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IMPACT OF PARAMETER ACCURACY ON AIRCRAFT STRUCTURAL INTEGRITY ESTIMATES

Scott A. Fawaz, Major, USAF

HQ USAF/DFEM
Department of Engineering Mechanics
2354 Fairchild Drive, Ste 6H2
USAF Academy, CO 80840

James A. Harter

Air Vehicles Directorate
2790 D Street, Street 504
Air Force Research Laboratory
WPAFB, OH 45433-7542

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AIR VEHICLES DIRECTORATE
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AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7542

NOTICE

JAMES H. HARTER, Aero Engr
Analytical Structural Mechanics Branch
Structures Division
Air Vehicles Directorate

WILLIAM C. SHIPMAN, CAPT, USAF
Deputy Chief,
Analytical Structural Mechanics Branch
Structures Division
Air Vehicles Directorate

CHRISTOPHER L. CLAY
Chief, Structures Division
Air Vehicles Directorate

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Scott A. Fawaz, Major, USAF (DFEM)
James A. Harter (VASM)

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HQ USAF/DFEM
Department of Engineering Mechanics
2354 Fairchild Drive, Ste 6H2
USAF Academy, CO 80840

Air Vehicles Directorate
2790 D Street, Street 504
Air Force Research Laboratory
WPAFB, OH 45433-7542

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14 ABSTRACT *(Maximum 200 Words)*
This report documents work performed to quantify the effect of various Linear Elastic Fracture Mechanics (LEFM) parameters and material properties on the life of aircraft structures. Automated computer methods were used to perform life comparisons using the Air Force crack growth life prediction software, AFGROW.

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Preface

The purpose of this research effort was to investigate the sensitivity of fatigue life estimates on the parameters used to generate the estimate. In doing so, the variance of the parameters was based first on statistical data if available, but in most cases reliable statistical data could not be found; therefore, engineering judgment was used. The results of this work are to be used by those in the research community, specifically the Analytical Structural Mechanics Branch, Structures Division, Air Vehicles Directorate, Air Force Research Laboratory (AFRL/VASM), to focus resources on investigating those parameters that can significantly affect the fatigue life estimates.

This work would not have been possible without the USAF's structural life prediction program, AFGROW, which is designed, developed, and maintained by Mr. Jim Harter, AFRL/VASM. Furthermore, the unique component object model capabilities in AFGROW reduced by a 100-fold the engineering time required to complete all of the parametric studies. Simply stated, analytical efforts of this magnitude could not be completed without AFGROW. Thus, a special thanks goes to Jim for not only making AFGROW the premier structural life prediction code in the world, but also for his advice and guidance in developing and executing the parameter studies..

1. Introduction

Metal fatigue is a complicated metallurgical process resulting in the premature failure or damage of a structure which is subject to cyclical loading. Fatigue in monolithic metallic structures has been scientifically studied since 1838.[1] This early work focused on machines of the day, rotating machinery in factories of every sort; however, in the USAF, the primary focus is on aircraft. The desire to avoid or reduce fatigue failures is motivated by safety and economic concerns. Paradoxically, as designers and engineers strive for more economically efficient structures, the fatigue, and thus, safety risk increases. For example, fuel efficiency in all vehicles is a function of the weight of the vehicle. If the weight is reduced, the vehicle can travel further on the same amount of fuel. Assuming that the lighter vehicle is made of the same material, as the weight decreases, the mean operating stress increases, thereby initiating and/or exacerbating the fatigue problem. This paradox is prevalent in most military vehicles where the trait of vehicle performance is supreme, with fatigue sensitivity and, ultimately, life-cycle cost is of secondary concern.

The USAF has implemented programs, discussed in section 2, to ensure safety of the fleet; however, life-cycle costs associated with fatigue damage remain unchecked. This problem is further aggravated by reduced defense budgets, resulting in less procurement of new aircraft. According to the National Material Advisory Board (NMAB), the USAF fleet is getting older and the fatigue problems can only increase.[2] The NMAB reached this conclusion by assessing the structural integrity of 35 USAF fixed-wing aircraft; USAF maintained aircraft listed in Figure 7 and maintained with contractor logistics support (CLS) aircraft in Figure 8. In addition, the NMAB stated that the safety of the fleet is being reduced by decreasing operational service and support (OS&S) budgets. Since ASIP is executed using OS&S funding, any decrease in these funds has a direct effect on structural integrity. Furthermore, reduced research and development (R&D) funding to address design, analysis, inspection, maintenance, and repair needs has also affected ASIP in terms of the fidelity of the structural integrity estimates.[3] The need for focusing the limited R&D resources on parameters that most greatly affect the structural integrity of an aircraft is paramount. This research effort aims to disclose those parameters.

This report is organized into two main sections. Section 2 discusses how the USAF manages the structural life of its aircraft as well as describing the parameter studies that are conducted and the analytical methodology used. Results and discussion of the

[1] Schutz, Walter, "A History of Fatigue," *Engineering Fracture Mechanics*, 54 (1996): 263.
[2] Tiffany, Charles F., "Aging of US Air Force Aircraft," 1997 USAF Structural Integrity Program Conference, 11 December 1997, 57.
[3] *Ibid.*, 58.

analyses are found in sections 3 and 4, with the conclusion and summary following in section 5.

2. Parameter Studies and Analytical Methodology

In the military and civil aviation industries in the U.S., the discipline of fracture mechanics is used to conduct damage tolerance analyses, DTA, to predict the fatigue life of a cyclically loaded structure. The USAF was first to establish formal damage tolerance requirements, DTR, in MIL-A-83444 and subsequently in AFGS-87221.[4] Similarly, the FAA developed and implemented DTRs in the Federal Aviation Regulation 25 (FAR/AC 25.571). Both civil and military DTR documents aim to guide aircraft manufacturers and maintainers in the design, development, production, use, and management of human-carrying aircraft.

In the following sections, the ASIP is discussed with emphasis on how LEFM is used in performing DTAs used in the ASIP process. Subsequently, the development and determination of the parameter study matrix to include the pertinent variables to be considered is discussed.

2.1. USAF Aircraft Structural Integrity Program

The USAF established the USAF ASIP 42 years ago as a result of flight safety degradation caused by fatigue failures of operational aircraft. The well-known crash of a General Dynamics F-111 in 1969 due to cracking in a critical wing pivot fitting led to a major restructuring of the ASIP program. Prior to the F-111 mishap, ASIP was based on the safe-life approach. Safe-life allows the structure to be used up to its fatigue life. Then it must be taken out of service regardless of whether cracking was present. After the F-111 mishap, ASIP was based on DTA and fail safety. Fail safety permits cracks to exist in the structure, but does not allow them to grow to a critical size undetected.

2.1.1. Determining and Setting Inspection Intervals

Prediction methods play an integral role in evaluating the damage tolerance of the aircraft in that they are used to specify inspection intervals for timely fatigue crack detection and to assess the residual strength reduction in the presence of fatigue cracks. Although important, the residual strength concerns are not within the scope of this research. The value of the slow crack growth methodology is assessed in a broad sense on whether it increases the safety and decreases the maintenance costs of both old aircraft in service and new aircraft still on the drawing board. A brief review of how the damage tolerance approach is implemented, as outlined in the DTRs contained in FAR/AC 25.571, illustrates how the crack growth prediction models are used. Figure 1 shows a generic crack growth curve where the crack grows from detectable, a_d, to permissible, a_p, to critical, a_c. The DTR specifies that the residual strength cannot fall below a permissible level and the crack associated with the permissible residual strength must be detected. The detectable crack size is not constant but depends on the method used for detection: visual, eddy current, ultrasonic, dye penetrant, or X-ray. The permissible crack size is

[4] Lincoln, John W., "Challenges for the Aircraft Structural Integrity Program," *Proc. of FAA/NASA International Symposium on Advanced Structural Integrity Methods for Airframe Durability and Damage Tolerance*, 4-6 May 1994, Hampton, VA, NASA-CP-3274, p. 409.

then the largest crack sustainable while maintaining the minimum residual strength as outlined by the DTR. Beyond the permissible crack size, normal operational loading can cause the crack to grow to a critical size, resulting in failure of the structural element and possibly catastrophic failure of the aircraft. Assuming the crack is just below the detectable size at t_1 shown in Figure 1, and the permissible crack size is reached at t_3 after H flights, inspections must be made at H/2 intervals in order to find and repair the crack. By setting the inspection interval, I, to H/2, the operator has two opportunities to detect and repair the crack before the critical crack size is reached. The designers know the structural details and operational stress levels, therefore, crack growth curves similar to Figure 1 must be generated for all fatigue critical locations.

2.2. Linear Elastic Fracture Mechanics

Engineering fracture mechanics was developed in response to structural failures and fractures in high-strength materials when subjected to small cyclical stress.[5] Although fatigue failures have occurred for centuries, understanding of the fracture process and fatigue crack growth was not understood until the 20th century. A. A. Griffith was the first to recognize that fracture occurs when certain conditions in the structure, and thus at the crack tip, are met. Without going through the theoretical derivation, Griffith showed that fracture occurs when the following conditions exist[6]:

$$
\begin{aligned}
G_I &= \frac{K_I^2}{E}\left(1-n^2\right) \Rightarrow K_I = \sqrt{\frac{G_I E}{1-n^2}} && \textit{plane strain} \\
G_I &= \frac{K_I^2}{E} \Rightarrow K_I = \sqrt{G_I E} && \textit{plane stress},
\end{aligned}
\tag{1}
$$

where K_I = mode I stress intensity factor, E = modulus of elasticity, G = mode I strain energy release rate, and ν = Poisson's ratio. See reference [7] for a detailed discussion of the three fracture modes, mode I (opening), mode II (sliding), mode III (tearing). Usually a crack begins from a very small size and grows until failure, but subcritical crack growth is not explained by the Griffith criteria. Paris, Gomez, and Anderson were the first to recognize the relationship between K and subcritical crack extension. They developed the following functional relationship[8]:

$$\frac{da}{dN} = C\Delta K^n, \tag{2}$$

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[5] Broek, D., Elementary Engineering Fracture Mechanics, Martinus Nijhoff Publishers, Dordrecht, 1986, p. 5.

[6] Griffith, A. A., "The Phenomena of Rupture and Flow in Solids," *Phil. Trans. Roy. Soc. of London*, A221 (1921): p. 190.

[7] Broek, 8.

[8] Paris, P. C., M. P. Gomez, and W. E. Anderson, "A Rational Analytic Theory of Fatigue," *The Trend in Engineering*, 13 (1961): p. 9.

where a = crack length, N = number of applied fatigue cycles, ΔK = stress intensity factor range, and C, n = empirically derived material constants. The stress intensity factor is represented as follows:

$$K = s\sqrt{pc}b, \qquad (3)$$

where s = applied remote stress, c = crack length, and b = boundary correction factor. In practice, K is calculated using equation (3) for a structural component subject to known loads. The crack extension created during the load cycles is then calculated using equation (2). Lastly, failure is determined when K_I or G_I exceeds the critical value for that particular material.

2.2.1. Limits and Applicability

LEFM is only valid when the material is linear, isotropic, and homogenous, and also when the plastic zone size around the crack tip is small. LEFM is most commonly used for predicting fatigue and fracture of low to moderately stressed monolithic metals although certain types of plastics[9] have also been analyzed. Theoretically, LEFM should not be used for composite materials since the material is neither isotropic nor homogeneous.

2.2.2. Crack Growth Laws

If a structure is subject to a constant amplitude, CA, loading spectrum as shown in Figure 2, the Paris crack growth law, equation (2), is sufficient to predict crack growth lives. However, if the structure is subject to a variable amplitude, VA, spectrum as shown in Figure 3 the Paris law is inadequate. Due to the changing load levels, crack growth can be accelerated or decelerated (retarded) as a function of the load sequencing and the Paris law cannot capture this behavior. This effect is known as load interaction effects or load sequence effects. For this study, the Paris law is used for CA loading and several load interaction models are used for VA loading as discussed below.

2.3. Development and Determination of Parameter Study Matrix

As seen in the Paris fatigue crack growth law, crack growth depends on the structural material and stress intensity factor. The stress intensity factor is a function of the applied load and geometry of the structure to be analyzed. Although this sounds simple, engineers and scientists have spent most of the 20th century trying to understand crack growth. The following sections discuss the various parameters that affect the determination of K and representation of the material behavior as it affects fatigue life.

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[9] Grandt, Jr., A. F., J. A. Harter, and B. J. Heath, "Transition of Part-Through-cracks at Holes into Through-the-Thickness Flaws," *Fracture Mechanics: Fifteenth Symposium*, ASTM STP 833, R. J. Sanford, Ed., American Society for Testing and Materials, Philadelphia, 1984, p. 7.

2.3.1. Initial Flaw Assumption

Regardless of which crack growth law is used, every crack growth analysis for a given structure begins with an initial flaw assumption, which is the size of the crack at time equals zero or, in terms of fatigue cycles, N = 0. ASIP requires that the initial flaw assumption, c_i, for a standard DTAs is c_i = 0.05 inch. Furthermore, for a durability analysis where the economic life is being calculated as opposed to fail safety, c_i = 0.02 inch. Lastly, if a multiple crack scenario exists or is expected, the primary crack is set at c_i = 0.05 inch. and the secondary crack at c_i = 0.005 inch. Where applicable, each of these initial crack lengths is used in the DTAs that follow in order to determine the effect of an inaccurate initial flaw assumption and the resulting effect on the fatigue life prediction.

2.3.2. Boundary Correction Factor

The solution of the elastic stress field at the crack tip was originally solved for an infinite sheet with a centrally located through-crack subject to a remotely applied tensile stress. The K_I solution for this case is given by equation (3) where the geometric correction factor b = 1.0. For all other load cases and geometric configurations, the b value must be determined. Fortunately, many of these b values are available in the open literature.[10-12] Obviously, using the appropriate b for a given crack scenario is extremely important. The effect of using the wrong b solution is examined by analyzing the crack scenarios listed in Table 1. The cracks emanate from a centrally located hole in a finite width plate subject to pure remote tension.

Table 1. Crack Configurations

Assumed Crack Configuration	Actual Crack Configuration
One Through-Crack at a Hole	Two Through-Cracks at a Hole
One Through-Crack at a Hole	One Corner Crack at a Hole
One Corner Crack at a Hole	Two Corner Cracks at a Hole

The crack configurations above are chosen since the DTA engineer routinely has to make an assumption regarding which cracking scenario is most likely since, in most instances, the only method of determining the actual cracking scenario is to perform extensive laboratory testing or destructive testing of in-service aircraft, two expensive options.

[10] Harter, James A., "AFGROW Users Guide and Technical Manual," AFRL-VA-WP-TR-1999-3016, February 1999, p. 130.

[11] NASGRO Fatigue Crack Growth Computer Program, Version 2.01, NASA JSC-22267A, 1994, p. C1-C35.

[12] Murakami, Y., *Stress Intensity Factors Handbook, Vol. 3*, The Society of Materials Science, Japan, Pergamon Press, Tokyo, p. 1

2.3.3. Load Interaction

The sequence or order in which a structure is loaded can greatly affect the crack growth rate and thus, the fatigue life. Depending on the loading sequence, crack growth can be accelerated or decelerated, and is known as load interaction or load sequence effects. More specifically, crack growth deceleration is known as retardation. Two schools of thought permeate the literature regarding what causes load interaction effect: models based on plasticity-induced crack closure and models based on the plastic zone ahead of the crack tip. Plasticity-induced crack closure is created when the plastically deformed material in the crack wake forces the crack to close even when crack opening loads are applied. A complete discussion of plasticity-induced crack closure can be found in references 13-20. In the simplest form, crack closure can be accounted for in the crack growth law by substituting an effective *K* for *K*, as follows:

$$\frac{da}{dN} = C\Delta K_{eff}{}^{n} \tag{4}$$

Many researchers have proposed relationships for K_{eff}; for example, Elber,[21,22] Walker,[23] Forman,[24] Newman,[25] and de Koning.[26] Due to the complexity of these models and the inability to automate the simulation process, examination of variations in crack closure models and parameters cannot be included in this study.

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[13] Chermahini, R. G., K. N. Shivakumar, and J. C. Newman Jr., "Three-Dimensional Aspects of Plasticity-Induced Fatigue Crack Closure," *Engineering Fracture Mechanics*, 1989 Vol. 34 No. 2, p. 393.
[14] Dawicke, D. S., A. F. Grandt Jr., and J. C. Newman Jr., "Three-Dimensional Crack Closure Behavior," *Engineering Fracture Mechanics*, 1990 Vol. 36 No. 1, p. 111.
[15] Elber, Wolf, "Fatigue Crack Closure Under Cyclic Tension," *Engineering Fracture Mechanics*, Vol. 2 (1970): p. 37.
[16] Elber, Wolf, "Equivalent Constant-Amplitude Concept for Crack Growth Under Spectrum Loading," Fatigue Crack Growth Under Spectrum Loads, ASTM 595, American Society for Testing and Materials, 1976, pp. 236.
[17] McClung, R. C. and H. Sehitoglu, "Closure and Growth of Fatigue Cracks at Notches," Journal of Engineering Materials and Technology, Vol. 114, Jan. 1992, 6.
[18] Newman Jr., J. C., "Prediction of Fatigue-Crack Growth Under Variable-Amplitude and Spectrum Loading Using a Closure Model," *Design of Fatigue and Fracture Resistant Structures ASTM STP 761*, P. R. Abelkis and C. M. Hudson, Eds., American Society for Testing and Materials, 1982, p. 270.
[19] Newman Jr., J. C., "Crack Opening Stress Equation for Fatigue Crack Growth," *International Journal of Fracture*, Vol. 24 (1984): p. R131-R135.
[20] Newman, Jr., J. C., "Fagitue-Life Prediction Methodology Using a Crack-Closure Model," *Journal of Engineering Materials and Technology*, Vol. 117 (1995): p. 434.
[21] Elber, "Equivalent Constant-Amplitude Concept…," p. 236.
[22] Elber, "Fatigue Crack Closure Under Cyclic Tension," p. 37.
[23] Walker, E. K., "Effects of Environments and Complex Load History on Fatigue Life," *ASTM STP 462*, (1970): p. 13.
[24] Forman, R. G., V. E. Kearney, and R. M. Engle, "Numerical Analysis of Crack Propagation in a Cyclical-Loaded Structure," *ASME Transactions, Journal of Basic Engineering*, Vol. 89D (1967): p. 459.
[25] Newman, "Prediction of Fatigue-Crack… ," p. 270.
[26] de Koning, A. U., H. J. ten Hoeve, and T. K. Henriksen, "Recent Advances in the Modelling of Crack Growth Under Fatigue Loading Conditions," *Proc. of FAA/NASA International Symposium on Advanced Structural Integrity Methods for Airframe Durability and Damage Tolerance*, 4-6 May 1994, Hampton, VA, NASA-CP-3274, p. 351.

Harter,[27] Wheeler,[28] and Willenborg, Engle, and Wood[29] have proposed that crack retardation is a result of the yield zone in front of the crack tip, and each have proposed empirical models to account for this behavior. Each of these models is evaluated to determine the effect of choice of the load interaction model on the fatigue life.

2.3.4. Crack Growth Rate Data

Metals used for primary structure in aircraft procured under ASIP must have fully characterized fatigue properties to determine the crack growth rate and fracture behavior. This data is generated as part of the material characterization effort and is traditionally part of the data package delivered to the USAF. All fatigue life predictions for the aircraft use the data developed during the material characterization effort. On the other hand, if the data is not available, the DTA engineer must rely on crack growth rate data from compilations such as those found in references 30 and 31 which, incidentally, are the most widely cited. Regardless of the source, the data is used in one of two ways. One, a continuous function is fit to the discrete ΔK-*da/dN* data points and the function is used in the life prediction. Several researchers, Paris et al.,[32] Walker,[33] Forman,[34] and Forman, Newman, and de Koning (FNK)[35] have proposed crack growth rate equations to fit empirical data. The first three equations perform well in the Paris stage II portion of the crack growth rate curve since the curve is nearly linear in this region; however, data used in the FNK relation has been rigorously manipulated to ensure that the curve fit is satisfactory for the entire sigmoidally shaped crack growth rate curve. An example of a crack growth rate curve of this type is shown in Figure 4. As illustrated by Figure 4, the crack growth rate curve is complex and not easily curve fitted; thus, approximations are typically necessary. One such approximation is assuming that the crack growth curve is linear or piecewise linear, as shown in Figures 5 and 6. Note that the material for all three curves, Figures 4 through 6, is 2024-T3 aluminum sheet.

Two, the ΔK-*da/dN* data is stored in a tabular format, and the crack growth program interrogates the data directly. If the analyst chooses to use a table lookup of the ΔK-*da/dN* data, the choice is simple if only one set of data is available; however, due to the variability inherent in experimental testing, several replicates of one test configuration are usually completed. As a result, the analyst now must decide how to use the data. For simplicity, assume three sets of ΔK-*da/dN* data. Good engineering practice dictates conducting individual crack growth analyses using the lower, mean, and upper bound of the ΔK-*da/dN* data sets. An example of such a data set is shown in Figure 9.

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[27] Harter, p. 114.
[28] Wheeler, O. M., "Spectrum Loading and Crack Growth," *ASME Publication*, 1971, p. 181.
[29] Willenborg, J., R. M. Engle, and H. A. Wood, "A Crack Growth Retardation Model Using an Effective Stress Concept," AFFDL-TM-71-1-FBR (1971), p. 2.
[30] MIL-HDBK-5G, *Metallic Materials and Elements for Aerospace Vehicle Structures*, 1 November 1994.
[31] Skinn, D. A., J. P. Gallagher, A. P. Berens, P. D. Huber, and J. Smith, "Damage Tolerant Design Handbook," WL-TR-94-4052, Air Force Materials Directorate, May 1994.
[32] Paris, p. 9.
[33] Walker, K.E., p. 13.
[34] Forman, p. 459.
[35] Forman, "NASGRO," p. 5.

Schijve found further evidence of the variability in crack growth rate data during his investigation of crack growth rate data of one material type obtained from seven different suppliers (Figure 10).[36] The difference in crack growth rate data is manifested in a difference in the fatigue life and can be quite significant. The maximum relative difference in lots from the same two suppliers shown in Figure 10 is approximately 40 percent. Between suppliers, the maximum relative difference is 74 percent. As can be expected, variation of this magnitude can severely alter the initial and recurring inspection intervals.

2.3.5. Stress Intensity Factor

The stress intensity factor, shown in equation form in equation (3), is a function of the applied stress, geometric configuration of the structure, and the crack length. Variation in the latter two parameters and the effects on K were discussed earlier. Since K is directly proportional to the applied stress, S, variation is S can have a significant impact on the fatigue life of the structure. The applied stress is varied by ±20 percent. Using state-of-the-art computational mechanics tools, finite element modeling, and assuming linear behavior, this small variation is routinely obtainable.

2.3.6. Yield Stress

The yield stress is important to fatigue life predictions in two ways: one, as a failure criteria and two, in load interaction calculations. Failure of a structure with a crack fails one of two ways either by exceeding the critical fracture toughness as discussed above or by having the material directly in front of the crack, known as the ligament, completely yielded. If the ligament yields, the structure can no longer carry load and is considered failed even though the structure has not fractured into two pieces. Although the yield stress values found in reference 30 are statistical quantities (A-basis and B-basis), insufficient data is available to determine the mean value and standard deviation. Therefore, since the yield stress is a material property, the same variation is used here as with the other material property parameters, ±5 percent and ±10 percent.

2.3.7. Fracture Toughness

The fracture toughness is the critical K value that, if exceeded, results in unstable, rapid crack extension. Depending on the thickness of the structure, the applied stress intensity factor, K_{app}, is compared to the plane strain fracture toughness, K_{Ic}, or the plane stress fracture toughness, K_c, to determine if failure will occur. As with most things in engineering, there are rarely absolutes; thus, a structure rarely experiences purely plane strain or stress, but somewhere in between. Relationships between the structural thickness and stress state, plane strain or stress, have been developed by several researchers, most notably Harter[37] and Newman.[38] The calculation of the relationship has

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[36] Schijve, J., "The Fatigue Life of Unnotched and Notched 2024-T3 Alclad Sheet Materials from Different Manufacturers," *National Aerospace laboratory NLR, TR 68093*, 1968, p. 20.
[37] Harter, p. 118.
[38] Newman, "Prediction of Fatigue-Crack… ," p. 270.

been incorporated into their respective fatigue life prediction programs. Both fracture toughness values have been varied ±5 percent and ±10 percent, which is a representative variation found in the literature.[39,40]

2.3.8. Threshold Stress Intensity Factor Range

The stress intensity factor value below which no crack growth occurs is known as the threshold stress intensity, ΔK_{th}. In other words, $K_{app} \geq \Delta K_{th}$ for the crack to start propagating. Although not discussed here in detail, research is currently underway to determine if the K_{th} is a physical quantity or simply an artifact of crack growth rate testing at low K values. Until there is a conclusion to this debate, DTA engineers currently use the K_{th}; therefore, variation in K_{th} affects the fatigue life. The same variation is used, ±5 percent and ±10 percent, as was used for the fracture toughness.

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[39] MIL-HDBK-5G.
[40] Skinn et al., DTA Handbook.

3. Discussion of Analysis Results

In view of the USAF's aging transport fleet, a transport aircraft fuselage crack scenario is chosen. Although the structure is quite complex, the problem is simplified by idealizing the structure to only include one or two cracks at a given structural detail. A narrow-body fuselage is chosen where typically the rivet hole diameter, d = 0.1875 inch, skin thickness, t = 0.063 inch, and the distance between rivets (rivet pitch), s = 1.14 inches. Five different cracking scenarios are used in this investigation: single through-crack at a hole (STCH), double through-crack at a hole (DTCH), single corner crack at a hole (SCCH), double corner crack at a hole (DCCH), and double oblique through-crack at a hole (DOTCH). At a minimum, the loading condition consists of remote tension, secondary bending, and bearing. For a more thorough discussion of the load transmission in fuselage skins see reference 41. For brevity, only remote tension is considered here. In the plane of the fuselage skin, the crack geometry for one or two cracks is shown in Figures 11 and 12, respectively. The details of the crack plane for each crack case are shown in Figures 13 through 17. The parametric analyses of the variables affecting the fatigue life performance of aircraft structure have been conducted and, based on the results, the parameters have been separated into primary and secondary factors and are discussed in detail below.

3.1. Discussion of Variance in Input Parameters

Variation data in the parameters affecting the fatigue life is difficult to obtain. Material data listed in reference 42 are derived values; in other words, the raw data is not available. Therefore, the mean as well as the standard deviation of the data is unknown. This applies for all the material data: yield stress, critical stress intensity factor, threshold stress intensity factor, load interaction parameters, and crack growth rate data. In addition, variation data for the calculated or derived values and assumptions - initial flaw size, boundary correction factor, and stress intensity factor - are typically not in the public domain because either it is proprietary or a sufficient sample size is not available. As a result, the parameter variation is determined using engineering judgment, as discussed below.

3.2. Initial Flaw Assumption Results

The initial flaw size mandated by ASIP as discussed previously was established in 1975 and was based on the observation at that time that not a single aircraft had failed in the time it took a 0.05 inch defect to grow to critical size.[43] The initial flaw assumptions of c_i = 0.05, 0.02, and 0.005 inch for damage tolerance, durability, and continuing damage, respectively, are known as the rogue flaw assumptions for each analysis type. The rogue

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[41] Fawaz, S. A., J. Schijve, and A. U. de Koning, "Fatigue Crack Growth in Riveted Lap-Splice Joints," *Proc. of the 19th Symposium of the International Committee on Aeronautical Fatigue*, 16-20 June 1997, Edinburgh, Scot. Scotland, UK: EMAS/SoMat Systems International Ltd, 1997, p. 554-555.
[42] MIL-HDBK-5G.
[43] Lincoln, John W., Electronic Communication, USAF Material Command, Aerospace Systems Command, Wright-Patterson AFB, OH. 17 Jan 2001.

flaw concept was established to account for variability in material and production processes and assumes that, depending on the analysis being conducted, a flaw exists in the structure prior to the first flight. The importance of the initial flaw assumption is clearly evident in Figure 18. Table 2 shows the initial flaw size, number of cycles to c = 0.05 inch, cycles at final fracture, and the percentage of the fatigue life spent growing from the initial flaw size to the ASIP mandated c_i = 0.05inch.

Table 2. Effect of Initial Flaw Assumption

Initial Flaw Assumption, c_i (in.)	Number of Cycles at c = 0.05 in.	Cycles at Final Fracture	$N_{0.05}$ (percent)
0.000787	36652	52021	70.4
0.005	9926	25347	39.2
0.02	3942	19331	20.4
0.05	0	15372	0

The initial crack length of 0.000787 inch. was chosen for analysis since this is size reported as being the inherent flaw size in a pristine sheet of 2024-T3 aluminum, a material property and not a function of the aircraft production process.[44,45] As evident in Table 2, the amount of the fatigue life spent in the small crack regime, $0.000787 \leq c \leq c_i$ inch is significant. Furthermore, the difference in fatigue lives between the smallest ASIP permitted initial crack length, c_i = 0.005 inch and 0.02 and 0.05 inch is 23.7 and 39.3 percent, respectively, both of which are nonnegligible.

The data shown in Figure 18 was for a STCH with an applied stress level of 20 ksi, which is slightly higher than the maximum stress level found in any of the transport aircraft flying today. As expected, the difference in fatigue lives as a function of the initial flaw assumption is present at all stress levels analyzed, $5 \leq S \leq 35$ ksi, as seen in Figure 19 and Figure 20. Note that the fatigue lives for stress levels below 10 ksi are quite large, resulting in poor resolution of the fatigue life data at the higher stress levels; therefore, the curves are truncated at S = 10 ksi. Similarly, the influence of the initial flaw assumption on the fatigue life is present for single and double corner cracks at a hole, as shown in Figure 21 and Figure 22. For the part-through-cracks, which are corner cracks that have not grown through the thickness of the sheet, the analysis was stopped once the crack penetrated the back surface. Using this method, only the corner crack K solution is used. In comparing the fatigue lives for the single and double through-cracks at a hole at each stress level for the three ASIP mandated initial flaw assumptions, the difference in

[44] Newman Jr., J. C. and P. R. Edwards, “Short-Crack Growth Behaviour in an Aluminum Alloy-An AGARD Cooperative Test Programme,” *AGARD-R-732*, Specialised Printing Services Limited, Essex, 1988, p. 20
[45] Edwards, P. R. and J. C. Newman Jr., “Short-Crack Growth Behaviour Various Aircraft Materials,” *AGARD-R-767*, Specialised Printing Services Limited, Essex, 1990, p. 14

fatigue lives can be quite large, as shown in Table 3. The effect of initial flaw assumption is larger for the part-through-cracks since the *K* solution is more sensitive to the crack size close to the hole edge.

Table 3. Effect of Initial Flaw Assumption on Fatigue Life for Single and Double Through and Corner Cracks at a Hole (percent)

	$N_{0.02}$ / $N_{0.05}$	$N_{0.005}$ / $N_{0.05}$
STCH	20 – 32	49 – 74
DTCH	40 – 61	95 – 156
SCCH	570 – 861	1818 – 4653
DCCH	667 – 1092	2464 – 5491

Recall that the ASIP-mandated initial flaw assumptions were based on data collected in the early 1970s using that era's crack detection technology. If new nondestructive inspection (NDI) technology could be used to increase the resolution and fidelity of crack detection and measurement, the initial flaw assumptions would be decreased. As a result, more accurate fatigue life predictions could be conducted and, thus, more appropriate aircraft crack inspection schedules determined.

3.3. Boundary Correction Factor

The opportunity to incorrectly assume the boundary correction factor that most accurately represents the cracking scenario in the structure is infinite; however, with engineering experience, this possibility is reduced considerably. As a result of inadequate NDI, the damage tolerance analyst is constantly faced with two cases: has a corner crack grown through the skin sheet, or does the primary crack (through or part-through-crack) have a secondary crack (continuing damage scenario) diametrically opposed on the other side of the rivet hole? For each initial flaw size assumption, each case is evaluated.

For case 1, two analyses are completed for each initial flaw assupmtion. In the first analysis, a SCCH is grown until it grows through the thickness of the sheet. For the second analysis, a STCH is grown to the crack length at which the corner crack analysis was halted, see Figure 23. Thus, for the same initial flaw assumptions, the effect of assuming an incorrect crack scenario is determined; see Figure 24 - Figure 26 and Table 4.

Table 4. Effects of Initial Flaw Size and Cracked Area on Fatigue Life, S = 5 ksi

Initial Flaw Size (in.)	Initial A_{STCH} / A_{SCCH} (%)	Relative Difference N_{STCH} vs. N_{SCCH} (%)
0.005	401.1	-15.8
0.02	100.3	5.6
0.05	40.1	19.6

In general, the difference in fatigue lives at the higher stress levels, $S > 15$, is negligible which is expected.[46] However, at the lower stress level, where most of the transport fleet operates, the difference is significant. For the smallest initial flaw size, the through-crack is growing faster than the corner crack, primarily due to the large difference in cracked area; however, at the larger initial flaw sizes, the cracked area difference is smaller, resulting in higher *K*s for the corner than the through-crack. Therefore, in conducting a damage tolerance or durability analysis, assuming that the initial flaw is a through-crack when it is actually a corner crack leads to nonconservative and unsafe fatigue life predictions.

For case 2, the effect of a continuing damage crack is evaluated for both through- and part-through cracks. As dictated by ASIP, the length of the continuing damage crack is 0.005 inch; however, no crack growth analysis program in the public domain has the capability to analyze unequal cracks at a hole for both through and part-through cracks. The AFGROW developers are currently working on this technology improvement. As a result, comparisons are made for the effect of a second crack for each of the initial flaw size assumptions as shown in Figure 27 through 29 for through-cracks and Figures 30 through 33 for part-through-cracks. For the through-cracks, the effect of the second crack is significant for all initial flaw assumptions and stress levels. The continuing damage crack reduces the fatigue life on average by 45, 70, and 100 percent for initial flaw assumptions of 0.005, 0.02, and 0.05 inch, respectively. As expected, at the higher stress levels and larger initial flaws, the reduction in the fatigue life is greater. For the corner cracks, the effect of the second cracks is not nearly as important as for the through-cracks. The continuing damage crack reduces the fatigue life on average by 5, 14, and 34 percent for initial flaw assumptions of 0.005, 0.02, and 0.05 inch, respectively. The amount of cracked area for the corner cracks is much less than the through-cracks; thus, the small corner cracks do not significantly affect the stress distribution around the hole. As a result, a small corner crack ($a_i = c_i = 0.005$ inch) does not feel the effect of a second, similarly sized crack on the opposite side of the hole.

Having an undetected crack opposite of the primary crack is more problematic for the through than part-through cracks. For the through-crack scenario, the inspection interval is set based on the DTA for the one crack; however, with two cracks, the crack growth life is faster, and the crack could grow to a critical size prior to the first inspection which was based on only one crack being present. For the corner crack scenario, the effect of

[46] Schijve, J. and F. A. Jacobs, "Fatigue Crack Propagation in Unnotched and Notched Aluminum Alloy Specimens," *NLR-TR M.2128*. Amsterdam, NL: National Aerospace Laboratory, 1964, p. 1.

the second crack is not as significant. The second crack would be detected for all initial flaw assumptions. For example, with an applied stress of 10 ksi and an initial flaw assumption of 0.05 inch, for one corner crack the fatigue life is 10,773 cycles, and for two corner cracks the fatigue life is 7,193 cycles. If the analyst assumed only one crack existed, the first inspection would be at 5,386 cycles (10,773 ÷ 2), which is less than the fatigue life if two cracks where present. Thus, the second crack would not go undetected, and the inspection intervals would be adjusted to reflect the appropriate cracking scenario.

3.4. Load Interaction

The open literature is riddled with publications on load interaction and the effects on the crack growth rate, retardation or acceleration, and fatigue life. As mentioned previously, this investigation considers only the Harter, Wheeler, and Willenborg models as these are the only models currently available in AFGROW. The Newman[47] and de Koning[48] models are definitely of interest but cannot be used in an automated manner; thus, investigations of this magnitude are time prohibitive.

For the three models used here, each has a closure or retardation parameter that is tuned such that analytical predictions match or are close to experimental results. The term tuned describes the iterative process of modifying the load interaction model parameter to obtain the highest correlation between the analytical and experimental results. For a model to be of any practical use once the load interaction parameter is tuned for a particular material, it should not change; hence, the load interaction parameter is a material property. Erroneous results are possible if the load interaction model is not tuned properly, as evidenced by the incorrect conclusions drawn by Walker, who conducted a similar parametric evaluation of load interaction models.[49] The closure parameter and associated value for each model is shown in Table 5. The parameter values in Table 5 are used for all fatigue life predictions when load interaction is considered.

[47] Newman Jr., J. C., "Prediction of Fatigue-Crack Growth Under Variable-Amplitude and Spectrum Loading Using a Closure Model," *Design of Fatigue and Fracture Resistant Structures ASTM STP 761*, P. R. Abelkis and C. M. Hudson, Eds., American Society for Testing and Materials, 1982, p. 277.

[48] de Koning, A. U., H. J. ten Hoeve, F. P. Grooteman, and C. J. Lof, "Advances in the Modeling of Cracks and Their Behaviour in Space Structures," *Proceedings of the European Conference on Spacecraft Structures, Materials, and Mechanical Testing*, Braunschweig, Germany, 4-6 Nov. 1998, p. 10.

[49] Walker, K., "An Evaluation of Empirical and Analytical Models for Predicting Fatigue Crack Propagation Load Interaction Effects," *Proc. of the 1997 USAF Structural Integrity Program Conference*, 2 - 4 Dec 1997, San Antonio, TX, p. 13.

Table 5. Load Interaction Model Parameters and Values

Load Interaction Model	Load Interaction Parameter	Load Interaction Parameter Value
Harter	Open Load Ratio	0.36
Wheeler	Shaping Exponent	0.86
Willenborg	Shutoff Ratio	3.00

Fatigue lives were calculated for a DTCH subject to pure tension loading using the FALSTAFF spectrum (see Figure 3, for no retardation and each of the retardation models). The results for each initial flaw size and for all stress levels are shown in Figures 33 through 35. Investigations on the effect of load sequence and interaction began over 40 years ago; thus, the variation in results shown here is astounding.[50] Each load interaction model has been tuned to predict the crack growth behavior in 2024-T3 aluminum. The average relative difference between each of the load interaction models for all initial flaw assumptions and stress levels is shown in Table 6 where the first model name is used as the reference solution in calculating the relative difference.

Table 6. Comparisons between Load Interaction Models

Load Interaction Model	Initial Flaw Assumption, c_i=0.005 inch (%)	Initial Flaw Assumption, c_i=0.02 inch (%)	Initial Flaw Assumption, c_i=0.05 in. (percent)
Harter vs. Willenborg	49	50	48
Harter vs. Wheeler	-12	-13	-24
Willenborg vs. Wheeler	-115	-122	-132

The large difference in results from the three models explains why ASIP does not, in general, allow the use of load interaction models when determining the fail safety of an aircraft. This does not mean that load interaction models are never used. On a case-by-case basis, the System Program Director (SPD) can approve such use and usually does so when the inspection interval without load interaction is expected to be overly conservative, resulting in frequent, labor intensive, and costly recurring inspections.

The need for further research and development in load interaction models is essential. The large variation in model results as shown in Table 6 results in either over- inspecting the aircraft or flying unsafe aircraft. Future research should not only determine which of the three models investigated here is the most appropriate, but also should compare these models with the Newman[51] and de Koning[52] closure models.

[50] Schijve, J. and F. A. Jacobs, "Program-Fatigue Tests on Notched Light Alloy Specimens of 2024 and 7075 Material," *NLR-TR M.2070*. Amsterdam, NL: National Aerospace Laboratory, 1960, p. 10

[51] Newman, "Prediction of Fatigue Crack Growth… ," p. 277.

Crack Growth Rate Data

Accurate crack growth rate data, commonly known as rate data, is paramount in conducting fatigue life predictions. The inherent variations in the rate data are inevitable due to the complexity of the fatigue process and inadequate testing procedures. The latter variation source is unacceptable and is easily avoided with proper use of current state-of-the-art fatigue testing machines.

Crack growth rate data was collected for 180 ksi 4340 steel at the AFRL using standard ASTM E647 specimens and test procedures. Two of the results are shown in Figure 9. The variation between the two tests is significant, especially in view of the log-log scale. Fatigue life predictions were conducted using the DTCH scenario subject to pure tension with a stress ratio, $R = 0.1$, since the data was collected using this R. The effect of the variation in rate data is significant for all initial flaw assumptions, $c_i = 0.005$, 0.02, and 0.05 inch, as can be seen in Figures 36 through 38. The range of relative differences between the lower level (LL) and mean value and upper level (UL) and mean value are listed in Table 7.

Table 7. Relative Differences in Fatigue Life using Crack Growth Rate Data from Two Tests of 180 ksi 4340 Steel

LL vs. Mean Rate Data (%)	UL vs. Mean Rate Data (%)	LL vs. UL Rate Data (%)
40 – 82	31 – 64	59 – 78

3.5. Stress Intensity Factor

The stress intensity factor is the crack driving force; thus, any variation in K undoubtedly will affect the fatigue life of the component. Recall from equation (3), $K = \sigma\sqrt{(\pi c)}\beta$, that K is a function of the applied stress, σ, crack length, c, and geometry of the component, β. The variance in the latter two parameters was discussed earlier. Variance in the applied stress could be eliminated if sufficient resources were used. Specifically, the applied stress is unknown for one of two reasons. One, a computational structural analysis of the fatigue critical location (FCL) was not conducted. Two, the FCL was not instrumented with any sort of measuring device which could be used to determine the stress state. Aircraft managers, not the engineers conducting the DADTAs, typically make both of these decisions. Thus the reality of not knowing the applied stress state remains.

To evaluate the effect of changes in the applied stress on the fatigue life, the DTCH scenario, see Figures 12 and 15, was used. Recall that the stress was varied ±20 percent for each of the seven stresses used; for example, if the mean value stress is 35 ksi, then the UL stress is 42 ksi, and the LL is 28 ksi. Again, all three initial flaw assumptions

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[52] de Koning, p. 10.

were used. The effect of the variation in stress for each initial flaw assumption is easy to see in Figures 38 through 41; however, for the $S > 10$ ksi, the resolution of these figures is insufficient. Therefore, in Figure 42 the relative difference between the mean and upper and lower bounds is shown for each stress level. The spike in relative difference at $S = 30$ ksi is a manifestation of the failure criterion used for these analyses. The crack is assumed to grow unstably and fracture the component if the applied stress intensity is greater than the critical stress intensity ($K_{app} \geq K_c$). In comparing the mean and lower limit values, the crack with the applied mean stress fractures almost immediately, resulting in a low fatigue life and high relative difference when compared to the lower limit value. Furthermore, variation from the mean value is constant, ±20 percent, but the relative difference between the mean and upper and lower values is not symmetric, further indicating the nonlinear relationship between stress, and hence stress intensity factor, and the fatigue life.

3.6. Yield Stress

The first set of analyses evaluated the variation in the yield stress as it affects the load interaction models and ultimately the fatigue life. The analysis was halted when $K_{app} \geq K_c$; thus, the only dependence on the yield stress is in the load interaction models. The second set of analyses uses the same variation in yield stress to evaluate the affect on the fatigue life; however, the analyses were stopped when net section stress exceeded the yield stress ($S_{net} \geq s_{ys}$). For both analyses, the DTCH scenario was used.

For all three initial flaw assumptions, c_i = 0.005, 0.02, and 0.05 inch, and for all load interaction models, the yield stress, range of values shown in Table 8, does not have a significant effect on the fatigue life for each of the load interaction models, as shown in Table 9. Interestingly, the Wheeler model is most sensitive for all combinations, suggesting this model should not be used except when the yield stress has been determined for the specific material (identical material type, heat treatment, lot, manufacture, etc.) in question.

Table 8. Range of Yield Stress Values

	Lower Limit (LL) (ksi)	Mean Value ($\bar{s}_{ys}$) (ksi)	Upper Limit (UL) (ksi)
A-basis	39.9	42.0[53]	44.1
B-basis	37.8	42.0[53]	46.2

[53] Fawaz, S. A. "Equivalent Initial Flaw Size Testing and Analysis," AFRL-VA-TR-2000-3024, Air Force Research Laboratory, Air Vehicles Directorate, Air Force Materiel Command, Wright-Patterson Air Force Base, OH 45433, 29.

Table 9. Maximum Relative Differences in Fatigue Life (percent)

A-basis		B-basis		Most Sensitive Load Interaction Model
LL vs. $\bar{s}_{ys}$	UL vs. $\bar{s}_{ys}$	LL vs. $\bar{s}_{ys}$	UL vs. $\bar{s}_{ys}$	
5.48	3.34	10.32	6.43	Wheeler

Although the effect of the yield stress on the load interaction models is small, as shown by Table 9, recall that the difference between the load interaction models for a given yield stress remains quite significant (see Figures 33 through 35).

In the second set of analyses, the yield stress was used as a failure criterion. If $S_{net} \geq s_{ys}$, failure is assumed to have occurred. For brevity, only the smallest initial flaw size was used, $c_i = 0.005$ inch, since whether the net section stress exceeds the yield stress is not dependent on initial flaw size. The same range in yield stress values as shown in Table 8 was used here. As can be seen in Figure 43, the yield stress has a significant affect on the fatigue life for the higher stress levels. A simple example can be instructive. For a given crack length and applied stress (net section stress is proportional to the applied stress) and an upper limit yield stress value, the structure does not fail since the $S_{net} \geq s_{ys}$ is not met. However, for the same crack length and applied stress with the lower limit yield stress value, the structure does fail ($S_{net} \geq s_{ys}$) since although the net section stress is the same, the yield stress is lower.

The number of cycles at failure is used in determining both the initial and recurring inspection intervals; therefore, variation in the yield stress, although not so important in terms of load interaction models, is quite important in terms of determining when the structure fails. Fortunately for transport aircraft fuselage skins, the variation in the yield stress is not important since the operating stresses are less than 20 ksi, above which the effect of the yield stress value becomes considerable. For fighter-type aircraft, much of the primary structure is stressed near and sometimes above the yield stress; therefore, the yield stress value has a large affect on initial and recurring inspection intervals.

3.7. Fracture Toughness

Somewhat similar to the yield stress investigations above, the fracture toughness influences structural failure. The stress state, plane stress or plane strain, of the structure is not known a priori and is calculated by AFGROW using K_{max} and specimen thickness for each applied load/stress cycle.[54] Once the stress state is known, the appropriate fracture toughness, plane strain (K_{Ic}) or plane stress (K_c), is chosen. The values used in this investigation are shown in Table 10. The fracture toughness of a material is a quasi-material property in that it is dependent not only on the material type but also on the geometry and thickness of the material. The analyses were stopped when the applied

[54] Harter, James A., "AFGROW Users Guide and Technical Manual," AFRL-VA-WP-TR-1999-3016, February 1999, 114.

stress intensity exceeded the fracture toughness ($K_{app} \geq K_c$). Here K_c is used generically to indicate the fracture toughness as a function of the specimen thickness. For both analyses, the DTCH scenario was used.

For all three initial flaw assumptions, c_i = 0.005, 0.02, and 0.05 inch, and for all load interaction models, the fracture toughness, range of values shown in Table 10, does not

Table 10. Range of Plane Stress and Strain Fracture Toughness Values

	K_c LL (ksi√in)	$\overline{K}_c$ (ksi√in)	K_c UL (ksi√in)	K_{Ic} LL (ksi√in)	$\overline{K}_{Ic}$ (ksi√in)	K_{Ic} UL (ksi√in)
A-basis	33.25	35.0[53]	36.75	59.64	62.78[53]	65.92
B-basis	31.25	35.0[53]	38.50	56.50	62.78[53]	69.05

have a significant effect on the fatigue life. The maximum relative difference between the mean A- and B-basis values and LL and UL values was -0.63 to 1.20 percent and occurred at the highest two stress levels, 30 and 35 ksi. The fatigue lives for the analyses with the higher stress levels is small; therefore, any change in the K_{Ic} or K_c and the resulting change in the fatigue life has a larger impact on the relative difference. In addition, the analyses were insensitive to changes in K_{Ic}, indicating the stress state of the specimen was plane stress.

3.8. Threshold Stress Intensity Factor Range

The threshold stress intensity factor range, DK_{th}, affects DADTAs in two ways; one, in the load interaction model, as is the case with the Willenborg model, or two, in the crack growth equation. Willenborg uses DK_{th} to calculate a reduction factor used to reduce the K value due to the yield zone in front of the crack tip (for additional information see reference 55). In the crack growth law, the applied DK must exceed the DK_{th}; otherwise the crack will not propagate. Thus, small changes in the DK_{th} may determine whether or not the structure is fatigue critical. The values used in this investigation are shown in Table 11. The analyses were stopped when the applied stress intensity exceeded the fracture toughness ($K_{app} \geq K_c$). For both analyses, the DTCH crack scenario was used.

For all three initial flaw assumptions, c_i = 0.005, 0.02, and 0.05 inch, and for all load interaction models, the DK_{th} does not have a significant affect on the fatigue life for each of the load interaction models. The maximum relative difference was -1.51 to 1.45 percent for the 2,268 analyses conducted for this parameter. Of course, if larger variation

[55] Willenborg, J., R. M. Engle, and H. A. Wood, "A Crack Growth Retardation Model Using an Effective Stress Concept." AFFDL-TM-71-1-FBR (1971), p. 2.

Table 11. Range of Threshold Stress Intensity Factor Values

	DK_{th} LL (ksi√in)	$\overline{\Delta K}_{th}$ (ksi√in)	DK_{th} UL (ksi√in)
B-basis	0.9264	1.0293[53]	1.1322

in the DK_{th} was possible, the effect might be more significant and the analysis would have to be re-evaluated.

4. Recommendation for Research and Development Resource Allocation

In view of the shrinking USAF R&D budget, the USAF and thus the AFRL can and must focus resource expenditure on those areas that most greatly affect the total life-cycle costs of the current fleet. Based on the parametric analyses completed and described in section 3, certain parameters have a dominant or first order effect with the remaining having a second order or minor effect. The distinction between first and second order effects was based on whether the life-cycle costs could be reduced via a more appropriate inspection schedule or if flight safety was affected. R&D spending on aircraft structural integrity must first focus on the first order parameters and only when they are fully understood should efforts be directed toward the second order parameters. The first order parameters are the initial flaw assumption, boundary correction factor, load interaction models, crack growth rate data, and stress intensity factor (applied stress). The secondary parameters are the yield stress, fracture toughness, and threshold stress intensity factor.

Each aircraft in the USAF active inventory has an ASIP program and generally an engineering services contract between the government and original equipment manufacturer (OEM) to provide support for all ASIP efforts. Depending on the age and size of the fleet, these contracts can be as large as $6 M per year for an individual aircraft type. Money spent in the R&D community can directly reduce these large yearly ASIP contracts. For example, consider fatigue critical locations that have fastener holes. Frequently, due to insufficient NDI capability to detect small cracks. the DTA engineer cannot be sure that only one crack is present. Thus, the DTA engineer has to make an estimate of the correct *K* solution. The prudent engineer will assume that there are two cracks. Using the method described in section 1, the initial and recurring inspections are calculated and listed in Table 12. As a result of the conservative assumption, two cracks versus one crack, the FCL receives two additional inspections. For a small fleet of

Table 12. Effect of K Solution on Inspection Schedule

Cracking Scenario	Fatigue Life (Cycles)	Initial Inspection (Cycles)	Recurring Inspection Interval (Cycles)	Inspection Schedule (Cycles)
SCCH	29,879	14,940	6,172	14,940 21,111 27,283
DCCH	21,411	10,707	2,649	10,707 13,356 16,004 18,653 21,301

aircraft, the two additional inspections do not add a significant amount to the life-cycle cost of the aircraft. However, consider that this inspection may be done on over a 1000 aircraft (C-5A/B, C-141B/C, C-130, C-9, etc.) and possibly at 200 locations.

Furthermore, the NDI technician can complete two inspections per hour, and the cost of his time is conservatively $30 per hour. In this example, the two additional inspections over the life of the fleet adds $6 M to the life-cycle costs. This example considers one type of FCL; typically, aircraft may have hundreds of types of FCLs.

Despite the opportunity to reduce life-cycle costs and increase safety, in FY99 AFRL spent 7 percent, in FY00, 18 percent, and FY01, an estimated 36 percent of their structural sustainment budget, which includes all aging aircraft programs, on the primary parameters. Needless to say, there is ample opportunity to affect the structural integrity of the USAF fleet by spending the necessary money now to meet the aircraft life goals stated in reference 2.

5. Conclusion and Summary

5.1. Summary of Findings

Through this parametric analysis of variables affecting the fatigue life and, thus, structural integrity of new and aging aircraft, the following conclusions are drawn. Only with an automated life prediction program can wide-range parameter studies be completed. AFGROW is the only code in the world with such a capability. Over one million fatigue life predictions were conducted in this effort. Eight parameters were identified that affect the fatigue life: initial flaw assumption, boundary correction factor, load interaction models, crack growth rate data, stress intensity factor, threshold stress intensity factor, yield stress, and critical stress intensity factor. The parameters are classified as primary or secondary based on their affect on the life-cycle costs, inspection schedule, and flight safety.

5.2. Principal Conclusions Restated

Each of the eight parameters and their affect on the fatigue life were thoroughly investigated. The primary factors are the initial flaw assumption, boundary correction factor, load interaction models, crack growth rate data, and stress intensity factor. The secondary parameters are the threshold stress intensity factor, yield stress, and critical stress intensity factor. Unfortunately, the USAF is not spending the necessary R&D money to better understand the effects of the primary parameters, especially in light of the extended service lives of the current fleet.

5.3. Implications of the Study

As a result of the lack of a focused effort on understanding the effects of the primary parameters, the USAF will be faced with one of two situations in the future. One, inappropriate inspection schedules will remain in place for the known fatigue critical locations, resulting in higher life-cycle costs. Two, as the USAF tries to extend the lives of the current fleet, it will not be using the most accurate analytical tools or material data; therefore, the life extension decision will not be as robust as it should. Spending money now investigating the primary parameters will pay manifold dividends in the future and ultimately will increase flight safety.

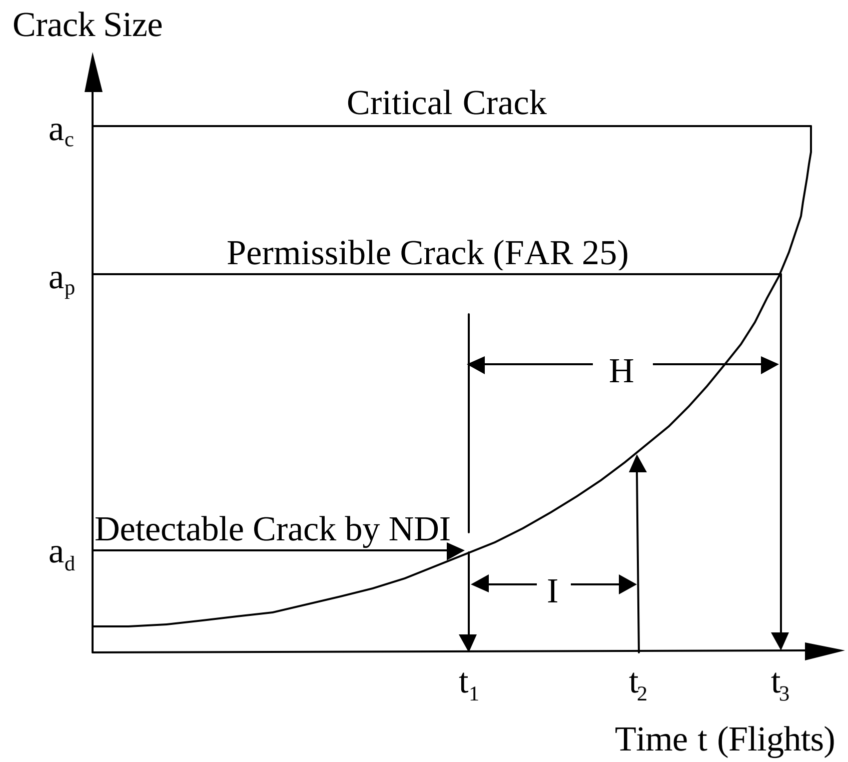


Figure 1. Crack Growth Curve, [5]

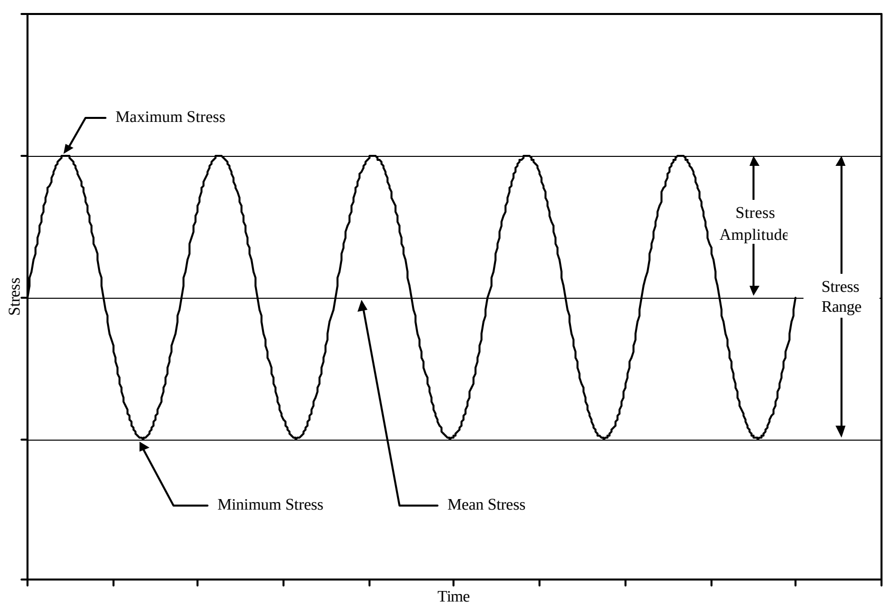


Figure 2. Constant Amplitude Spectrum

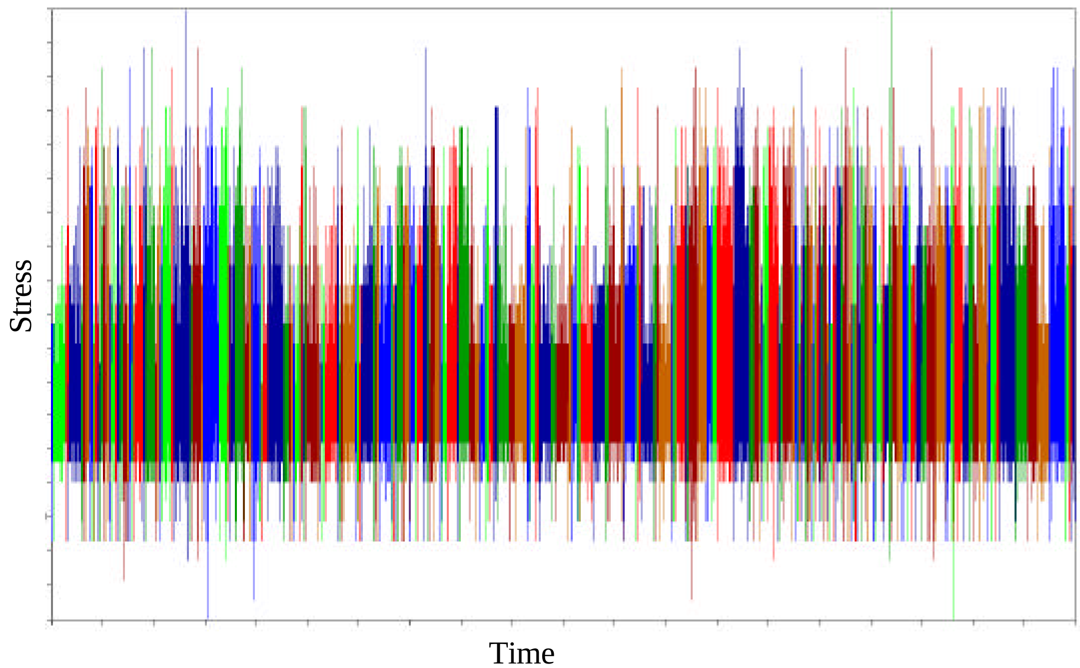


Figure 3. FALSTAFF Variable Amplitude Spectrum

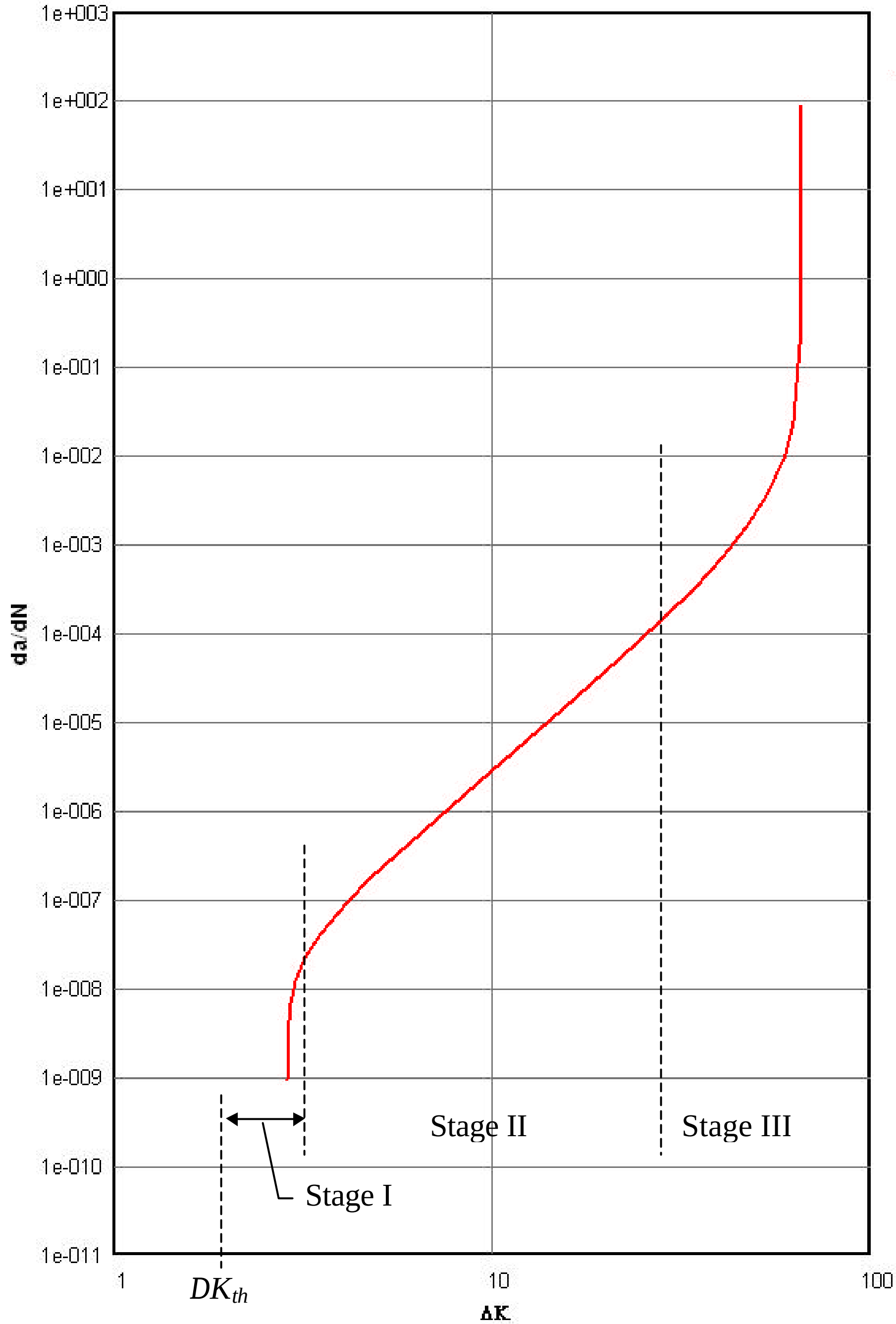


Figure 4. FNK Equation Representation of Crack Growth Rate Curve for 2024-T3 Aluminum Sheet, [10]

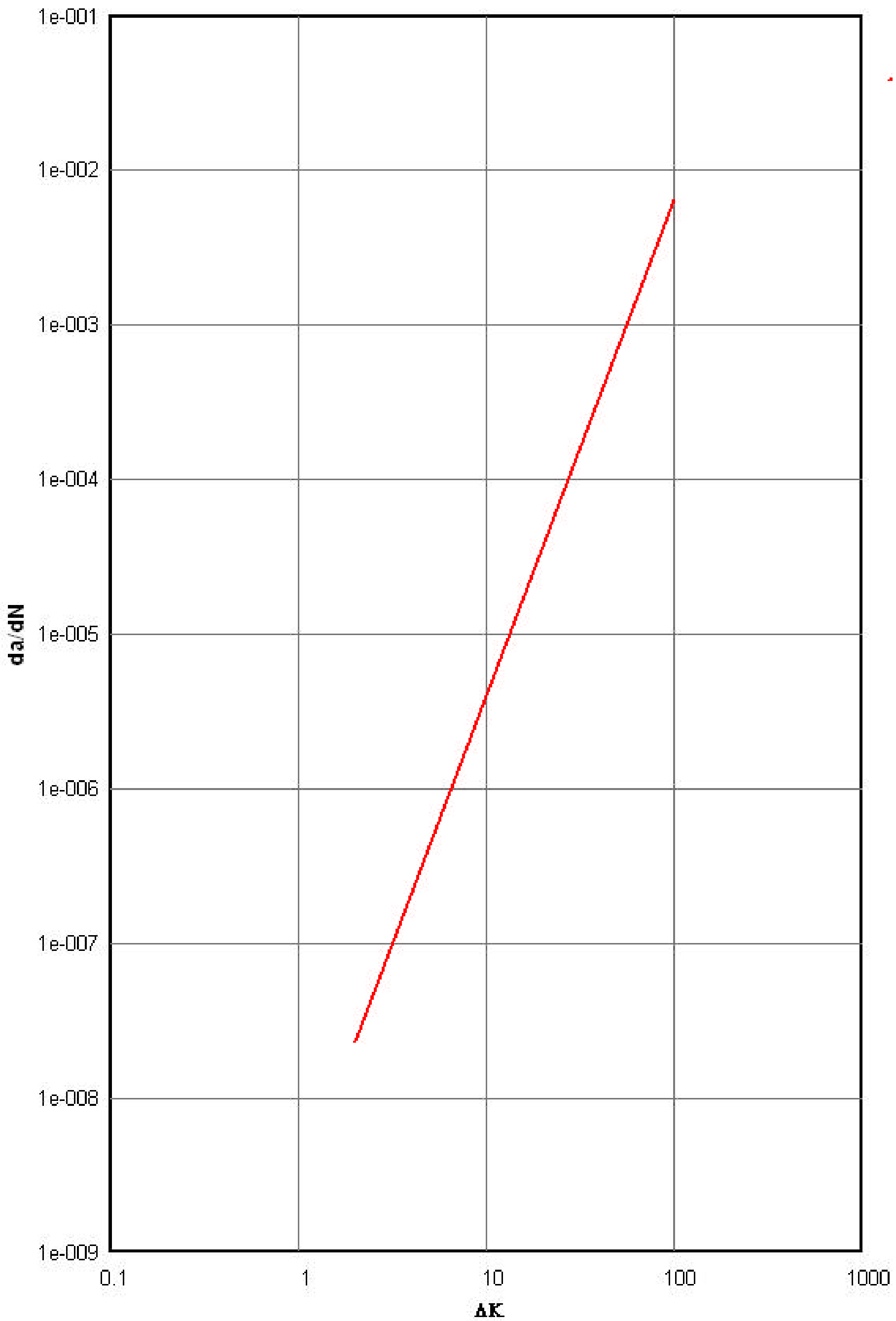


Figure 5. One-Segment Walker Equation Representation of Crack Growth Rate Curve for 2024-T3 Aluminum Sheet, [10]

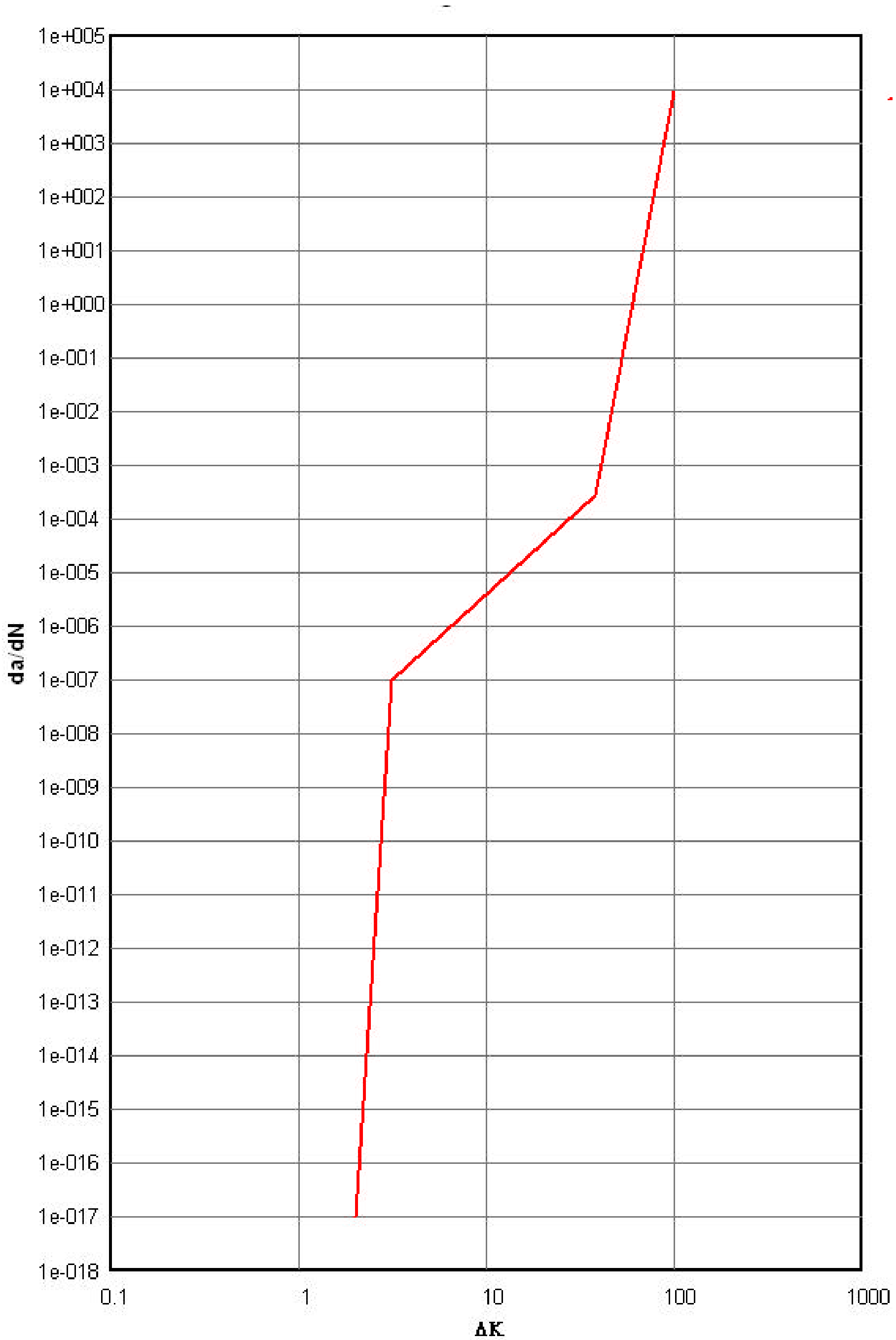


Figure 6. Three-Segment Walker Equation Representation of Crack Growth Rate Curve for 2024-T3 Aluminum Sheet, [10]

Aircraft Operator	Aircraft Type	Current Age Data: Years Since IOC	Current Age Data: Average Age (years)	Future Plans
Air Mobility Command	Airlifter and Tanker Aircraft			
	KC-135	41	35	Retain 25+ years. No replacement identified
	C-5	28	18	Retire C-5A in 10–15 years. No replacement identified
	C-141B	32	29	Retire over next 8 years. Replace with C-17
Air Combat Command	Bomber and Attack Aircraft			
	A-10	20	15	Retain 25+ years. No replacement identified
	B-52H	36	34	Retain 25+ years. No replacement identified
	B-1B	11	9	Retain 25+ years. No replacement identified
	F-15	23	12	Retire in 5–20 years. Replace with F-22
	F-16	18	8	Retire in 10–25 years. Replace with Joint Strike Fighter
	Other Aircraft			
	C-130E/H	36	20	Replace 1/3 over 5–25 years with C-130J
	E-3 (AWACS)	20	16	Retire in 17–25 years. No replacement identified
	E-8 (JSTARS)	0	15–20	Retire in 15–20 years. No replacement identified
	EC/AC-135	40	30–35	Retain 25+ years. No replacement identified
	U-2[a]	40	14	Retire in 15–25 years. No replacement identified
	EC-130E/H	36	20	Retire in 15–25 years. No replacement identified
	EF-111	30	29	Retire within next 4–5 years
Air Education and Training Command	Trainer Aircraft			
	T-37B	38	33	Retire in 2–12 years. Replace with JPATS
	T-38	36	29	Retain 25+ years. No replacement identified

[a]This aircraft was developed for the government and is maintained by the manufacturer rather than by an air logistics center.

Figure 7. USAF Maintained Fixed-Wing Fleet, [2]

Air Force Designation	Commercial Designation	Quantity	Average Age (years)	Operator(s)
E-4	Boeing 747-200	4	23	ACC
VC-25	Boeing 747-200	2	7	AMC
T-43	Boeing 737-200	13	24	ACC and ANG
C-137	Boeing 707-100/300	6	21	AMC
C-18	Boeing 707-323	6	N/A	AFMC, ACC, USAFA
C-22	Boeing 727-100	3	32	ANG
KC-10	McDonnell Douglas DC-10-30F	59	13	AMC
C-9	McDonnell Douglas DC-9-30	23	26	AMC, USAFE, PACAF
C-12	Beechcraft Super King Air 200	37	17	AFMC, PACAF, AETC
T-1A	Beechjet 400A	156	3	AETC
C-21	Learjet 35A	76	13	All commands
C-23	Shorts 330	3	13	AFMC
C-26	Fairchild SA227 Metroliner	40	5	ANG
C-27	Alenia G-222 Model 710A [a]	10	5	ACC
C-20	Gulfstream II, III, IV	13	10	AMC and USAFE
UV-18	Dehaviland DHC-6 Twin Otter	2	20	USAFA
E-9	Dehaviland DHC-8	2	N/A	ACC
T-3	Slingby T67M260 Firefly	112	3	AETC and USAFA

[a] Not a commercial aircraft, but a military transport originally built for the Italian Air Force.

Figure 8. CLS Maintained Fixed-Wing Fleet, [2]

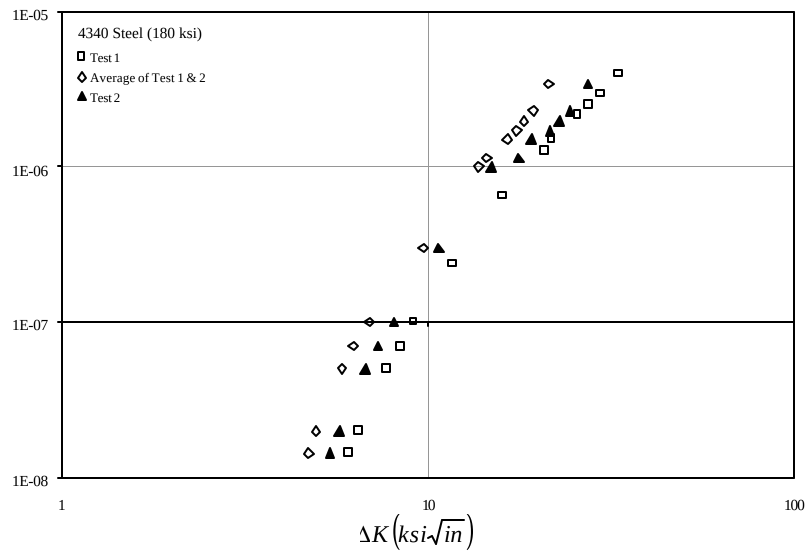


Figure 9. Variations in Crack Growth Rate Data, 4340 Steel

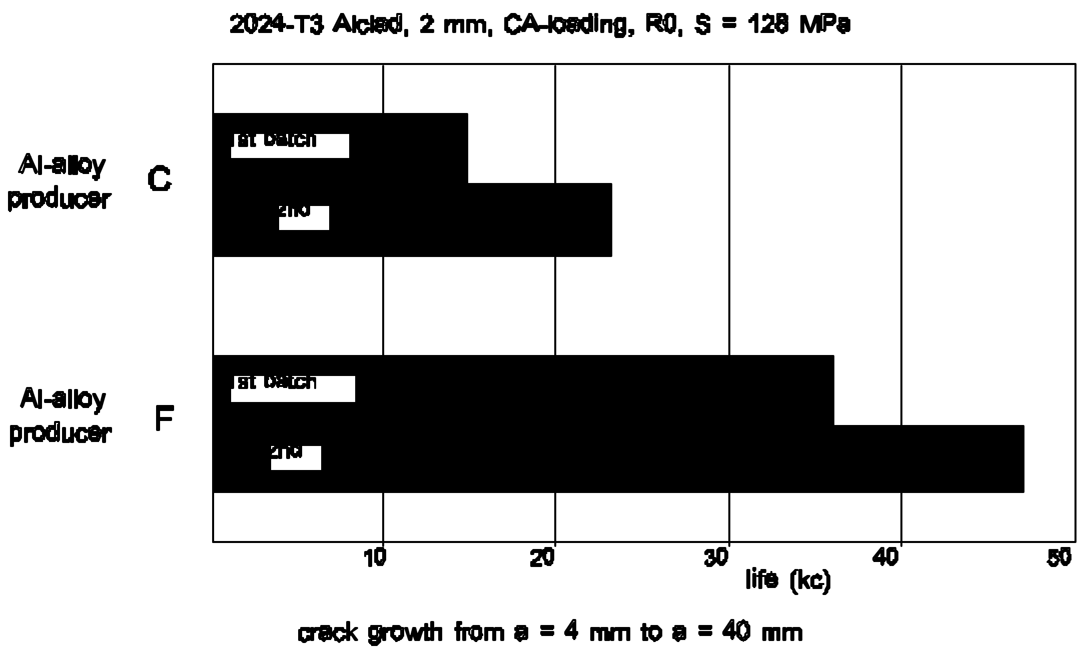
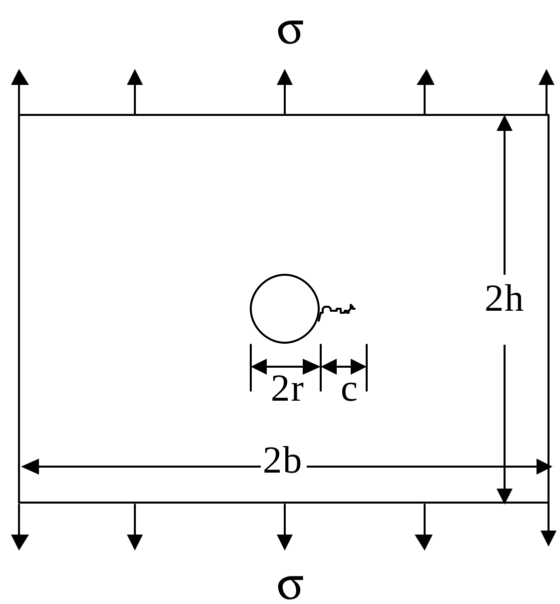
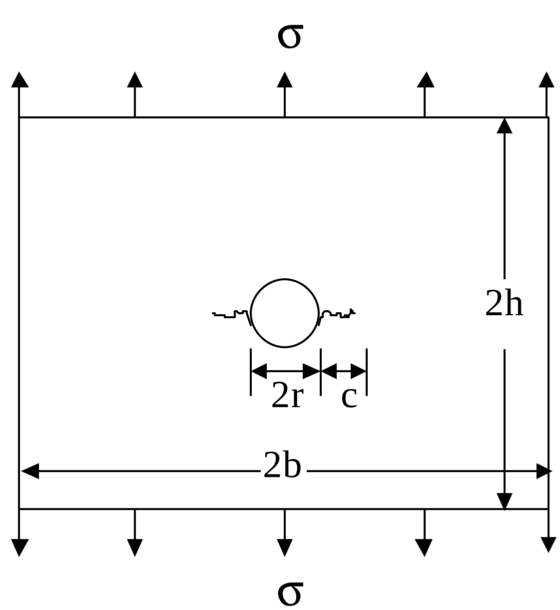


Figure 10. Variation in Fatigue Lives Identical Aluminum Alloy from Different Manufacturers, [36]



r/t = 1.49 t/b = 0.11

Figure 11. Single Crack at a Hole



r/t = 1.49 t/b = 0.011

Figure 12. Double Crack at a Hole

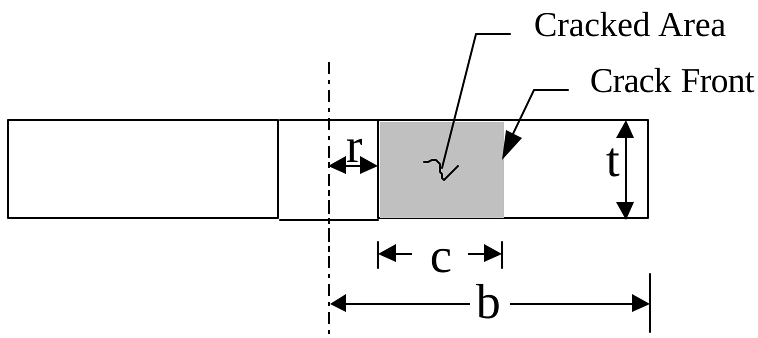


Figure 13. Single Through-Crack at a Hole (STCH)

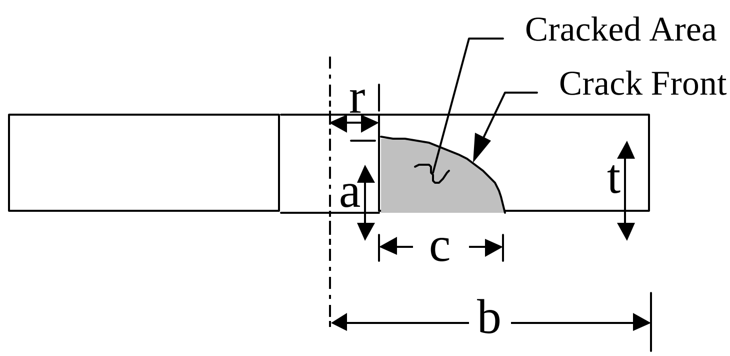


Figure 14. Single Corner Crack at a Hole (SCCH)

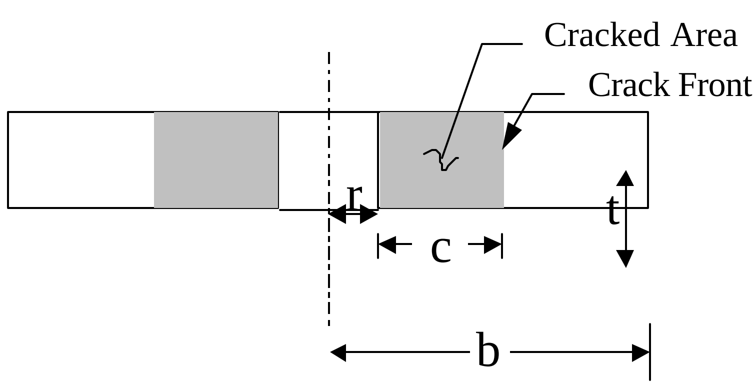


Figure 15. Double Through-Crack at a Hole

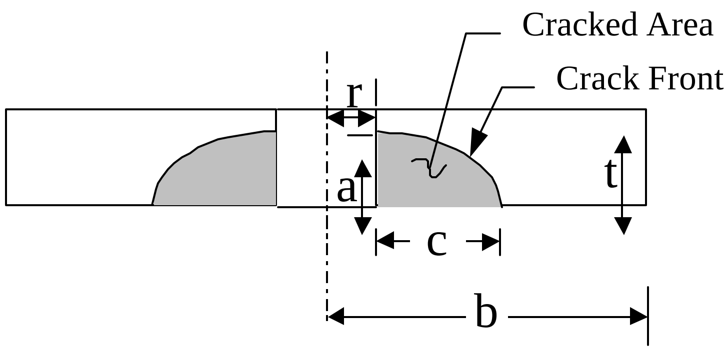


Figure 16. Double Corner Crack at a Hole

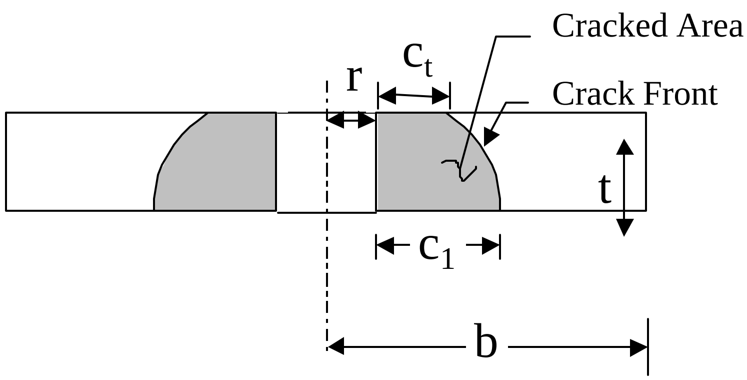


Figure 17. Double Oblique Through-Crack at a Hole

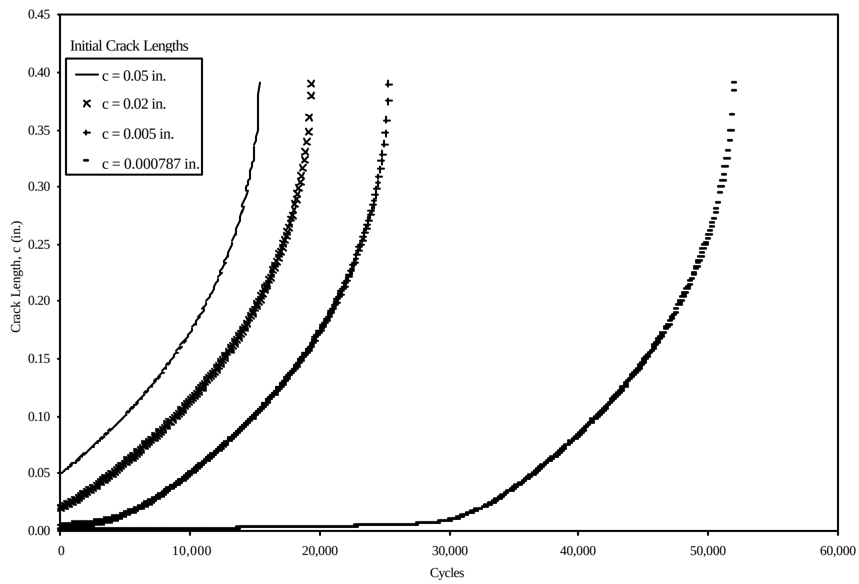


Figure 18. Effect of Initial Flaw Assumption on Fatigue Life

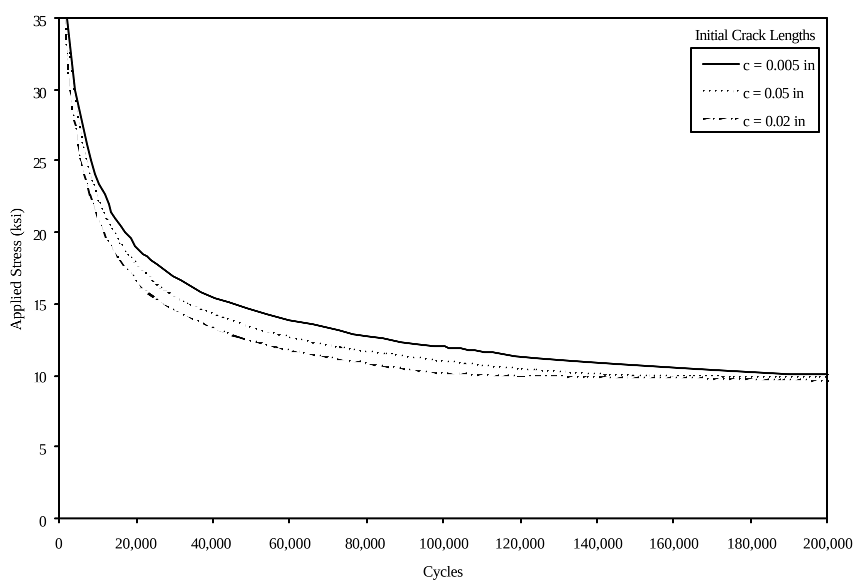


Figure 19. Effect of Initial Flaw Assumption on Fatigue Life (STCH)

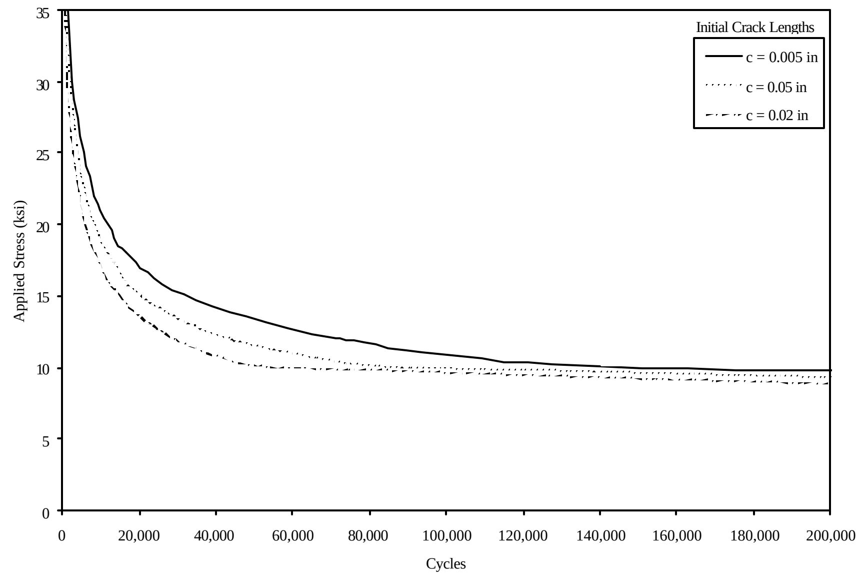


Figure 20. Effect of Initial Flaw Assumption on Fatigue Life (DTCH)

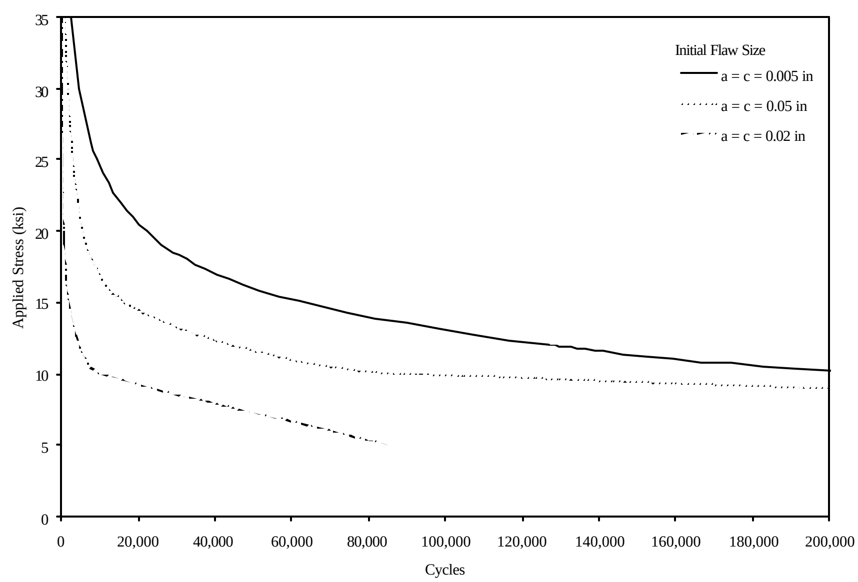


Figure 21. Effect of Initial Flaw Assumption on Fatigue Life (SCCH)

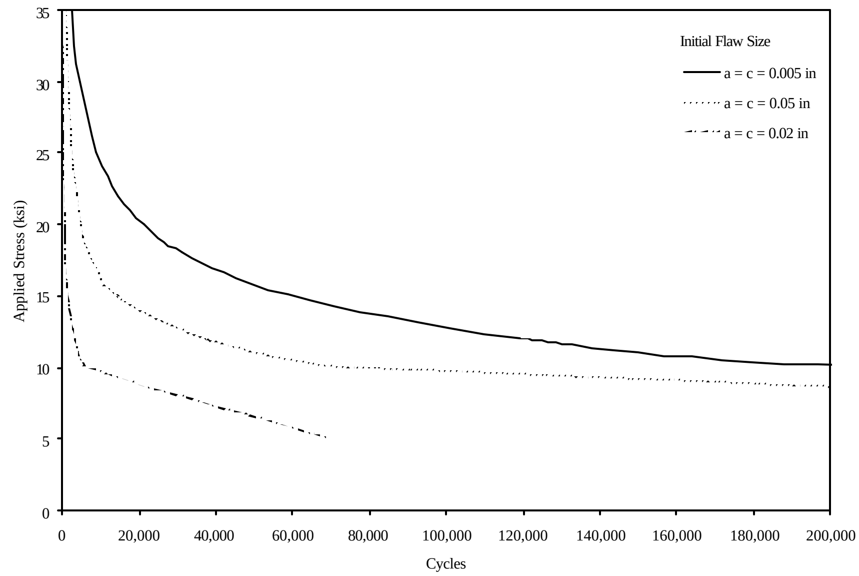


Figure 22. Effect of Initial Flaw Assumption on Fatigue Life (DCCH)

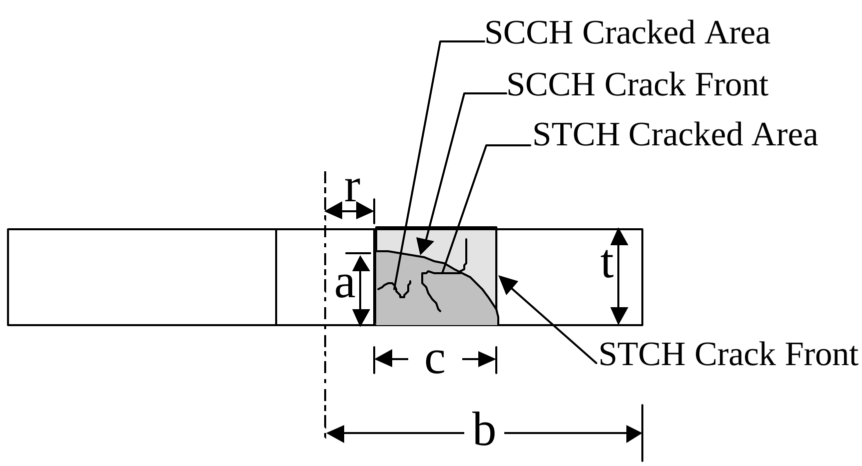


Figure 23. Cracking Scenario sed for Evaluating Effect of Boundary Correction Factor

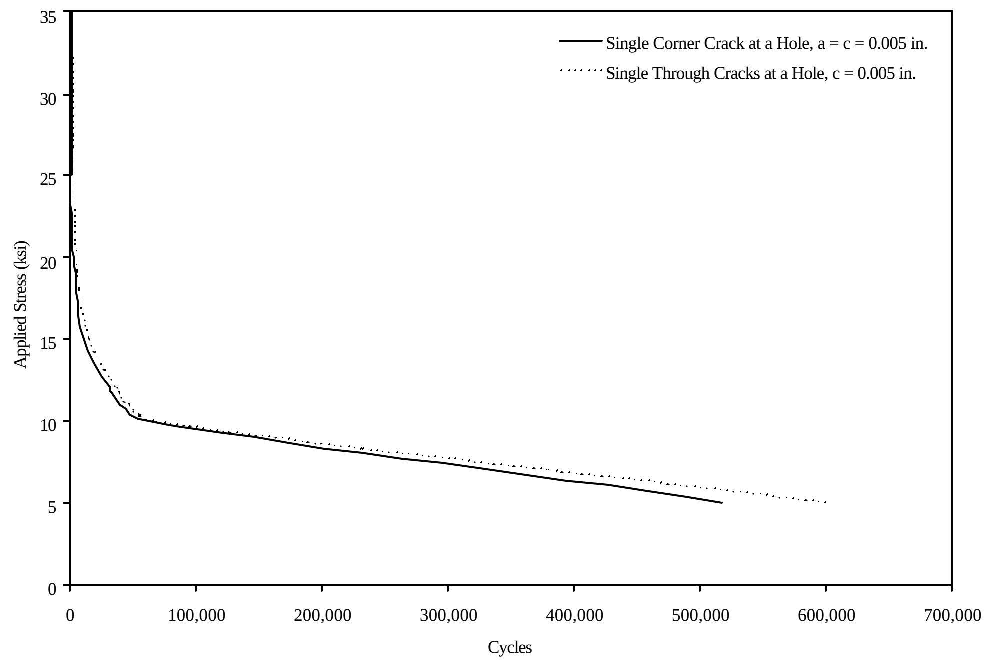


Figure 24. Effect of Initial Flaw Shape, c_i = 0.005 in.

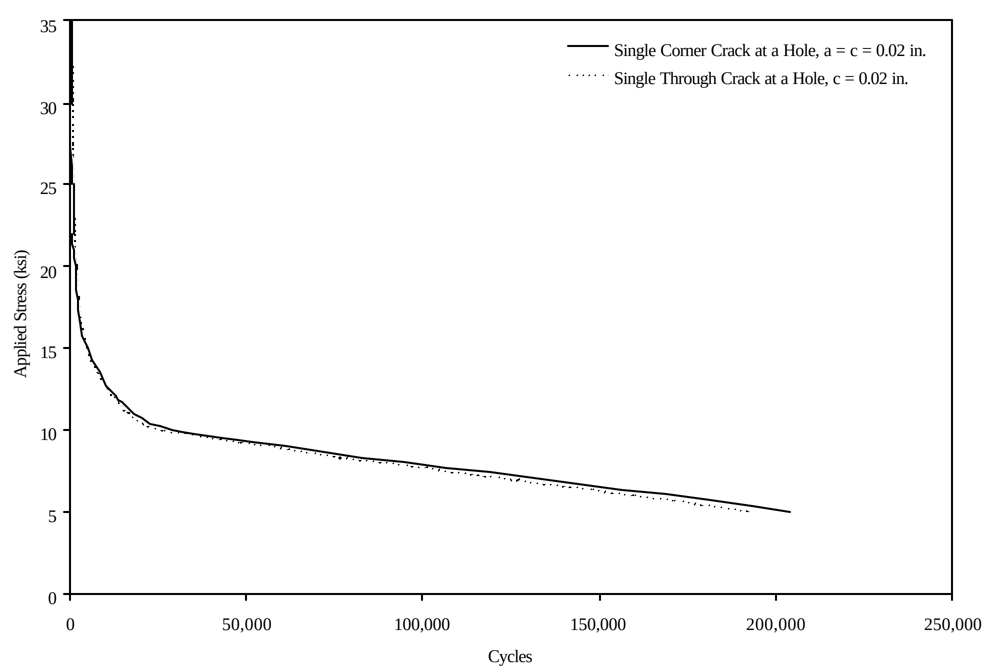


Figure 25. Effect of Initial Flaw Shape, c_i = 0.002 in.

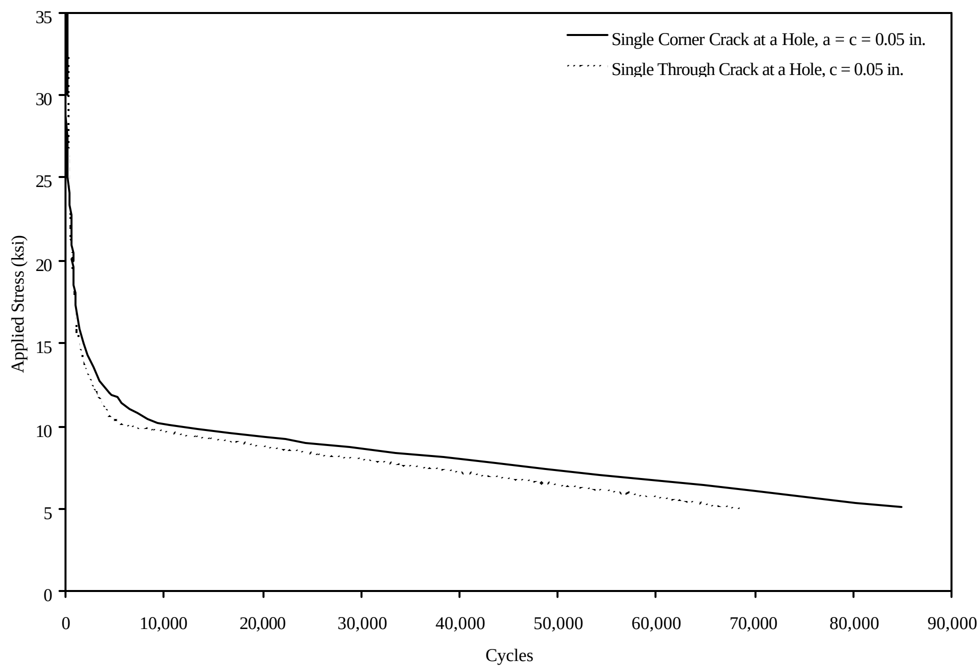


Figure 26. Effect of Initial Flaw Shape, c_i = 0.05 in.

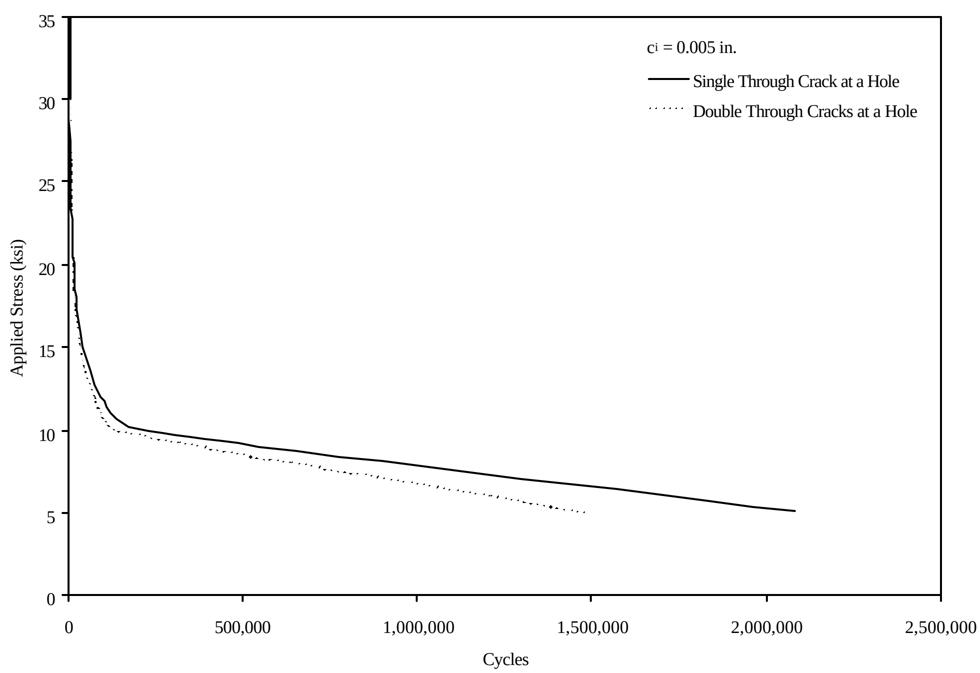


Figure 27. Effect of Through-Crack Continuing Damage, c_i = 0.005 in.

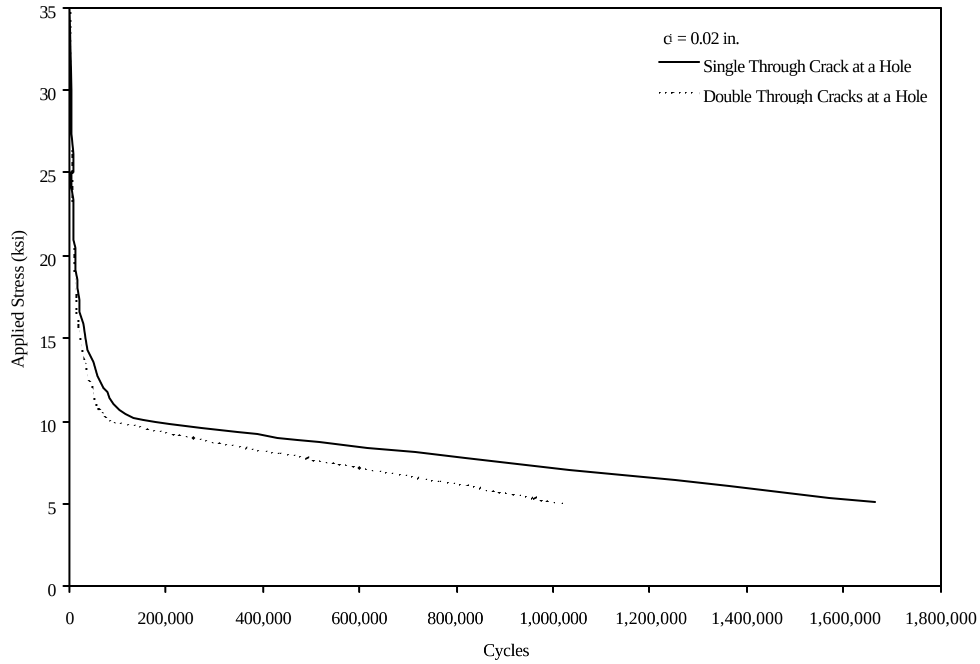


Figure 28. Effect of Through-Crack Continuing Damage, c_i = 0.02 in.

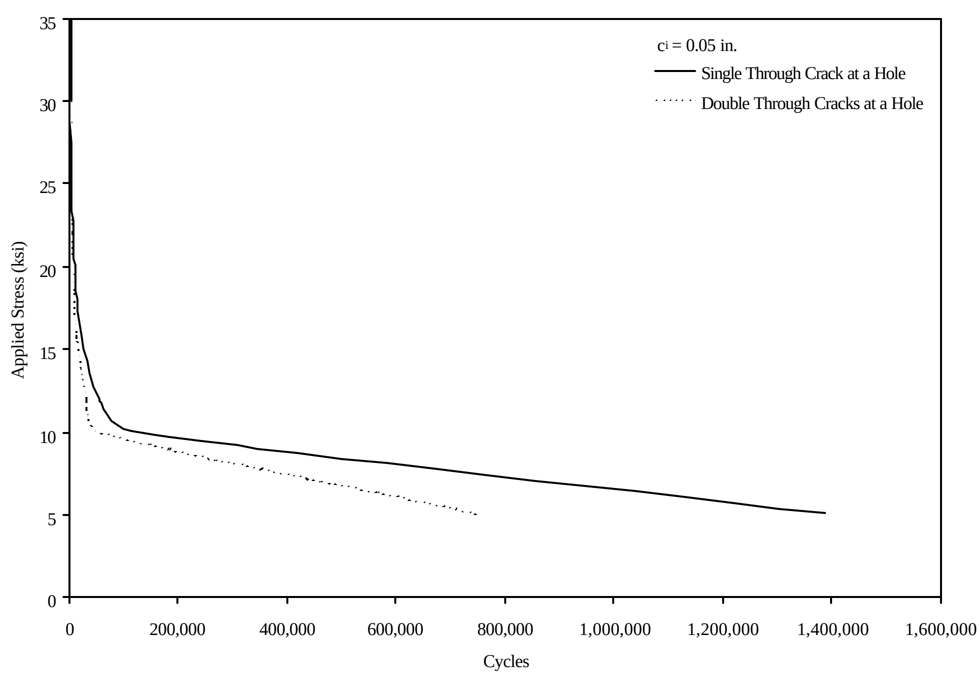


Figure 29. Effect of Through-Crack Continuing Damage, c_i = 0.05 in.

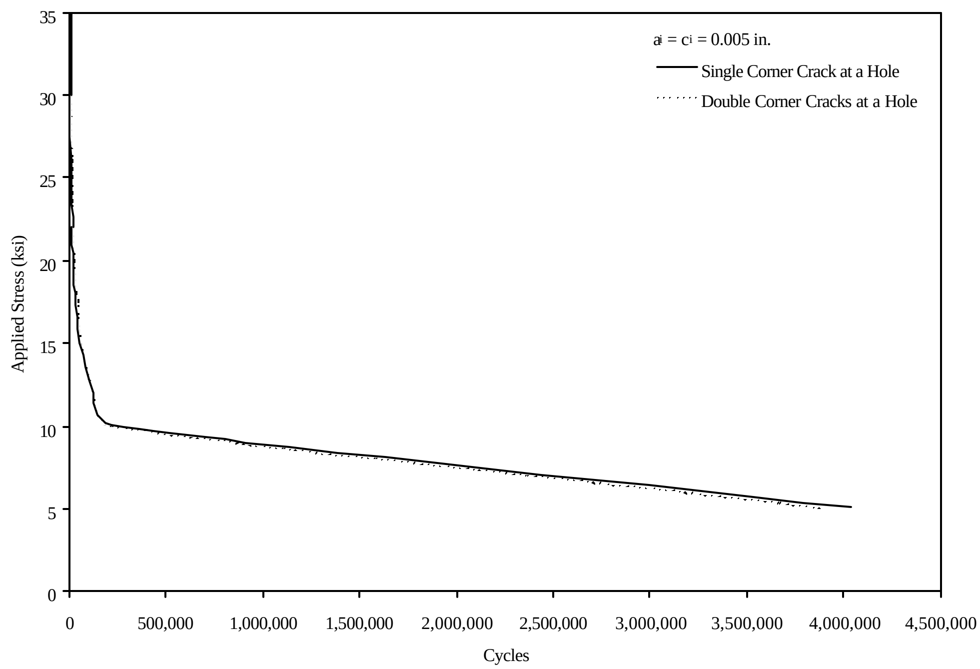


Figure 30. Effect of Corner Crack Continuing Damage, $a_i = c_i$ = 0.005 in.

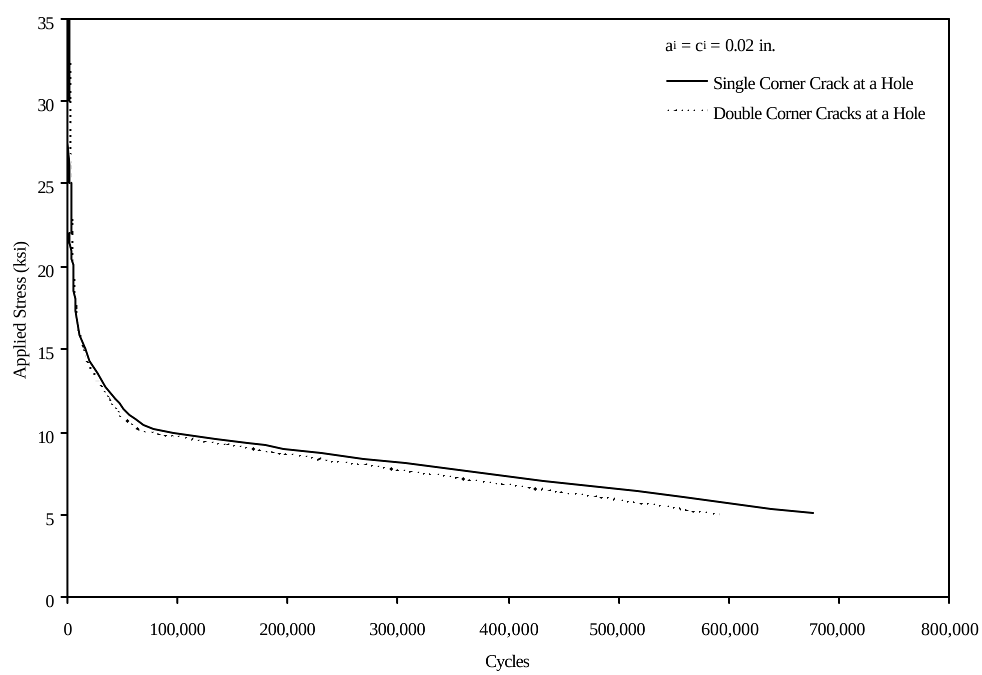


Figure 31. Effect of Corner Crack Continuing Damage, $a_i = c_i$ = 0.02 in.

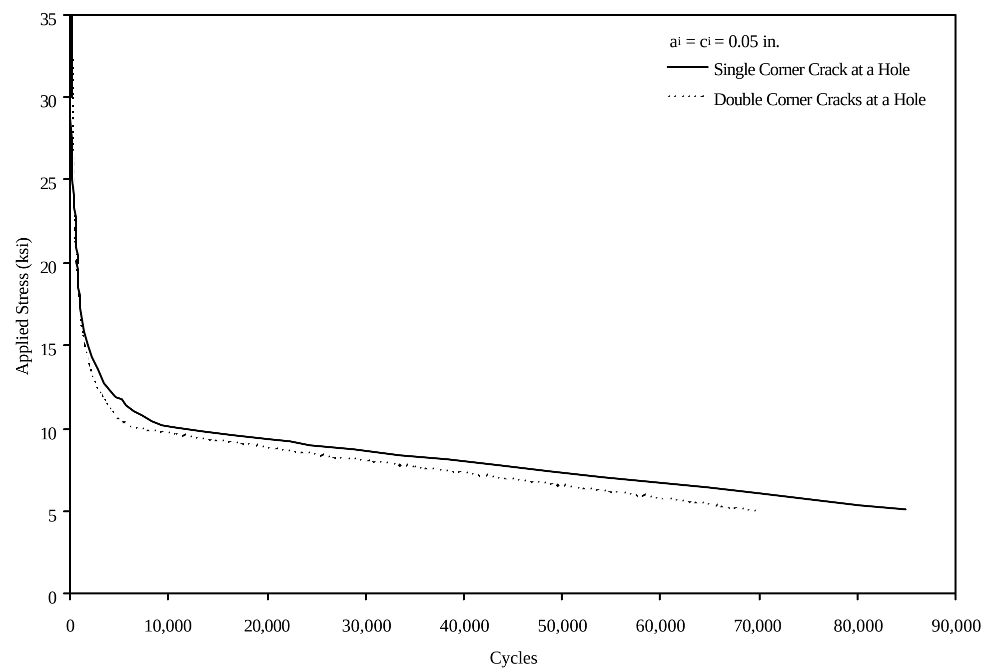


Figure 32. Effect of Corner Crack Continuing Damage, $a_i = c_i = 0.05$ in.

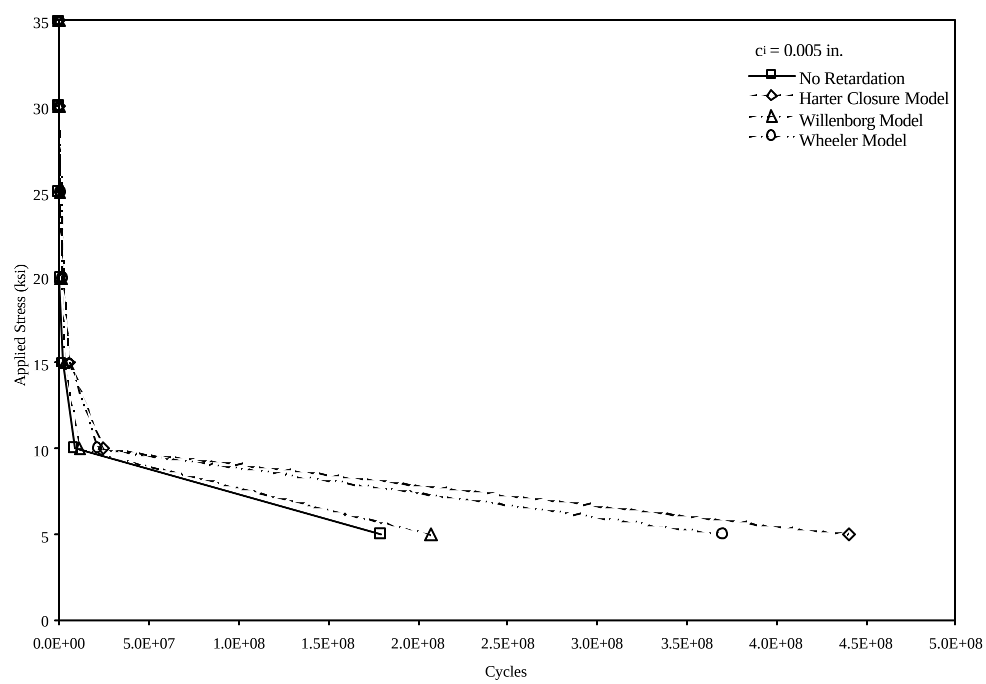


Figure 33. Load Interaction Models, $c_i = 0.005$ in.

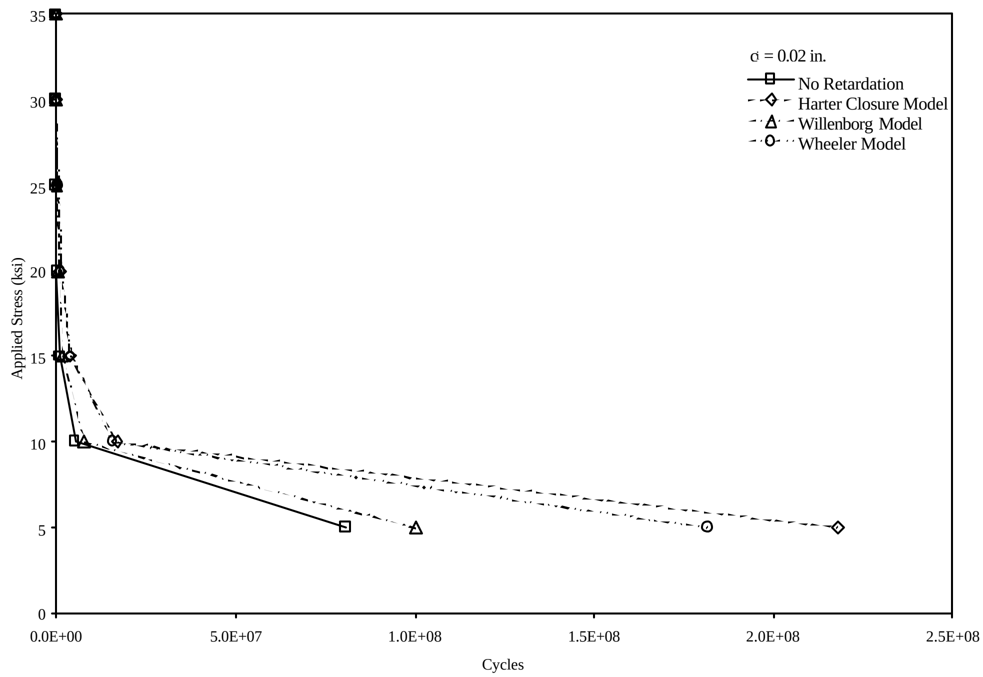


Figure 34. Load Interaction Models, c_i = 0.02 in.

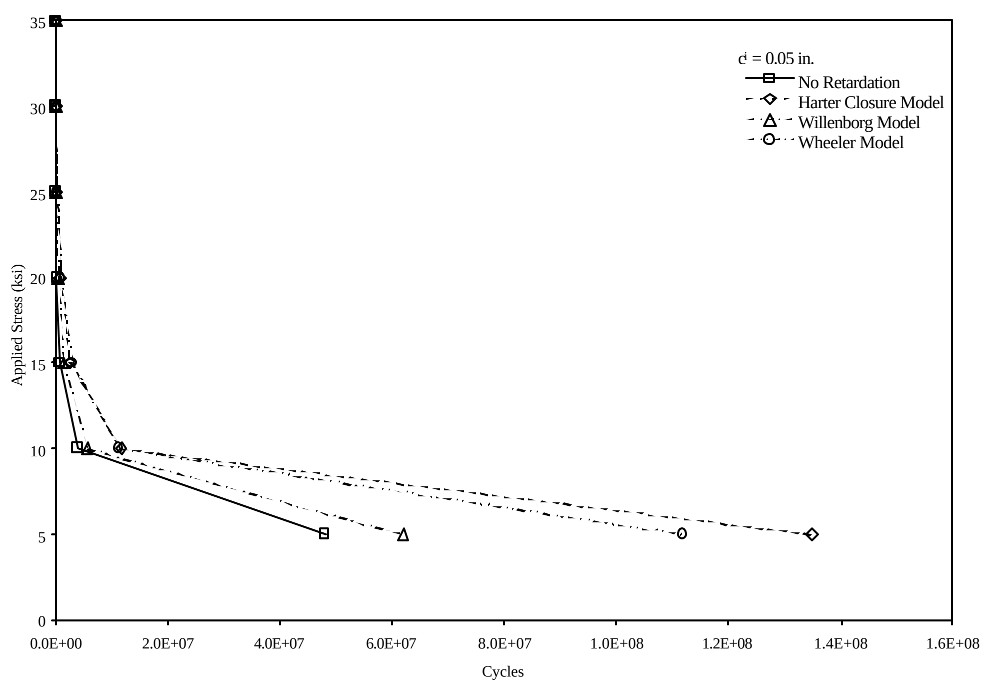


Figure 35. Load Interaction Models, c_i = 0.05 in.

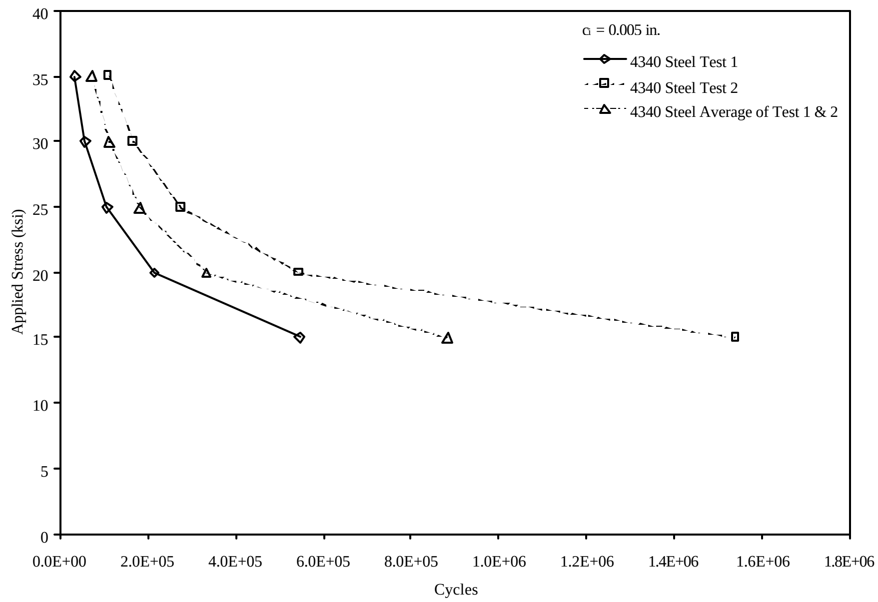


Figure 36. Fatigue Lives Using Varying 180 ksi 4340 Steel Crack Growth Rate Data, c_i = 0.005 in.

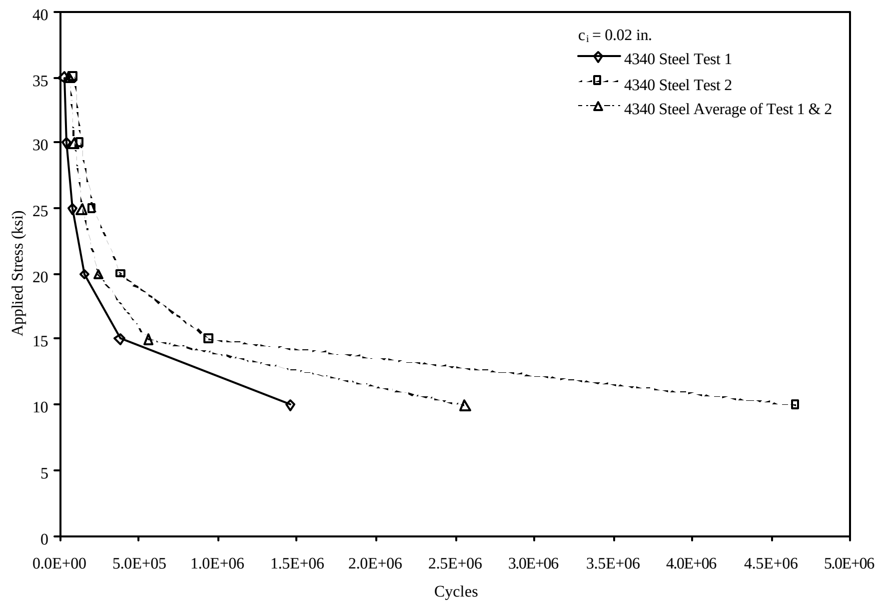


Figure 37. Fatigue Lives Using Varying 180 ksi 4340 Steel Crack Growth Rate Data, c_i = 0.02 in.

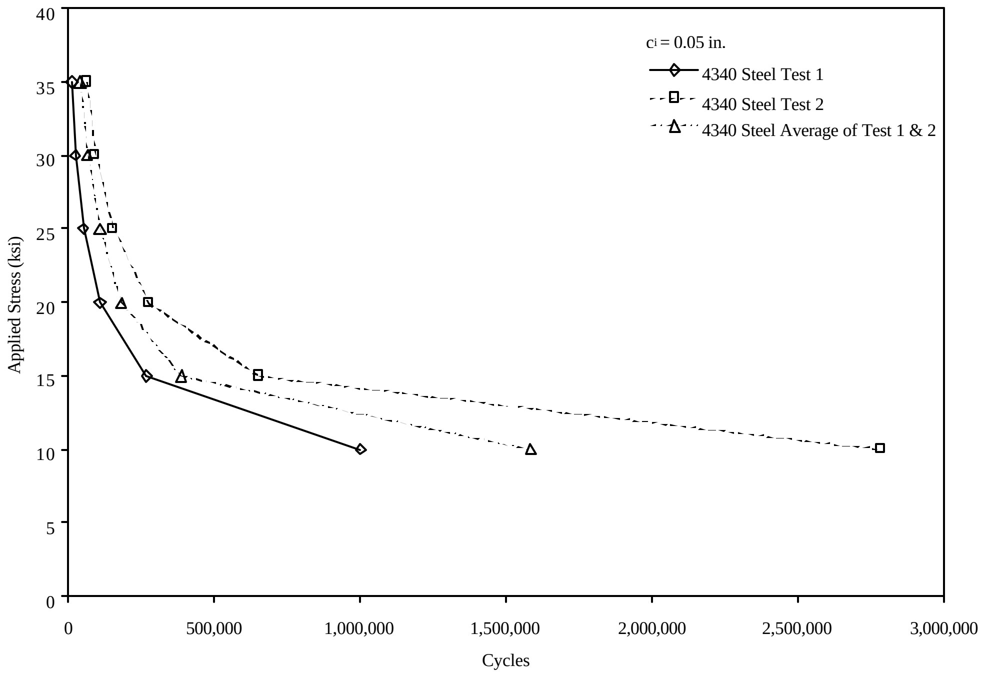


Figure 38. Fatigue Lives Using Varying 180 ksi 4340 Steel Crack Growth Rate Data, c_i = 0.05 in.

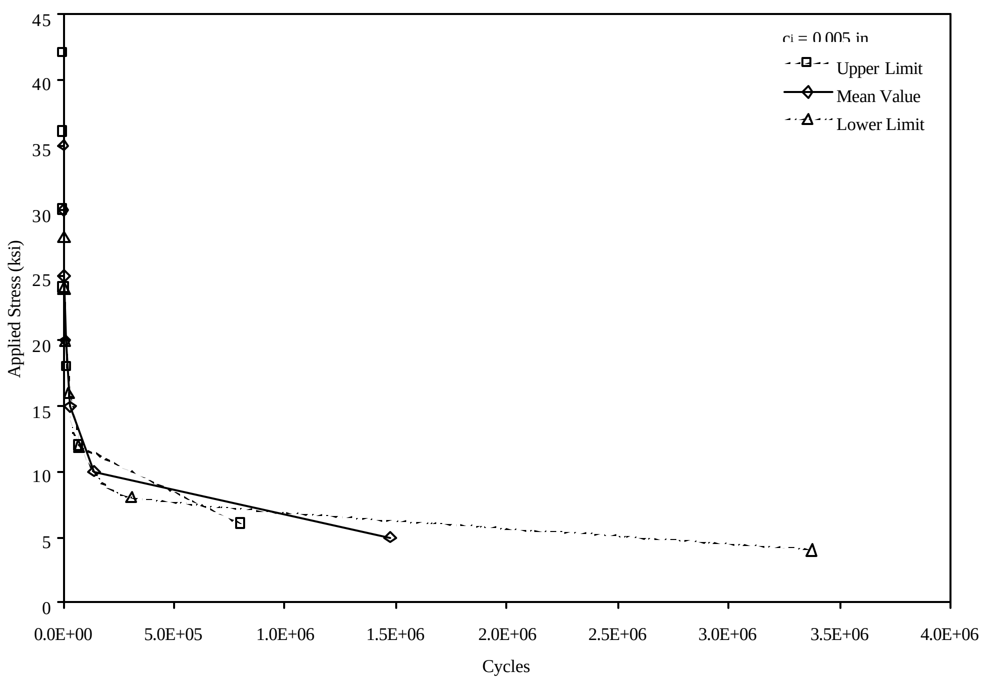


Figure 39. Effect of Variation in the Applied Stress, c_i = 0.005 in.

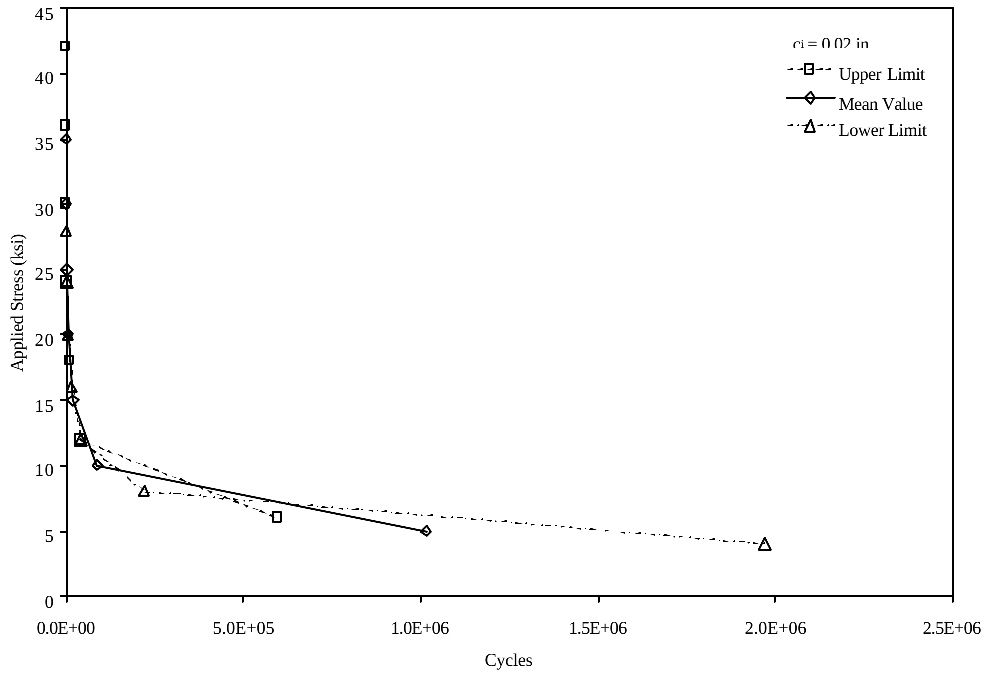


Figure 40. Effect of Variation in the Applied Stress, c_i = 0.02 in.

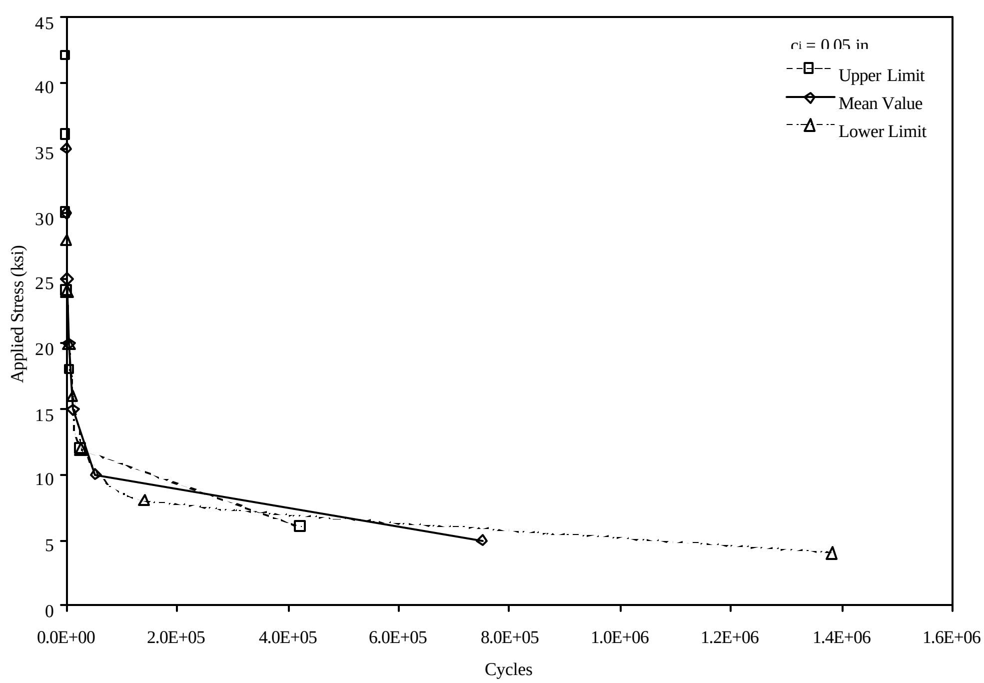


Figure 41. Effect of Variation in the Applied Stress, c_i = 0.05 in.

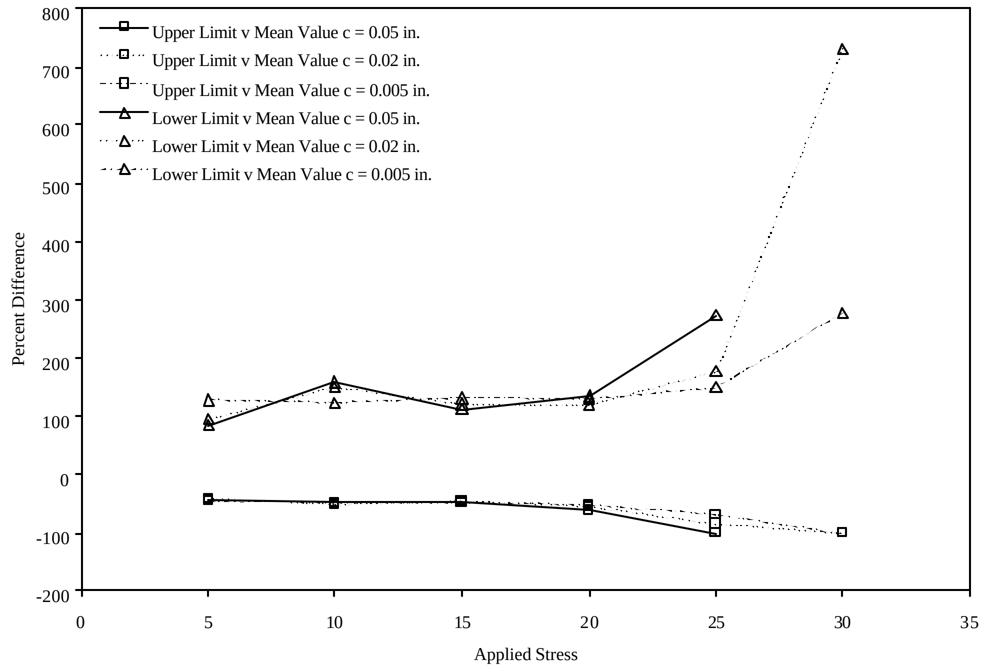


Figure 42. Effect of Variation in the Applied Stress

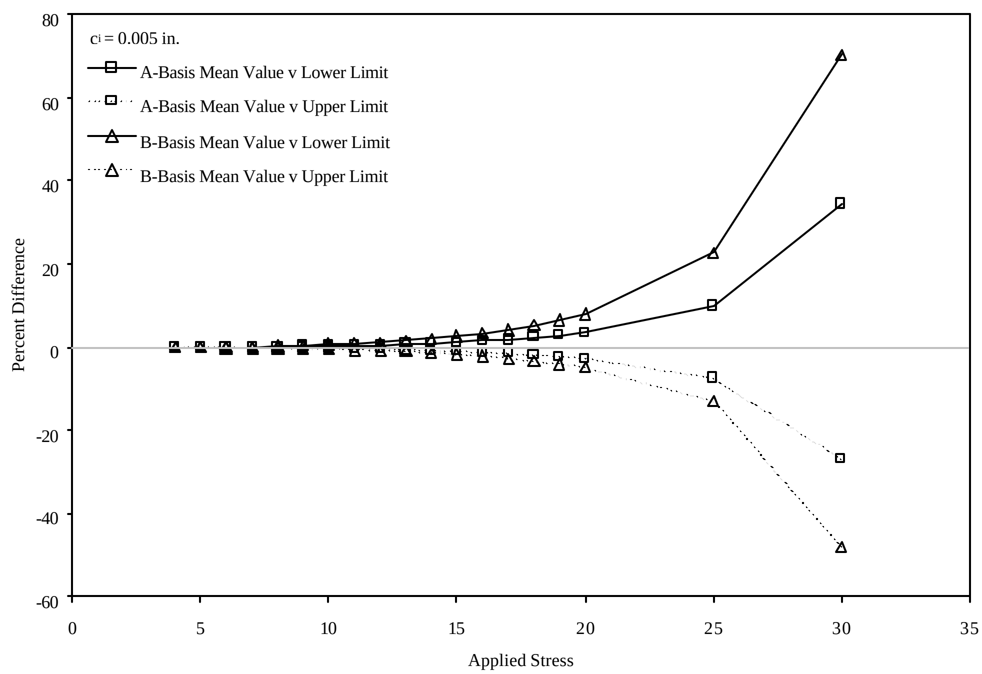


Figure 43. Effect of Variation in the Yield Stress, c_i = 0.005 in.

Appendix: AFGROW Component Object Model (COM) Visual Basic Programming Code

One vs. Two Through-cracks at Hole

```
Public WithEvents mAFGROW As AFGROW.Application


Public prefs As PredictPreferences
Public user_beta As UserDefinedBeta
Public table_lookup As TabularLookupMaterial
Public i As Integer
Public j As Integer
Public k As Integer
Dim W As Double
Dim t As Double
Dim D As Double
Dim Tension As Double
Dim Bending As Double
Dim Bearing As Double
Dim Count As Integer
Dim AArray(2) As Double
Dim CArray(2) As Double
Dim BaArray(2, 2) As Double
Dim BcArray(2, 2) As Double
Dim BTArray(5, 1) As Double
Dim KTable(22, 3) As Double
Dim SpectrumFile As String
```

```
Dim beta_result As Integer

Dim answer As Boolean

Dim NewRun As Boolean


Private Sub mAFGROW_PredictFinished(ByVal result As Integer, ByVal dblCycles As
Double, ByVal dblKc As Double, ByVal dblKa As Double, ByVal dblKct As Double,
ByVal dblC As Double, ByVal dblA As Double, ByVal dblCt As Double)

Sheet1.Cells(i, 7) = dblCycles

Sheet1.Cells(i, 8) = dblC


If result = 0 Then

  Sheet1.Cells(i, 9) = "Completed Normally"

ElseIf result = 1 Then

  Sheet1.Cells(i, 9) = "After one pass of the spectrum, growth was less than 1.0e-13
Program halted"

ElseIf result = 2 Then

  Sheet1.Cells(i, 9) = "Maximum Number of passes exceeded"

ElseIf result = 3 Then

  Sheet1.Cells(i, 9) = "Crack Length Exceeded Stop Value"

ElseIf result = 4 Then

  Sheet1.Cells(i, 9) = "Cycle Count Exceeded Stop Value"

ElseIf result = 10 Then

  Sheet1.Cells(i, 9) = "No Spectrum file specified... Can not Predict"

ElseIf result = 11 Then

  Sheet1.Cells(i, 9) = "Beta table has zero length... Can not Predict"

ElseIf result = 12 Then

  Sheet1.Cells(i, 9) = "Repair patch applied and initiation on...  Can not Predict! "

ElseIf result = 13 Then

  Sheet1.Cells(i, 9) = "Initiation is not allowed with this model. Can not Predict! "

ElseIf result = 14 Then
```

```
  Sheet1.Cells(i, 9) = "NASGRO equation Rhi value is to large"
ElseIf result = 20 Then
  Sheet1.Cells(i, 9) = "Wrong geometry for an oblique crack"
ElseIf result = 21 Then
  Sheet1.Cells(i, 9) = "The initial crack length in the thickness direction is greater than the input thickness.  Check data.."
ElseIf result = 22 Then
  Sheet1.Cells(i, 9) = "Error in spectrum file(s)"
ElseIf result = 23 Then
  Sheet1.Cells(i, 9) = "Unable to open plotfile"
ElseIf result = 24 Then
  Sheet1.Cells(i, 9) = "Error in Initiation. Predict stopped"
ElseIf result = 25 Then
  Sheet1.Cells(i, 9) = "The number of cycles to initiation is greater than 2.e+9. Predict stopped"
ElseIf result = 26 Then
  Sheet1.Cells(i, 9) = "Not enough memory to allocate spectrum"
ElseIf result = 27 Then
  Sheet1.Cells(i, 9) = "Only a BLOCKED spectrum may have more than one (1) cycle per stress level"
ElseIf result = 28 Then
  Sheet1.Cells(i, 9) = "Program termination by user"
ElseIf result = -1 Then
  Sheet1.Cells(i, 9) = "Unknown Error"
End If


Sheet4.Cells(1, 8) = Count
i = i + 1
If Sheet1.Cells(i, 2) > 0 Then
    CurrentBox.Text = CStr(i)
```

```
   Call Run
Else:
    answer = mAFGROW.Quit
    Set mAFGROW = Nothing
    Unload UserForm1
End If
End Sub

Private Sub CommandButton1_Click()
i = CInt(StartBox.Text)
CurrentBox.Text = CStr(i)
Call Run
End Sub

Private Sub CommandButton2_Click()
j = 6
Do While Sheet1.Cells(j, 2) > 0
  Sheet1.Cells(j, 7) = 0
  Sheet1.Cells(j, 8) = 0
  j = j + 1
Loop
End Sub

Private Sub CommandButton3_Click()
    answer = mAFGROW.Quit
    Set mAFGROW = Nothing
    Unload UserForm1
End Sub
```

```
Private Sub mAFGROW_TransitionInfo(ByVal nType As Long, ByVal nReason As Long, ByVal dStress As Double, ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object, ByVal iOutputInfo4 As Object)

Dim iOutput1 As AFGROW.OutputInfoInt

Dim iOutput2 As AFGROW.OutputInfoInt

Set iOutput1 = iOutputInfo1

If Model < 2000 Then Set iOutput2 = iOutputInfo2

NewRun = False

Sheet1.Cells(i, 11) = nType

Sheet1.Cells(i, 12) = dCycles

Sheet1.Cells(i, 13) = iOutput1.dCrackLength

Set iOutput1 = Nothing

End Sub


Private Sub UserForm_Activate()


Dim k As Integer

Dim UseBetaCorrection As Boolean

Dim UseTabularData As Boolean


Set mAFGROW = CreateObject("AFGROW.Application")

Set prefs = mAFGROW.PredictPreferences

Call mAFGROW.PredictPreferences.SetPropagationLimits(False, False, True, False, False, , 1.14, 1000000)

'SpectrumFile = Sheet1.Cells(3, 2)

prefs.bOutputToFile = False

Set user_beta = mAFGROW.UserDefinedBeta

Set table_lookup = mAFGROW.SetTabularLookupMaterial
```

```
mAFGROW.Visible = False

'set the user-defined beta information
UseBetaCorrection = Sheet1.Cells(2, 9)
If (UseBetaCorrection = True) Then
    mAFGROW.Model = uPartThrough
    j = 0
    Do While j < 3
    CArray(j) = Sheet2.Cells(j + 5, 2)
    k = 0
    Do While k < 3
    AArray(k) = Sheet2.Cells(4, k + 3)
    BaArray(j, k) = Sheet2.Cells(j + 5, k + 3)
    BcArray(j, k) = Sheet2.Cells(j + 10, k + 3)
    k = k + 1
    Loop
    j = j + 1
    Loop
    j = 0
    Do While j < 6
    BTArray(j, 0) = Sheet2.Cells(j + 16, 2)
    BTArray(j, 1) = Sheet2.Cells(j + 16, 3)
    j = j + 1
    Loop
    beta_result = user_beta.SetLineaInt(AArray, CArray, BaArray, BcArray)
    Dim middle As Variant
    middle = BTArray
    user_beta.aThroughCrackData = middle
```

```
End If

'Set the crack growth rate data using tabular look-up
UseTabularData = Sheet1.Cells(2, 10)
If (UseTabularData = True) Then
   k = 0
   Do While k < 4
   j = 0
   Do While j < 23
   If (k = 0 And j = 0) Then
      KTable(j, k) = 0#
   Else
      KTable(j, k) = Sheet3.Cells(j + 2, k + 2)
   End If
   j = j + 1
   Loop
   k = k + 1
   Loop
   table_lookup.sMaterialName = Sheet3.Cells(2, 6)
   Dim kVar As Variant
   kVar = KTable
   Call table_lookup.SetData(kVar, Sheet3.Cells(8, 7), Sheet3.Cells(8, 6), Sheet3.Cells(5,
7), Sheet3.Cells(5, 6), Sheet3.Cells(8, 9))
   table_lookup.dKc = Sheet3.Cells(5, 8)
   table_lookup.dKIc = Sheet3.Cells(5, 9)
   table_lookup.dPoissonsRatio = Sheet3.Cells(5, 10)
   table_lookup.dThermalEx = Sheet3.Cells(8, 8)
   table_lookup.dYield = Sheet3.Cells(8, 10)
   table_lookup.dYoungModulus = Sheet3.Cells(8, 11)
```

```
Else
    mAFGROW.SetHarterTMaterial.SetActive (1)

End If
End Sub

Public Sub Run()
mAFGROW.PredictPreferences.bCycleByCycleSpCalc = True
mAFGROW.PredictPreferences.bCycleByCycleBetaCalc = True
mAFGROW.Units = UnitsEnglish
mAFGROW.SMF = Sheet1.Cells(i, 2)
mAFGROW.ConstAmplitudeSpectrum (Sheet1.Cells(i, 3))
mAFGROW.Model = Sheet1.Cells(i, 4)
mAFGROW.CrackLengthC = Sheet1.Cells(i, 6)
Call mAFGROW.SetRetardation(Sheet1.Cells(2, 11), 0, False, False)
'Geometry
W = Sheet1.Cells(2, 2)
t = Sheet1.Cells(2, 3)
D = Sheet1.Cells(2, 4)
Call mAFGROW.SetCrackedPlateWithHoleProp(W, t, D)
'Loads
Tension = Sheet1.Cells(2, 5)
Bending = Sheet1.Cells(2, 6)
Bearing = Sheet1.Cells(2, 7)
Call mAFGROW.SetLoad(Tension, Bending, Bearing)
prefs.sOutputFileName = Sheet1.Cells(i, 10)
NewRun = True
answer = mAFGROW.RunPredict
```

End Sub

One vs. Two Through-cracks at Hole

```
Public WithEvents mAFGROW As AFGROW.Application
Public prefs As PredictPreferences
Public user_beta As UserDefinedBeta
Public table_lookup As TabularLookupMaterial
Public i As Integer
Public j As Integer
Public k As Integer
Dim W As Double
Dim t As Double
Dim D As Double
Dim Tension As Double
Dim Bending As Double
Dim Bearing As Double
Dim Count As Integer
Dim AArray(2) As Double
Dim CArray(2) As Double
Dim BaArray(2, 2) As Double
Dim BcArray(2, 2) As Double
Dim BTArray(5, 1) As Double
Dim KTable(22, 3) As Double
Dim SpectrumFile As String
Dim beta_result As Integer
Dim answer As Boolean
Dim NewRun As Boolean
```

```
Private Sub mAFGROW_PredictFinished(ByVal result As Integer, ByVal dblCycles As
Double, ByVal dblKc As Double, ByVal dblKa As Double, ByVal dblKct As Double,
ByVal dblC As Double, ByVal dblA As Double, ByVal dblCt As Double)

Sheet1.Cells(i, 7) = dblCycles

Sheet1.Cells(i, 8) = dblC


If result = 0 Then

  Sheet1.Cells(i, 9) = "Completed Normally"

ElseIf result = 1 Then

  Sheet1.Cells(i, 9) = "After one pass of the spectrum, growth was less than 1.0e-13
Program halted"

ElseIf result = 2 Then

  Sheet1.Cells(i, 9) = "Maximum Number of passes exceeded"

ElseIf result = 3 Then

  Sheet1.Cells(i, 9) = "Crack Length Exceeded Stop Value"

ElseIf result = 4 Then

  Sheet1.Cells(i, 9) = "Cycle Count Exceeded Stop Value"

ElseIf result = 10 Then

  Sheet1.Cells(i, 9) = "No Spectrum file specified... Can not Predict"

ElseIf result = 11 Then

  Sheet1.Cells(i, 9) = "Beta table has zero length... Can not Predict"

ElseIf result = 12 Then

  Sheet1.Cells(i, 9) = "Repair patch applied and initiation on...  Can not Predict! "

ElseIf result = 13 Then

  Sheet1.Cells(i, 9) = "Initiation is not allowed with this model. Can not Predict! "

ElseIf result = 14 Then

  Sheet1.Cells(i, 9) = "NASGRO equation Rhi value is to large"

ElseIf result = 20 Then

  Sheet1.Cells(i, 9) = "Wrong geometry for an oblique crack"

ElseIf result = 21 Then
```

```
  Sheet1.Cells(i, 9) = "The initial crack length in the thickness direction is greater than the input thickness.  Check data.."

ElseIf result = 22 Then

  Sheet1.Cells(i, 9) = "Error in spectrum file(s)"

ElseIf result = 23 Then

  Sheet1.Cells(i, 9) = "Unable to open plotfile"

ElseIf result = 24 Then

  Sheet1.Cells(i, 9) = "Error in Initiation. Predict stopped"

ElseIf result = 25 Then

  Sheet1.Cells(i, 9) = "The number of cycles to initiation is greater than 2.e+9. Predict stopped"

ElseIf result = 26 Then

  Sheet1.Cells(i, 9) = "Not enough memory to allocate spectrum"

ElseIf result = 27 Then

  Sheet1.Cells(i, 9) = "Only a BLOCKED spectrum may have more than one (1) cycle per stress level"

ElseIf result = 28 Then

  Sheet1.Cells(i, 9) = "Program termination by user"

ElseIf result = -1 Then

  Sheet1.Cells(i, 9) = "Unknown Error"

End If


Sheet4.Cells(1, 8) = Count

i = i + 1

If Sheet1.Cells(i, 2) > 0 Then

   CurrentBox.Text = CStr(i)

   Call Run

Else:

   answer = mAFGROW.Quit

   Set mAFGROW = Nothing
```

```
    Unload UserForm1
End If
End Sub

Private Sub CommandButton1_Click()
i = CInt(StartBox.Text)
CurrentBox.Text = CStr(i)
Call Run
End Sub

Private Sub CommandButton2_Click()
j = 6
Do While Sheet1.Cells(j, 2) > 0
  Sheet1.Cells(j, 7) = 0
  Sheet1.Cells(j, 8) = 0
  Sheet1.Cells(j, 11) = " "
  Sheet1.Cells(j, 12) = 0
  Sheet1.Cells(j, 13) = 0
  Sheet1.Cells(j, 14) = 0
  j = j + 1
Loop
End Sub

Private Sub CommandButton3_Click()
    answer = mAFGROW.Quit
    Set mAFGROW = Nothing
    Unload UserForm1
End Sub
```

```
Private Sub mAFGROW_TransitionInfo(ByVal nType As Long, ByVal nReason As Long, ByVal dStress As Double, ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object, ByVal iOutputInfo4 As Object)

Dim iOutput1 As AFGROW.OutputInfoInt

Dim iOutput2 As AFGROW.OutputInfoInt

Set iOutput1 = iOutputInfo1

If Model < 2000 Then Set iOutput2 = iOutputInfo2

'If NewRun = True Then

'Count = 0

'End If

NewRun = False

'Count = Count + 1

Sheet1.Cells(i, 11) = nType

Sheet1.Cells(i, 12) = dCycles

Sheet1.Cells(i, 13) = iOutput1.dCrackLength

Sheet1.Cells(i, 14) = iOutput2.dCrackLength

'If Model < 2000 Then

'Sheet1.Cells(Count + 1, 14) = iOutput2.dCrackLength

'Sheet1.Cells(Count + 1, 15) = iOutput2.dBeta

'End If

Set iOutput1 = Nothing

End Sub


Private Sub UserForm_Activate()


Dim k As Integer

Dim UseBetaCorrection As Boolean

Dim UseTabularData As Boolean
```

```
Set mAFGROW = CreateObject("AFGROW.Application")
Set prefs = mAFGROW.PredictPreferences
prefs.bOutputToFile = False
Set user_beta = mAFGROW.UserDefinedBeta
Set table_lookup = mAFGROW.SetTabularLookupMaterial
mAFGROW.Visible = False

'set the user-defined beta information
UseBetaCorrection = Sheet1.Cells(2, 9)
If (UseBetaCorrection = True) Then
    mAFGROW.Model = uPartThrough
    j = 0
    Do While j < 3
    CArray(j) = Sheet2.Cells(j + 5, 2)
    k = 0
    Do While k < 3
    AArray(k) = Sheet2.Cells(4, k + 3)
    BaArray(j, k) = Sheet2.Cells(j + 5, k + 3)
    BcArray(j, k) = Sheet2.Cells(j + 10, k + 3)
    k = k + 1
    Loop
    j = j + 1
    Loop
    j = 0
    Do While j < 6
    BTArray(j, 0) = Sheet2.Cells(j + 16, 2)
    BTArray(j, 1) = Sheet2.Cells(j + 16, 3)
```

```
    j = j + 1
    Loop
    beta_result = user_beta.SetLineaInt(AArray, CArray, BaArray, BcArray)
    Dim middle As Variant
    middle = BTArray
    user_beta.aThroughCrackData = middle
End If

'Set the crack growth rate data using tabular look-up
UseTabularData = Sheet1.Cells(2, 10)
If (UseTabularData = True) Then
    k = 0
    Do While k < 4
    j = 0
    Do While j < 23
    If (k = 0 And j = 0) Then
        KTable(j, k) = 0#
    Else
        KTable(j, k) = Sheet3.Cells(j + 2, k + 2)
    End If
    j = j + 1
    Loop
    k = k + 1
    Loop
    table_lookup.sMaterialName = Sheet3.Cells(2, 6)
    Dim kVar As Variant
    kVar = KTable
    Call table_lookup.SetData(kVar, Sheet3.Cells(8, 7), Sheet3.Cells(8, 6), Sheet3.Cells(5,
7), Sheet3.Cells(5, 6), Sheet3.Cells(8, 9))
```

```
    table_lookup.dKc = Sheet3.Cells(5, 8)
    table_lookup.dKIc = Sheet3.Cells(5, 9)
    table_lookup.dPoissonsRatio = Sheet3.Cells(5, 10)
    table_lookup.dThermalEx = Sheet3.Cells(8, 8)
    table_lookup.dYield = Sheet3.Cells(8, 10)
    table_lookup.dYoungModulus = Sheet3.Cells(8, 11)
Else
    mAFGROW.SetHarterTMaterial.SetActive (1)


End If
End Sub


Public Sub Run()
mAFGROW.PredictPreferences.bCycleByCycleSpCalc = True
mAFGROW.PredictPreferences.bCycleByCycleBetaCalc = True
mAFGROW.Units = UnitsEnglish
mAFGROW.SMF = Sheet1.Cells(i, 2)
mAFGROW.ConstAmplitudeSpectrum (Sheet1.Cells(i, 3))
mAFGROW.Model = Sheet1.Cells(i, 4)
mAFGROW.CrackLengthA = Sheet1.Cells(i, 5)
mAFGROW.CrackLengthC = Sheet1.Cells(i, 6)
Call mAFGROW.SetRetardation(Sheet1.Cells(2, 11), 0, False, False)
If (mAFGROW.Model > 2000) Then
    Call mAFGROW.PredictPreferences.SetPropagationLimits(True, False, True, False,
False, Sheet.cells1(i - 10, 8), 1000000, 1000)
Else
    Call mAFGROW.PredictPreferences.SetPropagationLimits(False, False, True, False,
False, 1.14, 1000000, 1000)
End If
```

```
'Geometry
W = Sheet1.Cells(2, 2)
t = Sheet1.Cells(2, 3)
D = Sheet1.Cells(2, 4)
Call mAFGROW.SetCrackedPlateWithHoleProp(W, t, D)
'Loads
Tension = Sheet1.Cells(2, 5)
Bending = Sheet1.Cells(2, 6)
Bearing = Sheet1.Cells(2, 7)
Call mAFGROW.SetLoad(Tension, Bending, Bearing)
prefs.sOutputFileName = Sheet1.Cells(i, 10)
NewRun = True
answer = mAFGROW.RunPredict
End Sub
```

One Corner vs. One Through-crack at Hole

```
Public WithEvents mAFGROW As AFGROW.Application


Public prefs As PredictPreferences
Public user_beta As UserDefinedBeta
Public table_lookup As TabularLookupMaterial
Public i As Integer
Public j As Integer
Public k As Integer
Dim W As Double
Dim t As Double
Dim D As Double
Dim Tension As Double
Dim Bending As Double
```

```
Dim Bearing As Double
Dim crackstop As Double
Dim AArray(2) As Double
Dim CArray(2) As Double
Dim BaArray(2, 2) As Double
Dim BcArray(2, 2) As Double
Dim BTArray(5, 1) As Double
Dim KTable(22, 3) As Double
Dim SpectrumFile As String
Dim beta_result As Integer
Dim answer As Boolean
Dim NewRun As Boolean


Private Sub mAFGROW_PredictFinished(ByVal result As Integer, ByVal dblCycles As Double, ByVal dblKc As Double, ByVal dblKa As Double, ByVal dblKct As Double, ByVal dblC As Double, ByVal dblA As Double, ByVal dblCt As Double)
Sheet1.Cells(i, 7) = dblCycles
Sheet1.Cells(i, 8) = dblC

If result = 0 Then
  Sheet1.Cells(i, 9) = "Completed Normally"
ElseIf result = 1 Then
  Sheet1.Cells(i, 9) = "After one pass of the spectrum, growth was less than 1.0e-13 Program halted"
ElseIf result = 2 Then
  Sheet1.Cells(i, 9) = "Maximum Number of passes exceeded"
ElseIf result = 3 Then
  Sheet1.Cells(i, 9) = "Crack Length Exceeded Stop Value"
ElseIf result = 4 Then
```

```
  Sheet1.Cells(i, 9) = "Cycle Count Exceeded Stop Value"
ElseIf result = 10 Then
  Sheet1.Cells(i, 9) = "No Spectrum file specified... Can not Predict"
ElseIf result = 11 Then
  Sheet1.Cells(i, 9) = "Beta table has zero length... Can not Predict"
ElseIf result = 12 Then
  Sheet1.Cells(i, 9) = "Repair patch applied and initiation on...  Can not Predict! "
ElseIf result = 13 Then
  Sheet1.Cells(i, 9) = "Initiation is not allowed with this model. Can not Predict! "
ElseIf result = 14 Then
  Sheet1.Cells(i, 9) = "NASGRO equation Rhi value is to large"
ElseIf result = 20 Then
  Sheet1.Cells(i, 9) = "Wrong geometry for an oblique crack"
ElseIf result = 21 Then
  Sheet1.Cells(i, 9) = "The initial crack length in the thickness direction is greater than the
input thickness.  Check data.."
ElseIf result = 22 Then
  Sheet1.Cells(i, 9) = "Error in spectrum file(s)"
ElseIf result = 23 Then
  Sheet1.Cells(i, 9) = "Unable to open plotfile"
ElseIf result = 24 Then
  Sheet1.Cells(i, 9) = "Error in Initiation. Predict stopped"
ElseIf result = 25 Then
  Sheet1.Cells(i, 9) = "The number of cycles to initiation is greater than 2.e+9. Predict
stopped"
ElseIf result = 26 Then
  Sheet1.Cells(i, 9) = "Not enough memory to allocate spectrum"
ElseIf result = 27 Then
  Sheet1.Cells(i, 9) = "Only a BLOCKED spectrum may have more than one (1) cycle per
stress level"
```

```
ElseIf result = 28 Then
  Sheet1.Cells(i, 9) = "Program termination by user"
ElseIf result = -1 Then
  Sheet1.Cells(i, 9) = "Unknown Error"
End If

Sheet4.Cells(1, 8) = Count
i = i + 1
If Sheet1.Cells(i, 2) > 0 Then
    CurrentBox.Text = CStr(i)
    Call Run
Else:
    answer = mAFGROW.Quit
    Set mAFGROW = Nothing
    Unload UserForm1
End If
End Sub

Private Sub CommandButton1_Click()
i = CInt(StartBox.Text)
CurrentBox.Text = CStr(i)
Call Run
End Sub

Private Sub CommandButton2_Click()
j = 6
Do While Sheet1.Cells(j, 2) > 0
  Sheet1.Cells(j, 7) = 0
```

```
  Sheet1.Cells(j, 8) = 0
  Sheet1.Cells(j, 11) = " "
  Sheet1.Cells(j, 12) = 0
  Sheet1.Cells(j, 13) = 0
  Sheet1.Cells(j, 14) = 0
  j = j + 1
Loop
End Sub

Private Sub CommandButton3_Click()
    answer = mAFGROW.Quit
    Set mAFGROW = Nothing
    Unload UserForm1
End Sub

Private Sub mAFGROW_TransitionInfo(ByVal nType As Long, ByVal nReason As
Long, ByVal dStress As Double, ByVal dRStress As Double, ByVal dCycles As Double,
ByVal dPass As Long, ByVal iOutputInfo1 As Object, ByVal iOutputInfo2 As Object,
ByVal iOutputInfo3 As Object, ByVal iOutputInfo4 As Object)
Dim iOutput1 As AFGROW.OutputInfoInt
Dim iOutput2 As AFGROW.OutputInfoInt
Set iOutput1 = iOutputInfo1
If Model < 2000 Then Set iOutput2 = iOutputInfo2
NewRun = False
Sheet1.Cells(i, 11) = nType
Sheet1.Cells(i, 12) = dCycles
Sheet1.Cells(i, 13) = iOutput1.dCrackLength
Sheet1.Cells(i, 14) = iOutput2.dCrackLength
Set iOutput1 = Nothing
End Sub
```

```
Private Sub UserForm_Activate()

Dim k As Integer
Dim UseBetaCorrection As Boolean
Dim UseTabularData As Boolean

Set mAFGROW = CreateObject("AFGROW.Application")
Set prefs = mAFGROW.PredictPreferences
prefs.bOutputToFile = False
Set user_beta = mAFGROW.UserDefinedBeta
Set table_lookup = mAFGROW.SetTabularLookupMaterial
mAFGROW.Visible = False

'set the user-defined beta information
UseBetaCorrection = Sheet1.Cells(2, 9)
If (UseBetaCorrection = True) Then
    mAFGROW.Model = uPartThrough
    j = 0
    Do While j < 3
    CArray(j) = Sheet2.Cells(j + 5, 2)
    k = 0
    Do While k < 3
    AArray(k) = Sheet2.Cells(4, k + 3)
    BaArray(j, k) = Sheet2.Cells(j + 5, k + 3)
    BcArray(j, k) = Sheet2.Cells(j + 10, k + 3)
    k = k + 1
    Loop
```

```
    j = j + 1
    Loop
    j = 0
    Do While j < 6
    BTArray(j, 0) = Sheet2.Cells(j + 16, 2)
    BTArray(j, 1) = Sheet2.Cells(j + 16, 3)
    j = j + 1
    Loop
    beta_result = user_beta.SetLineaInt(AArray, CArray, BaArray, BcArray)
    Dim middle As Variant
    middle = BTArray
    user_beta.aThroughCrackData = middle
End If

'Set the crack growth rate data using tabular look-up
UseTabularData = Sheet1.Cells(2, 10)
If (UseTabularData = True) Then
    k = 0
    Do While k < 4
    j = 0
    Do While j < 23
    If (k = 0 And j = 0) Then
        KTable(j, k) = 0#
    Else
        KTable(j, k) = Sheet3.Cells(j + 2, k + 2)
    End If
    j = j + 1
    Loop
```

```
    k = k + 1
    Loop
    table_lookup.sMaterialName = Sheet3.Cells(2, 6)
    Dim kVar As Variant
    kVar = KTable
    Call table_lookup.SetData(kVar, Sheet3.Cells(8, 7), Sheet3.Cells(8, 6), Sheet3.Cells(5,
7), Sheet3.Cells(5, 6), Sheet3.Cells(8, 9))
    table_lookup.dKc = Sheet3.Cells(5, 8)
    table_lookup.dKIc = Sheet3.Cells(5, 9)
    table_lookup.dPoissonsRatio = Sheet3.Cells(5, 10)
    table_lookup.dThermalEx = Sheet3.Cells(8, 8)
    table_lookup.dYield = Sheet3.Cells(8, 10)
    table_lookup.dYoungModulus = Sheet3.Cells(8, 11)
Else
    mAFGROW.SetHarterTMaterial.SetActive (1)


End If
End Sub


Public Sub Run()
mAFGROW.PredictPreferences.bCycleByCycleSpCalc = True
mAFGROW.PredictPreferences.bCycleByCycleBetaCalc = True
mAFGROW.Units = UnitsEnglish
mAFGROW.SMF = Sheet1.Cells(i, 2)
mAFGROW.ConstAmplitudeSpectrum (Sheet1.Cells(i, 3))
mAFGROW.Model = Sheet1.Cells(i, 4)
mAFGROW.CrackLengthC = Sheet1.Cells(i, 6)
Call mAFGROW.SetRetardation(Sheet1.Cells(2, 11), 0, False, False)
If (mAFGROW.Model > 2000) Then
```

```
  crackstop = Sheet1.Cells(i - 10, 13)
  Call mAFGROW.PredictPreferences.SetPropagationLimits(True, False, True, False,
False, crackstop, 2000, 1000000)
Else
   Call mAFGROW.PredictPreferences.SetPropagationLimits(False, False, True, False,
False, 1.14, 2000, 1000000)
End If
'Geometry
W = Sheet1.Cells(2, 2)
t = Sheet1.Cells(2, 3)
D = Sheet1.Cells(2, 4)
Call mAFGROW.SetCrackedPlateWithHoleProp(W, t, D)
'Loads
Tension = Sheet1.Cells(2, 5)
Bending = Sheet1.Cells(2, 6)
Bearing = Sheet1.Cells(2, 7)
Call mAFGROW.SetLoad(Tension, Bending, Bearing)
prefs.sOutputFileName = Sheet1.Cells(i, 10)
NewRun = True
answer = mAFGROW.RunPredict
End Sub
```

One Segment vs. Three Segment Walker Material Data

```
Public WithEvents mAFGROW As AFGROW.Application


Public prefs As PredictPreferences
Public user_beta As UserDefinedBeta
Public table_lookup As TabularLookupMaterial
Public i As Integer
```

```
Public j As Integer
Public k As Integer
Dim W As Double
Dim t As Double
Dim D As Double
Dim Tension As Double
Dim Bending As Double
Dim Bearing As Double
Dim Count As Integer
Dim AArray(2) As Double
Dim CArray(2) As Double
Dim BaArray(2, 2) As Double
Dim BcArray(2, 2) As Double
Dim BTArray(5, 1) As Double
Dim KTable(22, 3) As Double
Dim WalkerTable1(1, 3) As Double
Dim WalkerTable3(3, 3) As Double
Dim SpectrumFile As String
Dim beta_result As Integer
Dim answer As Boolean
Dim NewRun As Boolean

Private Sub mAFGROW_PredictFinished(ByVal result As Integer, ByVal dblCycles As Double, ByVal dblKc As Double, ByVal dblKa As Double, ByVal dblKct As Double, ByVal dblC As Double, ByVal dblA As Double, ByVal dblCt As Double)
Sheet1.Cells(i, 7) = dblCycles
Sheet1.Cells(i, 8) = dblC

If result = 0 Then
```

```
  Sheet1.Cells(i, 9) = "Completed Normally"
ElseIf result = 1 Then
  Sheet1.Cells(i, 9) = "After one pass of the spectrum, growth was less than 1.0e-13
Program halted"
ElseIf result = 2 Then
  Sheet1.Cells(i, 9) = "Maximum Number of passes exceeded"
ElseIf result = 3 Then
  Sheet1.Cells(i, 9) = "Crack Length Exceeded Stop Value"
ElseIf result = 4 Then
  Sheet1.Cells(i, 9) = "Cycle Count Exceeded Stop Value"
ElseIf result = 10 Then
  Sheet1.Cells(i, 9) = "No Spectrum file specified... Can not Predict"
ElseIf result = 11 Then
  Sheet1.Cells(i, 9) = "Beta table has zero length... Can not Predict"
ElseIf result = 12 Then
  Sheet1.Cells(i, 9) = "Repair patch applied and initiation on...  Can not Predict! "
ElseIf result = 13 Then
  Sheet1.Cells(i, 9) = "Initiation is not allowed with this model. Can not Predict! "
ElseIf result = 14 Then
  Sheet1.Cells(i, 9) = "NASGRO equation Rhi value is to large"
ElseIf result = 20 Then
  Sheet1.Cells(i, 9) = "Wrong geometry for an oblique crack"
ElseIf result = 21 Then
  Sheet1.Cells(i, 9) = "The initial crack length in the thickness direction is greater than the
input thickness.  Check data.."
ElseIf result = 22 Then
  Sheet1.Cells(i, 9) = "Error in spectrum file(s)"
ElseIf result = 23 Then
  Sheet1.Cells(i, 9) = "Unable to open plotfile"
```

```
ElseIf result = 24 Then
  Sheet1.Cells(i, 9) = "Error in Initiation. Predict stopped"
ElseIf result = 25 Then
  Sheet1.Cells(i, 9) = "The number of cycles to initiation is greater than 2.e+9. Predict
stopped"
ElseIf result = 26 Then
  Sheet1.Cells(i, 9) = "Not enough memory to allocate spectrum"
ElseIf result = 27 Then
  Sheet1.Cells(i, 9) = "Only a BLOCKED spectrum may have more than one (1) cycle per
stress level"
ElseIf result = 28 Then
  Sheet1.Cells(i, 9) = "Program termination by user"
ElseIf result = -1 Then
  Sheet1.Cells(i, 9) = "Unknown Error"
End If


Sheet4.Cells(1, 8) = Count
i = i + 1
If Sheet1.Cells(i, 2) > 0 Then
   CurrentBox.Text = CStr(i)
   Call Run
Else:
   answer = mAFGROW.Quit
   Set mAFGROW = Nothing
   Unload UserForm1
End If
End Sub


Private Sub CommandButton1_Click()
```

```
i = CInt(StartBox.Text)
CurrentBox.Text = CStr(i)
Call Run
End Sub

Private Sub CommandButton2_Click()
j = 6
Do While Sheet1.Cells(j, 2) > 0
  Sheet1.Cells(j, 7) = 0
  Sheet1.Cells(j, 8) = 0
  Sheet1.Cells(j, 9) = " "
  j = j + 1
Loop
End Sub

Private Sub CommandButton3_Click()
    answer = mAFGROW.Quit
    Set mAFGROW = Nothing
    Unload UserForm1
End Sub

Private Sub mAFGROW_PredictInfo(ByVal Model As Long, ByVal dStress As Double,
ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal
iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object,
ByVal iOutputInfo4 As Object)
Dim iOutput1 As AFGROW.OutputInfoInt
Dim iOutput2 As AFGROW.OutputInfoInt

Set iOutput1 = iOutputInfo1
If Model < 2000 Then Set iOutput2 = iOutputInfo2
```

```
If NewRun = True Then
j = 1
Do While ((j < 500) Or (Sheet4.Cells(j + 1, 1) = " "))
  Sheet4.Cells(j + 1, 1) = " "
  Sheet4.Cells(j + 1, 2) = " "
  Sheet4.Cells(j + 1, 3) = " "
  Sheet4.Cells(j + 1, 4) = " "
  Sheet4.Cells(j + 1, 5) = " "
  j = j + 1
Loop
Count = 0
End If
NewRun = False
If Count < 30000 Then
    Count = Count + 1
    Sheet4.Cells(Count + 1, 1) = dCycles
    Sheet4.Cells(Count + 1, 2) = iOutput1.dCrackLength
    Sheet4.Cells(Count + 1, 3) = iOutput1.dBeta
    If Model < 2000 Then
        Sheet4.Cells(Count + 1, 4) = iOutput2.dCrackLength
        Sheet4.Cells(Count + 1, 5) = iOutput2.dBeta
    End If
End If
Set iOutput1 = Nothing
End Sub

Private Sub mAFGROW_TransitionInfo(ByVal nType As Long, ByVal nReason As Long, ByVal dStress As Double, ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object, ByVal iOutputInfo4 As Object)
```

```
Dim iOutput1 As AFGROW.OutputInfoInt
Dim iOutput2 As AFGROW.OutputInfoInt

Set iOutput1 = iOutputInfo1
If Model < 2000 Then Set iOutput2 = iOutputInfo2
NewRun = False
Sheet1.Cells(i, 11) = nType
Sheet1.Cells(i, 12) = dCycles
Sheet1.Cells(i, 13) = iOutput1.dCrackLength
Set iOutput1 = Nothing
End Sub

Private Sub UserForm_Activate()

Dim k As Integer
Dim UseBetaCorrection As Boolean
Dim UseTabularData As Boolean
Dim MaterialModel As String
Dim iWalkerSegments As Integer
Dim dParameter As Double
Dim bKmax As Boolean
Dim bNetSection As Boolean

Set mAFGROW = CreateObject("AFGROW.Application")
Set prefs = mAFGROW.PredictPreferences
Set user_beta = mAFGROW.UserDefinedBeta
Set table_lookup = mAFGROW.SetTabularLookupMaterial
bNetSection = Sheet1.Cells(2, 11)
```

```
bKmax = Sheet1.Cells(2, 12)

MaterialModel = Sheet1.Cells(2, 16)

Call mAFGROW.PredictPreferences.SetPropagationLimits(False, True, bKmax, False,
bNetSection, 1.14, 5000000, 2000)

mAFGROW.PredictPreferences.bCycleByCycleSpCalc = Sheet1.Cells(3, 14)

mAFGROW.PredictPreferences.bCycleByCycleBetaCalc = Sheet1.Cells(3, 13)

prefs.bOutputToFile = False

mAFGROW.PredictPreferences.dGrowthIncrementPr = Sheet1.Cells(2, 15)

mAFGROW.Units = UnitsEnglish

mAFGROW.Visible = False


'set the user-defined beta information

UseBetaCorrection = Sheet1.Cells(2, 9)

If (UseBetaCorrection = True) Then

   mAFGROW.Model = uPartThrough

   j = 0

   Do While j < 3

   CArray(j) = Sheet2.Cells(j + 5, 2)

   k = 0

   Do While k < 3

   AArray(k) = Sheet2.Cells(4, k + 3)

   BaArray(j, k) = Sheet2.Cells(j + 5, k + 3)

   BcArray(j, k) = Sheet2.Cells(j + 10, k + 3)

   k = k + 1

   Loop

   j = j + 1

   Loop

   j = 0

   Do While j < 6
```

```
   BTArray(j, 0) = Sheet2.Cells(j + 16, 2)
   BTArray(j, 1) = Sheet2.Cells(j + 16, 3)
   j = j + 1
   Loop
   beta_result = user_beta.SetLineaInt(AArray, CArray, BaArray, BcArray)
   Dim middle As Variant
   middle = BTArray
   user_beta.aThroughCrackData = middle
End If

'Set the crack growth rate data using tabular look-up
UseTabularData = Sheet1.Cells(2, 10)
If (UseTabularData = True) Then
   k = 0
   Do While k < 4
   j = 0
   Do While j < 23
   If (k = 0 And j = 0) Then
      KTable(j, k) = 0#
   Else
      KTable(j, k) = Sheet3.Cells(j + 2, k + 2)
   End If
   j = j + 1
   Loop
   k = k + 1
   Loop
   table_lookup.sMaterialName = Sheet3.Cells(2, 6)
   Dim kVar As Variant
```

```
    kVar = KTable
    Call table_lookup.SetData(kVar, Sheet3.Cells(8, 7), Sheet3.Cells(8, 6), Sheet3.Cells(5,
7), Sheet3.Cells(5, 6), Sheet3.Cells(8, 9))
    table_lookup.dKc = Sheet3.Cells(5, 8)
    table_lookup.dKIc = Sheet3.Cells(5, 9)
    table_lookup.dPoissonsRatio = Sheet3.Cells(5, 10)
    table_lookup.dThermalEx = Sheet3.Cells(8, 8)
    table_lookup.dYield = Sheet3.Cells(8, 10)
    table_lookup.dYoungModulus = Sheet3.Cells(8, 11)
ElseIf MaterialModel = HarterT Then
    mAFGROW.SetHarterTMaterial.SetActive (1)
ElseIf MaterialModel = Walker Then
    Call mAFGROW.SetWalkerMaterial.SetActive
    iWalkerSegments = Sheet1.Cells(2, 17)
    Dim Wvar As Variant
    If iWalkerSegments = 1 Then
        WalkerTable1(0, 0) = Sheet3.Cells(20, 6)
        WalkerTable1(0, 1) = Sheet3.Cells(20, 7)
        WalkerTable1(0, 2) = Sheet3.Cells(20, 8)
        Wvar = WalkerTable1
        mAFGROW.SetWalkerMaterial.aCurveSegments = Wvar
    ElseIf iWalkerSegments = 3 Then
        k = 0
        Do While k < 3
        j = 0
        Do While j < 3
        WalkerTable3(j, k) = Sheet3.Cells(j + 22, k + 6)
        j = j + 1
        Loop
```

```
        k = k + 1
        Loop
        Wvar = WalkerTable3
        mAFGROW.SetWalkerMaterial.aCurveSegments = Wvar
        'Call mAFGROW.SetWalkerMaterial.aCurveSegments(Wvar)
    End If
    mAFGROW.SetWalkerMaterial.sMaterialName = Sheet3.Cells(2, 6)
    mAFGROW.SetWalkerMaterial.dKc = Sheet3.Cells(5, 8)
    mAFGROW.SetWalkerMaterial.dKIc = Sheet3.Cells(5, 9)
    mAFGROW.SetWalkerMaterial.dPoissonsRatio = Sheet3.Cells(5, 10)
    mAFGROW.SetWalkerMaterial.dThermalEx = Sheet3.Cells(8, 8)
    mAFGROW.SetWalkerMaterial.dYield = Sheet3.Cells(8, 10)
    mAFGROW.SetWalkerMaterial.dYoungModulus = Sheet3.Cells(8, 11)
    mAFGROW.SetWalkerMaterial.dRhi = Sheet3.Cells(8, 6)
    mAFGROW.SetWalkerMaterial.dRlo = Sheet3.Cells(8, 7)
    mAFGROW.SetWalkerMaterial.dThreshold = Sheet3.Cells(8, 9)

End If
End Sub

Public Sub Run()
Dim strSpectrumType As String

mAFGROW.SMF = Sheet1.Cells(i, 2)
strSpectrumType = Sheet1.Cells(2, 8)
If strSpectrumType = "CA" Then
    mAFGROW.ConstAmplitudeSpectrum (Sheet1.Cells(i, 3))
Else
```

```
    SpectrumFile = Sheet1.Cells(3, 2)
End If
Call mAFGROW.OpenSpectrumFile(SpectrumFile)
mAFGROW.Model = Sheet1.Cells(i, 4)
mAFGROW.CrackLengthC = Sheet1.Cells(i, 6)
'Get Retardation Parameters
If Sheet1.Cells(i, 5) = 0 Then
    dParameter = 0
ElseIf Sheet1.Cells(i, 5) = 2 Then
    dParameter = 0.36
ElseIf Sheet1.Cells(i, 5) = 1 Then
    dParameter = 3
ElseIf Sheet1.Cells(i, 5) = 3 Then
    dParameter = 0.86
End If
Call mAFGROW.SetRetardation(Sheet1.Cells(i, 5), dParameter, True, False)
'Geometry
W = Sheet1.Cells(2, 2)
t = Sheet1.Cells(2, 3)
D = Sheet1.Cells(2, 4)
Call mAFGROW.SetCrackedPlateWithHoleProp(W, t, D)
'Loads
Tension = Sheet1.Cells(2, 5)
Bending = Sheet1.Cells(2, 6)
Bearing = Sheet1.Cells(2, 7)
Call mAFGROW.SetLoad(Tension, Bending, Bearing)
'prefs.sOutputFileName = Sheet1.Cells(i, 10)
NewRun = True
```

```
answer = mAFGROW.RunPredict
End Sub
```

Stress Intensity Factor (Applied Stress)

```
Public WithEvents mAFGROW As AFGROW.Application


Public prefs As PredictPreferences
Public user_beta As UserDefinedBeta
Public table_lookup As TabularLookupMaterial
Public i As Integer
Public j As Integer
Public k As Integer
Dim W As Double
Dim t As Double
Dim D As Double
Dim Tension As Double
Dim Bending As Double
Dim Bearing As Double
Dim Count As Integer
Dim AArray(2) As Double
Dim CArray(2) As Double
Dim BaArray(2, 2) As Double
Dim BcArray(2, 2) As Double
Dim BTArray(5, 1) As Double
Dim KTable(22, 3) As Double
Dim SpectrumFile As String
Dim beta_result As Integer
Dim answer As Boolean
Dim NewRun As Boolean
```

```
Private Sub mAFGROW_PredictFinished(ByVal result As Integer, ByVal dblCycles As Double, ByVal dblKc As Double, ByVal dblKa As Double, ByVal dblKct As Double, ByVal dblC As Double, ByVal dblA As Double, ByVal dblCt As Double)

Sheet1.Cells(i, 7) = dblCycles

Sheet1.Cells(i, 8) = dblC


If result = 0 Then

  Sheet1.Cells(i, 9) = "Completed Normally"

ElseIf result = 1 Then

  Sheet1.Cells(i, 9) = "After one pass of the spectrum, growth was less than 1.0e-13 Program halted"

ElseIf result = 2 Then

  Sheet1.Cells(i, 9) = "Maximum Number of passes exceeded"

ElseIf result = 3 Then

  Sheet1.Cells(i, 9) = "Crack Length Exceeded Stop Value"

ElseIf result = 4 Then

  Sheet1.Cells(i, 9) = "Cycle Count Exceeded Stop Value"

ElseIf result = 10 Then

  Sheet1.Cells(i, 9) = "No Spectrum file specified... Can not Predict"

ElseIf result = 11 Then

  Sheet1.Cells(i, 9) = "Beta table has zero length... Can not Predict"

ElseIf result = 12 Then

  Sheet1.Cells(i, 9) = "Repair patch applied and initiation on...  Can not Predict! "

ElseIf result = 13 Then

  Sheet1.Cells(i, 9) = "Initiation is not allowed with this model. Can not Predict! "

ElseIf result = 14 Then

  Sheet1.Cells(i, 9) = "NASGRO equation Rhi value is to large"

ElseIf result = 20 Then

  Sheet1.Cells(i, 9) = "Wrong geometry for an oblique crack"
```

```
ElseIf result = 21 Then
  Sheet1.Cells(i, 9) = "The initial crack length in the thickness direction is greater than the input thickness.  Check data.."
ElseIf result = 22 Then
  Sheet1.Cells(i, 9) = "Error in spectrum file(s)"
ElseIf result = 23 Then
  Sheet1.Cells(i, 9) = "Unable to open plotfile"
ElseIf result = 24 Then
  Sheet1.Cells(i, 9) = "Error in Initiation. Predict stopped"
ElseIf result = 25 Then
  Sheet1.Cells(i, 9) = "The number of cycles to initiation is greater than 2.e+9. Predict stopped"
ElseIf result = 26 Then
  Sheet1.Cells(i, 9) = "Not enough memory to allocate spectrum"
ElseIf result = 27 Then
  Sheet1.Cells(i, 9) = "Only a BLOCKED spectrum may have more than one (1) cycle per stress level"
ElseIf result = 28 Then
  Sheet1.Cells(i, 9) = "Program termination by user"
ElseIf result = -1 Then
  Sheet1.Cells(i, 9) = "Unknown Error"
End If


Sheet4.Cells(1, 8) = Count
i = i + 1
If Sheet1.Cells(i, 2) > 0 Then
   CurrentBox.Text = CStr(i)
   Call Run
Else:
   answer = mAFGROW.Quit
```

```
    Set mAFGROW = Nothing
    Unload UserForm1
End If
End Sub

Private Sub CommandButton1_Click()
i = CInt(StartBox.Text)
CurrentBox.Text = CStr(i)
Call Run
End Sub

Private Sub CommandButton2_Click()
j = 6
Do While Sheet1.Cells(j, 2) > 0
  Sheet1.Cells(j, 7) = 0
  Sheet1.Cells(j, 8) = 0
  Sheet1.Cells(j, 9) = " "
  j = j + 1
Loop
End Sub

Private Sub CommandButton3_Click()
    answer = mAFGROW.Quit
    Set mAFGROW = Nothing
    Unload UserForm1
End Sub

Private Sub mAFGROW_PredictInfo(ByVal Model As Long, ByVal dStress As Double,
ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal
```

```
iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object,
ByVal iOutputInfo4 As Object)

Dim iOutput1 As AFGROW.OutputInfoInt

Dim iOutput2 As AFGROW.OutputInfoInt

Set iOutput1 = iOutputInfo1

If Model < 2000 Then Set iOutput2 = iOutputInfo2

If NewRun = True Then

j = 1

Do While ((j < 500) Or (Sheet4.Cells(j + 1, 1) = " "))

  Sheet4.Cells(j + 1, 1) = " "

  Sheet4.Cells(j + 1, 2) = " "

  Sheet4.Cells(j + 1, 3) = " "

  Sheet4.Cells(j + 1, 4) = " "

  Sheet4.Cells(j + 1, 5) = " "

  j = j + 1

Loop

Count = 0

End If

NewRun = False

Count = Count + 1

Sheet4.Cells(Count + 1, 1) = dCycles

Sheet4.Cells(Count + 1, 2) = iOutput1.dCrackLength

Sheet4.Cells(Count + 1, 3) = iOutput1.dBeta

If Model < 2000 Then

Sheet4.Cells(Count + 1, 4) = iOutput2.dCrackLength

Sheet4.Cells(Count + 1, 5) = iOutput2.dBeta

End If

Set iOutput1 = Nothing

End Sub
```

```
Private Sub mAFGROW_TransitionInfo(ByVal nType As Long, ByVal nReason As
Long, ByVal dStress As Double, ByVal dRStress As Double, ByVal dCycles As Double,
ByVal dPass As Long, ByVal iOutputInfo1 As Object, ByVal iOutputInfo2 As Object,
ByVal iOutputInfo3 As Object, ByVal iOutputInfo4 As Object)

Dim iOutput1 As AFGROW.OutputInfoInt

Dim iOutput2 As AFGROW.OutputInfoInt

Set iOutput1 = iOutputInfo1

If Model < 2000 Then Set iOutput2 = iOutputInfo2

NewRun = False

Sheet1.Cells(i, 11) = nType

Sheet1.Cells(i, 12) = dCycles

Sheet1.Cells(i, 13) = iOutput1.dCrackLength

Set iOutput1 = Nothing

End Sub


Private Sub UserForm_Activate()


Dim k As Integer

Dim UseBetaCorrection As Boolean

Dim UseTabularData As Boolean

Dim Kmax As Double


Set mAFGROW = CreateObject("AFGROW.Application")

Set prefs = mAFGROW.PredictPreferences

Kmax = Sheet1.Cells(2, 12)

Call mAFGROW.PredictPreferences.SetPropagationLimits(False, False, False, True,
True, 1.14, 10000000, Kmax)

prefs.bOutputToFile = False

Set user_beta = mAFGROW.UserDefinedBeta
```

```
Set table_lookup = mAFGROW.SetTabularLookupMaterial
mAFGROW.Visible = False

'set the user-defined beta information
UseBetaCorrection = Sheet1.Cells(2, 9)
If (UseBetaCorrection = True) Then
    mAFGROW.Model = uPartThrough
    j = 0
    Do While j < 3
    CArray(j) = Sheet2.Cells(j + 5, 2)
    k = 0
    Do While k < 3
    AArray(k) = Sheet2.Cells(4, k + 3)
    BaArray(j, k) = Sheet2.Cells(j + 5, k + 3)
    BcArray(j, k) = Sheet2.Cells(j + 10, k + 3)
    k = k + 1
    Loop
    j = j + 1
    Loop
    j = 0
    Do While j < 6
    BTArray(j, 0) = Sheet2.Cells(j + 16, 2)
    BTArray(j, 1) = Sheet2.Cells(j + 16, 3)
    j = j + 1
    Loop
    beta_result = user_beta.SetLineaInt(AArray, CArray, BaArray, BcArray)
    Dim middle As Variant
    middle = BTArray
```

```
   user_beta.aThroughCrackData = middle
End If

'Set the crack growth rate data using tabular look-up
UseTabularData = Sheet1.Cells(2, 10)
If (UseTabularData = True) Then
   k = 0
   Do While k < 4
   j = 0
   Do While j < 23
   If (k = 0 And j = 0) Then
      KTable(j, k) = 0#
   Else
      KTable(j, k) = Sheet3.Cells(j + 2, k + 2)
   End If
   j = j + 1
   Loop
   k = k + 1
   Loop
   table_lookup.sMaterialName = Sheet3.Cells(2, 6)
   Dim kVar As Variant
   kVar = KTable
   Call table_lookup.SetData(kVar, Sheet3.Cells(8, 7), Sheet3.Cells(8, 6), Sheet3.Cells(5,
7), Sheet3.Cells(5, 6), Sheet3.Cells(8, 9))
   table_lookup.dKc = Sheet3.Cells(5, 8)
   table_lookup.dKIc = Sheet3.Cells(5, 9)
   table_lookup.dPoissonsRatio = Sheet3.Cells(5, 10)
   table_lookup.dThermalEx = Sheet3.Cells(8, 8)
   table_lookup.dYield = Sheet3.Cells(8, 10)
```

```
    table_lookup.dYoungModulus = Sheet3.Cells(8, 11)
Else
    mAFGROW.SetHarterTMaterial.SetActive (1)

End If
End Sub

Public Sub Run()
mAFGROW.PredictPreferences.bCycleByCycleSpCalc = True
mAFGROW.PredictPreferences.bCycleByCycleBetaCalc = True
mAFGROW.Units = UnitsEnglish
mAFGROW.SMF = Sheet1.Cells(i, 2)
mAFGROW.ConstAmplitudeSpectrum (Sheet1.Cells(i, 3))
mAFGROW.Model = Sheet1.Cells(i, 4)
mAFGROW.CrackLengthC = Sheet1.Cells(i, 6)
Call mAFGROW.SetRetardation(Sheet1.Cells(2, 11), 0, False, False)
'Geometry
W = Sheet1.Cells(2, 2)
t = Sheet1.Cells(2, 3)
D = Sheet1.Cells(2, 4)
Call mAFGROW.SetCrackedPlateWithHoleProp(W, t, D)
'Loads
Tension = Sheet1.Cells(2, 5)
Bending = Sheet1.Cells(2, 6)
Bearing = Sheet1.Cells(2, 7)
Call mAFGROW.SetLoad(Tension, Bending, Bearing)
prefs.sOutputFileName = Sheet1.Cells(i, 10)
NewRun = True
```

```
answer = mAFGROW.RunPredict
End Sub
```

Critical Stress Intensity Factor

```
Public WithEvents mAFGROW As AFGROW.Application


Public prefs As PredictPreferences
Public user_beta As UserDefinedBeta
Public table_lookup As TabularLookupMaterial
Public i As Integer
Public j As Integer
Public k As Integer
Dim W As Double
Dim t As Double
Dim D As Double
Dim Tension As Double
Dim Bending As Double
Dim Bearing As Double
Dim Count As Integer
Dim AArray(2) As Double
Dim CArray(2) As Double
Dim BaArray(2, 2) As Double
Dim BcArray(2, 2) As Double
Dim BTArray(5, 1) As Double
Dim KTable(22, 3) As Double
Dim SpectrumFile As String
Dim beta_result As Integer
Dim answer As Boolean
Dim NewRun As Boolean
```

```
Private Sub mAFGROW_PredictFinished(ByVal result As Integer, ByVal dblCycles As Double, ByVal dblKc As Double, ByVal dblKa As Double, ByVal dblKct As Double, ByVal dblC As Double, ByVal dblA As Double, ByVal dblCt As Double)

Sheet1.Cells(i, 7) = dblCycles

Sheet1.Cells(i, 8) = dblC


If result = 0 Then

  Sheet1.Cells(i, 9) = "Completed Normally"

ElseIf result = 1 Then

  Sheet1.Cells(i, 9) = "After one pass of the spectrum, growth was less than 1.0e-13 Program halted"

ElseIf result = 2 Then

  Sheet1.Cells(i, 9) = "Maximum Number of passes exceeded"

ElseIf result = 3 Then

  Sheet1.Cells(i, 9) = "Crack Length Exceeded Stop Value"

ElseIf result = 4 Then

  Sheet1.Cells(i, 9) = "Cycle Count Exceeded Stop Value"

ElseIf result = 10 Then

  Sheet1.Cells(i, 9) = "No Spectrum file specified... Can not Predict"

ElseIf result = 11 Then

  Sheet1.Cells(i, 9) = "Beta table has zero length... Can not Predict"

ElseIf result = 12 Then

  Sheet1.Cells(i, 9) = "Repair patch applied and initiation on...  Can not Predict! "

ElseIf result = 13 Then

  Sheet1.Cells(i, 9) = "Initiation is not allowed with this model. Can not Predict! "

ElseIf result = 14 Then

  Sheet1.Cells(i, 9) = "NASGRO equation Rhi value is to large"

ElseIf result = 20 Then

  Sheet1.Cells(i, 9) = "Wrong geometry for an oblique crack"
```

```
ElseIf result = 21 Then
  Sheet1.Cells(i, 9) = "The initial crack length in the thickness direction is greater than the input thickness.  Check data.."
ElseIf result = 22 Then
  Sheet1.Cells(i, 9) = "Error in spectrum file(s)"
ElseIf result = 23 Then
  Sheet1.Cells(i, 9) = "Unable to open plotfile"
ElseIf result = 24 Then
  Sheet1.Cells(i, 9) = "Error in Initiation. Predict stopped"
ElseIf result = 25 Then
  Sheet1.Cells(i, 9) = "The number of cycles to initiation is greater than 2.e+9. Predict stopped"
ElseIf result = 26 Then
  Sheet1.Cells(i, 9) = "Not enough memory to allocate spectrum"
ElseIf result = 27 Then
  Sheet1.Cells(i, 9) = "Only a BLOCKED spectrum may have more than one (1) cycle per stress level"
ElseIf result = 28 Then
  Sheet1.Cells(i, 9) = "Program termination by user"
ElseIf result = -1 Then
  Sheet1.Cells(i, 9) = "Unknown Error"
End If


Sheet4.Cells(1, 8) = Count
i = i + 1
If Sheet1.Cells(i, 2) > 0 Then
   CurrentBox.Text = CStr(i)
   Call Run
Else:
   answer = mAFGROW.Quit
```

```
    Set mAFGROW = Nothing
    Unload UserForm1
End If
End Sub

Private Sub CommandButton1_Click()
i = CInt(StartBox.Text)
CurrentBox.Text = CStr(i)
Call Run
End Sub

Private Sub CommandButton2_Click()
j = 6
Do While Sheet1.Cells(j, 2) > 0
  Sheet1.Cells(j, 7) = 0
  Sheet1.Cells(j, 8) = 0
  Sheet1.Cells(j, 9) = " "
  j = j + 1
Loop
End Sub

Private Sub CommandButton3_Click()
    answer = mAFGROW.Quit
    Set mAFGROW = Nothing
    Unload UserForm1
End Sub

Private Sub mAFGROW_PredictInfo(ByVal Model As Long, ByVal dStress As Double,
ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal
```

```
iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object,
ByVal iOutputInfo4 As Object)

Dim iOutput1 As AFGROW.OutputInfoInt

Dim iOutput2 As AFGROW.OutputInfoInt


Set iOutput1 = iOutputInfo1

If Model < 2000 Then Set iOutput2 = iOutputInfo2

If NewRun = True Then

j = 1

Do While ((j < 500) Or (Sheet4.Cells(j + 1, 1) = " "))

  Sheet4.Cells(j + 1, 1) = "  "

  Sheet4.Cells(j + 1, 2) = " "

  Sheet4.Cells(j + 1, 3) = " "

  Sheet4.Cells(j + 1, 4) = " "

  Sheet4.Cells(j + 1, 5) = " "

  j = j + 1

Loop

Count = 0

End If

NewRun = False

If Count < 30000 Then

    Count = Count + 1

    Sheet4.Cells(Count + 1, 1) = dCycles

    Sheet4.Cells(Count + 1, 2) = iOutput1.dCrackLength

    Sheet4.Cells(Count + 1, 3) = iOutput1.dBeta

    If Model < 2000 Then

        Sheet4.Cells(Count + 1, 4) = iOutput2.dCrackLength

        Sheet4.Cells(Count + 1, 5) = iOutput2.dBeta

    End If
```

```
End If
Set iOutput1 = Nothing
End Sub


Private Sub mAFGROW_TransitionInfo(ByVal nType As Long, ByVal nReason As Long, ByVal dStress As Double, ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object, ByVal iOutputInfo4 As Object)
Dim iOutput1 As AFGROW.OutputInfoInt
Dim iOutput2 As AFGROW.OutputInfoInt


Set iOutput1 = iOutputInfo1
If Model < 2000 Then Set iOutput2 = iOutputInfo2
NewRun = False
Sheet1.Cells(i, 11) = nType
Sheet1.Cells(i, 12) = dCycles
Sheet1.Cells(i, 13) = iOutput1.dCrackLength
Set iOutput1 = Nothing
End Sub


Private Sub UserForm_Activate()


Dim k As Integer
Dim UseBetaCorrection As Boolean
Dim UseTabularData As Boolean
Dim dParameter As Double
Dim bKmax As Boolean
Dim bNetSection As Boolean


Set mAFGROW = CreateObject("AFGROW.Application")
```

```
Set prefs = mAFGROW.PredictPreferences
Set user_beta = mAFGROW.UserDefinedBeta
Set table_lookup = mAFGROW.SetTabularLookupMaterial
bNetSection = Sheet1.Cells(2, 11)
bKmax = Sheet1.Cells(2, 12)
Call mAFGROW.PredictPreferences.SetPropagationLimits(False, True, bKmax, False,
bNetSection, 1.14, 10000000, 2000)
mAFGROW.PredictPreferences.bCycleByCycleSpCalc = Sheet1.Cells(3, 14)
mAFGROW.PredictPreferences.bCycleByCycleBetaCalc = Sheet1.Cells(3, 13)
prefs.bOutputToFile = False
mAFGROW.PredictPreferences.dGrowthIncrementPr = Sheet1.Cells(2, 15)
mAFGROW.Units = UnitsEnglish
mAFGROW.Visible = False

'set the user-defined beta information
UseBetaCorrection = Sheet1.Cells(2, 9)
If (UseBetaCorrection = True) Then
   mAFGROW.Model = uPartThrough
   j = 0
   Do While j < 3
   CArray(j) = Sheet2.Cells(j + 5, 2)
   k = 0
   Do While k < 3
   AArray(k) = Sheet2.Cells(4, k + 3)
   BaArray(j, k) = Sheet2.Cells(j + 5, k + 3)
   BcArray(j, k) = Sheet2.Cells(j + 10, k + 3)
   k = k + 1
   Loop
   j = j + 1
```

```
    Loop
    j = 0
    Do While j < 6
    BTArray(j, 0) = Sheet2.Cells(j + 16, 2)
    BTArray(j, 1) = Sheet2.Cells(j + 16, 3)
    j = j + 1
    Loop
    beta_result = user_beta.SetLineaInt(AArray, CArray, BaArray, BcArray)
    Dim middle As Variant
    middle = BTArray
    user_beta.aThroughCrackData = middle
End If

'Set the crack growth rate data using tabular look-up
UseTabularData = Sheet1.Cells(2, 10)
If (UseTabularData = True) Then
    k = 0
    Do While k < 4
    j = 0
    Do While j < 23
    If (k = 0 And j = 0) Then
        KTable(j, k) = 0#
    Else
        KTable(j, k) = Sheet3.Cells(j + 2, k + 2)
    End If
    j = j + 1
    Loop
    k = k + 1
```

```
    Loop
    table_lookup.sMaterialName = Sheet3.Cells(2, 6)
    Dim kVar As Variant
    kVar = KTable
    Call table_lookup.SetData(kVar, Sheet3.Cells(8, 7), Sheet3.Cells(8, 6), Sheet3.Cells(5,
7), Sheet3.Cells(5, 6), Sheet3.Cells(8, 9))
    table_lookup.dKc = Sheet3.Cells(5, 8)
    table_lookup.dKIc = Sheet3.Cells(5, 9)
    table_lookup.dPoissonsRatio = Sheet3.Cells(5, 10)
    table_lookup.dThermalEx = Sheet3.Cells(8, 8)
    table_lookup.dYield = Sheet3.Cells(8, 10)
    table_lookup.dYoungModulus = Sheet3.Cells(8, 11)
Else
    mAFGROW.SetHarterTMaterial.SetActive (1)


End If
End Sub


Public Sub Run()
Dim strSpectrumType As String


mAFGROW.SMF = Sheet1.Cells(i, 2)
strSpectrumType = Sheet1.Cells(2, 8)
If strSpectrumType = "CA" Then
    mAFGROW.ConstAmplitudeSpectrum (Sheet1.Cells(i, 3))
Else
    SpectrumFile = Sheet1.Cells(3, 2)
End If
Call mAFGROW.OpenSpectrumFile(SpectrumFile)
```

```
mAFGROW.Model = Sheet1.Cells(i, 4)
mAFGROW.CrackLengthC = Sheet1.Cells(i, 6)
'Get Fracture Toughness Values
table_lookup.dKc = Sheet1.Cells(i, 11)
table_lookup.dKIc = Sheet1.Cells(i, 12)
'Get Retardation Parameters
If Sheet1.Cells(i, 5) = 0 Then
   dParameter = 0
ElseIf Sheet1.Cells(i, 5) = 2 Then
   dParameter = 0.36
ElseIf Sheet1.Cells(i, 5) = 1 Then
   dParameter = 3
ElseIf Sheet1.Cells(i, 5) = 3 Then
   dParameter = 0.86
End If
Call mAFGROW.SetRetardation(Sheet1.Cells(i, 5), dParameter, True, False)
'Geometry
W = Sheet1.Cells(2, 2)
t = Sheet1.Cells(2, 3)
D = Sheet1.Cells(2, 4)
Call mAFGROW.SetCrackedPlateWithHoleProp(W, t, D)
'Loads
Tension = Sheet1.Cells(2, 5)
Bending = Sheet1.Cells(2, 6)
Bearing = Sheet1.Cells(2, 7)
Call mAFGROW.SetLoad(Tension, Bending, Bearing)
NewRun = True
answer = mAFGROW.RunPredict
```

End Sub

Load Interaction Models and Critical Stress Intensity Factor

```
Public WithEvents mAFGROW As AFGROW.Application

Public prefs As PredictPreferences
Public user_beta As UserDefinedBeta
Public table_lookup As TabularLookupMaterial
Public i As Integer
Public j As Integer
Public k As Integer
Dim W As Double
Dim t As Double
Dim D As Double
Dim Tension As Double
Dim Bending As Double
Dim Bearing As Double
Dim Count As Integer
Dim AArray(2) As Double
Dim CArray(2) As Double
Dim BaArray(2, 2) As Double
Dim BcArray(2, 2) As Double
Dim BTArray(5, 1) As Double
Dim KTable(22, 3) As Double
Dim SpectrumFile As String
Dim beta_result As Integer
Dim answer As Boolean
Dim NewRun As Boolean
```

```
Private Sub mAFGROW_PredictFinished(ByVal result As Integer, ByVal dblCycles As Double, ByVal dblKc As Double, ByVal dblKa As Double, ByVal dblKct As Double, ByVal dblC  As Double, ByVal dblA As Double, ByVal dblCt As Double)

Sheet1.Cells(i, 7) = dblCycles

Sheet1.Cells(i, 8) = dblC


If result = 0 Then

  Sheet1.Cells(i, 9) = "Completed Normally"

ElseIf result = 1 Then

  Sheet1.Cells(i, 9) = "After one pass of the spectrum, growth was less than 1.0e-13 Program halted"

ElseIf result = 2 Then

  Sheet1.Cells(i, 9) = "Maximum Number of passes exceeded"

ElseIf result = 3 Then

  Sheet1.Cells(i, 9) = "Crack Length Exceeded Stop Value"

ElseIf result = 4 Then

  Sheet1.Cells(i, 9) = "Cycle Count Exceeded Stop Value"

ElseIf result = 10 Then

  Sheet1.Cells(i, 9) = "No Spectrum file specified... Can not Predict"

ElseIf result = 11 Then

  Sheet1.Cells(i, 9) = "Beta table has zero length... Can not Predict"

ElseIf result = 12 Then

  Sheet1.Cells(i, 9) = "Repair patch applied and initiation on...  Can not Predict! "

ElseIf result = 13 Then

  Sheet1.Cells(i, 9) = "Initiation is not allowed with this model. Can not Predict! "

ElseIf result = 14 Then

  Sheet1.Cells(i, 9) = "NASGRO equation Rhi value is to large"

ElseIf result = 20 Then

  Sheet1.Cells(i, 9) = "Wrong geometry for an oblique crack"

ElseIf result = 21 Then
```

```
  Sheet1.Cells(i, 9) = "The initial crack length in the thickness direction is greater than the input thickness.  Check data.."
ElseIf result = 22 Then
  Sheet1.Cells(i, 9) = "Error in spectrum file(s)"
ElseIf result = 23 Then
  Sheet1.Cells(i, 9) = "Unable to open plotfile"
ElseIf result = 24 Then
  Sheet1.Cells(i, 9) = "Error in Initiation. Predict stopped"
ElseIf result = 25 Then
  Sheet1.Cells(i, 9) = "The number of cycles to initiation is greater than 2.e+9. Predict stopped"
ElseIf result = 26 Then
  Sheet1.Cells(i, 9) = "Not enough memory to allocate spectrum"
ElseIf result = 27 Then
  Sheet1.Cells(i, 9) = "Only a BLOCKED spectrum may have more than one (1) cycle per stress level"
ElseIf result = 28 Then
  Sheet1.Cells(i, 9) = "Program termination by user"
ElseIf result = -1 Then
  Sheet1.Cells(i, 9) = "Unknown Error"
End If


Sheet4.Cells(1, 8) = Count
i = i + 1
If Sheet1.Cells(i, 2) > 0 Then
   CurrentBox.Text = CStr(i)
   Call Run
Else:
   answer = mAFGROW.Quit
   Set mAFGROW = Nothing
```

```
    Unload UserForm1
End If
End Sub

Private Sub CommandButton1_Click()
i = CInt(StartBox.Text)
CurrentBox.Text = CStr(i)
Call Run
End Sub

Private Sub CommandButton2_Click()
j = 6
Do While Sheet1.Cells(j, 2) > 0
  Sheet1.Cells(j, 7) = 0
  Sheet1.Cells(j, 8) = 0
  Sheet1.Cells(j, 9) = " "
  j = j + 1
Loop
End Sub

Private Sub CommandButton3_Click()
    answer = mAFGROW.Quit
    Set mAFGROW = Nothing
    Unload UserForm1
End Sub

Private Sub mAFGROW_PredictInfo(ByVal Model As Long, ByVal dStress As Double,
ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal
iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object,
ByVal iOutputInfo4 As Object)
```

```
Dim iOutput1 As AFGROW.OutputInfoInt
Dim iOutput2 As AFGROW.OutputInfoInt

Set iOutput1 = iOutputInfo1
If Model < 2000 Then Set iOutput2 = iOutputInfo2
If NewRun = True Then
j = 1
Do While ((j < 500) Or (Sheet4.Cells(j + 1, 1) = " "))
  Sheet4.Cells(j + 1, 1) = " "
  Sheet4.Cells(j + 1, 2) = " "
  Sheet4.Cells(j + 1, 3) = " "
  Sheet4.Cells(j + 1, 4) = " "
  Sheet4.Cells(j + 1, 5) = " "
  j = j + 1
Loop
Count = 0
End If
NewRun = False
If Count < 30000 Then
    Count = Count + 1
    Sheet4.Cells(Count + 1, 1) = dCycles
    Sheet4.Cells(Count + 1, 2) = iOutput1.dCrackLength
    Sheet4.Cells(Count + 1, 3) = iOutput1.dBeta
    If Model < 2000 Then
        Sheet4.Cells(Count + 1, 4) = iOutput2.dCrackLength
        Sheet4.Cells(Count + 1, 5) = iOutput2.dBeta
    End If
End If
```

```
Set iOutput1 = Nothing

End Sub


Private Sub mAFGROW_TransitionInfo(ByVal nType As Long, ByVal nReason As Long, ByVal dStress As Double, ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object, ByVal iOutputInfo4 As Object)

Dim iOutput1 As AFGROW.OutputInfoInt

Dim iOutput2 As AFGROW.OutputInfoInt


Set iOutput1 = iOutputInfo1

If Model < 2000 Then Set iOutput2 = iOutputInfo2

NewRun = False

Sheet1.Cells(i, 11) = nType

Sheet1.Cells(i, 12) = dCycles

Sheet1.Cells(i, 13) = iOutput1.dCrackLength

Set iOutput1 = Nothing

End Sub


Private Sub UserForm_Activate()


Dim k As Integer

Dim UseBetaCorrection As Boolean

Dim UseTabularData As Boolean

Dim dParameter As Double

Dim bKmax As Boolean

Dim bNetSection As Boolean


Set mAFGROW = CreateObject("AFGROW.Application")

Set prefs = mAFGROW.PredictPreferences
```

```
Set user_beta = mAFGROW.UserDefinedBeta

Set table_lookup = mAFGROW.SetTabularLookupMaterial

bNetSection = Sheet1.Cells(2, 11)

bKmax = Sheet1.Cells(2, 12)

Call mAFGROW.PredictPreferences.SetPropagationLimits(False, False, bKmax, False,
bNetSection, 1.14, 10000000, 2000)

mAFGROW.PredictPreferences.bCycleByCycleSpCalc = Sheet1.Cells(3, 14)

mAFGROW.PredictPreferences.bCycleByCycleBetaCalc = Sheet1.Cells(3, 13)

prefs.bOutputToFile = False

mAFGROW.PredictPreferences.dGrowthIncrementPr = Sheet1.Cells(2, 15)

mAFGROW.Units = UnitsEnglish

mAFGROW.Visible = False


'set the user-defined beta information

UseBetaCorrection = Sheet1.Cells(2, 9)

If (UseBetaCorrection = True) Then

   mAFGROW.Model = uPartThrough

   j = 0

   Do While j < 3

   CArray(j) = Sheet2.Cells(j + 5, 2)

   k = 0

   Do While k < 3

   AArray(k) = Sheet2.Cells(4, k + 3)

   BaArray(j, k) = Sheet2.Cells(j + 5, k + 3)

   BcArray(j, k) = Sheet2.Cells(j + 10, k + 3)

   k = k + 1

   Loop

   j = j + 1

   Loop
```

```
    j = 0
    Do While j < 6
    BTArray(j, 0) = Sheet2.Cells(j + 16, 2)
    BTArray(j, 1) = Sheet2.Cells(j + 16, 3)
    j = j + 1
    Loop
    beta_result = user_beta.SetLineaInt(AArray, CArray, BaArray, BcArray)
    Dim middle As Variant
    middle = BTArray
    user_beta.aThroughCrackData = middle
End If

'Set the crack growth rate data using tabular look-up
UseTabularData = Sheet1.Cells(2, 10)
If (UseTabularData = True) Then
    k = 0
    Do While k < 4
    j = 0
    Do While j < 23
    If (k = 0 And j = 0) Then
        KTable(j, k) = 0#
    Else
        KTable(j, k) = Sheet3.Cells(j + 2, k + 2)
    End If
    j = j + 1
    Loop
    k = k + 1
    Loop
```

```
   table_lookup.sMaterialName = Sheet3.Cells(2, 6)
    Dim kVar As Variant
   kVar = KTable
   Call table_lookup.SetData(kVar, Sheet3.Cells(8, 7), Sheet3.Cells(8, 6), Sheet3.Cells(5,
7), Sheet3.Cells(5, 6), Sheet3.Cells(8, 9))
   table_lookup.dKc = Sheet3.Cells(5, 8)
   table_lookup.dKIc = Sheet3.Cells(5, 9)
   table_lookup.dPoissonsRatio = Sheet3.Cells(5, 10)
   table_lookup.dThermalEx = Sheet3.Cells(8, 8)
   table_lookup.dYield = Sheet3.Cells(8, 10)
   table_lookup.dYoungModulus = Sheet3.Cells(8, 11)
Else
    mAFGROW.SetHarterTMaterial.SetActive (1)


End If
End Sub


Public Sub Run()
Dim strSpectrumType As String


mAFGROW.SMF = Sheet1.Cells(i, 2)
strSpectrumType = Sheet1.Cells(2, 8)
If strSpectrumType = "CA" Then
   mAFGROW.ConstAmplitudeSpectrum (Sheet1.Cells(i, 3))
Else
   SpectrumFile = Sheet1.Cells(3, 2)
End If
Call mAFGROW.OpenSpectrumFile(SpectrumFile)
mAFGROW.Model = Sheet1.Cells(i, 4)
```

```
mAFGROW.CrackLengthC = Sheet1.Cells(i, 6)
'Get Retardation Parameters
If Sheet1.Cells(i, 5) = 0 Then
   dParameter = 0
ElseIf Sheet1.Cells(i, 5) = 2 Then
   dParameter = 0.36
ElseIf Sheet1.Cells(i, 5) = 1 Then
   dParameter = 3
ElseIf Sheet1.Cells(i, 5) = 3 Then
   dParameter = 0.86
End If
Call mAFGROW.SetRetardation(Sheet1.Cells(i, 5), dParameter, True, False)
'Geometry
W = Sheet1.Cells(2, 2)
t = Sheet1.Cells(2, 3)
D = Sheet1.Cells(2, 4)
Call mAFGROW.SetCrackedPlateWithHoleProp(W, t, D)
'Loads
Tension = Sheet1.Cells(2, 5)
Bending = Sheet1.Cells(2, 6)
Bearing = Sheet1.Cells(2, 7)
Call mAFGROW.SetLoad(Tension, Bending, Bearing)
NewRun = True
answer = mAFGROW.RunPredict
End Sub
```

Load Interaction Models and Yield Stress

```
Public WithEvents mAFGROW As AFGROW.Application
```

```
Public prefs As PredictPreferences
Public user_beta As UserDefinedBeta
Public table_lookup As TabularLookupMaterial
Public i As Integer
Public j As Integer
Public k As Integer
Dim W As Double
Dim t As Double
Dim D As Double
Dim Tension As Double
Dim Bending As Double
Dim Bearing As Double
Dim Count As Integer
Dim AArray(2) As Double
Dim CArray(2) As Double
Dim BaArray(2, 2) As Double
Dim BcArray(2, 2) As Double
Dim BTArray(5, 1) As Double
Dim KTable(22, 3) As Double
Dim SpectrumFile As String
Dim beta_result As Integer
Dim answer As Boolean
Dim NewRun As Boolean

Private Sub mAFGROW_PredictFinished(ByVal result As Integer, ByVal dblCycles As
Double, ByVal dblKc As Double, ByVal dblKa As Double, ByVal dblKct As Double,
ByVal dblC As Double, ByVal dblA As Double, ByVal dblCt As Double)
Sheet1.Cells(i, 7) = dblCycles
Sheet1.Cells(i, 8) = dblC
```

```
If result = 0 Then
  Sheet1.Cells(i, 9) = "Completed Normally"
ElseIf result = 1 Then
  Sheet1.Cells(i, 9) = "After one pass of the spectrum, growth was less than 1.0e-13
Program halted"
ElseIf result = 2 Then
  Sheet1.Cells(i, 9) = "Maximum Number of passes exceeded"
ElseIf result = 3 Then
  Sheet1.Cells(i, 9) = "Crack Length Exceeded Stop Value"
ElseIf result = 4 Then
  Sheet1.Cells(i, 9) = "Cycle Count Exceeded Stop Value"
ElseIf result = 10 Then
  Sheet1.Cells(i, 9) = "No Spectrum file specified... Can not Predict"
ElseIf result = 11 Then
  Sheet1.Cells(i, 9) = "Beta table has zero length... Can not Predict"
ElseIf result = 12 Then
  Sheet1.Cells(i, 9) = "Repair patch applied and initiation on...  Can not Predict! "
ElseIf result = 13 Then
  Sheet1.Cells(i, 9) = "Initiation is not allowed with this model. Can not Predict! "
ElseIf result = 14 Then
  Sheet1.Cells(i, 9) = "NASGRO equation Rhi value is to large"
ElseIf result = 20 Then
  Sheet1.Cells(i, 9) = "Wrong geometry for an oblique crack"
ElseIf result = 21 Then
  Sheet1.Cells(i, 9) = "The initial crack length in the thickness direction is greater than the
input thickness.  Check data.."
ElseIf result = 22 Then
  Sheet1.Cells(i, 9) = "Error in spectrum file(s)"
```

```
ElseIf result = 23 Then
  Sheet1.Cells(i, 9) = "Unable to open plotfile"
ElseIf result = 24 Then
  Sheet1.Cells(i, 9) = "Error in Initiation. Predict stopped"
ElseIf result = 25 Then
  Sheet1.Cells(i, 9) = "The number of cycles to initiation is greater than 2.e+9. Predict
stopped"
ElseIf result = 26 Then
  Sheet1.Cells(i, 9) = "Not enough memory to allocate spectrum"
ElseIf result = 27 Then
  Sheet1.Cells(i, 9) = "Only a BLOCKED spectrum may have more than one (1) cycle per
stress level"
ElseIf result = 28 Then
  Sheet1.Cells(i, 9) = "Program termination by user"
ElseIf result = -1 Then
  Sheet1.Cells(i, 9) = "Unknown Error"
End If


Sheet4.Cells(1, 8) = Count
i = i + 1
If Sheet1.Cells(i, 2) > 0 Then
   CurrentBox.Text = CStr(i)
   Call Run
Else:
   answer = mAFGROW.Quit
   Set mAFGROW = Nothing
   Unload UserForm1
End If
End Sub
```

```
Private Sub CommandButton1_Click()
i = CInt(StartBox.Text)
CurrentBox.Text = CStr(i)
Call Run
End Sub

Private Sub CommandButton2_Click()
j = 6
Do While Sheet1.Cells(j, 2) > 0
  Sheet1.Cells(j, 7) = 0
  Sheet1.Cells(j, 8) = 0
  Sheet1.Cells(j, 9) = " "
  j = j + 1
Loop
End Sub

Private Sub CommandButton3_Click()
    answer = mAFGROW.Quit
    Set mAFGROW = Nothing
    Unload UserForm1
End Sub

Private Sub mAFGROW_PredictInfo(ByVal Model As Long, ByVal dStress As Double,
ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal
iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object,
ByVal iOutputInfo4 As Object)
Dim iOutput1 As AFGROW.OutputInfoInt
Dim iOutput2 As AFGROW.OutputInfoInt
```

```
Set iOutput1 = iOutputInfo1
If Model < 2000 Then Set iOutput2 = iOutputInfo2
If NewRun = True Then
j = 1
Do While ((j < 500) Or (Sheet4.Cells(j + 1, 1) = " "))
  Sheet4.Cells(j + 1, 1) = " "
  Sheet4.Cells(j + 1, 2) = " "
  Sheet4.Cells(j + 1, 3) = " "
  Sheet4.Cells(j + 1, 4) = " "
  Sheet4.Cells(j + 1, 5) = " "
  j = j + 1
Loop
Count = 0
End If
NewRun = False
If Count < 30000 Then
    Count = Count + 1
    Sheet4.Cells(Count + 1, 1) = dCycles
    Sheet4.Cells(Count + 1, 2) = iOutput1.dCrackLength
    Sheet4.Cells(Count + 1, 3) = iOutput1.dBeta
    If Model < 2000 Then
        Sheet4.Cells(Count + 1, 4) = iOutput2.dCrackLength
        Sheet4.Cells(Count + 1, 5) = iOutput2.dBeta
    End If
End If
Set iOutput1 = Nothing
End Sub
```

```
Private Sub mAFGROW_TransitionInfo(ByVal nType As Long, ByVal nReason As
Long, ByVal dStress As Double, ByVal dRStress As Double, ByVal dCycles As Double,
ByVal dPass As Long, ByVal iOutputInfo1 As Object, ByVal iOutputInfo2 As Object,
ByVal iOutputInfo3 As Object, ByVal iOutputInfo4 As Object)

Dim iOutput1 As AFGROW.OutputInfoInt

Dim iOutput2 As AFGROW.OutputInfoInt


Set iOutput1 = iOutputInfo1

If Model < 2000 Then Set iOutput2 = iOutputInfo2

NewRun = False

Sheet1.Cells(i, 11) = nType

Sheet1.Cells(i, 12) = dCycles

Sheet1.Cells(i, 13) = iOutput1.dCrackLength

Set iOutput1 = Nothing

End Sub


Private Sub UserForm_Activate()


Dim k As Integer

Dim UseBetaCorrection As Boolean

Dim UseTabularData As Boolean

Dim dParameter As Double

Dim bKmax As Boolean

Dim bNetSection As Boolean


Set mAFGROW = CreateObject("AFGROW.Application")

Set prefs = mAFGROW.PredictPreferences

Set user_beta = mAFGROW.UserDefinedBeta

Set table_lookup = mAFGROW.SetTabularLookupMaterial

bNetSection = Sheet1.Cells(2, 11)
```

```
bKmax = Sheet1.Cells(2, 12)
Call mAFGROW.PredictPreferences.SetPropagationLimits(False, False, bKmax, False,
bNetSection, 1.14, 10000000, 2000)
mAFGROW.PredictPreferences.bCycleByCycleSpCalc = Sheet1.Cells(3, 14)
mAFGROW.PredictPreferences.bCycleByCycleBetaCalc = Sheet1.Cells(3, 13)
prefs.bOutputToFile = False
mAFGROW.PredictPreferences.dGrowthIncrementPr = Sheet1.Cells(2, 15)
mAFGROW.Units = UnitsEnglish
mAFGROW.Visible = False


'set the user-defined beta information
UseBetaCorrection = Sheet1.Cells(2, 9)
If (UseBetaCorrection = True) Then
   mAFGROW.Model = uPartThrough
   j = 0
   Do While j < 3
   CArray(j) = Sheet2.Cells(j + 5, 2)
   k = 0
   Do While k < 3
   AArray(k) = Sheet2.Cells(4, k + 3)
   BaArray(j, k) = Sheet2.Cells(j + 5, k + 3)
   BcArray(j, k) = Sheet2.Cells(j + 10, k + 3)
   k = k + 1
   Loop
   j = j + 1
   Loop
   j = 0
   Do While j < 6
   BTArray(j, 0) = Sheet2.Cells(j + 16, 2)
```

```
   BTArray(j, 1) = Sheet2.Cells(j + 16, 3)
   j = j + 1
   Loop
   beta_result = user_beta.SetLineaInt(AArray, CArray, BaArray, BcArray)
   Dim middle As Variant
   middle = BTArray
   user_beta.aThroughCrackData = middle
End If

'Set the crack growth rate data using tabular look-up
UseTabularData = Sheet1.Cells(2, 10)
If (UseTabularData = True) Then
   k = 0
   Do While k < 4
   j = 0
   Do While j < 23
   If (k = 0 And j = 0) Then
      KTable(j, k) = 0#
   Else
      KTable(j, k) = Sheet3.Cells(j + 2, k + 2)
   End If
   j = j + 1
   Loop
   k = k + 1
   Loop
   table_lookup.sMaterialName = Sheet3.Cells(2, 6)
   Dim kVar As Variant
   kVar = KTable
```

```
    Call table_lookup.SetData(kVar, Sheet3.Cells(8, 7), Sheet3.Cells(8, 6), Sheet3.Cells(5, 7), Sheet3.Cells(5, 6), Sheet3.Cells(8, 9))

    table_lookup.dKc = Sheet3.Cells(5, 8)

    table_lookup.dKIc = Sheet3.Cells(5, 9)

    table_lookup.dPoissonsRatio = Sheet3.Cells(5, 10)

    table_lookup.dThermalEx = Sheet3.Cells(8, 8)

    table_lookup.dYield = Sheet3.Cells(8, 10)

    table_lookup.dYoungModulus = Sheet3.Cells(8, 11)

Else

    mAFGROW.SetHarterTMaterial.SetActive (1)


End If

End Sub


Public Sub Run()

Dim strSpectrumType As String


mAFGROW.SMF = Sheet1.Cells(i, 2)

strSpectrumType = Sheet1.Cells(2, 8)

If strSpectrumType = "CA" Then

    mAFGROW.ConstAmplitudeSpectrum (Sheet1.Cells(i, 3))

Else

    SpectrumFile = Sheet1.Cells(3, 2)

End If

Call mAFGROW.OpenSpectrumFile(SpectrumFile)

mAFGROW.Model = Sheet1.Cells(i, 4)

mAFGROW.CrackLengthC = Sheet1.Cells(i, 6)

'Get Retardation Parameters

If Sheet1.Cells(i, 5) = 0 Then
```

```
   dParameter = 0
ElseIf Sheet1.Cells(i, 5) = 2 Then
   dParameter = 0.36
ElseIf Sheet1.Cells(i, 5) = 1 Then
   dParameter = 3
ElseIf Sheet1.Cells(i, 5) = 3 Then
   dParameter = 0.86
End If
Call mAFGROW.SetRetardation(Sheet1.Cells(i, 5), dParameter, True, False)
'Geometry
W = Sheet1.Cells(2, 2)
t = Sheet1.Cells(2, 3)
D = Sheet1.Cells(2, 4)
Call mAFGROW.SetCrackedPlateWithHoleProp(W, t, D)
'Loads
Tension = Sheet1.Cells(2, 5)
Bending = Sheet1.Cells(2, 6)
Bearing = Sheet1.Cells(2, 7)
Call mAFGROW.SetLoad(Tension, Bending, Bearing)
NewRun = True
answer = mAFGROW.RunPredict
End Sub
```

Load Interaction Models

```
Public WithEvents mAFGROW As AFGROW.Application


Public prefs As PredictPreferences
Public user_beta As UserDefinedBeta
Public table_lookup As TabularLookupMaterial
```

```
Public i As Integer
Public j As Integer
Public k As Integer
Dim W As Double
Dim t As Double
Dim D As Double
Dim Tension As Double
Dim Bending As Double
Dim Bearing As Double
Dim Count As Integer
Dim AArray(2) As Double
Dim CArray(2) As Double
Dim BaArray(2, 2) As Double
Dim BcArray(2, 2) As Double
Dim BTArray(5, 1) As Double
Dim KTable(22, 3) As Double
Dim SpectrumFile As String
Dim beta_result As Integer
Dim answer As Boolean
Dim NewRun As Boolean

Private Sub mAFGROW_PredictFinished(ByVal result As Integer, ByVal dblCycles As
Double, ByVal dblKc As Double, ByVal dblKa As Double, ByVal dblKct As Double,
ByVal dblC As Double, ByVal dblA As Double, ByVal dblCt As Double)
Sheet1.Cells(i, 7) = dblCycles
Sheet1.Cells(i, 8) = dblC

If result = 0 Then
  Sheet1.Cells(i, 9) = "Completed Normally"
```

ElseIf result = 1 Then

  Sheet1.Cells(i, 9) = "After one pass of the spectrum, growth was less than 1.0e-13 Program halted"

ElseIf result = 2 Then

  Sheet1.Cells(i, 9) = "Maximum Number of passes exceeded"

ElseIf result = 3 Then

  Sheet1.Cells(i, 9) = "Crack Length Exceeded Stop Value"

ElseIf result = 4 Then

  Sheet1.Cells(i, 9) = "Cycle Count Exceeded Stop Value"

ElseIf result = 10 Then

  Sheet1.Cells(i, 9) = "No Spectrum file specified... Can not Predict"

ElseIf result = 11 Then

  Sheet1.Cells(i, 9) = "Beta table has zero length... Can not Predict"

ElseIf result = 12 Then

  Sheet1.Cells(i, 9) = "Repair patch applied and initiation on... Can not Predict! "

ElseIf result = 13 Then

  Sheet1.Cells(i, 9) = "Initiation is not allowed with this model. Can not Predict! "

ElseIf result = 14 Then

  Sheet1.Cells(i, 9) = "NASGRO equation Rhi value is to large"

ElseIf result = 20 Then

  Sheet1.Cells(i, 9) = "Wrong geometry for an oblique crack"

ElseIf result = 21 Then

  Sheet1.Cells(i, 9) = "The initial crack length in the thickness direction is greater than the input thickness. Check data.."

ElseIf result = 22 Then

  Sheet1.Cells(i, 9) = "Error in spectrum file(s)"

ElseIf result = 23 Then

  Sheet1.Cells(i, 9) = "Unable to open plotfile"

ElseIf result = 24 Then

```
  Sheet1.Cells(i, 9) = "Error in Initiation. Predict stopped"
ElseIf result = 25 Then
  Sheet1.Cells(i, 9) = "The number of cycles to initiation is greater than 2.e+9. Predict
stopped"
ElseIf result = 26 Then
  Sheet1.Cells(i, 9) = "Not enough memory to allocate spectrum"
ElseIf result = 27 Then
  Sheet1.Cells(i, 9) = "Only a BLOCKED spectrum may have more than one (1) cycle per
stress level"
ElseIf result = 28 Then
  Sheet1.Cells(i, 9) = "Program termination by user"
ElseIf result = -1 Then
  Sheet1.Cells(i, 9) = "Unknown Error"
End If


Sheet4.Cells(1, 8) = Count
i = i + 1
If Sheet1.Cells(i, 2) > 0 Then
   CurrentBox.Text = CStr(i)
   Call Run
Else:
   answer = mAFGROW.Quit
   Set mAFGROW = Nothing
   Unload UserForm1
End If
End Sub


Private Sub CommandButton1_Click()
i = CInt(StartBox.Text)
```

```
CurrentBox.Text = CStr(i)
Call Run
End Sub

Private Sub CommandButton2_Click()
j = 6
Do While Sheet1.Cells(j, 2) > 0
  Sheet1.Cells(j, 7) = 0
  Sheet1.Cells(j, 8) = 0
  Sheet1.Cells(j, 9) = " "
  j = j + 1
Loop
End Sub

Private Sub CommandButton3_Click()
    answer = mAFGROW.Quit
    Set mAFGROW = Nothing
    Unload UserForm1
End Sub

Private Sub mAFGROW_PredictInfo(ByVal Model As Long, ByVal dStress As Double,
ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal
iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object,
ByVal iOutputInfo4 As Object)
Dim iOutput1 As AFGROW.OutputInfoInt
Dim iOutput2 As AFGROW.OutputInfoInt

Set iOutput1 = iOutputInfo1
If Model < 2000 Then Set iOutput2 = iOutputInfo2
If NewRun = True Then
```

```
j = 1
Do While ((j < 500) Or (Sheet4.Cells(j + 1, 1) = " "))
  Sheet4.Cells(j + 1, 1) = " "
  Sheet4.Cells(j + 1, 2) = " "
  Sheet4.Cells(j + 1, 3) = " "
  Sheet4.Cells(j + 1, 4) = " "
  Sheet4.Cells(j + 1, 5) = " "
  j = j + 1
Loop
Count = 0
End If
NewRun = False
If Count < 30000 Then
    Count = Count + 1
    Sheet4.Cells(Count + 1, 1) = dCycles
    Sheet4.Cells(Count + 1, 2) = iOutput1.dCrackLength
    Sheet4.Cells(Count + 1, 3) = iOutput1.dBeta
    If Model < 2000 Then
        Sheet4.Cells(Count + 1, 4) = iOutput2.dCrackLength
        Sheet4.Cells(Count + 1, 5) = iOutput2.dBeta
    End If
End If
Set iOutput1 = Nothing
End Sub

Private Sub mAFGROW_TransitionInfo(ByVal nType As Long, ByVal nReason As
Long, ByVal dStress As Double, ByVal dRStress As Double, ByVal dCycles As Double,
ByVal dPass As Long, ByVal iOutputInfo1 As Object, ByVal iOutputInfo2 As Object,
ByVal iOutputInfo3 As Object, ByVal iOutputInfo4 As Object)
Dim iOutput1 As AFGROW.OutputInfoInt
```

```
Dim iOutput2 As AFGROW.OutputInfoInt

Set iOutput1 = iOutputInfo1
If Model < 2000 Then Set iOutput2 = iOutputInfo2
NewRun = False
Sheet1.Cells(i, 11) = nType
Sheet1.Cells(i, 12) = dCycles
Sheet1.Cells(i, 13) = iOutput1.dCrackLength
Set iOutput1 = Nothing
End Sub

Private Sub UserForm_Activate()

Dim k As Integer
Dim UseBetaCorrection As Boolean
Dim UseTabularData As Boolean
Dim dParameter As Double

Set mAFGROW = CreateObject("AFGROW.Application")
Set prefs = mAFGROW.PredictPreferences
Set user_beta = mAFGROW.UserDefinedBeta
Set table_lookup = mAFGROW.SetTabularLookupMaterial
Call mAFGROW.PredictPreferences.SetPropagationLimits(False, False, True, False,
True, 1.14, 10000000, 2000)
mAFGROW.PredictPreferences.bCycleByCycleSpCalc = Sheet1.Cells(3, 13)
mAFGROW.PredictPreferences.bCycleByCycleBetaCalc = Sheet1.Cells(3, 12)
prefs.bOutputToFile = False
dParameter = Sheet1.Cells(4, 11)
Call mAFGROW.SetRetardation(Sheet1.Cells(2, 11), dParameter, True, False)
```

```
mAFGROW.PredictPreferences.dGrowthIncrementPr = Sheet1.Cells(2, 14)
mAFGROW.Units = UnitsEnglish
mAFGROW.Visible = False

'set the user-defined beta information
UseBetaCorrection = Sheet1.Cells(2, 9)
If (UseBetaCorrection = True) Then
   mAFGROW.Model = uPartThrough
   j = 0
   Do While j < 3
   CArray(j) = Sheet2.Cells(j + 5, 2)
   k = 0
   Do While k < 3
   AArray(k) = Sheet2.Cells(4, k + 3)
   BaArray(j, k) = Sheet2.Cells(j + 5, k + 3)
   BcArray(j, k) = Sheet2.Cells(j + 10, k + 3)
   k = k + 1
   Loop
   j = j + 1
   Loop
   j = 0
   Do While j < 6
   BTArray(j, 0) = Sheet2.Cells(j + 16, 2)
   BTArray(j, 1) = Sheet2.Cells(j + 16, 3)
   j = j + 1
   Loop
   beta_result = user_beta.SetLineaInt(AArray, CArray, BaArray, BcArray)
   Dim middle As Variant
```

```
   middle = BTArray
   user_beta.aThroughCrackData = middle
End If

'Set the crack growth rate data using tabular look-up
UseTabularData = Sheet1.Cells(2, 10)
If (UseTabularData = True) Then
   k = 0
   Do While k < 4
   j = 0
   Do While j < 23
   If (k = 0 And j = 0) Then
      KTable(j, k) = 0#
   Else
      KTable(j, k) = Sheet3.Cells(j + 2, k + 2)
   End If
   j = j + 1
   Loop
   k = k + 1
   Loop
   table_lookup.sMaterialName = Sheet3.Cells(2, 6)
   Dim kVar As Variant
   kVar = KTable
   Call table_lookup.SetData(kVar, Sheet3.Cells(8, 7), Sheet3.Cells(8, 6), Sheet3.Cells(5,
7), Sheet3.Cells(5, 6), Sheet3.Cells(8, 9))
   table_lookup.dKc = Sheet3.Cells(5, 8)
   table_lookup.dKIc = Sheet3.Cells(5, 9)
   table_lookup.dPoissonsRatio = Sheet3.Cells(5, 10)
   table_lookup.dThermalEx = Sheet3.Cells(8, 8)
```

```
    table_lookup.dYield = Sheet3.Cells(8, 10)
    table_lookup.dYoungModulus = Sheet3.Cells(8, 11)
Else
    mAFGROW.SetHarterTMaterial.SetActive (1)

End If
End Sub

Public Sub Run()
Dim strSpectrumType As String

mAFGROW.SMF = Sheet1.Cells(i, 2)
strSpectrumType = Sheet1.Cells(2, 8)
If strSpectrumType = "CA" Then
    mAFGROW.ConstAmplitudeSpectrum (Sheet1.Cells(i, 3))
Else
    SpectrumFile = Sheet1.Cells(3, 2)
End If
Call mAFGROW.OpenSpectrumFile(SpectrumFile)
mAFGROW.Model = Sheet1.Cells(i, 4)
mAFGROW.CrackLengthC = Sheet1.Cells(i, 6)
'Geometry
W = Sheet1.Cells(2, 2)
t = Sheet1.Cells(2, 3)
D = Sheet1.Cells(2, 4)
Call mAFGROW.SetCrackedPlateWithHoleProp(W, t, D)
'Loads
Tension = Sheet1.Cells(2, 5)
```

```
Bending = Sheet1.Cells(2, 6)
Bearing = Sheet1.Cells(2, 7)
Call mAFGROW.SetLoad(Tension, Bending, Bearing)
prefs.sOutputFileName = Sheet1.Cells(i, 10)
NewRun = True
answer = mAFGROW.RunPredict
End Sub
```

Crack Growth Rate Data

```
Public WithEvents mAFGROW As AFGROW.Application


Public prefs As PredictPreferences
Public user_beta As UserDefinedBeta
Public table_lookup As TabularLookupMaterial
Public i As Integer
Public j As Integer
Public k As Integer
Dim W As Double
Dim t As Double
Dim D As Double
Dim Tension As Double
Dim Bending As Double
Dim Bearing As Double
Dim Count As Integer
Dim AArray(2) As Double
Dim CArray(2) As Double
Dim BaArray(2, 2) As Double
Dim BcArray(2, 2) As Double
Dim BTArray(5, 1) As Double
```

```
Dim KTable(13, 2) As Double

Dim SpectrumFile As String

Dim beta_result As Integer

Dim answer As Boolean

Dim NewRun As Boolean


Private Sub mAFGROW_PredictFinished(ByVal result As Integer, ByVal dblCycles As
Double, ByVal dblKc As Double, ByVal dblKa As Double, ByVal dblKct As Double,
ByVal dblC As Double, ByVal dblA As Double, ByVal dblCt As Double)

Sheet1.Cells(i, 7) = dblCycles

Sheet1.Cells(i, 8) = dblC


If result = 0 Then

  Sheet1.Cells(i, 9) = "Completed Normally"

ElseIf result = 1 Then

  Sheet1.Cells(i, 9) = "After one pass of the spectrum, growth was less than 1.0e-13
Program halted"

ElseIf result = 2 Then

  Sheet1.Cells(i, 9) = "Maximum Number of passes exceeded"

ElseIf result = 3 Then

  Sheet1.Cells(i, 9) = "Crack Length Exceeded Stop Value"

ElseIf result = 4 Then

  Sheet1.Cells(i, 9) = "Cycle Count Exceeded Stop Value"

ElseIf result = 10 Then

  Sheet1.Cells(i, 9) = "No Spectrum file specified... Can not Predict"

ElseIf result = 11 Then

  Sheet1.Cells(i, 9) = "Beta table has zero length... Can not Predict"

ElseIf result = 12 Then

  Sheet1.Cells(i, 9) = "Repair patch applied and initiation on...  Can not Predict! "

ElseIf result = 13 Then
```

```
  Sheet1.Cells(i, 9) = "Initiation is not allowed with this model. Can not Predict! "
ElseIf result = 14 Then
  Sheet1.Cells(i, 9) = "NASGRO equation Rhi value is to large"
ElseIf result = 20 Then
  Sheet1.Cells(i, 9) = "Wrong geometry for an oblique crack"
ElseIf result = 21 Then
  Sheet1.Cells(i, 9) = "The initial crack length in the thickness direction is greater than the input thickness.  Check data.."
ElseIf result = 22 Then
  Sheet1.Cells(i, 9) = "Error in spectrum file(s)"
ElseIf result = 23 Then
  Sheet1.Cells(i, 9) = "Unable to open plotfile"
ElseIf result = 24 Then
  Sheet1.Cells(i, 9) = "Error in Initiation. Predict stopped"
ElseIf result = 25 Then
  Sheet1.Cells(i, 9) = "The number of cycles to initiation is greater than 2.e+9. Predict stopped"
ElseIf result = 26 Then
  Sheet1.Cells(i, 9) = "Not enough memory to allocate spectrum"
ElseIf result = 27 Then
  Sheet1.Cells(i, 9) = "Only a BLOCKED spectrum may have more than one (1) cycle per stress level"
ElseIf result = 28 Then
  Sheet1.Cells(i, 9) = "Program termination by user"
ElseIf result = -1 Then
  Sheet1.Cells(i, 9) = "Unknown Error"
End If


Sheet4.Cells(1, 8) = Count
i = i + 1
```

```
If Sheet1.Cells(i, 2) > 0 Then
   CurrentBox.Text = CStr(i)
   Call Run
Else:
   answer = mAFGROW.Quit
   Set mAFGROW = Nothing
   Unload UserForm1
End If
End Sub

Private Sub CommandButton1_Click()
i = CInt(StartBox.Text)
CurrentBox.Text = CStr(i)
Call Run
End Sub

Private Sub CommandButton2_Click()
j = 6
Do While Sheet1.Cells(j, 2) > 0
  Sheet1.Cells(j, 7) = 0
  Sheet1.Cells(j, 8) = 0
  Sheet1.Cells(j, 9) = " "
  j = j + 1
Loop
End Sub

Private Sub CommandButton3_Click()
   answer = mAFGROW.Quit
```

```
    Set mAFGROW = Nothing
    Unload UserForm1
End Sub

Private Sub mAFGROW_PredictInfo(ByVal Model As Long, ByVal dStress As Double,
ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal
iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object,
ByVal iOutputInfo4 As Object)
Dim iOutput1 As AFGROW.OutputInfoInt
Dim iOutput2 As AFGROW.OutputInfoInt

Set iOutput1 = iOutputInfo1
If Model < 2000 Then Set iOutput2 = iOutputInfo2
If NewRun = True Then
j = 1
Do While ((j < 500) Or (Sheet4.Cells(j + 1, 1) = " "))
  Sheet4.Cells(j + 1, 1) = " "
  Sheet4.Cells(j + 1, 2) = " "
  Sheet4.Cells(j + 1, 3) = " "
  Sheet4.Cells(j + 1, 4) = " "
  Sheet4.Cells(j + 1, 5) = " "
  j = j + 1
Loop
Count = 0
End If
NewRun = False
If Count < 30000 Then
    Count = Count + 1
    Sheet4.Cells(Count + 1, 1) = dCycles
    Sheet4.Cells(Count + 1, 2) = iOutput1.dCrackLength
```

```
    Sheet4.Cells(Count + 1, 3) = iOutput1.dBeta
    If Model < 2000 Then
        Sheet4.Cells(Count + 1, 4) = iOutput2.dCrackLength
        Sheet4.Cells(Count + 1, 5) = iOutput2.dBeta
    End If
End If
Set iOutput1 = Nothing
End Sub

Private Sub mAFGROW_TransitionInfo(ByVal nType As Long, ByVal nReason As Long, ByVal dStress As Double, ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object, ByVal iOutputInfo4 As Object)
Dim iOutput1 As AFGROW.OutputInfoInt
Dim iOutput2 As AFGROW.OutputInfoInt

Set iOutput1 = iOutputInfo1
If Model < 2000 Then Set iOutput2 = iOutputInfo2
NewRun = False
Sheet1.Cells(i, 11) = nType
Sheet1.Cells(i, 12) = dCycles
Sheet1.Cells(i, 13) = iOutput1.dCrackLength
Set iOutput1 = Nothing
End Sub

Private Sub UserForm_Activate()

Dim k As Integer
Dim UseBetaCorrection As Boolean
Dim UseTabularData As Boolean
```

```
Dim dParameter As Double
Dim bKmax As Boolean
Dim bNetSection As Boolean

Set mAFGROW = CreateObject("AFGROW.Application")
Set prefs = mAFGROW.PredictPreferences
Set user_beta = mAFGROW.UserDefinedBeta
Set table_lookup = mAFGROW.SetTabularLookupMaterial
bNetSection = Sheet1.Cells(2, 11)
bKmax = Sheet1.Cells(2, 12)
Call mAFGROW.PredictPreferences.SetPropagationLimits(False, False, bKmax, False,
bNetSection, 1.14, 10000000, 2000)
mAFGROW.PredictPreferences.bCycleByCycleSpCalc = Sheet1.Cells(3, 14)
mAFGROW.PredictPreferences.bCycleByCycleBetaCalc = Sheet1.Cells(3, 13)
prefs.bOutputToFile = False
If mAFGROW.PredictPreferences.bCycleByCycleBetaCalc = False Then
   mAFGROW.PredictPreferences.dGrowthIncrementPr = Sheet1.Cells(2, 15)
End If
mAFGROW.Units = UnitsEnglish
mAFGROW.Visible = False

'set the user-defined beta information
UseBetaCorrection = Sheet1.Cells(2, 9)
If (UseBetaCorrection = True) Then
   mAFGROW.Model = uPartThrough
   j = 0
   Do While j < 3
   CArray(j) = Sheet2.Cells(j + 5, 2)
   k = 0
```

```
    Do While k < 3
    AArray(k) = Sheet2.Cells(4, k + 3)
    BaArray(j, k) = Sheet2.Cells(j + 5, k + 3)
    BcArray(j, k) = Sheet2.Cells(j + 10, k + 3)
    k = k + 1
    Loop
    j = j + 1
    Loop
    j = 0
    Do While j < 6
    BTArray(j, 0) = Sheet2.Cells(j + 16, 2)
    BTArray(j, 1) = Sheet2.Cells(j + 16, 3)
    j = j + 1
    Loop
    beta_result = user_beta.SetLineaInt(AArray, CArray, BaArray, BcArray)
    Dim middle As Variant
    middle = BTArray
    user_beta.aThroughCrackData = middle
End If

'Set the crack growth rate data using tabular look-up
UseTabularData = Sheet1.Cells(2, 10)
If (UseTabularData = True) Then
    k = 0
    Do While k < 3
    j = 0
    Do While j < 14
    If (k = 0 And j = 0) Then
```

```
        KTable(j, k) = 0#
    Else
        KTable(j, k) = Sheet3.Cells(j + 2, k + 2)
    End If
    j = j + 1
    Loop
    k = k + 1
    Loop
    table_lookup.sMaterialName = Sheet3.Cells(2, 6)
    Dim kVar As Variant
    kVar = KTable
    Call table_lookup.SetData(kVar, Sheet3.Cells(8, 7), Sheet3.Cells(8, 6), Sheet3.Cells(5,
7), Sheet3.Cells(5, 6), Sheet3.Cells(8, 9))
    table_lookup.dKc = Sheet3.Cells(5, 8)
    table_lookup.dKIc = Sheet3.Cells(5, 9)
    table_lookup.dPoissonsRatio = Sheet3.Cells(5, 10)
    table_lookup.dThermalEx = Sheet3.Cells(8, 8)
    table_lookup.dYield = Sheet3.Cells(8, 10)
    table_lookup.dYoungModulus = Sheet3.Cells(8, 11)
Else
    mAFGROW.SetHarterTMaterial.SetActive (1)


End If
End Sub


Public Sub Run()
Dim strSpectrumType As String


mAFGROW.SMF = Sheet1.Cells(i, 2)
```

```
strSpectrumType = Sheet1.Cells(2, 8)
If strSpectrumType = "CA" Then
   mAFGROW.ConstAmplitudeSpectrum (Sheet1.Cells(i, 3))
Else
   SpectrumFile = Sheet1.Cells(3, 2)
   Call mAFGROW.OpenSpectrumFile(SpectrumFile)
End If
mAFGROW.Model = Sheet1.Cells(i, 4)
mAFGROW.CrackLengthC = Sheet1.Cells(i, 6)
'Get Retardation Parameters
If Sheet1.Cells(i, 5) = 0 Then
   dParameter = 0
ElseIf Sheet1.Cells(i, 5) = 2 Then
   dParameter = 0.36
ElseIf Sheet1.Cells(i, 5) = 1 Then
   dParameter = 3
ElseIf Sheet1.Cells(i, 5) = 3 Then
   dParameter = 0.86
End If
Call mAFGROW.SetRetardation(Sheet1.Cells(i, 5), dParameter, True, False)
'Geometry
W = Sheet1.Cells(2, 2)
t = Sheet1.Cells(2, 3)
D = Sheet1.Cells(2, 4)
Call mAFGROW.SetCrackedPlateWithHoleProp(W, t, D)
'Loads
Tension = Sheet1.Cells(2, 5)
Bending = Sheet1.Cells(2, 6)
```

```
Bearing = Sheet1.Cells(2, 7)
Call mAFGROW.SetLoad(Tension, Bending, Bearing)
NewRun = True
answer = mAFGROW.RunPredict
End Sub
```

Threshold Stress Intensity Factor

```
Public WithEvents mAFGROW As AFGROW.Application

Public prefs As PredictPreferences
Public user_beta As UserDefinedBeta
Public table_lookup As TabularLookupMaterial
Public i As Integer
Public j As Integer
Public k As Integer
Dim W As Double
Dim t As Double
Dim D As Double
Dim Tension As Double
Dim Bending As Double
Dim Bearing As Double
Dim Count As Integer
Dim AArray(2) As Double
Dim CArray(2) As Double
Dim BaArray(2, 2) As Double
Dim BcArray(2, 2) As Double
Dim BTArray(5, 1) As Double
Dim KTable(22, 3) As Double
Dim SpectrumFile As String
```

```
Dim beta_result As Integer

Dim answer As Boolean

Dim NewRun As Boolean


Private Sub mAFGROW_PredictFinished(ByVal result As Integer, ByVal dblCycles As
Double, ByVal dblKc As Double, ByVal dblKa As Double, ByVal dblKct As Double,
ByVal dblC As Double, ByVal dblA As Double, ByVal dblCt As Double)

Sheet1.Cells(i, 7) = dblCycles

Sheet1.Cells(i, 8) = dblC


If result = 0 Then

  Sheet1.Cells(i, 9) = "Completed Normally"

ElseIf result = 1 Then

  Sheet1.Cells(i, 9) = "After one pass of the spectrum, growth was less than 1.0e-13
Program halted"

ElseIf result = 2 Then

  Sheet1.Cells(i, 9) = "Maximum Number of passes exceeded"

ElseIf result = 3 Then

  Sheet1.Cells(i, 9) = "Crack Length Exceeded Stop Value"

ElseIf result = 4 Then

  Sheet1.Cells(i, 9) = "Cycle Count Exceeded Stop Value"

ElseIf result = 10 Then

  Sheet1.Cells(i, 9) = "No Spectrum file specified... Can not Predict"

ElseIf result = 11 Then

  Sheet1.Cells(i, 9) = "Beta table has zero length... Can not Predict"

ElseIf result = 12 Then

  Sheet1.Cells(i, 9) = "Repair patch applied and initiation on...  Can not Predict! "

ElseIf result = 13 Then

  Sheet1.Cells(i, 9) = "Initiation is not allowed with this model. Can not Predict! "

ElseIf result = 14 Then
```

```
  Sheet1.Cells(i, 9) = "NASGRO equation Rhi value is to large"
ElseIf result = 20 Then
  Sheet1.Cells(i, 9) = "Wrong geometry for an oblique crack"
ElseIf result = 21 Then
  Sheet1.Cells(i, 9) = "The initial crack length in the thickness direction is greater than the
input thickness.  Check data.."
ElseIf result = 22 Then
  Sheet1.Cells(i, 9) = "Error in spectrum file(s)"
ElseIf result = 23 Then
  Sheet1.Cells(i, 9) = "Unable to open plotfile"
ElseIf result = 24 Then
  Sheet1.Cells(i, 9) = "Error in Initiation. Predict stopped"
ElseIf result = 25 Then
  Sheet1.Cells(i, 9) = "The number of cycles to initiation is greater than 2.e+9. Predict
stopped"
ElseIf result = 26 Then
  Sheet1.Cells(i, 9) = "Not enough memory to allocate spectrum"
ElseIf result = 27 Then
  Sheet1.Cells(i, 9) = "Only a BLOCKED spectrum may have more than one (1) cycle per
stress level"
ElseIf result = 28 Then
  Sheet1.Cells(i, 9) = "Program termination by user"
ElseIf result = -1 Then
  Sheet1.Cells(i, 9) = "Unknown Error"
End If


Sheet4.Cells(1, 8) = Count
i = i + 1
If Sheet1.Cells(i, 2) > 0 Then
   CurrentBox.Text = CStr(i)
```

```
    Call Run
Else:
    answer = mAFGROW.Quit
    Set mAFGROW = Nothing
    Unload UserForm1
End If
End Sub

Private Sub CommandButton1_Click()
i = CInt(StartBox.Text)
CurrentBox.Text = CStr(i)
Call Run
End Sub

Private Sub CommandButton2_Click()
j = 6
Do While Sheet1.Cells(j, 2) > 0
  Sheet1.Cells(j, 7) = 0
  Sheet1.Cells(j, 8) = 0
  Sheet1.Cells(j, 9) = " "
  j = j + 1
Loop
End Sub

Private Sub CommandButton3_Click()
    answer = mAFGROW.Quit
    Set mAFGROW = Nothing
    Unload UserForm1
```

```
End Sub


Private Sub mAFGROW_PredictInfo(ByVal Model As Long, ByVal dStress As Double,
ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal
iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object,
ByVal iOutputInfo4 As Object)

Dim iOutput1 As AFGROW.OutputInfoInt

Dim iOutput2 As AFGROW.OutputInfoInt


Set iOutput1 = iOutputInfo1

If Model < 2000 Then Set iOutput2 = iOutputInfo2

If NewRun = True Then

j = 1

Do While ((j < 500) Or (Sheet4.Cells(j + 1, 1) = " "))

  Sheet4.Cells(j + 1, 1) = " "

  Sheet4.Cells(j + 1, 2) = " "

  Sheet4.Cells(j + 1, 3) = " "

  Sheet4.Cells(j + 1, 4) = " "

  Sheet4.Cells(j + 1, 5) = " "

  j = j + 1

Loop

Count = 0

End If

NewRun = False

If Count < 30000 Then

    Count = Count + 1

    Sheet4.Cells(Count + 1, 1) = dCycles

    Sheet4.Cells(Count + 1, 2) = iOutput1.dCrackLength

    Sheet4.Cells(Count + 1, 3) = iOutput1.dBeta

    If Model < 2000 Then
```

```
        Sheet4.Cells(Count + 1, 4) = iOutput2.dCrackLength
        Sheet4.Cells(Count + 1, 5) = iOutput2.dBeta
    End If
End If
Set iOutput1 = Nothing
End Sub

Private Sub mAFGROW_TransitionInfo(ByVal nType As Long, ByVal nReason As Long, ByVal dStress As Double, ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object, ByVal iOutputInfo4 As Object)
Dim iOutput1 As AFGROW.OutputInfoInt
Dim iOutput2 As AFGROW.OutputInfoInt

Set iOutput1 = iOutputInfo1
If Model < 2000 Then Set iOutput2 = iOutputInfo2
NewRun = False
Sheet1.Cells(i, 11) = nType
Sheet1.Cells(i, 12) = dCycles
Sheet1.Cells(i, 13) = iOutput1.dCrackLength
Set iOutput1 = Nothing
End Sub

Private Sub UserForm_Activate()

Dim k As Integer
Dim UseBetaCorrection As Boolean
Dim UseTabularData As Boolean
Dim dParameter As Double
Dim bKmax As Boolean
```

```
Dim bNetSection As Boolean


Set mAFGROW = CreateObject("AFGROW.Application")
Set prefs = mAFGROW.PredictPreferences
Set user_beta = mAFGROW.UserDefinedBeta
Set table_lookup = mAFGROW.SetTabularLookupMaterial
bNetSection = Sheet1.Cells(2, 11)
bKmax = Sheet1.Cells(2, 12)
Call mAFGROW.PredictPreferences.SetPropagationLimits(False, True, bKmax, False,
bNetSection, 1.14, 10000000, 2000)
mAFGROW.PredictPreferences.bCycleByCycleSpCalc = Sheet1.Cells(3, 14)
mAFGROW.PredictPreferences.bCycleByCycleBetaCalc = Sheet1.Cells(3, 13)
prefs.bOutputToFile = False
mAFGROW.PredictPreferences.dGrowthIncrementPr = Sheet1.Cells(2, 15)
mAFGROW.Units = UnitsEnglish
mAFGROW.Visible = False


'set the user-defined beta information
UseBetaCorrection = Sheet1.Cells(2, 9)
If (UseBetaCorrection = True) Then
   mAFGROW.Model = uPartThrough
   j = 0
   Do While j < 3
   CArray(j) = Sheet2.Cells(j + 5, 2)
   k = 0
   Do While k < 3
   AArray(k) = Sheet2.Cells(4, k + 3)
   BaArray(j, k) = Sheet2.Cells(j + 5, k + 3)
   BcArray(j, k) = Sheet2.Cells(j + 10, k + 3)
```

```
    k = k + 1
    Loop
    j = j + 1
    Loop
    j = 0
    Do While j < 6
    BTArray(j, 0) = Sheet2.Cells(j + 16, 2)
    BTArray(j, 1) = Sheet2.Cells(j + 16, 3)
    j = j + 1
    Loop
    beta_result = user_beta.SetLineaInt(AArray, CArray, BaArray, BcArray)
    Dim middle As Variant
    middle = BTArray
    user_beta.aThroughCrackData = middle
End If

'Set the crack growth rate data using tabular look-up
UseTabularData = Sheet1.Cells(2, 10)
If (UseTabularData = True) Then
    k = 0
    Do While k < 4
    j = 0
    Do While j < 23
    If (k = 0 And j = 0) Then
        KTable(j, k) = 0#
    Else
        KTable(j, k) = Sheet3.Cells(j + 2, k + 2)
    End If
```

```
    j = j + 1
    Loop
    k = k + 1
    Loop
    table_lookup.sMaterialName = Sheet3.Cells(2, 6)
    Dim kVar As Variant
    kVar = KTable
    Call table_lookup.SetData(kVar, Sheet3.Cells(8, 7), Sheet3.Cells(8, 6), Sheet3.Cells(5, 
7), Sheet3.Cells(5, 6), Sheet3.Cells(8, 9))
    table_lookup.dKc = Sheet3.Cells(5, 8)
    table_lookup.dKIc = Sheet3.Cells(5, 9)
    table_lookup.dPoissonsRatio = Sheet3.Cells(5, 10)
    table_lookup.dThermalEx = Sheet3.Cells(8, 8)
    table_lookup.dYield = Sheet3.Cells(8, 10)
    table_lookup.dYoungModulus = Sheet3.Cells(8, 11)
Else
    mAFGROW.SetHarterTMaterial.SetActive (1)


End If
End Sub


Public Sub Run()
Dim strSpectrumType As String
Dim k As Integer
Dim UseTabularData As Boolean
Dim VaryTabularData As Boolean


mAFGROW.SMF = Sheet1.Cells(i, 2)
strSpectrumType = Sheet1.Cells(2, 8)
```

```
If strSpectrumType = "CA" Then
    mAFGROW.ConstAmplitudeSpectrum (Sheet1.Cells(i, 3))
Else
    SpectrumFile = Sheet1.Cells(3, 2)
End If
Call mAFGROW.OpenSpectrumFile(SpectrumFile)
mAFGROW.Model = Sheet1.Cells(i, 4)
mAFGROW.CrackLengthC = Sheet1.Cells(i, 6)
'Set the crack growth rate data using tabular look-up or Harter T
VaryMaterialData = Sheet1.Cells(2, 17)
If (VaryMaterialData = True) Then
    UseTabularData = Sheet1.Cells(2, 10)
    If (UseTabularData = True) Then
        k = 0
        Do While k < 4
        j = 0
        Do While j < 23
        If (k = 0 And j = 0) Then
            KTable(j, k) = 0#
        Else
            KTable(j, k) = Sheet3.Cells(j + 2, k + 2)
        End If
        j = j + 1
        Loop
        k = k + 1
        Loop
        table_lookup.sMaterialName = Sheet3.Cells(2, 6)
        Dim kVar As Variant
```

```
        kVar = KTable
        Call table_lookup.SetData(kVar, Sheet3.Cells(8, 7), Sheet3.Cells(8, 6),
Sheet3.Cells(5, 7), Sheet3.Cells(5, 6), Sheet1.Cells(i, 13))
        table_lookup.dKc = Sheet1.Cells(i, 11)
        table_lookup.dKIc = Sheet1.Cells(i, 12)
        table_lookup.dPoissonsRatio = Sheet3.Cells(5, 10)
        table_lookup.dThermalEx = Sheet3.Cells(8, 8)
        table_lookup.dYield = Sheet3.Cells(8, 10)
        table_lookup.dYoungModulus = Sheet3.Cells(8, 11)
    Else
        mAFGROW.SetHarterTMaterial.SetActive (1)
    End If
End If

'Get Retardation Parameters
If Sheet1.Cells(i, 5) = 0 Then
    dParameter = 0
ElseIf Sheet1.Cells(i, 5) = 2 Then
    dParameter = 0.36
ElseIf Sheet1.Cells(i, 5) = 1 Then
    dParameter = 3
ElseIf Sheet1.Cells(i, 5) = 3 Then
    dParameter = 0.86
End If
Call mAFGROW.SetRetardation(Sheet1.Cells(i, 5), dParameter, True, False)
'Geometry
W = Sheet1.Cells(2, 2)
t = Sheet1.Cells(2, 3)
D = Sheet1.Cells(2, 4)
```

```
Call mAFGROW.SetCrackedPlateWithHoleProp(W, t, D)
'Loads
Tension = Sheet1.Cells(2, 5)
Bending = Sheet1.Cells(2, 6)
Bearing = Sheet1.Cells(2, 7)
Call mAFGROW.SetLoad(Tension, Bending, Bearing)
NewRun = True
answer = mAFGROW.RunPredict
End Sub
```

Yield Stress

```
Public WithEvents mAFGROW As AFGROW.Application

Public prefs As PredictPreferences
Public user_beta As UserDefinedBeta
Public table_lookup As TabularLookupMaterial
Public i As Integer
Public j As Integer
Public k As Integer
Dim W As Double
Dim t As Double
Dim D As Double
Dim Tension As Double
Dim Bending As Double
Dim Bearing As Double
Dim Count As Integer
Dim AArray(2) As Double
Dim CArray(2) As Double
Dim BaArray(2, 2) As Double
```

```
Dim BcArray(2, 2) As Double

Dim BTArray(5, 1) As Double

Dim KTable(22, 3) As Double

Dim SpectrumFile As String

Dim beta_result As Integer

Dim answer As Boolean

Dim NewRun As Boolean


Private Sub mAFGROW_PredictFinished(ByVal result As Integer, ByVal dblCycles As
Double, ByVal dblKc As Double, ByVal dblKa As Double, ByVal dblKct As Double,
ByVal dblC As Double, ByVal dblA As Double, ByVal dblCt As Double)

Sheet1.Cells(i, 7) = dblCycles

Sheet1.Cells(i, 8) = dblC


If result = 0 Then

  Sheet1.Cells(i, 9) = "Completed Normally"

ElseIf result = 1 Then

  Sheet1.Cells(i, 9) = "After one pass of the spectrum, growth was less than 1.0e-13
Program halted"

ElseIf result = 2 Then

  Sheet1.Cells(i, 9) = "Maximum Number of passes exceeded"

ElseIf result = 3 Then

  Sheet1.Cells(i, 9) = "Crack Length Exceeded Stop Value"

ElseIf result = 4 Then

  Sheet1.Cells(i, 9) = "Cycle Count Exceeded Stop Value"

ElseIf result = 10 Then

  Sheet1.Cells(i, 9) = "No Spectrum file specified... Can not Predict"

ElseIf result = 11 Then

  Sheet1.Cells(i, 9) = "Beta table has zero length... Can not Predict"

ElseIf result = 12 Then
```

```
  Sheet1.Cells(i, 9) = "Repair patch applied and initiation on...  Can not Predict! "
ElseIf result = 13 Then
  Sheet1.Cells(i, 9) = "Initiation is not allowed with this model. Can not Predict! "
ElseIf result = 14 Then
  Sheet1.Cells(i, 9) = "NASGRO equation Rhi value is to large"
ElseIf result = 20 Then
  Sheet1.Cells(i, 9) = "Wrong geometry for an oblique crack"
ElseIf result = 21 Then
  Sheet1.Cells(i, 9) = "The initial crack length in the thickness direction is greater than the input thickness.  Check data.."
ElseIf result = 22 Then
  Sheet1.Cells(i, 9) = "Error in spectrum file(s)"
ElseIf result = 23 Then
  Sheet1.Cells(i, 9) = "Unable to open plotfile"
ElseIf result = 24 Then
  Sheet1.Cells(i, 9) = "Error in Initiation. Predict stopped"
ElseIf result = 25 Then
  Sheet1.Cells(i, 9) = "The number of cycles to initiation is greater than 2.e+9. Predict stopped"
ElseIf result = 26 Then
  Sheet1.Cells(i, 9) = "Not enough memory to allocate spectrum"
ElseIf result = 27 Then
  Sheet1.Cells(i, 9) = "Only a BLOCKED spectrum may have more than one (1) cycle per stress level"
ElseIf result = 28 Then
  Sheet1.Cells(i, 9) = "Program termination by user"
ElseIf result = -1 Then
  Sheet1.Cells(i, 9) = "Unknown Error"
End If
```

```
Sheet4.Cells(1, 8) = Count
i = i + 1
If Sheet1.Cells(i, 2) > 0 Then
   CurrentBox.Text = CStr(i)
   Call Run
Else:
   answer = mAFGROW.Quit
   Set mAFGROW = Nothing
   Unload UserForm1
End If
End Sub

Private Sub CommandButton1_Click()
i = CInt(StartBox.Text)
CurrentBox.Text = CStr(i)
Call Run
End Sub

Private Sub CommandButton2_Click()
j = 6
Do While Sheet1.Cells(j, 2) > 0
  Sheet1.Cells(j, 7) = 0
  Sheet1.Cells(j, 8) = 0
  Sheet1.Cells(j, 9) = " "
  j = j + 1
Loop
End Sub
```

```
Private Sub CommandButton3_Click()
    answer = mAFGROW.Quit
    Set mAFGROW = Nothing
    Unload UserForm1
End Sub


Private Sub mAFGROW_PredictInfo(ByVal Model As Long, ByVal dStress As Double,
ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal
iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object,
ByVal iOutputInfo4 As Object)
Dim iOutput1 As AFGROW.OutputInfoInt
Dim iOutput2 As AFGROW.OutputInfoInt
Set iOutput1 = iOutputInfo1
If Model < 2000 Then Set iOutput2 = iOutputInfo2
If NewRun = True Then
j = 1
Do While ((j < 500) Or (Sheet4.Cells(j + 1, 1) = " "))
  Sheet4.Cells(j + 1, 1) = " "
  Sheet4.Cells(j + 1, 2) = " "
  Sheet4.Cells(j + 1, 3) = " "
  Sheet4.Cells(j + 1, 4) = " "
  Sheet4.Cells(j + 1, 5) = " "
  j = j + 1
Loop
Count = 0
End If
NewRun = False
Count = Count + 1
Sheet4.Cells(Count + 1, 1) = dCycles
Sheet4.Cells(Count + 1, 2) = iOutput1.dCrackLength
```

```
Sheet4.Cells(Count + 1, 3) = iOutput1.dBeta

If Model < 2000 Then

Sheet4.Cells(Count + 1, 4) = iOutput2.dCrackLength

Sheet4.Cells(Count + 1, 5) = iOutput2.dBeta

End If

Set iOutput1 = Nothing

End Sub


Private Sub mAFGROW_TransitionInfo(ByVal nType As Long, ByVal nReason As Long, ByVal dStress As Double, ByVal dRStress As Double, ByVal dCycles As Double, ByVal dPass As Long, ByVal iOutputInfo1 As Object, ByVal iOutputInfo2 As Object, ByVal iOutputInfo3 As Object, ByVal iOutputInfo4 As Object)

Dim iOutput1 As AFGROW.OutputInfoInt

Dim iOutput2 As AFGROW.OutputInfoInt

Set iOutput1 = iOutputInfo1

If Model < 2000 Then Set iOutput2 = iOutputInfo2

NewRun = False

Sheet1.Cells(i, 11) = nType

Sheet1.Cells(i, 12) = dCycles

Sheet1.Cells(i, 13) = iOutput1.dCrackLength

Set iOutput1 = Nothing

End Sub


Private Sub UserForm_Activate()


Dim k As Integer

Dim UseBetaCorrection As Boolean

Dim UseTabularData As Boolean


Set mAFGROW = CreateObject("AFGROW.Application")
```

```
Set prefs = mAFGROW.PredictPreferences
Call mAFGROW.PredictPreferences.SetPropagationLimits(False, False, False, False,
True, 1.14, 10000000, 2000)
prefs.bOutputToFile = False
Set user_beta = mAFGROW.UserDefinedBeta
Set table_lookup = mAFGROW.SetTabularLookupMaterial
mAFGROW.Visible = False

'set the user-defined beta information
UseBetaCorrection = Sheet1.Cells(2, 9)
If (UseBetaCorrection = True) Then
   mAFGROW.Model = uPartThrough
   j = 0
   Do While j < 3
   CArray(j) = Sheet2.Cells(j + 5, 2)
   k = 0
   Do While k < 3
   AArray(k) = Sheet2.Cells(4, k + 3)
   BaArray(j, k) = Sheet2.Cells(j + 5, k + 3)
   BcArray(j, k) = Sheet2.Cells(j + 10, k + 3)
   k = k + 1
   Loop
   j = j + 1
   Loop
   j = 0
   Do While j < 6
   BTArray(j, 0) = Sheet2.Cells(j + 16, 2)
   BTArray(j, 1) = Sheet2.Cells(j + 16, 3)
   j = j + 1
```

```
    Loop
    beta_result = user_beta.SetLineaInt(AArray, CArray, BaArray, BcArray)
    Dim middle As Variant
    middle = BTArray
    user_beta.aThroughCrackData = middle
End If

'Set the crack growth rate data using tabular look-up
UseTabularData = Sheet1.Cells(2, 10)
If (UseTabularData = True) Then
    k = 0
    Do While k < 4
    j = 0
    Do While j < 23
    If (k = 0 And j = 0) Then
        KTable(j, k) = 0#
    Else
        KTable(j, k) = Sheet3.Cells(j + 2, k + 2)
    End If
    j = j + 1
    Loop
    k = k + 1
    Loop
    table_lookup.sMaterialName = Sheet3.Cells(2, 6)
    Dim kVar As Variant
    kVar = KTable
    Call table_lookup.SetData(kVar, Sheet3.Cells(8, 7), Sheet3.Cells(8, 6), Sheet3.Cells(5,
7), Sheet3.Cells(5, 6), Sheet3.Cells(8, 9))
    table_lookup.dKc = Sheet3.Cells(5, 8)
```

```
    table_lookup.dKIc = Sheet3.Cells(5, 9)
    table_lookup.dPoissonsRatio = Sheet3.Cells(5, 10)
    table_lookup.dThermalEx = Sheet3.Cells(8, 8)
    table_lookup.dYield = Sheet3.Cells(8, 10)
    table_lookup.dYoungModulus = Sheet3.Cells(8, 11)
Else
    mAFGROW.SetHarterTMaterial.SetActive (1)

End If
End Sub

Public Sub Run()
mAFGROW.PredictPreferences.bCycleByCycleSpCalc = True
mAFGROW.PredictPreferences.bCycleByCycleBetaCalc = True
mAFGROW.Units = UnitsEnglish
mAFGROW.SMF = Sheet1.Cells(i, 2)
mAFGROW.ConstAmplitudeSpectrum (Sheet1.Cells(i, 3))
mAFGROW.Model = Sheet1.Cells(i, 4)
mAFGROW.CrackLengthC = Sheet1.Cells(i, 6)
Call mAFGROW.SetRetardation(Sheet1.Cells(2, 11), 0, False, False)
'Geometry
W = Sheet1.Cells(2, 2)
t = Sheet1.Cells(2, 3)
D = Sheet1.Cells(2, 4)
Call mAFGROW.SetCrackedPlateWithHoleProp(W, t, D)
'Loads
Tension = Sheet1.Cells(2, 5)
Bending = Sheet1.Cells(2, 6)
```

```
Bearing = Sheet1.Cells(2, 7)
Call mAFGROW.SetLoad(Tension, Bending, Bearing)
prefs.sOutputFileName = Sheet1.Cells(i, 10)
NewRun = True
answer = mAFGROW.RunPredict
End Sub
```

Bibliography

Broek, D., *Elementary Engineering Fracture Mechanics*. Martinus Nijhoff Publishers, Dordrecht, 1986.

Chermahini, R. G., K. N. Shivakumar, and J. C. Newman Jr., “Three-Dimensional Aspects of Plasticity-Induced Fatigue Crack Closure,” *Engineering Fracture Mechanics*, 1989 Vol. 34 No. 2.

Dawicke, D. S., A. F. Grandt Jr., and J. C. Newman Jr., “Three-Dimensional Crack Closure Behavior,” *Engineering Fracture Mechanics*, 1990 Vol. 36 No. 1.

de Koning, A. U., H. J. ten Hoeve, and T. K. Henriksen, “Recent Advances in the Modelling of Crack Growth Under Fatigue Loading Conditions,” *Proc. of FAA/NASA International Symposium on Advanced Structural Integrity Methods for Airframe Durability and Damage Tolerance*, 4-6 May 1994, Hampton, VA, NASA-CP-3274.

de Koning, A. U., H. J. ten Hoeve, F. P. Grooteman, and C. J. Lof, “Advances in the Modeling of Cracks and Their Behaviour in Space Structures,” *Proc. of the European Conference on Spacecraft Structures, Materials, and Mechanical Testing*, Braunschweig, Germany, 4-6 Nov. 1998.

Edwards, P. R. and J. C. Newman Jr., “Short-Crack Growth Behaviour Various Aircraft Materials,” *AGARD-R-767*, Specialised Printing Services Limited, Essex, 1990.

Elber, Wolf, “Equivalent Constant-Amplitude Concept for Crack Growth Under Spectrum Loading,” *Fatigue Crack Growth Under Spectrum Loads, ASTM 595*, American Society for Testing and Materials, 1976.

Elber, Wolf. “Fatigue Crack Closure Under Cyclic Tension,” *Engineering Fracture Mechanics*, Vol. 2 (1970).

Fawaz, S. A., “Equivalent Initial Flaw Size Testing and Analysis,” *AFRL-VA-TR-2000-3024*, Air Force Research Laboratory, Air Vehicles Directorate, Air Force Materiel Command, Wright-Patterson Air Force Base, OH 45433.

Fawaz, S. A., J. Schijve, and A. U. de Koning., “Fatigue Crack Growth in Riveted Lap-Splice Joints,” *Proc. of the 19th Symposium of the International Committee on Aeronautical Fatigue*, 16-20 June 1997, Edinburgh, Scot. Scotland, UK: EMAS/SoMat Systems International Ltd, 1997.

Forman, R. G., V. E. Kearney, and R. M. Engle., “Numerical Analysis of Crack Propagation in a Cyclical-Loaded Structure.” *ASME Transactions, Journal of Basic Engineering*, Vol. 89D (1967).

Grandt, Jr., A. F., J. A. Harter, and B. J. Heath, “Transition of Part-Through-cracks at Holes into Through-the -Thickness Flaws,” *Fracture Mechanics: Fifteenth Symposium, ASTM STP 833*, R. J. Sanford, Ed., American Society for Testing and Materials, Philadelphia, 1984.

Griffith, A. A., “The Phenomena of Rupture and Flow in Solids.” *Phil. Trans. Roy. Soc. of London*, A221 (1921).

Harter, James A., “AFGROW Users Guide and Technical Manual,” *AFRL-VA-WP-TR-1999-3016*, February 1999.

Lincoln, John W., “Challenges for the Aircraft Structural Integrity Program,” *Proc. of FAA/NASA International Symposium on Advanced Structural Integrity Methods for*

Airframe Durability and Damage Tolerance, 4-6 May 1994, Hampton, VA, NASA-CP-3274.

Lincoln, John W., Electronic Communication, USAF Material Command, Aerospace Systems Command, Wright-Patterson AFB, OH. 17 Jan 2001.

McClung, R. C. and H. Sehitoglu, "Closure and Growth of Fatigue Cracks at Notches," *Journal of Engineering Materials and Technology*, Vol. 114, Jan. 1992.

MIL-HDBK-5G, *Metallic Materials and Elements for Aerospace Vehicle Structures*, 1 November 1994.

Murakami, Y., *Stress Intensity Factors Handbook, Volume 3*, The Society of Materials Science, Japan, Pergamon Press, Tokyo.

NASGRO Fatigue Crack Growth Computer Program, Version 2.01, NASA JSC-22267A, 1994.

Newman Jr., J. C., "Crack Opening Stress Equation for Fatigue Crack Growth," *International Journal of Fracture*, Vol. 24 (1984).

Newman Jr., J. C. and P. R. Edwards, "Short-Crack Growth Behaviour in an Aluminum Alloy-An AGARD Cooperative Test Programme," *AGARD-R-732*, Specialised Printing Services Limited, Essex, 1988.

Newman Jr., J. C., "Prediction of Fatigue-Crack Growth Under Variable-Amplitude and Spectrum Loading Using a Closure Model," *Design of Fatigue and Fracture Resistant Structures ASTM STP 761*, P. R. Abelkis and C. M. Hudson, Eds., American Society for Testing and Materials, 1982.

Newman, Jr., J. C., "Fagitue-Life Prediction Methodology Using a Crack-Closure Model," *Journal of Engineering Materials and Technology*, Vol. 117 (1995).

Paris, P. C., M. P. Gomez, and W. E. Anderson, "A Rational Analytic Theory of Fatigue," *The Trend in Engineering*, Vol. 13 (1961).

Schijve, J. and F. A. Jacobs, "Fatigue Crack Propagation in Unnotched and Notched Aluminum Alloy Specimens," *NLR-TR M.2128*, Amsterdam, NL: National Aerospace Laboratory, 1964.

Schijve, J. and F. A. Jacobs, "Program-Fatigue Tests on Notched Light Alloy Specimens of 2024 and 7075 Material," *NLR-TR M.2070*. Amsterdam, NL: National Aerospace Laboratory, 1960.

Schijve, J., "The Fatigue Life of Unnotched and Notched 2024-T3 Alclad Sheet Materials from Different Manufacturers," *National Aerospace laboratory NLR, TR 68093*, 1968.

Schutz, Walter, "A History of Fatigue," *Engineering Fracture Mechanics*, Vol. 54 (1996).

Skinn, D. A., J. P. Gallagher, A. P. Berens, P. D. Huber, and J. Smith, "Damage Tolerant Design Handbook," *WL-TR-94-4052*, Air Force Materials Directorate, May 1994.

Tiffany, Charles F., "Aging of US Air Force Aircraft." *Proc. of the 1997 USAF Structural Integrity Program Conference*, 2 - 4 Dec 1997, San Antonio, TX.

Walker, E. K., "Effects of Environments and Complex Load History on Fatigue Life." *ASTM STP 462*, (1970).

Walker, K., "An Evaluation of Empirical and Analytical Models for Predicting Fatigue Crack Propagation Load Interaction Effects." *Proc. of the 1997 USAF Structural Integrity Program Conference*, 2 - 4 Dec 1997, San Antonio, TX.

Wheeler, O. M., "Spectrum Loading and Crack Growth," *ASME Publication*, 1971.
Willenborg, J., R. M. Engle, and H. A. Wood, "A Crack Growth Retardation Model Using an Effective Stress Concept," *AFFDL-TM-71-1-FBR* (1971).

List of Acronyms

ACRONYM	DESCRIPTION
AFI	Air Force Instruction
AFRL	Air Force Research Laboratory
AFR	Air Force Regulation
AFGS	Air Force Guide Specification
ASIP	Aircraft Structural Integrity Program
CLS	Contractor logistics support
COM	Component object model
DADTA	Durability and damage tolerance analysis
DCCH	Double corner crack at a hole
DOTCH	Double oblique through-crack at a hole
DTA	Damage tolerance analysis
DTCH	Double through-crack at a hole
DTR	Damage Tolerance Requirements
FAR	Federal Aviation Regulation
FCL	Fatigue critical location
LEFM	Linear elastic fracture mechanics
LL	Lower level
NDI	Nondestructive inspection
NMAB	National Material Advisory Board
OEM	Original equipment manufacturere
OS&S	Operational service and support
R&D	Research and development
SCCH	Single corner crack at a hole
SPD	System Program Director
UL	Upper limit
USAF	United States Air Force
VA	Air Vehicles Directorate

Glossary

Plane stress. Internal transverse stresses in the body are zero.

Plane strain. Internal transverse strains in the body are zero.

A-Basis. At least 99 percent of the population of values is expected to equal or exceed the A-basis mechanical property allowable, with a confidence of 95 percent.[56]

B-basis. At least 90 percent of the population of values is expected to equal or exceed the B-basis mechanical property allowable, with a confidence of 95 percent.[57]

Yield stress. For nonferrous metals and most high strength steels, the yield stress is determined by drawing a line parallel to the elastic portion of the stress strain curve through a point representing zero stress at 0.002 strain.

Fracture toughness. The ability of a material to resist fracture.

[56] MIL-HDBK-5G, p. 1-9.
[57] *Ibid*., p. 1-9