AIR FORCE STRUCTURES

Structures Bulletin

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Subject: Methodology for Determination of Equivalent Flight Hours and Approaches to Communicate Usage Severity

References:

1. MIL-STD-1530C, Aircraft Structural Integrity Program, 1 Nov 2005.
2. Gallagher, J. P., "A Review of the Philosophies, Processes, Methods and Approaches that Protect In-Service Aircraft from the Scourge of Fatigue Failures," ICAF 2007, Naples, Italy, May 2007.
3. Babish, C. A., "Implication of Usage Severity and Variability Based on an F-16 Case Study", ICAF 2007, Naples, Italy, May 2007.
4. NATO RTO-TR-AVT-125, "Future Airframe Structural Lifing: Methods, Applications and Management", December 2008.
5. AFRL-RX-WP-TR-2008-4373, "Recommended Processes and Best Practices For Nondestructive Inspection (NDI) Of Safety-Of-Flight Structures", October 2008.

Purpose:

Proper execution of an Individual Aircraft Tracking (IAT) Program requires an understanding of the usage severity for each aircraft in the USAF fleet. Comparing actual usage to a reference usage is important to understand the usage severity and to assess the structural health and maintenance requirements for each "tail number". For the USAF, usage severity is determined by using the concept of Equivalent Flight Hours (EFH) as described in the Aircraft Structural Integrity Program Task V of MIL-STD-1530C (Reference 1). The purpose of this bulletin is to ensure that ASIP Managers and structural engineers understand the process to determine equivalent flight hours and to properly interpret and communicate usage severity.

Background:

Key MIL-STD-1530C paragraphs describing the Individual Aircraft Tracking (IAT) Program development and Force management execution are as follows:

1. Section 5.4.5 Individual Aircraft Tracking (IAT) Program Development: “A program to perform individual aircraft tracking shall be developed to obtain actual usage data that can be used to adjust maintenance intervals on an individual aircraft (“by tail number”) basis. All force aircraft shall have systems that record sufficient usage parameters that can be used to determine the damage growth rates throughout the aircraft structure. The systems shall have sufficient capacity and reliability to achieve a 90-percent minimum valid data capture rate of all flight data throughout the service life of the aircraft. The systems shall include serialization of interchangeable/replaceable aircraft structural components, as required. The IAT Program shall be ready to acquire data at the beginning of initial flight operations. If instrumentation and/or sensors are part of IAT Program, the instrumentation shall be incorporated into the full-scale static test described in 5.3.1, into the full-scale durability test described in 5.3.4, and into the flight and ground loads survey aircraft described in 5.3.3.1. Data systems should comply with the requirements of AFPD 63-14[1] and AFI 63-1401.”

2. Section 5.4.5.1 Tracking Analysis Methods: “Analysis methods shall be developed which adjust the inspection and modification times based on the actual measured usage of the individual aircraft. These methods shall have the ability to predict damage growth in all critical locations and in the appropriate environment as a function of the total measured usage, and to recognize changes in operational mission usage. *The methods shall also provide the ability to determine the equivalent flight hours.* The analysis methods and accompanying computer programs shall be provided to the USAF.”

3. Section 5.5 Force management execution: Force management shall be conducted by executing the FSMP. The maintenance schedule directed by the FSMP shall be adjusted for each aircraft by data received from the IAT Program. The FSMP shall be updated periodically to ensure it accurately and efficiently protects against structural failures. Updates to the FSMP shall be based on evaluations of changes in operational usage as well as assessments of new damage findings documented within the structural maintenance database. Periodic action shall be taken to ensure the reliability of the on-board usage data-gathering equipment is sufficient to achieve the required data capture rates.

4. Section 5.5.1 Individual Aircraft Tracking (IAT) program: IAT Program shall be used to adjust the inspection, modification, overhaul, and replacement times based on the actual, measured usage of the individual aircraft. The IAT Program shall be used to determine damage growth in the appropriate environment as a function of the total measured usage and to quantify changes in operational mission usage. *The IAT*

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[1] AFPD 63-14 was superseded by AFPD 63-1 on 3 April 2009.

Program shall also determine the equivalent flight hours (or other appropriate measures of damage such as landings, pressure cycles, etc.) and adjust the required maintenance schedule for all critical locations on each individual aircraft. The IAT Program shall forecast when aircraft structural component life limits will be reached. Data systems should comply with the requirements of AFPD 63-14 and AFI 63-1401.

Equivalent Flight Hours and Usage Severity:

An assessment of the usage severity of each aircraft can be accomplished using the concept of equivalent flight hours. As defined in MIL-STD-1530C, "Equivalent flight hours are the actual flight hours accumulated by an aircraft adjusted for the usage severity and compared to the design spectrum or to the baseline spectrum". Therefore, the IAT system must be able to determine individual aircraft actual usage and be able to compare this usage against a minimum of two reference spectra in terms of EFH.

In practice, the reference spectra from which EFH is determined should evolve as the program structural activity changes. Initially, EFH will be in terms of design usage only. From MIL-STD-1530C, "The design loads/environment spectrum is the spectrum of external loads and environments (chemical, thermal, etc.) used in the design of the aircraft and is representative of the spectrum that the typical force aircraft is expected to encounter within the design service life". As new baseline spectra are developed, EFH should be determined based on the most current representative usage. This current usage is called the baseline operational loads/environment spectrum (baseline spectrum), which in MIL-STD-1530C is an update of the design spectrum based on measured data from operational aircraft (e.g., data obtained from the loads/environment spectra survey). If the original full scale durability test (FSDT) spectrum is different than design, EFH should also be determined based on the FSDT spectrum. If a follow-on FSDT is conducted, EFH should also be determined using the follow-on test spectrum as the reference. Performing EFH calculations against multiple reference spectra enables several useful comparisons as follows:

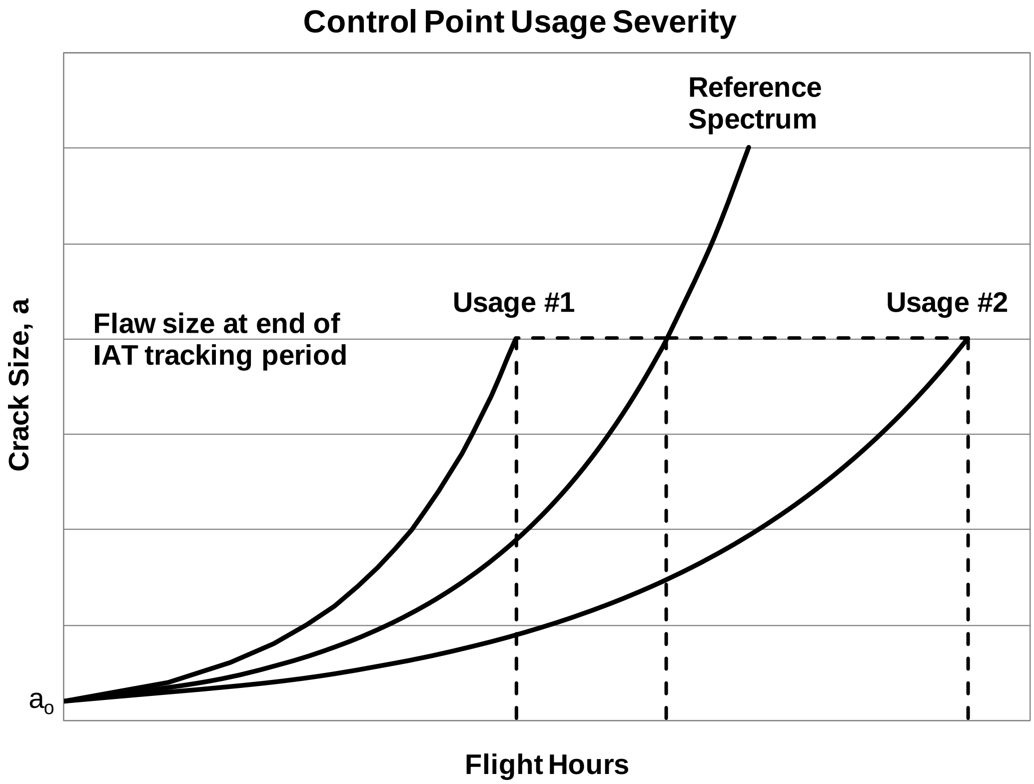
1. Actual usage compared to design. This illustrates cumulative deviations from design usage and indicates when the first baseline spectrum should be developed for use in Durability and Damage Tolerance Analysis (DADTA), Force Structural Maintenance Plan (FSMP), and IAT updates. After the baseline spectrum is developed, the design spectrum may not be useful for airframe usage severity. However, retaining the ability to perform EFH calculations against the design spectrum may be useful for aircraft systems components (e.g., flight control actuators) that do not have usage data collection and evaluation systems.

2. Actual usage compared to most current baseline spectrum. This comparison can be used to determine if an updated baseline spectrum should be generated as well as DADTA, FSMP, and IAT updates. MIL-STD-1530C recommends that these updates be accomplished every 5 years, although this comparison may indicate that a different frequency is appropriate.

3. Actual usage compared to FSDT. This comparison illustrates cumulative deviations from FSDT results (original or most recent). Projections of EFH results should be used to determine if an additional FSDT should be conducted to ensure that the FSDT life exceeds projected fleet EFH by at least a factor of 2.

Equivalent flight hours can be best described graphically as shown in Figure 1, depicting a notional crack growth curve of a control point using a reference spectrum (design, baseline, or FSDT). This crack growth curve can represent a *damage tolerance* control point (which will show crack growth from an initial flaw size a_o, to a critical flaw size a_{CRIT}.), or it can represent a *durability* control point (which will show crack growth from an initial flaw size a_o, to a flaw size representing functional impairment). Control points are critical structural locations which have detailed durability and damage tolerance information, and are typically used to monitor major structural components (e.g. – wing lower cover, fuselage upper crown, etc.). For comparison, two other crack growth curves generated from different IAT usage spectra are shown.

Figure 1.



Usage #1 shows a crack growth curve obtained from IAT data which describes usage *more* severe than the reference spectrum crack growth curve. In other words, this usage will generate a larger crack than the reference spectrum for the same number of flight hours, or when referenced to the common flaw size at the end of the IAT tracking period, will reach this size in fewer flight hours.

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Conversely, usage #2 describes a usage *less* severe than the reference spectrum and will generate smaller cracks at the same number of flight hours or will take more flight hours to reach a common crack size. EFH is obtained by comparing the IAT usage flight hours to the reference spectrum flight hours for a common crack size.

Usage severity is simply EFH divided by the actual flight hours (AFH), and is commonly called a severity factor (SF) or severity ratio.

Severity Factor = EFH / AFH

The severity factor is an important determinant to judge the sufficiency of the current baseline spectrum and the applicability of the most recent FSDT. If the severity factor obtained for a particular control point is significantly smaller than one when computed against the baseline spectrum, it would indicate that the actual usage is less severe than the baseline. Conversely, if the factor is significantly larger than one, then the actual usage is more severe than the baseline. In either case, a severity factor substantially different than one for a large number of control points should initiate a baseline spectrum update. A severity factor approximately equal to one would imply that the baseline spectrum is adequate to describe the actual usage.

A severity factor significantly larger than one when computed against the FSDT spectrum, would indicate that operational usage is more damaging than the test spectrum, and therefore, would bring the sufficiency of the test in question. If this is the case for a large number of control points representing a major structural component, then additional full scale testing may be required.

Additionally, the equivalent flight hours divided by the analytical control point life is commonly referred to as a damage index (DI). DI is a useful metric for programs that have a defined flight hour limit used in force planning.

Damage Index = EFH / Analytical Control Point Life

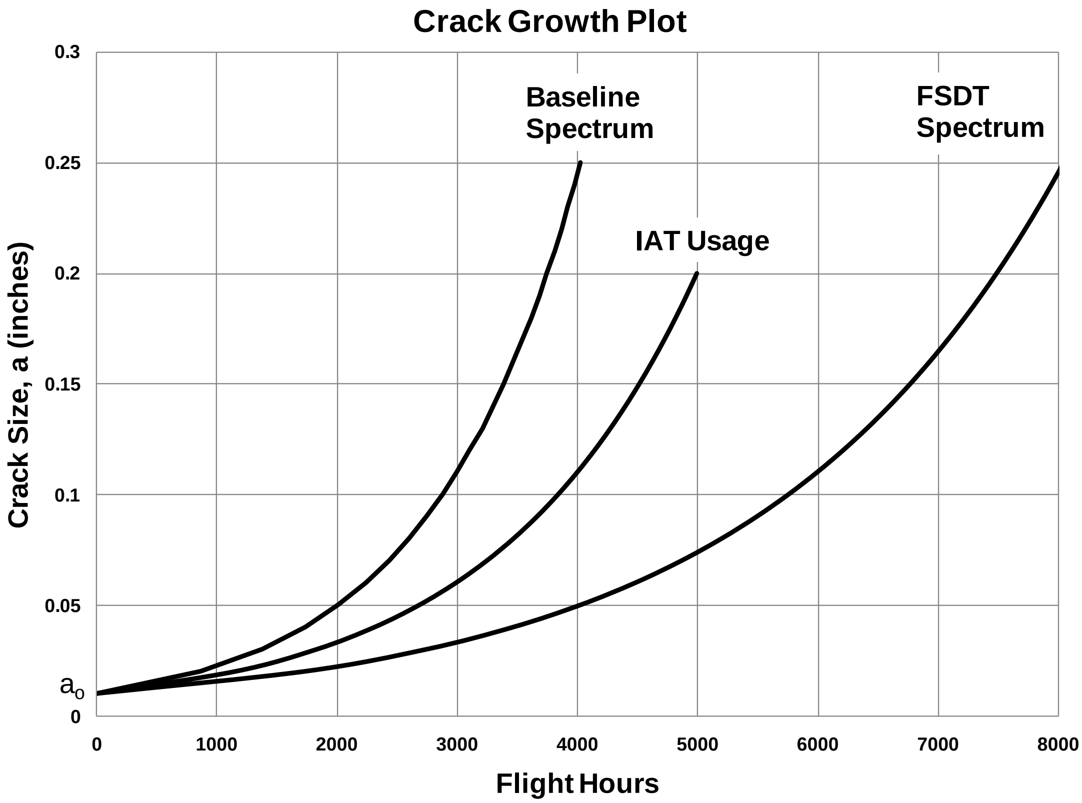
If the damage index approach is used, it is important to realize that EFH cannot exceed the control point life (the DI cannot be greater than one). One approach to preclude this issue is to select a control point with a long durability life (for example, 10 design lifetimes) whose life is expected to always be greater than the highest projected EFH value. The IAT tracking information for this high durability life control point can be used to compute the DI and adjust the inspection intervals for the corresponding damage tolerance control point.

Graphical Calculation of Equivalent Flight Hours:

To understand EFH in a graphical format, the following steps should be used:

Step 1: Select aircraft tail number and control point.
Step 2: Perform crack growth analysis using the FSDT spectrum.
Step 3: Perform crack growth analysis using the current baseline spectrum.
Step 4: Perform actual usage crack growth with information from the IAT program.
Step 5: Plot crack growth curves from Steps 2, 3, and 4 as shown in Figure 2. (For this example, the baseline spectrum crack growth is more severe and the FSDT spectrum crack growth is less severe than the IAT usage.)

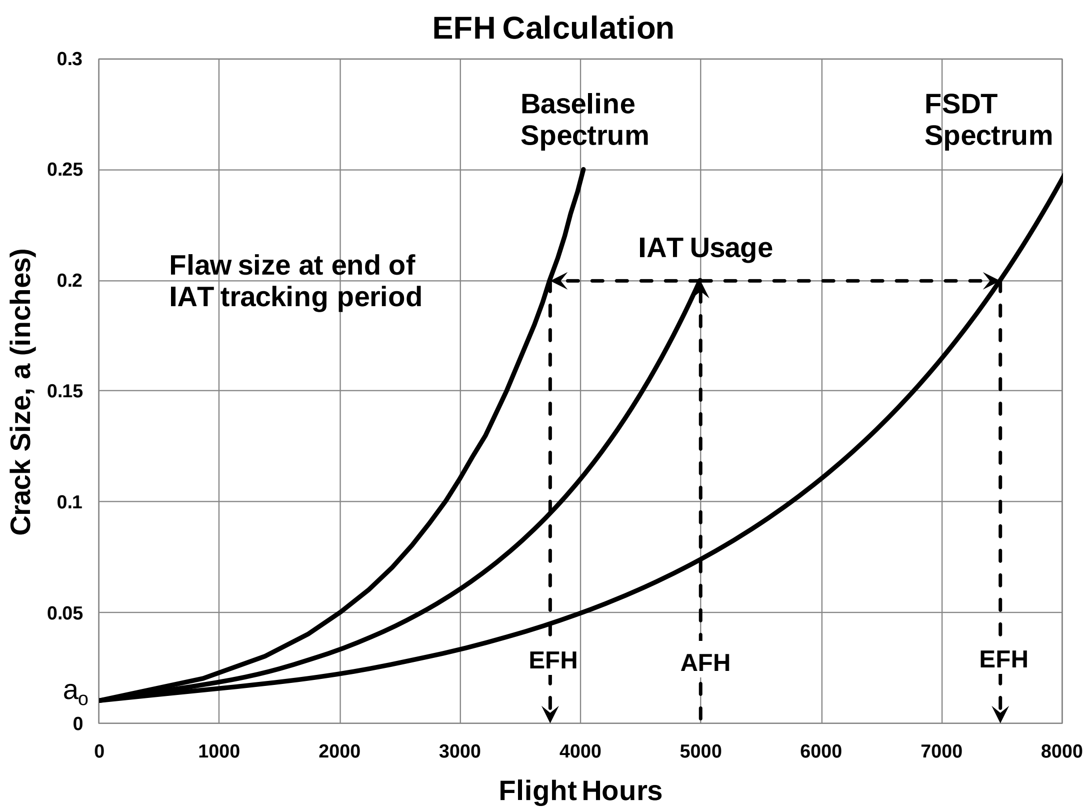
Figure 2.



Step 6: Calculate EFH using the following steps and Figure 3:

1. Identify the flight hours (5000 AFH) and flaw size (0.2 inch) at the end of IAT tracking period.
2. Using the common flaw size of 0.2 inch, find the intersection with the baseline spectrum crack growth curve and determine the flight hours associated with this flaw size. For this example, the equivalent flight hours compared to this reference spectrum is approximately 3750 EFH, or a severity factor of 0.75 (3750/5000). Since the severity factor is less than 1, this means that the IAT usage is less severe than the baseline spectrum.
3. Again using the common flaw size of 0.2 inch, find the intersection with the FSDT spectrum crack growth curve and determine the flight hours associated with this flaw size. The equivalent flight hours compared to this reference spectrum is approximately 7500 EFH or a severity factor of 1.5 (7500/5000). Since the severity factor is greater than 1, this means that the IAT usage is more severe than the FSDT spectrum.

Figure 3.



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Tabular Calculation of Equivalent Flight Hours:

In practice, tracking of IAT usage crack growth and calculating EFH will not be accomplished graphically, but instead will be performed using data in tabular form and will be manipulated using software tools. The design, baseline, and FSDT crack growth curves can be described by equations obtained from curve fit approximations or by tabular data output and interpolation schemes.

Most IAT reports summarize usage information by tail number and control point over a defined tracking or reporting period (commonly 6 months). Typically, an IAT report will contain the initial crack size at the beginning of the reporting period and the crack size at the end of the reporting period. This "delta" flaw growth is added to the final flaw size from the previous reporting period to obtain the final flaw size for the current reporting period. The final flaw size at the end of the reporting period is used to calculate the equivalent flight hours. After performing Steps 1 through 4 from the previous section, a table similar to Table 1 may be constructed to show how the IAT information may be compared with the reference spectra information.

Aircraft and Control Point	IAT Tracking Period				FSDT / Design Spectrum EFH at Final Crack Size	Baseline Spectrum EFH at Final Crack Size
	Flight Hours		Crack Size			
	Initial	Final	Initial	Final		

Table 1. Fleet Usage Tracking

To determine EFH, the final crack size for the current IAT reporting period becomes the common flaw size which has to be located in the reference spectra table. The corresponding flight hours are the equivalent flight hours compared to that particular spectrum. This "lookup" process can be easily automated and interpolation routines can be implemented to provide better precision. The EFH values can be used to automatically predict the flight hours and date for the next inspection of the control point on each tail number. Flight hour or date predictions can also be made to plan for repairs, modifications, or component replacements of structure associated with a particular control point.

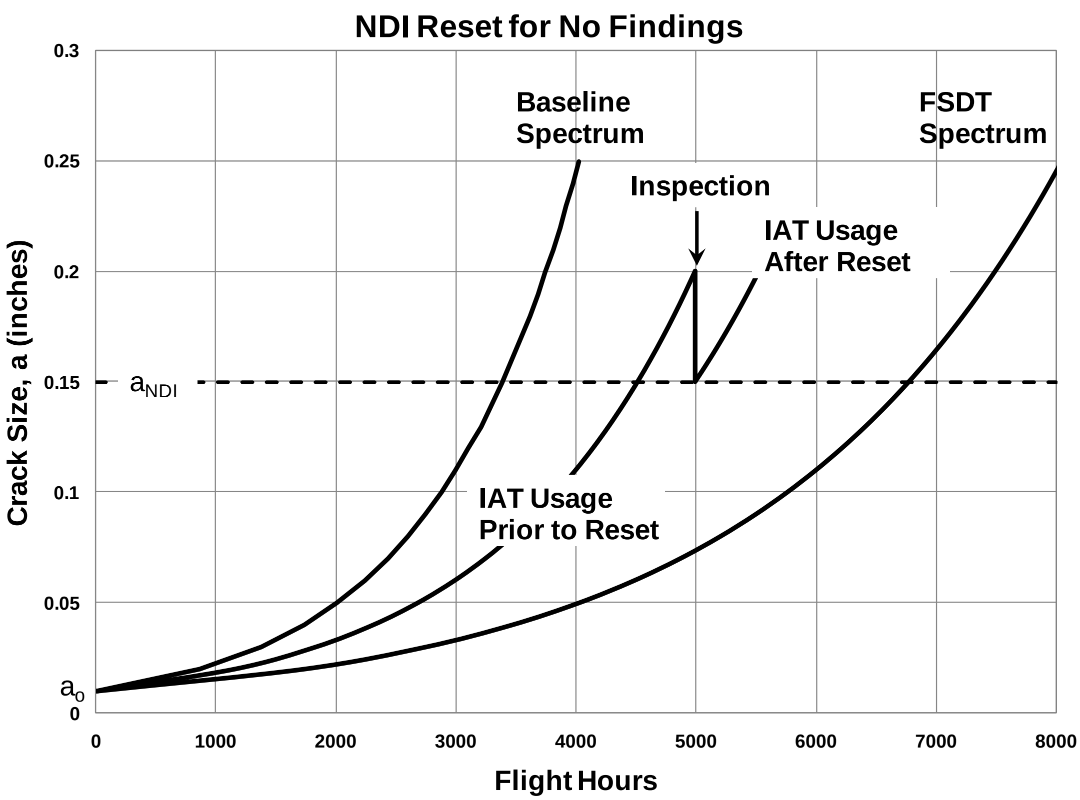
Flaw Size Reset:

In order to compute EFH over the service life of an aircraft, precautions must be taken when inspections are performed to preclude the loss of EFH data. If an inspection is performed and a crack is found, then the size of this crack becomes the final crack size for the EFH calculations. A repair will "reset" a_o to a new size at the AFH and EFH when the repair was performed, and the EFH at the time of repair must be added to subsequent EFH calculations.

If an inspection is performed and there are no findings, the flaw size is typically reset to a size associated with the capability of the NDI system (a_{NDI}) used to perform the inspection (Reference 5). In other words, after an inspection is performed with no findings, a_{NDI} becomes the initial crack size for the next IAT tracking period. Figure 4 illustrates the flaw size reset concept in graphical form with a less severe spectrum (FSDT) and a more severe spectrum (baseline) shown.

If a crack is found or the flaw size is reset to a_{NDI} after an inspection, the EFH should be immediately determined. Future EFH calculations will be meaningless unless the EFH is calculated and book-kept at the time of the inspection and repair. *This is why IAT inspection feedback (both "findings AND "non-findings") is important!*

Figure 4.



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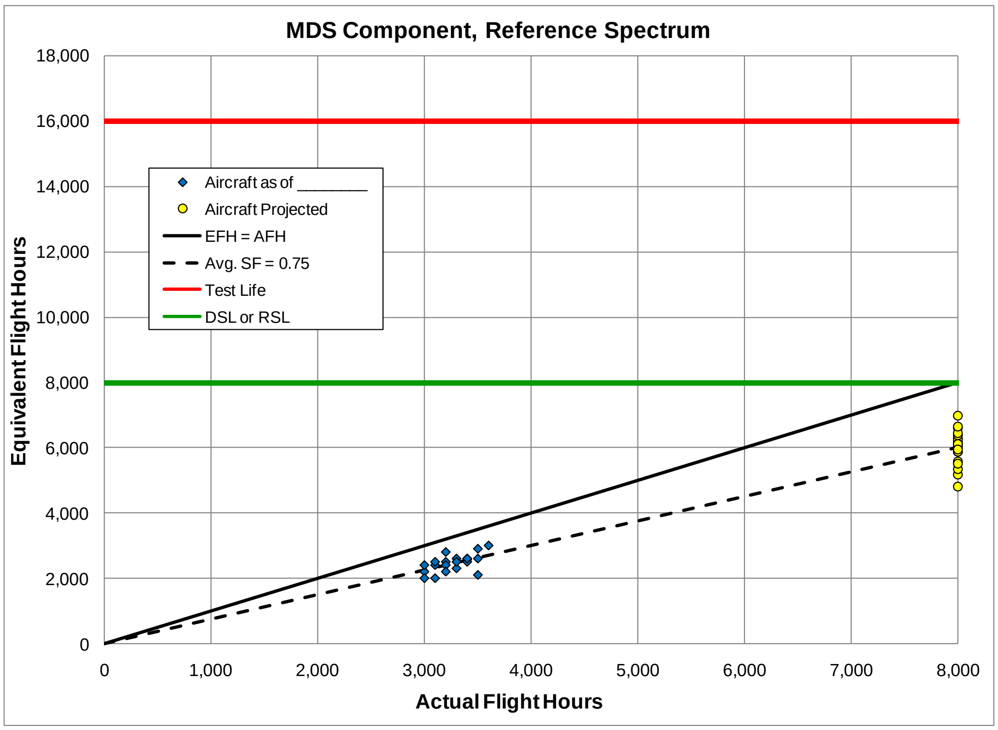
Fleet Equivalent Flight Hours:

To determine whether the actual usage is more or less severe than the baseline design usage, one approach is to compare the equivalent flight hours with the actual flight hours for all aircraft at a control point. The average EFH for the whole fleet can be plotted against AFH as shown in Figure 5. The ratio of the slopes of the fleet average actual usage to the reference line (EFH=AFH) is the average severity factor (Avg. SF).

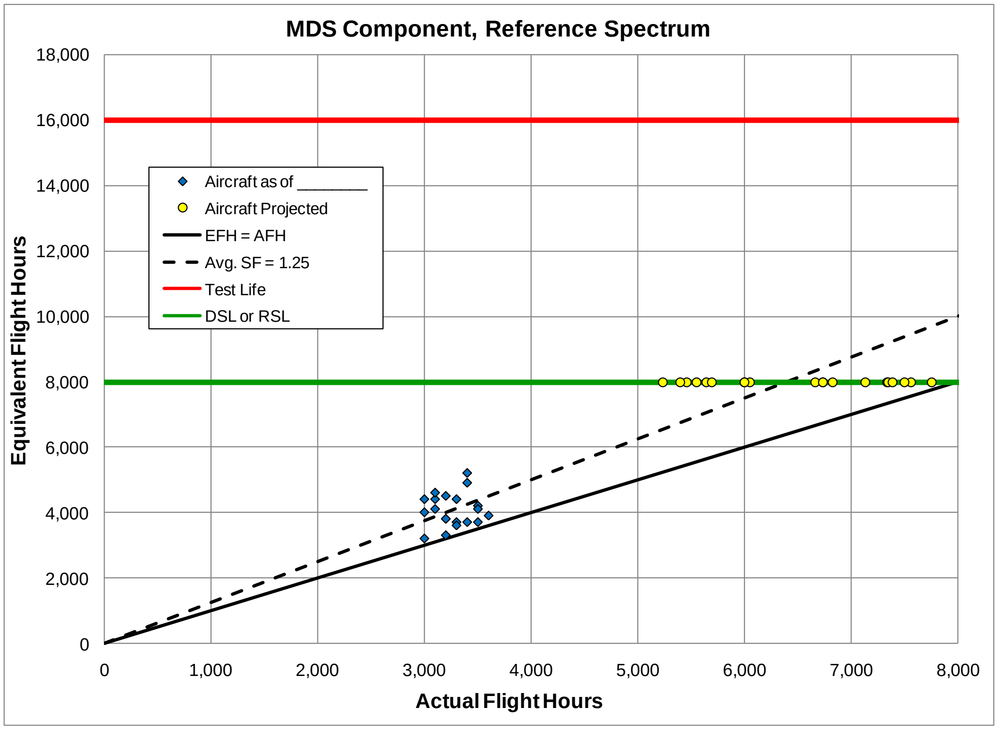
Figure 5.



This approach is a convenient way to quickly communicate usage severity and variability and the implications to force structure planners. This example indicates that the overall fleet usage is less severe than the reference, and also shows the projected EFH at a planned retirement point of 8000 AFH. The Design Service Life (DSL) or Revised Service Life (RSL) values can also be shown on these plots for comparisons. Additionally, the FSDT life and/or a factored test life can be plotted to help determine appropriate force management actions. The appropriate value to be used for a factored test life is dependent upon the structural integrity risk of the FSDT findings.

In Figure 6, an example is given for a more severe usage, and indicates the projected AFH at which a life limit is reached. This type of plot is useful if a “hard” EFH limit has been established based on test results or a quantitative risk assessment. Additionally, this information may be useful to plan for future risk assessments or to provide first-order estimates of retrofit/replacement schedules. Projecting to a fixed AFH (Figure 5) or a fixed EFH (Figure 6) can be done regardless of the severity of the control point.

Figure 6.



In lieu of displaying EFH information in terms of the average fleet usage (Figures 5 and 6), a plot similar to Figure 7 can be generated to show the most and least severe usage in terms of maximum or minimum SF (Max. SF and Min. SF respectively).

Figure 7.

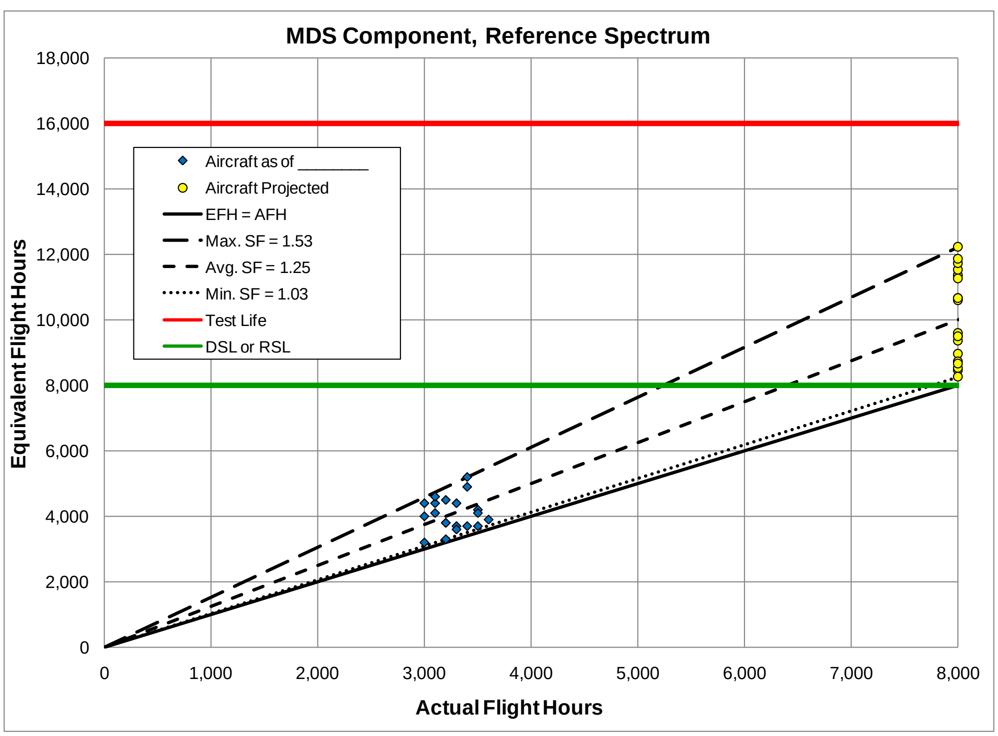


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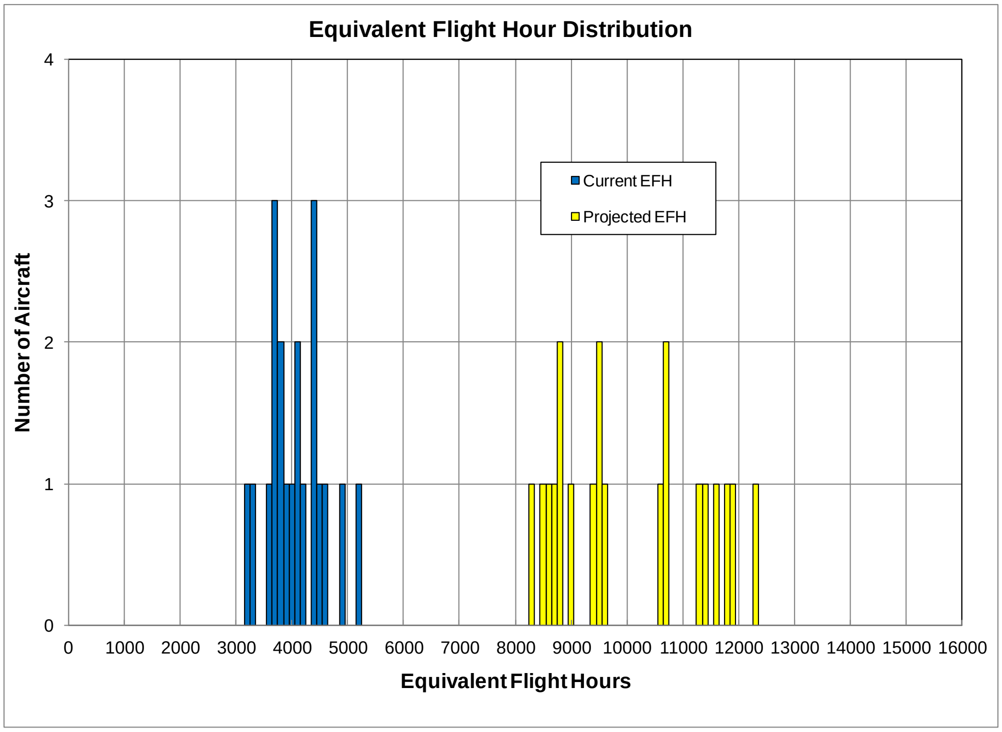
Figure 8 shows the EFH of current and projected fleet usage in a histogram format. This type of plot provides a better picture of the distribution of EFH and is especially useful for large aircraft fleets. As in the previous Figures, the test and service lives can also be plotted to evaluate usage against those references.

Figure 8.



Figures 5 through 8 describe various approaches that ASIP managers and structural engineers can use to communicate fleet usage severity and to develop appropriate force management actions for the aircraft fleet. In addition to the force management actions, it important to understand the root cause of any deviations from the reference spectra. These deviations may be a result of new missions, differing mission mix, a change in the training syllabus, wartime deployments, etc. Identification of the root cause of high usage severities should prompt discussions with the aircraft users to possibly minimize or eliminate operations driving the high severity factors.

Summary:

In summary, equivalent flight hours is the preferred approach to determine usage severity, inspection intervals, and maintenance strategies for every aircraft in the USAF fleet. It is recommended that ASIP managers and structural engineers use the EFH calculation methods and EFH graphical plots described in this bulletin to ensure consistency across the USAF fleet and to ensure that common information regarding usage severity is presented to leadership.

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