

8.1 Force Structural Management

Tasks IV and V of the ASIP guidelines of MIL-HDBK-1530 define the force management tasks for preserving the airworthiness of an aircraft throughout its design life. According to Berens, et al. [1981], force management is the "specification and direction of inspections, preventive maintenance, repairs, modifications, and damage assessments required to economically prevent structural failure and preserve the strength and rigidity of the individual airframe during its useful life." The basic objective of ASIP is to ensure operational safety and readiness of the aircraft. Force Management objectives are to:

- 1) Prevent structural failures through an effective maintenance program of inspections, repairs and modifications.
- 2) Preserve structural strength and rigidity through an effective preventive maintenance program of environmental protection and economic repair or replacement of deteriorating parts.
- 3) Minimize structural maintenance costs by eliminating unnecessary structural maintenance actions through effective application of data on test and operational failure modes and data on individual aircraft usage.
- 4) Provide a basis for planning of system phase-out and future force structure.

The guidelines of ASIP Task IV are directed at the manufacturer generated, force management data package that provides the design usage FSMP and the mechanism for collecting and analyzing data for updating the FSMP as required. Task V is directed at the implementation of the force management activities by the Air Force. [Figures 8.1.1](#) and [8.1.2](#) from MIL-HDBK-1530 are functional flow diagrams of Tasks IV and V, respectively.

Under Task IV of ASIP, the airframe contractor devises a Force Management Plan that contains three essential parts: 1) the Force Structural Maintenance Plan (FSMP), 2) the Loads/Environment Spectra Survey (L/ESS), and 3) the Individual Aircraft Tracking (IAT) Program.

The initial FSMP presents the schedule for inspections and maintenance actions for aircraft that are accumulating damage according to the design loads spectra usage predictions. It is updated when the baseline operational load spectra are developed.

The L/ESS is a data collection and analysis program designed to provide the data to develop the baseline operational load spectra. A number of the force aircraft, usually about twenty percent, are fitted with data measuring and recording equipment. Parameters such as accelerations, angular rates, airspeed, altitude, weight and other load indicative quantities are obtained in a time history form as the aircraft are flown. The data are categorized by mission type and segment, and load histories are calculated for the critical areas of the aircraft. These are the same areas which were identified in the critical parts list and which will be subjected to subsequent inspection and possible repair or modification during maintenance actions. The new baseline operational damage accumulation rates based on the L/ESS data are used to update the FSMP.

The IAT program is also a data collection and analysis effort that is applied to each aircraft of the force. The minimum amount of data is collected that will allow the estimation of the damage being accumulated. Comparison with the baseline damage accumulation predictions allows modification of the FSMP to account for the differences in usage of each aircraft.

The planning for these three parts of the FSMP should begin with the initial design studies and the fracture control plan. Crack growth techniques used during the design are also those used in the IAT and FSMP portions of the program and should be formulated to permit easy incorporation. Studies made for evaluation of the effect of different load parameters on the loads computation and subsequently on crack growth calculations should be used in development of the parameter list for the L/ESS program. Accuracy requirements and parameter ranges should be selected to be commensurate with the methods of analysis.

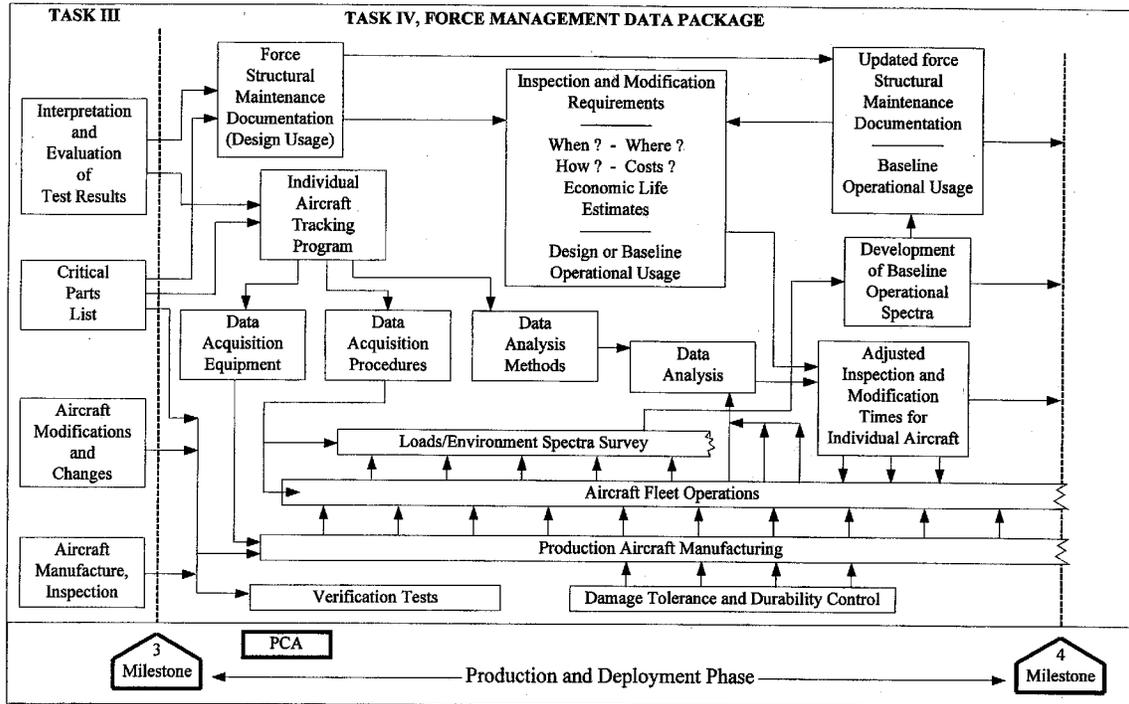


Figure 8.1.1. Functional Flow Diagram of ASIP Task IV from MIL-HDBK-1530

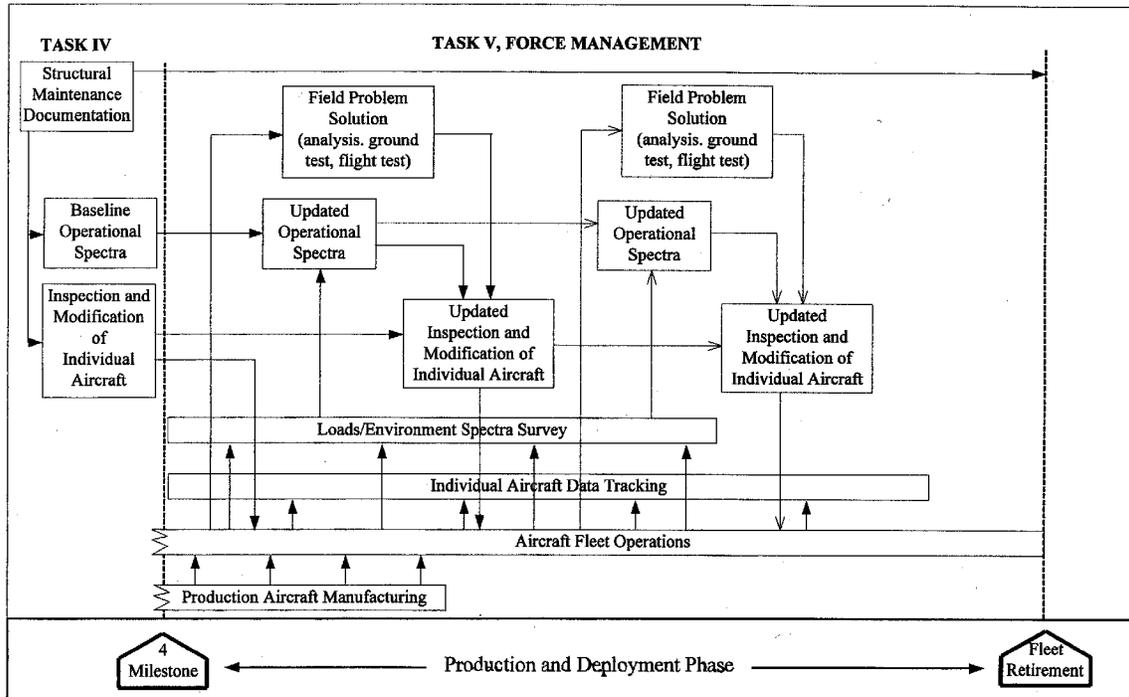


Figure 8.1.2. Functional Flow Diagram of ASIP Task V from MIL-HDBK-1530

The following subsections present general descriptive comments for the three major elements of force management. See Berens, et al. [1981] for more complete descriptions and discussions of these topics.

8.1.1 Force Structural Maintenance Plan (FSMP)

The FSMP is a schedule for performing the maintenance actions necessary to maintain structural integrity throughout the life of a fleet. In principle, the FSMP provides the Office of Primary Responsibility (OPR) sufficient detail for the establishment of budgetary, structural integrity and maintenance plans. The FSMP is initially based on design usage and is updated whenever significant changes occur in the fleet environment/stress histories. Such changes are detected through the data of the Loads/Environment Spectra Survey (L/ESS) elements. To maintain the airworthiness of the individual aircraft, the FSMP is keyed to the data generated under the Individual Aircraft Tracking (IAT) element. [Figure 8.1.3](#) is a schematic from Berens, et al. [1981] depicting the relation between the damage tolerance analyses, the operational data collection and analysis programs and FSMP.

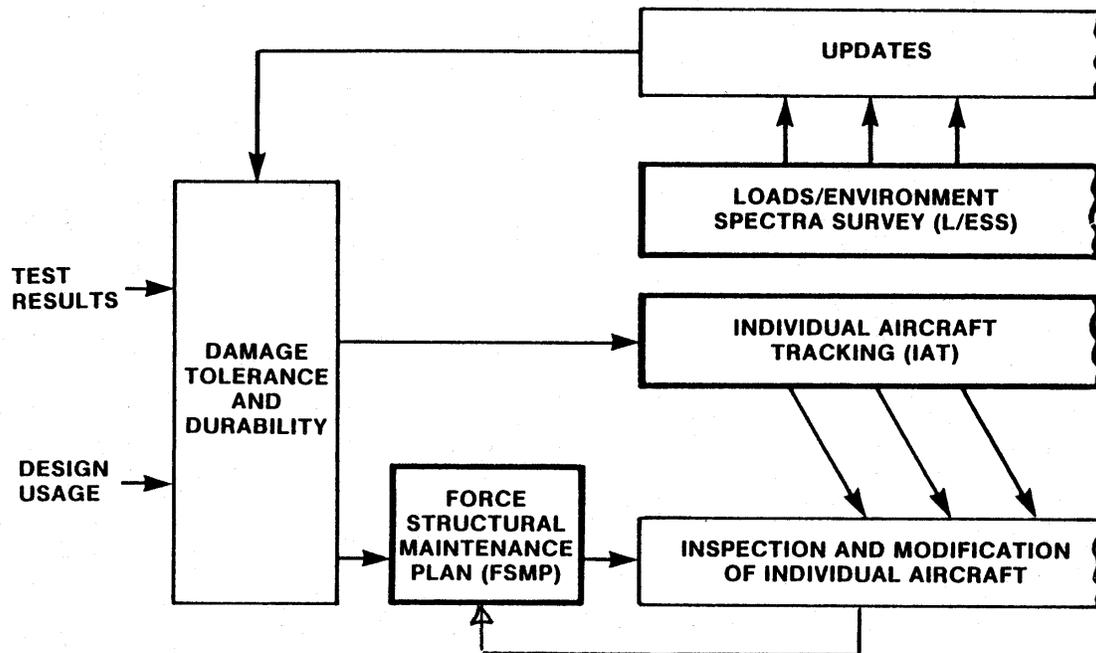


Figure 8.1.3 Relation of FSMP to IAT and L/ESS Elements of ASIP

The FSMP should contain:

- 1) all of the anticipated inspection, repair, and modification actions,
- 2) the critical locations and the crack sizes that trigger the required maintenance actions for individual airframes, and
- 3) supporting data required for the procedures of the Air Force Technical Order System.

The critical locations and critical crack sizes are the key items of the damage tolerance approach to structural integrity. [Figure 8.1.4](#) is a generic schematic for the process of determining inspection intervals for a monitored location for three or more inspection cycles.

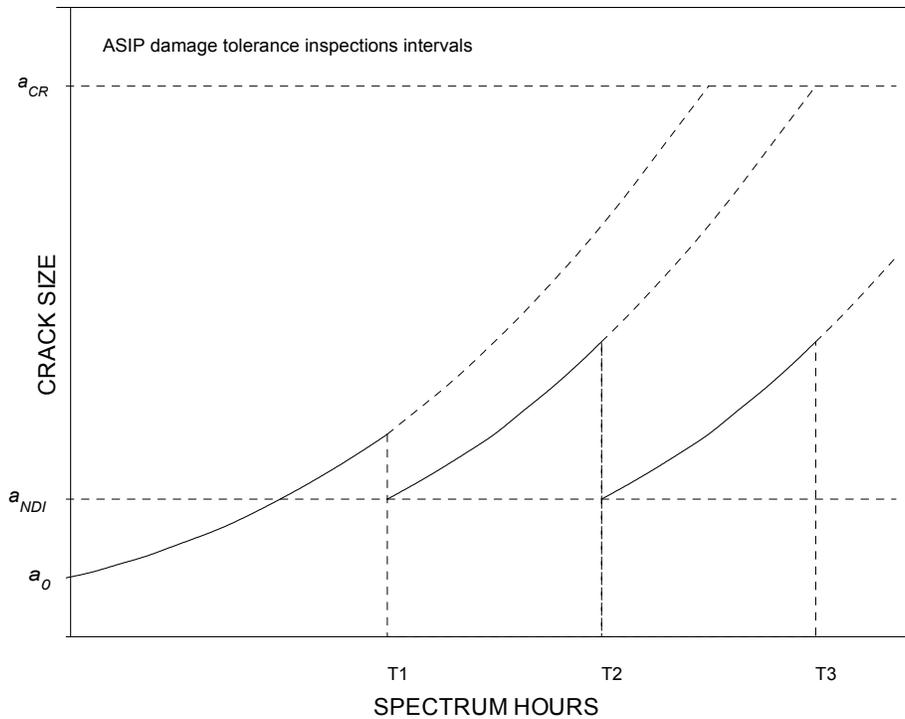


Figure 8.1.4 Schematic of Inspection Interval Determination

Inspections for safety are scheduled at one half of the flight hours for an assumed initial crack to grow to critical in the anticipated stress environment. For pristine structure, the initial crack size, a_0 , is representative of flaws that might be in a structural detail as a result of manufacturing (see Section 1.3.4.1). After an inspection, the initiating flaw size, a_{NDI} , is the reliably detected crack size of the NDI method for the location. See Section 3.1. The crack size versus time curves are adjusted to account for variations in usage severity that are experienced by individual airframes.

The FSMP is based initially on the design loads spectrum, but as data is obtained from the L/ESS program a new operational baseline loads spectrum is developed and the FSMP is updated to reflect the operational usage.

The IAT program, also based originally on the design loads spectrum, is updated to reflect the L/ESS data. This update may involve changes in the IAT method but usually only includes changes in the crack growth rate in terms of the usage parameters being recorded by the IAT program.

[Figure 8.1.5](#) from Berens, et al. [1981] shows the time sequence relation of these Force Management activities. The final activity is the airplane maintenance and the accumulation of these records.

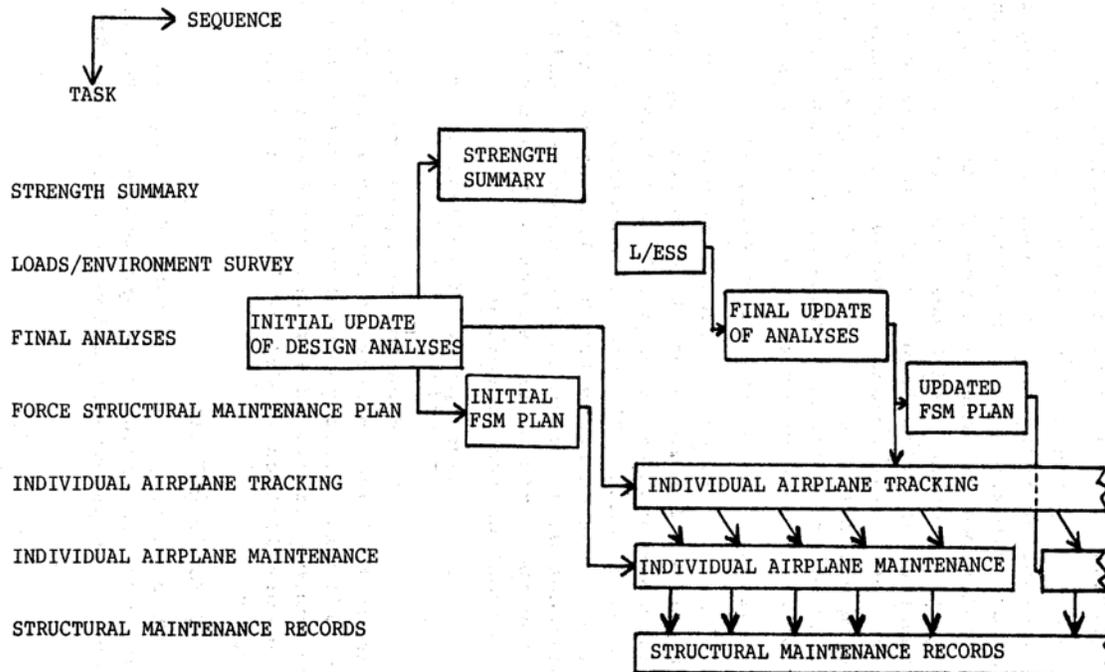


Figure 8.1.5 Sequence of Force Management Elements [Berens, et al., 1981]

The final FSM plan and all of the test results and analysis conducted during the design, manufacture, and testing of the aircraft form the final data package which is delivered to the Air Force. It substantiates the damage tolerance characteristics of the structure and describes how it may be maintained during the life of the aircraft.

A transition period normally occurs during which the contractor trains the user in all stages of the L/ESS, IAT, and FSM plan. It is essential that the user assume the same regard for the treatment of damage critical parts that was practiced during manufacture. The damage tolerance analysis is highly dependent on the size of the initial quality flaw. Manufacture processes and handling were watched so that quality was preserved. It is now the responsibility of the user to handle the aircraft in the same manner. Disregard for the structure could result in complete loss of all the previous efforts and could invalidate all of the tracking efforts.

It is the responsibility of the Air Force user to obtain the data from the L/ESS to be used in the baseline analysis update. Early collection of L/ESS data will lead to the most accurate use of the IAT data. Recognition of this operation as part of the fracture control plan should aid in the proper conduct of the task. Keeping the equipment in service and striving for the maximum amount of data return will lead to the most accurate final results. (This is, in part, also dependent on a selection of parameters that are easy to record.) Recording equipment and transducers should have a high reliability and be easy to use.

8.1.2 Loads/Environment Spectra Survey (L/ESS)

As noted earlier, the initial FSMP is based on the design load spectrum with its corresponding stress sequences at the critical locations. Experience has shown that the actual usage spectrum usually differs significantly from that anticipated at the design stage of development. Accordingly, ASIP calls for a data collection and analysis program to ascertain the baseline usage spectrum of

the fleet. The results of L/ESS provide the data for checking design load assumptions and for updating the FSMP through new crack growth curves of updated damage tolerance analyses. L/ESS does not directly impact decision making in the development of the FSMP.

The L/ESS objectives are met through the collection of time histories of sufficient parameters to characterize the magnitude, frequency, and order of the stresses being encountered at the monitored structural locations. MIL-HDBK-1530 recommends that 100 percent of operational aircraft be instrumented to measure relevant load parameters but that the data from 10 to 20 percent of the fleet be used to capture valid operational loads spectra. The assumption is made that the monitored flights are representative of all flights in a known stratification of usage such as type of mission or mission segment. The collected data are compared to the design spectrum and analyses are updated as needed. The L/ESS process continues through the life of the fleet so that data are available when change in usage dictates the need to update the damage tolerance analyses.

The L/ESS influences the FSMP through the damage tolerance analyses and analyses that feed the crack growth curves of the IAT. When sufficient data have been collected from the L/ESS to begin to define a spectrum, it can be compared with the design data that were used to generate the IAT analyses. Variations in the usage parameter distributions can be determined. Various comparisons can be made depending on the parameters being measured and analyzed in the tracking function. It is noted that the IAT parameters typically comprise a subset of the L/ESS parameters. Exceptions occur when strains are used as IAT parameters but not used in the L/ESS. Commonly, comparisons are made on the basis of differences in the load factor spectra. If the L/ESS is representative of the force usage, then the comparisons should be within sampling variation. If the spectra are significantly different, the L/ESS methods should be examined and possibly modified or the IAT methods should be examined and modified.

8.1.3 Individual Aircraft Tracking (IAT)

The Individual Aircraft Tracking (IAT) plan is an integral element of MIL-HDBK-1530. The plan is constructed by the airframe contractor as part of the Task IV, Force Management Data package. The plan is implemented by the Air Force under Task V, Force Management. The objective of IAT is to provide data on each aircraft that reflects differences in usage from that of the baseline spectra of the FSMP.

The basic concept of the IAT plan is as follows. The FSMP specifies the timing of required structural inspections and modifications and estimates the costs for repairs and inspections. These times and quantities are based on the FSMP crack growth curves as calculated from the relevant baseline (average) spectrum. Since the baseline stress histories that were used to generate these crack growth curves are not necessarily representative of the actual experience of individual aircraft, a method is needed to account for the individual differences. This is done in the IAT Program by collecting, processing and accumulating data descriptive of every flight of each airframe in a fleet. There is considerable variability in the degree of complexity of the necessary data systems required for different fleets of aircraft.

From the parameters measured in the IAT program, a crack growth increment per flight or per flight hour is computed and accumulated for each aircraft in the fleet. Comparing the observed crack growth plot with the predicted plot provides a determination of equivalent flight units for the current usage level. [Figure 8.1.6](#) from Berens, et al. [1981] shows this comparison. The baseline usage life remaining until damage size a_f is reached is (t^*-t) . The life t^* defined a specified maintenance action time. At any specific time, the total fleet can be viewed as having a distribution

of remaining life as expressed in terms of the baseline flight hours. Such information is then used for scheduling the maintenance activity.

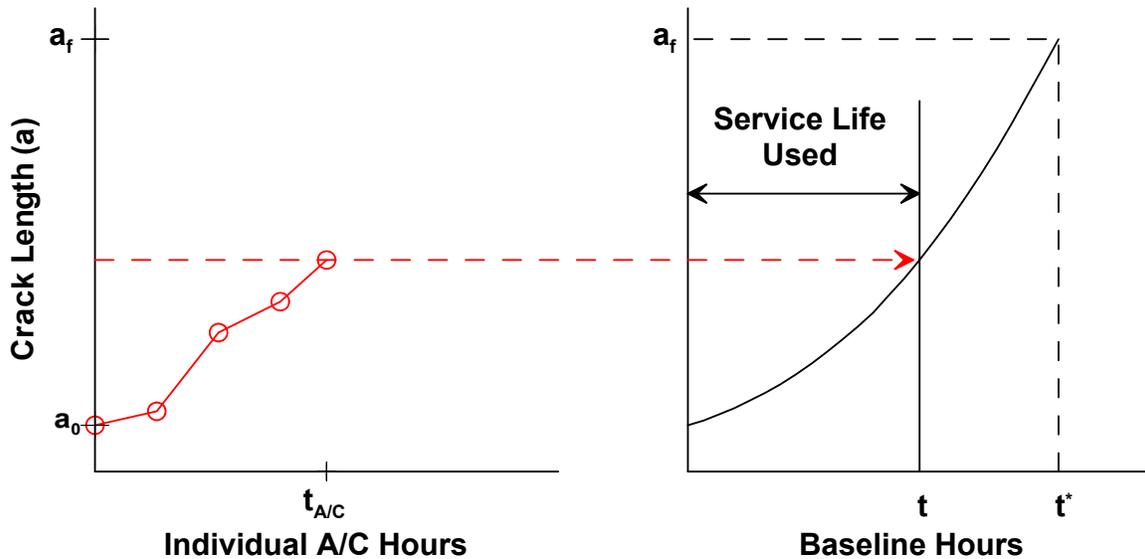


Figure 8.1.6. Relating Individual Aircraft Usage to FSM Plan Usage [Berens, et al., 1981]

Establishing the IAT plan involves the following steps:

- 1) the selection of the aircraft flight condition descriptions or parameters,
- 2) the development of a method to translate these parameters into incremental crack growth,
- 3) the translation of this crack growth into a measure of time which can be projected to a future date for the scheduling of some maintenance activity, and
- 4) the definition of a data processing system for maintaining and updating all of the analyses and record keeping.

There are many approaches to IAT as driven by the use and structural complexity of the fleet. Generally, in the past bomber/transport type aircraft have been tracked using crew reporting forms while attack/fighter/trainer aircraft have used load and flight parameters to reflect the more variable usage. See Clay, et al. [1978] for a description of the crack growth tracking methods developed during the 1970's. Many of these methods are still in use but the modern micro-processor based data recording systems are permitting the use of more sophisticated methods. See Selder & Liu [1997] for an example that calculates damage based on cycle-by-cycle crack growth analysis at each control point. These processors are also blurring the distinction between data collection for L/ESS and IAT.