performance, is desireable. For the current studies, such a procedure has been developed. While the procedure does not consider every aspect of the overall RFC problem for a multi-component and multi-failure-mode engine, it captures the major characteristics of an effective statistical feedback loop based upon field performance.

The developed procedure is a trade-off between (1) providing effective feedback into the RFC decision-making algorithm and (2) providing enough simplicity to allow development, software incorporation, and detailed evaluation within the limitations of these studies. The major capabilities and limitations are listed in Appendix B in the comment cards of the applicable PERFCT computer program.

Figure C-1 was previously described in the text (Figure 7-6) and is reproduced here for convenience. It illustrates the major aspects of the
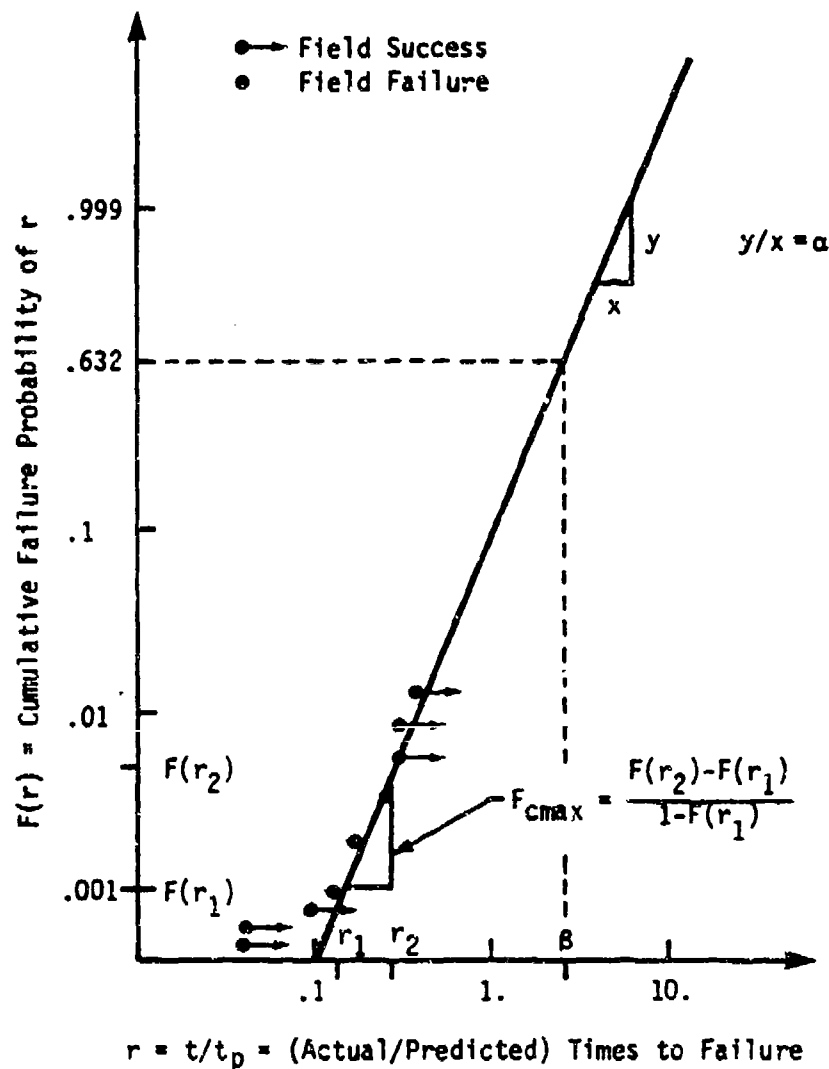
Figure C-1 - Schematic Guide to Procedure for Setting Maximum Time (t_2) to Next RFC Inspection. Past Experience, Field Failures, and Successes are Used to Estimate α and β and to Continually Update These Estimates. Then, at any Given Time, with Known α, β, t_1, t_p, and Maximum Allowable Failure Probability F_{cmax}, we can Calculate (r_2, t_2) Graphically as Above, or from Eq. (7-175).

statistical update procedure. A two-parameter Weibull distribution is used to characterize the field performance data. This distribution was chosen mainly for its ease of mathematical application to the problem and, in part, based upon its traditional use to model certain fatigue processes. However, sensitivity studies indicate that any reasonable two-parameter distribution, used in the same way as the Weibull distribution is herein, will provide very similar results since two-parameters are quite adequate to fit a probability distribution, such as shown in Figure C-1, to mainly "success data" and very few failures.

One qualification for the utilized two-parameter Weibull distribution is that it "overreacts" if high-time outliers are present in the set of fatigue data under analysis. This problem is illustrated in detail in Reference (8). This outlier problem can <u>not</u> impact the typical RFC procedure adversely since the outliers must occur at values of r (= actual/predicted times to failure) much greater than 1. This implies the use of life-based safety factors significantly less than 1, an absurd practice for life extension decisions of critical components. A second and more important qualification of the Weibull distribution is that it permits only <u>monotonic</u> changes in failure rate with time $\lambda(t)$. Thus, the bathtub curve in Figure 7-7 cannot be modeled with the Weibull model. More complex models can be used but it would be helpful to transform them into a "Weibull-like" equation to allow use of the simplified procedures described next.

The two-parameter Weibull distribution is expressed as

$$F(r) = 1 - \exp[-(r/\beta)^{\alpha}]; \ r, \alpha, \beta > 0 \tag{C-1}$$

C-3

where F is the unconditional cumulative failure probability of a component before age t, where $t = rt_p$. t_p and r are defined in Figure C-1 as the predicted time to failure after inspection and as the ratio of allowable (or actual) to predicted life. α is the shape- or scatter-parameter which is related to the standard deviation "s" of the log of life-prediction parameter "r" through

$$\alpha = 0.556/s(\log r)$$

Finally, β is the scale parameter representing the near-mean value of r where $F(\beta) = 1 - 1/e = 0.632$.

An estimate of both α and β are required before the first RFC decision is made. These prior estimates will be primarily based upon laboratory-observed scatter and mean life performance which are suitably modified to account for other in-service sources of variation anticipated during the RFC process. The best method of making prior estimates of α and β is to use PERFCT to perform a Monte Carlo simulation of the fleet under realistic conditions but for fleet sizes and/or engine lifetimes much greater than actual, in order to create some simulated failures on the computer. Since the simulation can be constructed to contain most of the expected source of life prediction variation, the α avϕ β values can be taken directly from the simulation.

The most important pre-RFC parameter estimation is that of parameter α since it (AL) is used during the entire application of RFC unless and until a failure occurs. BET, the prior estimate of β is also used until the field-data-based estimate (8, 9),

C-4

$$BETM = \hat{\beta} = \left[\sum_{\substack{all \\ components}} r_i{}^{AL}\Big/NFF \right]^{1/AL} \tag{C-2}$$

(where NFF is the total number of failures or 1, whichever is greater) pro-
duces a value larger than the prior estimate, BET. Thus, the prior estimate
is always used to compute the failure probabilities until and unless it is
proven to be too conservative by enough successful fleet performance.

If one or more failures occur, it is possible to estimate α from the
field data. Based upon exhaustive studies referenced in (8), the maximum
likelihood estimate (MLE) method is used. These estimates are derived (9)
from the implicit equation

$$\frac{\sum\limits_{\substack{all \\ components}} r_i{}^{ALM} \ln r_i}{\sum\limits_{\substack{all \\ components}} r_i{}^{ALM}} - (1/ALM) - \sum_{\substack{all\ failed \\ components}} \ln r_j/NFF = 0 \tag{C-3}$$

where ALM is the MLE of α and the implicit solution is conducted with a
successive-approximation numerical method in Subroutine MLE in PERFCT
(Appendix B).

Since the hopefully small number of field failures are not adequate to
characterize α very accurately, the procedure has been designed to use a
weighted average (ALU) of the field data and the prior estimates of α, ALM and
AL, respectively. The estimate of α that is actually used is calculated from

$$ALU = \sqrt{(W1 + W2)/(W1/ALM^2 + W2/AL^2)}, \qquad (C-4)$$

where W1 and W2 are weights computed from W1 = NFF and W2 = XEFF. Here, XEFF is specified by the analyst as the "equivalent" number of failures in the heterogeneous data used in the AL prior estimate. Great confidence in this prior estimate might be reflected by a value like XEFF = 10., while a "guess-timate" value of AL might result in a specification of XEFF less than one. Since α is inversely proportional to s(log r) and since the accuracy of estimating s(log r) is approximately proportional to the square root of the number of failures in the utilized data set (8), Equation (C-4) is a statistically correct weighting of two estimates of α according to their respective variances.

The actually used estimate of β, BETU, is then computed (9) from

$$BETU = \left[\sum_{\substack{all \\ components}} r_i^{ALU} / NFF \right]^{1/ALU} \qquad (C-5)$$

C.1   Conditional Failure Probability Estimate

Once the estimates of α and β, ALU and BETU, have been decided upon, it remains to compute the amount of life extension permitted for a given allowable maximum failure probability F_{cmax}. It would be incorrect to simply substitute F_{cmax}, ALU, and BETU for the parameters in Equation (C-1) and solve for the value of r as the ratio of allowable-to-predicted life for the next extension. This is because Equation (C-1) gives the unconditional cumulative

failure probability for a part cycled from 0 to $t = rt_p$. As shown in Figure C-1 it is the conditional failure probability that is of interest given that the part has lasted to the present time, t_1, at which the RFC decision is made. The conditional probability of failure F_c between times t_1 (the present) and t_2 is given by

$$F_c = (F(r_2) - F(r_1))/(1 - F(r_1)) \qquad (C-6)$$

where $r_2 = t_2/t_p$ and $r_1 = t_1/t_p$. Using equations (C-1) and (C-6) to solve t_2 we obtain $\hat{N}_{allow} = t_2 = r_2 t_p$, where

$$r_2 = [r_1^{ALU} + BETU^{ALU} \log(1/(1-F_{cmax}))]^{1/ALU} \qquad (C-7)$$

Since the disks in general cannot be inspected exactly at time $\hat{N}_{allow} = t_2$, the next lower inspection time is scheduled using Equations (3-18) and (3-19) in the text.

The above "update" or "field-feedback" procedure has worked very well. It performs almost as well as the constant safety factor procedure under optimum safety factor conditions where the RFC procedure contains no major errors and is applied often (i.e., every 750 cycles). Most importantly, the update procedure provides for effective RFC in the presence of much longer inspection intervals or of errors that totally devastate the no-feedback, constant-safety factor procedures.

Several areas of improvement have already been identified for the update procedure. The simplest and most obvious improvement is to apply the

C-7

formula more frequently than it is now. Specifically, instead of updating every minimum inspection interval, it is recommended that the frequency of update be increased at least to the point where an update is conducted immediately after any field failure. This higher update frequency should produce optimum results at least as good as those produced by the "perfect-safety-factor" deterministic procedure. It is anticipated that any actual application of the probabilistic update technique would be conducted nearly continuously. The initial development herein did not provide for continuous update because of prohibitive computer costs for the extensive series of simulations we conducted.

The next three capabilities that should be incorporated are to (1) include feedback from <u>destructive</u> examination of retired components, (2) allow for more than one component and type of failure/inspection site to be included in the conditional failure probability calculations, and (3) permit different "r" distributions to be used for old and young components, where advisable. While the mathematics to add these capabilities are very straightforward, the bookkeeping necessary to include them in a computer program and, especially, to simulate them over the history of the fleet is expected to be somewhat tedious and involve significant execution-time computer costs.

One of the favorable aspects of the chosen statistical update procedure, is that it allows all knowledge of the phenomena and field experience to be directly incorporated into the RFC decision making process. Further, the graphical interpretation of the "actual/predicted" procedure in Figure C-1 is very similar to that used by gas turbine and other vendors who design and specify allowable life for life-limited, fatigue, or wearout-critical compo-

nents. Finally, the update procedure, while requiring the <u>initial</u> choice of a safety factor or its equivalent, acts automatically to optimize the safety factor as field data become available.

APPENDIX E
PERFCT OUTPUT

The most salient output of the PERFCT program's simulations of disk
fleets (Section 4) and test units (Section 5) is presented here as a series of
Tables. Each table corresponds to a data point in the figures of Sections 4
or 5, plotting average RFC dollar gain ($\overline{G}$) versus safety factor (SF) or
failure probability (F_{cmax}). The tabulated output includes subfleet introduc-
tion times and numbers of engines, inspections, replacements, and failures.

E-1

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=1.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2248	466	7	-2905.
2	750.	375	2250	432	4	13848.
3	1500.	375	2250	434	2	24480.
4	2250.	375	2250	438	3	19016.
TOTALS:		1500	8998	1770	16	13610.

E-2

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=1.50.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	593	2	21241.
2	750.	375	2250	548	1	27497.
3	1500.	375	2249	508	1	28301.
4	2250.	375	2250	568	1	27103.
TOTALS:		1500	8998	2217	5	26035.

E-3

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET-XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	680	0	30177.
2	750.	375	2249	660	0	30577.
3	1500.	375	2250	677	1	24941.
4	2250.	375	2250	651	1	25443.
TOTALS:		1500	8998	2668	2	27784.

E-4

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.80.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	832	0	27137.
2	750.	375	2250	837	0	27056.
3	1500.	375	2250	796	0	27876.
4	2250.	375	2249	777	1	22903.
TOTALS:		1500	8998	3242	1	26243.

E-5

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=3.30.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	903	0	25717.
2	750.	375	2250	899	0	25816.
3	1500.	375	2250	866	0	26476.
4	2250.	375	2249	864	0	26497.
TOTALS:		1500	8998	3532	0	26127.

E-6

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	957	0	24637.
2	750.	375	2250	952	0	24756.
3	1500.	375	2250	927	0	25256.
4	2250.	375	2249	945	0	24877.
TOTALS:		1500	8998	3781	0	24882.

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=5.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1017	0	23437.
2	750.	375	2250	1009	0	23617.
3	1500.	375	2250	1012	0	23556.
4	2250.	375	2248	1034	0	23078.
TOTALS:		1500	8997	4072	0	23422.

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1075	0	22277.
2	750.	375	2250	1063	0	22137.
3	1500.	375	2250	1043	0	22936.
4	2250.	375	2248	1118	0	21398.
TOTALS:		1500	8997	4319	0	22187.

1500 DISK PERFECT CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH PERFECTION.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 52815. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	524	88	0	42933.
2	750.	375	495	72	0	43288.
3	1500.	375	508	79	0	43141.
4	2250.	375	492	72	0	43290.
TOTALS:		1500	2019	311	0	43163.

E-10

1500 DISK FAIL CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH PERFECTION.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 52813. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	566	89	89	-432077.
2	750.	375	529	71	71	-335638.
3	1500.	375	533	73	73	-346366.
4	2250.	375	531	75	75	-356960.
TOTALS:		1500	2159	308	308	-367760.

E-11

1500 DISK STND CASE-500 KHZ OUTSIDE LAB INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   759. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	533	1	27778.
2	750.	375	2250	475	4	12810.
3	1500.	375	2250	517	0	33455.
4	2250.	375	2249	526	0	33255.
TOTALS:		1500	8998	2061	5	26825.

E-12

1500 DISK STND CASE-500 KHZ OUTSIDE LAB INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.60.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	631	1	25018.
2	750.	375	2250	578	2	21561.
3	1500.	375	2249	594	0	31896.
4	2250.	375	2250	608	1	26302.
TOTALS:		1500	8998	2411	4	26399.

E-13

1500 DISK STND CASE-500 KHZ OUTSIDE LAB INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=3.30.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	688	1	24678.
2	750.	375	2250	624	2	20661.
3	1500.	375	2249	629	0	31196.
4	2250.	375	2250	615	1	26162.
TOTALS:		1500	8798	2556	4	25674.

E-14

1500 DISK STND CASE-500 KHZ OUTSIDE LAB INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	⁻24	1	23958.
2	750.	375	2249	654	1	25357.
3	1500.	375	2250	686	0	30075.
4	2250.	375	2250	668	0	30435.
TOTALS:		1500	8998	2732	2	27457.

E-18

1500 DISK STND CASE-500 KHZ OUTSIDE LAB INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=5.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	766	0	28456.
2	750.	375	2249	759	1	23257.
3	1500.	375	2250	727	0	29255.
4	2250.	375	2250	755	0	28696.
TOTALS:		1500	8998	3067	1	27416.

E-16

1500 DISK STND CASE-500 KHZ OUTSIDE LAB INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLL/ GAIN PER ENGINE
1	0.	375	2248	795	0	27857.
2	750.	375	2250	792	1	22617.
3	1500.	375	2250	785	0	28096.
4	2250.	375	2250	789	0	28016.
TOTALS:		1500	8998	3161	1	26646.

E-17

1500 DISK STND CASE- 1 MHZ OUTSIDE LAB INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	667	1	25099.
2	750.	375	2249	660	0	30576.
3	1500.	375	2250	686	0	30076.
4	2250.	375	2250	653	1	25403.
TOTALS:		1500	8998	2666	2	27788.

E-18

1500 DISK STND CASE- 1 MHZ OUTSIDE LAB INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.60.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2248	788	0	27997.
2	750.	375	2250	782	0	28156.
3	1500.	375	2250	791	0	27976.
4	2250.	375	2250	782	0	28156.
TOTALS:		1500	8998	3143	0	28071.

E-19

1500 DISK STND CASE- 1 MHZ OUTSIDE LAB INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=3.30.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2248	843	0	26897.
2	750.	375	2250	831	0	27176.
3	1500.	375	2250	825	0	27296.
4	2250.	375	2250	812	0	27556.
TOTALS:		1500	8998	3311	0	27231.

E-20

1500 DISK STND CASE- 1 MHZ OUTSIDE LAB INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	909	0	25597.
2	750.	375	2250	880	0	26196.
3	1500.	375	2250	893	0	25936.
4	2250.	375	2249	865	0	26476.
TOTALS:		1500	8998	3547	0	26051.

E-21

1500 DISK STND CASE- 1 MHZ OUTSIDE LAB INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=5.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	972	0	24337.
2	750.	375	2250	926	0	25276.
3	1500.	375	2250	939	0	25016.
4	2250.	375	2249	916	0	25456.
TOTALS:		1500	8998	3753	0	25021.

E-22

1500 DISK STND CASE- 1 MHZ OUTSIDE LAB INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1005	0	23677.
2	750.	375	2250	960	0	24596.
3	1500.	375	2250	955	0	24696.
4	2250.	375	2249	975	0	24277.
TOTALS:		1500	8998	3895	0	24311.

E-23

1500 DISK STND CASE-HYPOTHETICAL INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=1.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	176	5	13587.
2	750.	375	2250	171	5	13726.
3	1500.	375	2250	149	2	30159.
4	2250.	375	2250	149	7	3507.
TOTALS:		1500	8999	645	19	15245.

E-24

1500 DISK STND CASE-HYPOTHETICAL INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=1.50.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	244	3	22882.
2	750.	375	2250	236	1	33739.
3	1500.	375	2250	210	2	28936.
4	2250.	375	2250	219	4	18093.
TOTALS:		1500	8999	909	10	25917.

1500 DISK STND CASE-HYPOTHETICAL INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	310	2	26900.
2	750.	375	2250	310	1	32279.
3	1500.	375	2250	283	2	27468.
4	2250.	375	2249	283	2	27450.
TOTALS:		1500	8998	1186	7	28524.

1500 DISK STND CASE-HYPOTHETICAL INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.60.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2248	415	1	30119.
2	750.	375	2250	428	1	29920.
3	1500.	375	2250	408	0	35635.
4	2250.	375	2250	427	0	35255.
TOTALS:		1500	8998	1678	2	32732.

1500 DISK STND CASE-HYPOTHETICAL INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=3.30.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.30   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	504	1	28358.
2	750.	375	2250	490	0	33995.
3	1500.	375	2250	450	0	34795.
4	2250.	375	2249	481	1	28823.
TOTALS:		1500	8998	1925	2	31493.

E-28

1500 DISK STND CASE-HYPOTHETICAL INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	617	0	31436.
2	750.	375	2250	535	0	33096.
3	1500.	375	2249	560	0	32576.
4	2250.	375	2250	560	1	27262.
TOTALS:		1500	8998	2272	1	31092.

E-29

1500 DISK STND CASE-HYPOTHETICAL INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=5.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	680	0	30176.
2	750.	375	2249	651	0	30556.
3	1500.	375	2250	696	0	29876.
4	2250.	375	2250	633	0	31135.
TOTALS:		1500	8998	2670	0	30436.

E-30

1500 DISK STND CASE-HYPOTHETICAL INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2248	758	0	28597.
2	750.	375	2250	748	0	28836.
3	1500.	375	2250	758	0	28636.
4	2250.	375	2250	755	0	28696.
TOTALS:		1500	8998	3019	0	28691.

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 1526C.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	943	479	5	8233.
2	750.	375	875	423	4	14759.
3	1500.	375	861	373	4	15778.
4	2250.	375	916	450	4	14163.
TOTALS:		1500	3595	1725	17	13233.

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.20.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	937	494	5	7936.
2	750.	375	873	432	4	14556.
3	1500.	375	866	396	4	15296.
4	2250.	375	909	455	3	19413.
TOTALS:		1500	3585	1777	16	14306.

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.80.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	900	498	5	7876.
2	750.	375	852	448	5	8957.
3	1500.	375	908	484	3	10848.
4	2250.	375	872	455	2	24772.
TOTALS:		1500	3532	1885	15	13113.

E-34

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=3.30.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	1034	549	4	12117.
2	750.	375	1003	505	2	23700.
3	1500.	375	1062	556	0	33310.
4	2250.	375	1037	527	0	33903.
TOTALS:		1500	4136	2137	6	25757.

E-35

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	1229	650	1	25983.
2	750.	375	1214	599	1	27034.
3	1500.	375	1250	652	0	31290.
4	2250.	375	1197	590	0	32558.
TOTALS:		1500	4890	2491	2	29216.

E-36

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=5.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	1455	800	0	28181.
2	750.	375	1427	770	0	28035.
3	1500.	375	1429	781	0	28614.
4	2250.	375	1430	789	0	28454.
TOTALS:		1500	5741	3140	0	28521.

1500 DISK *STND* CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0003.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1196	0	19857.
2	750.	375	2250	1196	0	19877.
3	1500.	375	2249	1181	0	20157.
4	2250.	375	2249	1179	0	20197.
TOTALS:		1500	8997	4752	0	20022.

1500 DISK *STND* CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1194	0	19897.
2	750.	375	2250	1195	0	19897.
3	1500.	375	2249	1182	0	20137.
4	2250.	375	2249	1177	0	20237.
TOTALS:		1500	8997	4748	0	20042.

1500 DISK *STND* CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0020.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1194	0	19897.
2	750.	375	2250	1195	0	19897.
3	1500.	375	2249	1182	0	20137.
4	2250.	375	2249	1177	0	20237.
TOTALS:		1500	8997	4748	0	20042.

E-40

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0050.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1172	0	20357.
2	750.	375	2250	1186	0	20077.
3	1500.	375	2249	1154	0	20697.
4	2250.	375	2249	1157	0	20637.
TOTALS:		1500	8997	4669	0	20437.

E-41

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0100.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1135	0	21077.
2	750.	375	2250	1144	0	20917.
3	1500.	375	2249	1110	0	21577.
4	2250.	375	2249	1097	0	21037.
TOTALS:		1500	8997	4486	0	21352.

E-42

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0200.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1072	0	22337.
2	750.	375	2250	1012	0	23557.
3	1500.	375	2250	733	0	25136.
4	2250.	375	2248	893	0	25898.
TOTALS:		1500	8997	3910	0	24232.

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0500.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	824	0	27297.
2	750.	375	2250	750	0	28790.
3	1500.	375	2250	556	1	27363.
4	2250.	375	2249	466	2	23010.
TOTALS:		1500	8998	2596	3	26819.

E-44

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.1000.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	669	0	30397.
2	750.	375	2250	543	6	969.
3	1500.	375	2250	424	0	35316.
4	2250.	375	2249	338	6	5016.
TOTALS:		1500	8998	1974	12	17924.

E-45

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0001.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1193	0	19859.
2	750.	375	2250	1196	0	19877.
3	1500.	375	2249	1181	0	20157.
4	2250.	375	2249	1179	0	20200.
TOTALS:		1500	8997	4752	0	20023.

E-46

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0003.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 15260.   1.000   4.00   1.00   1   3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1196	0	19859.
2	750.	375	2250	1196	0	19877.
3	1500.	375	2249	1181	0	20157.
4	2250.	375	2249	1179	0	20200.
TOTALS:		1500	8997	4752	0	20023.

E-47

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	1789	1066	0	22704.
2	750.	375	1784	1038	0	23285.
3	1500.	375	1771	1002	0	24012.
4	2250.	375	1773	1032	0	23394.
TOTALS:		1500	7117	4138	0	23349.

E-48

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0020.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	1512	927	0	25615.
2	750.	375	1514	935	0	25489.
3	1500.	375	1490	878	0	26642.
4	2250.	375	1519	931	0	25566.
TOTALS:		1500	6035	3671	0	25828.

E-49

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0050.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	1240	783	0	28657.
2	750.	375	1240	771	1	23583.
3	1500.	375	1236	748	0	29377.
4	2250.	375	1228	753	0	29282.
TOTALS:		1500	4944	3055	1	27725.

E-50

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0100.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	1016	626	4	10588.
2	750.	375	1101	705	1	24977.
3	1500.	375	1260	780	0	28724.
4	2250.	375	1224	762	0	29104.
TOTALS:		1500	4601	2873	5	23348.

E-51

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0200.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 15260. 1.000   4.90   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	868	498	5	7894.
2	750.	375	1019	625	2	21292.
3	1500.	375	1032	630	0	31846.
4	2250.	375	1008	609	0	32279.
TOTALS:		1500	3927	2362	7	23328.

E-52

1500 DISK STND CASE-HI RES PROBE INSP. (AHAT=.125)
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	694	0	29897.
2	750.	375	2249	679	0	30197.
3	1500.	375	2250	686	0	30076.
4	2250.	375	2250	680	1	24863.
TOTALS:		1500	8998	2739	1	28758.

E-53

1500 DISK STND CASE-HI RES PROBE INSP. (AHAT=.125)
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	957	0	24637.
2	750.	375	2250	952	0	24756.
3	1500.	375	2250	927	0	25256.
4	2250.	375	2249	945	0	24877.
TOTALS:		1500	8998	3781	0	24882.

E-54

1500 DISK STND CASE-HI RES PROBE INSP. (AHAT=.125)
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1075	0	22277.
2	750.	375	2250	1083	0	22137.
3	1500.	375	2250	1043	0	22936.
4	2250.	375	2248	1118	0	21398.
TOTALS:		1500	8997	4319	0	22187.

E-55

1500 DISK STND CASE-HI RES PROBE INSP. (AHAT=.500)
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	680	0	30177.
2	750.	375	2249	660	0	30577.
3	1500.	375	2250	677	1	24944.
4	2250.	375	2250	651	1	25443.
TOTALS:		1500	8998	2668	2	27784.

E-56

1500 DISK STND CASE-HI RES PROBE INSP. (AHAT=.500)
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	957	0	24637.
2	750.	375	2250	952	0	24756.
3	1500.	375	2250	927	0	25256.
4	2250.	375	2249	945	0	24877.
TOTALS:		1500	8998	3781	0	24882.

E-57

1500 DISK STND CASE-HI RES PROBE INSP. (AHAT=.500)
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1075	0	22277.
2	750.	375	2250	1083	0	22137.
3	1500.	375	2250	1043	0	22936.
4	2250.	375	2248	1118	0	21598.
TOTALS:		1500	8997	4319	0	22187.

E-58

1500 DISK STND CASE-HI RES PROBE INSP. (AHAT=HUGE)
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	680	0	30177.
2	750.	375	2249	660	0	30577.
3	1500.	375	2250	677	1	24941.
4	2250.	375	2250	651	1	25443.
TOTALS:		1500	8998	2668	2	27784.

E-59

1500 DISK STND CASE-HI RES PROBE INSP. (AHAT=HUGE)
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	957	0	24637.
2	750.	375	2250	952	0	24756.
3	1500.	375	2250	927	0	25256.
4	2250.	375	2249	945	0	24877.
TOTALS:		1500	8998	3781	0	24882.

E-60

1500 DISK STND CASE-HI RES PROBE INSP. (AHAT=HUGE)
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1075	0	22277.
2	750.	375	2250	1083	0	22137.
3	1500.	375	2250	1043	0	22936.
4	2250.	375	2248	1118	0	21398.
TOTALS:		1500	8997	4319	0	22187.

E-61

1500 5-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	391	1	30654.
2	750.	375	2250	363	4	15232.
3	1500.	375	2250	400	3	19771.
4	2250.	375	2250	380	1	30861.
TOTALS:		1500	9000	1534	9	24129.

E-62

1500 5-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	583	0	32135.
2	750.	375	2250	590	0	31995.
3	1500.	375	2250	584	4	10782.
4	2250.	375	2250	601	2	21103.
TOTALS:		1500	9000	2358	6	24004.

E-63

1500 5-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	743	0	28935.
2	750.	375	2250	694	0	29915.
3	1500.	375	2250	685	3	14077.
4	2250.	375	2250	687	1	24722.
TOTALS:		1500	9000	2809	4	24412.

E-64

1500 5-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR, SF=8.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	795	0	27896.
2	750.	375	2250	748	1	23497.
3	1500.	375	2250	786	1	22741.
4	2250.	375	2250	762	1	23222.
TOTALS:		1500	9000	3091	3	24339.

E-65

1500 2-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	176	3	24307.
2	750.	375	2250	156	3	24671.
3	1500.	375	2249	162	7	3158.
4	2250.	375	2250	188	4	18673.
TOTALS:		1500	8999	682	17	17702.

E-66

1500 2-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	264	2	27862.
2	750.	375	2250	262	2	27898.
3	1500.	375	2249	257	2	27964.
4	2250.	375	2250	280	4	16072.
TOTALS:		1500	8999	1063	10	25149.

E-67

1500 2-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	329	2	26562.
2	750.	375	2249	312	0	37534.
3	1500.	375	2250	332	0	37154.
4	2250.	375	2250	353	3	20733.
TOTALS:		1500	8999	1326	5	30496.

E-68

1500 2-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=8.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	372	1	31017.
2	750.	375	2249	366	0	36454.
3	1500.	375	2250	370	1	31047.
4	2250.	375	2250	377	2	25596.
TOTALS:		1500	8999	1485	4	31029.

E-69

1500 1-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	103	3	2711.
2	750.	375	2250	90	7	4619.
3	1500.	375	2250	105	7	4355.
4	2250.	375	2250	99	9	-6207.
TOTALS:		1500	9000	397	26	7119.

1500 1-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	159	3	24615.
2	750.	375	2250	128	6	9232.
3	1500.	375	2250	153	5	14066.
4	2250.	375	2250	154	7	3362.
TOTALS:		1500	9000	594	21	12819.

1500 1-HOLE DISK STND CASE-H1 RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	185	2	29408.
2	750.	375	2250	169	2	29721.
3	1500.	375	2250	179	5	13548.
4	2250.	375	2250	181	9	-7850.
TOTALS:		1500	9000	714	18	16207.

1500 1-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=9.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	226	1	53936.
2	750.	375	2250	213	3	23508.
3	1500.	375	2250	199	3	23807.
4	2250.	375	2250	238	7	1688.
TOTALS:		1500	9000	876	14	20734.

1500 5-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	878	0	26236.
2	750.	375	2250	852	1	21418.
3	1500.	375	2250	850	1	21462.
4	2250.	375	2250	858	0	26635.
TOTALS:		1500	9000	3438	2	23938.

1500 5-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0050.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	850	0	26796.
2	750.	375	2250	830	1	21857.
3	1500.	375	2250	803	0	27736.
4	2250.	375	2250	779	1	22882.
TOTALS:		1500	9000	3262	2	24818.

1500 5-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0200.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.09   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	727	0	29255.
2	750.	375	2250	643	0	30935.
3	1500.	375	2250	542	4	11600.
4	2250.	375	2250	452	4	13446.
TOTALS:		1500	9000	2364	8	21309.

1500 2-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	455	1	29357.
2	750.	375	2249	442	0	34934.
3	1500.	375	2250	453	0	34734.
4	2250.	375	2250	458	2	23976.
TOTALS:		1500	8999	1808	3	30750.

1500 2-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0050.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	431	1	29837.
2	750.	375	2249	402	1	30407.
3	1500.	375	2250	374	0	36314.
4	2250.	375	2250	385	2	25430.
TOTALS:		1500	8999	1592	4	30499.

1500 2-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0200.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	327	2	28602.
2	750.	375	2250	287	2	27413.
3	1500.	375	2249	261	4	17200.
4	2250.	375	2250	289	8	-4474.
TOTALS:		1500	8999	1164	16	16635.

E-79

1500 1-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	269	1	33076.
2	750.	375	2250	249	3	22766.
3	1500.	375	2250	263	3	22527.
4	2250.	375	2250	277	6	6241.
TOTALS:		1500	9000	1058	13	21158.

E-80

1500 1-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0050.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	259	1	33276.
2	750.	375	2250	239	3	22987.
3	1500.	375	2250	261	3	22567.
4	2250.	375	2250	269	6	6401.
TOTALS:		1500	9000	1028	13	21308.

E-81

1500 1-HOLE DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0200.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	233	2	28448.
2	750.	375	2250	213	3	23507.
3	1500.	375	2250	216	3	23467.
4	2250.	375	2250	246	7	1527.
TOTALS:		1500	9000	908	15	19237.

E-82

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5087. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	634	1	25759.
2	750.	375	2249	598	0	31817.
3	1500.	375	2250	626	1	25961.
4	2250.	375	2250	615	1	26163.
TOTALS:		1500	8998	2473	3	27425.

E-83

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.80.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5087. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	813	0	27517.
2	750.	375	2250	833	0	27136.
3	1500.	375	2250	723	0	28136.
4	2250.	375	2249	739	1	22672.
TOTALS:		1500	8998	3218	1	26365.

E-84

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=3.30.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5087. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	912	0	25537.
2	750.	375	2250	893	0	25936.
3	1500.	375	2250	883	0	26136.
4	2250.	375	2249	849	0	26797.
TOTALS:		1500	8998	3537	0	26192.

E-85

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5087. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	993	0	23917.
2	750.	375	2250	970	0	24397.
3	1500.	375	2250	974	0	24316.
4	2250.	375	2248	1015	0	23458.
TOTALS:		1500	8997	3952	0	24022.

E-86

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5087. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1135	0	21077.
2	750.	375	2250	1135	0	21097.
3	1500.	375	2249	1101	0	21757.
4	2250.	375	2249	1137	0	21037.
TOTALS:		1500	8997	4508	0	21242.

E-87

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 45731. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2248	814	0	27477.
2	750.	375	2250	795	0	27896.
3	1500.	375	2250	806	0	27676.
4	2250.	375	2250	762	1	23223.
TOTALS:		1500	8998	3177	1	26568.

E-88

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 45781. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	999	0	23797.
2	750.	375	2250	994	0	23916.
3	1500.	375	2250	962	0	24556.
4	2250.	375	2248	995	0	23857.
TOTALS:		1500	8997	3950	0	24032.

E-89

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 45781. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1075	0	22277.
2	750.	375	2250	1068	0	22437.
3	1500.	375	2250	1046	0	22876.
4	2250.	375	2248	1114	0	21478.
TOTALS:		1500	8997	4303	0	22267.

E-90

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   750. 45781. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4930	889	1	86043.
2	0.	200	4990	835	2	70855.
3	0.	200	4925	905	0	95500.
4	0.	200	5010	811	5	49651.
TOTALS:		800	19855	3440	8	77562.

E-91

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.80.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   750. 45781. 1.000   4.00   1.09   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4809	1009	0	60069.
2	0.	200	4830	985	2	71254.
3	0.	200	4381	940	1	83595.
4	0.	200	4856	967	3	62269.
TOTALS:		800	19376	3901	6	76302.

E-92

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=3.50.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   750. 45781. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4766	1055	3	57002.
2	0.	200	4768	1051	1	76155.
3	0.	200	.4806	1019	0	89845.
4	0.	200	4746	1030	1	76808.
TOTALS:		800	19086	4205	5	75667.

E-93

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.90.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   750. 45781. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4733	1067	0	86367.
2	0.	200	4607	1218	1	70360.
3	0.	200	4585	1241	1	66929.
4	0.	200	.4829	993	3	60957.
TOTALS:		800	18754	4539	5	71578.

E-94

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=5.00.

XMIN,XRMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   750. 45781.   1.000   4.00   1.00   1. 3

SUBFLEET IC #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4589	1235	1	69175.
2	0.	200	4541	1288	0	76710.
3	0.	200	4588	1239	2	59042.
4	0.	200	4604	1227	0	79723.
TOTALS:		800	18322	4989	3	71163.

E-95

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   750. 45781.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4375	1463	0	68376.
2	0.	200	4489	1347	0	74035.
3	0.	200	4501	1326	2	54779.
4	0.	200	4558	1261	0	77697.
TOTALS:		800	17923	5397	2	68722.

E-96

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 45781.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	920	518	46	-341945.
2	0.	200	830	433	39	-257571.
3	0.	200	958	465	43	-309325.
4	0.	200	797	402	45	-326109.
TOTALS:		800	3505	1818	172	-308738.

E-07

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.80.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 45781.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	911	560	50	-383912.
2	0.	200	777	429	37	-247369.
3	0.	200	891	486	42	-300339.
4	0.	200	734	427	46	-337246.
TOTALS:		800	3313	1902	175	-317217.

E-98

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=3.30.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 45781.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	872	565	44	-324323.
2	0.	200	740	450	39	-268476.
3	0.	200	911	555	49	-373697.
4	0.	200	808	461	37	-249237.
TOTALS:		800	3331	2031	169	-303931.

E-99

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 45781.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	1062	623	26	-146757.
2	0.	200	1043	600	28	-165402.
3	0.	200	1100	608	32	-206065.
4	0.	200	986	555	33	-213290.
TOTALS:		800	4196	2386	119	-182879.

E-100

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=5.00.

XNMIN,XNMAX,XNPI,SASS,AL,DET,XEFF,IPR=   500. 75000. 45781. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	1365	680	13	-20201.
2	0.	200	1311	611	16	-46877.
3	0.	200	1404	668	15	-39689.
4	0.	200	1337	656	18	-69014.
TOTALS:		800	5417	2615	62	-43945.

E-101

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 45781. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	1590	775	7	35088.
2	0.	200	1598	686	9	19545.
3	0.	200	1608	688	12	-10899.
4	0.	200	1518	697	9	18946.
TOTALS:		800	6314	2846	37	15670.

E-102

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   500. 45781. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	3399	1956	1	34645.
2	0.	200	4001	1848	0	49726.
3	0.	200	4058	1796	0	52418.
4	0.	200	3984	1869	0	48721.
TOTALS:		800	15942	7469	1	46378.

E-103

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0050.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   500. 45781.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4231	1590	0	61673.
2	0.	200	4228	1600	0	61374.
3	0.	200	4287	1542	0	64336.
4	0.	200	4299	1519	0	65103.
TOTALS:		800	17045	6251	0	63122.

E-104

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0200.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   500. 45781.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4837	976	3	61599.
2	0.	200	4931	882	4	56186.
3	0.	200	4882	925	4	53950.
4	0.	200	4989	829	0	98984.
TOTALS:		800	19639	3612	11	67680.

E-105

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 45781.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	2509	1577	0	65628.
2	0.	200	2442	1540	2	47360.
3	0.	200	2507	1548	1	56744.
4	0.	200	2492	1542	1	57648.
TOTALS:		800	9950	6207	4	56843.

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0050.

XNMIN,XMMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 45781.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	1891	1298	2	59065.
2	0.	200	1861	1289	2	59345.
3	0.	200	1892	1283	3	49973.
4	0.	200	1902	1247	2	61832.
TOTALS:		800	7546	5117	9	57554.

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0100.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 45781.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	1506	1059	4	51340.
2	0.	200	1463	1037	4	52470.
3	0.	200	1486	1020	8	13373.
4	0.	200	1493	1032	3	62308.
TOTALS:		800	5948	4148	19	44873.

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0200.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 45781.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	1315	943	11	-12938.
2	0.	200	1235	879	15	-49655.
3	0.	200	1325	903	11	-10965.
4	0.	200	1241	843	17	-66208.
TOTALS:		800	5116	3568	54	-35441.

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	5084	733	5	53601.
2	0.	200	5147	671	3	76679.
3	0.	200	5181	633	2	88462.
4	0.	200	5148	666	6	46857.
TOTALS:		800	20560	2703	16	66400.

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.80.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	5031	789	2	80993.
2	0.	200	5016	795	1	90438.
3	0.	200	4991	831	3	68967.
4	0.	200	5048	778	3	71586.
TOTALS:		800	20086	3193	9	77996.

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=3.30.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4954	874	2	76986.
2	0.	200	4904	920	1	84626.
3	0.	200	4989	842	3	68595.
4	0.	200	4982	840	2	78518.
TOTALS:		800	19829	3476	8	77181.

E-112

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4854	962	1	82330.
2	0.	200	4837	983	1	81443.
3	0.	200	4876	953	3	63191.
4	0.	200	4858	956	3	62596.
TOTALS:		800	19425	3854	8	72390.

E-113

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=5.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4762	1052	0	87914.
2	0.	200	4747	1080	2	66906.
3	0.	200	4594	1234	0	79356.
4	0.	200	4811	1016	3	59926.
TOTALS:		800	18914	4382	5	73526.

E-114

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4604	1217	0	80022.
2	0.	200	4570	1258	1	68168.
3	0.	200	4662	1164	2	62693.
4	0.	200	4594	1232	1	69326.
TOTALS:		800	18430	4871	4	70052.

E-115

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	1443	501	12	-1385.
2	0.	200	1431	528	16	-42403.
3	0.	200	1503	499	14	-21372.
4	0.	200	1474	533	8	37061.
TOTALS:		800	5851	2061	50	-7024.

E-116

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.80.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	1768	648	4	71116.
2	0.	200	1712	619	7	42721.
3	0.	200	1730	612	8	32889.
4	0.	200	1645	596	7	43793.
TOTALS:		800	6855	2475	26	47631.

E-117

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=3.30.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	1985	710	7	37747.
2	0.	200	1889	656	5	60924.
3	0.	200	1991	698	2	88502.
4	0.	200	1914	630	5	61933.
TOTALS:		800	7779	2694	19	62277.

E-118

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	2099	757	4	65370.
2	0.	200	2089	737	5	56426.
3	0.	200	2155	725	3	77064.
4	0.	200	2135	721	2	87066.
TOTALS:		800	8478	2940	14	71467.

E-119

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=5.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	2456	886	1	88495.
2	0.	200	2469	824	2	81681.
3	0.	200	2567	872	0	97437.
4	0.	200	2421	799	5	52740.
TOTALS:		800	9913	3381	8	80589.

E-120

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	2668	1023	2	71673.
2	0.	200	2619	981	1	83730.
3	0.	200	2690	976	0	93510.
4	0.	200	2665	1006	4	52836.
TOTALS:		800	10542	3986	7	75439.

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5160. 1.330   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1191	0	19957.
2	750.	375	2250	1179	0	20217.
3	1500.	375	2249	1156	0	20657.
4	2250.	375	2249	1156	0	20657.
TOTALS:		1500	8997	4682	0	20372.

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0020.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5160. 1.330   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1174	0	20297.
2	750.	375	2250	1163	0	20537.
3	1500.	375	2249	1125	0	21277.
4	2250.	375	2249	1109	0	21597.
TOTALS:		1500	8997	4571	0	20927.

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0050.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5160. 1.330   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1140	0	20977.
2	750.	375	2250	1107	0	21657.
3	1500.	375	2250	1049	0	22816.
4	2250.	375	2248	1070	0	22358.
TOTALS:		1500	8997	4366	0	21952.

E-124

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0100.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5160. 1.330   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1071	0	22357.
2	750.	375	2250	1027	0	23257.
3	1500.	375	2250	912	0	25556.
4	2250.	375	2248	896	0	25838.
TOTALS:		1500	8997	3906	0	24252.

E-125

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0200.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5160. 1.330   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	994	0	23897.
2	750.	375	2250	906	0	25676.
3	1500.	375	2250	766	0	28476.
4	2250.	375	2249	663	0	30517.
TOTALS:		1500	8998	3329	0	27142.

E-126

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0500.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5160. 1.330   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	771	1	23040.
2	750.	375	2250	663	1	25199.
3	1500.	375	2250	526	2	22628.
4	2250.	375	2249	432	1	29812.
TOTALS:		1500	8998	2392	5	25170.

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0003.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 48106. 0.750   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1194	0	19897.
2	750.	375	2250	1195	0	19897.
3	1500.	375	2249	1182	0	20137.
4	2250.	375	2249	1177	0	20237.
TOTALS:		1500	8997	4748	0	20042.

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 48106. 0.750   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1194	0	19897.
2	750.	375	2250	1195	0	19897.
3	1500.	375	2249	1182	0	20137.
4	2250.	375	2249	1177	0	20237.
TOTALS:		1500	8997	4748	0	20042.

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0020.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 48106. 0.750   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1194	0	19897.
2	750.	375	2250	1195	0	19897.
3	1500.	375	2249	1182	0	20137.
4	2250.	375	2249	1177	0	20237.
TOTALS:		1500	8997	4748	0	20042.

E-130

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0650.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 48106. 0.750   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1172	0	20337.
2	750.	375	2250	1186	0	20077.
3	1500.	375	2249	1158	0	20617.
4	2250.	375	2249	1168	0	20417.
TOTALS:		1500	8997	4684	0	20362.

E-131

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0100.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 48106. 0.750   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1135	0	21077.
2	750.	375	2250	1150	0	20797.
3	1500.	375	2249	1126	0	21257.
4	2250.	375	2249	1122	0	21337.
TOTALS:		1500	8997	4533	0	21117.

E-132

1500 DISK SKIP CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0200.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 48106. 0.750   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1079	0	22197.
2	750.	375	2250	1024	0	23317.
3	1500.	375	2250	940	0	24996.
4	2250.	375	2248	907	0	25618.
TOTALS:		1500	8997	3950	0	24032.

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	254	11	-20024.
2	750.	375	2250	232	10	-14160.
3	1500.	375	2250	225	8	-3342.
4	2250.	375	2250	256	16	-46622.
TOTALS:		1500	8999	967	45	-21037.

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	254	11	-20024.
2	750.	375	2250	232	10	-14160.
3	1500.	375	2250	225	8	-3342.
4	2250.	375	2250	256	16	-46622.
TOTALS:		1500	8999	967	45	-21037.

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	311	8	-5150.
2	750.	375	2250	292	9	-10035.
3	1500.	375	2250	273	3	22356.
4	2250.	375	2250	299	7	453.
TOTALS:		1500	8999	1175	27	1906.

E-136

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=8.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	438	4	13656.
2	750.	375	2250	429	4	13884.
3	1500.	375	2250	428	1	29898.
4	2250.	375	2250	396	6	3854.
TOTALS:		1500	8999	1691	15	15323.

E-137

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=   10.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	649	2	20129.
2	750.	375	2250	646	1	25536.
3	1500.	375	2250	640	0	30994.
4	2250.	375	2249	643	1	25582.
TOTALS:		1500	8998	2578	4	25558.

E-138

1500 DISK ISTRES=2 CASE-H1 RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 48106.   0.750   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	254	11	-20024.
2	750.	375	2250	232	10	-14160.
3	1500.	375	2250	225	8	-3342.
4	2250.	375	2250	256	16	-46622.
TOTALS:		1500	8999	967	45	-21037.

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IFR=   750.   750. 48106. 0.750   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	254	11	-20024.
2	750.	375	2250	232	10	-14160.
3	1500.	375	2250	225	8	-3342.
4	2250.	375	2250	256	16	-46622.
TOTALS:		1500	8999	967	45	-21037.

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 48106. 0.750   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	254	11	-20024.
2	750.	375	2250	232	10	-14160.
3	1500.	375	2250	225	8	-3342.
4	2250.	375	2250	256	16	-46622.
TOTALS:		1500	8999	967	45	-21037.

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5160. 1.330   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	363	6	4490.
2	750.	375	2250	347	9	-11156.
3	1500.	375	2250	310	1	32256.
4	2250.	375	2250	343	4	15618.
TOTALS:		1500	8999	1363	20	10302.

E-142

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750.   5160.   1.330   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2248	896	0	25837.
2	750.	375	2158	883	1	20797.
3	1500.	375	2250	838	0	27035.
4	2250.	375	2250	878	0	26235.
TOTALS:		1500	8998	3495	1	24976.

E-143

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750.   5160.   1.330   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1194	0	19897.
2	750.	375	2250	1195	0	19897.
3	1500.	375	2249	1182	0	20137.
4	2250.	375	2249	1177	0	20237.
TOTALS:		1500	8997	4748	0	20042.

E-144

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0005.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750.   15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1123	0	21316.
2	750.	375	2250	1147	1	15517.
3	1500.	375	2249	1132	0	21136.
4	2250.	375	2249	1133	0	21117.
TOTALS:		1500	8997	4535	1	19771.

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1101	1	16417.
2	750.	375	2250	1123	1	15996.
3	1500.	375	2249	1154	0	20697.
4	2250.	375	2249	1131	0	21157.
TOTALS:		1500	8997	4509	2	18567.

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0050.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	864	3	10498.
2	750.	375	2249	909	3	9583.
3	1500.	375	2250	903	1	20401.
4	2250.	375	2250	895	0	25895.
TOTALS:		1500	8998	3571	7	16594.

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0200.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	458	5	7933.
2	750.	375	2249	378	7	-1127.
3	1500.	375	2250	306	4	16312.
4	2250.	375	2250	297	9	-10126.
TOTALS:		1500	8998	1439	25	3248.

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 48106. 0.750   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2248	978	3	8184.
2	750.	375	2250	1087	4	707.
3	1500.	375	2250	1134	0	21116.
4	2250.	375	2249	1210	0	19577.
TOTALS:		1500	8997	4409	7	12396.

1500 DISK ISTRES=2 LEAD-THE-FLEET CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 48106. 0.750   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	964	3	8483.
2	5250.	375	2249	1050	0	22776.
3	10500.	375	2250	1004	0	23715.
4	15750.	375	2249	1011	0	23555.
TOTALS:		1500	8997	4029	3	19632.

1500 DISK ISTRES=2 NO-FLEET-LEADER CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 48106. 0.750   4.00   1.90   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	950	2	14097.
2	0.	375	2250	946	5	-1805.
3	0.	375	2249	935	3	9047.
4	0.	375	2250	920	3	9381.
TOTALS:		1500	8998	3751	13	7680.

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0050.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 48106. 0.750   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	807	4	6299.
2	750.	375	2250	862	4	5207.
3	1500.	375	2249	894	0	25894.
4	2250.	375	2250	861	1	21241.
TOTALS:		1500	8998	3424	9	14660.

E-152

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0200.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 48106. 0.750   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	468	6	2411.
2	750.	375	2249	420	8	-7319.
3	1500.	375	2250	394	4	14554.
4	2250.	375	2250	336	10	-16266.
TOTALS:		1500	8998	1618	28	-1655.

E-153

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5160. 1.330   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1161	0	20157.
2	750.	375	2250	1149	0	20817.
3	1500.	375	2249	1113	0	21517.
4	2250.	375	2249	1069	0	22397.
TOTALS:		1500	8997	4512	0	21222.

1500 DISK ISTRES=2 LEAD-THE-FLEET CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XIMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5160. 1.330   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1218	0	19417.
2	5250.	375	2249	1112	0	21537.
3	10500.	375	2250	1023	0	23336.
4	15750.	375	2249	925	0	25275.
TOTALS:		1500	8997	4278	0	22391.

1500 DISK ISTRES=2 NO-FLEET-LEADER CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XIMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5160. 1.330   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2248	1165	0	20455.
2	0.	375	2250	1140	0	20997.
3	0.	375	2250	1127	0	21257.
4	0.	375	2249	1140	0	20977.
TOTALS:		1500	8997	4572	0	20922.

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0050.

XNMIN,XIMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5160. 1.330   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1036	0	23057.
2	750.	375	2250	877	0	24257.
3	1500.	375	2250	705	1	24378.
4	2250.	375	2249	520	2	22728.
TOTALS:		1500	8998	3138	3	24105.

1500 DISK ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0200.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 5160. 1.330   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2248	827	0	27217.
2	750.	375	2250	657	7	-6641.
3	1500.	375	2250	482	2	23503.
4	2250.	375	2250	400	8	-6925.
TOTALS:		1500	8998	2366	17	9288.

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 1

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2248	797	0	27817.
2	750.	375	2250	766	2	17797.
3	1500.	375	2250	794	2	17263.
4	2250.	375	2250	757	2	18023.
TOTALS:		1500	8998	3114	6	20225.

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 1

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1121	0	21357.
2	750.	375	2250	1062	0	22556.
3	1500.	375	2250	1084	0	22116.
4	2250.	375	2248	1140	0	20958.
TOTALS:		1500	8997	4407	0	21747.

E-100

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 1

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1230	0	19177.
2	750.	375	2250	1183	0	20137.
3	1500.	375	2250	1216	8	19476.
4	2250.	375	2249	1227	0	19237.
TOTALS:		1500	8998	4855	0	19507.

E-101

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=8.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260. 1.000   4.00   1.00   1. 2

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2248	701	1	24401.
2	750.	375	2250	693	0	29936.
3	1500.	375	2250	654	0	30716.
4	2250.	375	2250	650	1	25455.
TOTALS:		1500	8998	2698	2	27627.

E-102

1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IFR=   750.   750. 15260. 1.000   4.00   1.00   1. 2

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	970	0	24377.
2	750.	375	2250	943	0	24936.
3	1500.	375	2250	927	0	25256.
4	2250.	375	2249	962	0	24537.
TOTALS:		1500	8998	3802	0	24777.

1500 DISK STND CASE-HI RES PROCE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPP=   750.   750. 15260.   1.000   4.00   1.00   1. 2

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2249	1080	0	22177.
2	750.	375	2250	1098	0	21837.
3	1500.	375	2250	1054	0	22716.
4	2250.	375	2248	1128	0	21198.
TOTALS:		1500	8997	4360	0	21982.

BETTER CYCLE COUNT 1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 2

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	712	1	24218.
2	750.	375	2250	699	0	29816.
3	1500.	375	2250	669	0	30416.
4	2250.	375	2250	724	1	24002.
TOTALS:		1500	9000	2804	2	27113.

BETTER CYCLE COUNT 1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 2

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	1016	0	23476.
2	750.	375	2250	1031	0	23176.
3	1500.	375	2250	1043	0	22957.
4	2250.	375	2250	1071	0	22377.
TOTALS:		1500	9000	4161	0	22992.

E-186

BETTER CYCLE COUNT 1500 DISK STND CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750.   750. 15260.   1.000   4.00   1.00   1. 2

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	2250	1204	0	19717.
2	750.	375	2250	1188	0	20037.
3	1500.	375	2250	1182	0	20157.
4	2250.	375	2250	1188	0	20037.
TOTALS:		1500	9000	4762	0	19987.

E-187

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   500. 15260.   1.000   4.00   1.00   1. 1

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4937	882	15	-53688.
2	0.	200	4924	899	16	-64402.
3	0.	200	5055	779	11	-8240.
4	0.	200	4950	871	11	-13130.
TOTALS:		800	19866	3431	53	-34865.

E-188

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   500. 15260.   1.000   4.00   1.00   1. 1

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4523	1315	5	25626.
2	0.	200	4563	1277	3	47463.
3	0.	200	4547	1309	4	36338.
4	0.	200	4553	1281	10	-22919.
TOTALS:		800	18186	5182	22	21627.

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   500. 15260.   1.000   4.00   1.00   1. 9

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4197	1654	1	49271.
2	0.	200	4207	1641	3	29779.
3	0.	200	4274	1580	2	43000.
4	0.	200	4234	1628	2	40889.
TOTALS:		800	16912	6503	8	40735.

E-170

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=2.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 15260.   1.000   4.00   1.00   1. 1

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	1526	631	65	-538188.
2	0.	200	1549	628	52	-407961.
3	0.	200	1518	582	60	-485784.
4	0.	200	1489	617	58	-467343.
TOTALS:		800	6082	2458	235	-474819.

E-171

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFET. FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 15260.   1.000   4.00   1.00   1. 1

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	2176	915	31	-212608.
2	0.	200	2150	905	20	-102065.
3	0.	200	2230	908	20	-102449.
4	0.	200	2221	904	24	-141946.
TOTALS:		800	8777	3632	95	-139767.

E-172

806 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=6.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 15260.   1.000   4.00   1.00   1. 1

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	2789	1234	8	1387.
2	0.	200	2739	1189	13	-46637.
3	0.	200	2816	1275	8	-451.
4	0.	200	2817	1210	4	42917.
TOTALS:		800	11161	4908	33	-596.

E-173

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0016.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   500. 15260.   1.000   4.00   1.00   1. 1

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	3714	2150	0	35465.
2	0.	200	3721	2145	1	25514.
3	0.	200	3713	2158	0	35156.
4	0.	200	3705	2177	0	34421.
TOTALS:		800	14853	8630	1	32584.

E-174

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0036.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   500. 15260.   1.000   4.00   1.00   1. 1

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	3885	1920	1	35128.
2	0.	200	4009	1800	0	51115.
3	0.	200	4000	1806	0	50752.
4	0.	200	3954	1849	0	48597.
TOTALS:		800	15848	7375	1	46399.

E-175

CRO DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0200.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500.   500. 15260.   1.000   4.00   1.00   1. 1

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	4797	1029	8	9243.
2	0.	200	4713	1115	12	-34903.
3	0.	200	4798	1039	5	39140.
4	0.	200	4765	1069	9	-2440.
TOTALS:		800	19074	4252	34	2760.

E-176

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0010.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 15260.   1.000   4.00   1.00   1. 1

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	3058	2005	0	43468.
2	0.	200	3030	1947	3	16220.
3	0.	200	3019	1971	2	24638.
4	0.	200	3043	1941	0	46407.
TOTALS:		800	12150	7864	5	32683.

E-177

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0050.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000. 15260.   1.000   4.00   1.00   1. 1

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	2506	1714	3	28297.
2	0.	200	2449	1706	5	8842.
3	0.	200	2461	1672	9	-29842.
4	0.	200	2451	1688	4	19432.
TOTALS:		800	9467	6780	21	6682.

800 DISK OLD CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0200.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   500. 75000 15260. 1.000   4.00   1.00   1. 1

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	200	2154	1031	30	-208121.
2	0.	200	212	1048	22	-128714.
3	0.	200	2153	1098	26	-171276.
4	0.	200	2118	1015	19	-97541.
TOTALS:		800	8552	4192	97	-151413.

E-179

1500 TEST SPECIMEN ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 23029. 0.900   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	534	58	41	27016.
2	750.	375	529	45	35	29691.
3	1500.	375	541	54	43	26153.
4	2250.	375	537	58	41	24989.
TOTALS:		1500	2141	215	160	27062.

E-180

1500 TEST SPECIMEN ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH CONSTANT SAFETY FACTOR. SF=4.00.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	933	77	25	36875.
2	750.	375	923	63	15	37168.
3	1500.	375	931	72	24	33334.
4	2250.	375	931	76	20	34865.
TOTALS:		1500	3718	288	84	34560.

E-181

1500 TEST SPECIMEN ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0500.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 23029. 0.900   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	853	246	25	29398.
2	750.	375	880	246	11	35103.
3	1500.	375	868	219	21	31611.
4	2250.	375	868	217	19	32482.
TOTALS:		1500	3469	928	76	32149.

E-182

1500 TEST SPECIMEN ISTRES=2 CASE-HI RES PROBE INSPECTION
INSPECTION TIME SPECIFIED WITH STATISTICAL UPDATE. MAX ALLOWABLE FAILURE PROBABILITY=0.0500.

XNMIN,XNMAX,XNPI,SASS,AL,BET,XEFF,IPR=   750. 75000. 15260. 1.000   4.00   1.00   1. 3

SUBFLEET ID #	TIME INTRODUCED	NUMBER OF ENGINES	NUMBER OF INSPECTIONS	NUMBER OF REPLACEMENTS	NUMBER OF FAILURES	RFC DOLLAR GAIN PER ENGINE
1	0.	375	1151	274	17	31941.
2	750.	375	1175	253	8	36031.
3	1500.	375	1154	235	17	32803.
4	2250.	375	1030	217	11	35651.
TOTALS:		1500	4510	979	53	34105.