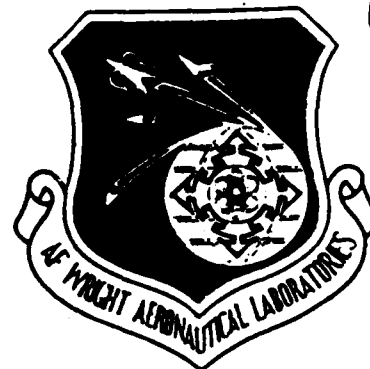


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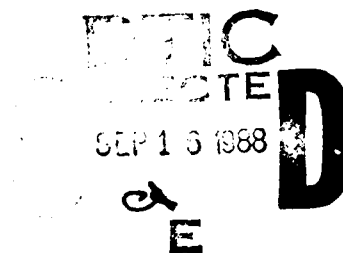


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19 October 1987

FINAL REPORT FOR PERIOD October 1983 - September 1987

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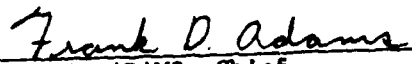
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This technical report has been reviewed and is approved for publication.

  
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structural durability of P/M alloys. The EIFS distribution is common to all spectra and stress levels for a given material and can be conveniently used to quantify structural performance of P/M alloys. The analyzed data demonstrated that initial fatigue quality and spectrum fatigue crack growth resistance of P/M alloys are better compared with baseline materials. From the fatigue quality model parameters obtained in this study, reliability was determined as a function of maximum stress level in spectrum loading. Results showed that reliability of P/M alloys is superior to that of baseline materials for a given stress level.

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## SUMMARY

This report summarizes a research program aimed at achieving the following goals:

1. To quantify the failure processes in rapidly solidified technology (RST) structures in order to characterize their damage tolerance and durability.
2. To develop a "figure of merit" within the framework of fracture-based design which will reflect the relative merit of RST material versus conventional construction.

A preliminary trade study had established an F-16 aft fuselage bulkhead (FS446) as a prime configuration for weight savings of Powder Metallurgy alloys over conventional ingot metallurgy aluminum alloys. Spectrum fatigue tests were conducted on approximately 150 test coupons designed to model a critical location in the F-16 FS446 bulkhead. Tests were conducted on two different P/M alloys, CW67 and 7091, and compared to two ingot metallurgy aluminum alloys, 7475-T7351 and 2124-T851. Also, 7071 material produced under two manufacturing technologies, machined plate and net shape forging were compared.

Spectrum fatigue tests were conducted under two types of spectrum load histories, HUD34 and NOR1. HUD34 is a tension-compression type spectrum representing the 500-hour block spectrum for the F-16 FS446 bulkhead, while NOR1 is a tension-dominated type spectrum representing the B-1 wing carry-through box spectrum. Test results obtained from spectrum fatigue tests were analyzed based upon the equivalent initial flaw size (EIFS) concept. Methodology used in comparing RST structures with conventional I/M structures is presented and discussed. Techniques which can be used in design studies are proposed.

## FOREWORD

This report was prepared by General Dynamics/Fort Worth Division, Fort Worth, Texas, for the Structural Integrity Branch, Structures Division, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio under Contract F33615-83-C-3227. Ms. Margery Artley of AFWAL/FIBEC, was the Project Engineer.

General Dynamics/Fort Worth Division was the contractor for this program. Dr. W. R. Garver served as Program Manager. Dr. D. Y. Lee and Mr. D. E. Gordon were Principal Investigators.

Many individuals at General Dynamics contributed to this program. All tests were performed in General Dynamics' Materials and Processes Laboratory by R. O. Nay under the direction of R. L. Jones. Fractographic readings were made by K. M. Koepsel and S. B. Kirschner. R. W. Haile, R. S. Prowant, and M. A. Osterkamp developed computer software for the program. B. S. Head and P. L. Carper performed all nondestructive examinations of the test specimens. J. H. Chung conducted crack growth predictions. S. R. Fisk typed the report.

This report is the Final Technical Report for this program, covering all work during the period October, 1983 through September, 1987.

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## SECTION I

### INTRODUCTION

The current Air Force structural integrity [MIL-A-87221, Ref. 1] design specifications require that an aircraft be designed to meet both damage tolerance [MIL-A-83444, Ref. 2] and durability [MIL-A-8866B, Ref. 3, and MIL-A-8867B, Ref. 4] requirements. Using a fracture mechanics approach, these design criteria assume that initial quality of aircraft primary structures must be such that there is no catastrophic failure nor widespread damage accumulation within one design service life.

The selection of the initial flaw size and geometry to be used for design is one of the most important tasks in implementing the damage tolerance and durability requirements. The flaw sizes and geometries currently specified in MIL-A-83444 and MIL-A-8866B have been developed primarily for conventional ingot metallurgy (I/M) aerospace alloys. With the advent of rapid solidification processing (RSP), the data base for establishing initial flaw sizes must be expanded for RSP Powder Metallurgy alloys. The main objective of this study is to provide data for two types of RSP structural concepts that can be used to base assumptions of initial flaw size and geometry for direct use within the current Air Force specifications.

A second goal of this program is to provide the designer with a realistic way to assess design trade-offs for using high strength P/M alloys over conventional I/M alloys. A methodology similar to that used in assessing advanced joining concepts was used [5]. Based on this methodology, the reliability of high strength P/M alloys can be compared to conventional I/M alloys.

## SECTION II

### BACKGROUND OF RSP ALUMINUM ALLOYS

During recent years, improvements in mechanical properties of aluminum alloys have been achieved by rapid solidification processing (RSP). Extending control of microstructure via higher solidification rates has led to the development of unique alloy systems [6].

Fine grains, small constituents and dispersoids, as well as a homogeneous distribution of alloy elements, have been developed as a direct consequence of Rapid Solidification (RS) processes, including Powder Metallurgy (P/M). The uniformity in microstructures achieved in RS alloys created superior combinations of mechanical properties and resulted in an improved balance between strength, toughness, fatigue properties and corrosion resistance.

Unfortunately, the cost of RST structural aluminum alloys remains higher than those produced from standard ingot metallurgy. Therefore, their applications are limited to components where superior performance requirements must justify their use. The growth of P/M alloys has also been constrained by the size of billets available for processing into wrought products. Quality and end-product consistency have also hindered acceptance of aluminum wrought P/M products, particularly in aerospace applications. Even though P/M alloys exhibit significantly greater combinations of strength and fracture toughness compared to conventional ingot alloys, inclusions which can be introduced during processing must be controlled in order for these materials to be reliable in critical applications. It has been recognized that one of the most important factors controlling the fatigue performance of RST materials is the cleanliness of the RST material [6]. For example, it has been revealed that recent failures of Boeing's 7090 landing gear forgings for the 757 were associated with large inclusions of size about 0.060 inch [7].

Table 1 lists the compositions of I/M and several P/M alloys which have been developed by Alcoa. These alloys contain Zn, Mg, and Cu and utilize various types and amounts of dispersoid forming elements such as Cr, Zr, Co, or Ni to control recrystallization.

Table I Nominal Compositions\* of 7XXX Aluminum P/M Alloy

| Alloy |     | Zn  | Mg  | Cu  | Co  | Cr   | Zr   | Ni  | O    | Al   | Ref. |
|-------|-----|-----|-----|-----|-----|------|------|-----|------|------|------|
| 7075  | I/M | 5.6 | 2.5 | 1.6 | --- | 0.23 | ---  | --- | ---  | Bal. |      |
| 7050  | I/M | 6.2 | 2.2 | 2.3 | --- | ---  | 0.12 | --- | ---  | Bal. |      |
| 7090  |     | 8.0 | 2.5 | 1.0 | 1.5 | ---  | ---  | --- | 0.35 | Bal. | a    |
| 7091  |     | 6.5 | 2.5 | 1.0 | 0.4 | ---  | ---  | --- | 0.35 | Bal. | a    |
| CW67  |     | 9.0 | 2.5 | 1.5 | --- | ---  | 0.14 | 0.1 | 0.35 | Bal. | b    |

(a) Aluminum Company of America, Tech Brief, March, 1985

(b) Alcoa IRAD, April, 1983

\* Elements in Weight %

The advantage that P/M alloys have over slowly cooled I/M alloys is the ability to utilize rapid solidification to refine the dispersoid size and spacing as well as dendrite arm spacing.

The refined microstructural features in the atomized powder ultimately results in a fine grain size in the wrought alloy with improved combinations of properties as demonstrated in Figure 1. In die forgings, P/M alloys 7090 and 7091 in a T7 temper have better strength and toughness than I/M 7075 [8]. Continued development of 7XXX P/M alloys [9] has led to the second generation alloy designated by Alcoa as CW67. As shown in Figure 1, this alloy which has twice the fracture toughness as 7090 with equivalent strength, is expected to play a major role in the continued commercialization of 7000 series P/M alloys for aerospace applications.

P/M alloys also exhibit superior corrosion resistance compared to I/M alloys. Figure 2 shows that P/M alloys offer between 10 to 20 percent greater strength compared to 7075-T73 and had no failures [10] in short-transverse tensile bars stressed at 45 ksi (310 MPa).

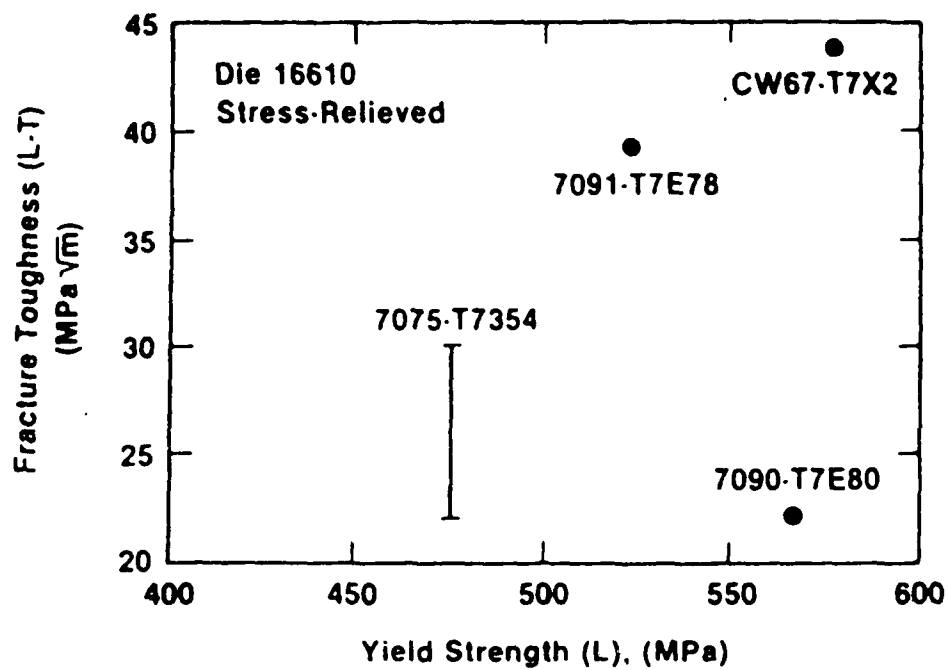


Figure 1. Fracture Toughness and Yield Strength for 7XXX P/M Versus 7075 1/M Forgings

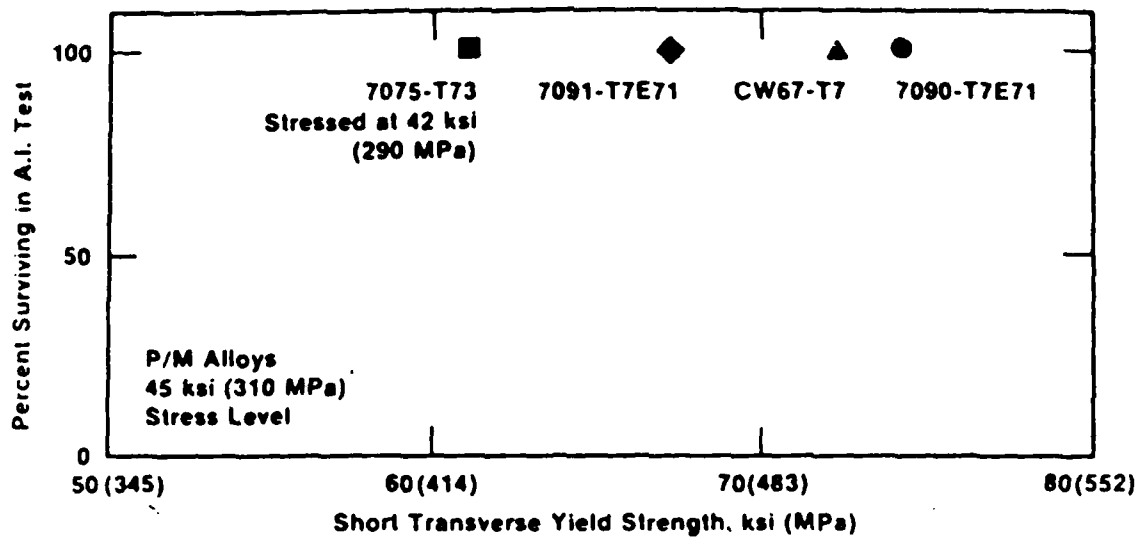


Figure 2. Results of ASTM G44-75 SCC Tests for T7 Type Tempers

## SECTION III

### EXPERIMENTAL PROCEDURES

#### 3.1 SELECTION OF RST TEST ELEMENT

A list of 48 fracture critical parts were obtained from the F-16C/D aircraft as potential parts to be replaced by P/M alloys. An F-16 aft fuselage bulkhead (FS446) was chosen for this study as a prime configuration since a preliminary trade study predicted good weight savings from P/M alloys for this application (Figure 3). Potential cracking problems were known to exist in this bulkhead, also. This also provided a good opportunity to compare two manufacturing technologies, machined plate vs. net shape forging. Therefore, spectrum fatigue test specimens were designed to model a critical location in the F-16 FS446 bulkhead as shown in Figure 4. The test element geometry is shown in Figure 5.

Load transfer between 1/4" fastener holes was accomplished with a composite strap. Mylar tape between the strap and the specimen minimizes fretting that would promote crack initiation at locations away from the fastener holes. Specimens were tested in the as-machined condition with no additional surface treatment. No intentional pre-flaws were introduced.

#### 3.2 SELECTION OF MATERIALS

The high strength P/M aluminum alloys selected for this program were CW67-extrusions, 7091-extrusions, and 7091-forgings. Both the Alcoa second generation alloy, CW67, and first generation alloy, 7091, were discussed in Section II. The CW67 and 7091 extrusions were obtained in the form of bars (1.5 inch thick and 4.5 inch wide). The CW67 material was obtained in the T7E91 heat treat. This heat treat consisted of:

- (a) Solution treatment at 910°F for 2 hrs,
- (b) cold water quench,
- (c) artificially aging at 250°F for 24 hrs. followed by
- (d) artificially aging at 325°F for 1 hr.

The 7091 material was obtained in the T7E69 heat treat. This heat treatment is shown in Table 2. The 7091-forgings were

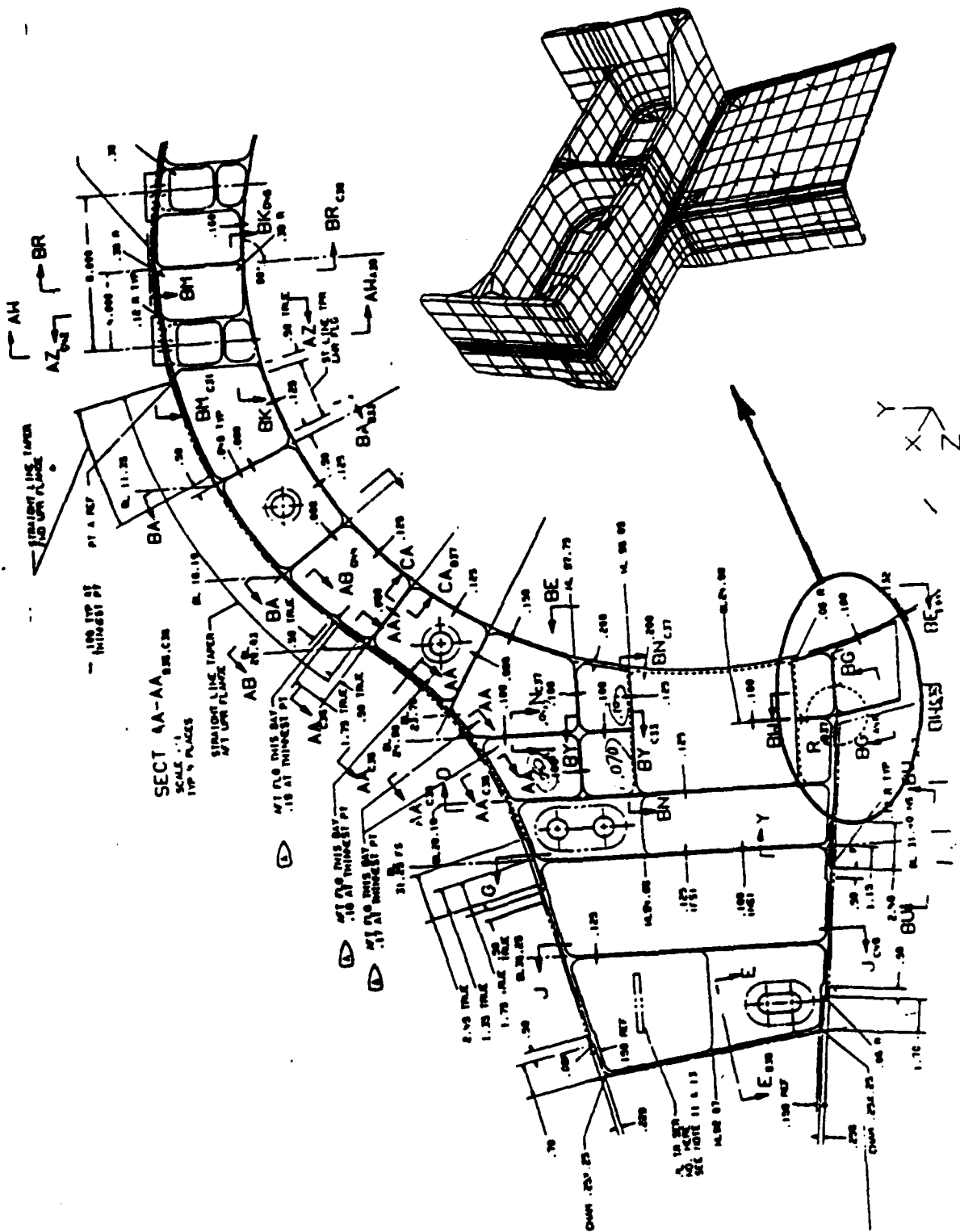
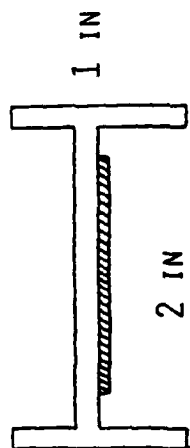
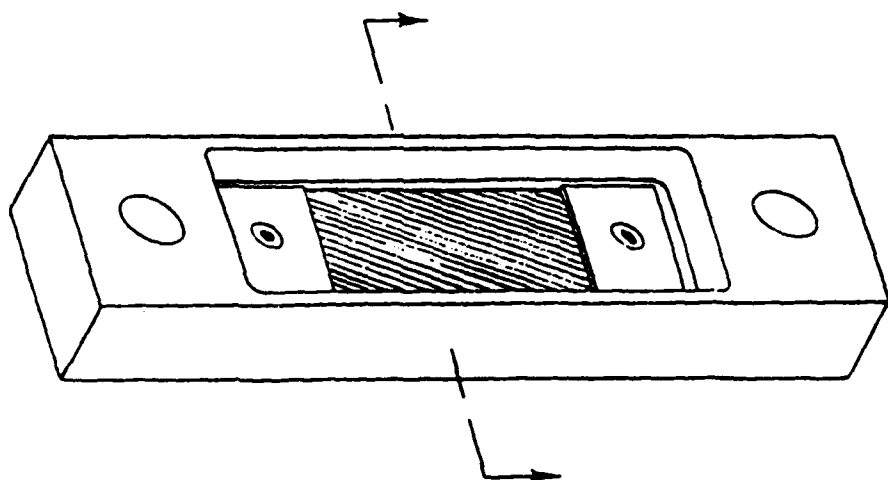


Figure 3. Drawing of FS 446 Bulkhead On F-16 Aircraft



REPRESENTS TYPICAL MACHINED  
POCKET WITH LOADED FASTENER

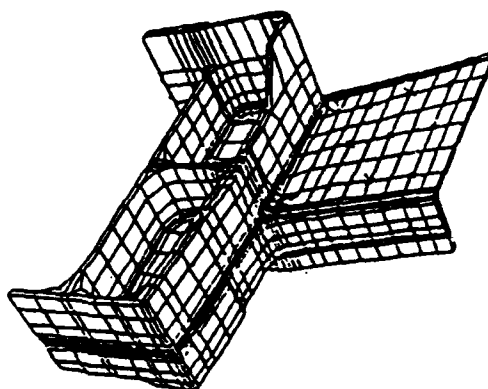


Figure 4. Test Element Design

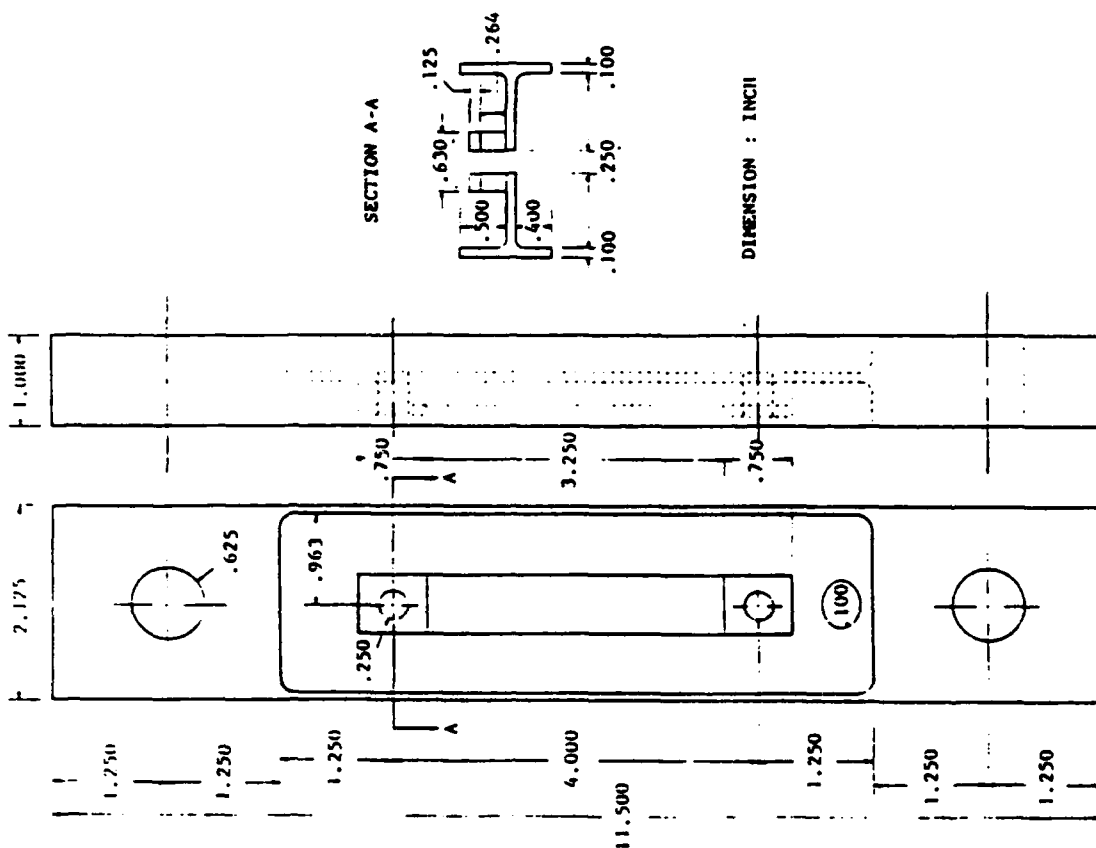


Figure 5. Test Element Geometry

TABLE 2. PROCEDURE USED IN HEAT TREATING 7091 P/M ALUMINUM ALLOY

|                           | 7091-EXTRUSIONS | 7091-FORGINGS |
|---------------------------|-----------------|---------------|
| SOLUTION TREATMENT        | 920°F, 2 HRS    | 920°F, 2 HRS  |
| WATER QUENCH              | R. T.           | R. T.         |
| STRESS RELIEF             | 3% STRETCH      | NONE          |
| NATURAL AGING             | R. T., 5 DAYS   | R. T., 5 DAYS |
| 1ST STEP ARTIFICIAL AGING | 250°F, 24 HRS   | 250°F, 24 HRS |
| 2ND STEP ARTIFICIAL AGING | 325°F, 8 HRS    | 325°F, 20 HRS |

prepared from 7091-T7E69 extruded bars by a precision forging process at Pioneer Aluminum Forging Company, Colorado Springs, Colorado. A hydraulic press was used for forging preheated (3 hours at 800°F) blanks of 7091. During the forging process, the die temperature was also 800°F. Forged specimens were air cooled to room temperature. Post forging heat treatments are also shown in Table 2.

During the final step of artificial aging, the forged material was heated at 325°F until hardness values similar to the extruded material were obtained (Figure 6). Longer times were required for aging at 325°F (20 hrs) for the forged material as compared to the extruded material (8 hrs. at 325°F).

The baseline materials selected were 2124-plate and 7475-plate. Both materials are used on the F-16 aircraft.

The 2124-T851 aluminum plate alloy is used extensively in the F-16 fuselage in various thicknesses up to 5.5 inches. Its fracture toughness is not as high as 7475 but its crack growth resistance is very good, particularly in a corrosive media under spectrum loading [11]. The 2124-T851 aluminum alloy is currently being used in the F-16 aft fuselage bulkhead (FS446).

The 7475-T7351 aluminum plate alloy was selected because it is representative of the primary material of the F-16 aircraft for safety-of-flight structure up to 4.0-inches thick. Thin plate (0.625-inch) is used for the lower wing skin, where fracture control is a prime design requirement. Thicker plate (1.0-4.0 inches) is used for wing spars and certain of the thinner center fuselage lower bulkhead segments. This material is also used in the aft fuselage to a limited extent. The combination of this alloy and temper exhibits high resistance to exfoliation and stress corrosion cracking in all directions, and has extremely high fracture toughness [11].

All 2124-T851 and 7475-T7351 test coupons were obtained from plate (1.5 inch thick). All material used in the program was obtained from Aluminum Company of America.

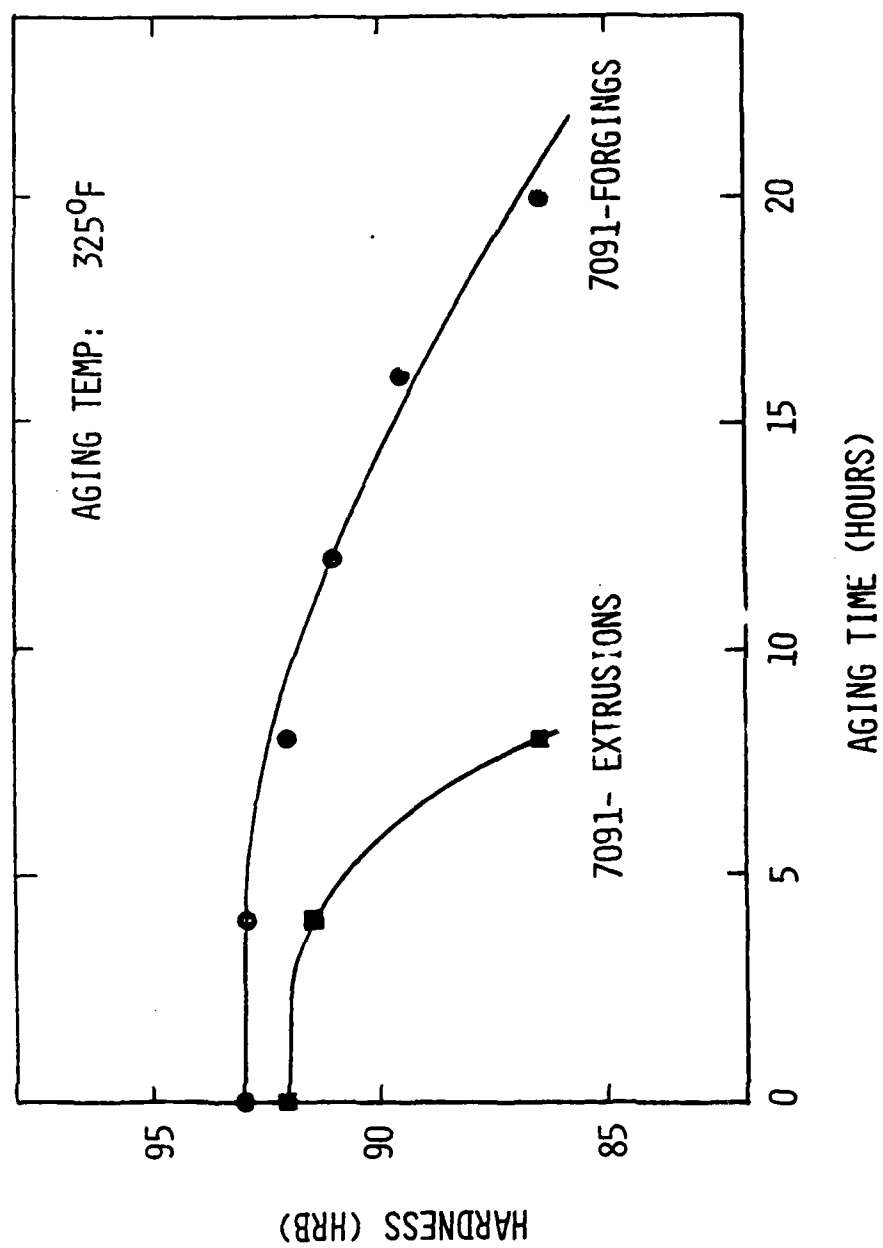


Figure 6. Aging Characteristics of 7091 Aluminum Alloy

### 3.3 LOAD HISTORY DEVELOPMENT AND SPECTRUM FATIGUE TESTING

Spectrum fatigue tests were conducted under two types of spectrum load histories, HUD34 and NOR1 (Figures 7 and 8). HUD34 represents the 500-hour block spectrum for the F-16 FS446 bulkhead (A tension-compression type spectrum), while NOR1 represents the B-1 wing carry-through box spectrum (a tension-dominated type spectrum). All specimens were spectrum fatigue tested for the equivalent of three design lives or until failure, whichever occurred first. One design life for HUD34 and NOR1 are 8,000 and 13,500 flight hours, respectively. Following testing, unfailed specimens were monotonically tested to failure and residual strength of each specimen was recorded. The crack growth data were determined by a fractographic method [5] using a Bausch and Lomb stereomicroscope and digital X-Y stage micrometers. The data were read continuously from the final crack length back to the origin. Both spectra produced easily distinguishable markings on the fracture surfaces (Figures 8 and 9).

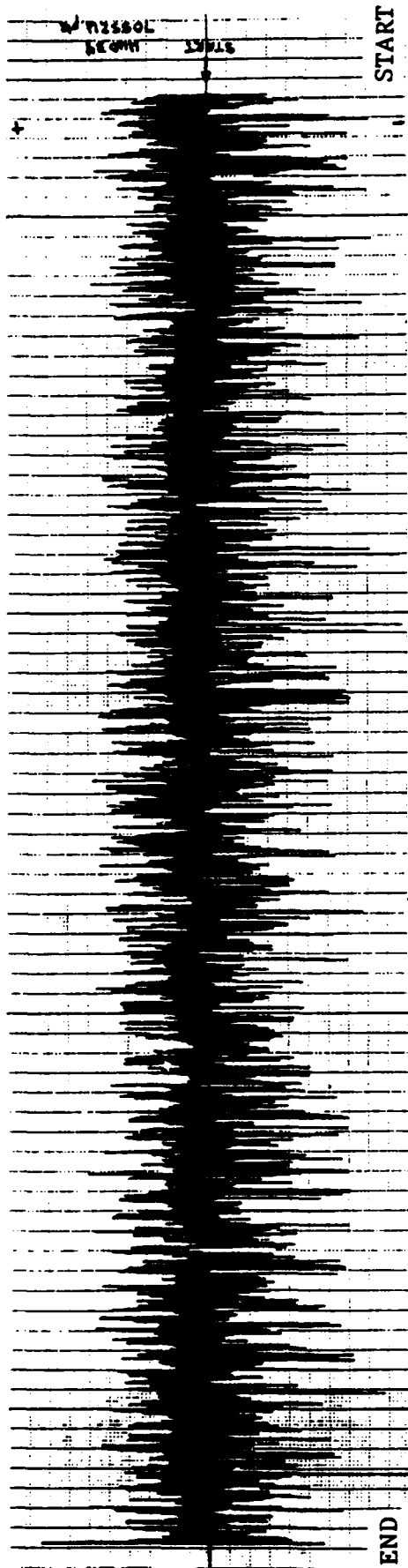
For tests conducted under the HUD34 test spectrum, maximum tensile stresses of 35 ksi and 40 ksi were selected for the 2124-T851 aluminum alloy while maximum tensile stresses of 40 ksi and 45 ksi were selected for the 7091 and CW67 P/M materials (Table 3). For spectrum fatigue studies conducted under the NOR1 spectrum, maximum tensile stresses of 45 ksi and 50 ksi were used (Table 3).

Testing was conducted in computer-controlled test frames within the Materials and Processing Group Laboratory. Load cells in these facilities were periodically calibrated under Air Force supervision. Test rates were set so that program and feedback loads agreed to within two percent at all load levels. Due to the design of the test specimen, no lateral constraints were required during testing.

Table 3 summarizes the spectrum fatigue test plan. The experimental results obtained from the spectrum fatigue testing are presented in Section 5.

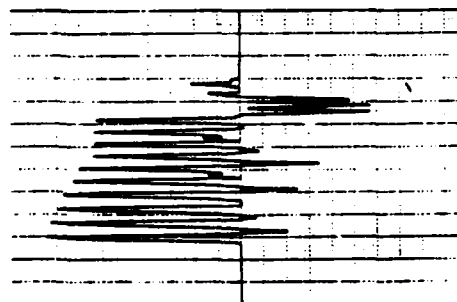
### 3.4 INSPECTION PROCEDURES

Nondestructive techniques were used to characterize all fastener holes subjected to cyclic loading. For determining initial hole quality, eddy current techniques and dial bore gauge



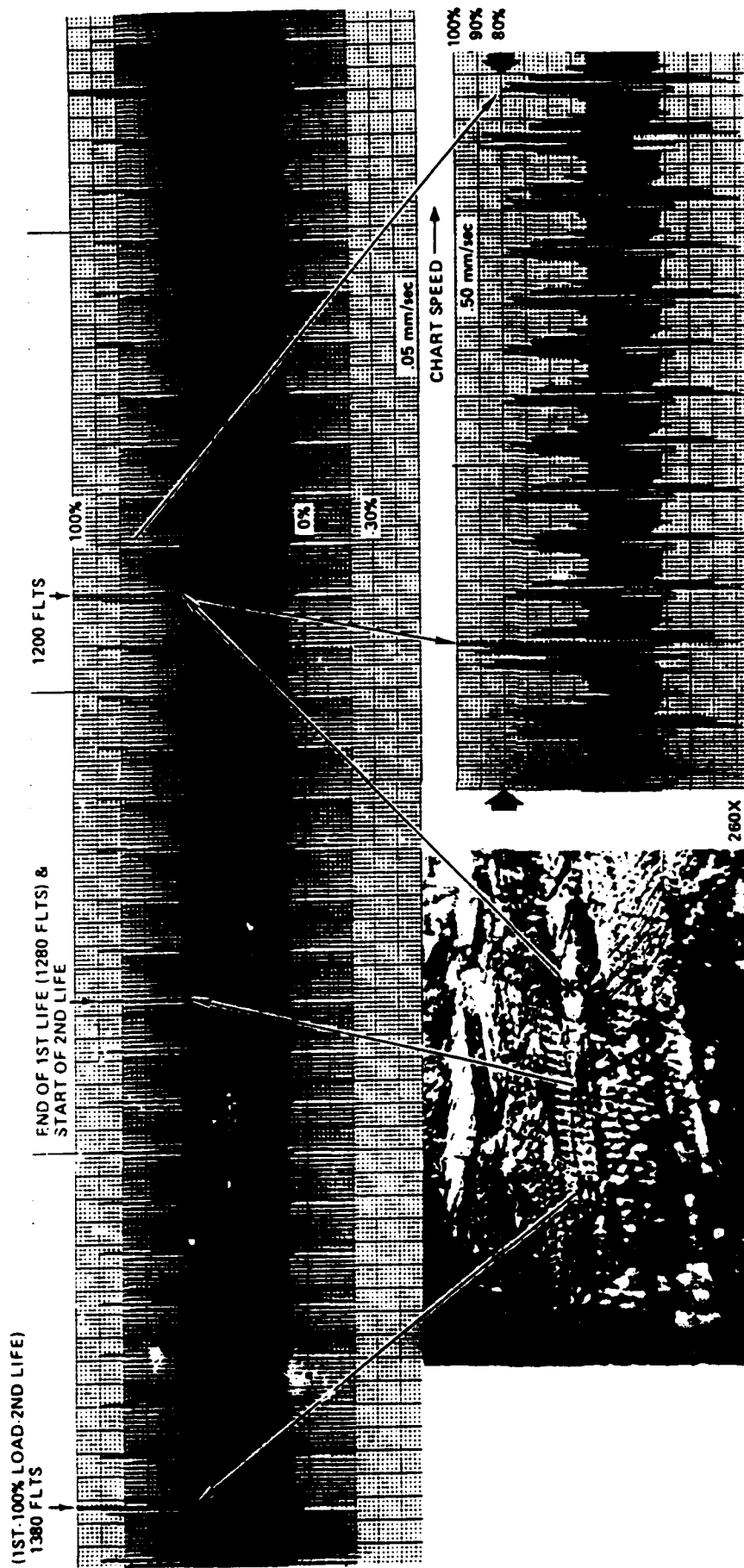
1 BLOCK = 500 FLIGHT HOURS

LAST 50 LOAD POINTS



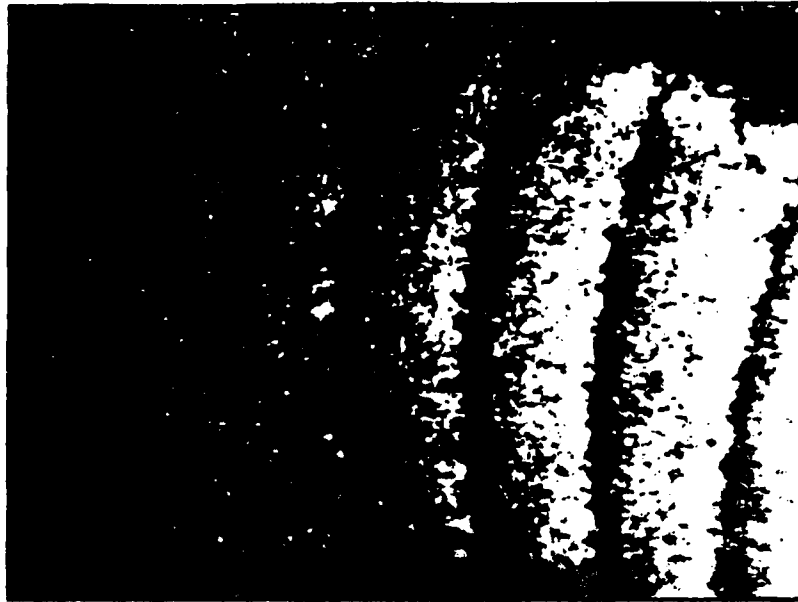
NUMBER OF LOAD POINTS : 70552  
 MAXIMUM TENSION LOAD : + 85%  
 MINIMUM COMPRESSION LOAD : -100%

Figure 7. HUD 34 Test Spectrum



SEGMENT OF B1-BOMBER SPECTRUM SHOWING TRANSITION FROM 1ST TO 2ND LIFE

Figure 8. NOR 1 Test Spectrum



7091 Extrusion

40X

Figure 9. Fractographic Markings On A 7091 Extrusion  
Fracture Surface Exposed To HUD 34 Spectrum

TABLE 3 SPECTRUM FATIGUE TEST MATRIX

| MATERIAL       | SPECTRUM | STRESS | NO. OF SPECIMENS |
|----------------|----------|--------|------------------|
| 2124-T851      | HUD34    | 35     | 15               |
|                | HUD34    | 40     | 15               |
|                | NOR1     | 45     | 10               |
| 7475-T7351     | NOR1     | 45     | 10               |
| 7091-EXTRUSION | HUD34    | 40     | 15               |
|                | HUD34    | 45     | 15               |
|                | NOR1     | 45     | 10               |
|                | NOR1     | 50     | 10               |
| 7091-FORGING   | HUD34    | 40     | 9                |
|                | HUD34    | 45     | 9                |
| CW67-EXTRUSION | HUD34    | 40     | 10               |
|                | HUD34    | 45     | 10               |
|                | NOR1     | 45     | 10               |

measurements were made. Comparisons were made between NDI parameters as measured by the different inspection techniques and fatigue properties. Cracks initiated at the fastener holes in all test specimens. They initiated from inclusions, defects, out of roundness of holes and axial scratches.

Since control of inclusions is a major problem in the high strength P/M aluminum alloys, ultrasonic and x-ray inspections were also made of all RST test coupons prior to cyclic loading. Both inspection techniques are known to be particularly sensitive to detecting inclusions.

In the 7091-forged specimens, surface residual stresses in the test coupons were also considered. In the forged material, the residual stress distributions are considered an additional unknown variable which could affect spectrum fatigue performance. All NDI techniques used in this program are shown in Table 4. All inspection procedures are described below.

#### 3.4.1 Eddy Current

Eddy current procedures for inspecting fastener hole quality were similar to those described in the "Initial Quality of Advanced Joining Concepts" program [5] and "Fastener Hole Quality" program [12]. An automated eddy current inspection unit was used for inspecting fastener holes. The unit consists of an Automation Industries EM 3300 eddy current unit, a mini-scanner head and a dual channel recorder. The eddy current signal, after being filtered and amplified, is sent to a dual channel recorder, where the data is then plotted.

Considerable insight was gained during the Fastener Hole Quality program [12] into the types of initial defects that most seriously affect the fatigue behavior of fastener holes. The axial or vertical scratch in a fastener hole has been identified as an initial defect that significantly affects the fatigue behavior of fastener holes under no-load transfer conditions. Consequently, the eddy current technique has been optimized to detect axial scratches. Shown in Figure 10 are eddy current signatures of typical manufacturing induced axial scratches. A signal-to-noise ratio of about 7 has been achieved in the detection of this type of initial defect.

TABLE 4. NDI TEST MATRIX

|                       |                                         |
|-----------------------|-----------------------------------------|
| • RST MATERIALS       |                                         |
| ULTRASONIC            | - INCLUSIONS, VOIDS, (FORGING LAPS)     |
| X-RADIOGRAPHY         | - INCLUSIONS, VOIDS, (FORGING LAPS)     |
| EDDY CURRENT          | - CRACKS, SCRATCHES IN FASTENER HOLES   |
| DIAL BORE GAGE        | - DIAMETER, ROUNDNESS OF FASTENER HOLES |
| • CONVENTIONAL ALLOYS |                                         |
| EDDY CURRENT          |                                         |
| DIAL BORE GAGE        |                                         |

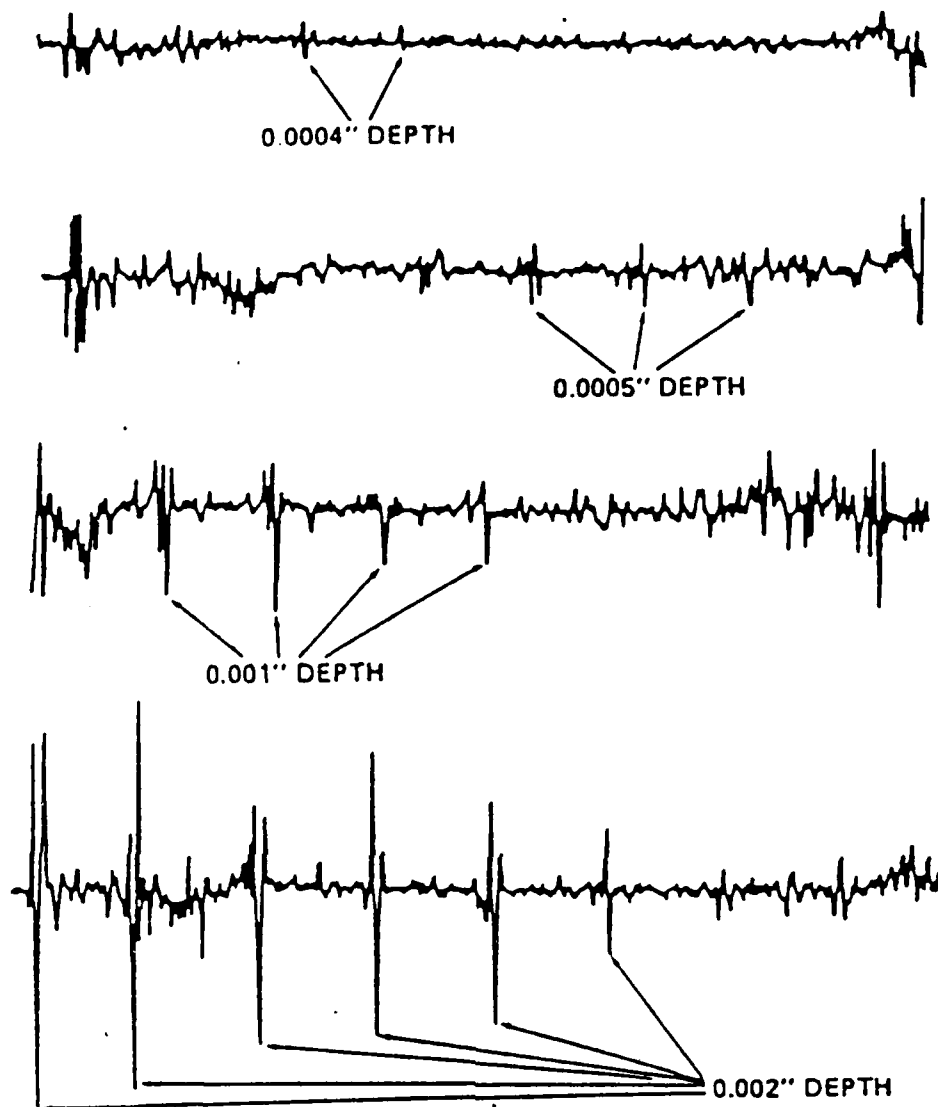


Figure 10. Sensitivity of Eddy Current To Surface Defects

Despite the sensitivity of eddy current inspection, it is difficult to detect some of the axial scratches or voids which can adversely affect fatigue performance. It is possible, however, to monitor variations in hole dimensions, such as hole out-of-roundness, with eddy current inspection. Also, surface roughness can easily be detected.

#### 3.4.2 Dial Bore Gauge

A dial bore gauge (Boise Model No. 1) was used to measure the diameter of the fastener holes at different orientations (Figure 11), and thus, give a relative measure of out-of-roundness (OOR). Measurements were taken at different depths in the hole, also, to determine if hole tapering was present. Numbering of the holes for dial bore gauge and eddy current measurements were in accordance with Figure 11.

#### 3.4.3 X-Radiography

In the inspection of the 7091 and CW-67 coupons, a Field Emission Corporation Faxitron, Model 805, radiographic inspection system was used. Specimens were mounted such that the center of the x-ray beam were normal to the face of the specimen. A film-to-source distance (FTSD) of 22.0 inches was used. X-ray parameters found to work best were either 35 kv, 3 ma, for 5 minutes or 35 kv 3 ma, for 6.5 minutes. The longer exposure time is slightly more effective for the detection of higher density inclusions which might be present. Kodak Type AA film was used.

#### 3.4.4 Ultrasonic

Ultrasonic inspections were performed on all P/M specimens in the transmission mode. Ultrasonic C-scans were taken, with the samples immersed in an Automation Industries research tank. Measurements were made with 5MHz transducers with a separation of 5.0 inches. A flaw level of 20 percent was used for these scans.

#### 3.4.5 X-ray Diffraction

For surface residual stress measurements, a portable Ruud-Barrett Residual Stress System was used [13]. This system used x-ray diffraction techniques to measure residual stresses (Figure 12).

| DIAMETERS      |   |   |
|----------------|---|---|
| DEPTH<br>ANGLE | X | Y |
| A              |   |   |
| B              |   |   |
| C              |   |   |
| D              |   |   |
|                |   |   |

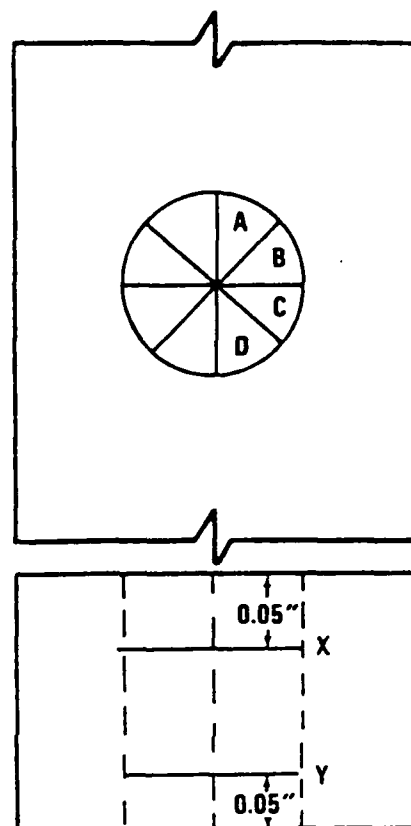


Figure 11. Dial Bore Gauge Inspection Scheme

## PORTABLE RUUD-BARRETT RESIDUAL STRESS SYSTEM



Figure 12. Portable Ruud-Barrett Residual Stress System

In two specimens, residual stress depth profiles were obtained. These measurements were obtained by etching away different thicknesses of material and measuring the depth of removed material.

## SECTION IV

### DURABILITY AND DAMAGE TOLERANCE METHODS DEVELOPMENT

In this section, techniques used in predicting fatigue crack growth (FCG) and determining the equivalent initial flaw size (EIFS) are described. Comparisons of crack growth predictions with actual crack growth data are presented in Section V. EIFS distributions of actual test results are also shown in Section V.

#### 4.1 CRACK GROWTH ANALYSIS

Crack growth analyses were conducted using a computer code called RXN. The RXN computer code is a production code used at General Dynamics/Fort Worth Division [14]. The RXN code is an improved version of R5N which has been used in previous programs [5].

The existing RXN program can analyze up to fifteen different crack geometries using any combination of seven different crack growth models and four retardation models. The combination of geometry type/retardation model/crack growth model is defined simply by selecting the respective values for three input variables. Table 5 lists the specific geometry types, retardation models, and crack growth laws internally available in the program.

These new features available on RXN are especially valuable. First stress intensity factors for both surface flaws [15] and corner cracks at loaded bolt holes [16] are available for the case of bending loading as well as for uniform tension stress. Second, the Rockwell/Chang retardation Model [17] helps to correct for compressive loading effects.

Finally, the tabular input options for the stress intensity factor (either corner bolt hole or through flaws) allows complex or unique stress intensity factor solutions to be incorporated into the crack growth analysis.

For the predictions used in this program, the "Modified Walker Crack Growth Equation" was used in conjunction with the "Generalized Willenborg Retardation Model." These options are listed in Table 5.

TABLE 5. RXN CRACK GROWTH PROGRAM CAPABILITIES

| GEOMETRY TYPES        | RETARDATION MODELS         | CRACK GROWTH LAWS |
|-----------------------|----------------------------|-------------------|
| PT SF TEN (CONST. MF) | WHEELER                    | PARIS             |
| PT SF TEN (EQ. MF)    | GENERALIZED                | FORMAN            |
| PT SF TEN (NEWMAN)    | MULTI-PARAMETER YIELD ZONE | MODIFIED FORMAN   |
| PT SF BEND (NEWMAN)   | ROCKWELL/CHIANG            | WALKER $\Delta K$ |
| TT SF TEN             | NO RETARDATION             | WALKER KMAX       |
| CF AT HOLE TEN        |                            | VROMAN/CHIANG     |
| CF AT HOLE BER        |                            | TABULAR           |
| CF AT HOLE TEN + BER  |                            |                   |
| TT AT HOLE TEN        |                            |                   |
| TT AT HOLE BER        |                            |                   |
| TT AT HOLE TEN + BER  |                            |                   |
| CF AT EDGE TEN        |                            |                   |
| TT AT EDGE TEN        |                            |                   |
| CF (INPUT SIF)        |                            |                   |
| TT (INPUT SIF)        |                            |                   |

PT - PART THROUGH THICKNESS FLAW

CF - CORNER FLAW

TEN - TENSION STRESS

BER - BEARING STRESS

TT - THROUGH THICKNESS FLAW

SF - SURFACE FLAW

BEND - BENDING STRESS

SIF - STRESS INTENSITY FACTOR

All crack growth analyses were conducted for the HUD34 spectrum at a nominal stress level of 40 ksi. Analyses were performed for single and double (symmetric) cracks emanating from the critical fastener holes. Both corner and through cracks were considered. All analyses used appropriate stress intensity factor estimates for loaded bolt holes. The starting crack size was taken as 0.001 inch. Analyses were terminated upon reaching the estimated critical crack size or upon reaching two design lifetimes. Crack geometries are shown in Figure 13.

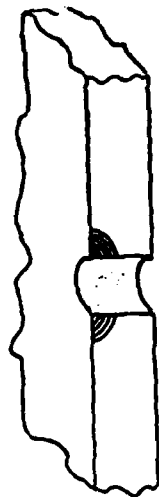
Calculations were conducted for three different materials, 2124-T851, 7475-T7351, and 7091-extrusions. Results of these calculations are shown in Figure 14-16. A comparison of materials for two corner plus a through crack is shown in Figure 17. According to the analysis, superior crack growth resistance is obtained in the 7475-T7351 material as compared to 7091-T7E69 and 2124-T851. Comparisons of predicted crack growth and actual crack growth will be discussed in Section V.

Following a methodology developed previously at GD/FWD [18,19] and using a modified secant method [20], crack growth rate ( $\frac{\Delta a}{\Delta t}$ ) was predicted as a function of crack length,  $a$ . These calculations were conducted for crack geometries, spectra, and stress level shown in Figures 14-16.

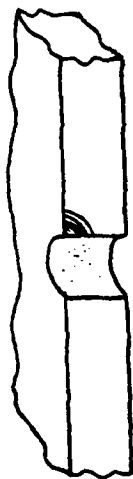
Figures 18-20 summarize the crack growth analyses for three different materials, 2124-T851, 7475-T7351, and 7091-T7E69. A comparison of these materials for two corner and one through crack is shown in Figure 21. Predictions based on this methodology are discussed in Section V.

#### 4.2 DETERMINATION OF EQUIVALENT INITIAL FLAW SIZE

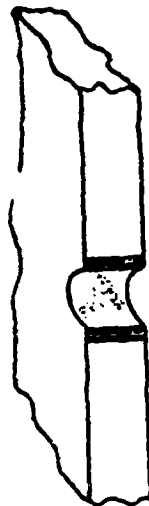
A model for initial fatigue quality based on the equivalent initial flaw size (EIFS) concept has been established from several preceding programs [5,12,21,22]. Many details of the model which support its usage will not be presented here. Several variations in modeling crack growth to fit fractographic data have been presented [5,12,21]. However, the model followed in this program is similar to that used in the "Initial Quality of Advanced Joining Concepts" program [5].



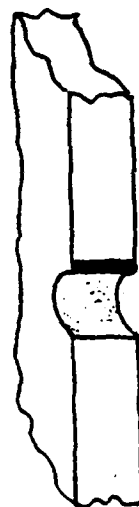
DOUBLE CORNER



SINGLE CORNER



DOUBLE THROUGH



SINGLE THROUGH

Figure 13. Initial Crack Geometries For Crack Growth Predictions

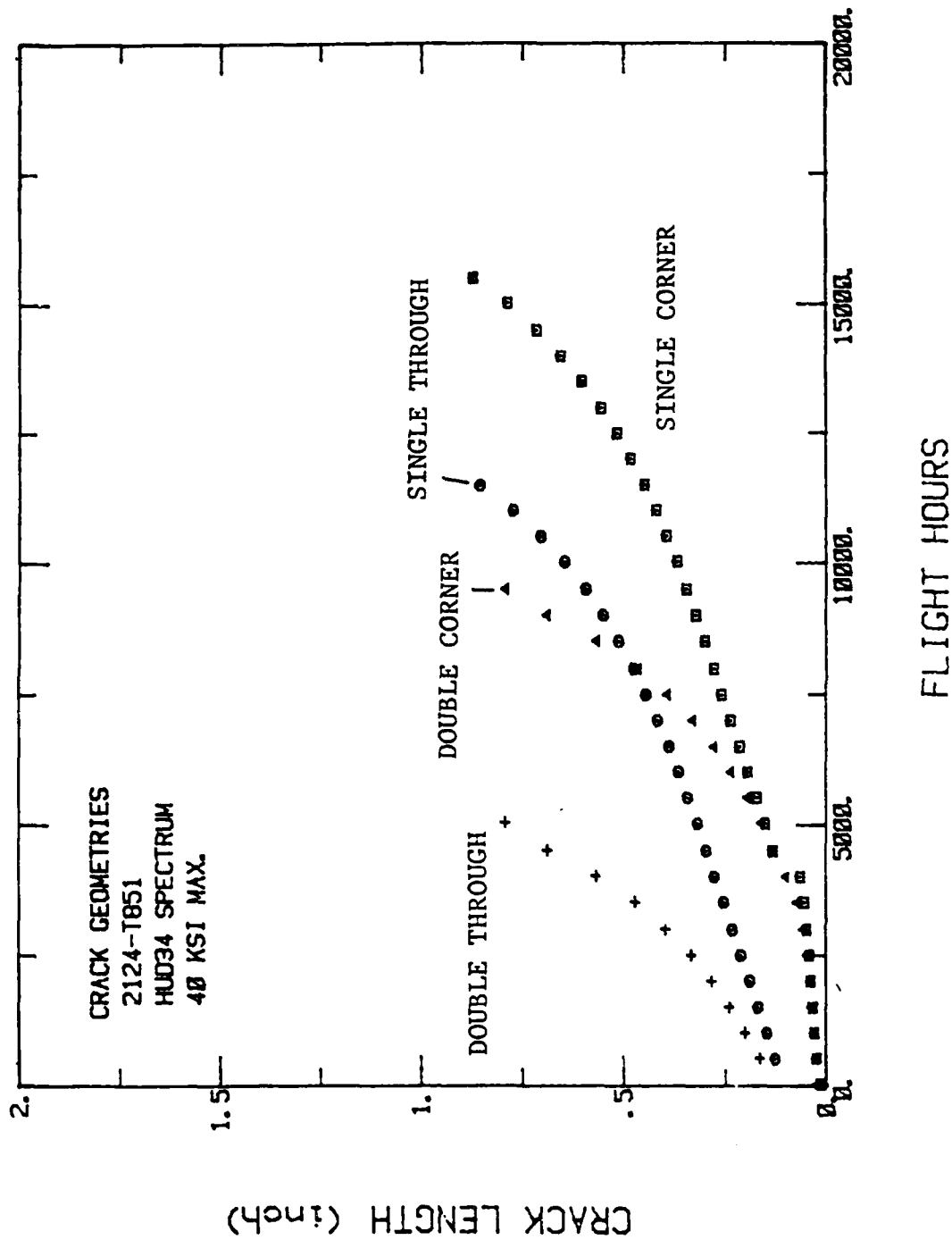


Figure 14. Crack Growth Predictions For 2124-T851 Aluminum Alloy

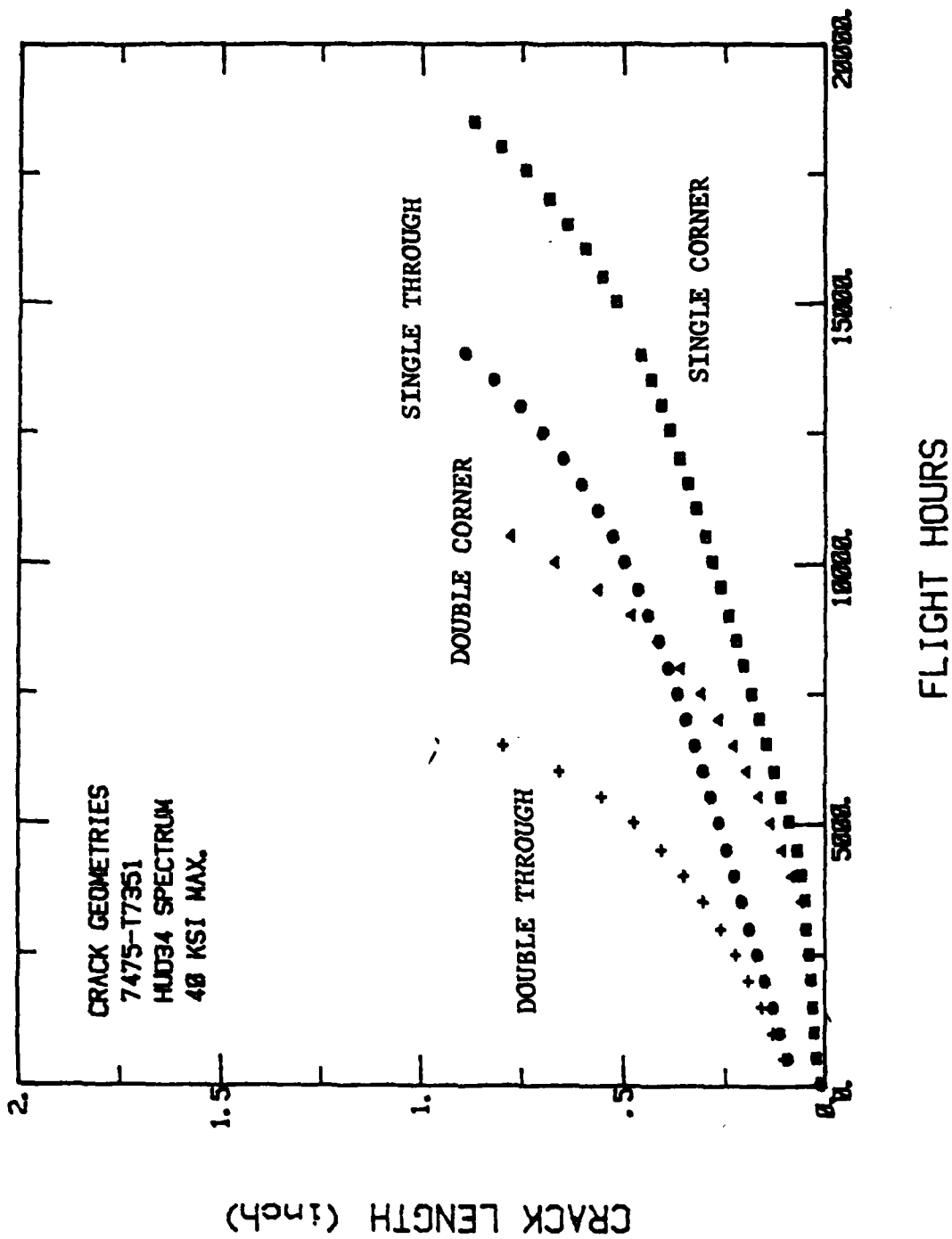


Figure 15. Crack Growth Predictions for 7475-T7351 Aluminum Alloy

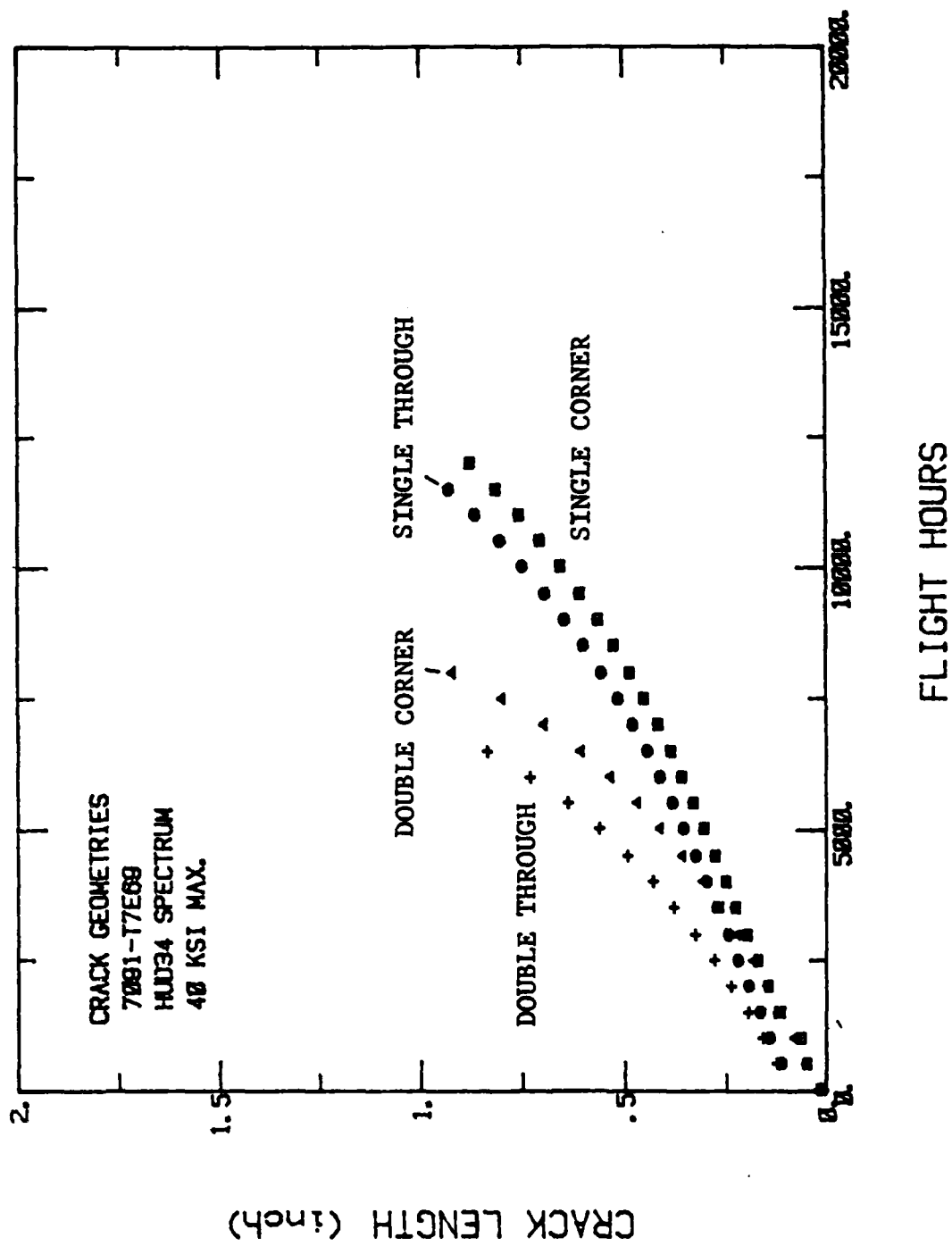


Figure 16. Crack Growth Predictions for 7091-T7E69 Aluminum Alloy

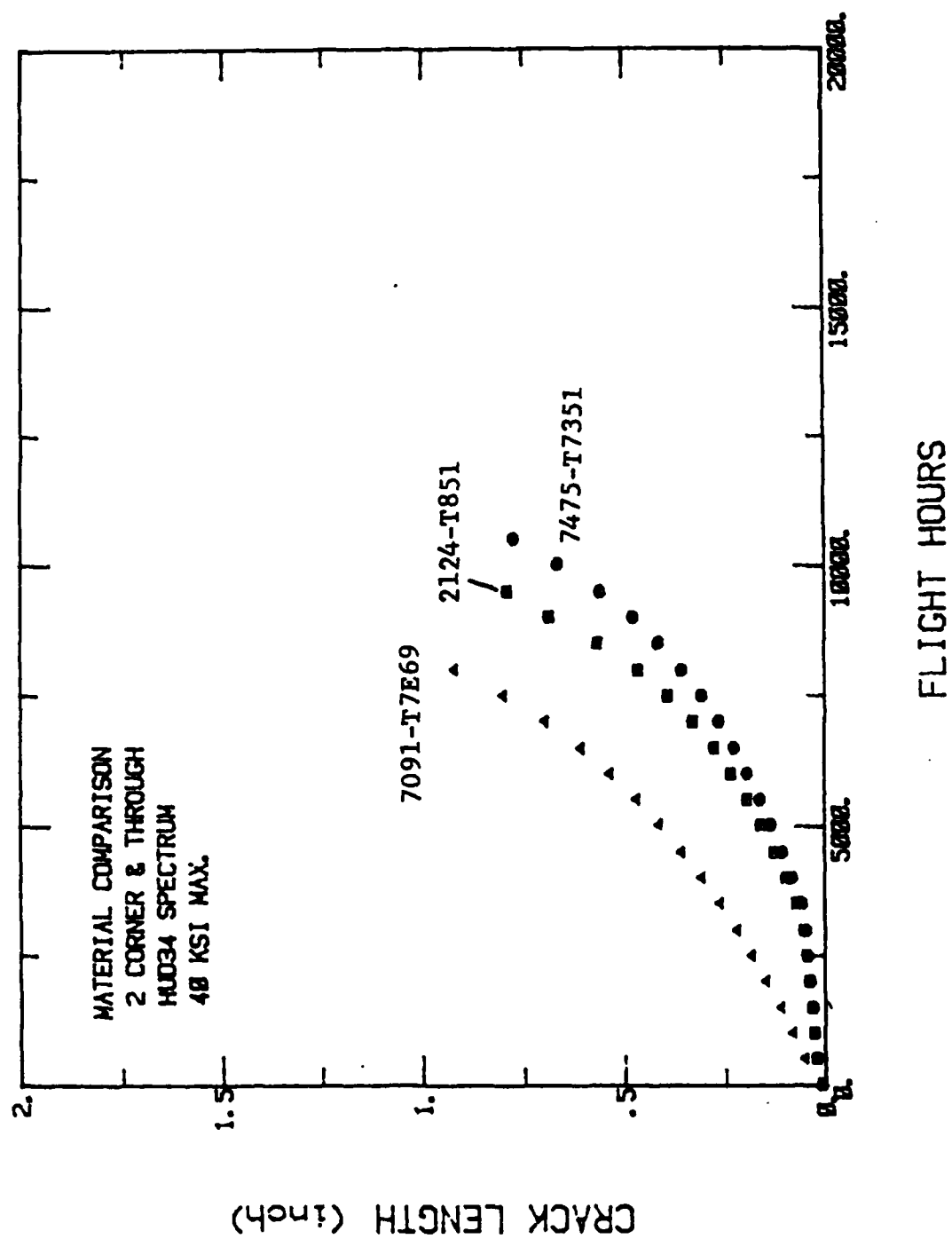


Figure 17. Crack Growth Prediction Comparisons for Three Aluminum Alloys

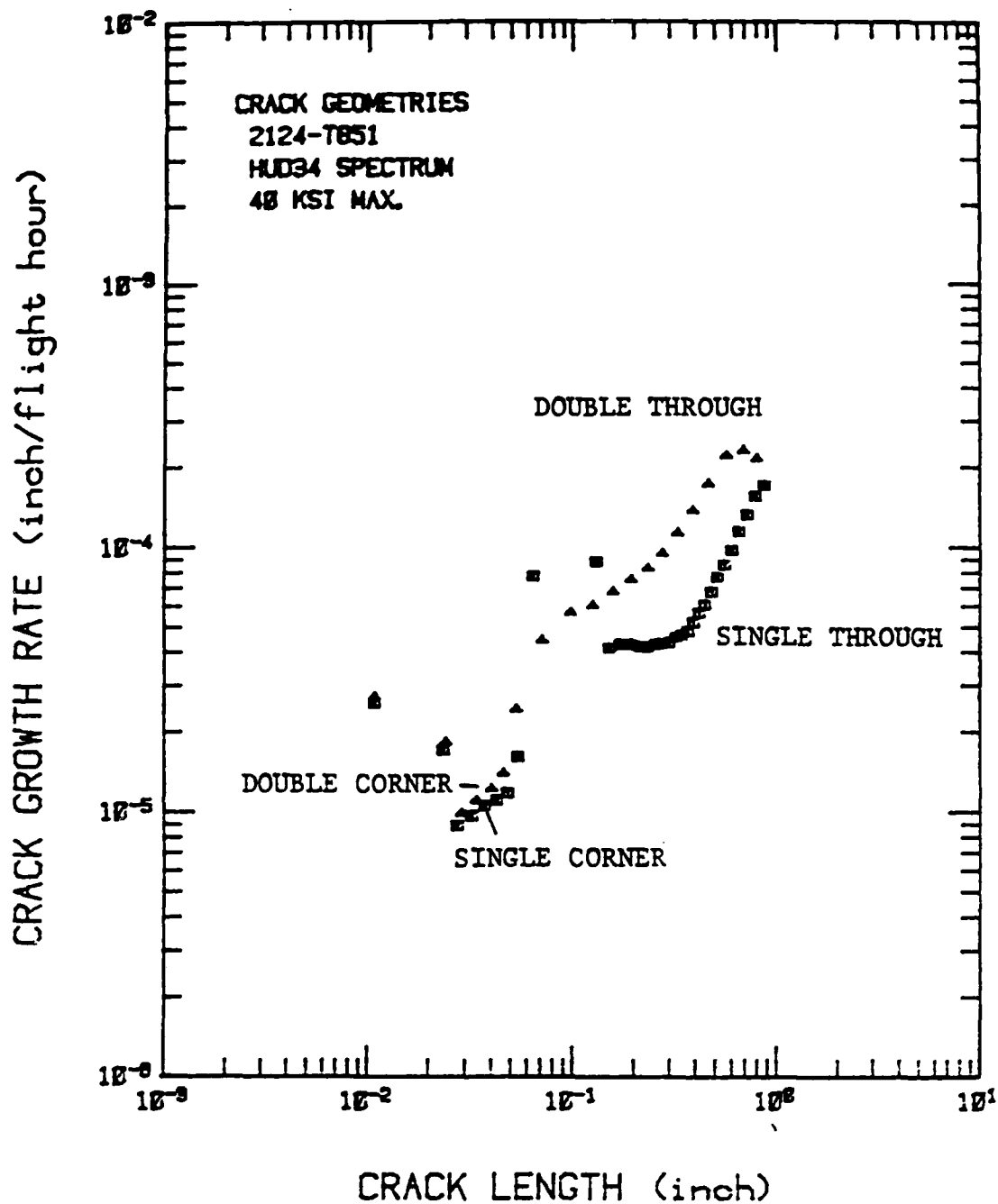


Figure 18. Crack Growth Rate Predictions for 2124-T851 Aluminum Alloy

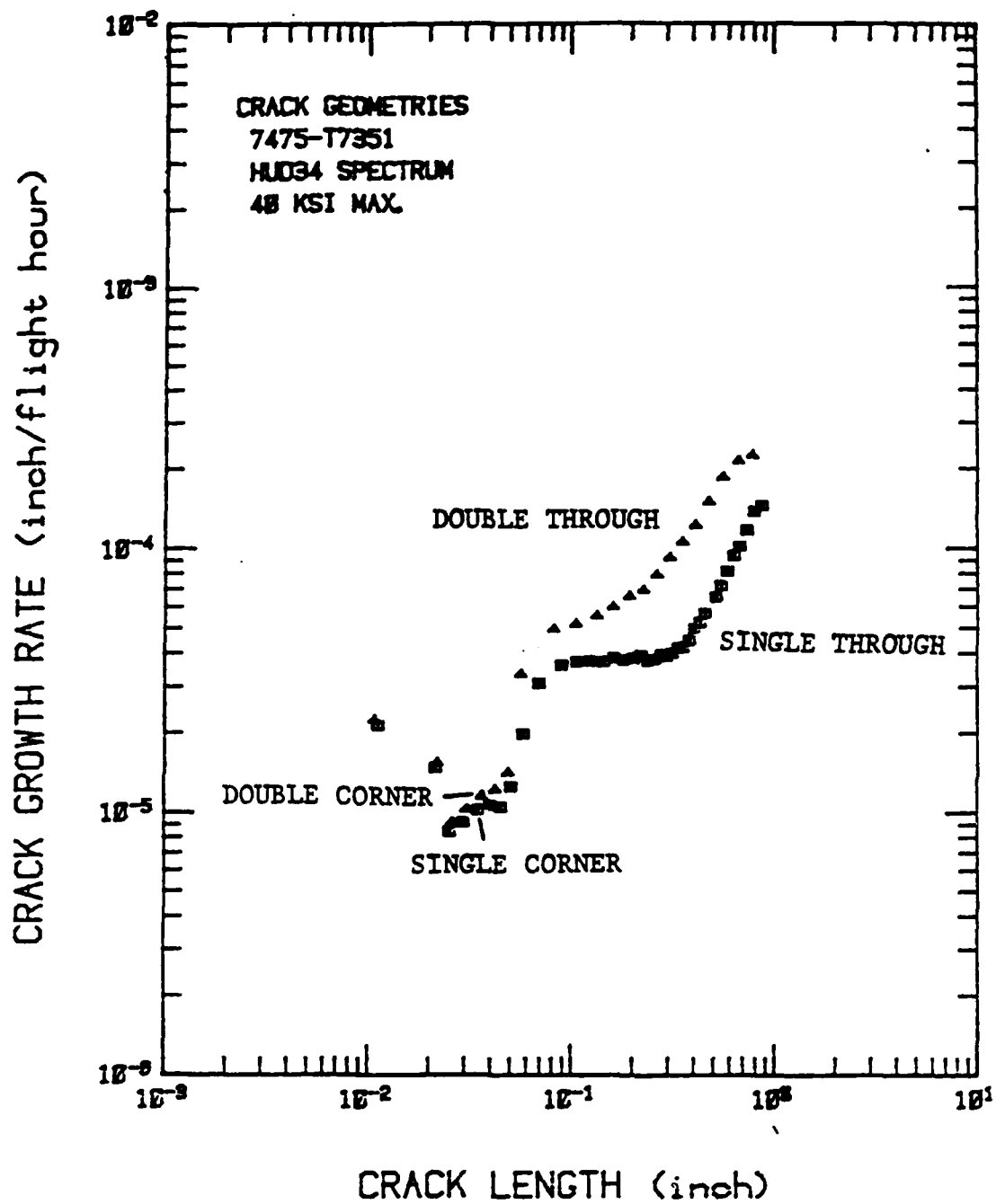


Figure 19. Crack Growth Rate Predictions for 7475-T7351 Aluminum Alloy

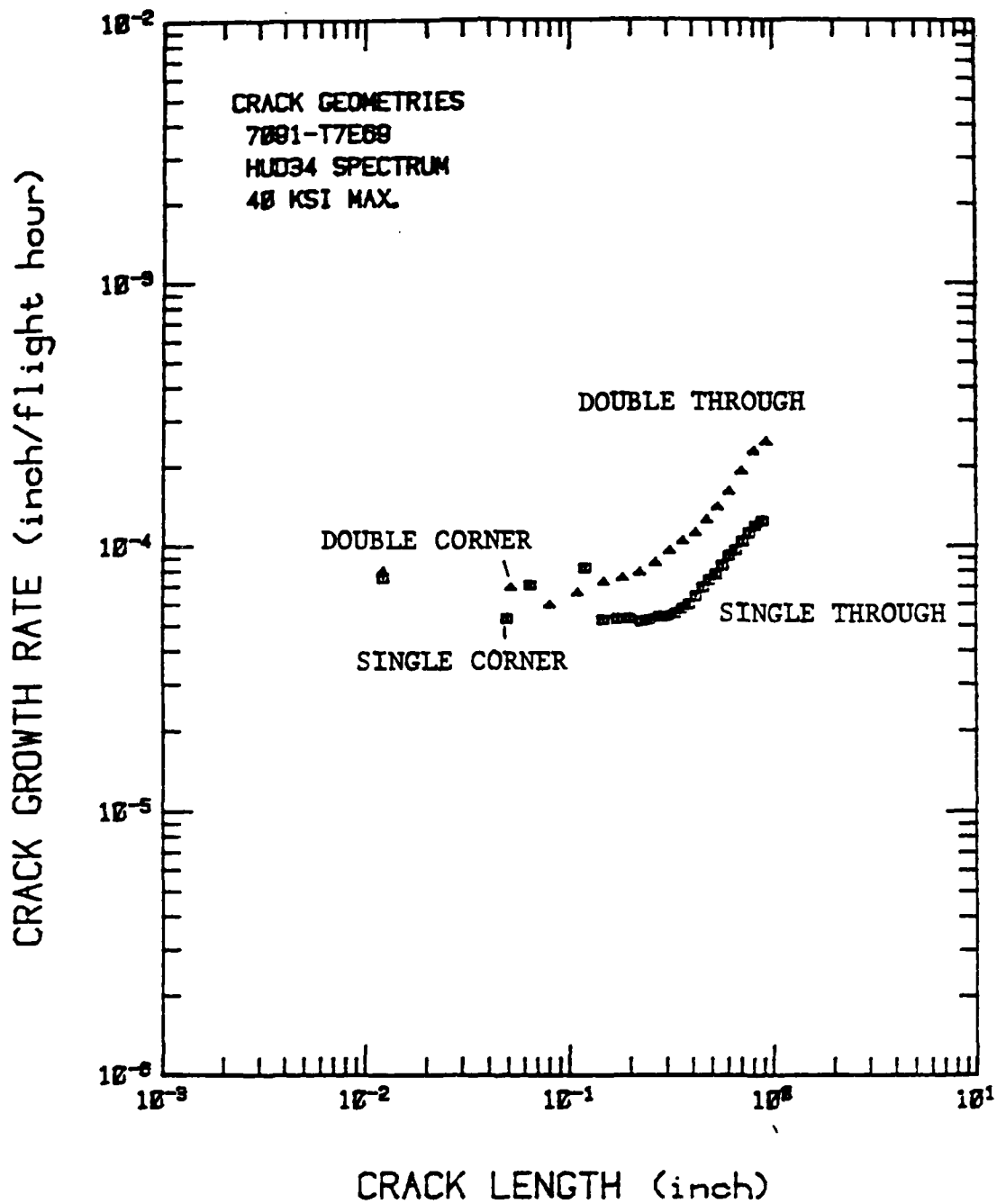


Figure 20. Crack Growth Rate Predictions for 7091-T7E69 Aluminum Alloy

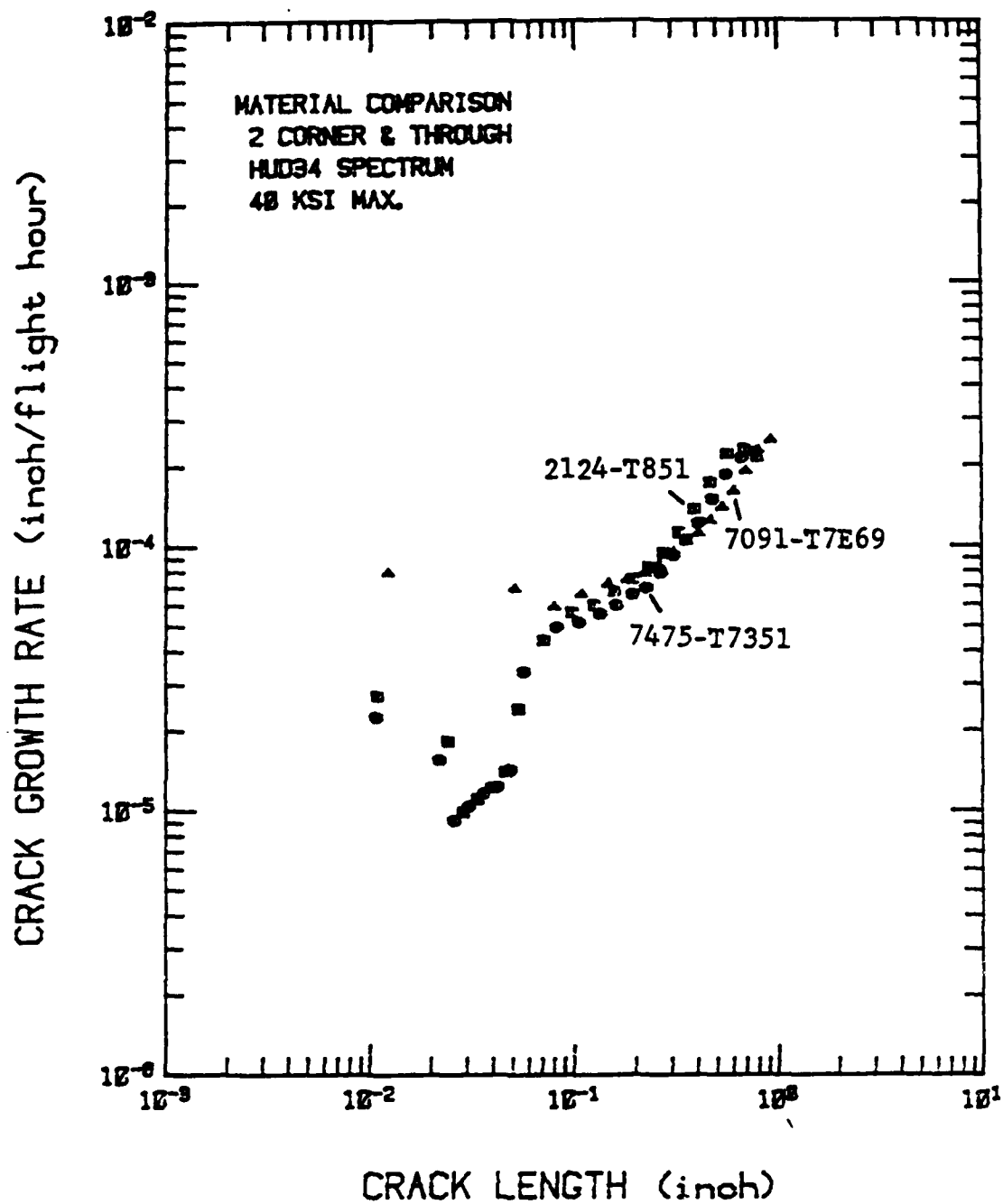


Figure 21. Crack Growth Rate Prediction Comparisons for Three Aluminum Alloys

One of the most important factors governing the structural performance of advanced structural concepts is the initial fatigue quality (IFQ). IFQ defines the initial manufactured state of a structural detail with respect to crack growth which is expected to occur in service. The IFQ for a group of replicate details can be presented by a distribution of equivalent initial flaw sizes (EIFS). Given that a crack occurs in a structure during service, the EIFS is the size of a hypothetical initial flaw which would result in the observed crack. The EIFS can be derived using fractography from fatigue test results. Crack growth observed after fatigue testing (fractography) is extrapolated backward to estimate EIFS. An EIFS distribution is obtained by fitting a statistical distribution to EIFS data sets.

An arbitrary crack size  $a_0$  can be selected such that it can be unambiguously observed. The time required for an initial defect to become a fatigue crack of size  $a_0$  is defined as the time-to-crack-initiation (TTCI). In general, the EIFS distribution is chosen so that the crack growth rate maps the EIFS distribution into the observed TTCI distribution. A conceptual description of the IFQ model is shown in Figure 22.

It has long been noted that fatigue failure distributions can be fit by three-parameter Weibull distributions. Since failure in fracture critical structure corresponds to attainment of the critical crack size, it is reasonable to hope that this distributional form is appropriate for all crack sizes of interest. Preceding programs show [5,18,19] that observed TTCI values for small crack sizes can usually be fit very well by a three-parameter Weibull distribution.

Therefore, a fractographically observed TTCI distribution can be expressed as:

$$F_T(t) = P[T \leq t] = 1 - \exp \left\{ - \left[ \frac{t - \epsilon}{\beta} \right]^\alpha \right\} ; t > \epsilon \quad (1)$$

where  $T$  is a random variable indicating TTCI and  $F_T(t)$  is just  $P[TTCI \leq t]$ . The Weibull parameter  $\alpha$ , is the shape parameter,  $\beta$  is the scale parameter, and  $\epsilon$  is the lower bound of TTCI. The parameters  $\alpha$ ,  $\beta$  and  $\epsilon$ , are determined from a best-fit of fractography data, according to conditions discussed further below.



The crack growth rate over the crack size range of interest is assumed to be expressed as:

$$\left| \frac{da(t)}{dt} = Q[a(t)]^b \right. \quad (2)$$

where  $a(t)$  is the crack size at time  $t$ , and  $Q$  and  $b$  are constants that are determined from the least square fit of all  $\log da/dt$  vs.  $\log a$  pairs of the sample.

Integrating Eq. (2) from  $t = 0$  to  $t = T$ , the relationship between the crack size at  $t = 0$ ,  $a(0)$  (i.e., EIFS), and that at  $t = T$  (i.e.  $a_0$ ) is found to be:

$$\left| \text{EIFS} = a(0) = \frac{a_0}{(1 + a_0^c cQT)^{1/c}} \right. \quad (3)$$

where  $c = b - 1$ .

Combining Eq. (1) and (3), one may obtain the EIFS distribution as:

$$\left| \begin{aligned} F_{a(0)}(x) &= \exp \left\{ - \left[ \frac{x^{-c} - x_u^{-c}}{cQ\beta} \right]^a \right\} ; 0 < x \leq x_u \\ &= 1 ; x \geq x_u \end{aligned} \right. \quad (4)$$

where  $F_{a(0)}(x)$  is just  $P[\text{EIFS} < x]$  and where  $x_u$  is the upper bound of the EIFS which is defined as:

$$x_u = [a_0^{-c} + cQ\epsilon]^{-1/c} \quad (5)$$

Therefore, the EIFS distribution can be determined from Eq. (4), if the parameters  $Q$ ,  $c = b-1$ ,  $\alpha$ ,  $\beta$ , and  $\epsilon$  are properly calibrated based on the fractographic data.

As mentioned previously, EIFS is intuitively a generic property of such factors as the material, manufacturing/assembly techniques, and workmanship and should be independent of load spectrum and stress level. Eq. (4) shows that the necessary conditions to ensure that the EIFS distribution is generic among two or more data sets are:

$$\begin{aligned} b_1 &= b_2 = \dots = b_n \\ \alpha_1 &= \alpha_2 = \dots = \alpha_n \\ Q_1\beta_1 &= Q_2\beta_2 = \dots = Q_n\beta_n \end{aligned} \quad (6)$$

Accordingly, it is recommended that any sample of identically prepared test elements be randomly split into at least two groups (Figure 23). These should be tested at different stress levels. If possible, a third group tested with a different spectrum is desirable. Then all fractography is least squares fit subject to the conditions given in Eq. (6). Adequate fits to the data have been found so far using this procedure, and this procedure ensures that the EIFS is as generic as can be among the conditions tested. Testing at two stress levels also reveals the dependence of crack growth on stress level, which is useful for performing trade studies.

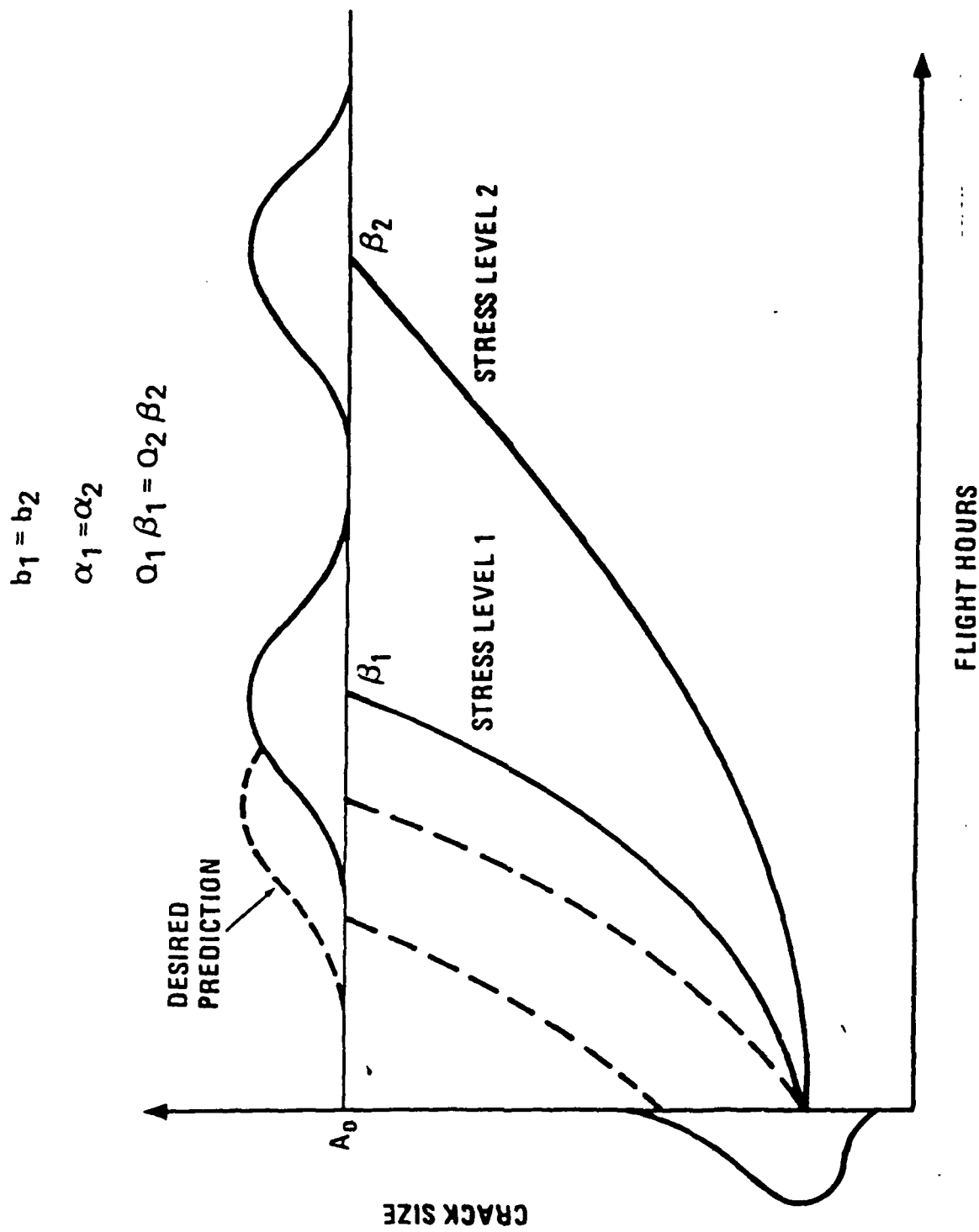


Figure 23. Generic EIFS Concept

## SECTION V

### RESULTS AND DISCUSSION

In this section, all experimental results are presented and analyzed. These results include: (1) basic mechanical properties, (2) NDI results, and (3) spectrum fatigue tests. Spectrum fatigue results are divided into the following categories: (a) time-to-failure (TTF), (b) fatigue crack growth rate (FCGR), (c) time-to-crack-initiation (TTCl), and (d) measurements of equivalent initial flaw size (EIFS).

Also, in this section, the durability and damage tolerance of RST structures are discussed. Methodology used in comparing RST structures with conventional I/M structures is presented and discussed. Techniques which can be used in design studies are proposed.

#### 5.1 MECHANICAL PROPERTIES

Table 6 shows basic mechanical properties of 2124-T851, 7475-T7351, 7091-T7E69 extruded material, 7091-forgings, and CW67-T7E91 extruded material.

Improved strength is observed in the RST P/M alloys as compared to the ingot metallurgy materials. Ultimate tensile strengths as high as 90 ksi were observed in the CW67 extruded material in the (L) orientation.

Fracture toughness values of CW67-T7E91 are quite high, also. Values as high as 50 ksi  $\sqrt{\text{in.}}$  (L-T orientation) were obtained from one billet of material. These toughness values are comparable to values obtained for 7475-T7351 (48 ksi  $\sqrt{\text{in.}}$ ) and higher than those obtained in 7091-T7E69 and 2124-T851 (36 ksi  $\sqrt{\text{in.}}$  and 29 ksi  $\sqrt{\text{in.}}$ , respectively.

By controlling the heat treat, the mechanical properties of 7091-forgings were quite similar to values obtained for 7091-extrusions (Table 6). As discussed in Section III, final aging times at 325°F were extended in the 7091-forged material in order to achieve these strength values.

TABLE 6. BASIC MECHANICAL PROPERTIES OF LONGITUDINAL ORIENTATION

| MATERIAL   | YIELD<br>STRENGTH<br>(ksi) | TENSILE<br>STRENGTH<br>(ksi) | PERCENT<br>ELONGATION<br>(%) | FRACTURE<br>TOUGHNESS<br>(ksi $\sqrt{\text{in.}}$ ) |
|------------|----------------------------|------------------------------|------------------------------|-----------------------------------------------------|
| 2124-T851  | 64                         | 71                           | 9                            | 29                                                  |
| 7475-T7351 | 63                         | 73                           | 14                           | 48                                                  |
| 7091-T7E69 | 75                         | 83                           | 14                           | 36                                                  |
| 7091-FORG. | 73                         | 80                           | 15                           | --                                                  |
| CW67-T7E91 | 86                         | 90                           | 12                           | 50                                                  |

Results of mechanical tests conducted on CW67 extrusions are shown in Table 7. The first batch of spectrum fatigue coupons tested were obtained from a CW67 powder billet, #514553-2. The specimens tested later were obtained from powder billets, #514570 and #514571. Higher strengths and larger fracture toughness values were obtained for material obtained from billet #514553-2. Better fatigue properties were also obtained from test coupons fabricated from this billet. Fatigue properties are discussed in Section 5.3. Slightly higher elongation and reduction of area was obtained in CW67 extrusions obtained from billets #514570 and #514571.

Some anisotropy was observed in basic mechanical properties for the CW67 extrusions. Ultimate tensile strengths are observed to decrease from 90.7 ksi in the front (L) orientation to 82.7 ksi in the rear (ST) orientation for material from the #514553-2 billet. Fracture toughness values decreased from 49.8 ksi  $\sqrt{\text{in.}}$  in the (L-T) orientation to 24.1  $\sqrt{\text{ksi}}$  in. in the (S-L) orientation for the same material.

## 5.2 NDI RESULTS

### 5.2.1 Baseline Specimens

Eddy current and dial bore gauge measurements were made on all fastener holes of the spectrum fatigue test coupons. NDI parameters such as eddy current amplitude, hole out-of-roundness, and hole diameter were measured and compared to fatigue life.

Typical eddy current scans for fastener holes in two test coupons, are shown in Figure 24. Also shown is the eddy current signature from a reference hole containing a 0.022-inch-deep fatigue crack. In general, no correlation was observed between eddy current amplitude and fatigue life. Typical results where eddy current amplitude is plotted as a function of fatigue life is shown in Figure 25. These results are shown for 7475-T7351 test coupons imposed to the NOR 1 spectrum. Eddy current results indicated that the hole quality was fairly equivalent in all of the holes.

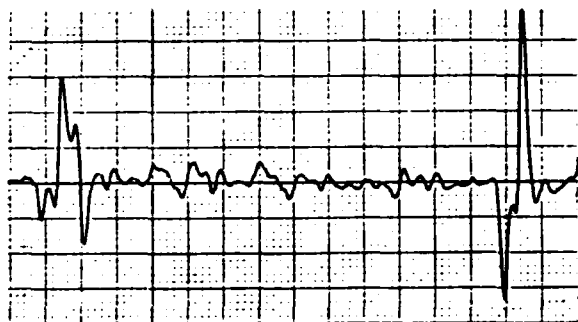
Dial bore gauge results also indicated little correlation between hole quality parameters such as out-of-roundness or oversized holes with fatigue life. Results are shown in Figures 26-

TABLE 7. RESULTS OF MECHANICAL TESTS ON CW67 EXTRUSION

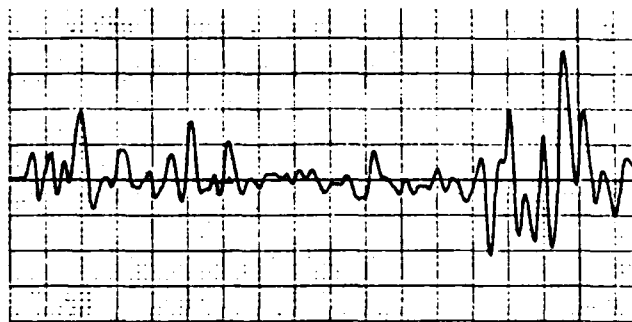
| Billet No.        | Temper | Location of Test Specimens | Specimen Orientation | UTS (ksi) | YS (ksi) | EL ( %) | RA ( %) | K <sub>1c</sub> (ksi $\sqrt{\text{in.}}$ ) |
|-------------------|--------|----------------------------|----------------------|-----------|----------|---------|---------|--------------------------------------------|
| 514553-2          | T7E91  | Front                      | L (L-T)              | 90.7      | 86.2     | 11.8    | 23      | 49.8                                       |
|                   |        |                            | LT (T-L)             | 85.9      | 81.6     | 10.9    | 23      | 29.8                                       |
|                   |        |                            | ST (S-L)             | 84.0      | 74.3     | 8.6     | 13      | 24.1                                       |
|                   |        | Rear                       | L (L-T)              | 89.7      | 85.0     | 12.3    | 24      | 49.8                                       |
|                   |        |                            | LT (T-L)             | 84.0      | 79.8     | 10.7    | 26      | 31.0                                       |
|                   |        |                            | ST (S-L)             | 82.7      | 73.6     | 9.9     | 22      | 27.3                                       |
| 514570 and 514571 |        | Front                      | L(L-T)               | 89.2      | 84.7     | 12.9    | 31.0    | 44.1                                       |
|                   |        |                            | LT(T-L)              | 84.7      | 78.4     | 12.9    | 25.2    | 24.0                                       |
|                   |        |                            | ST (S-L)             | 82.2      | 72.9     | 8.7     | 18.0    | 20.4                                       |
|                   |        | Rear                       | L(L-T)               | 86.4      | 81.3     | 13.3    | 34.4    | 45.7                                       |
|                   |        |                            | LT(T-L)              | 81.0      | 74.1     | 12.0    | 27.9    | 26.1                                       |
|                   |        |                            | ST(S-L)              | 81.3      | 68.8     | 9.7     | 18.2    | 25.5                                       |

\* Results obtained from Alcoa.

(a) 2124 Specimen 2124-6(1)



(b) Specimen 2124-41(2)



(c) Standard specimen - .022" fatigue crack

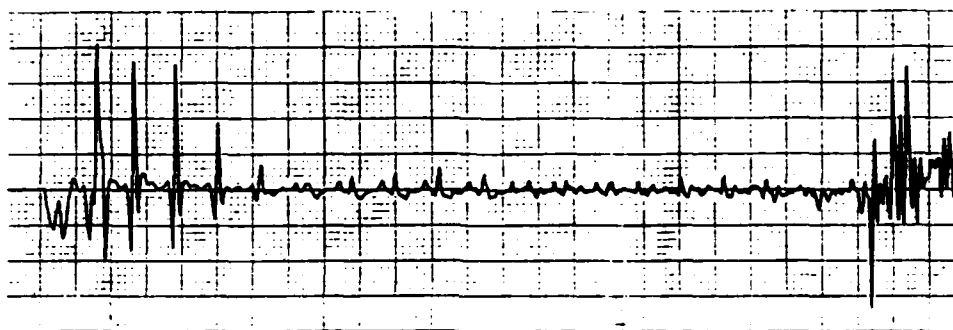


Figure 24. Typical Eddy Current Bolt Hole Scans.

(a) Specimen No. 2124-6, (b) Specimen No. 2124-41,  
(c) Standard Specimen with .022 Inch Fatigue Crack

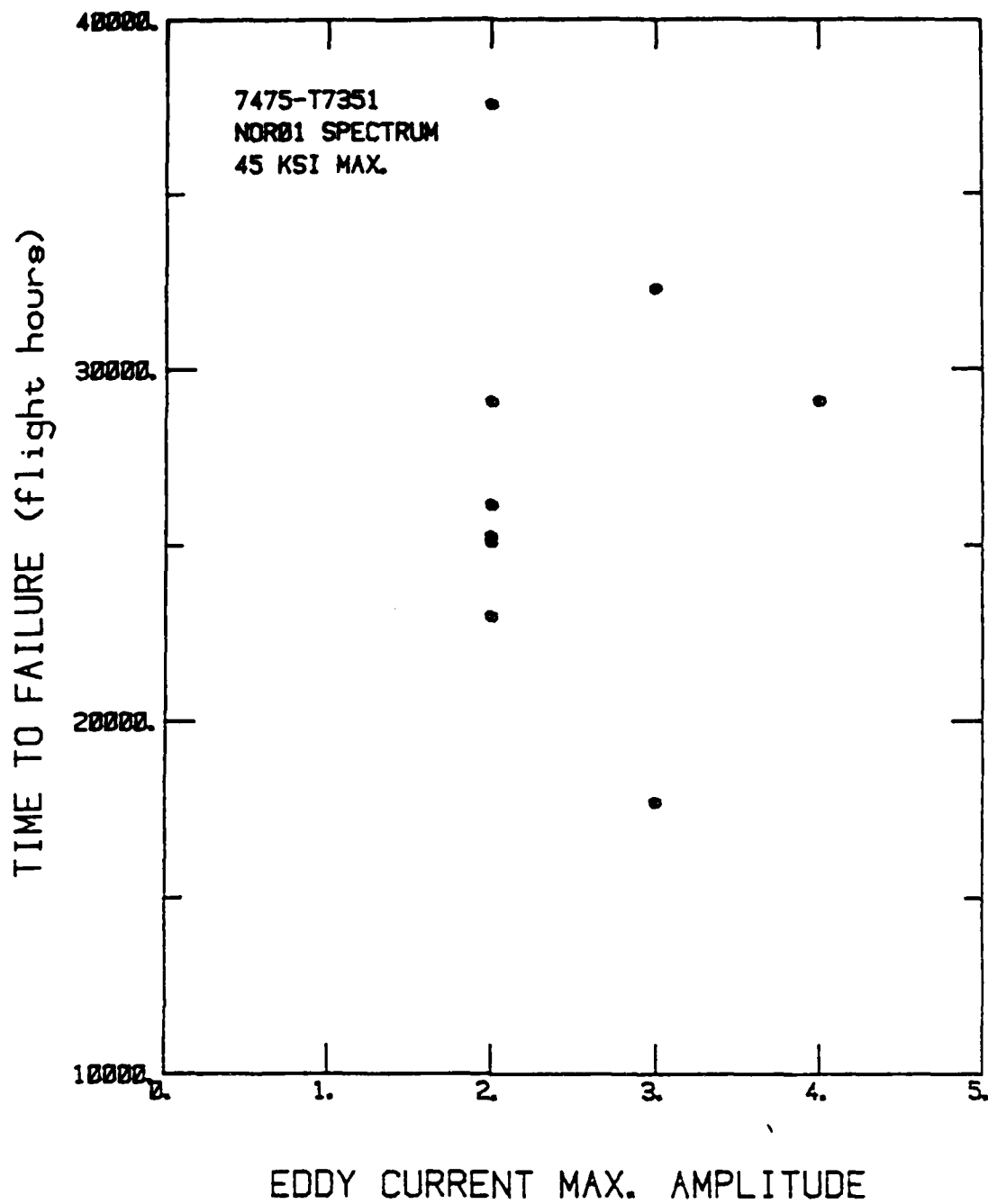


Figure 25. Eddy Current Amplitude Versus Time-To-Failure  
In 7475-T7351 Aluminum Alloy

27 for 7475-T7351 test coupons tested under the NOR 1 spectrum at a maximum spectrum stress of 45 ksi.

The results of little or no correlation between fatigue behavior and hole quality as measured by the two different NDE techniques are consistent with results obtained from the "Fastener Hole Quality" [12] and "Initial Quality of Advanced Joining Concept programs" [5]. In the "Fastener Hole Quality" program, flaws which degraded the cosmetic hole quality, such as rifling marks, gouges, drill tool chatter marks, etc., did not necessarily affect structural fatigue performance.

#### 5.2.2 RST Specimens

Eddy current and dial bore gauge measurements were also made on all fastener holes in the RST test coupons. In addition, ultrasonic and x-ray inspections were made on all of the P/M specimens and residual stress measurements were made on the 7091-forged test coupons. Ultrasonic and x-ray inspections were only made on the RST test coupons since control of inclusions is considered extremely important in these materials. Both ultrasonic and x-ray inspection techniques are considered sensitive NDI techniques for detecting these inclusions.

Similar to results obtained for baseline coupons, no correlation between NDI parameters such as eddy current amplitude, hole out-of-roundness, and hole diameter and fatigue life were obtained in the RST materials.

Ultrasonic and x-ray inspections of the RST test coupons revealed no large inclusions or voids in these materials. A typical ultrasonic C-scan of the 7091 material is shown in Figure 28. Inspections of the 7091-forged test coupons did not reveal any defects due to forging such as forging laps.

Residual stress measurements taken on the surface of the 7091-forged coupons before testing indicated small compressive stresses. The depth of this compressive layer measured less than 0.010 inch deep as shown in residual stress depth profile measurements (Table 8). Little correlation between magnitude of the surface residual stresses and time-to-failure were observed in 7091-forged coupons tested under the HUD34 spectrum at a maximum stress level of 45 ksi (Figure 29).

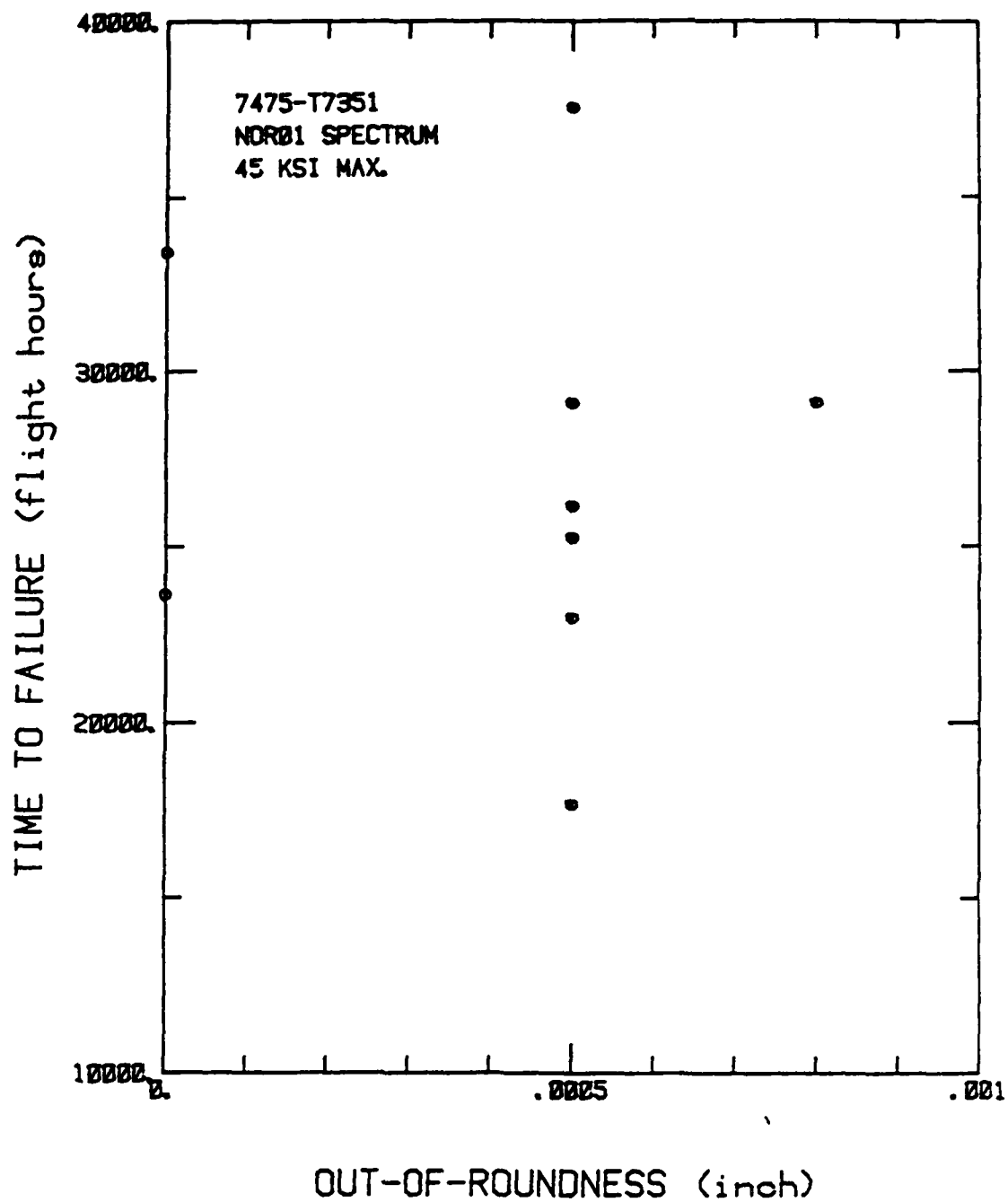


Figure 26. Hole Out-Of-Roundness Versus Time-To-Failure In  
7475-T7351 Aluminum Alloy

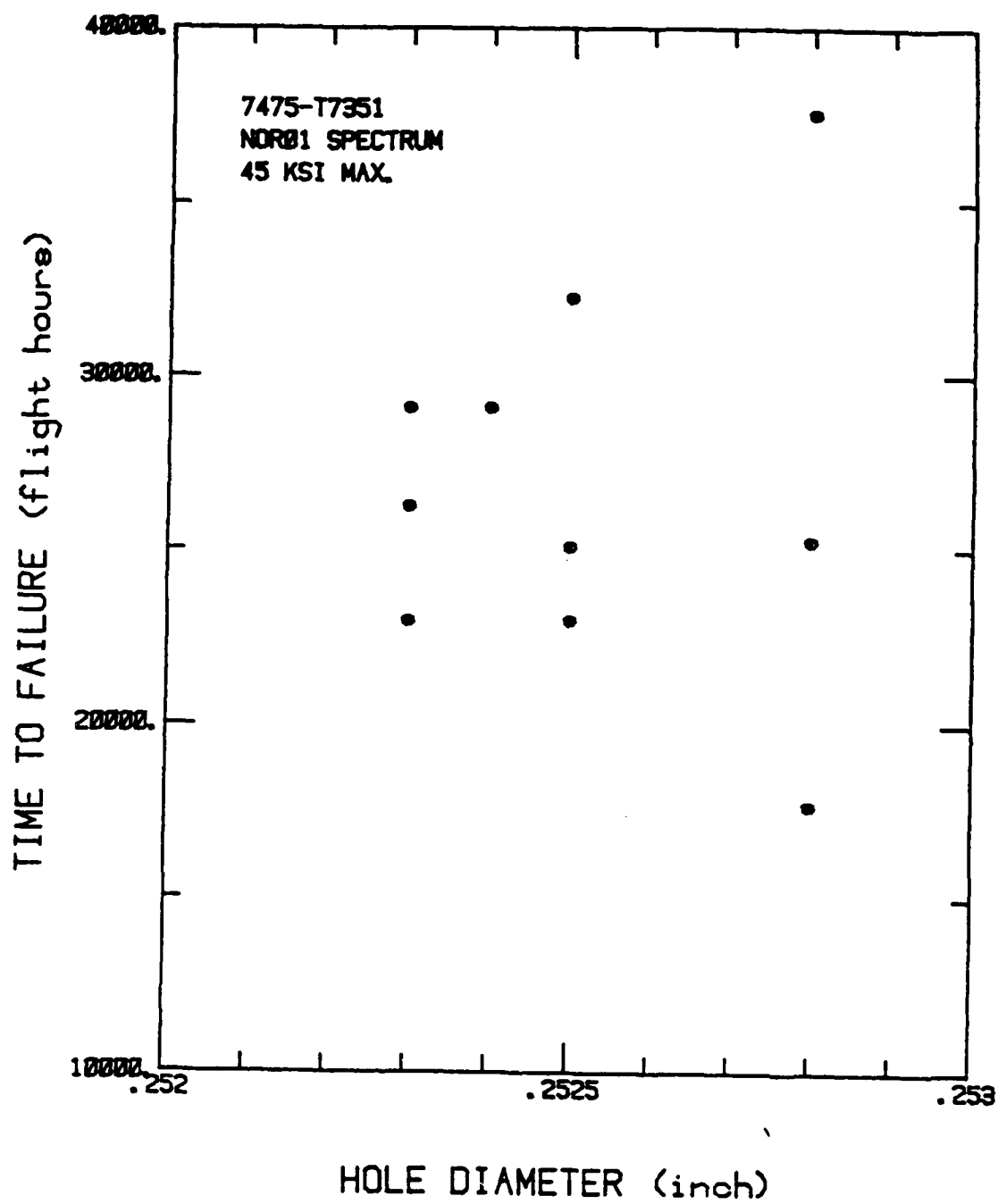
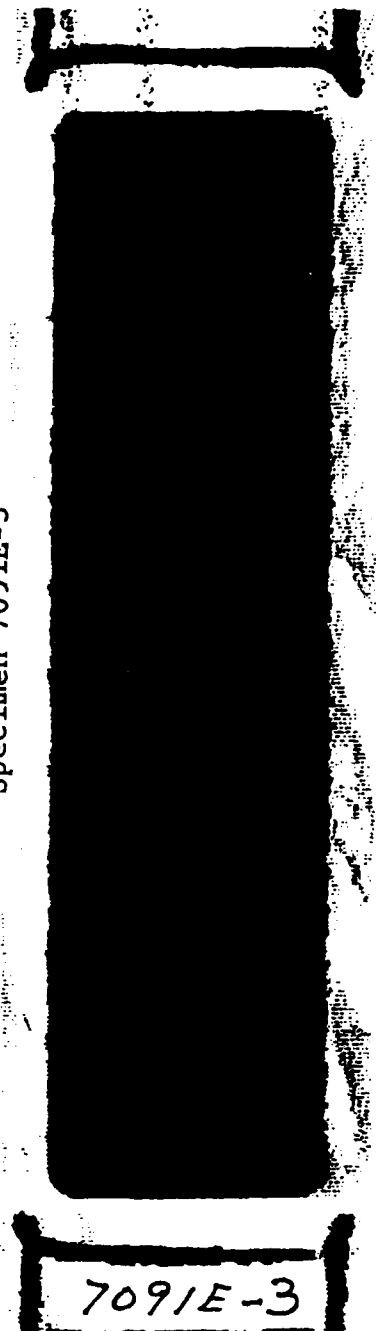


Figure 27. Hole Diameter Versus Time-To-Failure In  
7475-T7351 Aluminum Alloy

Specimen 7091E-3



Specimen 7091E-5

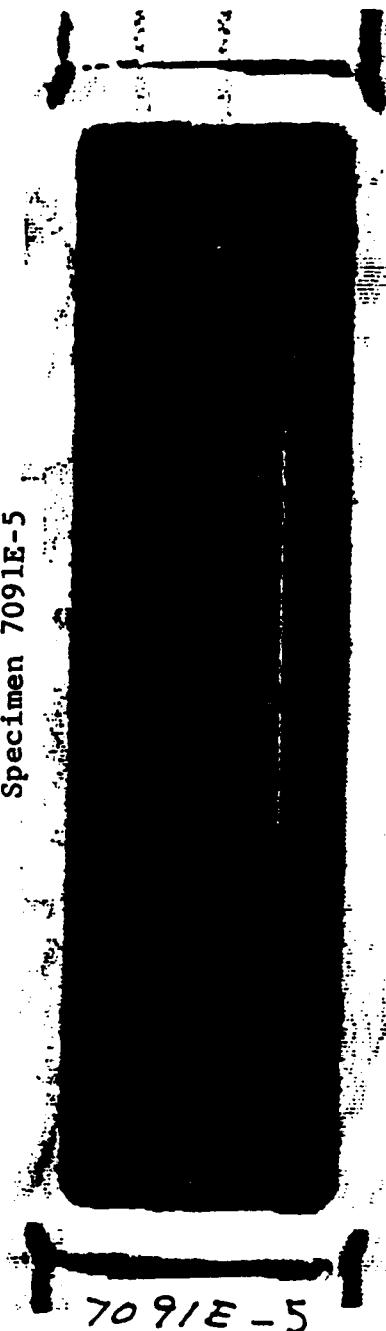


Figure 28. Typical Ultrasonic C-Scan In 7091 Aluminum Alloy

TABLE 8. RESIDUAL STRESS DEPTH PROFILE

| <u>7091F-12</u>              |                               | <u>7091F-17</u>              |                               |
|------------------------------|-------------------------------|------------------------------|-------------------------------|
| <u>DEPTH</u><br><u>(In.)</u> | <u>STRESS</u><br><u>(ksi)</u> | <u>DEPTH</u><br><u>(In.)</u> | <u>STRESS</u><br><u>(ksi)</u> |
| SURFACE                      | -10                           | SURFACE                      | -16                           |
| 0.001                        | -12                           | 0.002                        | -14                           |
| 0.002                        | -13                           | 0.004                        | -14                           |
| 0.010                        | -1                            | 0.010                        | -2                            |

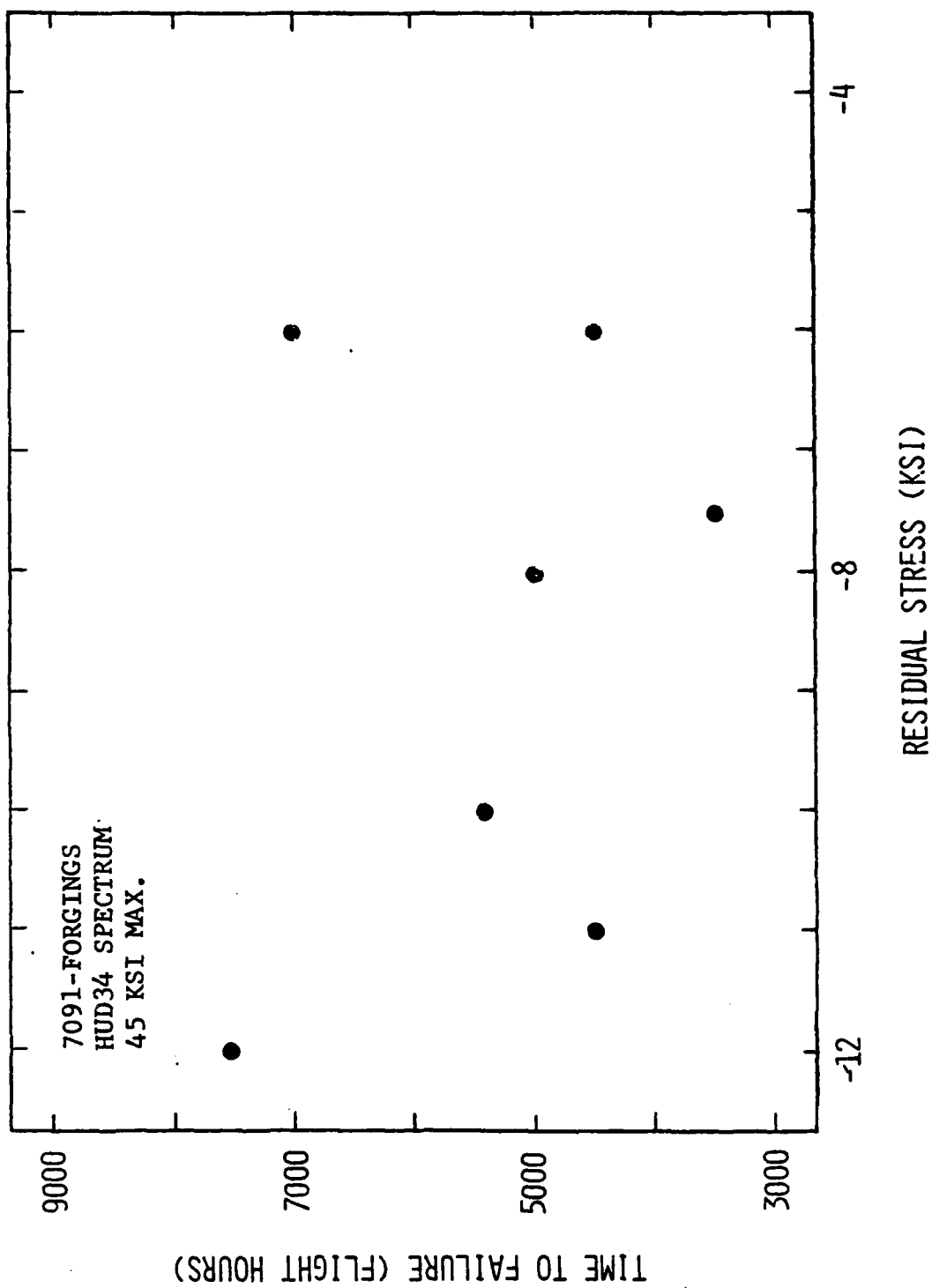


Figure 29. Residual Stress Versus Time-To-Failure In  
7091-Forged Specimens

### 5.3 SPECTRUM FATIGUE TESTS

Results of the spectrum fatigue tests are given in this section. Results are based on approximately 150 tests. The section is divided into four areas: (a) time-to-failure (TTF), (b) fatigue crack growth rate (FCGR), (c) time-to-crack-initiation (TTCI), and (d) measurements of equivalent initial flaw size (EIFS).

All spectrum fatigue crack growth data were analyzed based upon the equivalent initial flaw size (EIFS) concept [5,12,18,21,22]. The basic elements of the initial fatigue quality (IFQ) model include a power law crack growth description containing parameters  $Q$  and  $b$  and a Weibull distribution describing the time for a fatigue crack to grow to any arbitrary size,  $a_0$ . The Weibull distribution is described by parameters  $\alpha$ ,  $\beta$ , and  $\epsilon$ . The concepts of the IFQ model and the procedures for determining IFQ model parameters are described in detail in Section 4.2.

Table 9 summarizes the IFQ model parameters for this program. Table 9 shows that the values of  $b$ ,  $\alpha$ , and  $Q\beta$  do not vary with the test condition. These invariance conditions must be satisfied in order for the equivalent initial flaw size (EIFS) distribution to be generic, that is, independent of spectrum or stress level. This property is desirable since we expect the initial fatigue quality to depend on structural concept, material, and manufactured quality rather than on subsequent service conditions.

The information in Table 9 is a complete description of the results of approximately one hundred fifty spectrum tests. It contains all the information necessary for determining the crack growth performance of each structural concept. It is the information needed for predicting crack growth behavior, as shown in Section 4.  $Q$  and  $b$  in Table 9 describe the average crack growth for each test condition, according to equation (2). The parameters  $\alpha$  and  $\beta$ , describe the time to initiate a crack of arbitrary size  $a_0$ . The upper bound of the EIFS distribution,  $x_U$ , is determined by the other parameters.

TABLE 9 INITIAL FATIGUE QUALITY MODEL PARAMETERS

| SPECIMEN   | SPECTRUM | STRESS<br>(KSI) | $a_0$<br>(IN.) | $X_U$<br>(IN.) | $Q$                       | $b$    | $\alpha$ | $\beta$ | $Q\beta$ | TTF<br>(FHrs) | $a_{crit}$<br>(IN.) |
|------------|----------|-----------------|----------------|----------------|---------------------------|--------|----------|---------|----------|---------------|---------------------|
| 2124-1851  | HUD34    | 35              | 0.15           | 0.15           | 3.4012 X 10 <sup>-4</sup> | 0.8209 | 2.8556   | 11088   | 3.7713   | 14993         | .74                 |
|            | HUD34    | 40              | 0.15           | 0.15           | 7.8911 X 10 <sup>-4</sup> | 0.8209 | 2.8556   | 4779    | 3.7713   | 5886          | .49                 |
|            | NOR1     | 45              | 0.15           | 0.15           | 2.6592 X 10 <sup>-4</sup> | 0.8209 | 2.8556   | 14182   | 3.7713   | 15423         | .59                 |
| 7475-T7351 | NOR1     | 45              | 0.15           | 0.15           | 1.5314 X 10 <sup>-4</sup> | 0.8343 | 3.5257   | 20749   | 3.1776   | 26465         | .69                 |
| 7091-EXTR. | HUD34    | 40              | 0.15           | 0.15           | 1.4106 X 10 <sup>-4</sup> | 0.6096 | 2.4417   | 9830    | 1.3866   | 17997         | .78                 |
|            | HUD34    | 45              | 0.15           | 0.15           | 3.8433 X 10 <sup>-4</sup> | 0.6096 | 2.4417   | 3608    | 1.3866   | 7309          | .80                 |
|            | NOR1     | 45              | 0.15           | 0.15           | 6.5999 X 10 <sup>-5</sup> | 0.6096 | 2.4417   | 21009   | 1.3866   | 36949         | .74                 |
|            | NOR1     | 50              | 0.15           | 0.15           | 1.3795 X 10 <sup>-4</sup> | 0.6096 | 2.4417   | 10051   | 1.3866   | 15238         | .72                 |
| 7091-FORG. | HUD34    | 40              | 0.15           | 0.15           | 1.7583 X 10 <sup>-4</sup> | 0.5622 | 2.6221   | 6709    | 1.1796   | 11667         | .80                 |
|            | HUD34    | 45              | 0.15           | 0.15           | 3.7679 X 10 <sup>-4</sup> | 0.5622 | 2.6221   | 3131    | 1.1796   | 5544          | .80                 |
| CW67       | HUD34    | 40              | 0.15           | 0.15           | 2.1798 X 15 <sup>-4</sup> | 0.7094 | 2.6717   | 6386    | 1.5818   | 14360         | .92                 |
|            | HUD34    | 45              | 0.15           | 0.15           | 4.2535 X 10 <sup>-4</sup> | 0.7094 | 2.6717   | 3940    | 1.5818   | 10572         | .91                 |
|            | NOR1     | 45              | 0.15           | 0.15           | 1.0663 X 10 <sup>-4</sup> | 0.7094 | 2.6717   | 15732   | 1.5818   | 21939         | .89                 |

### 5.3.1 Time-To-Failure (TTF)

A summary of spectrum fatigue test results are given in Table 10. Average time-to-failure (TTF) values are given along with the standard deviation. In general, stress levels were selected such that fatigue failure was achieved before three lifetimes were completed. Table 10 shows that the P/M alloys (CW67-T7E91 and 7091-T7E69) exhibit longer total time-to-failure (TTF) than the I/M alloys (2124-T851 and 7475-T7351). In general, scatter of experimental data, was observed to be no greater in the high strength P/M alloys than in the I/M alloys. Only one group of P/M specimens, (7091-T7E69 under the data set R1NR45) exhibited a fairly large standard deviation in TTF.

Material comparisons in TTF were made in terms of Weibull probability plots. In Figures 30-32, comparisons are made where tests were conducted under identical spectra and stress levels. For test coupons tested under the HUD34 spectrum at a maximum stress level of 40 ksi, optimum fatigue life was obtained in the 7091-extruded test coupons survived three lifetimes (24,000 flight hours) without failing. Considerable improvement in fatigue life was observed in the 7091 P/M material as compared to the 2124-T851 I/M test coupons. Average TTF values for the 7091-extruded specimens were approximately three times as large as for 2124-T851 (17,997 flight hours as compared to 5,886 flight hours). Some degradation in fatigue life was observed in the 7091-forged material as compared to extruded specimens. However, superior TTF was still observed in the P/M forged material as compared to 2124-T851 (Figure 30).

CW67 P/M material tested under the HUD34 spectrum at a maximum stress of 40 ksi were obtained from billets, #514570 and #514571. Coupons tested from these billets had inferior spectrum fatigue properties compared to specimens obtained from billet #514553.

However, the CW67 test coupons from these billets still had considerable improvement in total fatigue life as compared to the 2124-T851 I/M test coupons (Figure 30).

For coupons tested under the HUD 34 spectrum at a maximum stress level of 45 ksi, largest TTF values were obtained in CW67-T7E91 P/M material (Figure 31). Extruded CW67 coupons used in these tests were from billet #514553 which showed superior fatigue properties. An increase in TTF of 45 percent was obtained

TABLE 10. SUMMARY OF SPECTRUM FATIGUE TESTS RESULTS

| MATERIAL    | SPECTRUM | STRESS         |  | DATA SET<br>NAME | NUMBER OF<br>SPECIMENS | AVERAGE           |            | STANDARD<br>DEVIATION |
|-------------|----------|----------------|--|------------------|------------------------|-------------------|------------|-----------------------|
|             |          | LEVEL<br>(ksi) |  |                  |                        | TTF<br>(Ft. Hrs.) | (Ft. Hrs.) |                       |
| 2124-T851   | HUD34    | 35             |  | C1HD35           | 15                     | 14,933            |            | 5,558                 |
|             | HUD34    | 40             |  | C1HD40           | 15                     | 5,886             |            | 1,276                 |
|             | NOR1     | 45             |  | C1NR45           | 10                     | 15,423            |            | 5,162                 |
| 7475-T7351  | NOR1     | 45             |  | C2NR45           | 11                     | 26,465            |            | 5,104                 |
| 7091-T7E69  | HUD34    | 40             |  | R1HD40           | 14                     | 17,997            |            | 5,997                 |
|             | HUD34    | 45             |  | R1HD45           | 15                     | 7,309             |            | 2,807                 |
|             | NOR1     | 45             |  | R1NR45           | 10                     | 26,949            |            | 10,282                |
|             | NOR1     | 50             |  | R1NR50           | 10                     | 15,238            |            | 3,233                 |
| 7091-FORG.  | HUD34    | 40             |  | R2HD40           | 9                      | 11,667            |            | 2,667                 |
|             | HUD34    | 45             |  | R2HD45           | 9                      | 5,544             |            | 1,362                 |
| CW-67-T7E91 | HUD 34   | 40             |  | R3HD40           | 10                     | 14,360            |            | 5090                  |
|             | HUD 34   | 45             |  | R3HD45           | 8                      | 10,572            |            | 1250                  |
|             | NOR 1    | 45             |  | R3NR45           | 10                     | 21,939            |            | 5650                  |

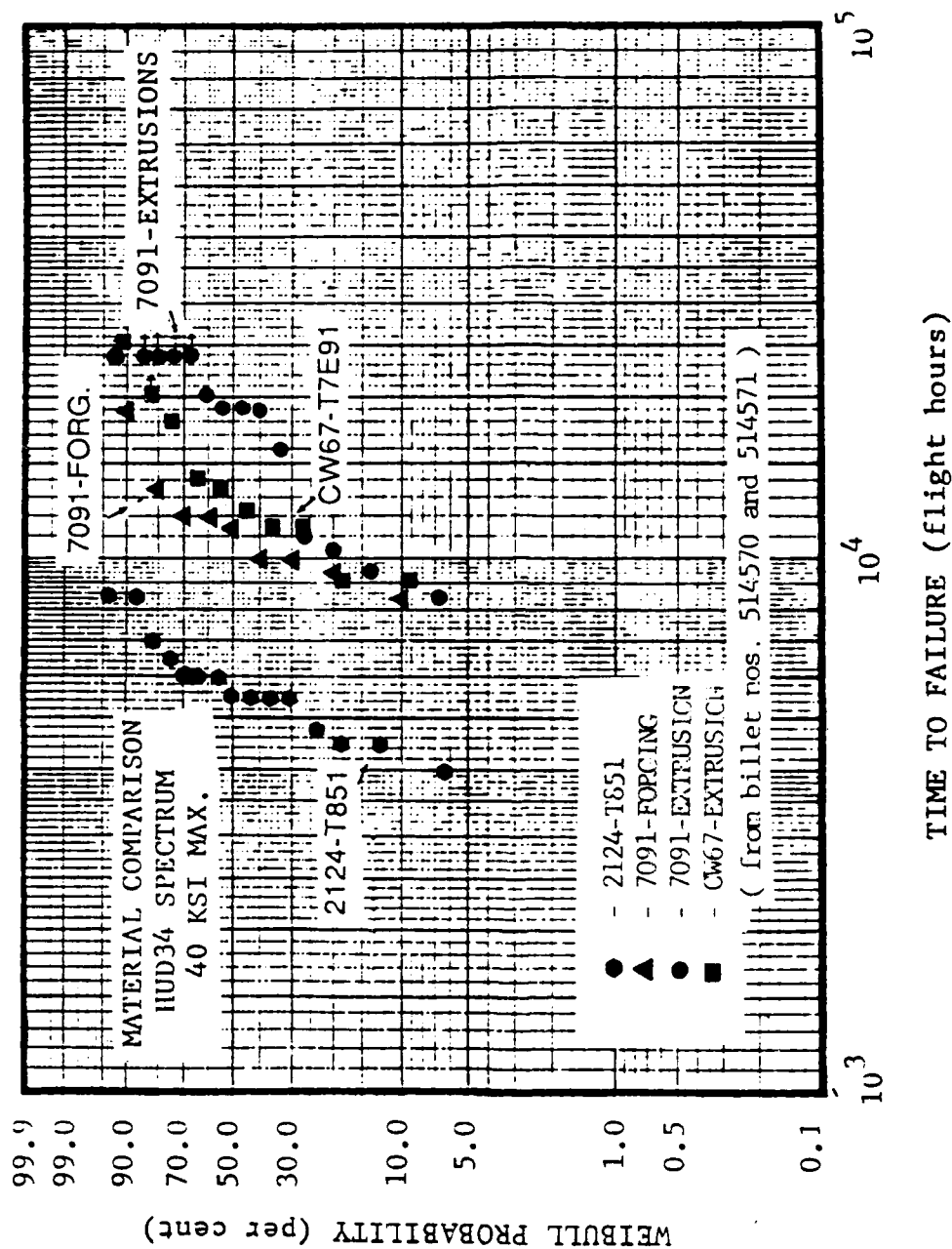


FIGURE 30. Time-To-Failure Comparisons For Materials Tested Under The HUD 34 Spectrum (Maximum Stress = 40 ksi)

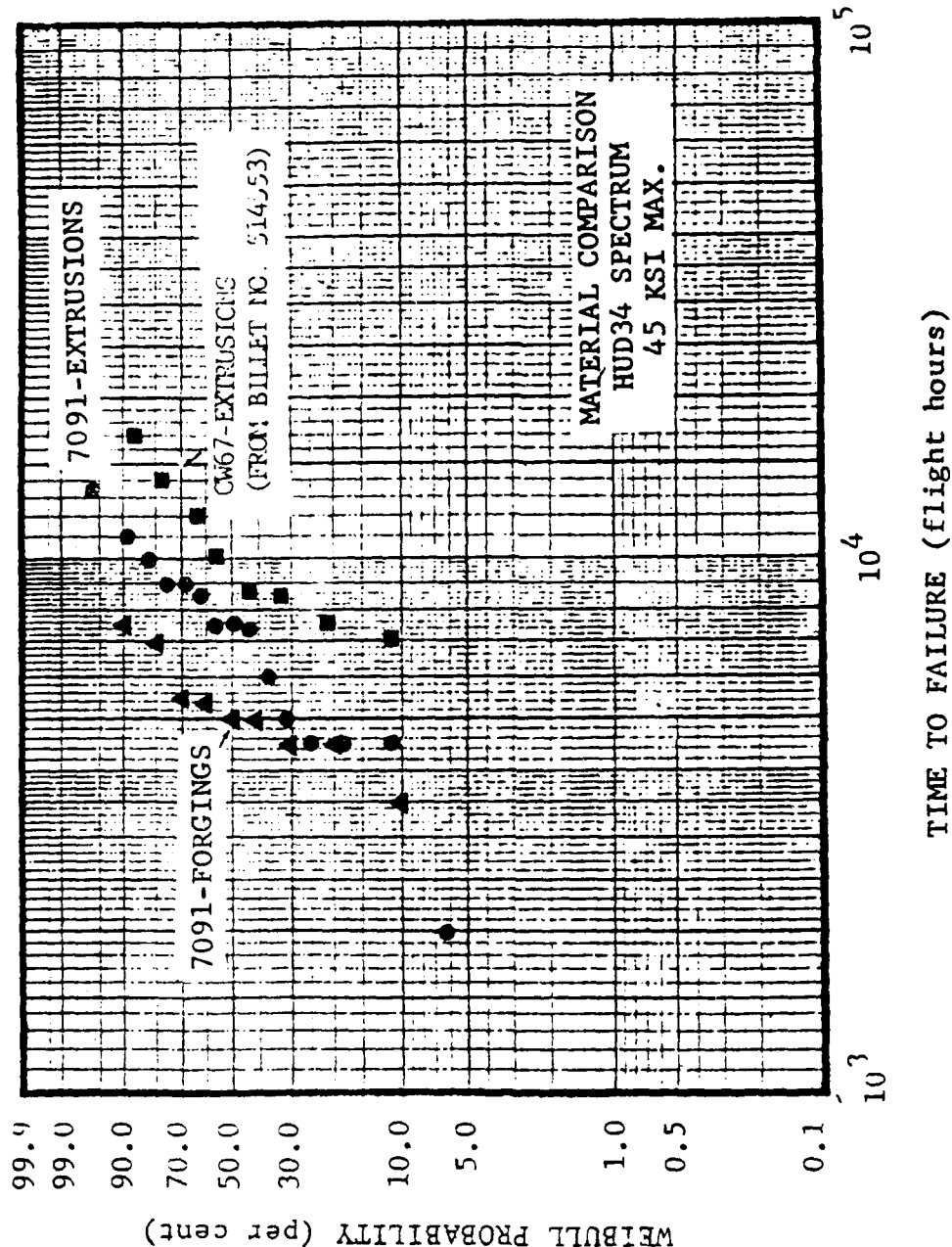


FIGURE 31. Time-To-Failure Comparisons For RST Material  
(HUD 34 Spectrum, Maximum Stress = 45 ksi)

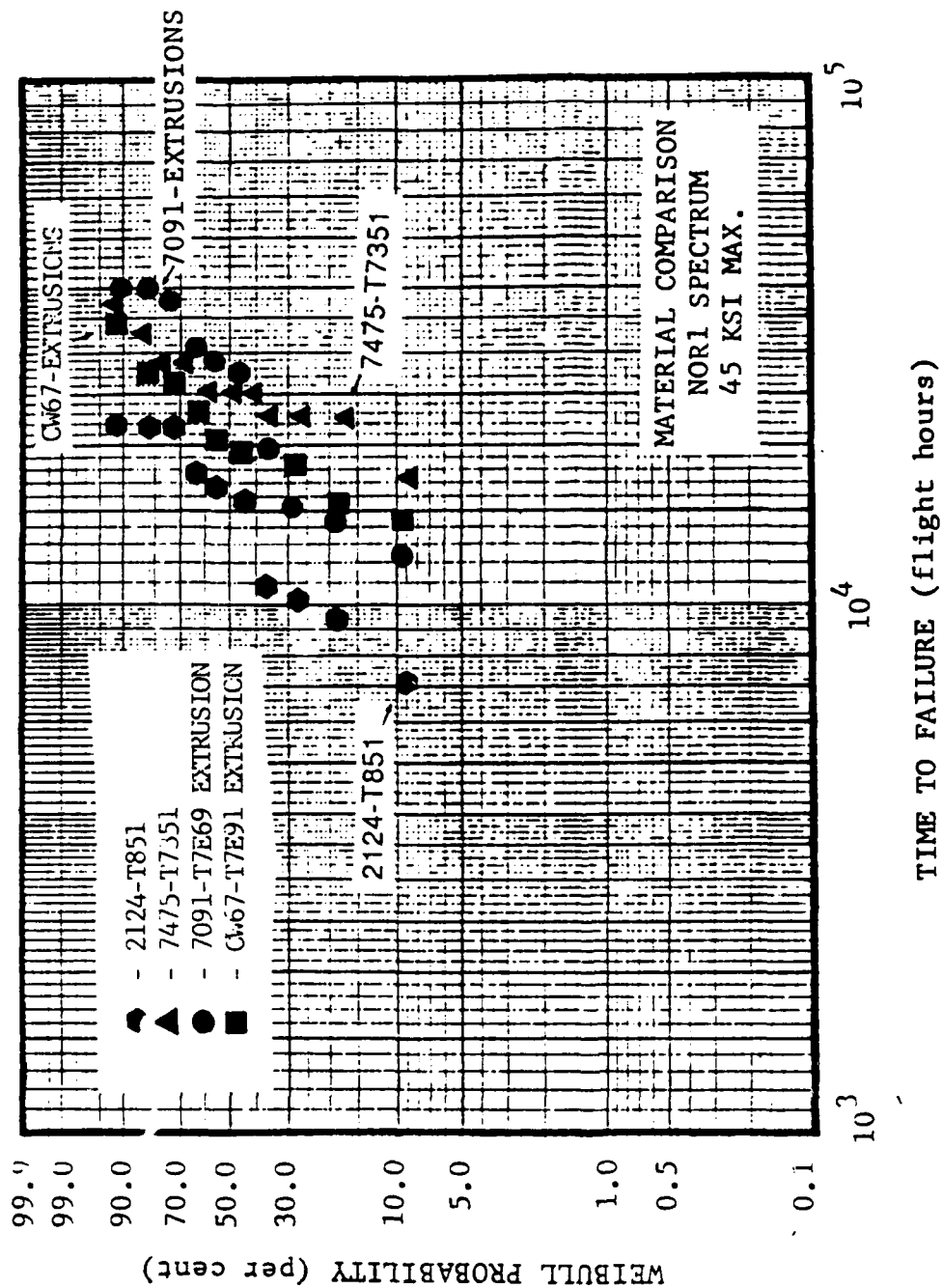


Figure 32. Time-To-Failure Comparisons for Materials Tested Under The NOR 1 Spectrum (Maximum Stress = 45 ksi)

over extruded 7091-T7E69 at this stress level. Some degradation in fatigue life was observed in the 7091-forged material as compared to extruded material at the 45 ksi stress level, also.

Results for test coupons tested under the NOR1 spectrum at a maximum stress level of 45 ksi are shown in Figure 32. For the I/M alloys, 7475-T7351 exhibited superior fatigue performance over 2124-T851. The average values of TTF for 7475-T7351 was 26,465 flight hours compared to 15,423 flight hours for 2124-T851. Experimental scatter was about the same in the two I/M materials. Considerably more scatter was observed in the P/M 7091-extruded material. The lower ranked 7091 test coupons exhibited poorer fatigue performance than 7475-T7351 test specimens whereas the higher ranked 7091 specimens exhibited better TTF than 7475-T7351. Average values of TTF were approximately the same in the two materials (26,949 flight hours for 7091-T7E69 vs. 26,465 flight hours for 7475-T7351).

Five CW67 test coupons tested under the NOR 1 spectrum were obtained from billet #514553 while the other five coupons were fabricated from billets #514570 and #514571. All of the better performing CW67 test coupons (longer TTF) were obtained from the #514553 billet. Average values of TTF for CW67 specimens from billet #514553 were 26,121 flight hours. This value is approximately the same as obtained for 7091-T7E69 and 7475-T7351 (26,949 flight hours and 26,465 flight hours, respectively). However, average values of TTF for CW67 coupons from billets #514570 and #514571 were 17,557 flight hours. Although greater than the average TTF obtained for 2124-T851 (15,423 flight hours), this value is still considerably less than obtained for 7091-T7E69, 7475-T7351, and CW67-T7E91 (from billet #514553).

Largest critical crack lengths were obtained in the CW67-T7E91 extrusions (Table 9). Crack lengths of primary cracks reached approximately 0.9 inch before failure occurred in all three data sets. Smallest critical crack lengths occurred in 2124-T851. Critical crack sizes ranged from 0.49 inches for the HUD34, 40 ksi data set to 0.74 inch for material tested under the HUD34, 35 ksi data set (Table 9). These results are consistent with fracture toughness values for these two alloys where CW67 extrusions had the largest plane strain fracture toughness values and 2124-T851 had the poorest fracture toughness of the materials tested.

Figures 30 and 32, show improvement of fatigue performance in 7091 over 2124 is much greater under the tension-compression HUD34 spectrum than under the tension-dominated NOR1 spectrum. This seems to be related to cyclic stability of materials. A recent study [23] has demonstrated that cyclic stability of materials strongly depends on the type of load histories encountered. Under strain-controlled low cycle fatigue tests with strain ratio -1, 2124-T851 exhibits cyclic softening behavior, while 7091-T7E69 is cyclically stable. However, cyclic softening behavior of 2124-T851 disappears when strain ratios are increased to 0 and 0.3. Therefore, the greater difference in fatigue performance between 2124-T851 and 7091-T7E69 under the tension-compression HUD34 spectrum can at least be partially attributed to cyclic softening behavior of 2124-T851.

The stress level dependence on fatigue life can be observed for 2124-T851 in Figure 33. A considerable decrease in average TTF is observed at 40 ksi. More scatter is observed at the lower stress level as expected. The stress level dependence on fatigue properties will be discussed in Section 5.4.2.

### 5.3.2 Fatigue Crack Growth Rate (FCGR)

Fracture critical structures using the "Damage Tolerance Concept" rely on slow crack growth in order to withstand two design lives before failure. Therefore, it is important to separate the crack initiation stage from propagation in analyzing fatigue data. The crack growth rates of P/M alloys compared to I/M alloys are presented and analyzed in this section.

Procedures used in crack growth analysis assuming different crack geometries were discussed in Section 4.1. Calculations were conducted for three different materials, 2124-T851, 7475-T7351, and 7090-extrusions. Comparisons between predicted data and actual data are shown in Figures 34-35 for 2124-T851 and 7091-T7E69. Actual data was compared to assumed double corner cracks and double through cracks. Results indicated comparable prediction results to test data in 2124-T851 (Figure 34). However, the crack growth analysis in 7091-T7E69 was somewhat conservative. Actual crack growth rates in this material were considerably better than the model had predicted (Figure 35).

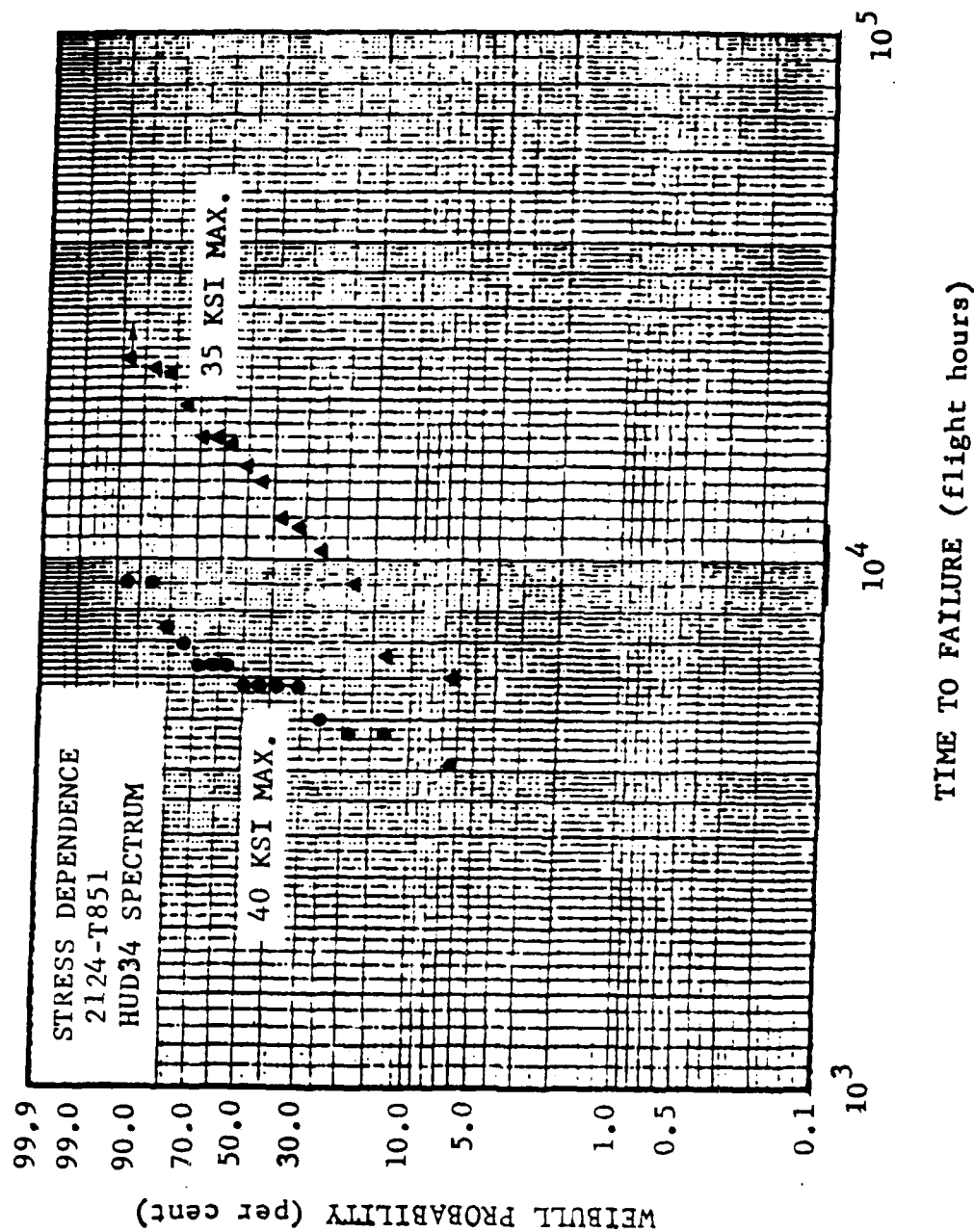


Figure 33. Time-To-Failure Plots Showing Stress Dependence

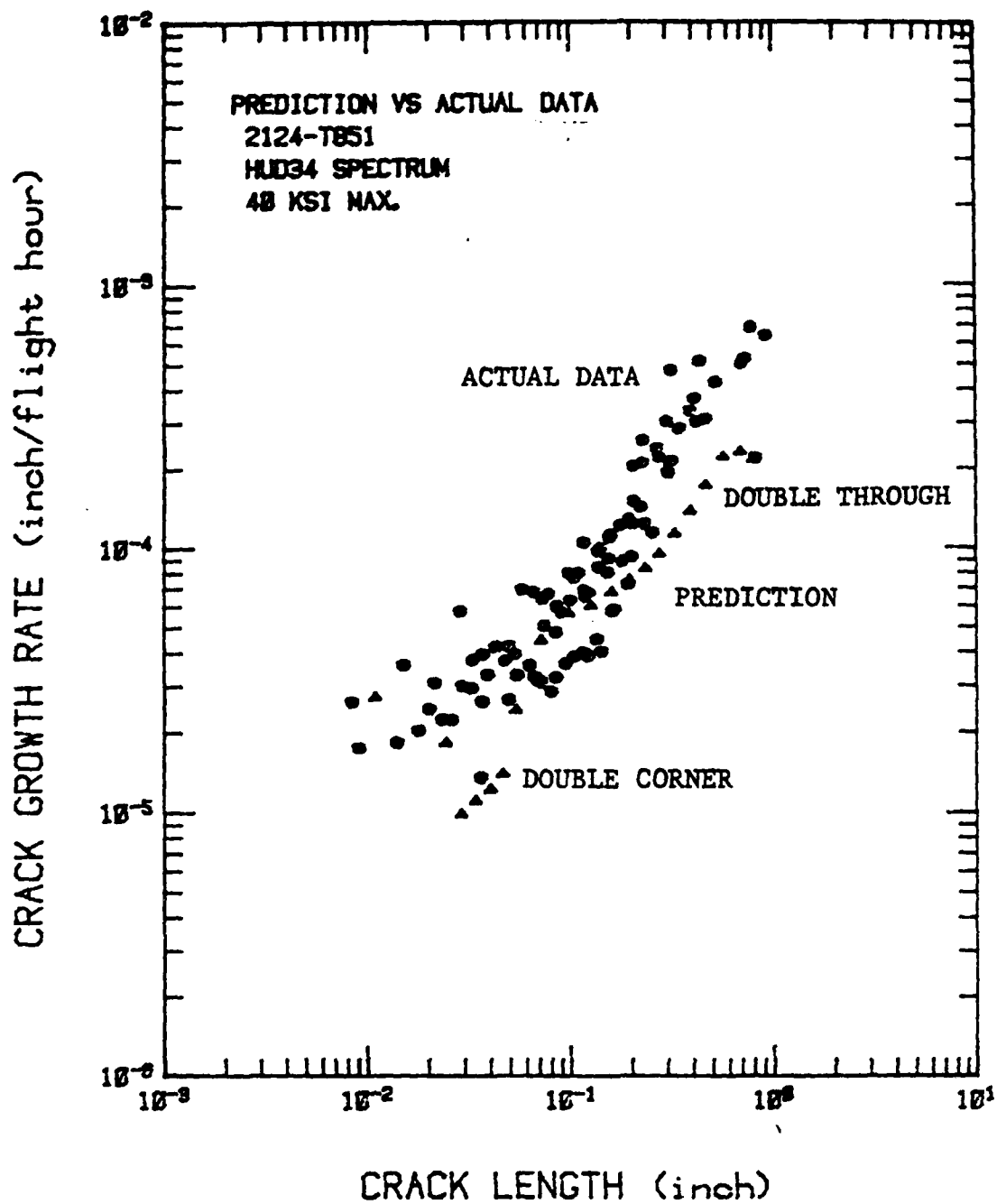


Figure 34. Crack Growth Rates For 2124-T851 Aluminum Alloy (HUD 34 Spectrum)

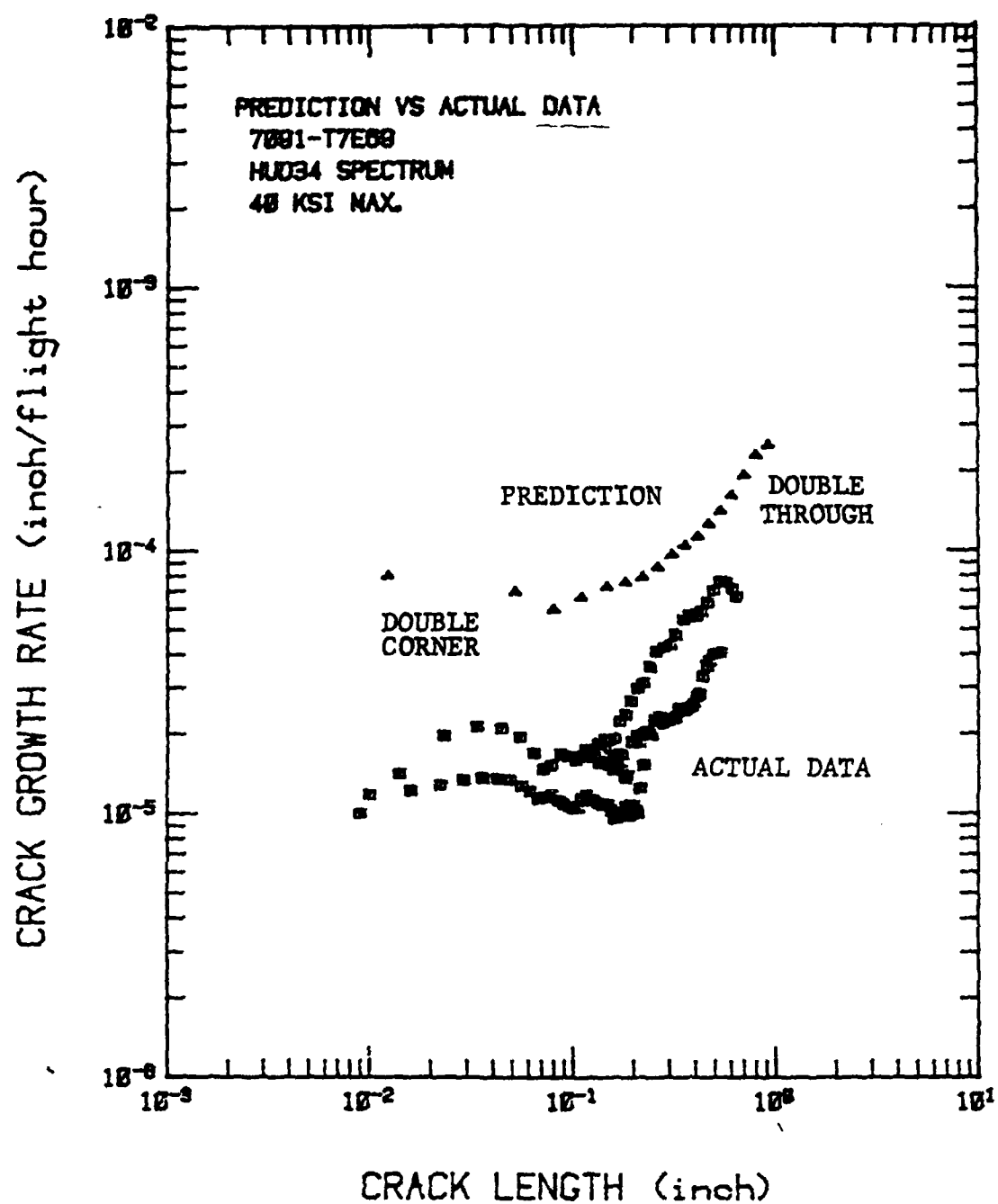


Figure 35. Crack Growth Rates For 7091-T7E69 Aluminum Alloy (HUD 34 Spectrum)

A comparison of crack growth rate as a function of crack length between the P/M materials and I/M alloys is shown in Figures 36-37. Comparisons are shown for both HUD34 and NOR 1 spectra. Crack growth rates were determined from eq. 2 where  $a(t)$  is the crack size at time  $t$ , and  $Q$  and  $b$  are constants that were determined from the least square fit of all  $\log da/dt$  vs.  $\log a$  pairs of the sample. Values of  $Q$  and  $b$  for all data sets are listed in Table 9. Individual  $Q$  and  $b$  values for all test coupons are listed in Appendix B.

A slower crack growth rate is observed in the RST materials especially at larger crack lengths. The poorest crack growth rate performance was obtained in 2124-T851 plate for tests conducted under both the HUD34 and NOR1 spectra. Crack growth rates in the 7091-forged material were intermediate between the 7091-extruded material and 2124-T851 (Figure 36). Crack growth rate comparisons between CW67-T7E91 and 7091-T7E91 were dependent on the billets from which the CW67 material had been extruded. Extrusions from billets #514570 and #514571 showed inferior crack propagation characteristics compared to 7091-T7E69 (Figures 36-37). However, CW67 test coupons fabricated from the billet #514553-2 showed superior crack growth rate compared to 7091-T7E91.

Crossover effects are observed in comparing spectrum crack growth rates of the RST materials with 7475-T7351 plate run under the NOR1 spectrum. For smaller crack lengths, the crack growth resistance of 7475-T7351 is superior, while at larger crack lengths, the crack propagation behavior of the P/M-T7E69 material is better. These results are consistent with constant amplitude crack growth comparisons between 7091-T7E69 and 7475-T7351 where it was found that for low  $\Delta K$  values, 7475 had superior crack growth resistance, and at high values of stress intensity factor, 7091 had better resistance [24]. The ranking between P/M and I/M aluminum alloys in spectrum fatigue crack growth resistance has been found to be strongly dependent on the type of load histories encountered [25].

Additional crack growth curves based on the "Initial Fatigue Quality" (IFQ) Model are presented in Section 5. The technique used in generating these crack growth curves was presented in Section IV.

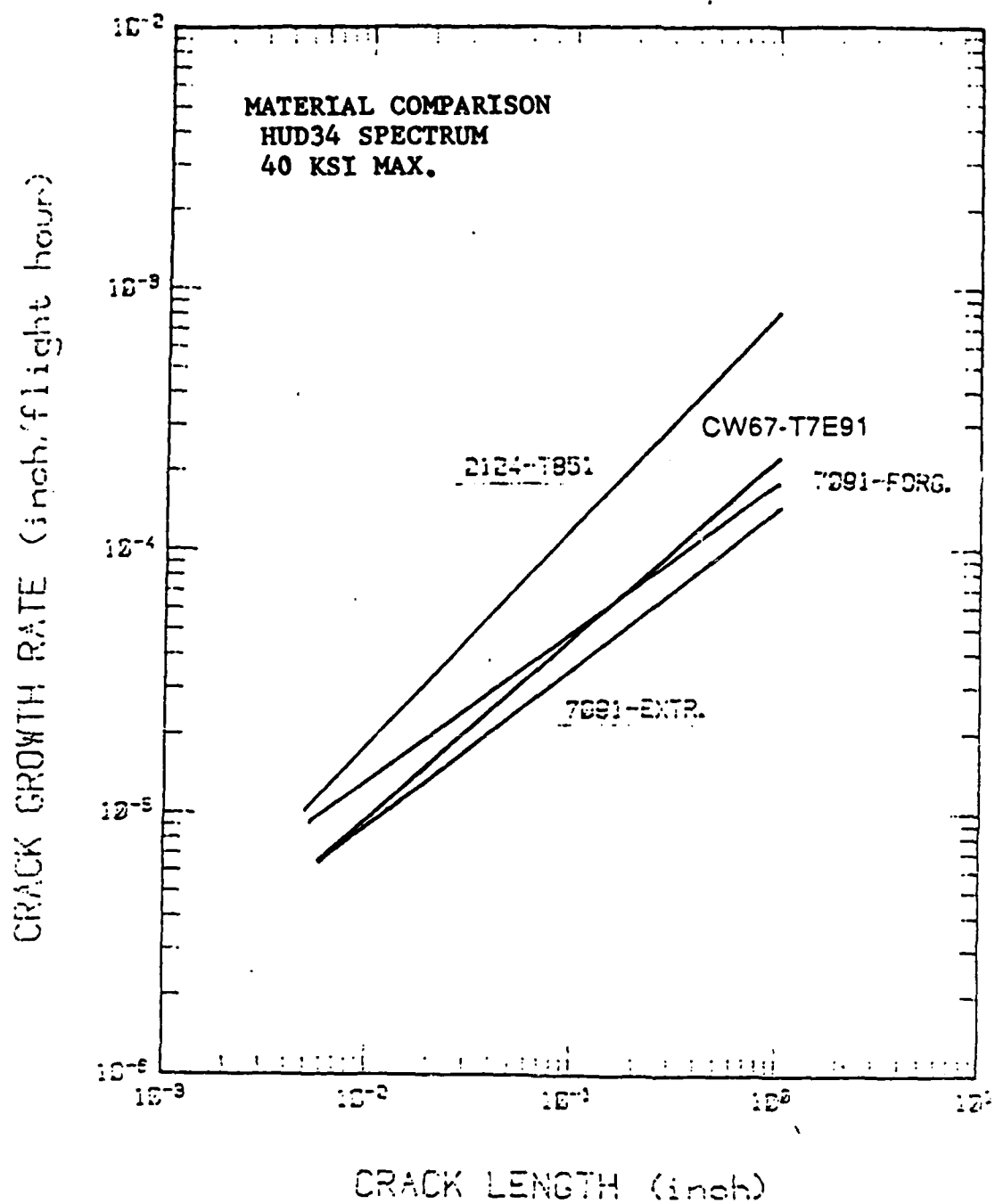


Figure 36. Crack Growth Rates of 2124-T851, 7091-T7E69, CW67-T7E91, and 7091-Forgings As A Function Of Crack Length Under The HUD 34 Spectrum

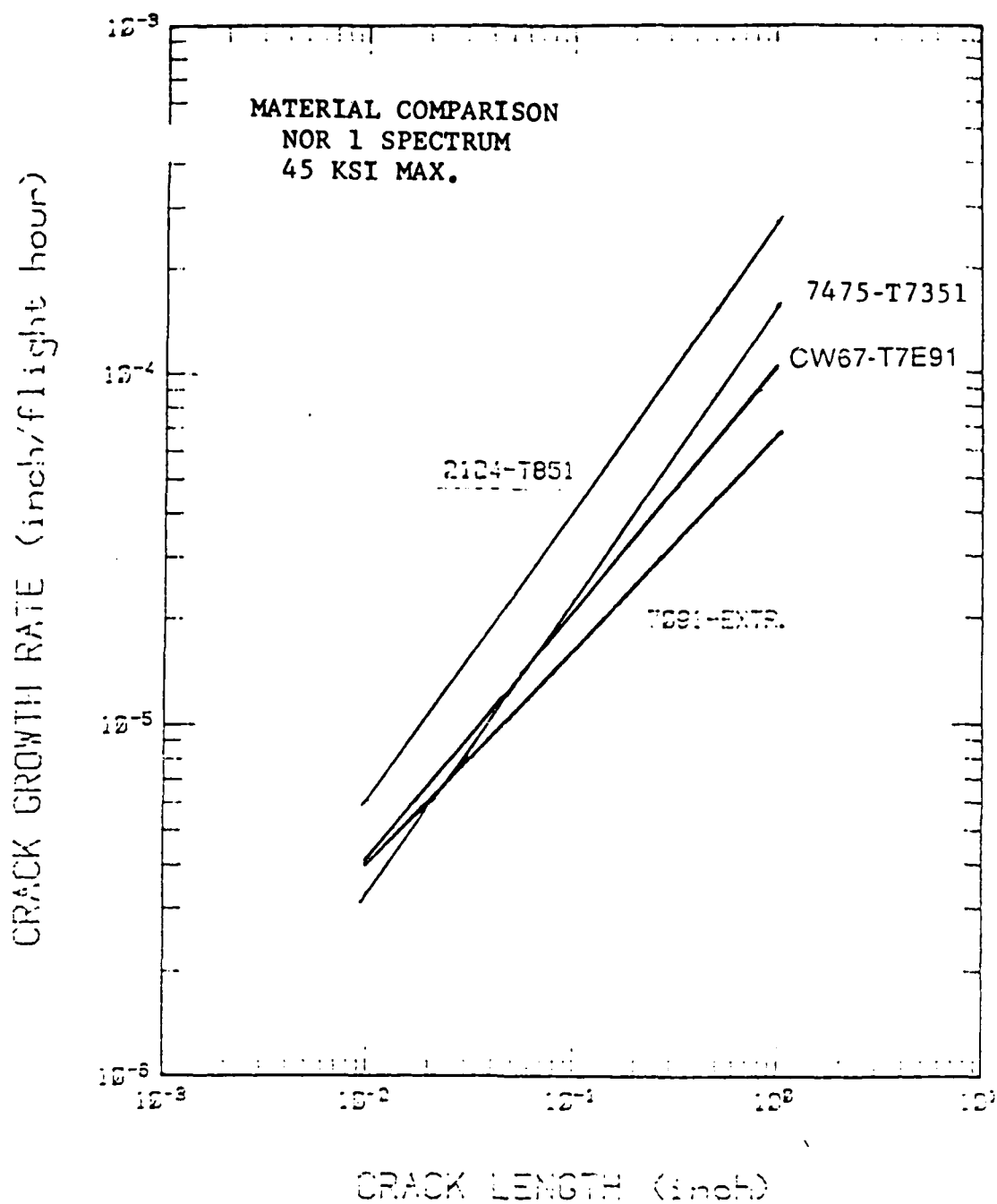


Figure 37. Crack Growth Rates Of 2124-T851, 7475-T7351, 7091-T7E69, and CW67-T7E91 As A Function Of Crack Length Under The NOR 1 Spectrum

Additional crack growth curves based on the "Initial Fatigue Quality" (IFQ) Model are presented in Section 5. The technique used in generating these crack growth curves was presented in Section IV.

### 5.3.3 Time-To-Crack-Initiation (TTCI)

The time required for an initial defect to become a fatigue crack of size 0.150 inch was used to define the arbitrary crack size  $a_0$  in this program. This value was easily obtainable from fractographic results.

As presented in Section IV, observed TTCI values are known to be fit very well by a three-parameter Weibull distribution. Therefore, a fractographically observed TTCI distribution can be expressed as shown in Eq. (1). The parameter  $T$  is a random variable indicating TTCI,  $\alpha$  is the shape parameter,  $\beta$  is the scale parameter, and  $\epsilon$  is the lower bound of TTCI.

Eq (1) may be transformed into:

$$\log \left\{ -\ln [1 - F_T(t)] \right\} = \alpha \log (t - \epsilon) - \alpha \log \beta \quad (7)$$

Eq. (7) shows that  $-\ln[1 - F_T(t)]$  vs.  $(t - \epsilon)$  is plotted as a straight line on log-log scale paper.

Figures 38-42 show the TTCI distributions obtained from this program. Each data point represents the  $-\ln [1 - 1/(n + 1)]$  vs.  $(TTCI - \epsilon)$  pair for each specimen, where  $i/(n + 1)$  is the TTCI rank of the specimen within the individual data set. The straight line in Figures 38-42 is the  $F_T(t)$  distribution giving the best least squares fit to the plotted  $-\ln[1 - F_T(t)]$  vs.  $(TTCI - \epsilon)$ .  $F_T(t)$  can be calculated from Eq. (1) using the parameters  $\alpha$ ,  $\beta$ , and  $\epsilon$ . The parameters  $\alpha$  and  $\beta$  are presented in Table 9. The parameter  $\epsilon$  was equal to zero for all analyses. The slopes of the straight lines in Figures 38-42 are directly related to the parameter  $\alpha$ . As mentioned earlier, the parameter  $\alpha$  is not expected to be a function of the spectrum type and stress level. Therefore, a set of identical test specimens is expected to have the same slope even though tested under various spectrum types and stress levels.

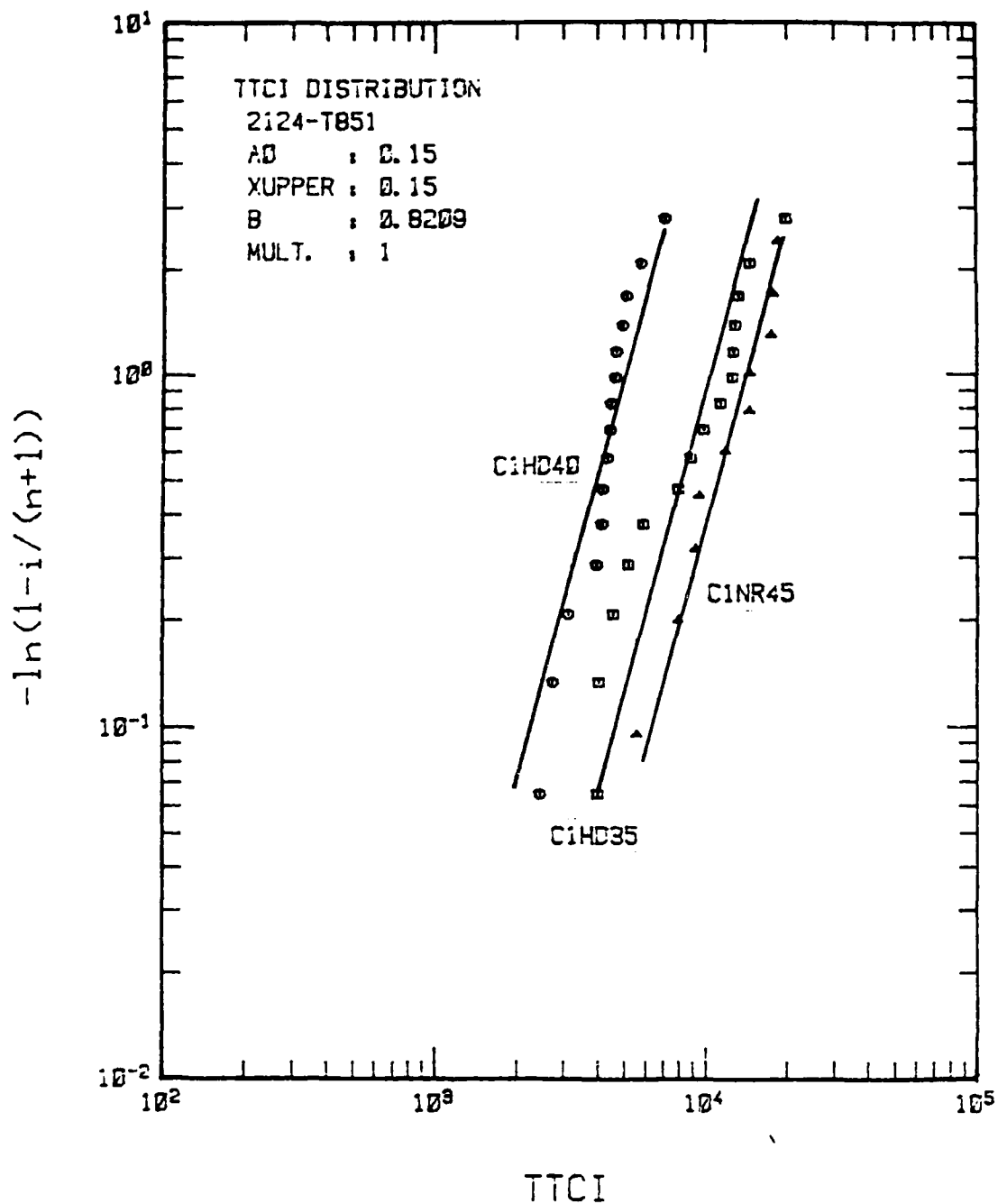


Figure 38. TTCI Distributions For 2124-T851 Aluminum Alloy

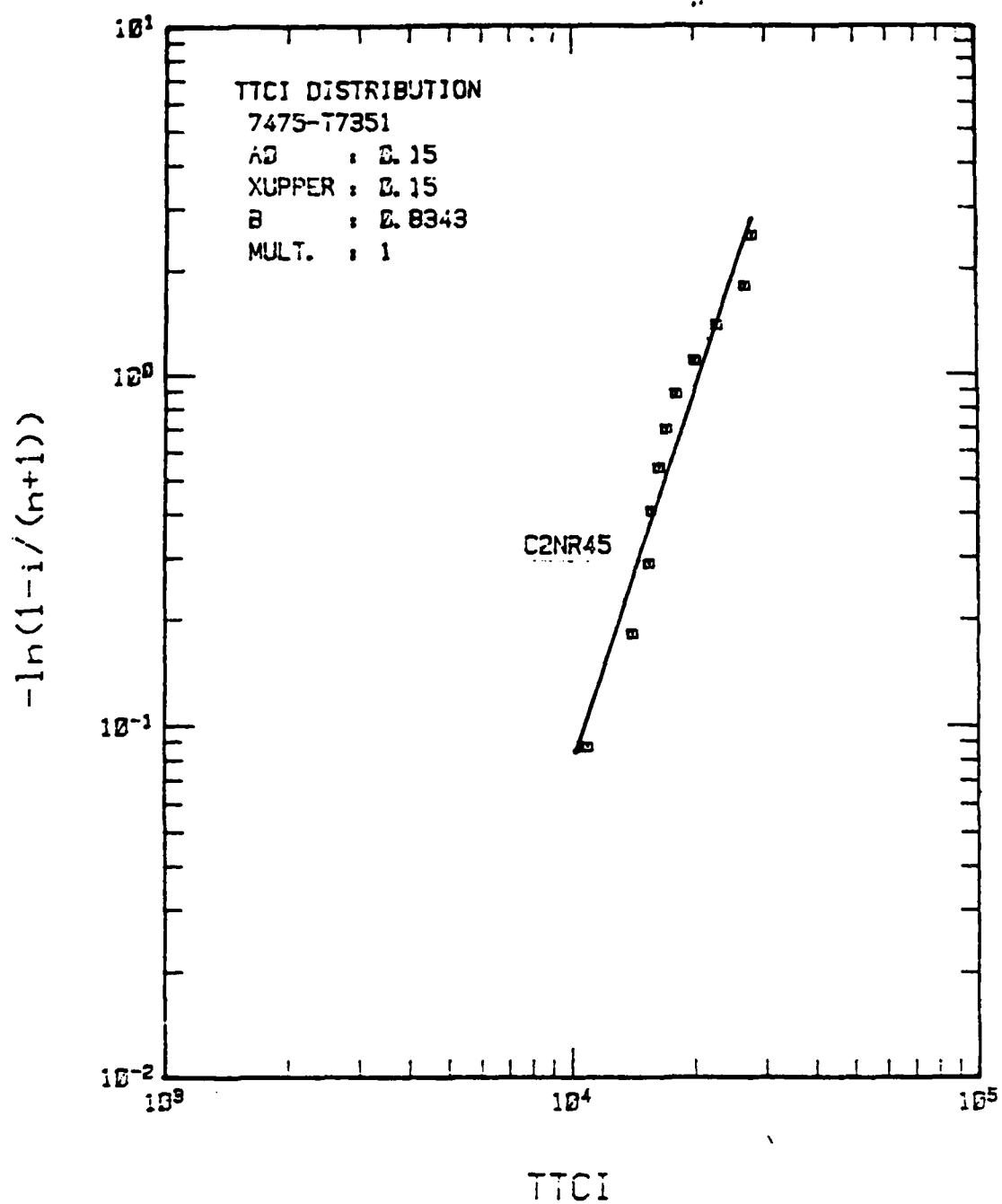


Figure 39. TCI Distributions For 7475-T7351 Aluminum Alloy

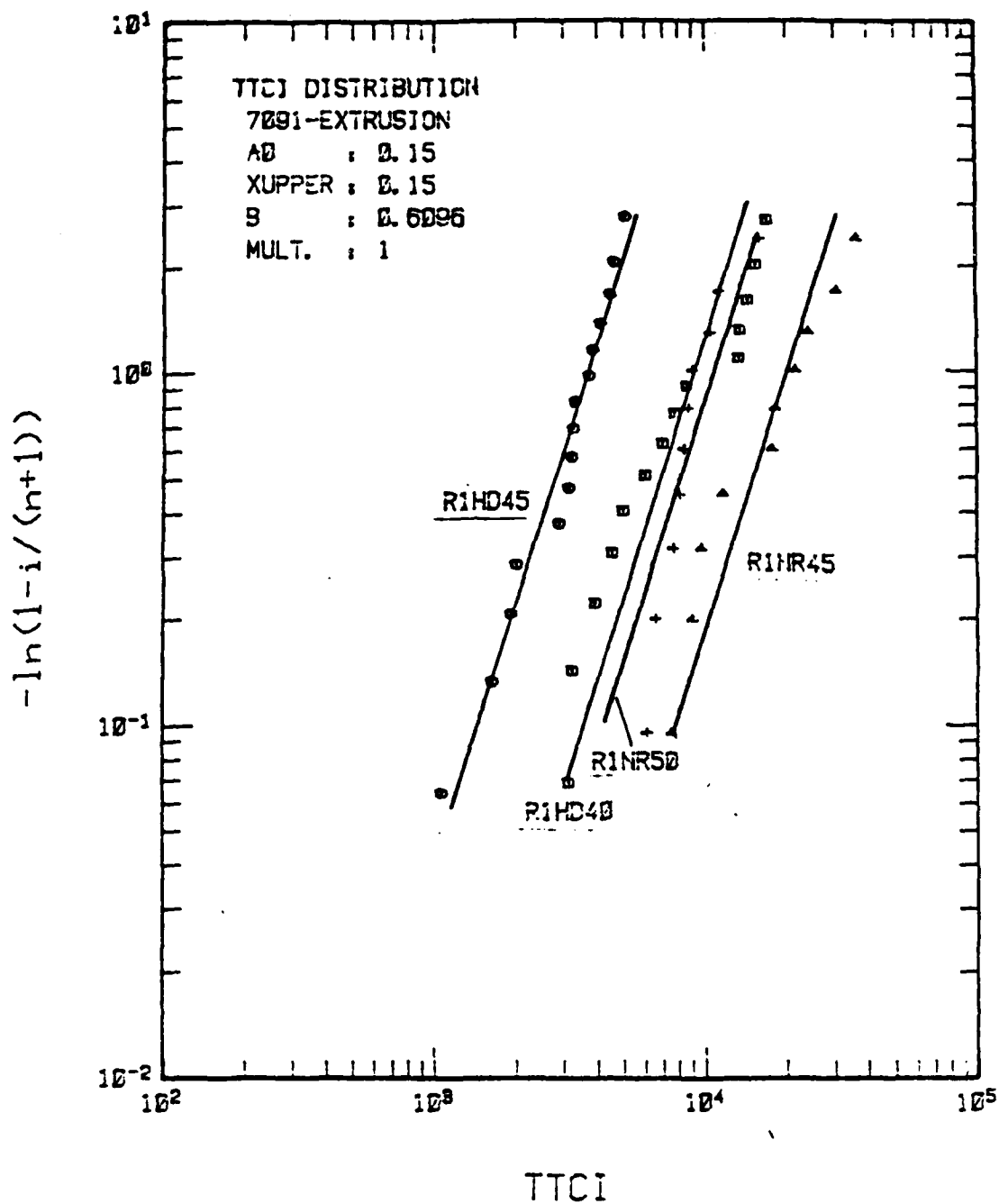


Figure 40. TTCI Distributions For 7091-Extrusion

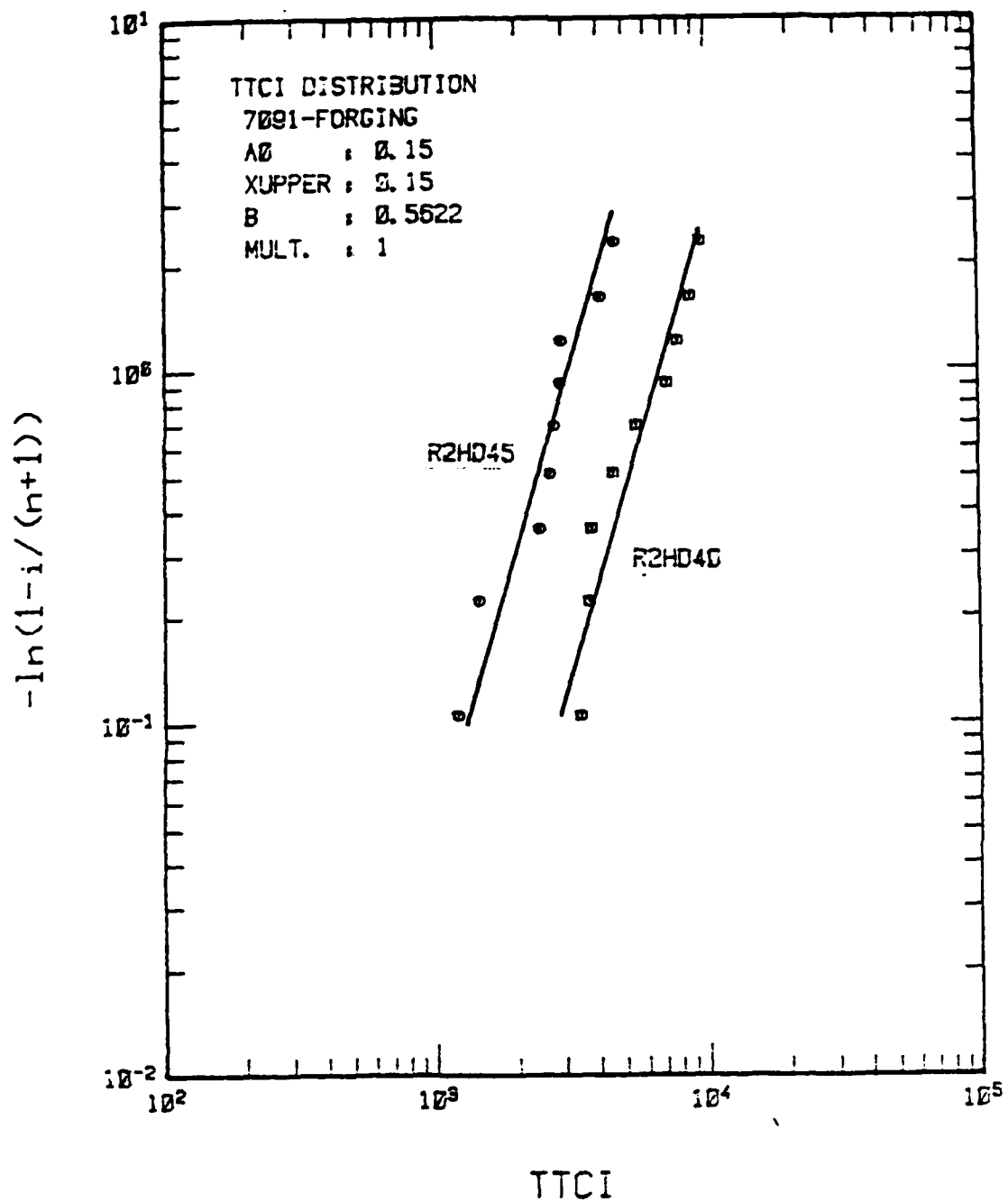


Figure 41 . TTCI Distributions For 7091-Forging

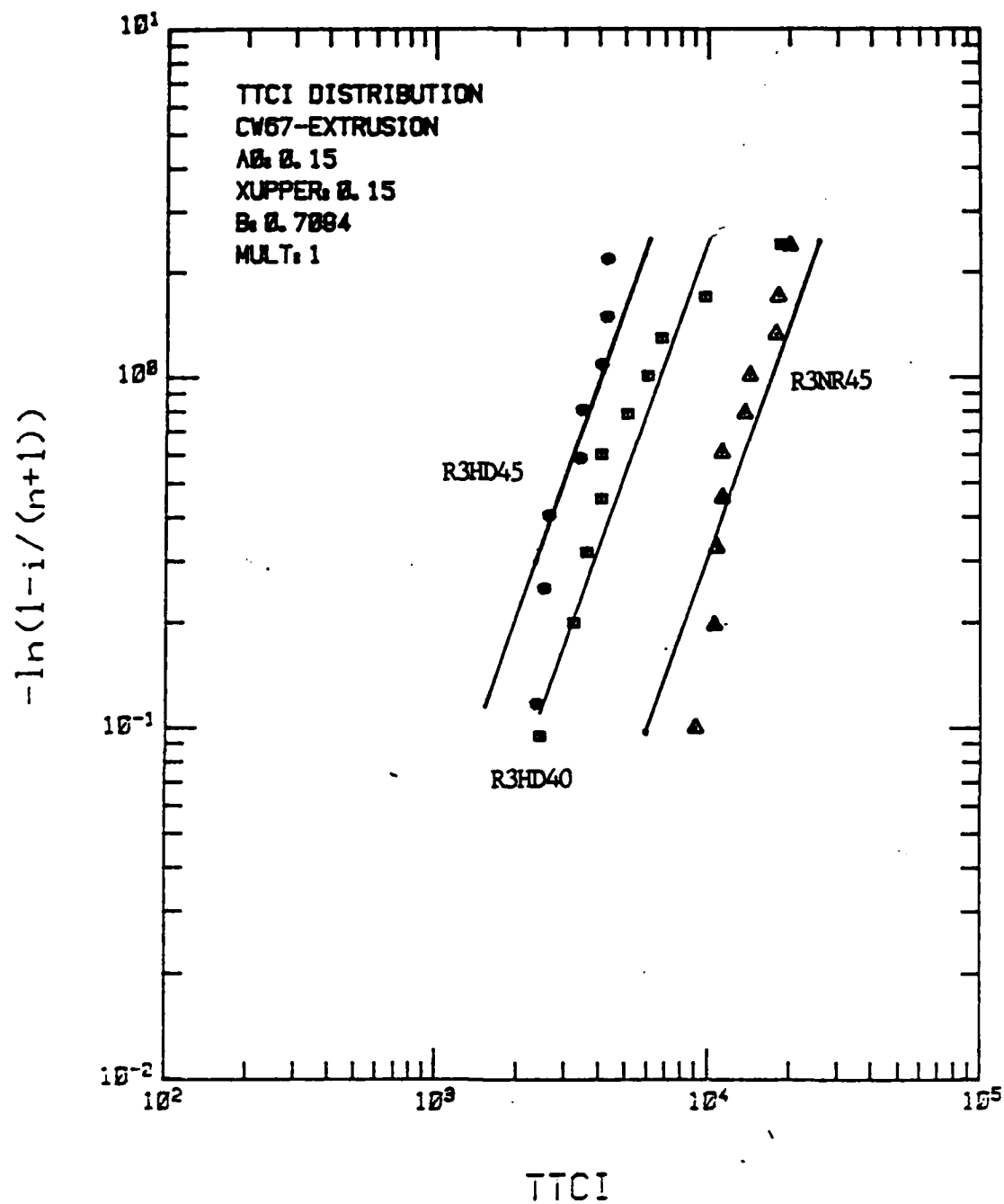


Figure 42. TTCI Distributions For CW67-Extrusion

The observed TTCl values are fit quite well by a three-parameter Weibull distribution. The data points from two different types of spectra and two different stress levels are fit well by TTCl distributions with the same slope.

A comparison of materials based on TTCl results are shown in Figures 43-44. Superior crack initiation resistance is obtained in the 7091 P/M material. Increased scatter is observed in this alloy, however. The poorest performing 7091-T7E69 specimens performed only slightly better than the poorest 2124-T851 coupons under both spectra. Crossover effects between 7475-T7351 and 7091-T7E69 were observed in the TTCl data for the NOR1 spectrum, also. This crossover effect, however, was due to the increased scatter in the experimental data for 7091-extrusions as compared to the I/M 7475-T7351 material. The control of inclusions in the RS P/M alloys will be expected to strongly influence crack initiation. By proper control, the worst performing P/M specimens would be eliminated therefore reducing the experimental scatter.

The TTCl distribution for CW67 extruded material tested under the HUD34 spectrum was similar to 7091-forged specimens (Figure 43). Better performing CW67-T7E91 and 7091-forged specimens had TTCl values intermediate between 2124-T851 and 7091-T7E69 extruded specimens. For CW67 specimens tested under the NOR1 specimens, a relatively small scatter in TTCl values was obtained (Figure 44). Poorer performing CW67 coupons had improved TTCl values over 7091-T7E69 extruded material and 2124-T851 plate.

#### 5.3.4 Measurements of EIFS Distribution

As described in Section 4.2, the EIFS distribution can be derived from the TTCl distribution by extrapolating TTCl backward using an assumed crack growth equation (Eq. 2). In that particular equation,  $a(t)$  is the crack size at time  $t$ ,  $Q$  and  $b$  are constants. The EIFS distribution can be written as (Eq. 4), where  $x$  is a random variable indicating  $a(0)$ , the crack size at time zero (or EIFS),  $c$  is  $b-1$ , and  $x_U$  is the upper bound of the EIFS distribution which is defined in Eq. 5. Eq. (4) can be used to find the probability that the EIFS is less than a given size,  $x$ , using parameters for any structural concept found in Table 9.

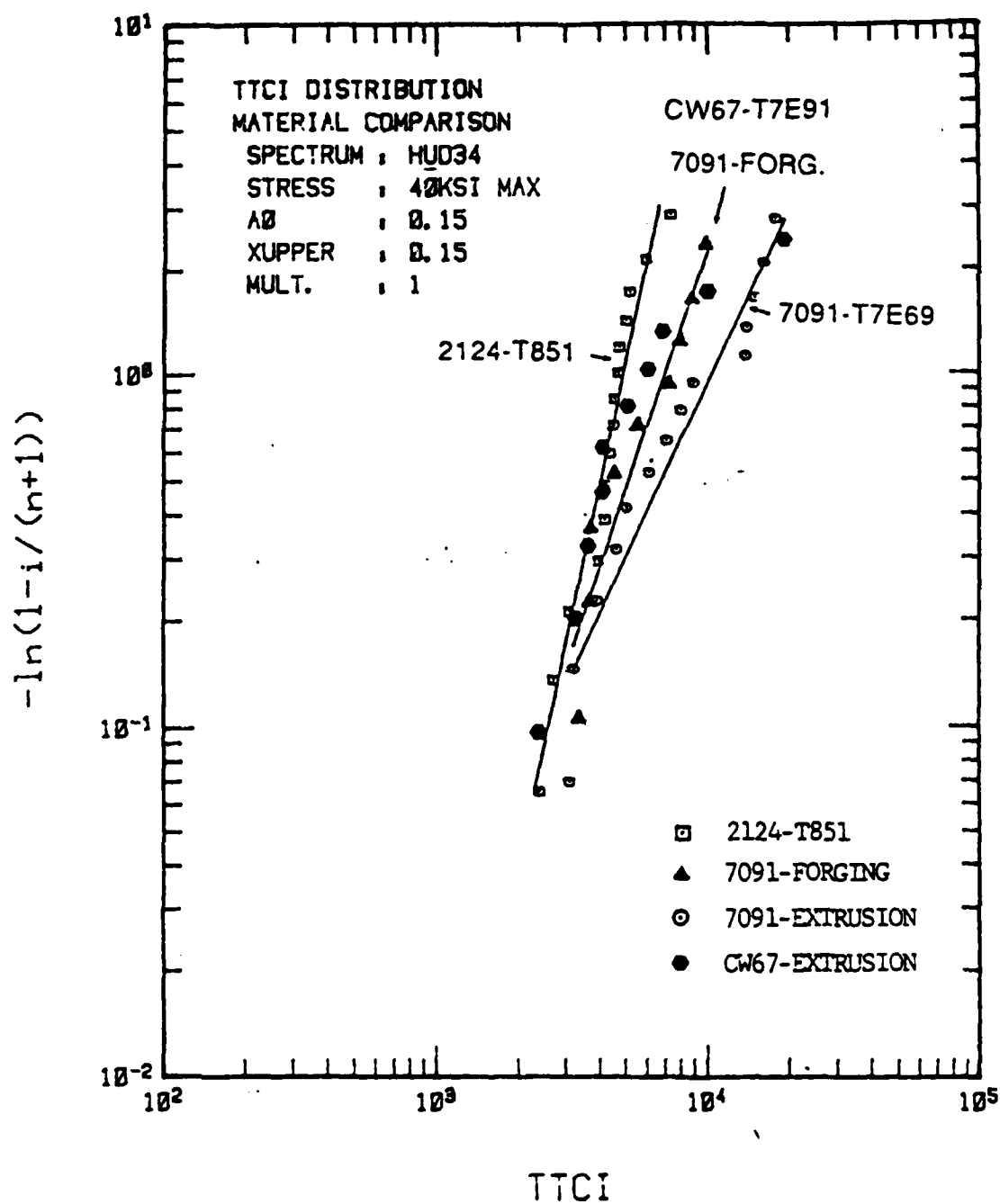


Figure 43. TTCI Comparisons For Three Aluminum Alloys  
(HUD 34 Spectrum)

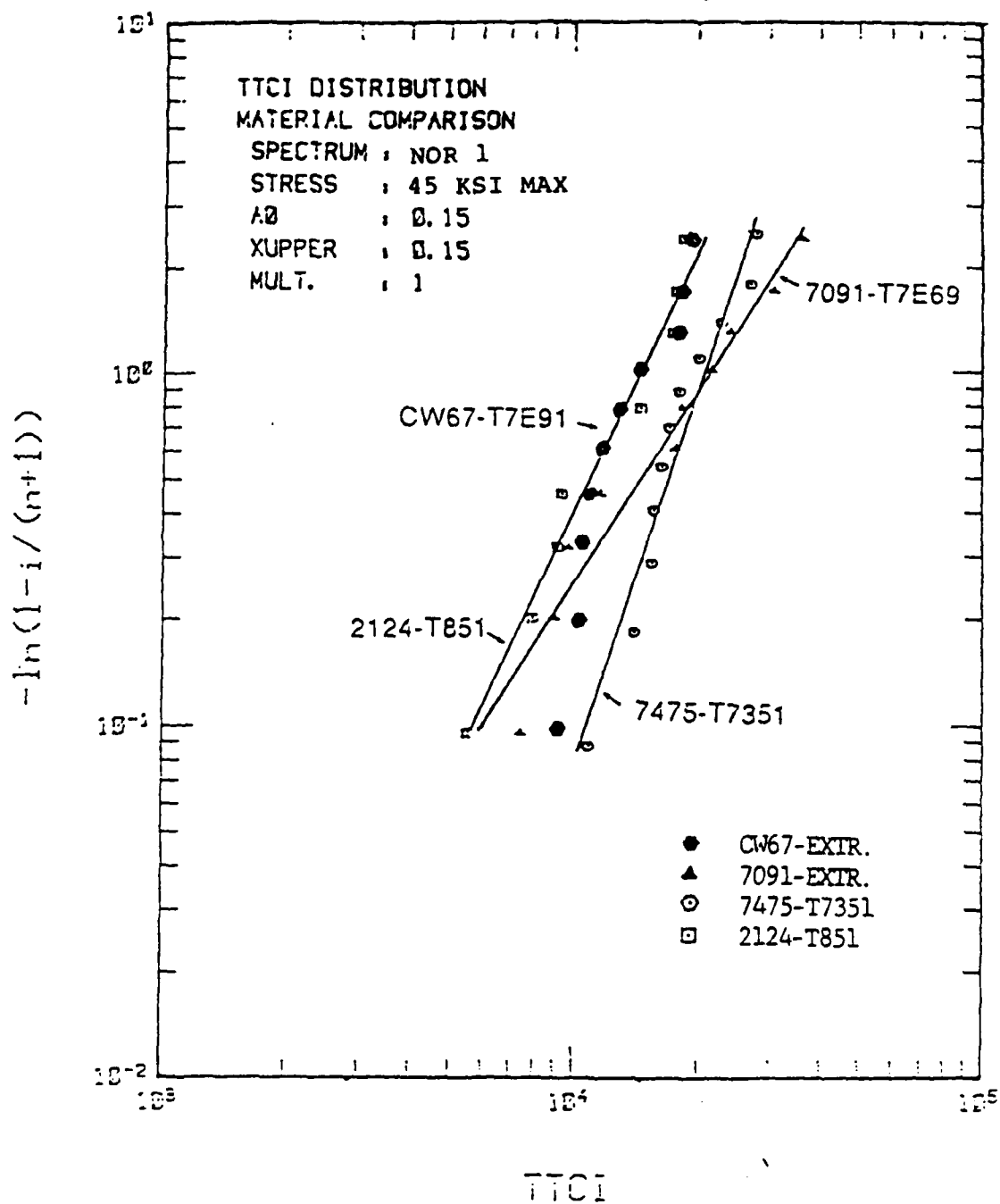


Figure 44. TTCI Comparisons For Four Aluminum Alloys (NOR 1 Spectrum)

Individual EIFS values for all test coupons are listed in Appendix B. In some instances the EIFS for a specimen may be given as a negative number. This, in effect, causes the analysis to predict that some time is required to reach a crack length of zero. We interpret this physically to mean that some time was required to initiate fatigue cracks in our unflawed specimens. In these cases the backward extrapolation of the crack growth curve can intersect the abscissa at positive time, or intersect the ordinate at negative crack size. For such cases,  $x$  in Eq. (4) is negative so that Eq. (4) is undefined. This can be remedied by using Eq. (8) whenever  $x$  is negative.

$$F_{a(0)}(x) = \exp \left\{ - \left[ \frac{-(-x)^{-c} - x_u^{-c}}{cQ\beta} \right]^\alpha \right\} \quad (8)$$

Eq. (4) may be transformed into:

$$\log \left[ -\ln F_{a(0)}(x) \right] = \alpha \log (x^{-c} - x_u^{-c}) - \alpha \log cQ\beta \quad (9)$$

Eq. (9) shows that  $-\ln F_{a(0)}(x)$  vs.  $(x^{-c} - x_u^{-c})$  is plotted as a straight line on log-log paper. The slope of the straight line is directly related to the parameter  $\alpha$ . Figures 45-49 show the EIFS distributions obtained from this program. Each data point in Figures 45-49 represents the  $-\ln(i/n+1)$  vs.  $(EIFS^{-c} - x_u^{-c})$  pair for each specimen, where  $i/(n+1)$  is the EIFS rank of the specimen among the set of identical test specimens. The straight lines in Figures 45-49 are plotted from  $-\ln F_{a(0)}(x)$  vs.  $(x^{-c} - x_u^{-c})$ .  $F_{a(0)}(x)$  can be calculated from Eq. (4) using the parameters  $Q$ ,  $b$ ,  $\alpha$ ,  $\beta$ , and  $x_u$  presented in Table 9.

As shown in Figures 45-49, the experimental EIFS distributions (data points) are reasonably fit by the best fit EIFS function (straight lines) given by Eq. (4). For a given set of identical test specimens, all the data points obtained from different test conditions merge more or less into a single EIFS distribution. This tends to confirm the assumption that the EIFS distribution is generic, as described in Section 4.2.

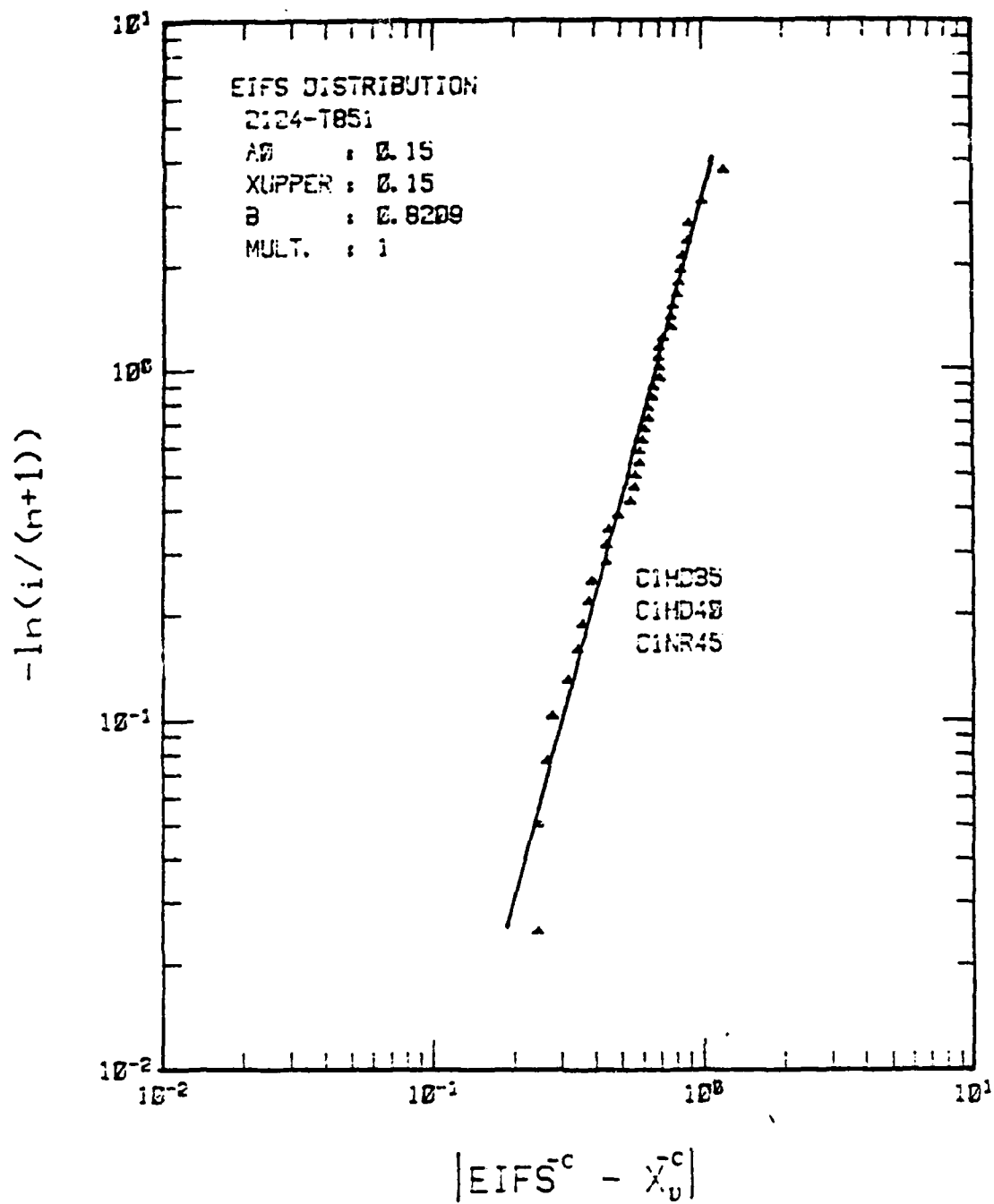


Figure 45. EIFS Distributions For 2124-T851 Aluminum Alloy

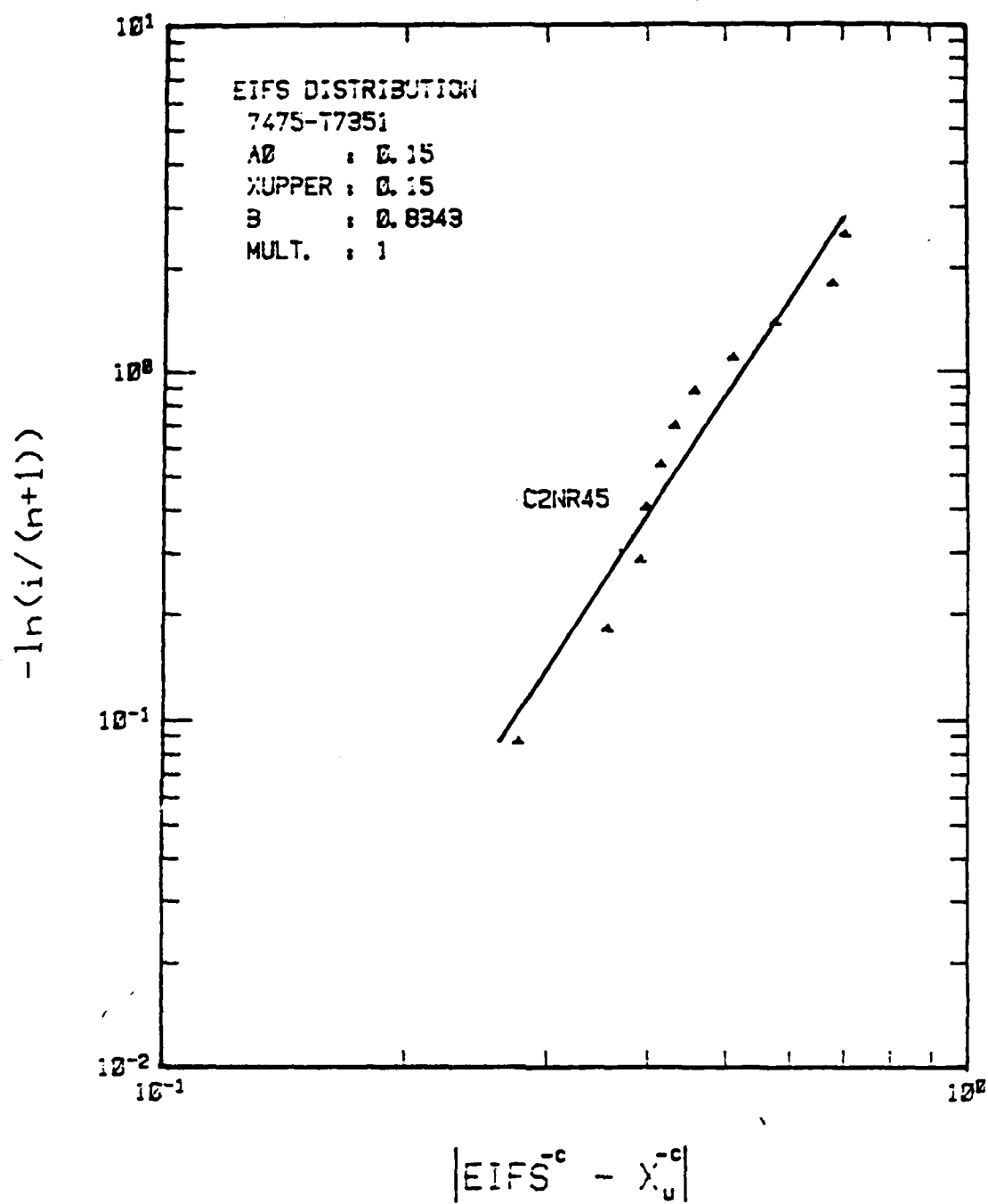


Figure 46. EIFS Distributions For 7475-T7351 Aluminum Alloy

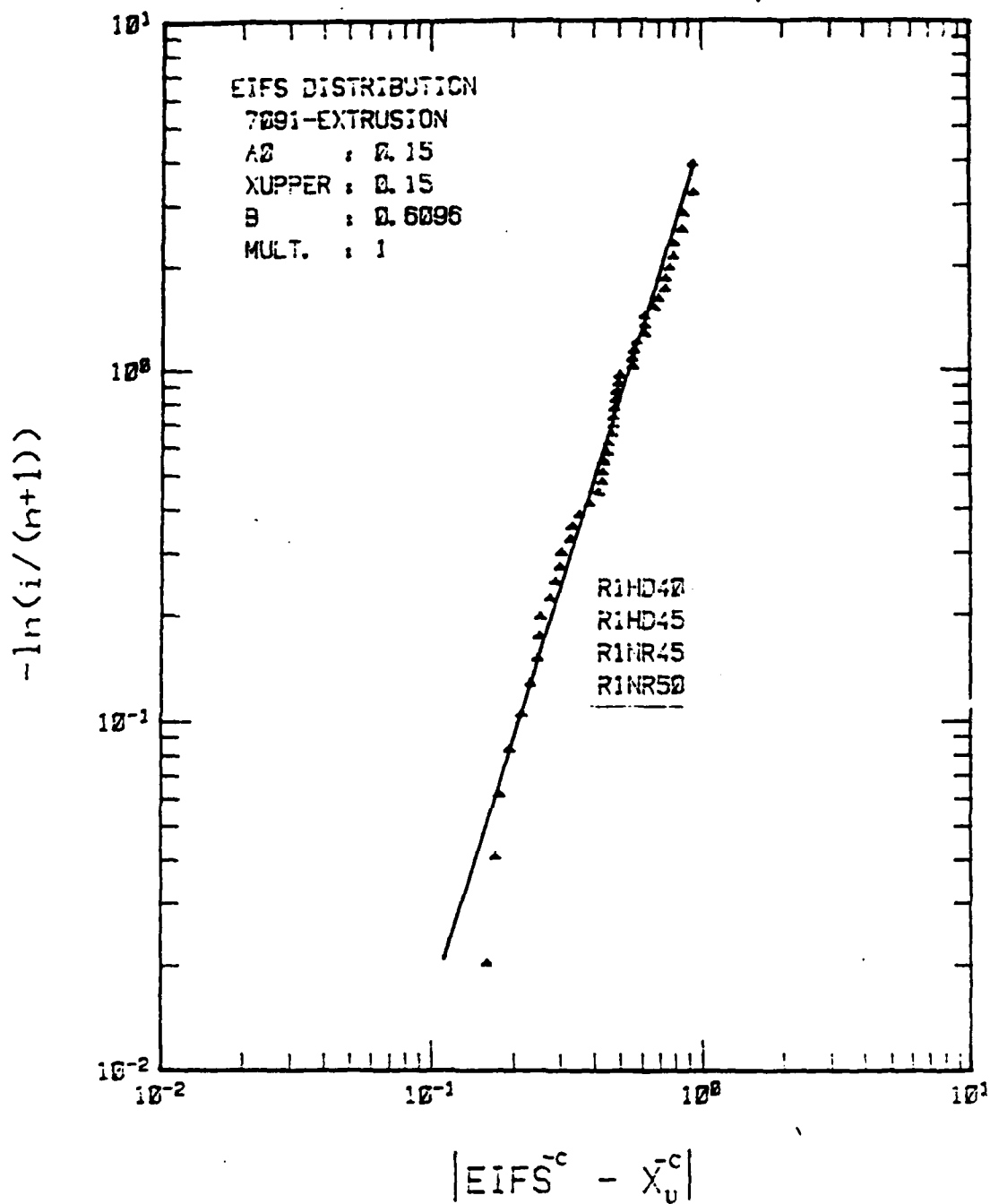


Figure 47. EIFS Distributions For 7091-Extrusion

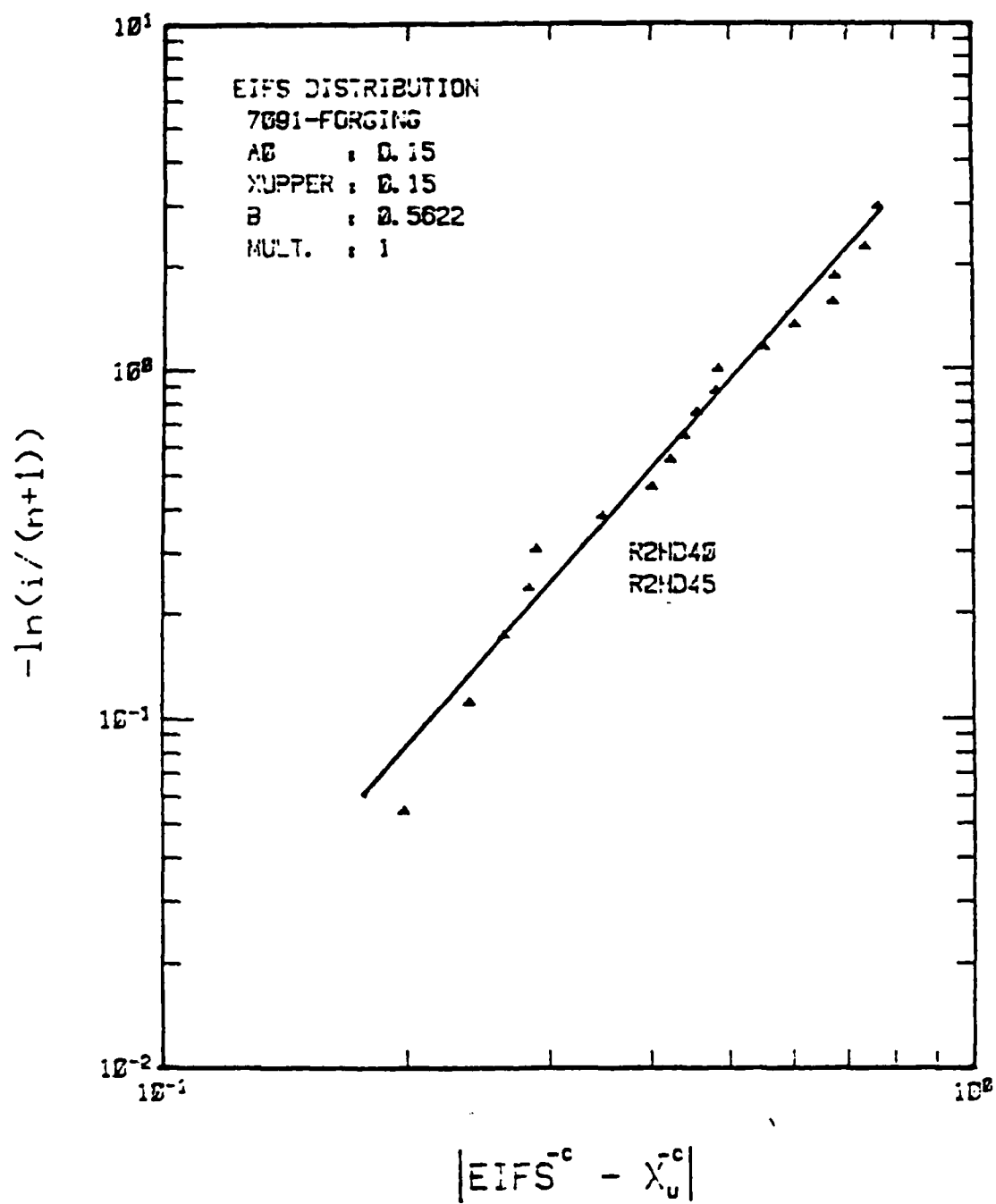


Figure 48. EIFS Distributions For 7091-Forging

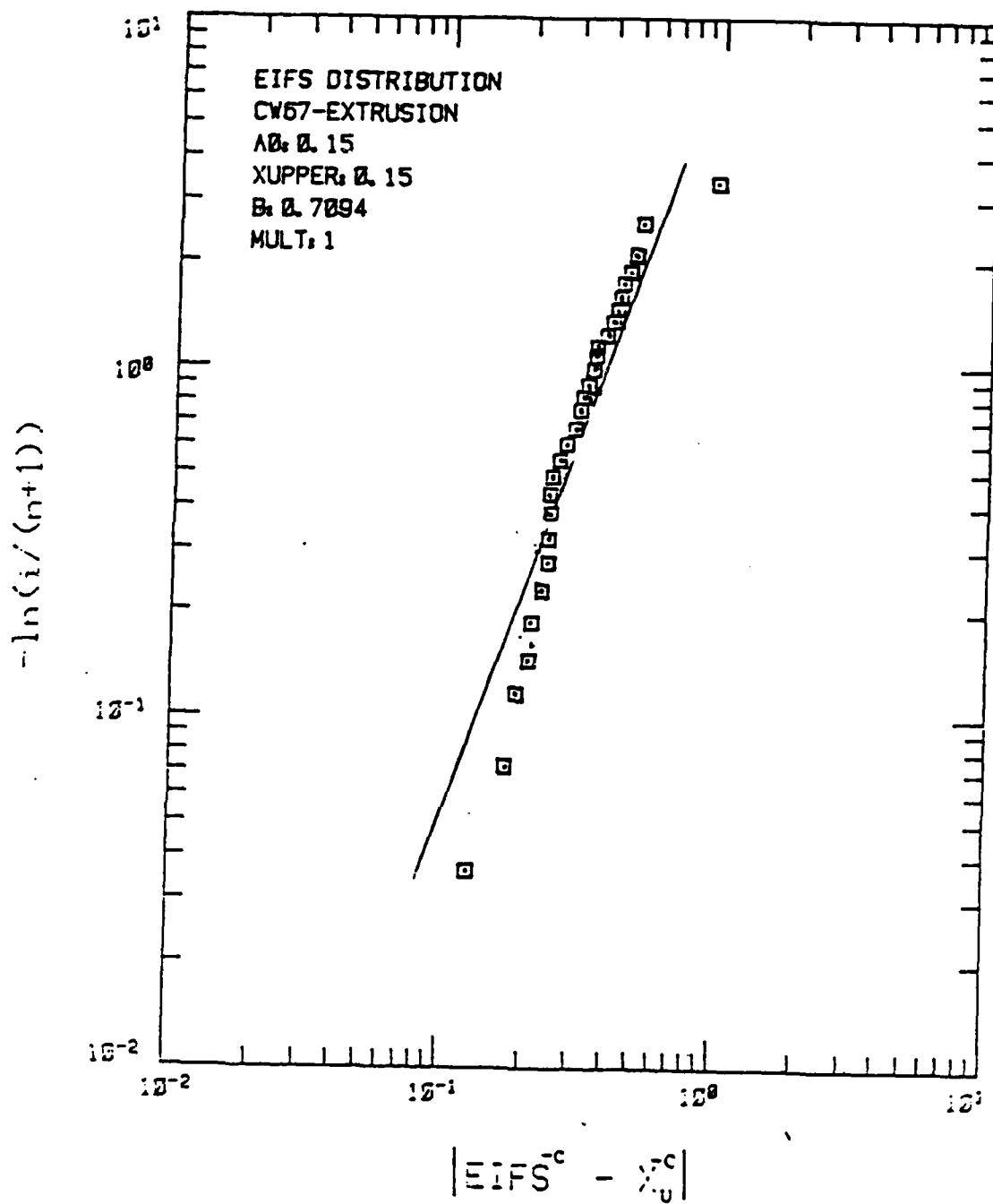


Figure 49. EIFS Distributions For CW67-Extrusion

On comparing EIFS values of RST materials with I/M alloys, EIFS values of 7091-T7E69 extrusions were considerably less than 2124-T851 plate. This difference is reflected in Table 11 where the average TTCl and EIFS values are shown for the different spectra. The average EIFS values for 7475-T7351 plate tested under the NOR1 spectrum were intermediate between 7091-T7E69 extrusions and CW67-T7E91 extrusions with the 7091-T7E69 material having the smallest EIFS values. Average EIFS values for 7091-forgings were slightly higher than initial flaw sizes obtained for 7091-extrusions.

Comparisons of  $EIFS^{-c} \cdot x_0^{-c}$  distributions between P/M alloys and I/M alloys are shown in Figures 50-52. Comparisons are shown for both the tension-compression HUD34 spectrum and tensile-dominated NOR1 spectrum. As mentioned previously, the EIFS distribution plots for a given material are fairly independent of spectrum.

On comparing 7091 extruded material with 7475-T7351 material, crossover effects are also observed in the EIFS distributions. Again, the crossover effect is due to greater scatter in the 7091-extrusion experimental data. The poorer performing 7091-extrusion coupons have larger EIFS values than the poorer 7475-T7351 specimens. Correspondingly, the better performing 7091-T7E69 coupons have lower EIFS values than 7475-T7351.

## 5.4 DURABILITY ANALYSIS BASED ON IFQ MODEL

### 5.4.1 Crack Growth Modeling

Using the Initial Fatigue Quality (IFQ) model, the crack growth rate over the crack size range of interest is assumed to be expressed as Eq. 2, where  $a(t)$  is the crack size at time  $t$ , and  $Q$  and  $b$  are constants that are determined from the least square fit of all  $\log da/dt$  vs.  $\log a$  pairs of the sample.

Integrating Eq. (2) from  $t = 0$  to  $t = t$  will give the time required for an initial defect to become a fatigue crack of size  $a(t)$ :

$$t = -\frac{1}{cQ} \left[ a^{-c}(t) - a^{-c}(0) \right] \quad (10)$$

TABLE 11. AVERAGE TTCI AND EIFS OF EACH MATERIAL

• UNDER HUD34, 40 KSI

|            | AVG. TTCI       | AVG. EIFS                    |
|------------|-----------------|------------------------------|
| 2124-T851  | 4396 FLT. HOURS | $3.5980 \times 10^{-4}$ INCH |
| 7091-EXTR. | 8756            | $-1.0847 \times 10^{-2}$     |
| 7091-FORG. | 6015            | $-8.0123 \times 10^{-3}$     |
| CW67-EXTR. | 6358            | $-8.0224 \times 10^{-4}$     |

• UNDER NOR1, 45 KSI

|            | AVG. TTCI | AVG. EIFS                    |
|------------|-----------|------------------------------|
| 2124-T851  | 12643     | $1.4831 \times 10^{-3}$ INCH |
| 7475-T7351 | 18657     | $1.4404 \times 10^{-3}$      |
| 7091-EXTR. | 18636     | $-9.4831 \times 10^{-3}$     |
| CW67-EXTR. | 13467     | $4.644 \times 10^{-3}$       |

• UNDER HUD34, 45 KSI

|            | AVG. TTCI | AVG. EIFS                    |
|------------|-----------|------------------------------|
| 7091-EXTR. | 3227      | $1.0233 \times 10^{-3}$ INCH |
| 7091-FORG. | 2786      | $8.2078 \times 10^{-3}$      |
| CW67-EXTR. | 3373      | $4.4522 \times 10^{-3}$      |

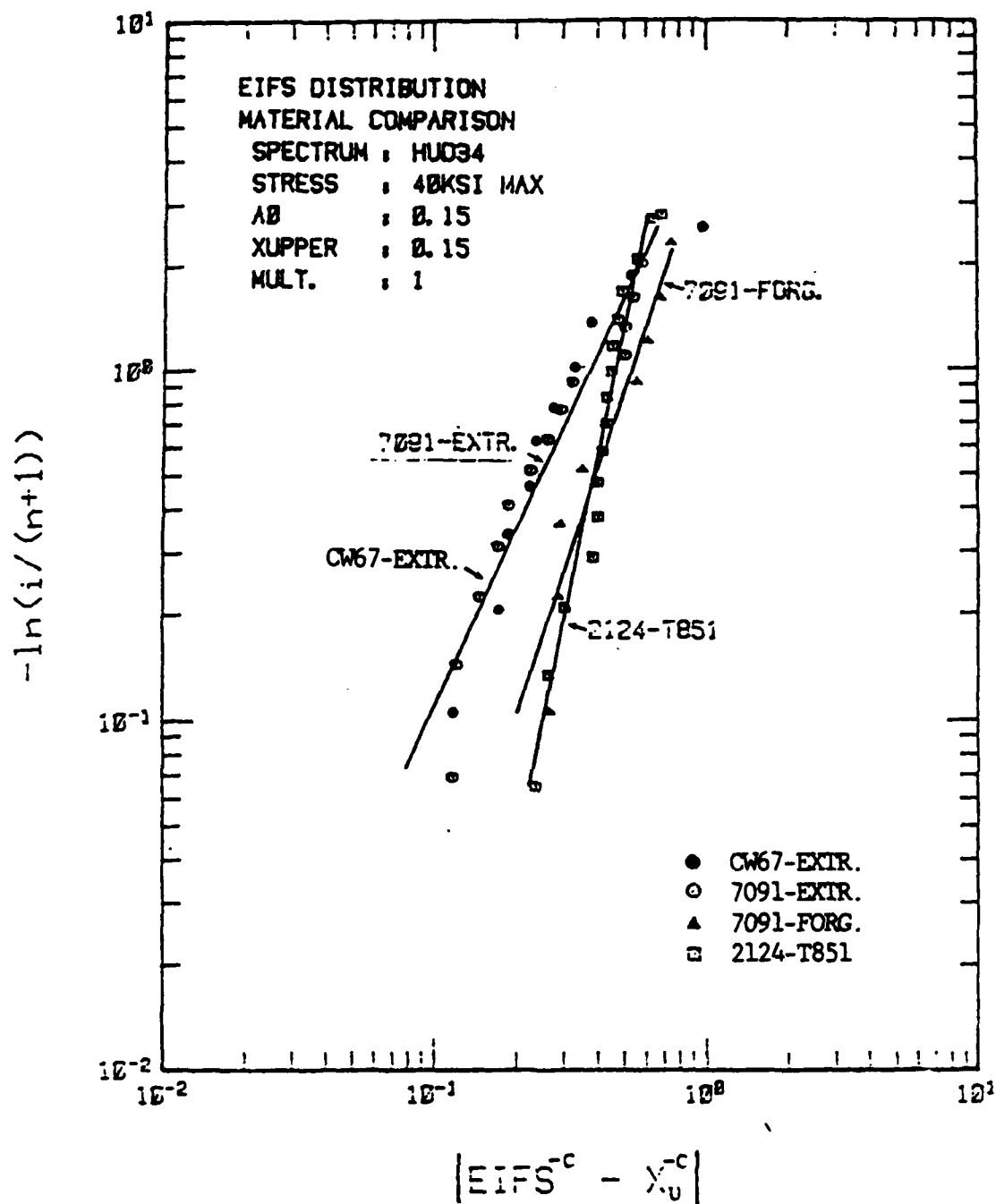


Figure 50. EIFS Comparisons For Three Aluminum Alloys  
(HUD 34 Spectrum)

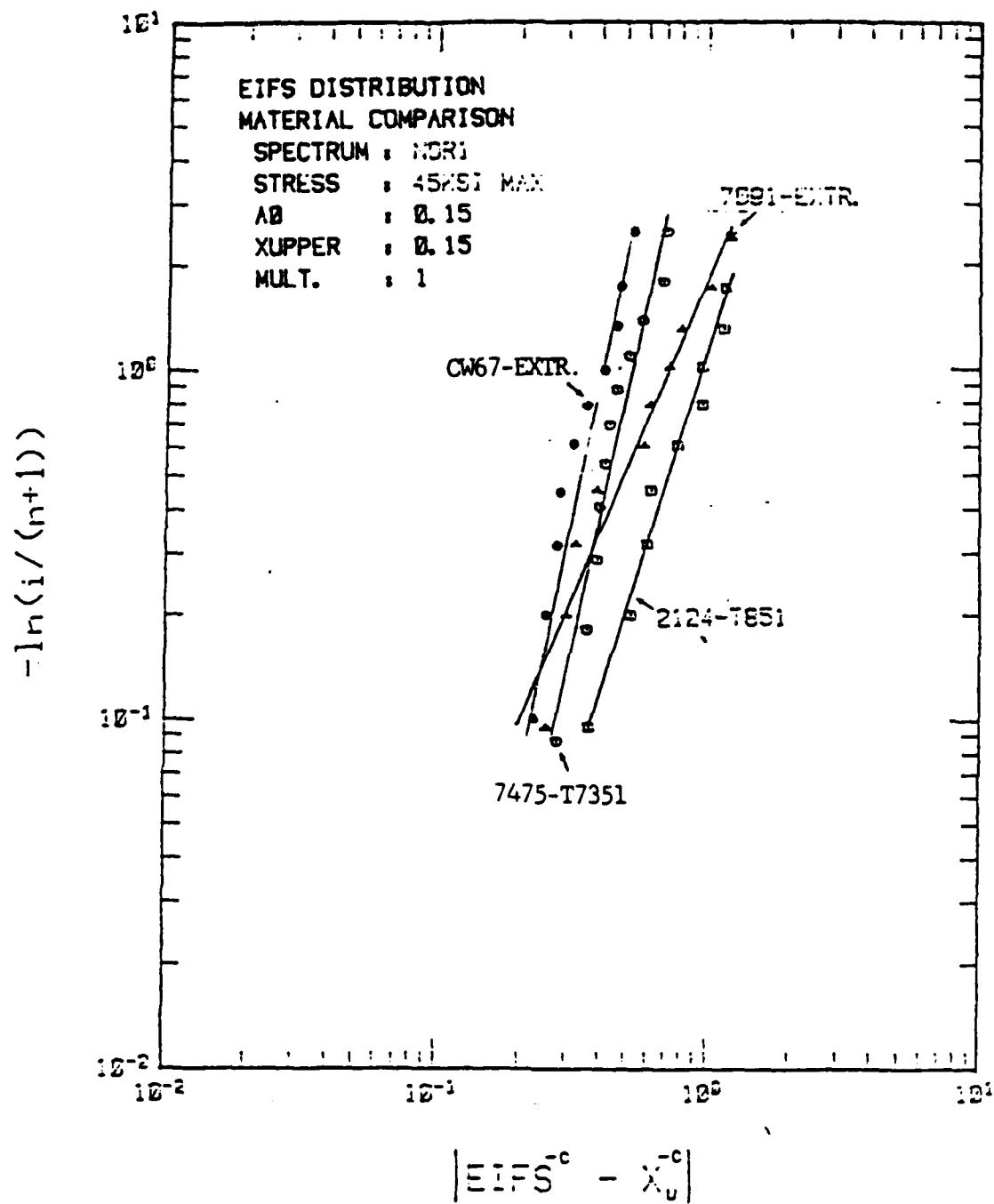


Figure 51. EIFS Comparisons For Four Aluminum Alloys  
(NOR 1 Spectrum)

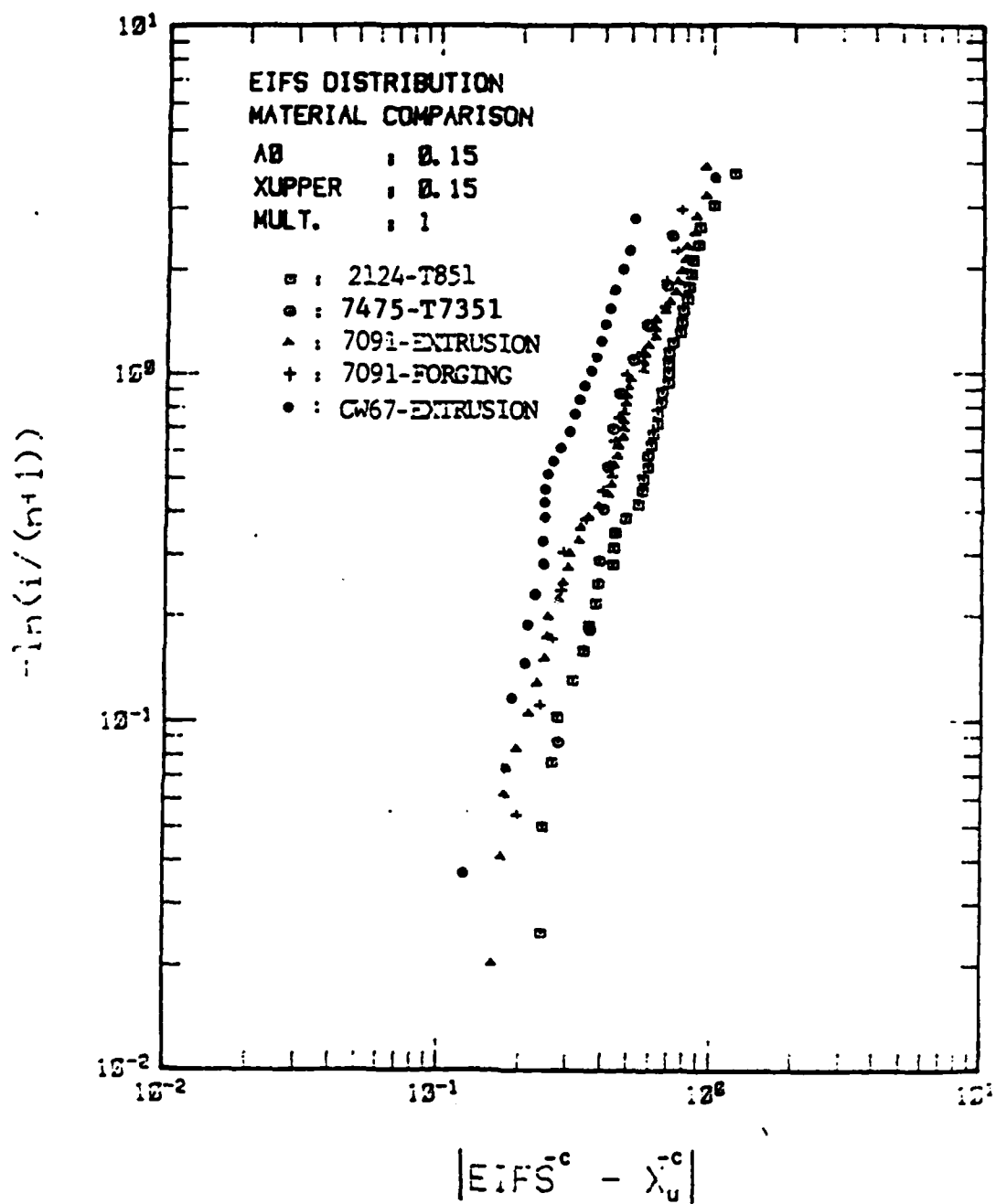


Figure 52. EIFS Comparisons (Pooled Data)

Using Eq. (10) the crack growth behavior of P/M alloys can be compared to I/M samples assuming the  $a(0)$  or EIFS values are known. By using an average EIFS value for each data set (Table 11), the following crack growth curves shown in Figures 53-55 can be generated. Results are shown for coupons tested under both the HUD34 and NOR1 test spectra. Eq. 10 can also be used to calculate time-to-failure (TTF). In this case, at  $t = 0$ ,  $a = a(0)$ , which is the EIFS. At  $t = \text{TTF}$ ,  $a = a(\text{TTF})$ , which is the crack size at failure, or critical crack size,  $a_{\text{crit}}$ . Calculated TTF values can be obtained from Figures 53-55 and compared to experimental values (Table 10). Relatively good agreement was obtained between calculated values of TTF and experimental average values.

Results from Figures 53-55 show superior crack growth resistance for the P/M aluminum alloys. The poorest crack growth behavior was obtained in 2124-T851 for coupons tested under both the HUD34 and NOR1 test spectra (Figures 53-54). The best crack growth life was obtained in 7091-T7E69 extruded material for tests conducted under NOR1 spectrum and HUD34 spectrum (40 ksi maximum stress). For tests conducted under the HUD 34 spectrum with a maximum stress of 45 ksi, maximum flight hours was obtained from the CW67-T7E91 material (Fig. 55). In this set of experiments, all of the CW67 test coupons were fabricated from the #514553-2 billet.

#### 5.4.2 Reliability and Figure of Merit

The durability of structures depends on both the EIFS distribution and crack growth rate. These two elements must be combined in order to judge their relative importance. A recommended method for properly considering both the EIFS distribution and the crack growth rate is to combine them to compute the flaw distribution after a desired service interval. This technique was used in the "Initial Quality of Advanced Joining Concepts" program [5]. The flaw distribution after service (FDAS) can be computed by transforming (1) and (4) to obtain:

$$F_{a(T)}(x) = P[a(T) \leq x]$$

$$= \exp \left\{ - \left[ \frac{x^{-c} - a_0^{-c} + cQT(T-\epsilon)}{cQ\beta} \right]^\alpha \right\} \quad (11)$$

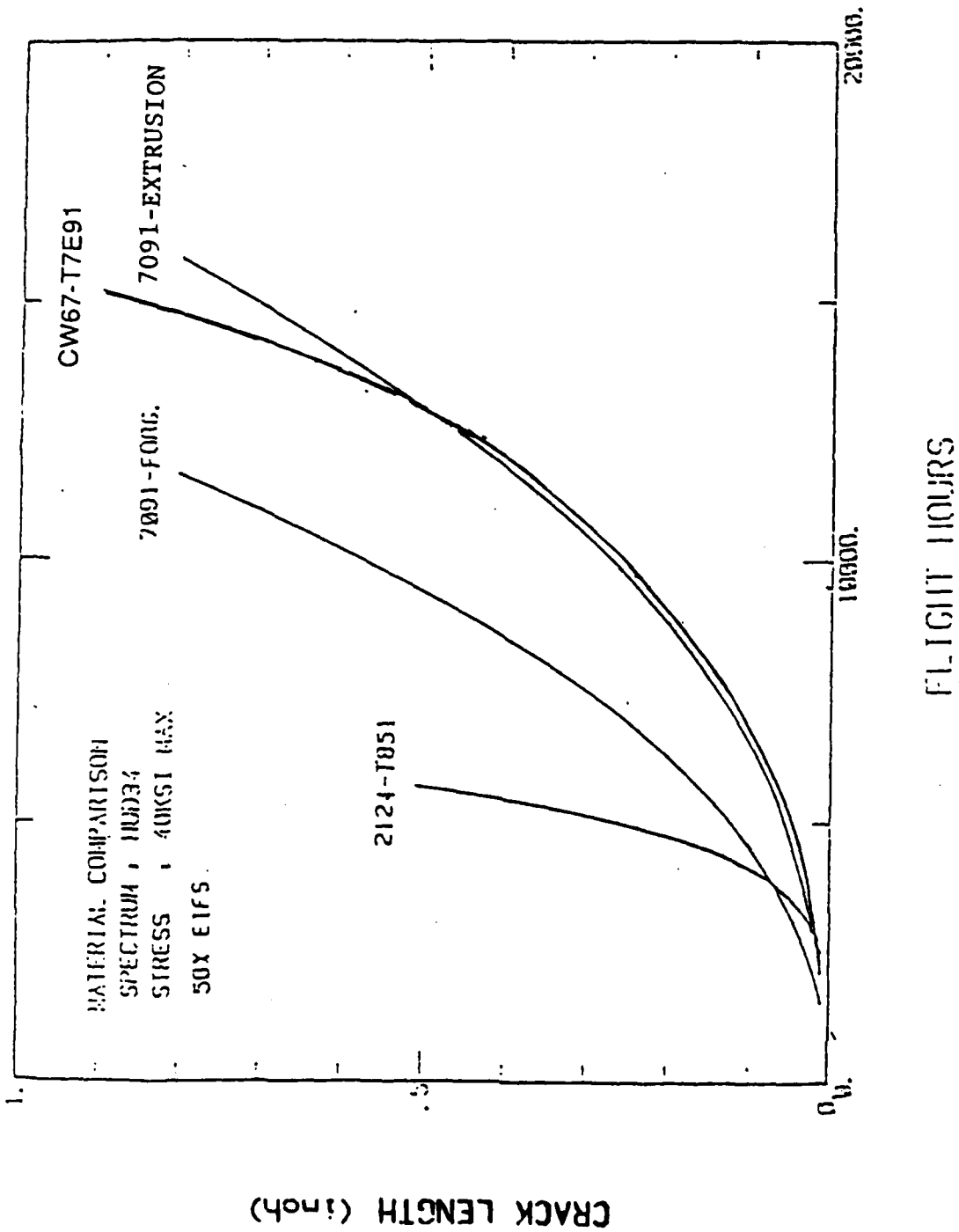


Figure 53. Crack Growth Comparisons in Three Aluminum Alloys (HUD 34 Spectrum, Maximum Stress = 40 ksi)

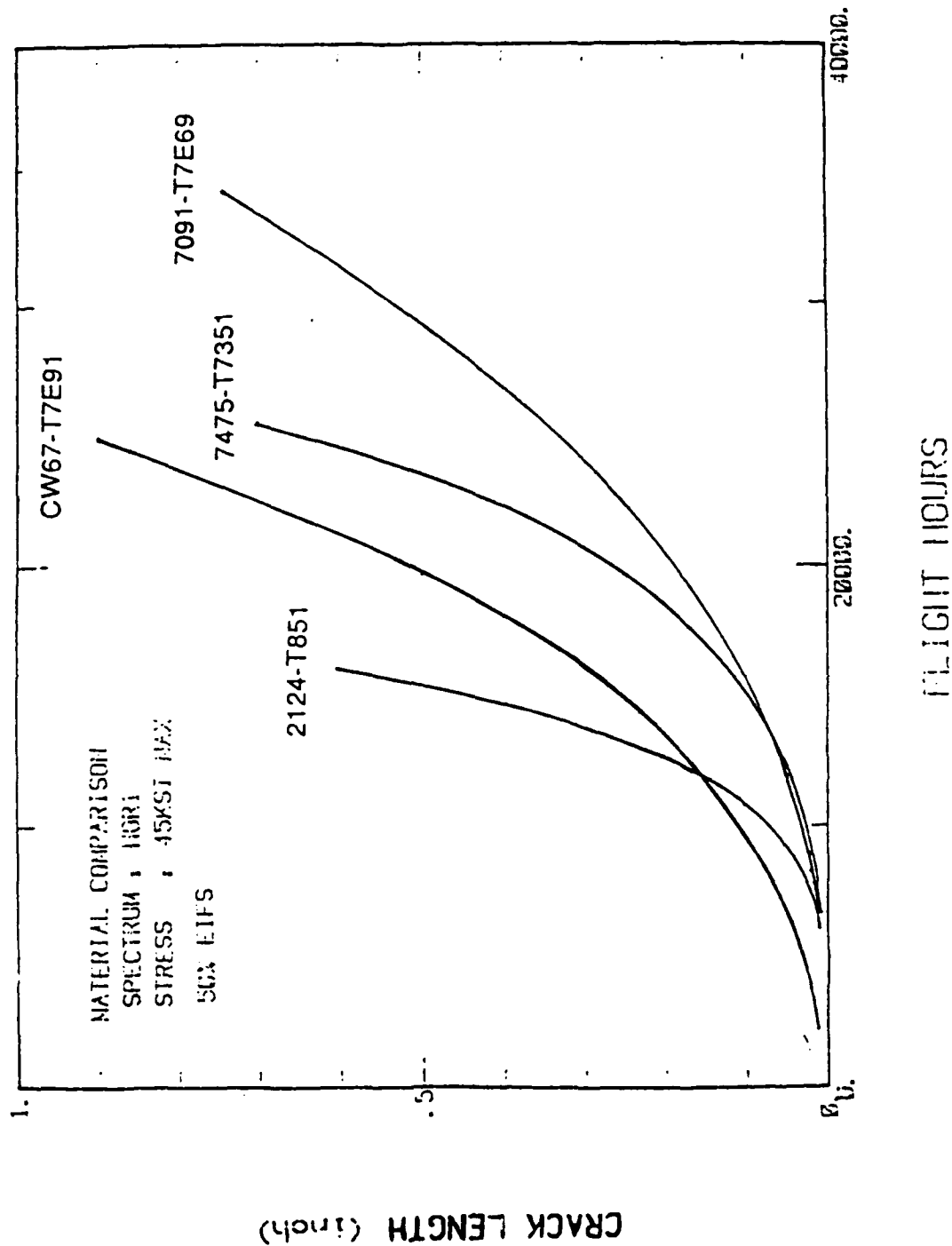


Figure 54. Crack Growth Comparisons In Four Aluminum Alloys (NOR 1 Spectrum)

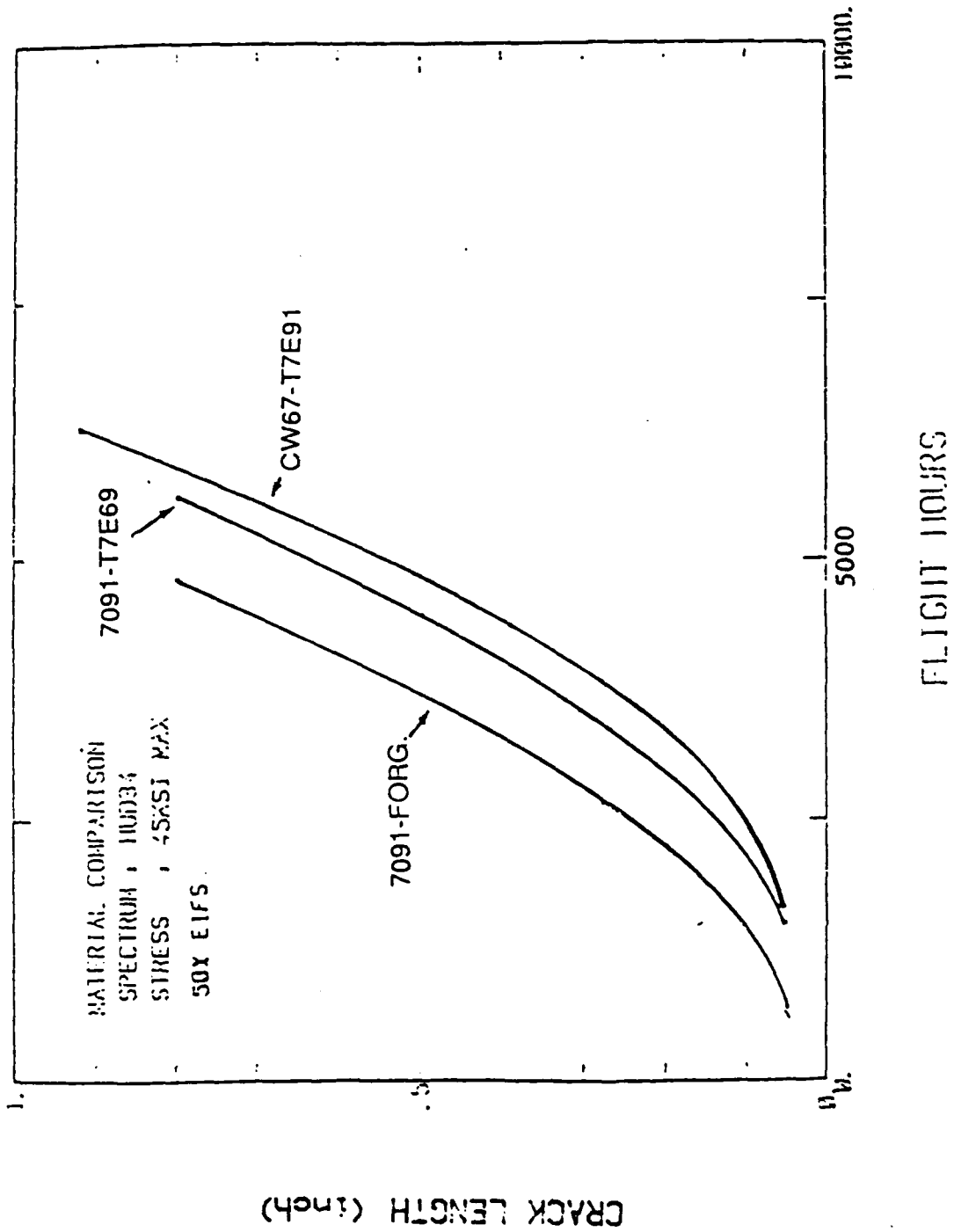


Figure 55. Crack Growth Comparisons In P/M Aluminum Alloys  
(HUD 34 Spectrum, Maximum Stress = 45 ksi)

where  $F_{a(T)}(x)$  is the distribution of flaws after time  $T$ .

Equation (11) can be used to find the cumulative flaw distribution for any conditions. The parameters  $a_0$ ,  $\alpha$ , and  $\beta$  are given in Table 9. The lower bound of TTCL,  $\epsilon$ , was set equal to zero in all of our analysis. The parameters  $Q$  and  $c$  (where  $c=b-1$ ) describe crack growth, which is a function of geometry and loading. These are already known for the test conditions of this program and are also given in Table 9. They can also be calculated using any valid crack growth prediction, such as a cycle-by-cycle computer analysis. The parameter  $x$  in Equation (11) can represent any flaw size of interest. If flaw sizes are extended to the critical crack size in Equation 11,  $x = a_{crit}$ , reliability of both RST structures and ingot metallurgy materials may be calculated at any service time.

From previous studies [5,12,18] it is shown that characteristic crack growth rate,  $Q$ , can be given as a function of stress level,  $\sigma$ , by:

$$Q = A\sigma^B \quad (12)$$

for a reasonable range of  $\sigma$ . Equation (12) provides the means for determining the effect of spectrum stress on structural performance. If  $Q$  is experimentally determined for two different stress levels, the constants  $A$  and  $B$  can be determined from Equation (12). Values of  $Q$  can then be calculated for any stress level.

Equations (11) and (12) were used to generate reliabilities and results are plotted in Figures 56-57 for the HUD34 spectrum at 16,000 flight hours and Figs. 58-59 for the NOR1 spectrum at 27,000 flight hours. Since aircraft structural reliabilities less than 90 percent are generally of little interest, a closer look at the regions of interest are shown in Figure 57 and Figure 59. These results indicate that at high reliabilities, P/M alloys can tolerate the most stress, or that the RST structures can be operated at higher stresses than the conventional I/M aluminum alloys.

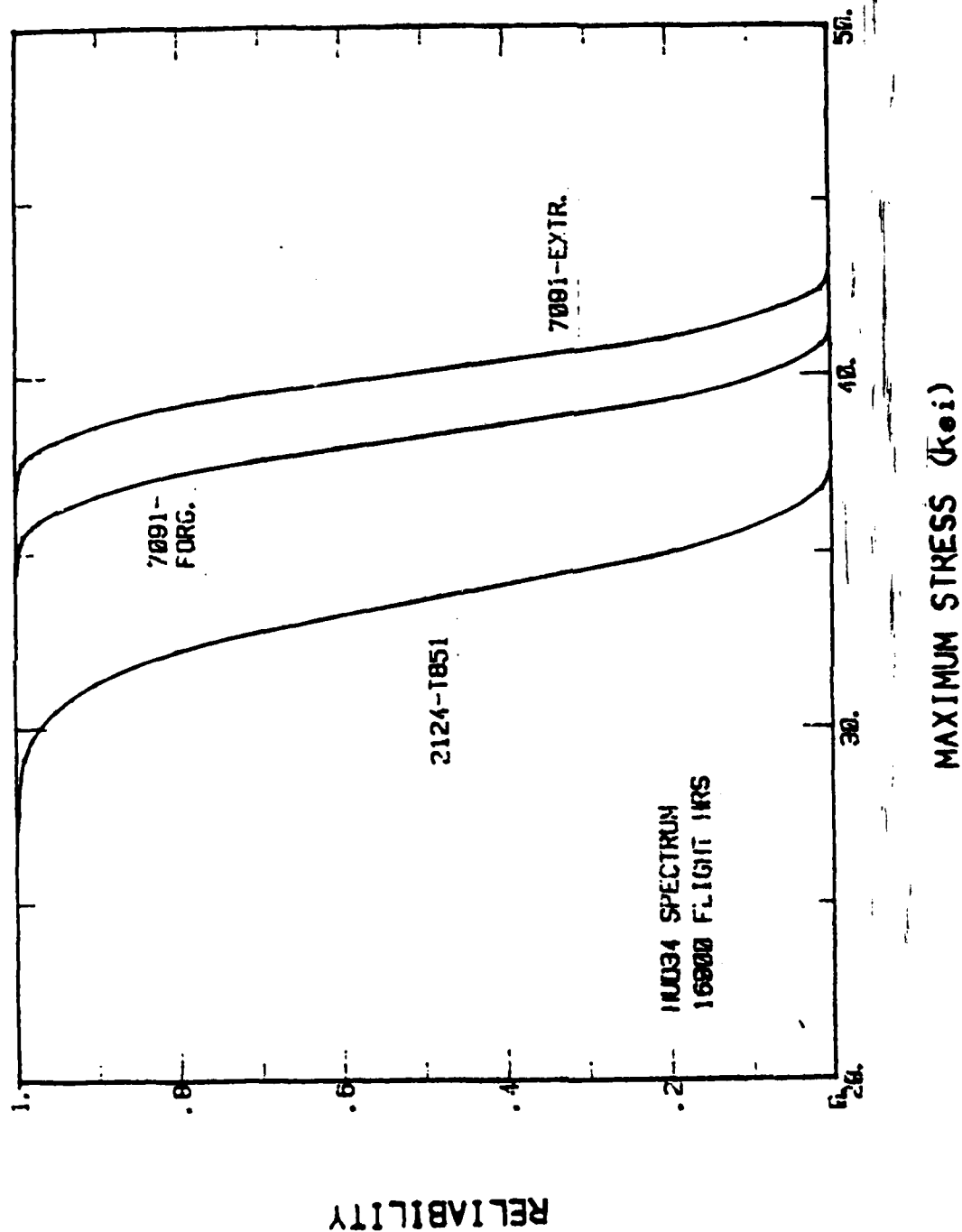


Figure 56. Comparison Of Structural Reliability Of P/M Aluminum Alloys Versus I/M Aluminum Alloys (11034 Spectrum At 16,000 Flight Hours)

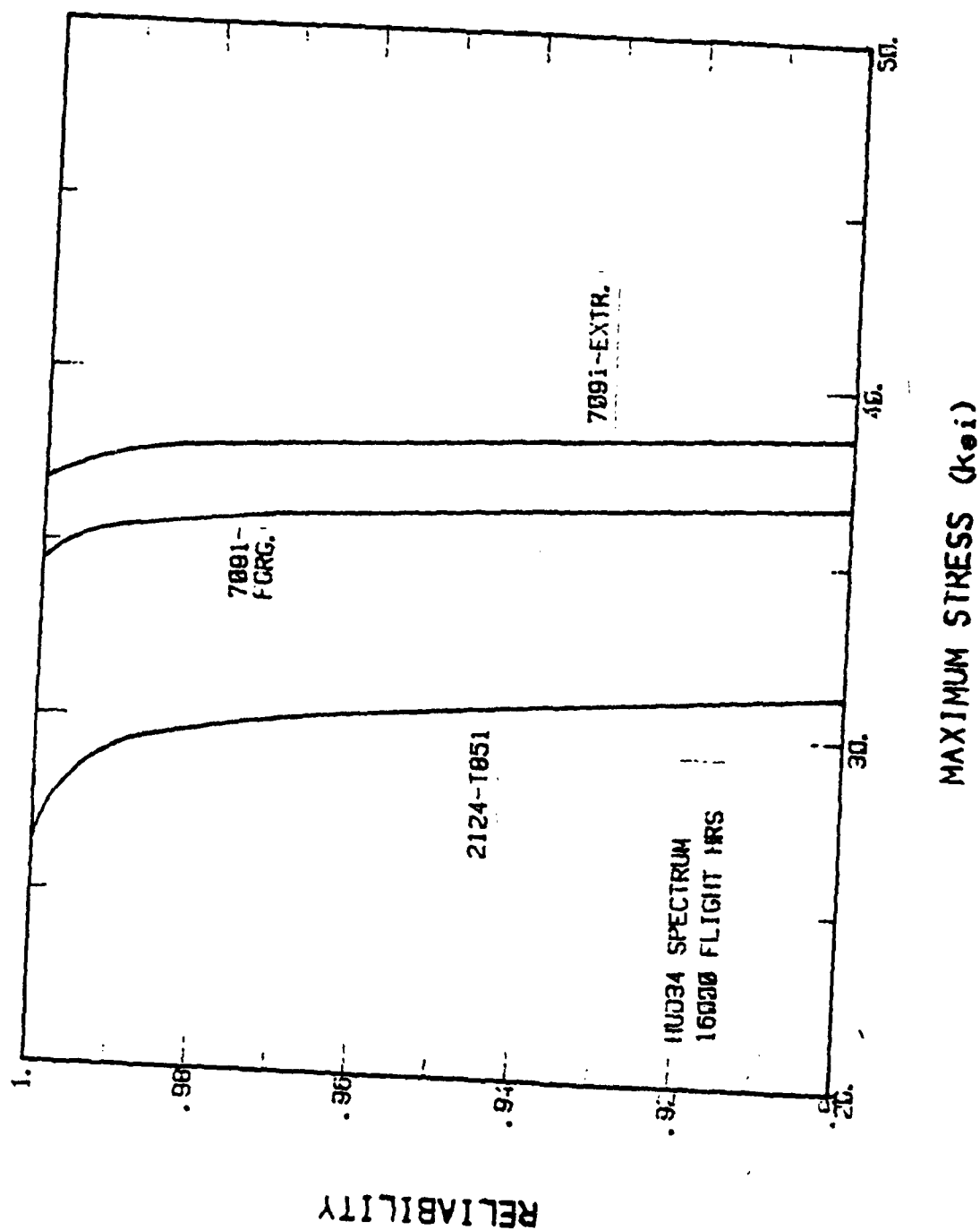


Figure 57. Comparison Of Reliability Above 90 Percent For Three Aluminum Alloys (HUD 34 Spectrum)

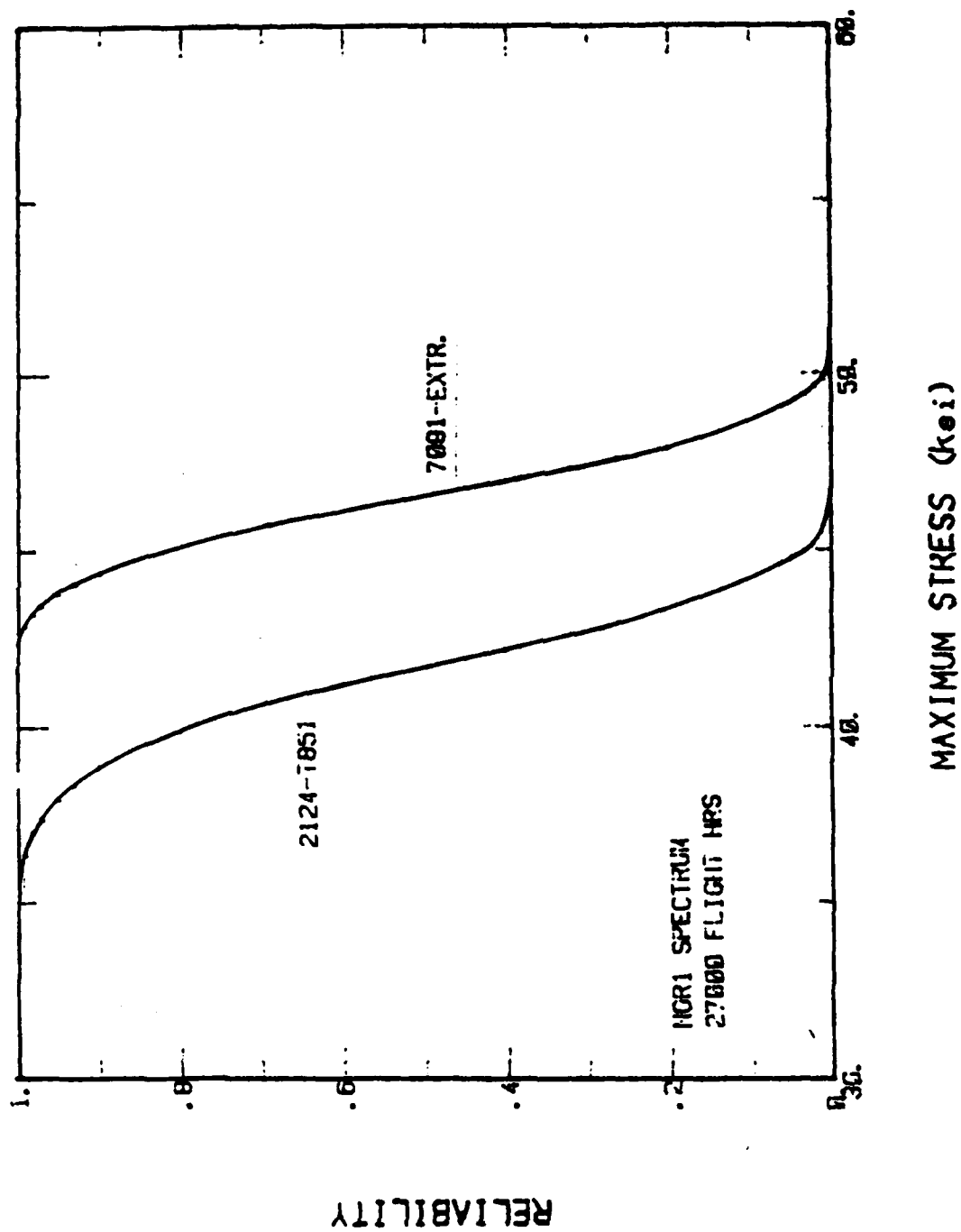


Figure 58. Comparison Of Structural Reliability Of P/M Aluminum Alloys Versus I/M Aluminum Alloys (NOR 1 Spectrum At 27,000 Flight Hours)

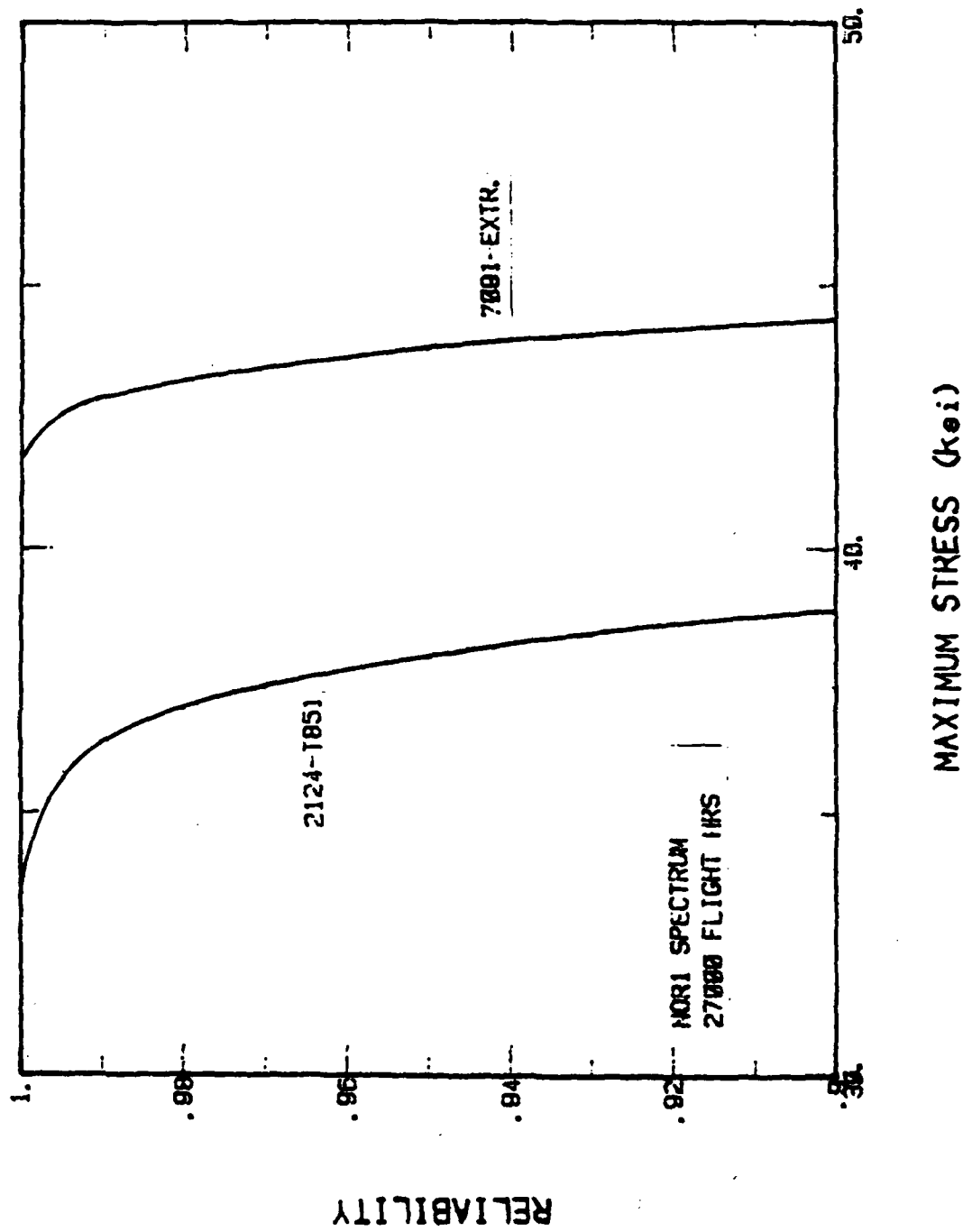


Figure 59. Comparison Of Reliability Above 90 Percent Of  
7091-Extrusion and 2124-T951 Plate (NOR 1  
Spectrum)

In these examples, the information desired is the probability that a flaw is less than  $a_{crit}$  after 16,000 flight hours (2 lifetimes) of the HUD34 spectrum and 27,000 flight hours of the NOR1 spectrum. A durability analysis such as used in this section for comparing structural reliability of P/M aluminum alloys versus I/M aluminum alloys (Figures 56-59) can be used for making "figure of merit" comparisons. This method gives quantitative, statistically based information for design comparison with relatively little effort.

In addition to durability comparisons, designers must often consider other factors in making "figure of merit" comparisons. These factors include density, strength, stiffness, corrosion resistance, cost, and availability of material. Studies have been conducted on determining how improvements in various properties affect weight savings in aircraft structures [26]. Results of these studies are shown in Figure 60. For example, a 10 percent weight savings can be achieved by a 10% decrease (improvement) in density, by a 30 percent increase in strength or by a 45 percent increase in stiffness. Depending on the specific component, damage-tolerance and fatigue are properties where improvements can also lead to weight savings.

The effects of the various engineering parameters will change in relative importance depending on both the mission of the aircraft and the governing failure mode (tension, compression, or other modes). The modulus of elasticity and the compression yield strength are more important in compression-critical structures, particularly in thin sections, and the fatigue resistance, fracture toughness, and tensile strength are more important in tension-critical applications.

For structural components requiring high strength plus excellent corrosion resistance, RST P/M aluminum alloys are particularly appealing. For example, P/M alloys offer between 10 to 20 percent greater strength than 7075-T73 which is commonly used in these applications. This translates into at least a 5 percent weight savings (Figure 60). However, when specific strength (strength/density) is considered, some of the potential weight savings is lost. Based on density comparisons, the density of CW67 is 0.104 lb./in.<sup>3</sup>. The density of 7475 is 0.101 lb./in.<sup>3</sup> and that of 2124 material is 0.100 lb./in.<sup>3</sup>. Based on density comparisons alone,

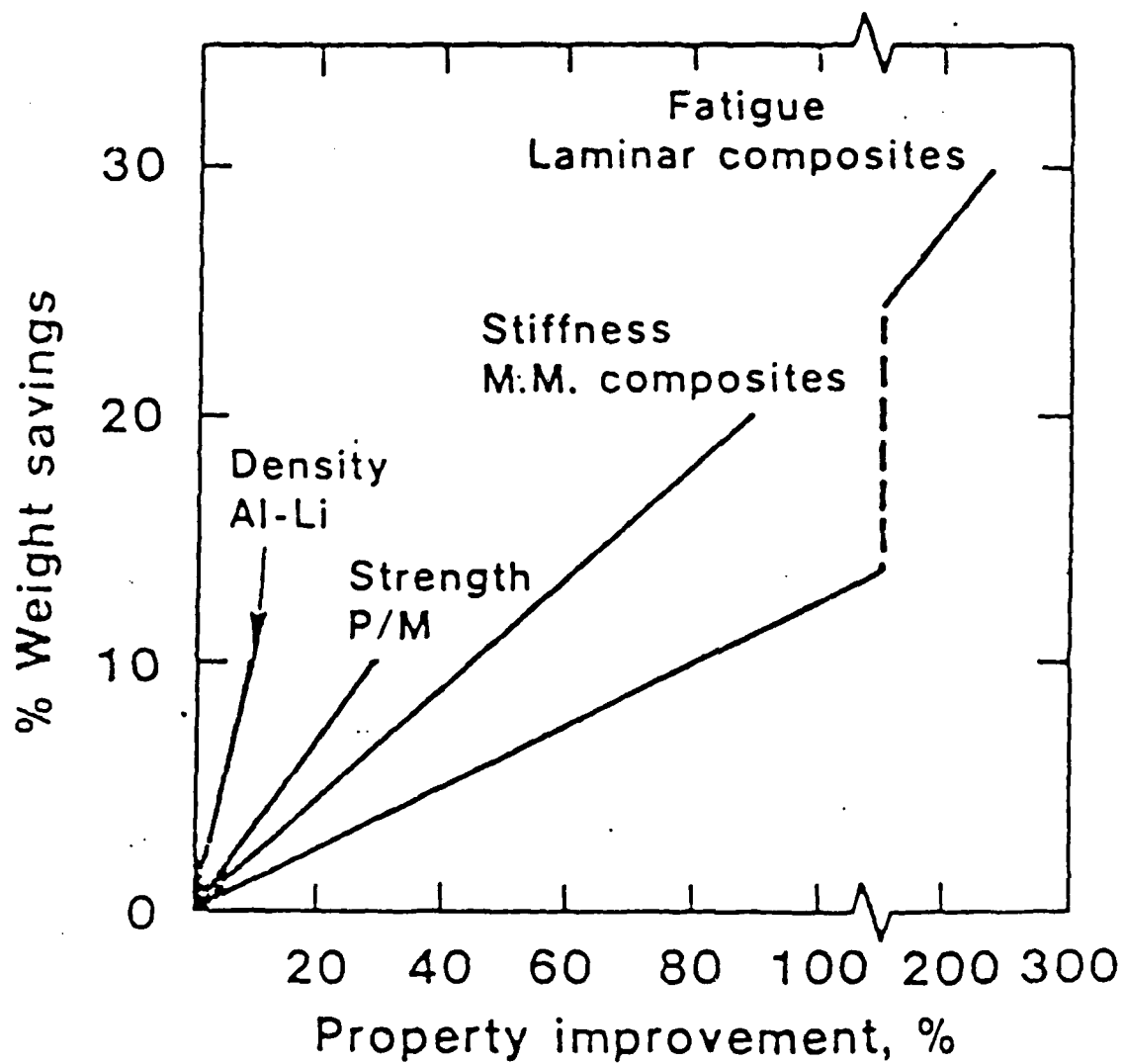


FIGURE 60. Effect Of Property Improvements On Weight Saving

weight penalty of approximately 3 percent is obtained by replacing conventional I/M alloys such as 7475 and 2124 with an RST P/M alloy such as CW67.

The cost of P/M products remains higher than those produced from standard ingot metallurgy. Therefore, their applications are limited to components where superior performance requirements must justify their use. The growth of P/M alloys has also been constrained by the size of billets available for processing into wrought products. In the past, RST P/M billets have been restricted to 300 lb. capacity. However, in the future this capacity can be raised to 4,000 lb. [27]. This should ease some of the past problems related to obtaining sufficient material.

## 5.5 SEVERITY OF SPECTRUM

A comparison of the HUD34 spectrum with the NOR1 spectrum in terms of spectrum severity is shown in Figure 60. A TTCI comparison for 7091-T7E91 extrusion tested at a maximum stress level of 45 ksi is shown. Much faster crack initiation is observed for the material tested under the HUD34 spectrum. These results are consistent with high compressive loads which are present in the HUD34 spectrum causing crack initiation to occur at an earlier stage.

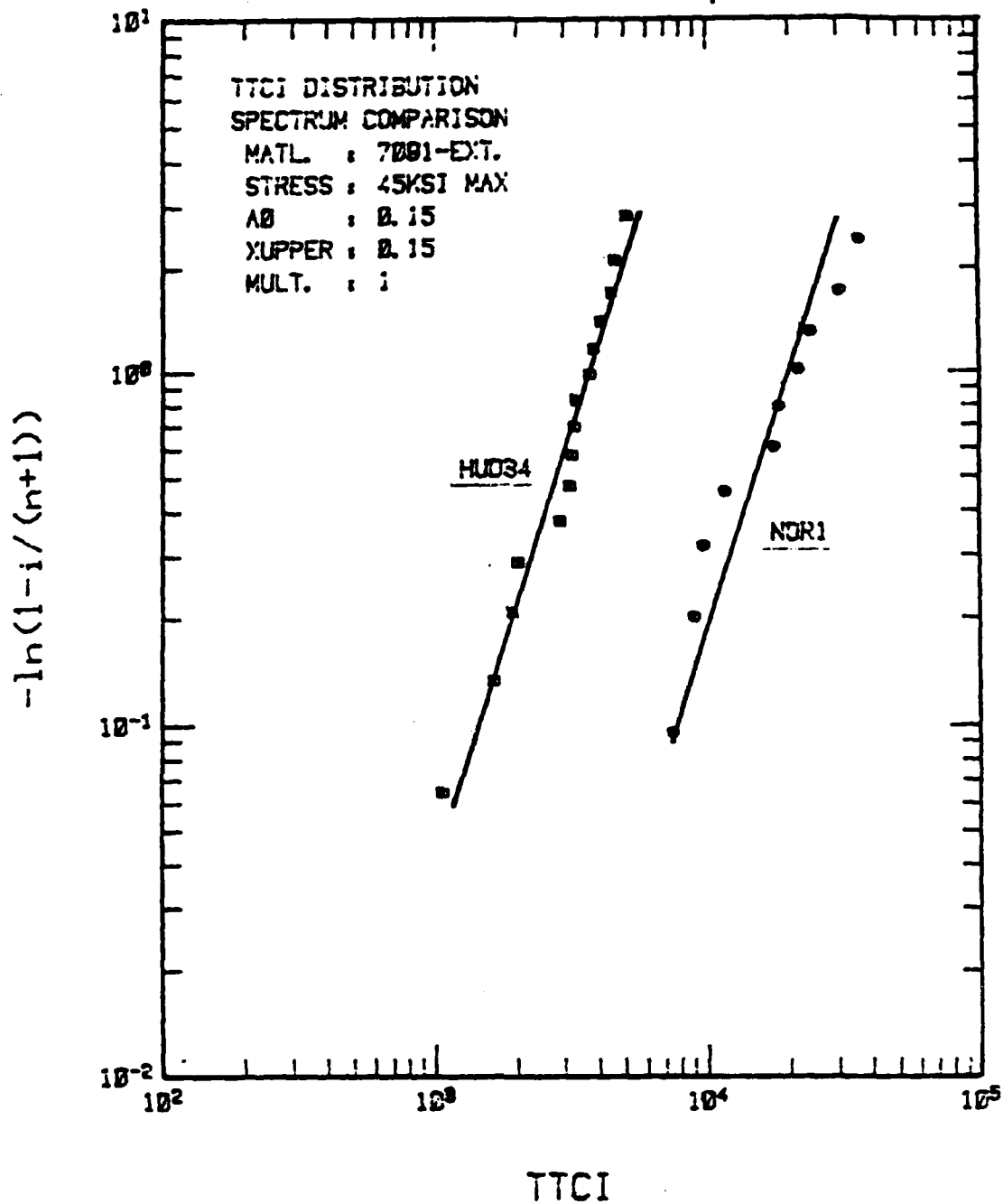


Figure 61. TTCI Distributions Of 7091-Extrusion Showing Comparison Of Load Spectra

8. Superior crack initiation resistance was observed in the higher ranked P/M specimens, especially extruded 7091-T7E69. However, lower ranked 7091-T7E69 test coupons exhibited little improvement in crack initiation resistance over I/M alloys tested. The control of inclusions in the RS P/M alloys will be expected to strongly influence crack initiation. By proper control, the worst performing P/M specimens would be eliminated therefore reducing the experimental scatter.
9. Experimental EIFS distributions of P/M and I/M materials were reasonably fit by a best fit EIFS function.
10. A fairly large variation in fatigue properties was observed in CW67 extruded material. Test coupons from one billet had significantly better durability than extrusions obtained from two other billets. These results emphasize the need for using material from different billets when generating design test data.
11. None of the inspection techniques provided correlations of NDI parameters with spectrum fatigue performance. It was concluded that the size of the flaws which influenced fatigue performance are smaller than can be detected with the NDI techniques used in these studies.

## SECTION VII

### RECOMMENDATIONS

1. High strength RST P/M aluminum alloys should be considered for usage in structures where I/M aluminum alloys such as 2124-T851 and 7475-T7351 are currently used. Potential weight savings exist with the RST aluminum alloys due to the improvement in fatigue properties. The type of spectrum loading needs to be considered when comparing RST P/M aluminum alloys with I/M aluminum alloys, however.
2. The high tensile strength, excellent corrosion resistance, good fracture toughness, and slow crack growth at large crack sizes, make CW67 particularly attractive for aerospace applications. However, the cause of variation in fatigue properties from billet to billet needs to be investigated. Testing material from different billets is recommended when generating design test data.
3. Effects of anisotropy in basic mechanical properties of CW67 on spectrum fatigue performance needs to be examined.
4. Durability and damage tolerance specification, based on the IFQ model should be considered for both RST P/M structures and conventional I/M structures. These methods based on element level testing, provide an effective compromise between the deterministic analysis and limited testing on the one hand, and very high costs associated with multiple structural tests, on the other.
5. Mechanisms responsible for the reduction in fatigue life of the forged material compared to extruded material needed to be investigated further. Correlations between parameters such as grain flow, forging variables, residual stress, etc. with fatigue properties need to be established.

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# LIST OF SYMBOLS

| <u>SYMBOL</u> | <u>DESCRIPTION</u>                            |
|---------------|-----------------------------------------------|
| RST           | Rapidly Solidified Technology                 |
| RSP           | Rapid Solidification Processing               |
| P/M           | Powder Metallurgy                             |
| I/M           | Ingot Metallurgy                              |
| ORR           | Out-Of-Roundness                              |
| FTSD          | Film-To-Source-Distance                       |
| FCGR          | Fatigue Crack Growth Rate                     |
| FCG           | Fatigue Crack Growth                          |
| $a$           | Crack Length                                  |
| $a_o$         | Crack Length at $t = T_{TCI}$                 |
| $a(o)$        | EIFS                                          |
| $a_{crit}$    | $a(TTF)$ , Critical Crack Size                |
| $b$           | Crack Growth Parameter                        |
| $c$           | $= b-1$                                       |
| EIFS          | Equivalent Initial Flaw Size                  |
| $F_{a(o)}(x)$ | $= P[a(o) < x]$                               |
| $F_T(t)$      | $= P[T < t]$                                  |
| FDAS          | $=$ Flaw Distribution After Service           |
| $i$           | Subscript Representing an Individual Specimen |
| $I$           | Subscript Representing an Individual Data Set |

LIST OF SYMBOLS (Continued)

| <u>SYMBOL</u> | <u>DESCRIPTION</u>                                |
|---------------|---------------------------------------------------|
| IFQ           | Initial Fatigue Quality                           |
| P[]           | Probability                                       |
| Q             | Crack Growth Parameter                            |
| $Q_i$         | Q for Specimen Using Pooled b                     |
| $Q_I$         | Q Obtained from Pooled Data Set                   |
| t             | Time                                              |
| T             | A Random Variable Indicating TTCI                 |
| TTCI          | Time to Crack Initiation                          |
| TTF           | Time to Failure                                   |
| x             | A Random Variable indicating EIFS                 |
| $x_u$         | Upper bound of EIFS                               |
| $\alpha$      | Shape Parameter of TTCI Distribution              |
| $\beta$       | Scale Parameter of TTCI Distribution              |
| $\epsilon$    | Lower Bound of TTCI Distribution                  |
| *             | <u>Superscript Representing a Pooled Data Set</u> |

## APPENDIX A

### Fractographic Crack Growth Data

Measured crack growth data for all of the data sets are listed in this section. Crack sizes are given in inches and time is given in flight hours. Data set notations used are listed in Table A-1. For example, C1HD35 refers to 2124-T851 material tested under the HUD 34 spectrum with a maximum stress of 35 ksi.

**A1 - POOLED DATA SETS FOR EIFS DETERMINATION**

| POOLED DATA SET | INDIVIDUAL DATA SET | NO OF SPECIMENS |
|-----------------|---------------------|-----------------|
| 2124-T851       | C1HD35              | 15              |
|                 | C1HD40              | 15              |
|                 | C1NR45              | 10              |
| 7475-T7351      | C2NR45              | 11              |
| 7091-EXTRUSION  | R1HD40              | 14              |
|                 | R1HD45              | 15              |
|                 | R1NR45              | 10              |
|                 | R1NR50              | 10              |
| 7091-FORGING    | R2HD40              | 9               |
|                 | R2HD45              | 9               |
| CM67-EXTRUSION  | R3HD40              | 10              |
|                 | R3HD45              | 8               |
|                 | R3NR45              | 10              |

2124-T851  
 HUD 34 SPECTRUM  
 35 KSI MAXIMUM STRESS

C1HD35-01

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 500.  | 0.0071 |
| 2     | 1000. | 0.0196 |
| 3     | 1500. | 0.0370 |
| 4     | 2000. | 0.0624 |
| 5     | 2500. | 0.0829 |
| 6     | 3000. | 0.1024 |
| 7     | 3500. | 0.1259 |
| 8     | 4000. | 0.1483 |
| 9     | 4500. | 0.1794 |
| 10    | 5000. | 0.2267 |
| 11    | 5500. | 0.2921 |
| 12    | 6000. | 0.6314 |

C1HD35-04

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 1500.  | 0.0207 |
| 2     | 2000.  | 0.0312 |
| 3     | 2500.  | 0.0436 |
| 4     | 3000.  | 0.0600 |
| 5     | 3500.  | 0.0759 |
| 6     | 4000.  | 0.0936 |
| 7     | 4500.  | 0.1086 |
| 8     | 5000.  | 0.1236 |
| 9     | 5500.  | 0.1384 |
| 10    | 6000.  | 0.1532 |
| 11    | 6500.  | 0.1727 |
| 12    | 7000.  | 0.1959 |
| 13    | 7500.  | 0.2242 |
| 14    | 8000.  | 0.2700 |
| 15    | 8500.  | 0.3267 |
| 16    | 9000.  | 0.4274 |
| 17    | 9500.  | 0.6035 |
| 18    | 10000. | 0.7887 |
| 19    | 10500. | 0.8285 |

C1HD35-02

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 2000. | 0.0092 |
| 2     | 2500. | 0.0247 |
| 3     | 3000. | 0.0446 |
| 4     | 3500. | 0.0601 |
| 5     | 4000. | 0.0757 |
| 6     | 4500. | 0.1451 |
| 7     | 5000. | 0.2945 |
| 8     | 5500. | 0.3811 |
| 9     | 6000. | 0.6729 |
| 10    | 6500. | 0.8741 |

C1HD35-05

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 3500.  | 0.0268 |
| 2     | 4000.  | 0.0391 |
| 3     | 4500.  | 0.0496 |
| 4     | 5000.  | 0.0606 |
| 5     | 5500.  | 0.0743 |
| 6     | 6000.  | 0.0840 |
| 7     | 6500.  | 0.0978 |
| 8     | 7000.  | 0.1166 |
| 9     | 7500.  | 0.1348 |
| 10    | 8000.  | 0.1516 |
| 11    | 8500.  | 0.1707 |
| 12    | 9000.  | 0.1963 |
| 13    | 9500.  | 0.2279 |
| 14    | 10000. | 0.2588 |
| 15    | 10500. | 0.3192 |
| 16    | 11000. | 0.4226 |
| 17    | 11500. | 0.8224 |

C1HD35-03

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 2000. | 0.0290 |
| 2     | 2500. | 0.0441 |
| 3     | 3000. | 0.0611 |
| 4     | 3500. | 0.0766 |
| 5     | 4000. | 0.0954 |
| 6     | 4500. | 0.1131 |
| 7     | 5000. | 0.1413 |
| 8     | 5500. | 0.1719 |
| 9     | 6000. | 0.2093 |
| 10    | 6500. | 0.2673 |
| 11    | 7000. | 0.3859 |
| 12    | 7500. | 0.5147 |
| 13    | 8000. | 0.6378 |
| 14    | 8500. | 0.7813 |
| 15    | 9000. | 0.8869 |

## C1HD35-06

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 5500.  | 0.0548 |
| 2     | 6000.  | 0.0696 |
| 3     | 6500.  | 0.0847 |
| 4     | 7000.  | 0.0957 |
| 5     | 7500.  | 0.1076 |
| 6     | 8000.  | 0.1195 |
| 7     | 8500.  | 0.1372 |
| 8     | 9000.  | 0.1580 |
| 9     | 9500.  | 0.1889 |
| 10    | 10000. | 0.2289 |
| 11    | 10500. | 0.2882 |
| 12    | 11000. | 0.3690 |
| 13    | 11500. | 0.5576 |
| 14    | 12000. | 0.8309 |

## C1HD35-07

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 7000.  | 0.0313 |
| 2     | 7500.  | 0.0404 |
| 3     | 8000.  | 0.0542 |
| 4     | 8500.  | 0.0687 |
| 5     | 9000.  | 0.0806 |
| 6     | 9500.  | 0.0921 |
| 7     | 10000. | 0.1058 |
| 8     | 10500. | 0.1216 |
| 9     | 11000. | 0.1373 |
| 10    | 11500. | 0.1552 |
| 11    | 12000. | 0.1799 |
| 12    | 12500. | 0.2037 |
| 13    | 13000. | 0.2862 |
| 14    | 13500. | 0.4169 |
| 15    | 14000. | 0.5829 |

## C1HD35-08

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 4500.  | 0.0297 |
| 2     | 5000.  | 0.0360 |
| 3     | 5500.  | 0.0434 |
| 4     | 6000.  | 0.0534 |
| 5     | 6500.  | 0.0604 |
| 6     | 7000.  | 0.0676 |
| 7     | 7500.  | 0.0776 |
| 8     | 8000.  | 0.0921 |
| 9     | 8500.  | 0.1060 |
| 10    | 9000.  | 0.1211 |
| 11    | 9500.  | 0.1364 |
| 12    | 10000. | 0.1589 |
| 13    | 10500. | 0.1746 |
| 14    | 11000. | 0.1869 |
| 15    | 11500. | 0.2096 |
| 16    | 12000. | 0.2293 |
| 17    | 12500. | 0.2582 |
| 18    | 13000. | 0.2771 |
| 19    | 13500. | 0.3096 |
| 20    | 14000. | 0.3492 |
| 21    | 14500. | 0.4100 |
| 22    | 15000. | 0.5156 |

## C1HD35-09

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 9000.  | 0.0635 |
| 2     | 9500.  | 0.0733 |
| 3     | 10000. | 0.0839 |
| 4     | 10500. | 0.0980 |
| 5     | 11000. | 0.1096 |
| 6     | 11500. | 0.1191 |
| 7     | 12000. | 0.1323 |
| 8     | 12500. | 0.1480 |
| 9     | 13000. | 0.1665 |
| 10    | 13500. | 0.1818 |
| 11    | 14000. | 0.1969 |
| 12    | 14500. | 0.2091 |
| 13    | 15000. | 0.2244 |
| 14    | 15500. | 0.2447 |
| 15    | 16000. | 0.3504 |
| 16    | 16500. | 0.6172 |

## C1HD35-10

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 4000.  | 0.0198 |
| 2     | 4500.  | 0.0262 |
| 3     | 5000.  | 0.0329 |
| 4     | 5500.  | 0.0392 |
| 5     | 6000.  | 0.0455 |
| 6     | 6500.  | 0.0517 |
| 7     | 7000.  | 0.0585 |
| 8     | 7500.  | 0.0658 |
| 9     | 8000.  | 0.0733 |
| 10    | 8500.  | 0.0809 |
| 11    | 9000.  | 0.0888 |
| 12    | 9500.  | 0.0955 |
| 13    | 10000. | 0.1007 |
| 14    | 10500. | 0.1078 |
| 15    | 11000. | 0.1155 |
| 16    | 11500. | 0.1238 |
| 17    | 12000. | 0.1345 |
| 18    | 12500. | 0.1461 |
| 19    | 13000. | 0.1589 |
| 20    | 13500. | 0.1704 |
| 21    | 14000. | 0.1839 |
| 22    | 14500. | 0.1972 |
| 23    | 15000. | 0.2178 |
| 24    | 15500. | 0.2417 |
| 25    | 16000. | 0.2695 |
| 26    | 16500. | 0.3051 |
| 27    | 17000. | 0.8268 |

## C1HD35-12

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 8500.  | 0.0519 |
| 2     | 9000.  | 0.0593 |
| 3     | 9500.  | 0.0659 |
| 4     | 10000. | 0.0729 |
| 5     | 10500. | 0.0794 |
| 6     | 11000. | 0.0886 |
| 7     | 11500. | 0.0964 |
| 8     | 12000. | 0.1030 |
| 9     | 12500. | 0.1104 |
| 10    | 13000. | 0.1183 |
| 11    | 13500. | 0.1290 |
| 12    | 14000. | 0.1396 |
| 13    | 14500. | 0.1481 |
| 14    | 15000. | 0.1568 |
| 15    | 15500. | 0.1680 |
| 16    | 16000. | 0.1845 |
| 17    | 16500. | 0.2030 |
| 18    | 17000. | 0.2214 |
| 19    | 17500. | 0.2368 |
| 20    | 18000. | 0.2706 |
| 21    | 18500. | 0.3216 |
| 22    | 19000. | 0.4181 |
| 23    | 19500. | 0.7850 |

## C1HD35-14

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 10500. | 0.0811 |
| 2     | 11000. | 0.0954 |
| 3     | 11500. | 0.1088 |
| 4     | 12000. | 0.1201 |
| 5     | 12500. | 0.1308 |
| 6     | 13000. | 0.1431 |
| 7     | 13500. | 0.1594 |
| 8     | 14000. | 0.1788 |
| 9     | 14500. | 0.2020 |
| 10    | 15000. | 0.2239 |
| 11    | 15500. | 0.2494 |
| 12    | 16000. | 0.2759 |
| 13    | 16500. | 0.3042 |
| 14    | 17000. | 0.3341 |
| 15    | 17500. | 0.3594 |
| 16    | 18000. | 0.3913 |
| 17    | 18500. | 0.4178 |
| 18    | 19000. | 0.4701 |
| 19    | 19500. | 0.5087 |
| 20    | 20000. | 0.5680 |
| 21    | 20500. | 0.6437 |
| 22    | 21000. | 0.6975 |
| 23    | 21500. | 0.7400 |
| 24    | 22000. | 0.7778 |
| 25    | 22500. | 0.8149 |
| 26    | 23000. | 0.8494 |

## C1HD35-11

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 6500.  | 0.0228 |
| 2     | 7000.  | 0.0290 |
| 3     | 7500.  | 0.0385 |
| 4     | 8000.  | 0.0457 |
| 5     | 8500.  | 0.0514 |
| 6     | 9000.  | 0.0590 |
| 7     | 9500.  | 0.0684 |
| 8     | 10000. | 0.0784 |
| 9     | 10500. | 0.0890 |
| 10    | 11000. | 0.1033 |
| 11    | 11500. | 0.1137 |
| 12    | 12000. | 0.1261 |
| 13    | 12500. | 0.1386 |
| 14    | 13000. | 0.1553 |
| 15    | 13500. | 0.1752 |
| 16    | 14000. | 0.2015 |
| 17    | 14500. | 0.2242 |
| 18    | 15000. | 0.2664 |
| 19    | 15500. | 0.3051 |
| 20    | 16000. | 0.3767 |
| 21    | 16500. | 0.4760 |
| 22    | 17000. | 0.7895 |

## C1HD35-13

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 500.   | 0.1078 |
| 2     | 1000.  | 0.1141 |
| 3     | 1500.  | 0.1171 |
| 4     | 2000.  | 0.1235 |
| 5     | 2500.  | 0.1302 |
| 6     | 3000.  | 0.1364 |
| 7     | 3500.  | 0.1432 |
| 8     | 4000.  | 0.1503 |
| 9     | 4500.  | 0.1558 |
| 10    | 5000.  | 0.1596 |
| 11    | 5500.  | 0.1631 |
| 12    | 6000.  | 0.1667 |
| 13    | 6500.  | 0.1724 |
| 14    | 7000.  | 0.1788 |
| 15    | 7500.  | 0.1834 |
| 16    | 8000.  | 0.1887 |
| 17    | 8500.  | 0.1917 |
| 18    | 9000.  | 0.1956 |
| 19    | 9500.  | 0.1997 |
| 20    | 10000. | 0.2047 |
| 21    | 10500. | 0.2096 |
| 22    | 11000. | 0.2119 |
| 23    | 11500. | 0.2184 |
| 24    | 12000. | 0.2271 |
| 25    | 12500. | 0.2350 |
| 26    | 13000. | 0.2435 |
| 27    | 13500. | 0.2493 |
| 28    | 14000. | 0.2598 |
| 29    | 14500. | 0.2658 |
| 30    | 15000. | 0.2741 |
| 31    | 15500. | 0.2837 |
| 32    | 16000. | 0.2951 |
| 33    | 16500. | 0.3048 |
| 34    | 17000. | 0.3096 |
| 35    | 17500. | 0.3256 |
| 36    | 18000. | 0.3397 |
| 37    | 18500. | 0.3534 |
| 38    | 19000. | 0.3698 |
| 39    | 19500. | 0.3921 |
| 40    | 20000. | 0.4088 |
| 41    | 20500. | 0.4496 |
| 42    | 21000. | 0.4947 |
| 43    | 21500. | 0.5410 |
| 44    | 22000. | 0.5739 |
| 45    | 22500. | 0.6137 |

## C1HD35-15

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 18000. | 0.1268 |
| 2     | 18500. | 0.1336 |
| 3     | 19000. | 0.1394 |
| 4     | 19500. | 0.1471 |
| 5     | 20000. | 0.1567 |
| 6     | 20500. | 0.1643 |
| 7     | 21000. | 0.1718 |
| 8     | 21500. | 0.1852 |
| 9     | 22000. | 0.1984 |
| 10    | 22500. | 0.2152 |
| 11    | 23000. | 0.2376 |
| 12    | 23500. | 0.2513 |
| 13    | 24000. | 0.2754 |

C1HD40-01

2124-T851

HUD 34 SPECTRUM

C1HD40-05

| Hours | Length |
|-------|--------|
| 500.  | 0.0274 |
| 1000. | 0.0457 |
| 1500. | 0.0649 |
| 2000. | 0.0869 |
| 2500. | 0.1285 |
| 3000. | 0.1802 |
| 3500. | 0.4236 |
| 4000. | 0.6378 |

40 KSI MAXIMUM STRESS

| Hours | Length |
|-------|--------|
| 500.  | 0.0141 |
| 1000. | 0.0233 |
| 1500. | 0.0365 |
| 2000. | 0.0496 |
| 2500. | 0.0631 |
| 3000. | 0.0855 |
| 3500. | 0.1232 |
| 4000. | 0.1526 |
| 4500. | 0.2041 |
| 5000. | 0.2759 |
| 5500. | 0.4259 |

C1HD40-02

| Hours | Length |
|-------|--------|
| 500.  | 0.0196 |
| 1000. | 0.0362 |
| 1500. | 0.0523 |
| 2000. | 0.0831 |
| 2500. | 0.1107 |
| 3000. | 0.1432 |
| 3500. | 0.1747 |
| 4000. | 0.2663 |
| 4500. | 0.3167 |

C1HD40-06

| Hours | Length |
|-------|--------|
| 1500. | 0.0090 |
| 2000. | 0.0196 |
| 2500. | 0.0328 |
| 3000. | 0.0486 |
| 3500. | 0.0654 |
| 4000. | 0.0947 |
| 4500. | 0.1645 |
| 5000. | 0.2188 |
| 5500. | 0.4148 |

C1HD40-03

| Hours | Length |
|-------|--------|
| 2000. | 0.0152 |
| 2500. | 0.0332 |
| 3000. | 0.0528 |
| 3500. | 0.0727 |
| 4000. | 0.1166 |
| 4500. | 0.1777 |

C1HD40-07

| Hours | Length |
|-------|--------|
| 2500. | 0.0287 |
| 3000. | 0.0575 |
| 3500. | 0.0982 |
| 4000. | 0.1380 |
| 4500. | 0.1826 |
| 5000. | 0.2275 |
| 5500. | 0.3934 |

C1HD40-04

| Hours | Length |
|-------|--------|
| 500.  | 0.0362 |
| 1000. | 0.0430 |
| 1500. | 0.0782 |
| 2000. | 0.1096 |
| 2500. | 0.1584 |
| 3000. | 0.2219 |
| 3500. | 0.3015 |
| 4000. | 0.5234 |
| 4500. | 0.7260 |
| 4809. | 0.9219 |

C1HD40-08

| Hours | Length |
|-------|--------|
| 3000. | 0.0691 |
| 3500. | 0.0849 |
| 4000. | 0.1168 |
| 4500. | 0.1540 |
| 5000. | 0.2079 |
| 5500. | 0.3047 |

## C1HD40-09

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 1500. | 0.0202 |
| 2     | 2000. | 0.0325 |
| 3     | 2500. | 0.0497 |
| 4     | 3000. | 0.0748 |
| 5     | 3500. | 0.1002 |
| 6     | 4000. | 0.1378 |
| 7     | 4500. | 0.1976 |
| 8     | 5000. | 0.2672 |
| 9     | 5500. | 0.4370 |
| 10    | 6000. | 0.7782 |

## C1HD40-13

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 500.  | 0.0084 |
| 2     | 1000. | 0.0215 |
| 3     | 1500. | 0.0392 |
| 4     | 2000. | 0.0547 |
| 5     | 2500. | 0.0721 |
| 6     | 3000. | 0.0855 |
| 7     | 3500. | 0.1044 |
| 8     | 4000. | 0.1239 |
| 9     | 4500. | 0.1432 |
| 10    | 5000. | 0.1643 |
| 11    | 5500. | 0.2017 |
| 12    | 6000. | 0.2565 |
| 13    | 6500. | 0.3165 |
| 14    | 7000. | 0.4705 |

## C1HD40-10

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 4000. | 0.0910 |
| 2     | 4500. | 0.1193 |
| 3     | 5000. | 0.1566 |
| 4     | 5500. | 0.2288 |
| 5     | 6000. | 0.4124 |

## C1HD40-14

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 4000. | 0.0102 |
| 2     | 4500. | 0.0255 |
| 3     | 5000. | 0.0372 |
| 4     | 5500. | 0.0665 |
| 5     | 6000. | 0.0916 |
| 6     | 6500. | 0.1173 |
| 7     | 7000. | 0.1439 |
| 8     | 7500. | 0.1792 |
| 9     | 8000. | 0.2477 |
| 10    | 8488. | 0.2773 |

## C1HD40-11

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 3000. | 0.0258 |
| 2     | 3500. | 0.0370 |
| 3     | 4000. | 0.0653 |
| 4     | 4500. | 0.1050 |
| 5     | 5000. | 0.1423 |
| 6     | 5500. | 0.2052 |
| 7     | 6000. | 0.3473 |

## C1HD40-15

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 1500. | 0.0091 |
| 2     | 2000. | 0.0179 |
| 3     | 2500. | 0.0295 |
| 4     | 3000. | 0.0479 |
| 5     | 3500. | 0.0668 |
| 6     | 4000. | 0.0804 |
| 7     | 4500. | 0.0953 |
| 8     | 5000. | 0.1167 |
| 9     | 5500. | 0.1354 |
| 10    | 6000. | 0.1615 |
| 11    | 6500. | 0.1928 |
| 12    | 7000. | 0.2340 |
| 13    | 7500. | 0.3162 |
| 14    | 8000. | 0.7058 |
| 15    | 8500. | 0.8153 |

## C1HD40-12

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 2500. | 0.0230 |
| 2     | 3000. | 0.0375 |
| 3     | 3500. | 0.0708 |
| 4     | 4000. | 0.0975 |
| 5     | 4500. | 0.1378 |
| 6     | 5000. | 0.1908 |
| 7     | 5500. | 0.3518 |
| 8     | 6000. | 0.4616 |
| 9     | 6500. | 0.6973 |

## C1NR45-02

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 3164. | 0.0114 |
| 2     | 4218. | 0.0232 |
| 3     | 5273. | 0.0388 |
| 4     | 6328. | 0.0653 |
| 5     | 7383. | 0.1140 |
| 6     | 8436. | 0.2480 |
| 7     | 9479. | 0.3700 |

## C1NR45-03

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 2109.  | 0.0107 |
| 2     | 3164.  | 0.0164 |
| 3     | 4219.  | 0.0315 |
| 4     | 5273.  | 0.0450 |
| 5     | 6328.  | 0.0621 |
| 6     | 7383.  | 0.0772 |
| 7     | 8437.  | 0.1084 |
| 8     | 9492.  | 0.1564 |
| 9     | 10534. | 0.2803 |

## C1NR45-04

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 1055.  | 0.0166 |
| 2     | 2110.  | 0.0209 |
| 3     | 3164.  | 0.0290 |
| 4     | 4219.  | 0.0384 |
| 5     | 5274.  | 0.0523 |
| 6     | 6328.  | 0.0645 |
| 7     | 7383.  | 0.0905 |
| 8     | 8438.  | 0.1154 |
| 9     | 9492.  | 0.1773 |
| 10    | 10547. | 0.2920 |
| 11    | 11170. | 0.6571 |

## C1NR45-05

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 5273.  | 0.0071 |
| 2     | 6328.  | 0.0120 |
| 3     | 7383.  | 0.0207 |
| 4     | 8436.  | 0.0289 |
| 5     | 9492.  | 0.0368 |
| 6     | 10547. | 0.0472 |
| 7     | 11601. | 0.0595 |
| 8     | 12656. | 0.0807 |
| 9     | 13500. | 0.1084 |
| 10    | 14554. | 0.1521 |
| 11    | 15609. | 0.2954 |
| 12    | 16018. | 0.6800 |

## C1NR45-06

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 6328.  | 0.0064 |
| 2     | 7383.  | 0.0138 |
| 3     | 8437.  | 0.0172 |
| 4     | 9492.  | 0.0252 |
| 5     | 10547. | 0.0406 |
| 6     | 11601. | 0.0580 |
| 7     | 12656. | 0.0848 |
| 8     | 13500. | 0.1071 |
| 9     | 14555. | 0.1510 |
| 10    | 15609. | 0.1992 |
| 11    | 16664. | 0.2488 |
| 12    | 16968. | 0.3244 |

## C1NR45-07

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 4219.  | 0.0166 |
| 2     | 5274.  | 0.0242 |
| 3     | 6328.  | 0.0384 |
| 4     | 7383.  | 0.0523 |
| 5     | 8438.  | 0.0649 |
| 6     | 9492.  | 0.0820 |
| 7     | 10547. | 0.1072 |
| 8     | 11602. | 0.1433 |
| 9     | 12656. | 0.1780 |
| 10    | 13500. | 0.2331 |
| 11    | 14555. | 0.2939 |
| 12    | 15610. | 0.3505 |
| 13    | 16664. | 0.4722 |
| 14    | 17719. | 0.5729 |
| 15    | 17768. | 0.7871 |

## C1NR45-08

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 5273.  | 0.0089 |
| 2     | 6328.  | 0.0134 |
| 3     | 7383.  | 0.0176 |
| 4     | 8436.  | 0.0248 |
| 5     | 9492.  | 0.0312 |
| 6     | 10547. | 0.0384 |
| 7     | 11601. | 0.0476 |
| 8     | 12656. | 0.0563 |
| 9     | 13500. | 0.0669 |
| 10    | 14554. | 0.0764 |
| 11    | 15609. | 0.0921 |
| 12    | 16664. | 0.1228 |
| 13    | 17719. | 0.1505 |
| 14    | 18773. | 0.1912 |
| 15    | 19828. | 0.2500 |
| 16    | 20883. | 0.4100 |
| 17    | 21398. | 0.8500 |

## C1NR45-09

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 3164.  | 0.0089 |
| 2     | 4218.  | 0.0119 |
| 3     | 5273.  | 0.0167 |
| 4     | 6328.  | 0.0232 |
| 5     | 7383.  | 0.0290 |
| 6     | 8436.  | 0.0356 |
| 7     | 9492.  | 0.0421 |
| 8     | 10547. | 0.0476 |
| 9     | 11601. | 0.0564 |
| 10    | 12656. | 0.0663 |
| 11    | 13500. | 0.0780 |
| 12    | 14554. | 0.0918 |
| 13    | 15609. | 0.1120 |
| 14    | 16664. | 0.1340 |
| 15    | 17719. | 0.1570 |
| 16    | 18773. | 0.1920 |
| 17    | 19828. | 0.2400 |
| 18    | 20883. | 0.3420 |
| 19    | 21704. | 0.8600 |

## C1NR45-10

| oint | Hours  | Length |
|------|--------|--------|
| 1    | 13500. | 0.0160 |
| 2    | 14555. | 0.0310 |
| 3    | 15610. | 0.0531 |
| 4    | 16664. | 0.0929 |
| 5    | 17719. | 0.1217 |
| 6    | 18774. | 0.1673 |
| 7    | 19828. | 0.2336 |
| 8    | 20883. | 0.4137 |
| 9    | 21821. | 0.5215 |

## C1NR45-01

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 3164. | 0.0280 |
| 2     | 4218. | 0.0500 |
| 3     | 5273. | 0.1300 |
| 4     | 6328. | 0.2100 |
| 5     | 7372. | 0.6000 |

7475-T7351  
NOR 1 SPECTRUM  
45 KSI MAXIMUM STRESS

C2NR45-01

C2NR45-03

| Point | Hours  | Length | Point | Hours  | Length |
|-------|--------|--------|-------|--------|--------|
| 1     | 2109.  | 0.0093 | 1     | 7383.  | 0.0234 |
| 2     | 3164.  | 0.0147 | 2     | 8436.  | 0.0322 |
| 3     | 4218.  | 0.0218 | 3     | 9492.  | 0.0473 |
| 4     | 5273.  | 0.0316 | 4     | 10547. | 0.0622 |
| 5     | 6328.  | 0.0445 | 5     | 11601. | 0.0833 |
| 6     | 7383.  | 0.0590 | 6     | 12656. | 0.1110 |
| 7     | 8436.  | 0.0798 | 7     | 13500. | 0.1352 |
| 8     | 9492.  | 0.1045 | 8     | 14554. | 0.1614 |
| 9     | 10547. | 0.1394 | 9     | 15609. | 0.1943 |
| 10    | 11601. | 0.1684 | 10    | 16664. | 0.2306 |
| 11    | 12656. | 0.2021 | 11    | 17719. | 0.2663 |
| 12    | 13500. | 0.2412 | 12    | 18773. | 0.3062 |
| 13    | 14554. | 0.2951 | 13    | 19829. | 0.3564 |
| 14    | 15609. | 0.3847 | 14    | 20883. | 0.4251 |
| 15    | 16664. | 0.5450 | 15    | 21937. | 0.5384 |
| 16    | 17705. | 0.8200 | 16    | 22979. | 0.7100 |

C2NR45-02

C2NR45-04

| Point | Hours  | Length | Point | Hours  | Length |
|-------|--------|--------|-------|--------|--------|
| 1     | 4218.  | 0.0089 | 1     | 5273.  | 0.0145 |
| 2     | 5273.  | 0.0143 | 2     | 6328.  | 0.0191 |
| 3     | 6328.  | 0.0205 | 3     | 7383.  | 0.0256 |
| 4     | 7383.  | 0.0284 | 4     | 8436.  | 0.0314 |
| 5     | 8436.  | 0.0362 | 5     | 9492.  | 0.0383 |
| 6     | 9492.  | 0.0452 | 6     | 10547. | 0.0492 |
| 7     | 10547. | 0.0551 | 7     | 11601. | 0.0672 |
| 8     | 11601. | 0.0663 | 8     | 12656. | 0.0985 |
| 9     | 12656. | 0.0786 | 9     | 14554. | 0.1312 |
| 10    | 13500. | 0.0963 | 10    | 15609. | 0.1534 |
| 11    | 14554. | 0.1140 | 11    | 16664. | 0.1817 |
| 12    | 15609. | 0.1323 | 12    | 17719. | 0.2158 |
| 13    | 16664. | 0.1586 | 13    | 18773. | 0.2540 |
| 14    | 17719. | 0.1933 | 14    | 19828. | 0.3036 |
| 15    | 18773. | 0.2310 | 15    | 20883. | 0.3866 |
| 16    | 19828. | 0.2853 | 16    | 21937. | 0.4869 |
| 17    | 20883. | 0.3585 | 17    | 22979. | 0.6290 |
| 18    | 21937. | 0.4650 |       |        |        |
| 19    | 22979. | 0.6020 |       |        |        |

## C2NR45-05

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 3164.  | 0.0040 |
| 2     | 4218.  | 0.0071 |
| 3     | 5273.  | 0.0114 |
| 4     | 6328.  | 0.0159 |
| 5     | 7383.  | 0.0235 |
| 6     | 8436.  | 0.0306 |
| 7     | 9492.  | 0.0374 |
| 8     | 10547. | 0.0453 |
| 9     | 11601. | 0.0549 |
| 10    | 12656. | 0.0652 |
| 11    | 13500. | 0.0784 |
| 12    | 14554. | 0.0950 |
| 13    | 15609. | 0.1184 |
| 14    | 16664. | 0.1410 |
| 15    | 17719. | 0.1643 |
| 16    | 18773. | 0.1942 |
| 17    | 19828. | 0.2333 |
| 18    | 20883. | 0.2796 |
| 19    | 21937. | 0.3433 |
| 20    | 22992. | 0.4350 |
| 21    | 24047. | 0.5920 |
| 22    | 25089. | 0.8400 |

## C2NR45-07

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 5273.  | 0.0064 |
| 2     | 6328.  | 0.0108 |
| 3     | 7383.  | 0.0156 |
| 4     | 8436.  | 0.0211 |
| 5     | 9492.  | 0.0272 |
| 6     | 10547. | 0.0377 |
| 7     | 11601. | 0.0476 |
| 8     | 12656. | 0.0584 |
| 9     | 13500. | 0.0705 |
| 10    | 14554. | 0.0840 |
| 11    | 15609. | 0.1015 |
| 12    | 16664. | 0.1192 |
| 13    | 17719. | 0.1429 |
| 14    | 18773. | 0.1635 |
| 15    | 19828. | 0.1882 |
| 16    | 20883. | 0.2227 |
| 17    | 21937. | 0.2661 |
| 18    | 22992. | 0.3174 |
| 19    | 24047. | 0.3809 |
| 20    | 25101. | 0.4812 |
| 21    | 26144. | 0.6620 |

## C2NR45-06

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 15609. | 0.1481 |
| 2     | 16664. | 0.1650 |
| 3     | 17718. | 0.1802 |
| 4     | 18773. | 0.1885 |
| 5     | 19828. | 0.2071 |
| 6     | 20882. | 0.2308 |
| 7     | 21937. | 0.2725 |
| 8     | 22992. | 0.3034 |
| 9     | 24046. | 0.3673 |
| 10    | 25101. | 0.4609 |
| 11    | 25256. | 0.5586 |

## C2NR45-08

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 15610. | 0.0143 |
| 2     | 16664. | 0.0219 |
| 3     | 17719. | 0.0312 |
| 4     | 18774. | 0.0481 |
| 5     | 19828. | 0.0692 |
| 6     | 20883. | 0.0896 |
| 7     | 21938. | 0.1199 |
| 8     | 22992. | 0.1579 |
| 9     | 24047. | 0.1976 |
| 10    | 25102. | 0.2388 |
| 11    | 26156. | 0.2965 |
| 12    | 27000. | 0.3740 |
| 13    | 28055. | 0.4782 |
| 14    | 29095. | 0.6011 |

## C2NR45-09

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 11602. | 0.0209 |
| 2     | 12656. | 0.0316 |
| 3     | 13500. | 0.0468 |
| 4     | 14554. | 0.0619 |
| 5     | 15609. | 0.0740 |
| 6     | 16664. | 0.0920 |
| 7     | 17718. | 0.1077 |
| 8     | 18773. | 0.1158 |
| 9     | 19828. | 0.1416 |
| 10    | 20882. | 0.1679 |
| 11    | 21937. | 0.1941 |
| 12    | 22992. | 0.2100 |
| 13    | 24046. | 0.2372 |
| 14    | 25101. | 0.2736 |
| 15    | 26156. | 0.3207 |
| 16    | 27000. | 0.4377 |
| 17    | 28055. | 0.7900 |
| 18    | 29095. | 0.6179 |

## C2NR45-11

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 21937. | 0.0817 |
| 2     | 22992. | 0.0967 |
| 3     | 24047. | 0.1117 |
| 4     | 25101. | 0.1274 |
| 5     | 26156. | 0.1406 |
| 6     | 28054. | 0.1771 |
| 7     | 29109. | 0.2027 |
| 8     | 30164. | 0.2286 |
| 9     | 31218. | 0.2581 |
| 10    | 32273. | 0.2903 |
| 11    | 33328. | 0.3323 |
| 12    | 34382. | 0.3876 |
| 13    | 35437. | 0.4581 |
| 14    | 36492. | 0.5774 |
| 15    | 37534. | 0.7322 |

## C2NR45-10

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 19828. | 0.0143 |
| 2     | 20883. | 0.0197 |
| 3     | 21938. | 0.0284 |
| 4     | 22992. | 0.0475 |
| 5     | 24047. | 0.0647 |
| 6     | 25102. | 0.0776 |
| 7     | 26156. | 0.0912 |
| 8     | 27000. | 0.1203 |
| 9     | 28055. | 0.1620 |
| 10    | 29110. | 0.2045 |
| 11    | 30164. | 0.2689 |
| 12    | 31219. | 0.3429 |
| 13    | 32250. | 0.6272 |

| MATERIAL       | SPECTRUM | STRESS |
|----------------|----------|--------|
| 7091-EXTRUSION | HUD34    | 40     |

1) R1HD40-01

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 1000. | 0.0218 |
| 2     | 1500. | 0.0379 |
| 3     | 2000. | 0.0743 |
| 4     | 2500. | 0.1055 |
| 5     | 3000. | 0.1417 |
| 6     | 3500. | 0.1734 |
| 7     | 4000. | 0.2107 |
| 8     | 4500. | 0.2472 |
| 9     | 5000. | 0.2872 |
| 10    | 5500. | 0.3263 |
| 11    | 6000. | 0.3590 |
| 12    | 6500. | 0.4183 |
| 13    | 7000. | 0.5070 |
| 14    | 7500. | 0.5974 |
| 15    | 8000. | 0.6719 |
| 16    | 8500. | 0.8546 |

R1HD40-03

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 500.   | 0.0202 |
| 2     | 1000.  | 0.0371 |
| 3     | 1500.  | 0.0702 |
| 4     | 2000.  | 0.1003 |
| 5     | 2500.  | 0.1285 |
| 6     | 3000.  | 0.1408 |
| 7     | 3500.  | 0.1664 |
| 8     | 4000.  | 0.1354 |
| 9     | 4500.  | 0.2063 |
| 10    | 5000.  | 0.2251 |
| 11    | 5500.  | 0.2497 |
| 12    | 6000.  | 0.3794 |
| 13    | 6500.  | 0.3697 |
| 14    | 7000.  | 0.3484 |
| 15    | 7500.  | 0.4231 |
| 16    | 8000.  | 0.4971 |
| 17    | 8500.  | 0.5729 |
| 18    | 9000.  | 0.6234 |
| 19    | 9500.  | 0.7032 |
| 20    | 10000. | 0.7826 |
| 21    | 10500. | 0.8598 |

R1HD40-02

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 1000. | 0.0081 |
| 2     | 1500. | 0.0214 |
| 3     | 2000. | 0.0355 |
| 4     | 2500. | 0.0492 |
| 5     | 3000. | 0.0646 |
| 6     | 3500. | 0.0953 |
| 7     | 4000. | 0.1137 |
| 8     | 4500. | 0.1321 |
| 9     | 5000. | 0.1501 |
| 10    | 5500. | 0.1665 |
| 11    | 6000. | 0.1911 |
| 12    | 6500. | 0.2120 |
| 13    | 7000. | 0.2373 |
| 14    | 7500. | 0.2900 |
| 15    | 8000. | 0.3720 |
| 16    | 8500. | 0.4429 |
| 17    | 9000. | 0.5009 |
| 18    | 9500. | 0.7679 |

R1HD40-04

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 1000.  | 0.0145 |
| 2     | 1500.  | 0.0307 |
| 3     | 2000.  | 0.0561 |
| 4     | 2500.  | 0.0775 |
| 5     | 3000.  | 0.1040 |
| 6     | 3500.  | 0.1286 |
| 7     | 4000.  | 0.1567 |
| 8     | 4500.  | 0.1885 |
| 9     | 5000.  | 0.2236 |
| 10    | 5500.  | 0.2662 |
| 11    | 6000.  | 0.3124 |
| 12    | 6500.  | 0.3635 |
| 13    | 7000.  | 0.4170 |
| 14    | 7500.  | 0.4651 |
| 15    | 8000.  | 0.5269 |
| 16    | 8500.  | 0.5836 |
| 17    | 9000.  | 0.6414 |
| 18    | 9500.  | 0.6982 |
| 19    | 10000. | 0.7363 |
| 20    | 10500. | 0.7732 |
| 21    | 11000. | 0.8159 |

## R1HD40-05

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 1000.  | 0.0146 |
| 2     | 1500.  | 0.0240 |
| 3     | 2000.  | 0.0315 |
| 4     | 2500.  | 0.0371 |
| 5     | 3000.  | 0.0440 |
| 6     | 3500.  | 0.0524 |
| 7     | 4000.  | 0.0610 |
| 8     | 4500.  | 0.0704 |
| 9     | 5000.  | 0.0785 |
| 10    | 5500.  | 0.0868 |
| 11    | 6000.  | 0.0954 |
| 12    | 6500.  | 0.1040 |
| 13    | 7000.  | 0.1119 |
| 14    | 7500.  | 0.1212 |
| 15    | 8000.  | 0.1377 |
| 16    | 8500.  | 0.1473 |
| 17    | 9000.  | 0.1581 |
| 18    | 9500.  | 0.1709 |
| 19    | 10000. | 0.1864 |
| 20    | 10500. | 0.2025 |
| 21    | 11000. | 0.2173 |
| 22    | 11500. | 0.2280 |
| 23    | 12000. | 0.2560 |
| 24    | 12500. | 0.2879 |
| 25    | 13000. | 0.3070 |
| 26    | 13500. | 0.3247 |
| 27    | 14000. | 0.4553 |
| 28    | 14500. | 0.5461 |
| 29    | 15000. | 0.6552 |
| 30    | 15500. | 0.7679 |
| 31    | 15954. | 0.8218 |

## R1HD40-06

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 2500.  | 0.0480 |
| 2     | 3000.  | 0.0601 |
| 3     | 3500.  | 0.0766 |
| 4     | 4000.  | 0.0858 |
| 5     | 4500.  | 0.1113 |
| 6     | 5000.  | 0.1217 |
| 7     | 5500.  | 0.1339 |
| 8     | 6000.  | 0.1498 |
| 9     | 6500.  | 0.1624 |
| 10    | 7000.  | 0.1765 |
| 11    | 7500.  | 0.1915 |
| 12    | 8000.  | 0.2053 |
| 13    | 8500.  | 0.2180 |
| 14    | 9000.  | 0.2350 |
| 15    | 9500.  | 0.2534 |
| 16    | 10000. | 0.2678 |
| 17    | 10500. | 0.2844 |
| 18    | 11000. | 0.3031 |
| 19    | 11500. | 0.3242 |
| 20    | 12000. | 0.3503 |
| 21    | 12500. | 0.3737 |
| 22    | 13000. | 0.4019 |
| 23    | 13500. | 0.4327 |
| 24    | 14000. | 0.4664 |
| 25    | 14500. | 0.5057 |
| 26    | 15000. | 0.5575 |
| 27    | 15500. | 0.6002 |
| 28    | 16000. | 0.6453 |
| 29    | 16500. | 0.6900 |
| 30    | 17000. | 0.7240 |
| 31    | 17500. | 0.7600 |
| 32    | 18000. | 0.7995 |
| 33    | 18500. | 0.8780 |

R1HD40-07

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 7000.  | 0.0090 |
| 2     | 7500.  | 0.0140 |
| 3     | 8000.  | 0.0232 |
| 4     | 8500.  | 0.0338 |
| 5     | 9000.  | 0.0446 |
| 6     | 9500.  | 0.0549 |
| 7     | 10000. | 0.0640 |
| 8     | 10500. | 0.0718 |
| 9     | 11000. | 0.0787 |
| 10    | 11500. | 0.0870 |
| 11    | 12000. | 0.0955 |
| 12    | 12500. | 0.1034 |
| 13    | 13000. | 0.1113 |
| 14    | 13500. | 0.1198 |
| 15    | 14000. | 0.1286 |
| 16    | 14500. | 0.1361 |
| 17    | 15000. | 0.1440 |
| 18    | 15500. | 0.1517 |
| 19    | 16000. | 0.1593 |
| 20    | 16500. | 0.1664 |
| 21    | 17000. | 0.1750 |
| 22    | 17500. | 0.1831 |
| 23    | 18000. | 0.1886 |
| 24    | 18500. | 0.1935 |

R1HD40-08

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 1500.  | 0.0223 |
| 2     | 2000.  | 0.0403 |
| 3     | 2500.  | 0.0708 |
| 4     | 3000.  | 0.0939 |
| 5     | 3500.  | 0.1140 |
| 6     | 4000.  | 0.1315 |
| 7     | 4500.  | 0.1482 |
| 8     | 5000.  | 0.1632 |
| 9     | 5500.  | 0.1781 |
| 10    | 6000.  | 0.1931 |
| 11    | 6500.  | 0.2098 |
| 12    | 7000.  | 0.2247 |
| 13    | 7500.  | 0.2390 |
| 14    | 8000.  | 0.2566 |
| 15    | 8500.  | 0.2726 |
| 16    | 9000.  | 0.2910 |
| 17    | 9500.  | 0.3080 |
| 18    | 10000. | 0.3283 |
| 19    | 10500. | 0.3467 |
| 20    | 11000. | 0.3730 |
| 21    | 11500. | 0.4009 |
| 22    | 12000. | 0.4261 |
| 23    | 12500. | 0.4533 |
| 24    | 13000. | 0.4800 |
| 25    | 13500. | 0.5134 |
| 26    | 14000. | 0.5443 |
| 27    | 14500. | 0.5636 |
| 28    | 15000. | 0.5928 |
| 29    | 15500. | 0.6413 |
| 30    | 16000. | 0.6846 |
| 31    | 16500. | 0.7292 |
| 32    | 17000. | 0.7745 |
| 33    | 17500. | 0.8225 |
| 34    | 18000. | 0.9119 |
| 35    | 18500. | 0.9477 |
| 36    | 19000. | 0.9889 |

R1HD40-09

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 500.   | 0.0119 |
| 2     | 1000.  | 0.0242 |
| 3     | 1500.  | 0.0363 |
| 4     | 2000.  | 0.0469 |
| 5     | 2500.  | 0.0576 |
| 6     | 3000.  | 0.0670 |
| 7     | 3500.  | 0.0779 |
| 8     | 4000.  | 0.0894 |
| 9     | 4500.  | 0.1016 |
| 10    | 5000.  | 0.1139 |
| 11    | 5500.  | 0.1227 |
| 12    | 6000.  | 0.1328 |
| 13    | 6500.  | 0.1419 |
| 14    | 7000.  | 0.1506 |
| 15    | 7500.  | 0.1621 |
| 16    | 8000.  | 0.1723 |
| 17    | 8500.  | 0.1845 |
| 18    | 9000.  | 0.1984 |
| 19    | 9500.  | 0.2133 |
| 20    | 10000. | 0.2267 |
| 21    | 10500. | 0.2448 |
| 22    | 11000. | 0.2657 |
| 23    | 11500. | 0.2866 |
| 24    | 12000. | 0.3077 |
| 25    | 12500. | 0.3283 |
| 26    | 13000. | 0.3539 |
| 27    | 13500. | 0.3768 |
| 28    | 14000. | 0.4063 |
| 29    | 14500. | 0.4367 |
| 30    | 15000. | 0.4727 |
| 31    | 15500. | 0.5126 |
| 32    | 16000. | 0.5507 |
| 33    | 16500. | 0.5818 |
| 34    | 17000. | 0.6108 |
| 35    | 17500. | 0.6341 |
| 36    | 18000. | 0.6591 |
| 37    | 18500. | 0.6897 |
| 38    | 19000. | 0.7184 |
| 39    | 19500. | 0.7417 |
| 40    | 20000. | 0.7651 |
| 41    | 20500. | 0.7930 |

R1HD40-10

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 5000.  | 0.0101 |
| 2     | 5500.  | 0.0160 |
| 3     | 6000.  | 0.0223 |
| 4     | 6500.  | 0.0288 |
| 5     | 7000.  | 0.0357 |
| 6     | 7500.  | 0.0424 |
| 7     | 8000.  | 0.0493 |
| 8     | 8500.  | 0.0558 |
| 9     | 9000.  | 0.0620 |
| 10    | 9500.  | 0.0679 |
| 11    | 10000. | 0.0734 |
| 12    | 10500. | 0.0794 |
| 13    | 11000. | 0.0852 |
| 14    | 11500. | 0.0906 |
| 15    | 12000. | 0.0961 |
| 16    | 12500. | 0.1012 |
| 17    | 13000. | 0.1065 |
| 18    | 13500. | 0.1117 |
| 19    | 14000. | 0.1179 |
| 20    | 14500. | 0.1234 |
| 21    | 15000. | 0.1291 |
| 22    | 15500. | 0.1346 |
| 23    | 16000. | 0.1400 |
| 24    | 16500. | 0.1453 |
| 25    | 17000. | 0.1508 |
| 26    | 17500. | 0.1561 |
| 27    | 18000. | 0.1611 |
| 28    | 18500. | 0.1657 |
| 29    | 19000. | 0.1706 |
| 30    | 19500. | 0.1755 |
| 31    | 20000. | 0.1803 |
| 32    | 20500. | 0.1855 |
| 33    | 21000. | 0.1908 |
| 34    | 21500. | 0.1960 |
| 35    | 22000. | 0.2015 |
| 36    | 22500. | 0.2067 |
| 37    | 23000. | 0.2117 |
| 38    | 23500. | 0.2166 |
| 39    | 24000. | 0.2242 |

## R1HD40-11

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 6000.  | 0.0080 |
| 2     | 6500.  | 0.0154 |
| 3     | 7000.  | 0.0239 |
| 4     | 7500.  | 0.0336 |
| 5     | 8000.  | 0.0409 |
| 6     | 8500.  | 0.0486 |
| 7     | 9000.  | 0.0576 |
| 8     | 9500.  | 0.0725 |
| 9     | 10000. | 0.0840 |
| 10    | 10500. | 0.0937 |
| 11    | 11000. | 0.1030 |
| 12    | 11500. | 0.1117 |
| 13    | 12000. | 0.1218 |
| 14    | 12500. | 0.1308 |
| 15    | 13000. | 0.1411 |
| 16    | 13500. | 0.1515 |
| 17    | 14000. | 0.1608 |
| 18    | 14500. | 0.1706 |
| 19    | 15000. | 0.1815 |
| 20    | 15500. | 0.1920 |
| 21    | 16000. | 0.2029 |
| 22    | 16500. | 0.2142 |
| 23    | 17000. | 0.2243 |
| 24    | 17500. | 0.2362 |
| 25    | 18000. | 0.2472 |
| 26    | 18500. | 0.2583 |
| 27    | 19000. | 0.2688 |
| 28    | 19500. | 0.2793 |
| 29    | 20000. | 0.2907 |
| 30    | 20500. | 0.3027 |
| 31    | 21000. | 0.3162 |
| 32    | 21500. | 0.3281 |
| 33    | 22000. | 0.3412 |
| 34    | 22500. | 0.3550 |
| 35    | 23000. | 0.3709 |
| 36    | 23500. | 0.3860 |
| 37    | 24000. | 0.4031 |

## R1HD40-12

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 11500. | 0.1170 |
| 2     | 12000. | 0.1257 |
| 3     | 12500. | 0.1343 |
| 4     | 13000. | 0.1440 |
| 5     | 13500. | 0.1533 |
| 6     | 14000. | 0.1617 |
| 7     | 14500. | 0.1725 |
| 8     | 15000. | 0.1840 |
| 9     | 15500. | 0.1960 |
| 10    | 16000. | 0.2106 |
| 11    | 16500. | 0.2258 |
| 12    | 17000. | 0.2417 |
| 13    | 17500. | 0.2617 |
| 14    | 18000. | 0.2826 |
| 15    | 18500. | 0.3042 |
| 16    | 19000. | 0.3260 |
| 17    | 19500. | 0.3517 |
| 18    | 20000. | 0.3798 |
| 19    | 20500. | 0.4083 |
| 20    | 21000. | 0.4352 |
| 21    | 21500. | 0.4666 |
| 22    | 22000. | 0.4982 |
| 23    | 22500. | 0.5366 |
| 24    | 23000. | 0.5739 |
| 25    | 23500. | 0.6121 |
| 26    | 24000. | 0.6452 |

## R1HD40-13

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 8500.  | 0.1600 |
| 2     | 9000.  | 0.1682 |
| 3     | 9500.  | 0.1755 |
| 4     | 10000. | 0.1828 |
| 5     | 10500. | 0.1893 |
| 6     | 11000. | 0.1968 |
| 7     | 11500. | 0.2080 |
| 8     | 12000. | 0.2165 |
| 9     | 12500. | 0.2265 |
| 10    | 13000. | 0.2367 |
| 11    | 13500. | 0.2468 |
| 12    | 14000. | 0.2564 |
| 13    | 14500. | 0.2693 |
| 14    | 15000. | 0.2796 |
| 15    | 15500. | 0.2911 |
| 16    | 16000. | 0.3018 |
| 17    | 16500. | 0.3133 |
| 18    | 17000. | 0.3244 |
| 19    | 17500. | 0.3364 |
| 20    | 18000. | 0.3491 |
| 21    | 18500. | 0.3613 |
| 22    | 19000. | 0.3735 |
| 23    | 19500. | 0.3863 |
| 24    | 20000. | 0.3988 |
| 25    | 20500. | 0.4124 |
| 26    | 21000. | 0.4263 |
| 27    | 21500. | 0.4407 |
| 28    | 22000. | 0.4592 |
| 29    | 22500. | 0.4767 |
| 30    | 23000. | 0.4968 |
| 31    | 23500. | 0.5168 |
| 32    | 24000. | 0.5372 |

## R1HD40-14

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 6000.  | 0.0433 |
| 2     | 6500.  | 0.0473 |
| 3     | 7000.  | 0.0497 |
| 4     | 7500.  | 0.0524 |
| 5     | 8000.  | 0.0557 |
| 6     | 8500.  | 0.0592 |
| 7     | 9000.  | 0.0632 |
| 8     | 9500.  | 0.0693 |
| 9     | 10000. | 0.0752 |
| 10    | 10500. | 0.0862 |
| 11    | 11000. | 0.0921 |
| 12    | 11500. | 0.0980 |
| 13    | 12000. | 0.1056 |
| 14    | 12500. | 0.1131 |
| 15    | 13000. | 0.1213 |
| 16    | 13500. | 0.1309 |
| 17    | 14000. | 0.1418 |
| 18    | 14500. | 0.1533 |
| 19    | 15000. | 0.1659 |
| 20    | 15500. | 0.1795 |
| 21    | 16000. | 0.1959 |
| 22    | 16500. | 0.2147 |
| 23    | 17000. | 0.2315 |
| 24    | 17500. | 0.2502 |
| 25    | 18000. | 0.2718 |
| 26    | 18500. | 0.2931 |
| 27    | 19000. | 0.3176 |
| 28    | 19500. | 0.3417 |
| 29    | 20000. | 0.3693 |
| 30    | 20500. | 0.3973 |
| 31    | 21000. | 0.4281 |
| 32    | 21500. | 0.4646 |
| 33    | 22000. | 0.5020 |
| 34    | 22500. | 0.5429 |
| 35    | 23000. | 0.5831 |
| 36    | 23500. | 0.6275 |
| 37    | 24000. | 0.6628 |

## 7091-T7E69 EXT.

## HUD 34 SPECTRUM

## 45 KSI MAXIMUM STRESS

R1HD45-01

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 500.  | 0.0498 |
| 2     | 1000. | 0.1361 |
| 3     | 1500. | 0.3453 |
| 4     | 2000. | 0.8851 |

R1HD45-07

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 1000. | 0.0244 |
| 2     | 1500. | 0.0412 |
| 3     | 2000. | 0.0582 |
| 4     | 2500. | 0.0970 |
| 5     | 3000. | 0.1283 |
| 6     | 3500. | 0.1742 |
| 7     | 4000. | 0.2190 |
| 8     | 4500. | 0.2780 |
| 9     | 5000. | 0.3448 |
| 10    | 5500. | 0.4280 |
| 11    | 6000. | 0.5486 |
| 12    | 6500. | 0.6695 |
| 13    | 7000. | 0.7640 |
| 14    | 7373. | 0.9300 |

R1HD45-03

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 1000. | 0.0130 |
| 2     | 1500. | 0.0246 |
| 3     | 2000. | 0.0418 |
| 4     | 2500. | 0.0793 |
| 5     | 3000. | 0.1300 |
| 6     | 3500. | 0.2606 |
| 7     | 4000. | 0.3968 |
| 8     | 4500. | 0.6693 |

R1HD45-08

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 500.  | 0.0093 |
| 2     | 1000. | 0.0202 |
| 3     | 1500. | 0.0457 |
| 4     | 2000. | 0.0717 |
| 5     | 2500. | 0.0980 |
| 6     | 3000. | 0.1280 |
| 7     | 3500. | 0.1635 |
| 8     | 4000. | 0.1999 |
| 9     | 4500. | 0.2414 |
| 10    | 5000. | 0.3011 |
| 11    | 5500. | 0.3744 |
| 12    | 6000. | 0.4680 |
| 13    | 6500. | 0.5421 |
| 14    | 7000. | 0.6388 |
| 15    | 7500. | 0.7717 |

R1HD45-04

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 500.  | 0.0158 |
| 2     | 1000. | 0.0351 |
| 3     | 1500. | 0.0843 |
| 4     | 2000. | 0.1468 |
| 5     | 2500. | 0.2176 |
| 6     | 3000. | 0.2660 |
| 7     | 3500. | 0.3466 |
| 8     | 4000. | 0.4751 |
| 9     | 4500. | 0.6657 |

R1HD45-09

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 500.  | 0.0065 |
| 2     | 1000. | 0.0157 |
| 3     | 1500. | 0.0393 |
| 4     | 2000. | 0.0589 |
| 5     | 2500. | 0.0863 |
| 6     | 3000. | 0.1269 |
| 7     | 3500. | 0.1963 |
| 8     | 4000. | 0.2625 |
| 9     | 4500. | 0.3000 |
| 10    | 5000. | 0.3629 |
| 11    | 5500. | 0.4578 |
| 12    | 6000. | 0.5197 |
| 13    | 6500. | 0.6327 |
| 14    | 7000. | 0.7139 |
| 15    | 7500. | 0.7867 |

R1HD45-06

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 2000. | 0.0189 |
| 2     | 2500. | 0.0433 |
| 3     | 3000. | 0.0655 |
| 4     | 3500. | 0.0944 |
| 5     | 4000. | 0.1387 |
| 6     | 4500. | 0.1918 |
| 7     | 5000. | 0.2948 |
| 8     | 5500. | 0.4015 |
| 9     | 6000. | 0.8454 |

## R1HD45-10

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 1000. | 0.0056 |
| 2     | 1500. | 0.0159 |
| 3     | 2000. | 0.0286 |
| 4     | 2500. | 0.0565 |
| 5     | 3000. | 0.0758 |
| 6     | 3500. | 0.1109 |
| 7     | 4000. | 0.1239 |
| 8     | 4500. | 0.1564 |
| 9     | 5000. | 0.1903 |
| 10    | 5500. | 0.2494 |
| 11    | 6000. | 0.2954 |
| 12    | 6500. | 0.3484 |
| 13    | 7000. | 0.4284 |
| 14    | 7500. | 0.5586 |
| 15    | 8000. | 0.6906 |
| 16    | 8500. | 0.7844 |

## R1HD45-11

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 1500. | 0.0213 |
| 2     | 2000. | 0.0489 |
| 3     | 2500. | 0.0793 |
| 4     | 3000. | 0.1101 |
| 5     | 3500. | 0.1373 |
| 6     | 4000. | 0.1661 |
| 7     | 4500. | 0.1979 |
| 8     | 5000. | 0.2313 |
| 9     | 5500. | 0.2762 |
| 10    | 6000. | 0.3194 |
| 11    | 6500. | 0.3763 |
| 12    | 7000. | 0.4527 |
| 13    | 7500. | 0.5625 |
| 14    | 8000. | 0.6624 |
| 15    | 8500. | 0.7276 |
| 16    | 9000. | 0.7977 |

## R1HD45-12

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 1000. | 0.0307 |
| 2     | 1500. | 0.0640 |
| 3     | 2000. | 0.0961 |
| 4     | 2500. | 0.1277 |
| 5     | 3000. | 0.1567 |
| 6     | 3500. | 0.1827 |
| 7     | 4000. | 0.2114 |
| 8     | 4500. | 0.2427 |
| 9     | 5000. | 0.2827 |
| 10    | 5500. | 0.3222 |
| 11    | 6000. | 0.3760 |
| 12    | 6500. | 0.4374 |
| 13    | 7000. | 0.4995 |
| 14    | 7500. | 0.5771 |
| 15    | 8000. | 0.6672 |
| 16    | 8500. | 0.7225 |
| 17    | 9000. | 0.7759 |

## R1HD45-14

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 1000.  | 0.0162 |
| 2     | 1500.  | 0.0446 |
| 3     | 2000.  | 0.0654 |
| 4     | 2500.  | 0.0908 |
| 5     | 3000.  | 0.1121 |
| 6     | 3500.  | 0.1356 |
| 7     | 4000.  | 0.1553 |
| 8     | 4500.  | 0.1766 |
| 9     | 5000.  | 0.1936 |
| 10    | 5500.  | 0.2230 |
| 11    | 6000.  | 0.2494 |
| 12    | 6500.  | 0.2767 |
| 13    | 7000.  | 0.3077 |
| 14    | 7500.  | 0.3371 |
| 15    | 8000.  | 0.3743 |
| 16    | 8500.  | 0.4203 |
| 17    | 9000.  | 0.4545 |
| 18    | 9500.  | 0.5027 |
| 19    | 10000. | 0.5532 |
| 20    | 10500. | 0.6097 |
| 21    | 11000. | 0.6541 |

## R1HD45-15

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 1000.  | 0.0124 |
| 2     | 1500.  | 0.0246 |
| 3     | 2000.  | 0.0451 |
| 4     | 2500.  | 0.0711 |
| 5     | 3000.  | 0.0887 |
| 6     | 3500.  | 0.1069 |
| 7     | 4000.  | 0.1225 |
| 8     | 4500.  | 0.1438 |
| 9     | 5000.  | 0.1672 |
| 10    | 5500.  | 0.1918 |
| 11    | 6000.  | 0.2146 |
| 12    | 6500.  | 0.2333 |
| 13    | 7000.  | 0.2673 |
| 14    | 7500.  | 0.2975 |
| 15    | 8000.  | 0.3314 |
| 16    | 8500.  | 0.3750 |
| 17    | 9000.  | 0.4170 |
| 18    | 9500.  | 0.4667 |
| 19    | 10000. | 0.5264 |
| 20    | 10500. | 0.5629 |
| 21    | 11000. | 0.6062 |
| 22    | 11500. | 0.6396 |
| 23    | 12000. | 0.6912 |
| 24    | 12500. | 0.7414 |
| 25    | 13000. | 0.7963 |
| 26    | 13260. | 0.8722 |

## 7091-T7E69 EXT.

## NOR 1 SPECTRUM

## 45 KSI MAXIMUM STRESS

R1NR45-01

R1NR45-04

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 2109.  | 0.0092 |
| 2     | 3164.  | 0.0195 |
| 3     | 4218.  | 0.0375 |
| 4     | 5273.  | 0.0650 |
| 5     | 6328.  | 0.1060 |
| 6     | 7383.  | 0.1451 |
| 7     | 8436.  | 0.2119 |
| 8     | 9492.  | 0.2709 |
| 9     | 10547. | 0.3793 |
| 10    | 11601. | 0.5860 |
| 11    | 12647. | 0.6921 |

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 5273.  | 0.0164 |
| 2     | 6328.  | 0.0276 |
| 3     | 7383.  | 0.0427 |
| 4     | 8436.  | 0.0604 |
| 5     | 9492.  | 0.0862 |
| 6     | 10547. | 0.1176 |
| 7     | 11601. | 0.1487 |
| 8     | 12656. | 0.1760 |
| 9     | 13500. | 0.2160 |
| 10    | 14554. | 0.2600 |
| 11    | 15609. | 0.3050 |
| 12    | 16664. | 0.3600 |
| 13    | 17719. | 0.4700 |
| 14    | 18773. | 0.5800 |
| 15    | 19815. | 0.7100 |

R1NR45-02

R1NR45-05

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 5273.  | 0.0070 |
| 2     | 6328.  | 0.0176 |
| 3     | 7383.  | 0.0335 |
| 4     | 8436.  | 0.0817 |
| 5     | 9492.  | 0.1353 |
| 6     | 10547. | 0.2134 |
| 7     | 11601. | 0.3366 |
| 8     | 12656. | 0.4734 |
| 9     | 14540. | 0.7309 |

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 12656. | 0.0113 |
| 2     | 13500. | 0.0145 |
| 3     | 14554. | 0.0189 |
| 4     | 15609. | 0.0248 |
| 5     | 16664. | 0.0320 |
| 6     | 17719. | 0.0408 |
| 7     | 18773. | 0.0535 |
| 8     | 19828. | 0.0723 |
| 9     | 20883. | 0.1107 |
| 10    | 21937. | 0.1900 |
| 11    | 22992. | 0.2700 |
| 12    | 24047. | 0.3800 |
| 13    | 25101. | 0.4900 |
| 14    | 26156. | 0.5700 |
| 15    | 27000. | 0.6600 |
| 16    | 28054. | 0.7600 |

R1NR45-03

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 3110.  | 0.0002 |
| 2     | 3164.  | 0.0042 |
| 3     | 4219.  | 0.0113 |
| 4     | 5274.  | 0.0275 |
| 5     | 6328.  | 0.0385 |
| 6     | 7383.  | 0.0653 |
| 7     | 8438.  | 0.1233 |
| 8     | 9492.  | 0.1729 |
| 9     | 10547. | 0.2246 |
| 10    | 11603. | 0.2881 |
| 11    | 12656. | 0.3722 |
| 12    | 13500. | 0.4752 |
| 13    | 14555. | 0.5458 |
| 14    | 15605. | 0.7227 |

## R1NR45-06

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 9492.  | 0.0180 |
| 2     | 10547. | 0.0260 |
| 3     | 11601. | 0.0350 |
| 4     | 12656. | 0.0480 |
| 5     | 13500. | 0.0600 |
| 6     | 14554. | 0.0730 |
| 7     | 15609. | 0.0990 |
| 8     | 16664. | 0.1280 |
| 9     | 17719. | 0.1524 |
| 10    | 18773. | 0.1772 |
| 11    | 19828. | 0.2042 |
| 12    | 20883. | 0.2334 |
| 13    | 21937. | 0.2732 |
| 14    | 22992. | 0.3147 |
| 15    | 24047. | 0.3736 |
| 16    | 25101. | 0.4500 |
| 17    | 26156. | 0.5500 |
| 18    | 27000. | 0.6500 |
| 19    | 28054. | 0.7500 |
| 20    | 29095. | 0.8800 |

## R1NR45-07

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 7383.  | 0.0089 |
| 2     | 8436.  | 0.0121 |
| 3     | 9492.  | 0.0160 |
| 4     | 10547. | 0.0216 |
| 5     | 11601. | 0.0291 |
| 6     | 12656. | 0.0381 |
| 7     | 13500. | 0.0498 |
| 8     | 14554. | 0.0615 |
| 9     | 15609. | 0.0811 |
| 10    | 16664. | 0.1063 |
| 11    | 17719. | 0.1342 |
| 12    | 18773. | 0.1631 |
| 13    | 19828. | 0.1921 |
| 14    | 20883. | 0.2227 |
| 15    | 21937. | 0.2576 |
| 16    | 22992. | 0.2995 |
| 17    | 24047. | 0.3381 |
| 18    | 25101. | 0.3900 |
| 19    | 26156. | 0.4920 |
| 20    | 27000. | 0.5510 |
| 21    | 28054. | 0.6100 |
| 22    | 29109. | 0.6900 |
| 23    | 30153. | 0.7600 |

## R1NR45-08

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 6328.  | 0.0125 |
| 2     | 7383.  | 0.0177 |
| 3     | 8436.  | 0.0227 |
| 4     | 9492.  | 0.0292 |
| 5     | 10547. | 0.0351 |
| 6     | 11601. | 0.0418 |
| 7     | 12656. | 0.0481 |
| 8     | 13500. | 0.0549 |
| 9     | 14554. | 0.0617 |
| 10    | 15609. | 0.0718 |
| 11    | 16664. | 0.0807 |
| 12    | 17719. | 0.0904 |
| 13    | 18773. | 0.1009 |
| 14    | 19828. | 0.1113 |
| 15    | 20883. | 0.1211 |
| 16    | 21937. | 0.1310 |
| 17    | 22992. | 0.1405 |
| 18    | 24047. | 0.1507 |
| 19    | 25101. | 0.1610 |
| 20    | 26156. | 0.1725 |
| 21    | 27000. | 0.1862 |
| 22    | 28054. | 0.1999 |
| 23    | 29109. | 0.2198 |
| 24    | 30164. | 0.2444 |
| 25    | 31218. | 0.2708 |
| 26    | 32273. | 0.2983 |
| 27    | 33328. | 0.3284 |
| 28    | 34382. | 0.3840 |
| 29    | 35437. | 0.4400 |
| 30    | 36492. | 0.5050 |
| 31    | 37547. | 0.5900 |
| 32    | 38589. | 0.6600 |

## R1NR45-09

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 18773. | 0.0173 |
| 2     | 19828. | 0.0207 |
| 3     | 20883. | 0.0260 |
| 4     | 21937. | 0.0319 |
| 5     | 22992. | 0.0376 |
| 6     | 24047. | 0.0415 |
| 7     | 25101. | 0.0509 |
| 8     | 26156. | 0.0612 |
| 9     | 28054. | 0.0913 |
| 10    | 29109. | 0.1180 |
| 11    | 30164. | 0.1384 |
| 12    | 31218. | 0.1657 |
| 13    | 32273. | 0.1919 |
| 14    | 33328. | 0.2214 |
| 15    | 34382. | 0.2712 |
| 16    | 35437. | 0.3305 |
| 17    | 36492. | 0.4169 |
| 18    | 37547. | 0.5083 |
| 19    | 38601. | 0.5931 |
| 20    | 39656. | 0.6752 |
| 21    | 40500. | 0.7473 |

7091-T7E69  
NOR I SPECTRUM  
50 KSI MAXIMUM STRESS

R1NR50-01

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 4218.  | 0.0347 |
| 2     | 5273.  | 0.0553 |
| 3     | 6328.  | 0.0781 |
| 4     | 7383.  | 0.1141 |
| 5     | 8436.  | 0.1788 |
| 6     | 9492.  | 0.2903 |
| 7     | 10547. | 0.4526 |
| 8     | 11589. | .7390  |

R1NR50-02

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 2109.  | 0.0143 |
| 2     | 3164.  | 0.0351 |
| 3     | 4218.  | 0.0663 |
| 4     | 5273.  | 0.1079 |
| 5     | 6328.  | 0.1656 |
| 6     | 7383.  | 0.2284 |
| 7     | 8436.  | 0.3005 |
| 8     | 9492.  | 0.4049 |
| 9     | 10547. | 0.5360 |
| 10    | 11589. | 0.6827 |

R1NR50-03

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 3164.  | 0.0230 |
| 2     | 4218.  | 0.0521 |
| 3     | 5273.  | 0.0935 |
| 4     | 6328.  | 0.1387 |
| 5     | 7383.  | 0.1878 |
| 6     | 8436.  | 0.2751 |
| 7     | 9492.  | 0.4628 |
| 8     | 10547. | 0.7523 |
| 9     | 11589. | 0.8299 |

R1NR50-04

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 3164.  | 0.0196 |
| 2     | 4218.  | 0.0349 |
| 3     | 5273.  | 0.0515 |
| 4     | 6328.  | 0.0719 |
| 5     | 7383.  | 0.0957 |
| 6     | 8436.  | 0.1318 |
| 7     | 9492.  | 0.1643 |
| 8     | 10547. | 0.2999 |
| 9     | 11601. | 0.4604 |
| 10    | 12647. | 0.6146 |

R1NR50-05

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 2109.  | 0.0046 |
| 2     | 3164.  | 0.0164 |
| 3     | 4218.  | 0.0296 |
| 4     | 5273.  | 0.0496 |
| 5     | 6328.  | 0.0747 |
| 6     | 7383.  | 0.1108 |
| 7     | 8436.  | 0.1527 |
| 8     | 9492.  | 0.2015 |
| 9     | 10547. | 0.2545 |
| 10    | 11601. | 0.3227 |
| 11    | 12656. | 0.4244 |
| 12    | 14554. | 0.6573 |
| 13    | 15490. | 0.7844 |

R1NR50-06

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 3164.  | 0.0242 |
| 2     | 4218.  | 0.0406 |
| 3     | 5273.  | 0.0677 |
| 4     | 6328.  | 0.0978 |
| 5     | 7383.  | 0.1364 |
| 6     | 8436.  | 0.1810 |
| 7     | 9492.  | 0.2296 |
| 8     | 10547. | 0.2907 |
| 9     | 11601. | 0.3819 |
| 10    | 12656. | 0.4775 |
| 11    | 14554. | 0.6654 |
| 12    | 15595. | 0.7328 |

R1NR50-07

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 4218.  | 0.0197 |
| 2     | 5273.  | 0.0392 |
| 3     | 6328.  | 0.0733 |
| 4     | 7383.  | 0.1070 |
| 5     | 8436.  | 0.1408 |
| 6     | 9492.  | 0.1769 |
| 7     | 10547. | 0.2176 |
| 8     | 11601. | 0.2617 |
| 9     | 12656. | 0.3456 |
| 10    | 14554. | 0.5527 |
| 11    | 15595. | 0.6934 |

# R1NR50-08

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 4218.  | 0.0174 |
| 2     | 5273.  | 0.0328 |
| 3     | 6328.  | 0.0489 |
| 4     | 7383.  | 0.0738 |
| 5     | 8436.  | 0.0933 |
| 6     | 9492.  | 0.1230 |
| 7     | 10547. | 0.1526 |
| 8     | 11601. | 0.2100 |
| 9     | 12656. | 0.2754 |
| 10    | 14554. | 0.4833 |
| 11    | 15609. | 0.6460 |
| 12    | 16664. | 0.7468 |

# R1NR50-09

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 6328.  | 0.0088 |
| 2     | 7383.  | 0.0253 |
| 3     | 8436.  | 0.0483 |
| 4     | 9492.  | 0.0859 |
| 5     | 10547. | 0.1226 |
| 6     | 11601. | 0.1544 |
| 7     | 12656. | 0.2081 |
| 8     | 14554. | 0.3124 |
| 9     | 15609. | 0.4287 |
| 10    | 16664. | 0.5600 |
| 11    | 17705. | 0.6187 |

# R1NR50-10

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 492.   | 0.0291 |
| 2     | 10547. | 0.0397 |
| 3     | 11601. | 0.0511 |
| 4     | 12656. | 0.0647 |
| 5     | 14554. | 0.1023 |
| 6     | 15609. | 0.1381 |
| 7     | 16664. | 0.1751 |
| 8     | 17719. | 0.2531 |
| 9     | 18773. | 0.3374 |
| 10    | 19828. | 0.4598 |
| 11    | 20274. | 0.7920 |

7091-FORGING  
HUD 34 SPECTRUM  
40 KSI MAXIMUM STRESS

R2HD40-01

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 1000. | 0.0345 |
| 2     | 1500. | 0.0329 |
| 3     | 2000. | 0.0501 |
| 4     | 2500. | 0.0784 |
| 5     | 3000. | 0.1128 |
| 6     | 3500. | 0.1420 |
| 7     | 4000. | 0.1640 |
| 8     | 4500. | 0.1967 |
| 9     | 5000. | 0.2324 |
| 10    | 5500. | 0.2568 |
| 11    | 6000. | 0.2911 |
| 12    | 6500. | 0.3335 |
| 13    | 7000. | 0.3943 |
| 14    | 7500. | 0.4736 |
| 15    | 8000. | 0.5744 |
| 16    | 8500. | 0.8140 |

R2HD40-03

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 500.   | 0.0137 |
| 2     | 1000.  | 0.0270 |
| 3     | 1500.  | 0.0502 |
| 4     | 2000.  | 0.0772 |
| 5     | 2500.  | 0.1045 |
| 6     | 3000.  | 0.1287 |
| 7     | 3500.  | 0.1540 |
| 8     | 4000.  | 0.1846 |
| 9     | 4500.  | 0.2191 |
| 10    | 5000.  | 0.2552 |
| 11    | 5500.  | 0.2999 |
| 12    | 6000.  | 0.3457 |
| 13    | 6500.  | 0.3779 |
| 14    | 7000.  | 0.4181 |
| 15    | 7500.  | 0.4831 |
| 16    | 8000.  | 0.5365 |
| 17    | 8500.  | 0.6237 |
| 18    | 9000.  | 0.6700 |
| 19    | 9500.  | 0.7448 |
| 20    | 10000. | 0.8619 |

R2HD40-02

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 2000. | 0.0442 |
| 2     | 2500. | 0.0753 |
| 3     | 3000. | 0.1056 |
| 4     | 3500. | 0.1348 |
| 5     | 4000. | 0.1663 |
| 6     | 4500. | 0.2026 |
| 7     | 5000. | 0.2390 |
| 8     | 5500. | 0.2839 |
| 9     | 6000. | 0.3293 |
| 10    | 6500. | 0.3865 |
| 11    | 7000. | 0.4433 |
| 12    | 7500. | 0.5254 |
| 13    | 8000. | 0.6071 |
| 14    | 8500. | 0.7140 |
| 15    | 9000. | 0.8177 |
| 16    | 9500. | 0.9328 |

R2HD40-04

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 3000.  | 0.0239 |
| 2     | 3500.  | 0.0431 |
| 3     | 4000.  | 0.0604 |
| 4     | 4500.  | 0.0858 |
| 5     | 5000.  | 0.1165 |
| 6     | 5500.  | 0.1510 |
| 7     | 6000.  | 0.1973 |
| 8     | 6500.  | 0.2455 |
| 9     | 7000.  | 0.3020 |
| 10    | 7500.  | 0.3664 |
| 11    | 8000.  | 0.4443 |
| 12    | 8500.  | 0.5499 |
| 13    | 9000.  | 0.6579 |
| 14    | 9500.  | 0.7396 |
| 15    | 10000. | 0.8246 |

## R2HD40-05

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 1000.  | 0.0067 |
| 2     | 1500.  | 0.0138 |
| 3     | 2000.  | 0.0189 |
| 4     | 2500.  | 0.0260 |
| 5     | 3000.  | 0.0347 |
| 6     | 3500.  | 0.0448 |
| 7     | 4000.  | 0.0553 |
| 8     | 4500.  | 0.0698 |
| 9     | 5000.  | 0.0836 |
| 10    | 5500.  | 0.1016 |
| 11    | 6000.  | 0.1164 |
| 12    | 6500.  | 0.1311 |
| 13    | 7000.  | 0.1448 |
| 14    | 7500.  | 0.1616 |
| 15    | 8000.  | 0.1812 |
| 16    | 8500.  | 0.2088 |
| 17    | 9000.  | 0.2435 |
| 18    | 9500.  | 0.2911 |
| 19    | 10000. | 0.3393 |
| 20    | 10500. | 0.4508 |
| 21    | 11000. | 0.5552 |
| 22    | 11500. | 0.6969 |

## R2HD40-07

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 4000.  | 0.0051 |
| 2     | 4500.  | 0.0134 |
| 3     | 5000.  | 0.0252 |
| 4     | 5500.  | 0.0432 |
| 5     | 6000.  | 0.0617 |
| 6     | 6500.  | 0.0829 |
| 7     | 7000.  | 0.1076 |
| 8     | 7500.  | 0.1322 |
| 9     | 8000.  | 0.1599 |
| 10    | 8500.  | 0.1912 |
| 11    | 9000.  | 0.2359 |
| 12    | 9500.  | 0.2831 |
| 13    | 10000. | 0.3351 |
| 14    | 10500. | 0.4090 |
| 15    | 11000. | 0.5174 |
| 16    | 11500. | 0.6050 |
| 17    | 12000. | 0.7950 |

## R2HD40-08

## R2HD40-06

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 1500.  | 0.0072 |
| 2     | 2000.  | 0.0236 |
| 3     | 2500.  | 0.0481 |
| 4     | 3000.  | 0.0721 |
| 5     | 3500.  | 0.0989 |
| 6     | 4000.  | 0.1246 |
| 7     | 4500.  | 0.1491 |
| 8     | 5000.  | 0.1769 |
| 9     | 5500.  | 0.2043 |
| 10    | 6000.  | 0.2352 |
| 11    | 6500.  | 0.2656 |
| 12    | 7000.  | 0.2973 |
| 13    | 7500.  | 0.3323 |
| 14    | 8000.  | 0.3678 |
| 15    | 8500.  | 0.4051 |
| 16    | 9000.  | 0.4370 |
| 17    | 9500.  | 0.4960 |
| 18    | 10000. | 0.5532 |
| 19    | 10500. | 0.6167 |
| 20    | 11000. | 0.6832 |
| 21    | 11500. | 0.7625 |
| 22    | 12000. | 0.9209 |

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 8500.  | 0.0638 |
| 2     | 9000.  | 0.0840 |
| 3     | 9500.  | 0.1103 |
| 4     | 10000. | 0.1384 |
| 5     | 10500. | 0.2332 |
| 6     | 11000. | 0.2944 |
| 7     | 11500. | 0.4172 |
| 8     | 12000. | 0.5525 |
| 9     | 12500. | 0.7369 |
| 10    | 13000. | 0.8340 |
| 11    | 13500. | 0.9411 |

## R2HD40-09

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 3000.  | 0.0095 |
| 2     | 3500.  | 0.0185 |
| 3     | 4000.  | 0.0296 |
| 4     | 4500.  | 0.0378 |
| 5     | 5000.  | 0.0495 |
| 6     | 5500.  | 0.0623 |
| 7     | 6000.  | 0.0751 |
| 8     | 6500.  | 0.0889 |
| 9     | 7000.  | 0.1021 |
| 10    | 7500.  | 0.1153 |
| 11    | 8000.  | 0.1289 |
| 12    | 8500.  | 0.1435 |
| 13    | 9000.  | 0.1577 |
| 14    | 9500.  | 0.1731 |
| 15    | 10000. | 0.1948 |
| 16    | 10500. | 0.2143 |
| 17    | 11000. | 0.2333 |
| 18    | 11500. | 0.2517 |
| 19    | 12000. | 0.2747 |
| 20    | 12500. | 0.2942 |
| 21    | 13000. | 0.3227 |
| 22    | 13500. | 0.3466 |
| 23    | 14000. | 0.3577 |
| 24    | 14500. | 0.3915 |
| 25    | 15000. | 0.4313 |
| 26    | 15500. | 0.4621 |
| 27    | 16000. | 0.5085 |
| 28    | 16500. | 0.5228 |
| 29    | 17000. | 0.5458 |
| 30    | 17500. | 0.5632 |
| 31    | 18000. | 0.5801 |

7091-FORGING  
HUD 34 SPECTRUM  
45 KSI MAXIMUM STRESS

R2HD45-01

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 500.  | 0.0509 |
| 2     | 1000. | 0.1213 |
| 3     | 1500. | 0.1931 |
| 4     | 2000. | 0.2753 |
| 5     | 2500. | 0.4093 |
| 6     | 3000. | 0.5476 |
| 7     | 3500. | 0.6718 |

R2HD45-05

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 500.  | 0.0162 |
| 2     | 1000. | 0.0414 |
| 3     | 1500. | 0.0734 |
| 4     | 2000. | 0.1113 |
| 5     | 2500. | 0.1570 |
| 6     | 3000. | 0.1966 |
| 7     | 3500. | 0.2447 |
| 8     | 4000. | 0.3005 |
| 9     | 4500. | 0.4382 |
| 10    | 5000. | 0.8223 |

R2HD45-02

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 500.  | 0.0203 |
| 2     | 1000. | 0.0739 |
| 3     | 1500. | 0.1668 |
| 4     | 2000. | 0.2527 |
| 5     | 2500. | 0.3530 |
| 6     | 3000. | 0.4275 |
| 7     | 3500. | 0.4909 |
| 8     | 4000. | 0.5819 |
| 9     | 4500. | 0.8602 |

R2HD45-06

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 500.  | 0.0063 |
| 2     | 1000. | 0.0190 |
| 3     | 1500. | 0.0520 |
| 4     | 2000. | 0.0855 |
| 5     | 2500. | 0.1141 |
| 6     | 3000. | 0.1613 |
| 7     | 3500. | 0.2489 |
| 8     | 4000. | 0.3117 |
| 9     | 4500. | 0.4215 |
| 10    | 5000. | 0.5353 |
| 11    | 5411. | 1.0000 |

R2HD45-03

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 500.  | 0.0223 |
| 2     | 1000. | 0.0480 |
| 3     | 1500. | 0.0703 |
| 4     | 2000. | 0.0983 |
| 5     | 2500. | 0.1343 |
| 6     | 3000. | 0.2050 |
| 7     | 3500. | 0.2965 |
| 8     | 4000. | 0.5205 |
| 9     | 4500. | 0.7326 |

R2HD45-07

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 500.  | 0.0146 |
| 2     | 1000. | 0.0371 |
| 3     | 1500. | 0.0674 |
| 4     | 2000. | 0.1019 |
| 5     | 2500. | 0.1350 |
| 6     | 3000. | 0.1623 |
| 7     | 3500. | 0.2055 |
| 8     | 4000. | 0.2368 |
| 9     | 4500. | 0.2900 |
| 10    | 5000. | 0.3518 |
| 11    | 5500. | 0.3889 |
| 12    | 6000. | 0.4634 |
| 13    | 6500. | 0.6065 |
| 14    | 7000. | 0.7214 |

R2HD45-04

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 500.  | 0.0147 |
| 2     | 1000. | 0.0230 |
| 3     | 1500. | 0.0398 |
| 4     | 2000. | 0.0725 |
| 5     | 2500. | 0.1077 |
| 6     | 3000. | 0.1581 |
| 7     | 3500. | 0.2275 |
| 8     | 4000. | 0.2982 |
| 9     | 4500. | 0.3937 |
| 10    | 5000. | 0.5136 |

# R2HD45-08

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 1500. | 0.0198 |
| 2     | 2000. | 0.0425 |
| 3     | 2500. | 0.0618 |
| 4     | 3000. | 0.0820 |
| 5     | 3500. | 0.1129 |
| 6     | 4000. | 0.1438 |
| 7     | 4500. | 0.1816 |
| 8     | 5000. | 0.2168 |
| 9     | 5500. | 0.2732 |
| 10    | 6000. | 0.3652 |
| 11    | 6500. | 0.4842 |
| 12    | 7000. | 0.6678 |
| 13    | 7488. | 0.7994 |

# R2HD45-09

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 2500. | 0.0166 |
| 2     | 3000. | 0.0448 |
| 3     | 3500. | 0.0609 |
| 4     | 4000. | 0.0923 |
| 5     | 4500. | 0.1389 |
| 6     | 5000. | 0.1794 |
| 7     | 5500. | 0.2321 |
| 8     | 6000. | 0.2916 |
| 9     | 6500. | 0.4378 |
| 10    | 7000. | 0.6479 |
| 11    | 7500. | 0.7980 |

CW67-T7E91

HUD 34 SPECTRUM

40 KSI MAXIMUM STRESS

R3HD40-1

R3HD40-2

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 2000.  | 0.0111 |
| 2     | 2500.  | 0.0194 |
| 3     | 3000.  | 0.0289 |
| 4     | 3500.  | 0.0454 |
| 5     | 4000.  | 0.0667 |
| 6     | 4500.  | 0.0849 |
| 7     | 5000.  | 0.1042 |
| 8     | 5500.  | 0.1204 |
| 9     | 6000.  | 0.1332 |
| 10    | 6500.  | 0.1442 |
| 11    | 7000.  | 0.1547 |
| 12    | 7500.  | 0.1638 |
| 13    | 8000.  | 0.1726 |
| 14    | 8500.  | 0.1866 |
| 15    | 9000.  | 0.2015 |
| 16    | 9500.  | 0.2170 |
| 17    | 10000. | 0.2363 |
| 18    | 10500. | 0.2560 |
| 19    | 11000. | 0.2755 |
| 20    | 11500. | 0.3011 |
| 21    | 12000. | 0.3271 |
| 22    | 12500. | 0.3834 |
| 23    | 13000. | 0.4247 |
| 24    | 13500. | 0.4705 |
| 25    | 14000. | 0.5183 |
| 26    | 14500. | 0.5842 |
| 27    | 15000. | 0.6157 |
| 28    | 15500. | 0.6469 |
| 29    | 16000. | 0.7161 |
| 30    | 16500. | 0.7529 |
| 31    | 17000. | 0.7834 |
| 32    | 17500. | 0.8043 |
| 33    | 18000. | 0.8232 |
| 34    | 18013. | 0.9163 |

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 3000.  | 0.0262 |
| 2     | 3500.  | 0.0422 |
| 3     | 4000.  | 0.0630 |
| 4     | 4500.  | 0.0870 |
| 5     | 5000.  | 0.1084 |
| 6     | 5500.  | 0.1287 |
| 7     | 6000.  | 0.1500 |
| 8     | 6500.  | 0.1723 |
| 9     | 7000.  | 0.1943 |
| 10    | 7500.  | 0.2201 |
| 11    | 8000.  | 0.2508 |
| 12    | 8500.  | 0.2828 |
| 13    | 9000.  | 0.3136 |
| 14    | 9500.  | 0.3571 |
| 15    | 10000. | 0.4008 |
| 16    | 10500. | 0.4496 |
| 17    | 11000. | 0.4977 |
| 18    | 11500. | 0.5516 |
| 19    | 12000. | 0.6048 |
| 20    | 12500. | 0.6624 |
| 21    | 13000. | 0.7185 |
| 22    | 13500. | 0.7658 |
| 23    | 14000. | 0.8044 |
| 24    | 14010. | 0.9220 |

## R3HD40-3

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 2000. | 0.0261 |
| 2     | 2500. | 0.0416 |
| 3     | 3000. | 0.0623 |
| 4     | 3500. | 0.0973 |
| 5     | 4000. | 0.1423 |
| 6     | 4500. | 0.1964 |
| 7     | 5000. | 0.2525 |
| 8     | 5500. | 0.3136 |
| 9     | 6000. | 0.3748 |
| 10    | 6500. | 0.4421 |
| 11    | 7000. | 0.5371 |
| 12    | 7500. | 0.5958 |
| 13    | 8000. | 0.6739 |
| 14    | 8500. | 0.7560 |
| 15    | 9000. | 0.8129 |
| 16    | 9006. | 0.9380 |

## R3HD40-5

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 1500.  | 0.0253 |
| 2     | 2000.  | 0.0447 |
| 3     | 2500.  | 0.0707 |
| 4     | 3000.  | 0.0954 |
| 5     | 3500.  | 0.1183 |
| 6     | 4000.  | 0.1451 |
| 7     | 4500.  | 0.1694 |
| 8     | 5000.  | 0.1974 |
| 9     | 5500.  | 0.2292 |
| 10    | 6000.  | 0.2657 |
| 11    | 6500.  | 0.3017 |
| 12    | 7000.  | 0.3456 |
| 13    | 7500.  | 0.3906 |
| 14    | 8000.  | 0.4498 |
| 15    | 8500.  | 0.5115 |
| 16    | 9000.  | 0.5603 |
| 17    | 9500.  | 0.6271 |
| 18    | 10000. | 0.6947 |
| 19    | 10500. | 0.7640 |
| 20    | 11000. | 0.8322 |
| 21    | 11500. | 0.8789 |
| 22    | 11506. | 0.9317 |

## R3HD40-4

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 1000.  | 0.0181 |
| 2     | 1500.  | 0.0329 |
| 3     | 2000.  | 0.0472 |
| 4     | 2500.  | 0.0860 |
| 5     | 3000.  | 0.1133 |
| 6     | 3500.  | 0.1434 |
| 7     | 4000.  | 0.1733 |
| 8     | 4500.  | 0.2022 |
| 9     | 5000.  | 0.2380 |
| 10    | 5500.  | 0.2701 |
| 11    | 6000.  | 0.3064 |
| 12    | 6500.  | 0.3435 |
| 13    | 7000.  | 0.3812 |
| 14    | 7500.  | 0.4487 |
| 15    | 8000.  | 0.5208 |
| 16    | 8500.  | 0.5826 |
| 17    | 9000.  | 0.6437 |
| 18    | 9500.  | 0.6954 |
| 19    | 10000. | 0.7347 |
| 20    | 10500. | 0.7662 |
| 21    | 11000. | 0.7992 |
| 22    | 11500. | 0.8281 |
| 23    | 12000. | 0.8905 |
| 24    | 12008. | 0.9263 |

## R3HD40-6

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 2000.  | 0.0157 |
| 2     | 2500.  | 0.0288 |
| 3     | 3000.  | 0.0429 |
| 4     | 3500.  | 0.0647 |
| 5     | 4000.  | 0.0923 |
| 6     | 4500.  | 0.1166 |
| 7     | 5000.  | 0.1463 |
| 8     | 5500.  | 0.1764 |
| 9     | 6000.  | 0.2064 |
| 10    | 6500.  | 0.2421 |
| 11    | 7000.  | 0.2759 |
| 12    | 7500.  | 0.3178 |
| 13    | 8000.  | 0.3614 |
| 14    | 8500.  | 0.4040 |
| 15    | 9000.  | 0.4519 |
| 16    | 9500.  | 0.5001 |
| 17    | 10000. | 0.5531 |
| 18    | 10500. | 0.6054 |
| 19    | 11000. | 0.6590 |
| 20    | 11500. | 0.7100 |
| 21    | 12000. | 0.7537 |
| 22    | 12500. | 0.7927 |
| 23    | 13000. | 0.8276 |
| 24    | 13500. | 0.8688 |
| 25    | 13509. | 0.8890 |

## R3HD40-7

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 1000. | 0.0391 |
| 2     | 1500. | 0.0608 |
| 3     | 2000. | 0.1121 |
| 4     | 2500. | 0.1551 |
| 5     | 3000. | 0.1948 |
| 6     | 3500. | 0.2344 |
| 7     | 4000. | 0.2724 |
| 8     | 4500. | 0.3187 |
| 9     | 5000. | 0.3625 |
| 10    | 5500. | 0.4235 |
| 11    | 6000. | 0.5108 |
| 12    | 6500. | 0.5737 |
| 13    | 7000. | 0.6543 |
| 14    | 7500. | 0.7149 |
| 15    | 8000. | 0.8048 |
| 16    | 8500. | 0.8467 |
| 17    | 9000. | 0.8961 |
| 18    | 9006. | 0.9314 |

## R3HD40-9

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 14000. | 0.0393 |
| 2     | 14500. | 0.0539 |
| 3     | 15000. | 0.0679 |
| 4     | 15500. | 0.0800 |
| 5     | 16000. | 0.0932 |
| 6     | 16500. | 0.1085 |
| 7     | 17000. | 0.1159 |
| 8     | 17500. | 0.1242 |
| 9     | 18000. | 0.1329 |
| 10    | 18500. | 0.1488 |
| 11    | 19000. | 0.1654 |
| 12    | 19500. | 0.1806 |
| 13    | 20000. | 0.2017 |

## R3HD40-8

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 2000.  | 0.0352 |
| 2     | 2500.  | 0.0820 |
| 3     | 3000.  | 0.1322 |
| 4     | 3500.  | 0.1697 |
| 5     | 4000.  | 0.2147 |
| 6     | 4500.  | 0.2543 |
| 7     | 5000.  | 0.2930 |
| 8     | 5500.  | 0.3392 |
| 9     | 6000.  | 0.3889 |
| 10    | 6500.  | 0.4417 |
| 11    | 7000.  | 0.5002 |
| 12    | 7500.  | 0.5510 |
| 13    | 8000.  | 0.6205 |
| 14    | 8500.  | 0.6694 |
| 15    | 9000.  | 0.7126 |
| 16    | 9500.  | 0.7574 |
| 17    | 10000. | 0.7841 |
| 18    | 10500. | 0.8051 |
| 19    | 11000. | 0.8223 |
| 20    | 11500. | 0.8434 |
| 21    | 11508. | 0.9043 |

## R 3HD40-10

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 3000.  | 0.0124 |
| 2     | 3500.  | 0.0191 |
| 3     | 4000.  | 0.0269 |
| 4     | 4500.  | 0.0388 |
| 5     | 5000.  | 0.0502 |
| 6     | 5500.  | 0.0605 |
| 7     | 6000.  | 0.0716 |
| 8     | 6500.  | 0.0816 |
| 9     | 7000.  | 0.0919 |
| 10    | 7500.  | 0.1025 |
| 11    | 8000.  | 0.1134 |
| 12    | 8500.  | 0.1234 |
| 13    | 9000.  | 0.1338 |
| 14    | 9500.  | 0.1439 |
| 15    | 10000. | 0.1564 |
| 16    | 10500. | 0.1671 |
| 17    | 11000. | 0.1792 |
| 18    | 11500. | 0.1909 |
| 19    | 12000. | 0.2070 |
| 20    | 12500. | 0.2194 |
| 21    | 13000. | 0.2346 |
| 22    | 13500. | 0.2491 |
| 23    | 14000. | 0.2644 |
| 24    | 14500. | 0.2807 |
| 25    | 15000. | 0.2954 |
| 26    | 15500. | 0.3152 |
| 27    | 16000. | 0.3358 |
| 28    | 16500. | 0.3565 |
| 29    | 17000. | 0.3792 |
| 30    | 17500. | 0.4025 |
| 31    | 18000. | 0.4284 |
| 32    | 18500. | 0.4540 |
| 33    | 19000. | 0.4853 |
| 34    | 19500. | 0.5064 |
| 35    | 20000. | 0.5340 |
| 36    | 20500. | 0.5733 |
| 37    | 21000. | 0.6001 |
| 38    | 21500. | 0.6360 |
| 39    | 22000. | 0.6685 |
| 40    | 22500. | 0.6981 |
| 41    | 23000. | 0.7339 |
| 42    | 23500. | 0.7690 |
| 43    | 24000. | 0.8055 |
| 44    | 24500. | 0.8446 |
| 45    | 25000. | 0.9039 |
| 46    | 25018. | 0.9210 |

CW67-T7E91  
HUD 34 SPECTRUM  
45 KSI MAXIMUM STRESS

R 3HD45-1

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 2000.  | 0.0474 |
| 2     | 2500.  | 0.0740 |
| 3     | 3000.  | 0.0941 |
| 4     | 3500.  | 0.1167 |
| 5     | 4000.  | 0.1399 |
| 6     | 4500.  | 0.1577 |
| 7     | 5000.  | 0.1806 |
| 8     | 5500.  | 0.2019 |
| 9     | 6000.  | 0.2249 |
| 10    | 6500.  | 0.2492 |
| 11    | 7000.  | 0.2596 |
| 12    | 7500.  | 0.2731 |
| 13    | 8000.  | 0.2863 |
| 14    | 8500.  | 0.3019 |
| 15    | 9000.  | 0.3211 |
| 16    | 9500.  | 0.3475 |
| 17    | 10000. | 0.3716 |
| 18    | 10500. | 0.3922 |
| 19    | 11000. | 0.4180 |
| 20    | 11500. | 0.4485 |
| 21    | 12000. | 0.4826 |
| 22    | 12500. | 0.5178 |
| 23    | 13000. | 0.5563 |
| 24    | 13500. | 0.5964 |
| 25    | 14000. | 0.6402 |
| 26    | 14500. | 0.6756 |
| 27    | 15000. | 0.7182 |
| 28    | 15500. | 0.7542 |
| 29    | 16000. | 0.7737 |
| 30    | 16500. | 0.7916 |
| 31    | 17000. | 0.8113 |
| 32    | 17040. | 0.9150 |

R 3HD45-2

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 500.  | 0.0111 |
| 2     | 1000. | 0.0455 |
| 3     | 1500. | 0.0775 |
| 4     | 2000. | 0.1231 |
| 5     | 2500. | 0.1592 |
| 6     | 3000. | 0.1956 |
| 7     | 3500. | 0.2393 |
| 8     | 4000. | 0.2858 |
| 9     | 4500. | 0.3351 |
| 10    | 5000. | 0.3873 |
| 11    | 5500. | 0.4537 |
| 12    | 6000. | 0.5100 |
| 13    | 6500. | 0.5880 |
| 14    | 7000. | 0.6480 |
| 15    | 7500. | 0.7063 |
| 16    | 8000. | 0.7745 |
| 17    | 8480. | 0.9360 |

R 3HD45-3

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 1500. | 0.0408 |
| 2     | 2000. | 0.0875 |
| 3     | 2500. | 0.1376 |
| 4     | 3000. | 0.1920 |
| 5     | 3500. | 0.2606 |
| 6     | 4000. | 0.3327 |
| 7     | 4500. | 0.4060 |
| 8     | 5000. | 0.4768 |
| 9     | 5500. | 0.5597 |
| 10    | 6000. | 0.6240 |
| 11    | 6500. | 0.7070 |
| 12    | 7000. | 0.8118 |
| 13    | 7040. | 0.8834 |

R 3HD45-4

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 1500.  | 0.0221 |
| 2     | 2000.  | 0.0442 |
| 3     | 2500.  | 0.0692 |
| 4     | 3000.  | 0.0947 |
| 5     | 3500.  | 0.1190 |
| 6     | 4000.  | 0.1450 |
| 7     | 4500.  | 0.1736 |
| 8     | 5000.  | 0.2047 |
| 9     | 5500.  | 0.2309 |
| 10    | 6000.  | 0.2600 |
| 11    | 6500.  | 0.2877 |
| 12    | 7000.  | 0.3153 |
| 13    | 7500.  | 0.3532 |
| 14    | 8000.  | 0.3943 |
| 15    | 8500.  | 0.4406 |
| 16    | 9000.  | 0.4803 |
| 17    | 9500.  | 0.5490 |
| 18    | 10000. | 0.5878 |
| 19    | 10500. | 0.6536 |
| 20    | 11000. | 0.7196 |
| 21    | 11500. | 0.7798 |
| 22    | 12000. | 0.8330 |
| 23    | 12008. | 0.9230 |

## R 3HD45-5

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 1500. | 0.0196 |
| 2     | 2000. | 0.0375 |
| 3     | 2500. | 0.0660 |
| 4     | 3000. | 0.1095 |
| 5     | 3500. | 0.1540 |
| 6     | 4000. | 0.2040 |
| 7     | 4500. | 0.2630 |
| 8     | 5000. | 0.3400 |
| 9     | 5500. | 0.4260 |
| 10    | 6000. | 0.5330 |
| 11    | 6500. | 0.6060 |
| 12    | 7000. | 0.6490 |
| 13    | 7500. | 0.7190 |
| 14    | 8000. | 0.8130 |
| 15    | 8494. | 0.9170 |

## R 3HD45-7

| Point | Hours | Length |
|-------|-------|--------|
| 1     | 1000. | 0.0314 |
| 2     | 1500. | 0.0518 |
| 3     | 2000. | 0.0981 |
| 4     | 2500. | 0.1485 |
| 5     | 3000. | 0.2049 |
| 6     | 3500. | 0.2610 |
| 7     | 4000. | 0.3140 |
| 8     | 4500. | 0.3760 |
| 9     | 5000. | 0.4710 |
| 10    | 5500. | 0.5630 |
| 11    | 6000. | 0.6460 |
| 12    | 6500. | 0.7100 |
| 13    | 7000. | 0.7720 |
| 14    | 7500. | 0.8320 |
| 15    | 7520. | 0.9400 |

## R 3HD45-6

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 1000.  | 0.0205 |
| 2     | 1500.  | 0.0402 |
| 3     | 2000.  | 0.0574 |
| 4     | 2500.  | 0.0791 |
| 5     | 3000.  | 0.0995 |
| 6     | 3500.  | 0.1211 |
| 7     | 4000.  | 0.1397 |
| 8     | 4500.  | 0.1593 |
| 9     | 5000.  | 0.1821 |
| 10    | 5500.  | 0.2051 |
| 11    | 6000.  | 0.2324 |
| 12    | 6500.  | 0.2592 |
| 13    | 7000.  | 0.2863 |
| 14    | 7500.  | 0.3153 |
| 15    | 8000.  | 0.3440 |
| 16    | 8500.  | 0.3768 |
| 17    | 9000.  | 0.4105 |
| 18    | 9500.  | 0.4460 |
| 19    | 10000. | 0.4746 |
| 20    | 10500. | 0.5249 |
| 21    | 11000. | 0.5841 |
| 22    | 11500. | 0.6382 |
| 23    | 12000. | 0.6857 |
| 24    | 12500. | 0.7457 |
| 25    | 13000. | 0.7881 |
| 26    | 13500. | 0.8186 |
| 27    | 13998. | 0.9067 |

## R 3HD45-8

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 1500.  | 0.0290 |
| 2     | 2000.  | 0.0614 |
| 3     | 2500.  | 0.0944 |
| 4     | 3000.  | 0.1249 |
| 5     | 3500.  | 0.1563 |
| 6     | 4000.  | 0.1864 |
| 7     | 4500.  | 0.2191 |
| 8     | 5000.  | 0.2528 |
| 9     | 5500.  | 0.2908 |
| 10    | 6000.  | 0.3308 |
| 11    | 6500.  | 0.3650 |
| 12    | 7000.  | 0.4005 |
| 13    | 7500.  | 0.4780 |
| 14    | 8000.  | 0.5400 |
| 15    | 8500.  | 0.6120 |
| 16    | 9000.  | 0.6870 |
| 17    | 9500.  | 0.7640 |
| 18    | 10000. | 0.8390 |
| 19    | 10007. | 0.9110 |

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R3NR45-1

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 9492.  | 0.0118 |
| 2     | 10547. | 0.0184 |
| 3     | 11601. | 0.0265 |
| 4     | 12656. | 0.0370 |
| 5     | 13500. | 0.0490 |
| 6     | 14554. | 0.0678 |
| 7     | 15609. | 0.0936 |
| 8     | 16664. | 0.1284 |
| 9     | 17719. | 0.1693 |
| 10    | 18773. | 0.2177 |
| 11    | 19828. | 0.2721 |
| 12    | 20883. | 0.3344 |
| 13    | 21937. | 0.3958 |
| 14    | 22992. | 0.4570 |
| 15    | 24047. | 0.5540 |
| 16    | 25101. | 0.6583 |
| 17    | 26156. | 0.7549 |
| 18    | 27000. | 0.8280 |
| 19    | 27675. | 0.9220 |

R3NR45-3

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 7383.  | 0.0236 |
| 2     | 8436.  | 0.0462 |
| 3     | 9492.  | 0.0916 |
| 4     | 10547. | 0.1506 |
| 5     | 11601. | 0.2118 |
| 6     | 12656. | 0.2715 |
| 7     | 13500. | 0.3270 |
| 8     | 14554. | 0.3960 |
| 9     | 15609. | 0.4970 |
| 10    | 16664. | 0.5870 |
| 11    | 17719. | 0.6990 |
| 12    | 18773. | 0.7840 |
| 13    | 19575. | 0.9300 |

R3NR45-2

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 11601. | 0.0057 |
| 2     | 12656. | 0.0130 |
| 3     | 13500. | 0.0230 |
| 4     | 14554. | 0.0330 |
| 5     | 15609. | 0.0489 |
| 6     | 16664. | 0.0701 |
| 7     | 17719. | 0.0947 |
| 8     | 18773. | 0.1255 |
| 9     | 19828. | 0.1600 |
| 10    | 20883. | 0.1972 |
| 11    | 21937. | 0.2374 |
| 12    | 22992. | 0.2802 |
| 13    | 24047. | 0.3211 |
| 14    | 25101. | 0.3682 |
| 15    | 26156. | 0.4220 |
| 16    | 27000. | 0.4800 |
| 17    | 28054. | 0.5390 |
| 18    | 29109. | 0.6039 |
| 19    | 30164. | 0.6940 |
| 20    | 31218. | 0.7142 |
| 21    | 32273. | 0.7644 |
| 22    | 33328. | 0.8194 |
| 23    | 34155. | 0.8789 |

R3NR45-4

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 12656. | 0.0390 |
| 2     | 13500. | 0.0580 |
| 3     | 14554. | 0.0680 |
| 4     | 15609. | 0.0930 |
| 5     | 16664. | 0.1280 |
| 6     | 17719. | 0.1810 |
| 7     | 18773. | 0.2400 |
| 8     | 19828. | 0.3030 |
| 9     | 20883. | 0.3820 |
| 10    | 21937. | 0.4620 |
| 11    | 22992. | 0.5400 |
| 12    | 24047. | 0.6670 |
| 13    | 25101. | 0.8040 |
| 14    | 26156. | 0.8630 |
| 15    | 26190. | 0.8950 |

## R3NR45-5

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 7383.  | 0.0172 |
| 2     | 8436.  | 0.0296 |
| 3     | 9492.  | 0.0421 |
| 4     | 10547. | 0.0564 |
| 5     | 11601. | 0.0771 |
| 6     | 12656. | 0.1045 |
| 7     | 13500. | 0.1443 |
| 8     | 14554. | 0.2014 |
| 9     | 15609. | 0.2612 |
| 10    | 16664. | 0.3240 |
| 11    | 17719. | 0.3875 |
| 12    | 18773. | 0.4590 |
| 13    | 19828. | 0.5390 |
| 14    | 20883. | 0.6400 |
| 15    | 21937. | 0.8440 |
| 16    | 22950. | 0.9150 |

## R3NR45-8

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 5273.  | 0.0166 |
| 2     | 6328.  | 0.0266 |
| 3     | 7383.  | 0.0420 |
| 4     | 8436.  | 0.0687 |
| 5     | 9492.  | 0.1135 |
| 6     | 10547. | 0.1883 |
| 7     | 11601. | 0.2824 |
| 8     | 12656. | 0.3894 |
| 9     | 13500. | 0.5015 |
| 10    | 14554. | 0.6460 |
| 11    | 15609. | 0.7920 |
| 12    | 15660. | 0.8980 |

## R3NR45-6

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 5273.  | 0.0183 |
| 2     | 6328.  | 0.0257 |
| 3     | 7383.  | 0.0357 |
| 4     | 8436.  | 0.0519 |
| 5     | 9492.  | 0.0785 |
| 6     | 10547. | 0.1037 |
| 7     | 11601. | 0.1460 |
| 8     | 12656. | 0.1908 |
| 9     | 13500. | 0.2400 |
| 10    | 14554. | 0.3106 |
| 11    | 15609. | 0.3963 |
| 12    | 16664. | 0.5011 |
| 13    | 17719. | 0.6000 |
| 14    | 18773. | 0.6946 |
| 15    | 19826. | 0.8939 |

## R3NR45-9

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 6328.  | 0.0110 |
| 2     | 7383.  | 0.0151 |
| 3     | 8436.  | 0.0194 |
| 4     | 9492.  | 0.0261 |
| 5     | 10547. | 0.0367 |
| 6     | 11601. | 0.0507 |
| 7     | 12656. | 0.0764 |
| 8     | 13500. | 0.1200 |
| 9     | 14554. | 0.1727 |
| 10    | 15609. | 0.2621 |
| 11    | 16664. | 0.3635 |
| 12    | 17719. | 0.4818 |
| 13    | 18773. | 0.6123 |
| 14    | 19828. | 0.7340 |
| 15    | 20250. | 0.7845 |

## R3NR45-7

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 7383.  | 0.0295 |
| 2     | 8436.  | 0.0421 |
| 3     | 9492.  | 0.0682 |
| 4     | 10547. | 0.1070 |
| 5     | 11601. | 0.1515 |
| 6     | 12656. | 0.2086 |
| 7     | 13500. | 0.2634 |
| 8     | 14554. | 0.3377 |
| 9     | 15609. | 0.4538 |
| 10    | 16664. | 0.5964 |
| 11    | 17719. | 0.7412 |
| 12    | 18495. | 0.9075 |

## R3NR45-10

| Point | Hours  | Length |
|-------|--------|--------|
| 1     | 5273.  | 0.0112 |
| 2     | 6328.  | 0.0210 |
| 3     | 7383.  | 0.0472 |
| 4     | 8436.  | 0.1055 |
| 5     | 9492.  | 0.1857 |
| 6     | 10547. | 0.2832 |
| 7     | 11601. | 0.3728 |

## APPENDIX B

### Fractographic Analysis Program Parameters

The basic parameters obtained from the initial fatigue quality (IFQ) model are given in this section. These parameters include individual  $Q$ ,  $b$ ,  $TTCl$ , and  $EIFS$  values for each test coupon. Also, included are pooled  $Q$ ,  $b$ ,  $TTCl$ , and  $EIFS$  values for each data set. Data set notations used are listed in Table A-1. Pooled  $b$ ,  $\alpha$ , and  $Q_{\beta}$  values for each alloy are listed in Table 9.

# Fractography Analysis Program

## Summary for data set C1HD35

| Item           | Least Square | Arithmetic Average | Variance of Average |
|----------------|--------------|--------------------|---------------------|
| Q              | 0.16384E-03  | 0.40038E-03        | 0.18929E-03         |
| b              | 0.77743      | 1.08650            | 0.35728             |
| R2             | 0.64490      |                    |                     |
| Qhat           | 0.16384E-03  | 0.25580E-03        | 0.15879E-03         |
| Qhat*beta(mv)  | 1.71502      | 2.67775            | 1.66224             |
| Qhat*beta(mle) | 1.90044      | 2.96724            | 1.84195             |
| TICI           |              | 9809.              | 4599.               |
| EIFS           |              | 0.31780E-02        | 0.53501E-02         |

Here are the crack growth parameters for C1HD35  
Data type.

| Specimen | Q          | b       | R2     | qhat       | TICI   |
|----------|------------|---------|--------|------------|--------|
| 1        | 0.3532E-03 | 0.67632 | 0.8128 | 0.4984E-03 | 4033.  |
| 2        | 0.5587E-03 | 0.73460 | 0.9319 | 0.6728E-03 | 4529.  |
| 3        | 0.3334E-03 | 0.79328 | 0.9494 | 0.3494E-03 | 5147.  |
| 4        | 0.2175E-03 | 0.71952 | 0.8439 | 0.2629E-03 | 5892.  |
| 5        | 0.4796E-03 | 1.07995 | 0.8882 | 0.2833E-03 | 7951.  |
| 6        | 0.7393E-03 | 1.34747 | 0.9568 | 0.2917E-03 | 8819.  |
| 7        | 0.4804E-03 | 1.08743 | 0.9117 | 0.2753E-03 | 11362. |
| 8        | 0.2068E-03 | 0.87093 | 0.9344 | 0.1869E-03 | 9636.  |
| 9        | 0.6206E-03 | 1.46171 | 0.8473 | 0.1899E-03 | 12559. |
| 10       | 0.2611E-03 | 1.03925 | 0.7883 | 0.1594E-03 | 12658. |
| 11       | 0.3996E-03 | 1.09899 | 0.9280 | 0.2212E-03 | 12862. |
| 12       | 0.5991E-03 | 1.53414 | 0.9087 | 0.1513E-03 | 14610. |
| 13       | 0.1319E-03 | 1.40434 | 0.8587 | 0.5641E-04 | 3979.  |
| 14       | 0.1167E-03 | 0.64298 | 0.8986 | 0.1447E-03 | 13234. |
| 15       | 0.5077E-03 | 1.80656 | 0.9674 | 0.9336E-04 | 19665. |

| Specimen | Qhat * beta(mle) | Qhat * beta(mv) | EIFS        |
|----------|------------------|-----------------|-------------|
| 1        | 5.781370         | 5.217326        | 0.1411E-01  |
| 2        | 7.804647         | 7.043208        | 0.9710E-02  |
| 3        | 4.053202         | 3.657762        | 0.5866E-02  |
| 4        | 3.049329         | 2.751829        | 0.2985E-02  |
| 5        | 3.286667         | 2.966012        | 0.2571E-03  |
| 6        | 3.384031         | 3.053877        | 0.5868E-04  |
| 7        | 3.192903         | 2.881396        | 0.2935E-09  |
| 8        | 2.168270         | 1.956729        | 0.5080E-05  |
| 9        | 2.202825         | 1.987912        | -0.7782E-07 |
| 10       | 1.849256         | 1.668838        | -0.1419E-06 |
| 11       | 2.566116         | 2.315759        | -0.4104E-06 |
| 12       | 1.754636         | 1.583450        | -0.6595E-04 |
| 13       | 0.654283         | 0.590450        | 0.1468E-01  |
| 14       | 1.678060         | 1.514344        | -0.1900E-05 |
| 15       | 1.082966         | 0.977310        | -0.1787E-01 |

# Summary for data set C1HD40

| Item           | Least Square | Arithmetic Average | Variance of Average |
|----------------|--------------|--------------------|---------------------|
| q              | 0.46090E-03  | 0.59284E-03        | 0.34424E-03         |
| b              | 0.78999      | 0.83042            | 0.27294             |
| R2             | 0.89327      |                    |                     |
| Qhat           | 0.46090E-03  | 0.51899E-03        | 0.93577E-04         |
| Qhat*beta(mv)  | 2.34428      | 2.63973            | 0.47596             |
| Qhat*beta(mle) | 2.15482      | 2.42639            | 0.43749             |
| TTCI           |              | 4396.              | 1160.               |
| EIFS           |              | 0.42886E-03        | 0.10405E-03         |

Here are the crack growth parameters for C1HD40  
Data type

| Specimen | Q          | b       | R2     | qhat       | TTCI  | Ind. |
|----------|------------|---------|--------|------------|-------|------|
| 1        | 0.8472E-03 | 0.97022 | 0.9491 | 0.6175E-03 | 2724. | 1.0  |
| 2        | 0.2236E-03 | 0.52948 | 0.9234 | 0.4420E-03 | 3107. | 1.0  |
| 3        | 0.2907E-03 | 0.55969 | 0.9103 | 0.6102E-03 | 4302. | 1.0  |
| 4        | 0.7993E-03 | 1.05564 | 0.9761 | 0.5385E-03 | 2438. | 1.1  |
| 5        | 0.4945E-03 | 0.86094 | 0.9676 | 0.4477E-03 | 3952. | 1.0  |
| 6        | 0.6459E-03 | 0.83777 | 0.9518 | 0.6170E-03 | 4476. | 1.0  |
| 7        | 0.4105E-03 | 0.63102 | 0.8636 | 0.6136E-03 | 4141. | 1.0  |
| 8        | 0.9127E-03 | 1.22123 | 0.9916 | 0.4121E-03 | 4451. | 1.0  |
| 9        | 0.8073E-03 | 0.98267 | 0.9799 | 0.5726E-03 | 4131. | 1.0  |
| 10       | 0.1411E-02 | 1.36117 | 0.9733 | 0.5488E-03 | 4925. | 1.0  |
| 11       | 0.7558E-03 | 0.93573 | 0.9840 | 0.5762E-03 | 5084. | 1.0  |
| 12       | 0.6314E-03 | 0.84006 | 0.9805 | 0.6078E-03 | 4631. | 1.0  |
| 13       | 0.2125E-03 | 0.57882 | 0.8026 | 0.3747E-03 | 4666. | 1.0  |
| 14       | 0.1298E-03 | 0.35343 | 0.8619 | 0.4200E-03 | 7100. | 1.1  |
| 15       | 0.3209E-03 | 0.73845 | 0.8710 | 0.3860E-03 | 5808. | 1.0  |

Here are the crack growth parameters for C1HD40

| Specimen | Qhat * beta(mle) | Qhat * beta(mv) | EIFS        |
|----------|------------------|-----------------|-------------|
| 1        | 2.387129         | 3.140980        | 0.1943E-02  |
| 2        | 2.066604         | 2.248310        | 0.7081E-03  |
| 3        | 2.852626         | 3.103444        | 0.3226E-05  |
| 4        | 2.517619         | 2.738981        | 0.3728E-02  |
| 5        | 2.093275         | 2.277326        | 0.2836E-04  |
| 6        | 2.884685         | 3.138321        | 0.7084E-06  |
| 7        | 2.868645         | 3.120871        | 0.9740E-05  |
| 8        | 1.926738         | 2.096146        | 0.9103E-06  |
| 9        | 2.677131         | 2.912518        | 0.1032E-04  |
| 10       | 2.565566         | 2.791144        | 0.8622E-10  |
| 11       | 2.694059         | 2.930934        | -0.8107E-12 |
| 12       | 2.841464         | 3.091300        | 0.1164E-06  |
| 13       | 1.751997         | 1.906042        | 0.6978E-07  |
| 14       | 1.963709         | 2.136368        | -0.1031E-02 |
| 15       | 1.804655         | 1.963330        | -0.4261E-05 |

Summary for data set C1NR45

| Item           | Least Square | Arithmetic Average | Variance of Average |
|----------------|--------------|--------------------|---------------------|
| Q              | 0.51434E-03  | 0.55743E-03        | 0.30714E-03         |
| b              | 1.12859      | 1.06713            | 0.24606             |
| R2             | 0.90285      |                    |                     |
| Qhat           | 0.51434E-03  | 0.27413E-03        | 0.10563E-03         |
| Qhat*beta(mv)  | 7.23407      | 3.85554            | 1.48561             |
| Qhat*beta(mle) | 7.17883      | 3.82610            | 1.47427             |
| TTCI           |              | 12643.             | 4538.               |
| EIFS           |              | 0.14896E-02        | 0.35249E-02         |

Here are the crack growth parameters for C1NR45  
Data type

| Specimen | Q          | b       | R2     | qhat       | TTCI   |
|----------|------------|---------|--------|------------|--------|
| 1        | 0.6860E-03 | 0.94271 | 0.9753 | 0.5287E-03 | 5537.  |
| 2        | 0.3267E-03 | 0.79611 | 0.9708 | 0.3492E-03 | 7932.  |
| 3        | 0.3073E-03 | 0.91388 | 0.9582 | 0.2352E-03 | 9391.  |
| 4        | 0.1078E-02 | 1.41497 | 0.9824 | 0.2311E-03 | 9156.  |
| 5        | 0.9608E-03 | 1.26005 | 0.9418 | 0.2748E-03 | 14511. |
| 6        | 0.3258E-03 | 0.91778 | 0.9353 | 0.2479E-03 | 14540. |
| 7        | 0.8147E-03 | 1.35870 | 0.8611 | 0.2735E-03 | 11802. |
| 8        | 0.5065E-03 | 1.21410 | 0.9417 | 0.1782E-03 | 17699. |
| 9        | 0.3568E-03 | 1.15650 | 0.9363 | 0.1450E-03 | 17403. |
| 10       | 0.2112E-03 | 0.69648 | 0.9586 | 0.2777E-03 | 18463. |

| Specimen | Qhat * beta(mle) | Qhat * beta(mv) | EIFS        |
|----------|------------------|-----------------|-------------|
| 1        | 7.379910         | 7.436697        | 0.1133E-01  |
| 2        | 4.873246         | 4.910745        | 0.2195E-02  |
| 3        | 3.282090         | 3.307345        | 0.5973E-03  |
| 4        | 3.226236         | 3.251061        | 0.7528E-03  |
| 5        | 3.836109         | 3.865627        | 0.3918E-09  |
| 6        | 3.459988         | 3.486613        | 0.2669E-09  |
| 7        | 3.816987         | 3.846358        | 0.2485E-04  |
| 8        | 2.486647         | 2.505782        | -0.1192E-04 |
| 9        | 2.023756         | 2.039328        | -0.6317E-05 |
| 10       | 3.876023         | 3.905848        | -0.4669E-04 |

# Summary for data set C2NR45

| Item           | Least Square | Arithmetic Average | Variance of Average |
|----------------|--------------|--------------------|---------------------|
| Q              | 0.15314E-03  | 0.36890E-03        | 0.64975E-03         |
| b              | 0.83433      | 1.05968            | 0.64503             |
| R2             | 0.91519      |                    |                     |
| Qhat           | 0.15314E-03  | 0.15636E-03        | 0.30159E-04         |
| Qhat*beta(mv)  | 3.17757      | 3.24430            | 0.62576             |
| Qhat*beta(mle) | 3.15260      | 3.21881            | 0.62085             |
| TICI           |              | 18657.             | 5257.               |
| EIFS           |              | 0.14404E-02        | 0.24576E-02         |

Here are the crack growth parameters for C2NR45  
Data type

| Specimen | Q          | b       | R2     | qhat       | TICI   |
|----------|------------|---------|--------|------------|--------|
| 1        | 0.2183E-03 | 0.87964 | 0.9759 | 0.1968E-03 | 10914. |
| 2        | 0.1502E-03 | 0.83695 | 0.9666 | 0.1492E-03 | 16379. |
| 3        | 0.1439E-03 | 0.78469 | 0.9586 | 0.1580E-03 | 14077. |
| 4        | 0.1731E-03 | 0.90544 | 0.9785 | 0.1474E-03 | 15460. |
| 5        | 0.1591E-03 | 0.84334 | 0.9640 | 0.1555E-03 | 17075. |
| 6        | 0.2321E-02 | 2.96115 | 0.9551 | 0.1281E-03 | 15728. |
| 7        | 0.1349E-03 | 0.80379 | 0.9635 | 0.1454E-03 | 18068. |
| 8        | 0.1697E-03 | 0.77558 | 0.9902 | 0.1925E-03 | 22798. |
| 9        | 0.9642E-04 | 0.67399 | 0.7499 | 0.1312E-03 | 20167. |
| 10       | 0.3024E-03 | 0.99781 | 0.9606 | 0.2052E-03 | 27770. |
| 11       | 0.1884E-03 | 1.19416 | 0.9688 | 0.1108E-03 | 26788. |

| Specimen | Qhat * beta(mle) | Qhat * beta(mv) | EIFS       |
|----------|------------------|-----------------|------------|
| 1        | 4.051627         | 4.083716        | 0.8444E-02 |
| 2        | 3.071751         | 3.096079        | 0.9325E-03 |
| 3        | 3.251788         | 3.277542        | 0.2605E-02 |
| 4        | 3.033389         | 3.057413        | 0.1436E-02 |
| 5        | 3.200510         | 3.225857        | 0.6579E-03 |
| 6        | 2.636104         | 2.656982        | 0.1270E-02 |
| 7        | 2.992907         | 3.016610        | 0.3855E-03 |
| 8        | 3.963755         | 3.995147        | 0.1147E-04 |
| 9        | 2.700763         | 2.722152        | 0.1034E-03 |
| 10       | 4.223589         | 4.257040        | 0.2545E-09 |
| 11       | 2.280711         | 2.298774        | 0.1516E-07 |

# Summary for data set R1HD40

| Item           | Least Square | Arithmetic Average | Variance of Average |
|----------------|--------------|--------------------|---------------------|
| Q              | 0.79538E-04  | 0.10603E-03        | 0.67070E-04         |
| b              | 0.52518      | 0.49458            | 0.32274             |
| R2             | 0.64111      |                    |                     |
| Qhat           | 0.79538E-04  | 0.11576E-03        | 0.62915E-04         |
| Qhat*beta(mv)  | 0.73165      | 1.06480            | 0.57873             |
| Qhat*beta(mle) | 0.83266      | 1.21182            | 0.65864             |
| TTCI           |              | 8756.              | 4919.               |
| EIFS           |              | 0.12481E-01        | 0.17708E-01         |

Here are the crack growth parameters for R1HD40  
Data type

| Specimen | Q          | b       | R2      | qhat       | TTCI   |
|----------|------------|---------|---------|------------|--------|
| 1        | 0.2144E-03 | 0.52915 | 0.8733  | 0.2426E-03 | 3125.  |
| 2        | 0.2116E-03 | 0.60660 | 0.7882  | 0.2129E-03 | 4997.  |
| 3        | 0.1605E-03 | 0.51260 | 0.7976  | 0.1851E-03 | 3206.  |
| 4        | 0.1154E-03 | 0.30647 | 0.8984  | 0.1789E-03 | 3888.  |
| 5        | 0.1483E-03 | 0.75643 | 0.8459  | 0.1111E-03 | 8631.  |
| 6        | 0.9900E-04 | 0.59103 | 0.8667  | 0.1014E-03 | 6007.  |
| 7        | 0.1550E-04 | 0.00000 | -0.1212 | 0.7059E-04 | 15389. |
| 8        | 0.7401E-04 | 0.32288 | 0.6598  | 0.1046E-03 | 4557.  |
| 9        | 0.6161E-04 | 0.36462 | 0.8042  | 0.8967E-04 | 6965.  |
| 10       | 0.1126E-04 | 0.00000 | -0.5485 | 0.4633E-04 | 16928. |
| 11       | 0.2971E-04 | 0.16152 | 0.7694  | 0.7205E-04 | 13428. |
| 12       | 0.1318E-03 | 0.97734 | 0.9832  | 0.8189E-04 | 13320. |
| 13       | 0.6073E-04 | 0.79241 | 0.9520  | 0.4874E-04 | 7778.  |
| 14       | 0.1506E-03 | 1.00299 | 0.9835  | 0.7469E-04 | 14359. |

| Specimen | Qhat * beta(mle) | Qhat * beta(mv) | EIFS        |
|----------|------------------|-----------------|-------------|
| 1        | 2.540196         | 2.232023        | 0.4764E-01  |
| 2        | 2.228729         | 1.958343        | 0.1654E-01  |
| 3        | 1.937784         | 1.702694        | 0.4587E-01  |
| 4        | 1.872702         | 1.645508        | 0.3259E-01  |
| 5        | 1.162576         | 1.021534        | 0.6204E-07  |
| 6        | 1.061862         | 0.933038        | 0.7238E-02  |
| 7        | 0.738993         | 0.649339        | -0.7863E-01 |
| 8        | 1.095155         | 0.962292        | 0.2212E-01  |
| 9        | 0.938760         | 0.824871        | 0.2297E-02  |
| 10       | 0.485017         | 0.426175        | -0.1333     |
| 11       | 0.754229         | 0.662727        | -0.3255E-01 |
| 12       | 0.857249         | 0.753249        | -0.3070E-01 |
| 13       | 0.510241         | 0.448339        | 0.4299E-03  |
| 14       | 0.781948         | 0.687083        | -0.5140E-01 |

# Summary for data set R1HD45

| Item           | Least Square | Arithmetic Average | Variance of Average |
|----------------|--------------|--------------------|---------------------|
| Q              | 0.22222E-03  | 0.39332E-03        | 0.32580E-03         |
| b              | 0.52658      | 0.57324            | 0.19791             |
| R2             | 0.75040      |                    |                     |
| Qhat           | 0.22222E-03  | 0.36212E-03        | 0.24773E-03         |
| Qhat*beta(mv)  | 0.81914      | 1.33484            | 0.91320             |
| Qhat*beta(mle) | 0.77725      | 1.26658            | 0.86650             |
| TTCI           |              | 3227.              | 1165.               |
| EIFS           |              | 0.67746E-02        | 0.14543E-01         |

Here are the crack growth parameters for R1HD45  
Data type .

| Specimen | Q          | b       | R2     | qhat       | TTCI  |
|----------|------------|---------|--------|------------|-------|
| 1        | 0.1272E-02 | 0.67184 | 0.9868 | 0.1156E-02 | 1064. |
| 2        | 0.4284E-03 | 0.55328 | 0.9499 | 0.4732E-03 | 1920. |
| 3        | 0.8489E-03 | 0.85908 | 0.9939 | 0.4773E-03 | 3150. |
| 4        | 0.3830E-03 | 0.55180 | 0.9539 | 0.4271E-03 | 2024. |
| 5        | 0.3861E-03 | 0.58542 | 0.7851 | 0.4000E-03 | 1641. |
| 6        | 0.7477E-03 | 0.85652 | 0.9341 | 0.4548E-03 | 4115. |
| 7        | 0.3431E-03 | 0.68612 | 0.9810 | 0.3044E-03 | 3271. |
| 8        | 0.2422E-03 | 0.54077 | 0.9703 | 0.2752E-03 | 3322. |
| 9        | 0.2152E-03 | 0.47049 | 0.9674 | 0.2775E-03 | 3216. |
| 10       | 0.2279E-03 | 0.53446 | 0.9432 | 0.2647E-03 | 4486. |
| 11       | 0.1670E-03 | 0.39104 | 0.8402 | 0.2324E-03 | 3724. |
| 12       | 0.1339E-03 | 0.31238 | 0.7601 | 0.2022E-03 | 2881. |
| 13       | 0.2915E-03 | 0.91295 | 0.9692 | 0.1680E-03 | 5100. |
| 14       | 0.8820E-04 | 0.23419 | 0.6809 | 0.1593E-03 | 3858. |
| 15       | 0.1243E-03 | 0.43824 | 0.8484 | 0.1601E-03 | 4638. |

| Specimen | Qhat * beta(mle) | Qhat * beta(mv) | EIFS        |
|----------|------------------|-----------------|-------------|
| 1        | 4.042309         | 4.260170        | 0.5276E-01  |
| 2        | 1.655019         | 1.744217        | 0.1398E-01  |
| 3        | 1.669385         | 1.759357        | 0.8090E-06  |
| 4        | 1.493913         | 1.574428        | 0.1120E-01  |
| 5        | 1.398990         | 1.474389        | 0.2334E-01  |
| 6        | 1.590809         | 1.676546        | -0.6574E-02 |
| 7        | 1.064533         | 1.121907        | -0.1761E-04 |
| 8        | 0.962546         | 1.014423        | -0.5369E-04 |
| 9        | 0.970528         | 1.022835        | -0.1790E-05 |
| 10       | 0.925820         | 0.975717        | -0.1544E-01 |
| 11       | 0.812815         | 0.856622        | -0.1648E-02 |
| 12       | 0.707378         | 0.745502        | 0.3464E-03  |
| 13       | 0.587670         | 0.619343        | -0.4135E-01 |
| 14       | 0.557124         | 0.587150        | -0.2890E-02 |
| 15       | 0.559880         | 0.590055        | -0.2043E-01 |

# Summary for data set R1NR45

| Item           | Least Square | Arithmetic Average | Variance of Average |
|----------------|--------------|--------------------|---------------------|
| Q              | 0.10598E-03  | 0.13550E-03        | 0.50550E-04         |
| b              | 0.68351      | 0.70868            | 0.13442             |
| R2             | 0.87226      |                    |                     |
| Qhat           | 0.10598E-03  | 0.11354E-03        | 0.52126E-04         |
| Qhat*beta(mv)  | 2.13091      | 2.28292            | 1.04809             |
| Qhat*beta(mle) | 2.30370      | 2.46805            | 1.13308             |
| TTCI           |              | 18636.             | 9672.               |
| EIFS           |              | 0.10099E-01        | 0.14643E-01         |

Here are the crack growth parameters for R1NR45  
Data type

| Specimen | Q          | b       | R2     | qhat       | TTCI   |
|----------|------------|---------|--------|------------|--------|
| 1        | 0.1808E-03 | 0.64119 | 0.9778 | 0.1689E-03 | 7492.  |
| 2        | 0.2144E-03 | 0.62458 | 0.9849 | 0.2072E-03 | 9734.  |
| 3        | 0.1188E-03 | 0.47410 | 0.9369 | 0.1697E-03 | 8995.  |
| 4        | 0.1349E-03 | 0.67504 | 0.9735 | 0.1190E-03 | 11648. |
| 5        | 0.1960E-03 | 0.88058 | 0.9691 | 0.1053E-03 | 21595. |
| 6        | 0.1255E-03 | 0.76026 | 0.9774 | 0.9554E-04 | 17608. |
| 7        | 0.1051E-03 | 0.73312 | 0.9879 | 0.8099E-04 | 18300. |
| 8        | 0.6748E-04 | 0.74721 | 0.9175 | 0.5040E-04 | 23977. |
| 9        | 0.1473E-03 | 0.93605 | 0.9870 | 0.7443E-04 | 30662. |
| 10       | 0.6489E-04 | 0.61467 | 0.9190 | 0.6387E-04 | 36349. |

| Specimen | Qhat * beta(mle) | Qhat * beta(mv) | EIFS        |
|----------|------------------|-----------------|-------------|
| 1        | 3.672502         | 3.397033        | 0.3970E-01  |
| 2        | 4.503451         | 4.165654        | 0.2216E-01  |
| 3        | 3.688482         | 3.411815        | 0.2726E-01  |
| 4        | 2.587268         | 2.393201        | 0.1180E-01  |
| 5        | 2.289636         | 2.117894        | -0.1528E-02 |
| 6        | 2.076695         | 1.920925        | 0.6463E-04  |
| 7        | 1.760410         | 1.628364        | 0.1498E-05  |
| 8        | 1.095607         | 1.013427        | -0.6610E-02 |
| 9        | 1.617972         | 1.496610        | -0.5110E-01 |
| 10       | 1.388446         | 1.284301        | -0.1366     |

# Summary for data set R1NR50

| Item           | Least Square | Arithmetic Average | Variance of Average |
|----------------|--------------|--------------------|---------------------|
| Q              | 0.17273E-03  | 0.23089E-03        | 0.17823E-03         |
| b              | 0.65543      | 0.69492            | 0.27676             |
| R2             | 0.88742      |                    |                     |
| Qhat           | 0.17273E-03  | 0.16235E-03        | 0.25818E-04         |
| Qhat*beta(mv)  | 1.88470      | 1.77141            | 0.28170             |
| Qhat*beta(mle) | 1.69990      | 1.59771            | 0.25408             |
| TTCI           |              | 9245.              | 2850.               |
| EIFS           |              | 0.13356E-02        | 0.26249E-02         |

Here are the crack growth parameters for R1NR50  
Data type

| Specimen | Q          | b       | R2     | qhat       | TTCI   |
|----------|------------|---------|--------|------------|--------|
| 1        | 0.4087E-03 | 0.97399 | 0.9893 | 0.2061E-03 | 8101.  |
| 2        | 0.1650E-03 | 0.54429 | 0.9875 | 0.1867E-03 | 6090.  |
| 3        | 0.1692E-03 | 0.51749 | 0.8349 | 0.1979E-03 | 6579.  |
| 4        | 0.2566E-03 | 0.83704 | 0.9520 | 0.1573E-03 | 9015.  |
| 5        | 0.1373E-03 | 0.55644 | 0.9702 | 0.1541E-03 | 8374.  |
| 6        | 0.1122E-03 | 0.51902 | 0.9571 | 0.1312E-03 | 7723.  |
| 7        | 0.1337E-03 | 0.56390 | 0.9294 | 0.1457E-03 | 8712.  |
| 8        | 0.1514E-03 | 0.66748 | 0.9559 | 0.1350E-03 | 10454. |
| 9        | 0.1065E-03 | 0.43925 | 0.9228 | 0.1509E-03 | 11447. |
| 10       | 0.6684E-03 | 1.33031 | 0.9685 | 0.1587E-03 | 15952. |

| Specimen | Qhat * beta(mle) | Qhat * beta(mv) | EIFS        |
|----------|------------------|-----------------|-------------|
| 1        | 2.028134         | 2.248624        | 0.2720E-03  |
| 2        | 1.837334         | 2.037081        | 0.7606E-02  |
| 3        | 1.947120         | 2.158802        | 0.4617E-02  |
| 4        | 1.547552         | 1.715795        | -0.5188E-05 |
| 5        | 1.516578         | 1.681454        | 0.8601E-04  |
| 6        | 1.291330         | 1.431718        | 0.7711E-03  |
| 7        | 1.433652         | 1.589512        | 0.3812E-05  |
| 8        | 1.328654         | 1.473099        | -0.1874E-02 |
| 9        | 1.485240         | 1.646709        | -0.6456E-02 |
| 10       | 1.561550         | 1.731315        | -0.8514E-01 |

# Summary for data set R2HD40

| Item           | Least Square | Arithmetic Average | Variance of Average |
|----------------|--------------|--------------------|---------------------|
| Q              | 0.17073E-03  | 0.20292E-03        | 0.78807E-04         |
| b              | 0.54408      | 0.52727            | 0.15592             |
| R2             | 0.79959      |                    |                     |
| Qhat           | 0.17073E-03  | 0.20085E-03        | 0.57183E-04         |
| Qhat*beta(mv)  | 1.15349      | 1.35703            | 0.38635             |
| Qhat*beta(mle) | 1.15425      | 1.35793            | 0.38661             |
| TICI           |              | 6015.              | 2360.               |
| EIFS           |              | 0.53909E-02        | 0.73571E-02         |

Here are the crack growth parameters for R2HD40  
Data type

| Specimen | Q          | b       | R2     | qhat       | TICI  |
|----------|------------|---------|--------|------------|-------|
| 1        | 0.2273E-03 | 0.56699 | 0.8199 | 0.2254E-03 | 3670. |
| 2        | 0.2111E-03 | 0.53133 | 0.9295 | 0.2197E-03 | 3746. |
| 3        | 0.1601E-03 | 0.45454 | 0.9370 | 0.1893E-03 | 3415. |
| 4        | 0.2267E-03 | 0.53221 | 0.9676 | 0.2377E-03 | 5486. |
| 5        | 0.2475E-03 | 0.79132 | 0.9452 | 0.1468E-03 | 7168. |
| 6        | 0.1185E-03 | 0.32263 | 0.8800 | 0.1724E-03 | 4517. |
| 7        | 0.2550E-03 | 0.60881 | 0.9510 | 0.2314E-03 | 7829. |
| 8        | 0.3213E-03 | 0.64554 | 0.9039 | 0.2898E-03 | 9573. |
| 9        | 0.5873E-04 | 0.29203 | 0.7926 | 0.9534E-04 | 8727. |

| Specimen | Qhat * beta(mle) | Qhat * beta(mv) | EIFS        |
|----------|------------------|-----------------|-------------|
| 1        | 1.523647         | 1.522637        | -0.1380E-01 |
| 2        | 1.485452         | 1.484467        | 0.1261E-01  |
| 3        | 1.279507         | 1.278659        | 0.1817E-01  |
| 4        | 1.607232         | 1.606167        | 0.5334E-04  |
| 5        | 0.992269         | 0.991612        | -0.7293E-02 |
| 6        | 1.165365         | 1.164593        | 0.3889E-02  |
| 7        | 1.564250         | 1.563213        | -0.1674E-01 |
| 8        | 1.959133         | 1.957834        | -0.6445E-01 |
| 9        | 0.644550         | 0.644123        | -0.3695E-01 |

# Summary for data set R2HD45

| Item           | Least Square | Arithmetic Average | Variance of Average |
|----------------|--------------|--------------------|---------------------|
| Q              | 0.38774E-03  | 0.42791E-03        | 0.17778E-03         |
| b              | 0.62759      | 0.59750            | 0.21295             |
| R2             | 0.85807      |                    |                     |
| Qhat           | 0.38774E-03  | 0.36135E-03        | 0.67544E-04         |
| Qhat*beta(mv)  | 1.20522      | 1.12318            | 0.20995             |
| Qhat*beta(mle) | 1.21399      | 1.13135            | 0.21148             |
| TTCI           |              | 2786.              | 1095.               |
| EIFS           |              | 0.69617E-02        | 0.14059E-01         |

Here are the crack growth parameters for R2HD45  
Data type

| Specimen | Q          | b       | R2     | qhat       | TTCI  |
|----------|------------|---------|--------|------------|-------|
| 1        | 0.2999E-03 | 0.29381 | 0.8996 | 0.4385E-03 | 1201. |
| 2        | 0.3009E-03 | 0.30270 | 0.6866 | 0.4373E-03 | 1444. |
| 3        | 0.5738E-03 | 0.77569 | 0.9415 | 0.3781E-03 | 2666. |
| 4        | 0.7702E-03 | 0.92192 | 0.9743 | 0.3523E-03 | 2937. |
| 5        | 0.4731E-03 | 0.68793 | 0.8565 | 0.3716E-03 | 2431. |
| 6        | 0.5445E-03 | 0.59190 | 0.9191 | 0.4177E-03 | 2917. |
| 7        | 0.2012E-03 | 0.43751 | 0.8645 | 0.2496E-03 | 2761. |
| 8        | 0.3246E-03 | 0.65974 | 0.9222 | 0.2724E-03 | 4090. |
| 9        | 0.3629E-03 | 0.60627 | 0.9060 | 0.3347E-03 | 4631. |

| Specimen | Qhat * beta(mle) | Qhat * beta(mv) | EIFS        |
|----------|------------------|-----------------|-------------|
| 1        | 1.373058         | 1.363141        | 0.3756E-01  |
| 2        | 1.369226         | 1.359337        | 0.2463E-01  |
| 3        | 1.183766         | 1.175216        | -0.3334E-05 |
| 4        | 1.103048         | 1.095081        | -0.1002E-02 |
| 5        | 1.163350         | 1.154948        | 0.4677E-03  |
| 6        | 1.307781         | 1.298336        | -0.8560E-03 |
| 7        | 0.781382         | 0.775738        | -0.1255E-03 |
| 8        | 0.852766         | 0.846606        | -0.3801E-01 |
| 9        | 1.047794         | 1.040226        | -0.7843E-01 |

Summary for data set R3HD40

| Item           | Least<br>Square | Arithmetic<br>Average | Varian<br>of Aver... |
|----------------|-----------------|-----------------------|----------------------|
| Q              | 0.21369E-03     | 0.26464E-03           | 0.20911E-03          |
| b              | 0.72536         | 0.63953               | 0.27097              |
| R2             | 0.58613         |                       |                      |
| Qhat           | 0.21369E-03     | 0.24871E-03           | 0.10819E-03          |
| Qhat*beta(mu)  | 1.36456         | 1.58820               | 0.69084              |
| Qhat*beta(mle) | 1.74167         | 2.02712               | 0.88176              |
| TTCI           |                 | 6358.                 | 4772.                |
| EIFS           |                 | 0.16348E-01           | 0.16960E-01          |

ography Analysis Program

Here are the crack growth parameters for R3HD40  
Data type

| Specimen | Q          | b       | R2     | qhat       | TTCI   |
|----------|------------|---------|--------|------------|--------|
| 1        | 0.1567E-03 | 0.67826 | 0.5897 | 0.1643E-03 | 6773.  |
| 2        | 0.3254E-03 | 0.89106 | 0.6065 | 0.2539E-03 | 6000.  |
| 3        | 0.7768E-03 | 1.05246 | 0.6374 | 0.4855E-03 | 4078.  |
| 4        | 0.2034E-03 | 0.57502 | 0.5546 | 0.2411E-03 | 3610.  |
| 5        | 0.3405E-03 | 0.84746 | 0.6291 | 0.2909E-03 | 4097.  |
| 6        | 0.1834E-03 | 0.55095 | 0.6504 | 0.2267E-03 | 5062.  |
| 7        | 0.3524E-03 | 0.75201 | 0.5599 | 0.3362E-03 | 2441.  |
| 8        | 0.1718E-03 | 0.34727 | 0.2314 | 0.2440E-03 | 3224.  |
| 9        | 0.3522E-04 | 0.12122 | 0.2136 | 0.1323E-03 | 18537. |
| 10       | 0.9277E-04 | 0.57957 | 0.7682 | 0.1124E-03 | 975    |

| Specimen | Qhat * beta(mle) | Qhat * beta(mu) | EIFS        |
|----------|------------------|-----------------|-------------|
| 1        | 1.338916         | 1.049005        | 0.1368E-02  |
| 2        | 2.069772         | 1.621612        | 0.3678E-02  |
| 3        | 3.956650         | 3.099931        | 0.1937E-01  |
| 4        | 1.964786         | 1.539358        | 0.2633E-01  |
| 5        | 2.371250         | 1.857812        | 0.1912E-01  |
| 6        | 1.847327         | 1.447332        | 0.9143E-02  |
| 7        | 2.739768         | 2.146536        | 0.5120E-01  |
| 8        | 1.988585         | 1.558004        | 0.3327E-01  |
| 9        | 1.077971         | 0.844562        | -0.1705     |
|          | 0.916214         | 0.717830        | -0.1839E-04 |

## Fractography Analysis Program

Summary for data set R3HD45

| Item            | Least<br>Square | Arithmetic<br>Average | Variance<br>of Average |
|-----------------|-----------------|-----------------------|------------------------|
| Q               | 0.20410E-03     | 0.27488E-03           | 0.14805E-03            |
| b               | 0.55954         | 0.59487               | 0.22595                |
| R2              | 0.50806         |                       |                        |
| Qhat            | 0.20410E-03     | 0.29702E-03           | 0.10783E-03            |
| Qhat*beta(mic)  | 0.80424         | 1.17035               | 0.42488                |
| Qhat*beta(mile) | 0.70851         | 1.03105               | 0.37431                |
| TTCI            |                 | 3373.                 | 798.                   |
| EIFS            |                 | 0.44522E-02           | 0.54096E-              |

Here are the crack growth parameters for R3HD45  
Data type

| specimen | Q          | b       | R2     | qhat       | TTCI  |
|----------|------------|---------|--------|------------|-------|
| 1        | 0.1132E-03 | 0.55438 | 0.4374 | 0.1346E-03 | 4271. |
| 2        | 0.1625E-03 | 0.22483 | 0.7659 | 0.2926E-03 | 2364. |
| 3        | 0.3872E-03 | 0.61948 | 0.6423 | 0.4298E-03 | 2618. |
| 4        | 0.3106E-03 | 0.80560 | 0.5712 | 0.2734E-03 | 4091. |
| 5        | 0.2051E-03 | 0.41590 | 0.9300 | 0.3097E-03 | 3456. |
| 6        | 0.1058E-03 | 0.37881 | 0.8576 | 0.1655E-03 | 4266. |
| 7        | 0.4769E-03 | 0.79661 | 0.6377 | 0.4287E-03 | 2511. |
|          | 0.4376E-03 | 0.90336 | 0.5857 | 0.3418E-03 |       |

| specimen | Qhat * beta(mile) | Qhat * beta(mic) | EIF        |
|----------|-------------------|------------------|------------|
| 1        | 0.467149          | 0.530264         | 0.2846E-04 |
| 2        | 1.015652          | 1.152875         | 0.1315E-01 |
| 3        | 1.491930          | 1.693502         | 0.9785E-02 |
| 4        | 0.949125          | 1.077360         | 0.1088E-03 |
| 5        | 1.075223          | 1.220494         | 0.1431E-02 |
| 6        | 0.574663          | 0.652305         | 0.3083E-04 |
| 7        | 1.488284          | 1.689364         | 0.1042E-   |
|          | 1.186347          | 1.346633         | 0.1666E-   |

# Actography Analysis Program

Summary for data set R3NR45

| Item           | Least<br>Square | Arithmetic<br>Average | Variance<br>of Average |
|----------------|-----------------|-----------------------|------------------------|
| Q              | 0.16420E-03     | 0.21366E-03           | 0.13878E-03            |
| b              | 0.71707         | 0.74215               | 0.19543                |
| R2             | 0.88939         |                       |                        |
| Qhat           | 0.16420E-03     | 0.18086E-03           | 0.57636E-04            |
| Qhat*beta(mu)  | 2.58311         | 2.84524               | 0.90672                |
| Qhat*beta(mle) | 2.29264         | 2.52530               | 0.80476                |
| TTCI           |                 | 13467.                | 3514                   |
| EIFS           |                 | 0.46448E-02           | 0.51252E-02            |

Here are the crack growth parameters for R3NR45  
Data type

| Specimen | Q          | b       | R2     | qhat       | TTCI   |
|----------|------------|---------|--------|------------|--------|
| 1        | 0.1328E-03 | 0.70549 | 0.9940 | 0.1337E-03 | 17246. |
| 2        | 0.7131E-04 | 0.45998 | 0.9639 | 0.1090E-03 | 19536. |
| 3        | 0.1323E-03 | 0.47997 | 0.9638 | 0.1814E-03 | 10538. |
| 4        | 0.2532E-03 | 0.93220 | 0.8678 | 0.1860E-03 | 17181. |
| 5        | 0.1285E-03 | 0.64003 | 0.9572 | 0.1448E-03 | 13614. |
| 6        | 0.1845E-03 | 0.80427 | 0.9937 | 0.1550E-03 | 11698. |
| 7        | 0.2182E-03 | 0.79167 | 0.9959 | 0.1913E-03 | 11568. |
| 8        | 0.5744E-03 | 1.07910 | 0.9128 | 0.2999E-03 | 10117. |
|          |            | 0.97986 | 0.9764 | 0.1528E-03 | 14095. |
|          |            | 64896   | 0.9655 | 0.2547E-03 | 9078   |

| Specimen | Qhat * beta(mle) | Qhat * beta(mu) | EI          |
|----------|------------------|-----------------|-------------|
| 1        | 1.866909         | 2.103435        | 0.1799E-04  |
| 2        | 1.521865         | 1.714677        | -0.5213E-05 |
| 3        | 2.533206         | 2.854149        | 0.8436E-02  |
| 4        | 2.596993         | 2.926018        | 0.2114E-04  |
| 5        | 2.022134         | 2.278327        | 0.1613E-02  |
| 6        | 2.164225         | 2.438420        | 0.4942E-02  |
| 7        | 2.670831         | 3.009210        | 0.5269E-02  |
| 8        | 4.187189         | 4.717682        | 0.1005E-02  |
|          | 2.133332         | 2.403613        | 0.1136E-02  |
|          | 3.556328         | 4.006894        | 0.1496E-02  |