AFGROW Workshop 2024

Utilizing AFGROW for B-52 ASIP support

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HILL ENGINEERING
Predict. Test. Perform.

09/10/2024

Acknowledgements to the team

USAF A-10 ASIP (Hill AFB, UT)

- Brian Boeke, Jake Warner

USAF B-52 ASIP (Tinker AFB, OK)

- Travis Reese, Andrew Jones, Tyler Olheiser

Modern Technology Solutions Inc. (Las Vegas, NV)

- Casey Scott

Southwest Research Institute (San Antonio, TX)

- Lucky Smith, Jim Feiger

Hill Engineering (Marriott-Slaterville, UT / Rancho Cordova, CA)

- Dallen Andrew, Renan Ribeiro, Robert Pilarczyk

The Boeing Company (Oklahoma City, OK)

- Lee Ann McElroy, Jeremiah Pearce

Introduction

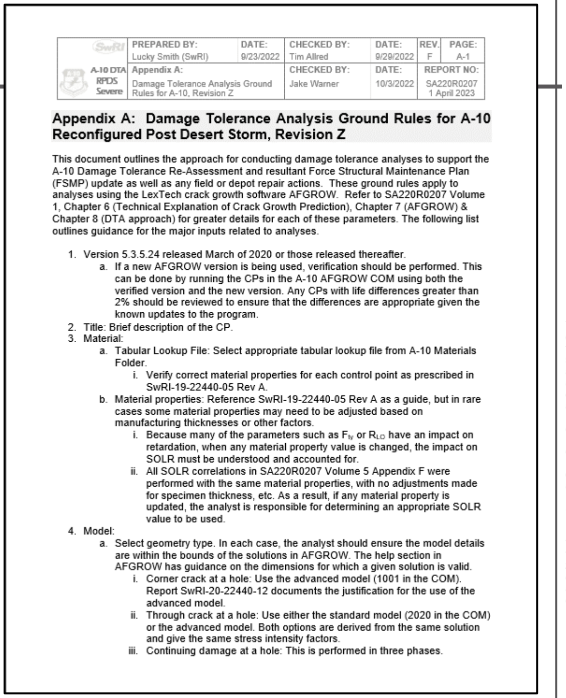
The B-52 ASIP team is pushing to start using AFGROW for their fleetwide DTA support

- OEM legacy crack growth analysis software (CRACKIT) is no longer being supported

B-52 and A-10 ASIP team working together to facilitate the transition

- Allows B-52 ASIP to be actively involved in analysis support
- Awareness of use/changes to SIF solutions, material models, and retardation model/parameters
- B-52 DTA ground rules in-work

This presentation covers some of the early work to facilitate the transition

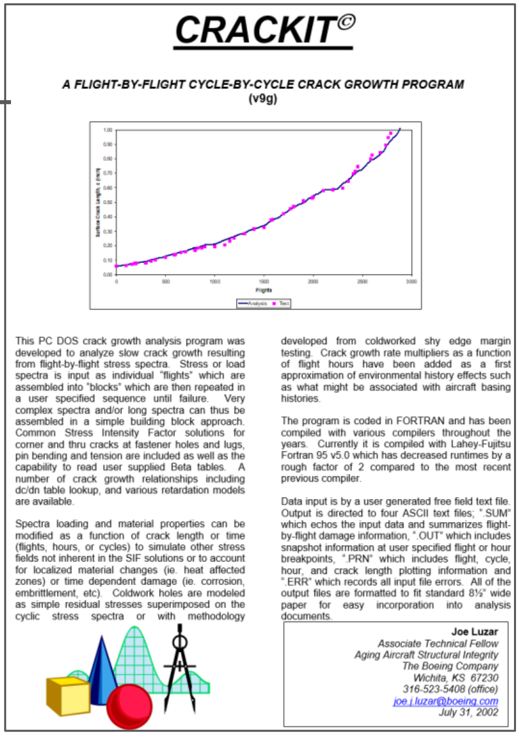


SwRI A-10 DTA RPDS Severe	PREPARED BY: Lucky Smith (SwRI)	DATE: 9/23/2022	CHECKED BY: Tim Allred	DATE: 9/29/2022	REV. F	PAGE: A-1
	Appendix A: Damage Tolerance Analysis Ground Rules for A-10, Revision Z		CHECKED BY: Jake Warner	DATE: 10/3/2022	REPORT NO: SA220R0207 1 April 2023	

Appendix A: Damage Tolerance Analysis Ground Rules for A-10 Reconfigured Post Desert Storm, Revision Z

This document outlines the approach for conducting damage tolerance analyses to support the A-10 Damage Tolerance Re-Assessment and resultant Force Structural Maintenance Plan (FSMP) update as well as any field or depot repair actions. These ground rules apply to analyses using the LexTech crack growth software AFGROW. Refer to SA220R0207 Volume 1, Chapter 6 (Technical Explanation of Crack Growth Prediction), Chapter 7 (AFGROW) & Chapter 8 (DTA approach) for greater details for each of these parameters. The following list outlines guidance for the major inputs related to analyses.

1. Version 5.3.5.24 released March of 2020 or those released thereafter.
    a. If a new AFGROW version is being used, verification should be performed. This can be done by running the CPs in the A-10 AFGROW COM using both the verified version and the new version. Any CPs with life differences greater than 2% should be reviewed to ensure that the differences are appropriate given the known updates to the program.
2. Title: Brief description of the CP.
3. Material:
    a. Tabular Lookup File: Select appropriate tabular lookup file from A-10 Materials Folder.
        i. Verify correct material properties for each control point as prescribed in SwRI-19-22440-05 Rev A.
    b. Material properties: Reference SwRI-19-22440-05 Rev A as a guide, but in rare cases some material properties may need to be adjusted based on manufacturing thicknesses or other factors.
        i. Because many of the parameters such as F_{ty} or R_{LO} have an impact on retardation, when any material property value is changed, the impact on SOLR must be understood and accounted for.
        ii. All SOLR correlations in SA220R0207 Volume 5 Appendix F were performed with the same material properties, with no adjustments made for specimen thickness, etc. As a result, if any material property is updated, the analyst is responsible for determining an appropriate SOLR value to be used.
4. Model:
    a. Select geometry type. In each case, the analyst should ensure the model details are within the bounds of the solutions in AFGROW. The help section in AFGROW has guidance on the dimensions for which a given solution is valid.
        i. Corner crack at a hole: Use the advanced model (1001 in the COM). Report SwRI-20-22440-12 documents the justification for the use of the advanced model.
        ii. Through crack at a hole: Use either the standard model (2020 in the COM) or the advanced model. Both options are derived from the same solution and give the same stress intensity factors.
        iii. Continuing damage at a hole: This is performed in three phases.



CRACKIT©

A FLIGHT-BY-FLIGHT CYCLE-BY-CYCLE CRACK GROWTH PROGRAM (v9g)

This PC DOS crack growth analysis program was developed to analyze slow crack growth resulting from flight-by-flight stress spectra. Stress or load spectra is input as individual "flights" which are assembled into "blocks" which are then repeated in a user specified sequence until failure. Very complex spectra and/or long spectra can thus be assembled in a simple building block approach. Common Stress Intensity Factor solutions for corner and thru cracks at fastener holes and lugs, pin bending and tension are included as well as the capability to read user supplied Beta tables. A number of crack growth relationships including dc/dn table lookup, and various retardation models are available.

Spectra loading and material properties can be modified as a function of crack length or time (flights, hours, or cycles) to simulate other stress fields not inherent in the SIF solutions or to account for localized material changes (ie. heat affected zones) or time dependent damage (ie. corrosion, embrittlement, etc). Coldwork holes are modeled as simple residual stresses superimposed on the cyclic stress spectra or with methodology developed from coldworked shy edge margin testing. Crack growth rate multipliers as a function of flight hours have been added as a first approximation of environmental history effects such as what might be associated with aircraft basing histories.

The program is coded in FORTRAN and has been compiled with various compilers throughout the years. Currently it is compiled with Lahey-Fujitsu Fortran 95 v5.0 which has decreased runtimes by a rough factor of 2 compared to the most recent previous compiler.

Data input is by a user generated free field text file. Output is directed to four ASCII text files; ".SUM" which echos the input data and summarizes flight-by-flight damage information, ".OUT" which includes snapshot information at user specified flight or hour breakpoints, ".PRN" which includes flight, cycle, hour, and crack length plotting information and ".ERR" which records all input file errors. All of the output files are formatted to fit standard 8½" wide paper for easy incorporation into analysis documents.

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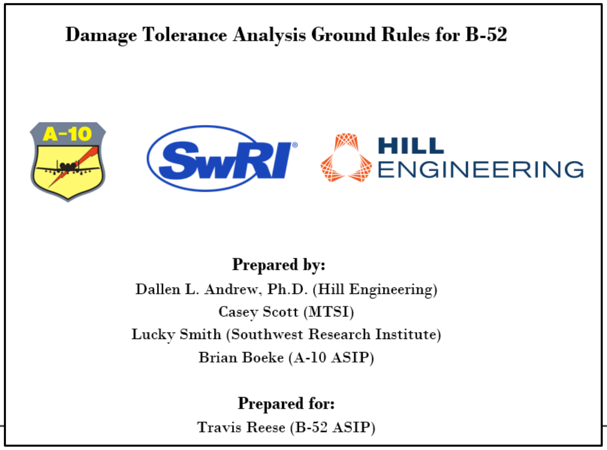

Damage Tolerance Analysis Ground Rules for B-52

A-10
SwRI
HILL ENGINEERING

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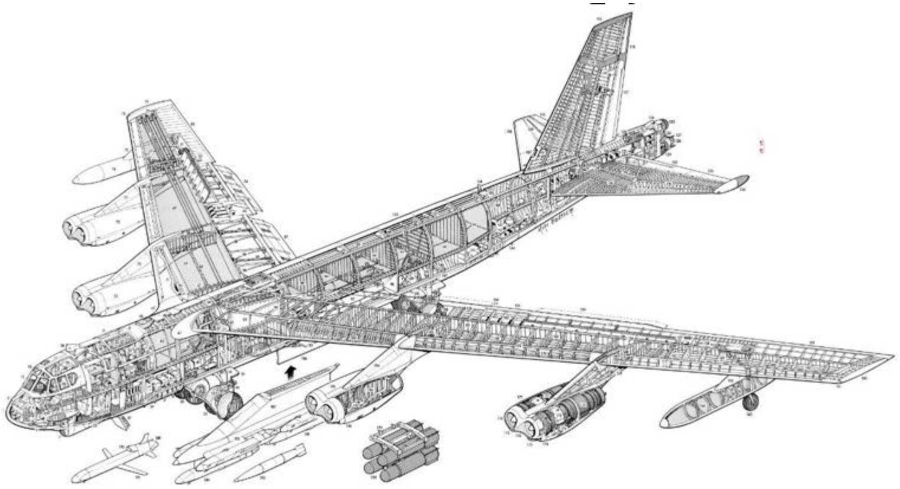
Prepared for:
Travis Reese (B-52 ASIP)

Fatigue critical details – overview

Large number of fatigue details for DTA

- Body/fuselage
- Wing (lower, upper, miscellaneous)
- Empennage



https://www.pinterest.com/pin/466544842622965428/

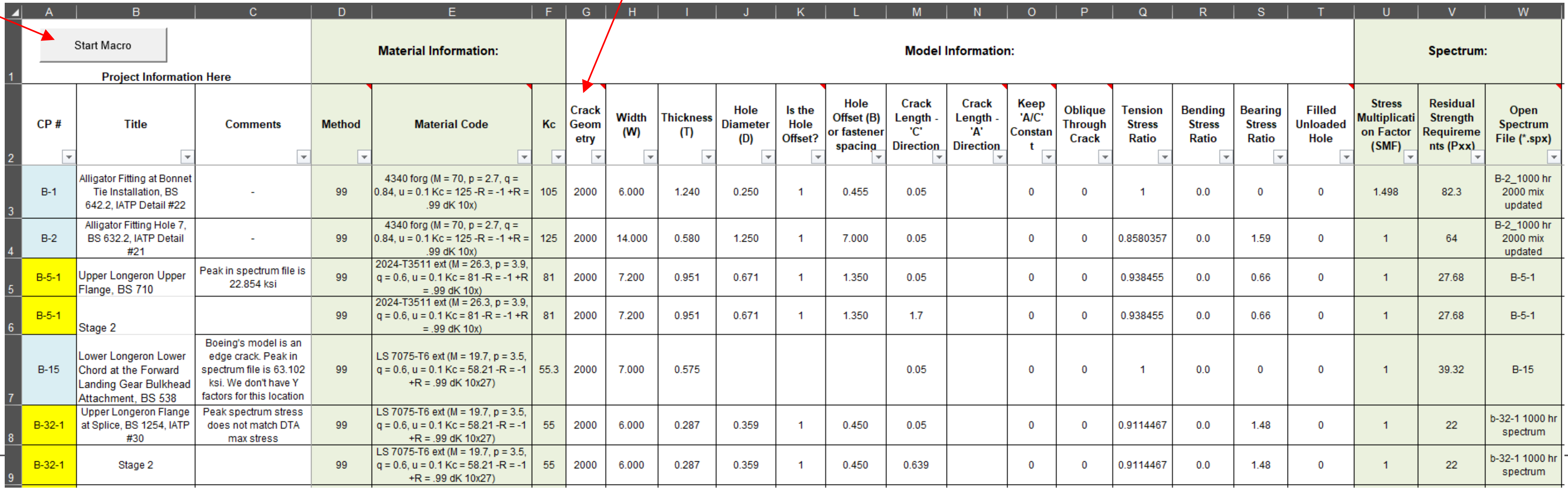
Current DTA method

- Boeing Y-factors
  - Unknown source (FEM, analytical solution, weight function, etc.)
- Walker equation material model
- Wheeler retardation model

AFGROW COM interface

The A-10 ASIP AFGROW COM interface is a good starting point

- Excel file that allows for running AFGROW in the background
  - User can run a single or multiple analyses sequentially without opening AFGROW
  - AFGROW .dax and output files are automatically generated and saved in the desired folder
- Excel file includes all relevant details for analysis in a tabular format
  - SIF model, material, geometry, loading, output parameters
- The transition would allow B-52 to run all/any details quickly and assess changes in results due to varying input parameters



Click to run AFGROW models

Detail name and description

Material definition

Model definition (SIF)

Geometry definition

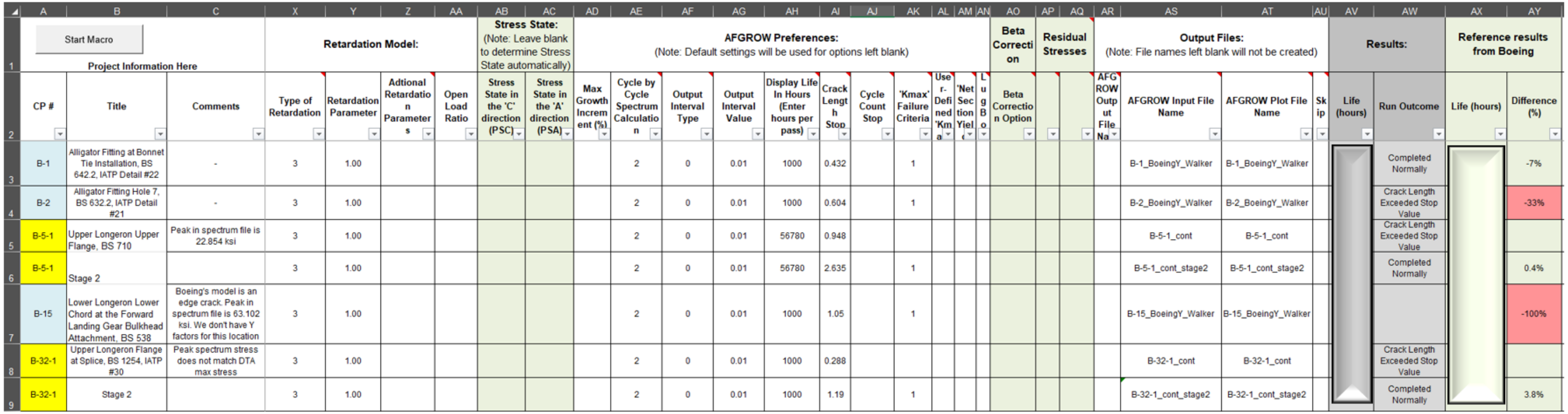
Spectrum definition

Project Information Here

CP #	Title	Comments	Method	Material Code	Kc	Crack Geometry	Width (W)	Thickness (T)	Hole Diameter (D)	Is the Hole Offset?	Hole Offset (B) or fastener spacing	Crack Length - 'C' Direction	Crack Length - 'A' Direction	Keep 'A/C' Constant	Oblique Through Crack	Tension Stress Ratio	Bending Stress Ratio	Bearing Stress Ratio	Filled Unloaded Hole	Stress Multiplication Factor (SMF)	Residual Strength Requirements (Pxx)	Open Spectrum File (*.spx)
			Material Information:			Model Information:														Spectrum:		
B-1	Alligator Fitting at Bonnet Tie Installation, BS 642.2, IATP Detail #22	-	99	4340 forg (M = 70, p = 2.7, q = 0.84, u = 0.1 Kc = 125 -R = -1 +R = .99 dK 10x)	105	2000	6.000	1.240	0.250	1	0.455	0.05		0	0	1	0.0	0	0	1.498	82.3	B-2_1000 hr 2000 mix updated
B-2	Alligator Fitting Hole 7, BS 632.2, IATP Detail #21	-	99	4340 forg (M = 70, p = 2.7, q = 0.84, u = 0.1 Kc = 125 -R = -1 +R = .99 dK 10x)	125	2000	14.000	0.580	1.250	1	7.000	0.05		0	0	0.8580357	0.0	1.59	0	1	64	B-2_1000 hr 2000 mix updated
B-5-1	Upper Longeron Upper Flange, BS 710	Peak in spectrum file is 22.854 ksi	99	2024-T3511 ext (M = 26.3, p = 3.9, q = 0.6, u = 0.1 Kc = 81 -R = -1 +R = .99 dK 10x)	81	2000	7.200	0.951	0.671	1	1.350	0.05		0	0	0.938455	0.0	0.66	0	1	27.68	B-5-1
B-5-1	Stage 2		99	2024-T3511 ext (M = 26.3, p = 3.9, q = 0.6, u = 0.1 Kc = 81 -R = -1 +R = .99 dK 10x)	81	2000	7.200	0.951	0.671	1	1.350	1.7		0	0	0.938455	0.0	0.66	0	1	27.68	B-5-1
B-15	Lower Longeron Lower Chord at the Forward Landing Gear Bulkhead Attachment, BS 538	Boeing's model is an edge crack. Peak in spectrum file is 63.102 ksi. We don't have Y factors for this location	99	LS 7075-T6 ext (M = 19.7, p = 3.5, q = 0.6, u = 0.1 Kc = 58.21 -R = -1 +R = .99 dK 10x27)	55.3	2000	7.000	0.575				0.05		0	0	1	0.0	0	0	1	39.32	B-15
B-32-1	Upper Longeron Flange at Splice, BS 1254, IATP #30	Peak spectrum stress does not match DTA max stress	99	LS 7075-T6 ext (M = 19.7, p = 3.5, q = 0.6, u = 0.1 Kc = 58.21 -R = -1 +R = .99 dK 10x27)	55	2000	6.000	0.287	0.359	1	0.450	0.05		0	0	0.9114467	0.0	1.48	0	1	22	b-32-1 1000 hr spectrum
B-32-1	Stage 2		99	LS 7075-T6 ext (M = 19.7, p = 3.5, q = 0.6, u = 0.1 Kc = 58.21 -R = -1 +R = .99 dK 10x27)	55	2000	6.000	0.287	0.359	1	0.450	0.639		0	0	0.9114467	0.0	1.48	0	1	22	b-32-1 1000 hr spectrum

AFGROW COM interface

The A-10 ASIP AFGROW COM interface is a good starting point to transition all B-52 details for use in AFGROW



Retardation definition

Results from AFGROW

Results from Boeing DTA

	A	B	C	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY
1	Start Macro Project Information Here			Retardation Model:				Stress State: (Note: Leave blank to determine Stress State automatically)		AFGROW Preferences: (Note: Default settings will be used for options left blank)											Beta Correction	Residual Stresses		Output Files: (Note: File names left blank will not be created)				Results:		Reference results from Boeing	
2	CP #	Title	Comments	Type of Retardation	Retardation Parameter	Adtional Retardation Parameters	Open Load Ratio	Stress State in the 'C' direction (PSC)	Stress State in the 'A' direction (PSA)	Max Growth Increment (%)	Cycle by Cycle Spectrum Calculation	Output Interval Type	Output Interval Value	Display Life In Hours (Enter hours per pass)	Crack Length Stop	Cycle Count Stop	'Kmax' Failure Criteria	User-Defined 'Kma	'Net Section Yiel	Lug Bo	Beta Correction Option			AFGROW Output File Na	AFGROW Input File Name	AFGROW Plot File Name	Skip	Life (hours)	Run Outcome	Life (hours)	Difference (%)
3	B-1	Alligator Fitting at Bonnet Tie Installation, BS 642.2, IATP Detail #22	-	3	1.00						2	0	0.01	1000	0.432		1								B-1_BoeingY_Walker	B-1_BoeingY_Walker			Completed Normally		-7%
4	B-2	Alligator Fitting Hole 7, BS 632.2, IATP Detail #21	-	3	1.00						2	0	0.01	1000	0.604		1								B-2_BoeingY_Walker	B-2_BoeingY_Walker			Crack Length Exceeded Stop Value		-33%
5	B-5-1	Upper Longeron Upper Flange, BS 710	Peak in spectrum file is 22.854 ksi	3	1.00						2	0	0.01	56780	0.948										B-5-1_cont	B-5-1_cont			Crack Length Exceeded Stop Value		
6	B-5-1	Stage 2		3	1.00						2	0	0.01	56780	2.635		1								B-5-1_cont_stage2	B-5-1_cont_stage2			Completed Normally		0.4%
7	B-15	Lower Longeron Lower Chord at the Forward Landing Gear Bulkhead Attachment, BS 538	Boeing's model is an edge crack. Peak in spectrum file is 63.102 ksi. We don't have Y factors for this location	3	1.00						2	0	0.01	1000	1.05		1								B-15_BoeingY_Walker	B-15_BoeingY_Walker					-100%
8	B-32-1	Upper Longeron Flange at Splice, BS 1254, IATP #30	Peak spectrum stress does not match DTA max stress	3	1.00						2	0	0.01	1000	0.288										B-32-1_cont	B-32-1_cont			Crack Length Exceeded Stop Value		
9	B-32-1	Stage 2		3	1.00						2	0	0.01	1000	1.19		1								B-32-1_cont_stage2	B-32-1_cont_stage2			Completed Normally		3.8%

AFGROW COM

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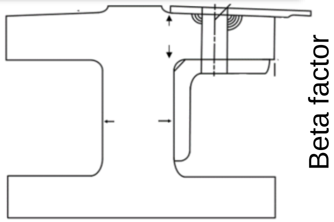
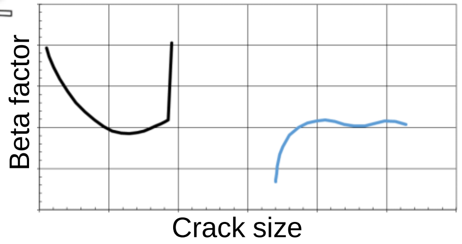
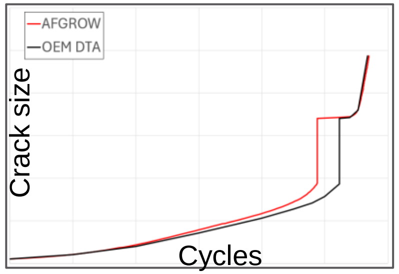
- User-defined models using OEM beta factors [redacted]
- Material models from OEM used to generate lookup tables for AFGROW
- Retardation used as OEM
- Initial results
  - Several details are closely reproduced (less than 10% relative difference in life)
  - Several details in the 10-30% relative difference range
  - Some details with relative difference beyond 30%
    - Differences may be coming from retardation formulation differences between software
    - More work required to understand differences

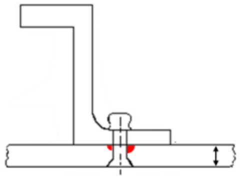
Example body detail

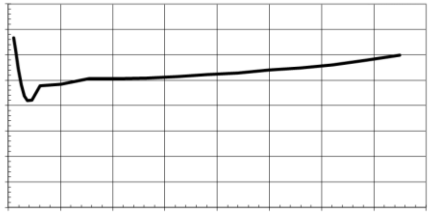


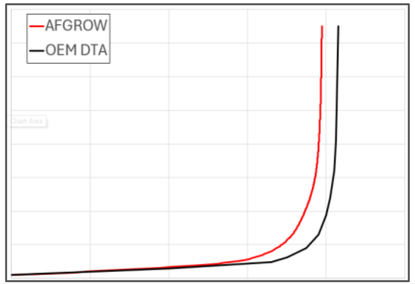




Example wing detail







This is a subset of fatigue details

CP #	Title	Continuing damage	Life (hours) AFGROW COM	Life (hours) Boeing	Life (hours) Difference relative to Boeing
B-1	Alligator Fitting at Bonnet Tie Installation, BS 642.2, IATP Detail #22		[redacted]	[redacted]	-7.1%
B-2	Alligator Fitting Hole 7, BS 632.2, IATP Detail #21		[redacted]	[redacted]	-33.0%
B-5-1	Upper Longeron Upper Flange, BS 710	✓	[redacted]	[redacted]	0.4%
B-32-1	Upper Longeron Flange at Splice, BS 1254, IATP #30	✓	[redacted]	[redacted]	3.8%
WL-9	S-2 Runout WS 1115, IATP Detail #38	✓	[redacted]	[redacted]	23.5%
WL-10-3	Rear Spar Chord Web Flange WS 1064, IATP Detail #39	✓	[redacted]	[redacted]	-8.6%
WL-26-2	Rear Spar Chord Skin Flange at WS 1029	✓	[redacted]	[redacted]	-10.2%
WL-27-2	Lower Skin at Front Spar WS 1029	✓	[redacted]	[redacted]	-7.7%
WL-27-3	Lower Front Spar Chord Web Flange WS 1029 IATP Detail #120	✓	[redacted]	[redacted]	-23.6%
WL-29-2	S-2 Skin Attachment WS 1072		[redacted]	[redacted]	-41.4%
WL-33-2	S-7 Skin Attachment Flange WS 1072	✓	[redacted]	[redacted]	-57.0%
WL-40-2	Lower Rear Spar Chord, Horizontal Flange, IATP Detail #121	✓	[redacted]	[redacted]	-3.5%
WL-45-2	Rear Spar Skin Flange WS 665, IATP Detail #6	✓	[redacted]	[redacted]	-13.5%
WL-50-2	Rear Spar Skin Flange WS 222	✓	[redacted]	[redacted]	12.9%
WL-50-3	Lower Rear Spar Chord, Web Flange, IATP Detail #122	✓	[redacted]	[redacted]	13.7%
WL-62-1	Rear Spar Chord Skin Flange WS 889, IATP Detail #7	✓	[redacted]	[redacted]	-26.3%
WL-62-3	Lower Rear Spar Chord, Vertical Flange to Web Attachment, IATP #116	✓	[redacted]	[redacted]	-0.2%
WL-65-1	Rear Spar Lower Chord Web, WS 589	✓	[redacted]	[redacted]	37.1%
WL-65-4	Wing Rear Spar Lower Chord - Skin Flange WS 589, IATP Detail #117	✓	[redacted]	[redacted]	-7.5%
WL-66-1	Wing Rear Spar, Web Attachment to Lower Chord, WS 780 – WS 790, IATP Detail #46	✓	[redacted]	[redacted]	1.5%
WL-78-1	Stiffener S-5 Lower Flange at Lower Wing Skin Attachment, WS 899, IATP Detail # TBD		[redacted]	[redacted]	-10.1%
WL-78-2	Lower Wing Skin at S-5, WS 899		[redacted]	[redacted]	-5.1%
WL-79-1	Lower Wing S-7 Skin Attachment Flange WS 933 IATP Detail #8		[redacted]	[redacted]	-8.2%
WL-79-2	Lower Wing Skin at S-7 Attachment Flange WS 933		[redacted]	[redacted]	-43.9%
WL-101	Read Spar Web at Fitting Hole, IATP Detail #48		[redacted]	[redacted]	125.6%
WM-1A	Inboard Nacelle Strut to Link Attachment Fitting – ECP 1175-212 CX, IATP Detail #15		[redacted]	[redacted]	-29.0%
WM-2	Inboard Nacelle Chord Angle at Rib #5 – ECP 1175-212 CX, IATP Detail #17		[redacted]	[redacted]	-15.3%
WU-2	Wing Upper Skin Fuel Filler Hole WS 260.6, IATP Detail #50		[redacted]	[redacted]	0.1%

AFGROW COM

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- Retardation used as OEM
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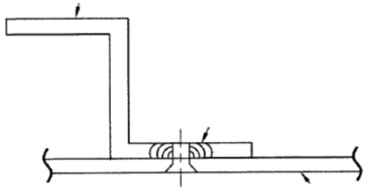
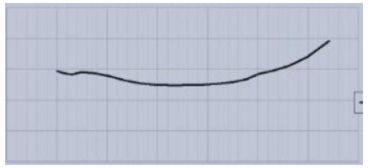
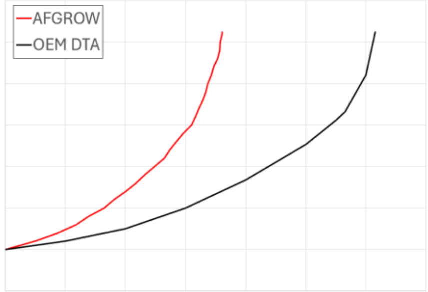
    - Differences may be coming from retardation formulation differences between software)
    - More work required to understand differences

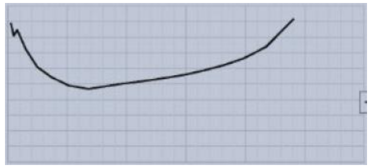
This is a subset of fatigue details

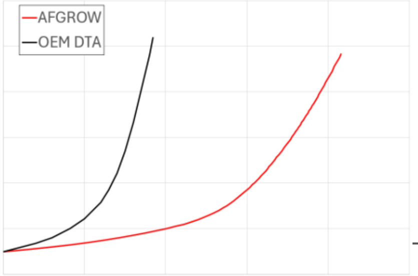
Example wing details that don't match well







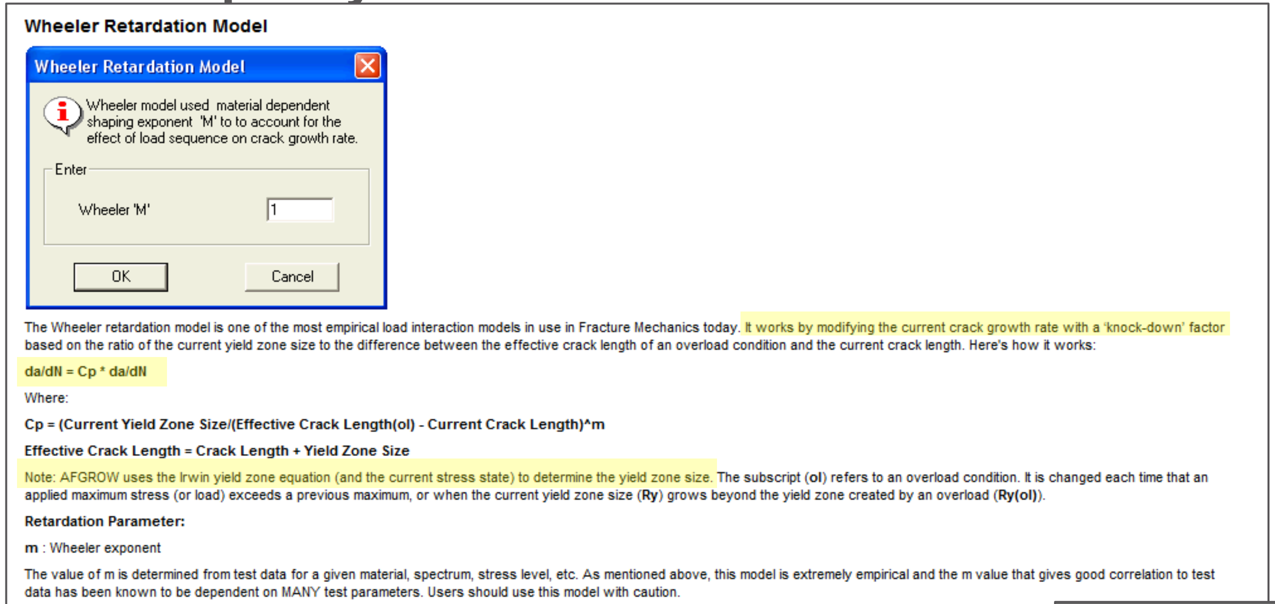




			Life (hours)			Recurring inspection interval (hours) Life from detectable/2			
CP #	Title	Continuing damage	AFGROW COM	Boeing	Difference relative to Boeing	AFGROW COM	Boeing	Result relative to PDM	Difference relative to Boeing
B-1	Alligator Fitting at Bonnet Tie Installation, BS 642.2, IATP Detail #22		[redacted]	[redacted]	-7.1%	[redacted]	[redacted]	Same	-7.1%
B-2	Alligator Fitting Hole 7, BS 632.2, IATP Detail #21		[redacted]	[redacted]	-33.0%	[redacted]	[redacted]	Same	-50.1%
B-5-1	Upper Longeron Upper Flange, BS 710	✓	[redacted]	[redacted]	0.4%	[redacted]	[redacted]	Same	85.6%
B-32-1	Upper Longeron Flange at Splice, BS 1254, IATP #30	✓	[redacted]	[redacted]	3.8%	[redacted]	[redacted]	Same	30.7%
WL-9	S-2 Runout WS 1115, IATP Detail #38	✓	[redacted]	[redacted]	23.5%	[redacted]	[redacted]	Same	-87.3%
WL-10-3	Rear Spar Chord Web Flange WS 1064, IATP Detail #39	✓	[redacted]	[redacted]	-8.6%	[redacted]	[redacted]	Same	6.0%
WL-26-2	Rear Spar Chord Skin Flange at WS 1029	✓	[redacted]	[redacted]	-10.2%	[redacted]	[redacted]	Same	-12.9%
WL-27-2	Lower Skin at Front Spar WS 1029	✓	[redacted]	[redacted]	-7.7%	[redacted]	[redacted]	Same	32.5%
WL-27-3	Lower Front Spar Chord Web Flange WS 1029 IATP Detail #120	✓	[redacted]	[redacted]	-23.6%	[redacted]	[redacted]	Same	-23.9%
WL-29-2	S-2 Skin Attachment WS 1072		[redacted]	[redacted]	-41.4%	[redacted]	[redacted]	Same	-5.4%
WL-33-2	S-7 Skin Attachment Flange WS 1072	✓	[redacted]	[redacted]	-57.0%	[redacted]	[redacted]	Different	-28.6%
WL-40-2	Lower Rear Spar Chord, Horizontal Flange, IATP Detail #121	✓	[redacted]	[redacted]	-3.5%	[redacted]	[redacted]	Same	29.2%
WL-45-2	Rear Spar Skin Flange WS 665, IATP Detail #6	✓	[redacted]	[redacted]	-13.5%	[redacted]	[redacted]	Same	-36.3%
WL-50-2	Rear Spar Skin Flange WS 222	✓	[redacted]	[redacted]	12.9%	[redacted]	[redacted]	Same	102.8%
WL-50-3	Lower Rear Spar Chord, Web Flange, IATP Detail #122	✓	[redacted]	[redacted]	13.7%	[redacted]	[redacted]	Same	13.7%
WL-62-1	Rear Spar Chord Skin Flange WS 889, IATP Detail #7	✓	[redacted]	[redacted]	-26.3%	[redacted]	[redacted]	Different	-65.7%
WL-62-3	Lower Rear Spar Chord, Vertical Flange to Web Attachment, IATP #116	✓	[redacted]	[redacted]	-0.2%	[redacted]	[redacted]	Same	-0.2%
WL-65-1	Rear Spar Lower Chord Web, WS 589	✓	[redacted]	[redacted]	37.1%	[redacted]	[redacted]	Same	567.2%
WL-65-4	Wing Rear Spar Lower Chord - Skin Flange WS 589, IATP Detail #117	✓	[redacted]	[redacted]	-7.5%	[redacted]	[redacted]	Same	-7.5%
WL-66-1	Wing Rear Spar, Web Attachment to Lower Chord, WS 780 – WS 790, IATP Detail #46	✓	[redacted]	[redacted]	1.5%	[redacted]	[redacted]	Same	76.1%
WL-78-1	Stiffener S-5 Lower Flange at Lower Wing Skin Attachment, WS 899, IATP Detail # TBD		[redacted]	[redacted]	-10.1%	[redacted]	[redacted]	Same	-4.3%
WL-78-2	Lower Wing Skin at S-5, WS 899		[redacted]	[redacted]	-5.1%	[redacted]	[redacted]	Same	17.2%
WL-79-1	Lower Wing S-7 Skin Attachment Flange WS 933 IATP Detail #8		[redacted]	[redacted]	-8.2%	[redacted]	[redacted]	Same	-3.1%
WL-79-2	Lower Wing Skin at S-7 Attachment Flange WS 933		[redacted]	[redacted]	-43.9%	[redacted]	[redacted]	Same	11.4%
WL-101	Read Spar Web at Fitting Hole, IATP Detail #48		[redacted]	[redacted]	125.6%	[redacted]	[redacted]	Same	110.7%
WM-1A	Inboard Nacelle Strut to Link Attachment Fitting – ECP 1175-212 CX, IATP Detail #15		[redacted]	[redacted]	-29.0%	[redacted]	[redacted]	Same	-63.4%
WM-2	Inboard Nacelle Chord Angle at Rib #5 – ECP 1175-212 CX, IATP Detail #17		[redacted]	[redacted]	-15.3%	[redacted]	[redacted]	Same	-29.1%
WU-2	Wing Upper Skin Fuel Filler Hole WS 260.6, IATP Detail #50		[redacted]	[redacted]	0.1%	[redacted]	[redacted]	Same	-3.1%

AFGROW COM

Retardation implementation between AFGROW and OEM software may be a key reason of discrepancy



Wheeler Retardation Model

The Wheeler retardation model is one of the most empirical load interaction models in use in Fracture Mechanics today. It works by modifying the current crack growth rate with a 'knock-down' factor based on the ratio of the current yield zone size to the difference between the effective crack length of an overload condition and the current crack length. Here's how it works:

da/dN = Cp * da/dN

Where:

Cp = (Current Yield Zone Size/(Effective Crack Length(ol) - Current Crack Length)^m

Effective Crack Length = Crack Length + Yield Zone Size

Note: AFGROW uses the Irwin yield zone equation (and the current stress state) to determine the yield zone size. The subscript (**ol**) refers to an overload condition. It is changed each time that an applied maximum stress (or load) exceeds a previous maximum, or when the current yield zone size (**Ry**) grows beyond the yield zone created by an overload (**Ry(ol)**).

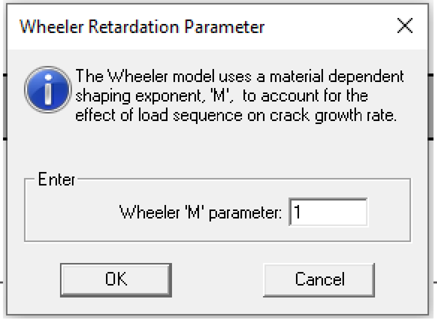
Retardation Parameter:

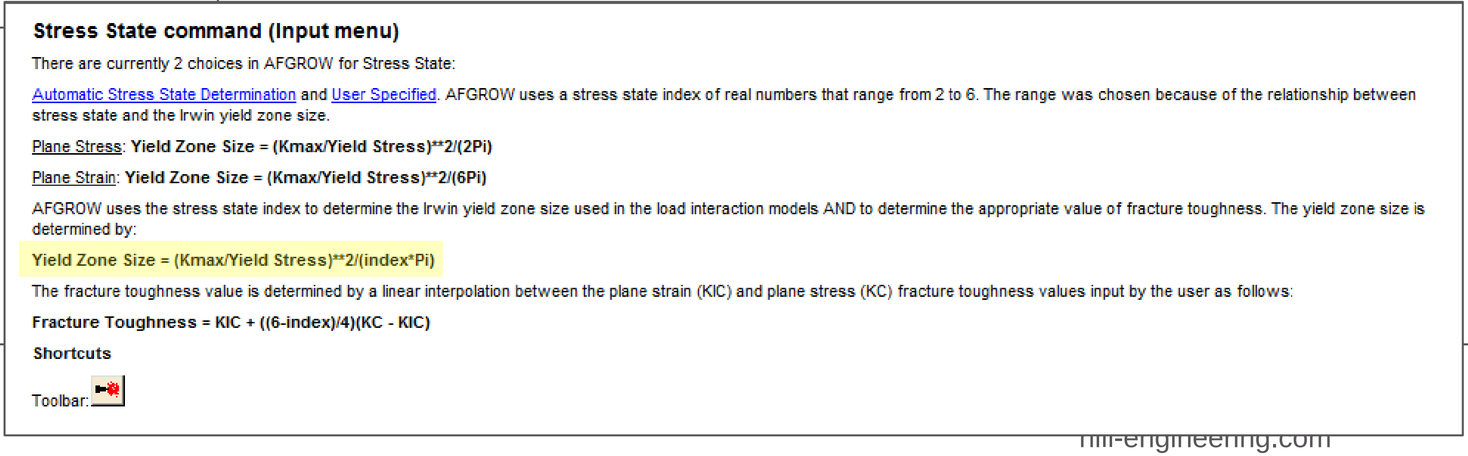
m : Wheeler exponent

The value of m is determined from test data for a given material, spectrum, stress level, etc. As mentioned above, this model is extremely empirical and the m value that gives good correlation to test data has been known to be dependent on MANY test parameters. Users should use this model with caution.

AFGROW computes a knock-down factor for da/dN

- Depends on the yield zone size
  - Depends on the stress state (plane stress, plane strain)
  - We use automatic stress state determination
    - AFGROW computes index (between 2 (plane stress) and 6 (plane strain))





Stress State command (Input menu)

There are currently 2 choices in AFGROW for Stress State:

Automatic Stress State Determination and User Specified. AFGROW uses a stress state index of real numbers that range from 2 to 6. The range was chosen because of the relationship between stress state and the Irwin yield zone size.

Plane Stress: **Yield Zone Size = (Kmax/Yield Stress)**2/(2Pi)**

Plane Strain: **Yield Zone Size = (Kmax/Yield Stress)**2/(6Pi)**

AFGROW uses the stress state index to determine the Irwin yield zone size used in the load interaction models AND to determine the appropriate value of fracture toughness. The yield zone size is determined by:

Yield Zone Size = (Kmax/Yield Stress)2/(index*Pi)**

The fracture toughness value is determined by a linear interpolation between the plane strain (KIC) and plane stress (KC) fracture toughness values input by the user as follows:

Fracture Toughness = KIC + ((6-index)/4)(KC - KIC)

Shortcuts

Toolbar:

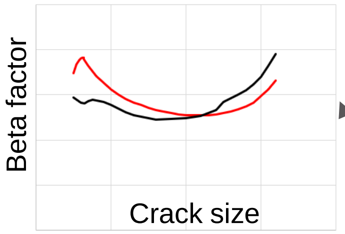
AFGROW COM

Plans for near future and implementation of the COM

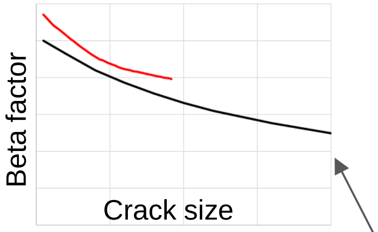
- Use advanced AFGROW models instead of user-defined beta models
    - Significant differences arise when using AFGROW advanced models
    - However, majority of details still satisfy planned inspection interval
- Use tabular material data with the typical non-linear behavior near the threshold and fracture
- Calibrate retardation models based on spectrum crack growth testing that is in work at SwRI for several details

Example differences in beta factors

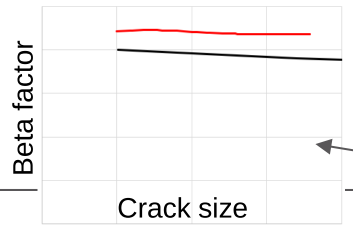
WL-29-2

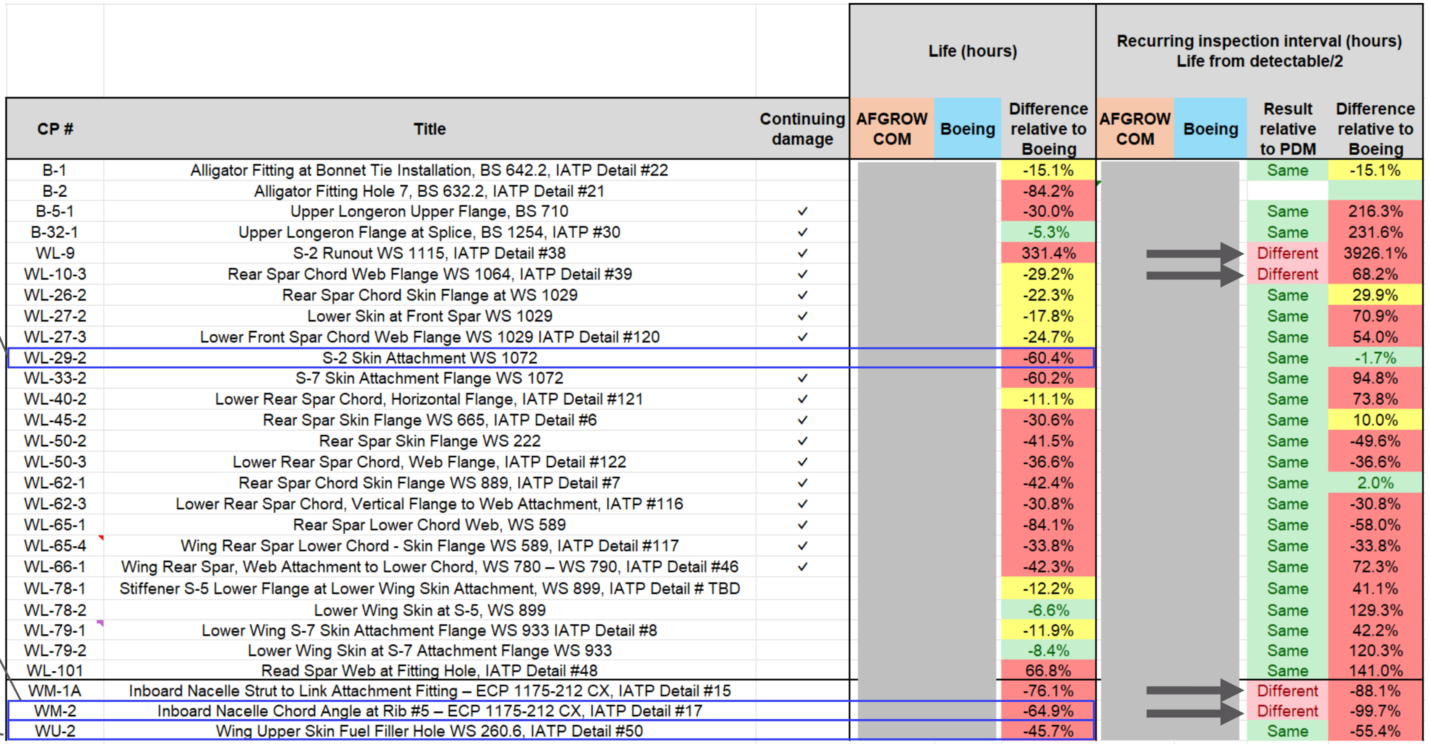


WM-2



WU-2





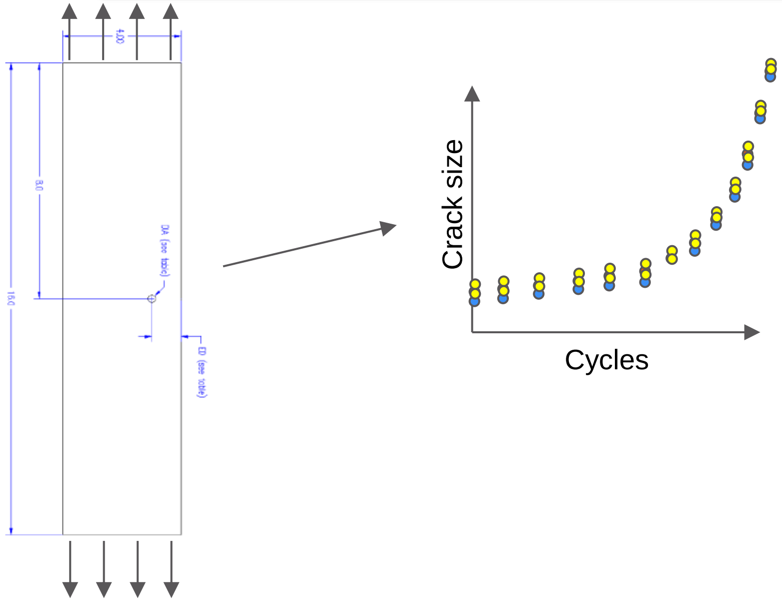
CP #	Title	Continuing damage	Life (hours)			Recurring inspection interval (hours) Life from detectable/2			
			AFGROW COM	Boeing	Difference relative to Boeing	AFGROW COM	Boeing	Result relative to PDM	Difference relative to Boeing
B-1	Alligator Fitting at Bonnet Tie Installation, BS 642.2, IATP Detail #22				-15.1%			Same	-15.1%
B-2	Alligator Fitting Hole 7, BS 632.2, IATP Detail #21				-84.2%				
B-5-1	Upper Longeron Upper Flange, BS 710	✓			-30.0%			Same	216.3%
B-32-1	Upper Longeron Flange at Splice, BS 1254, IATP #30	✓			-5.3%			Same	231.6%
WL-9	S-2 Runout WS 1115, IATP Detail #38	✓			331.4%			Different	3926.1%
WL-10-3	Rear Spar Chord Web Flange WS 1064, IATP Detail #39	✓			-29.2%			Different	68.2%
WL-26-2	Rear Spar Chord Skin Flange at WS 1029	✓			-22.3%			Same	29.9%
WL-27-2	Lower Skin at Front Spar WS 1029	✓			-17.8%			Same	70.9%
WL-27-3	Lower Front Spar Chord Web Flange WS 1029 IATP Detail #120	✓			-24.7%			Same	54.0%
WL-29-2	S-2 Skin Attachment WS 1072				-60.4%			Same	-1.7%
WL-33-2	S-7 Skin Attachment Flange WS 1072	✓			-60.2%			Same	94.8%
WL-40-2	Lower Rear Spar Chord, Horizontal Flange, IATP Detail #121	✓			-11.1%			Same	73.8%
WL-45-2	Rear Spar Skin Flange WS 665, IATP Detail #6	✓			-30.6%			Same	10.0%
WL-50-2	Rear Spar Skin Flange WS 222	✓			-41.5%			Same	-49.6%
WL-50-3	Lower Rear Spar Chord, Web Flange, IATP Detail #122	✓			-36.6%			Same	-36.6%
WL-62-1	Rear Spar Chord Skin Flange WS 889, IATP Detail #7	✓			-42.4%			Same	2.0%
WL-62-3	Lower Rear Spar Chord, Vertical Flange to Web Attachment, IATP #116	✓			-30.8%			Same	-30.8%
WL-65-1	Rear Spar Lower Chord Web, WS 589	✓			-84.1%			Same	-58.0%
WL-65-4	Wing Rear Spar Lower Chord - Skin Flange WS 589, IATP Detail #117	✓			-33.8%			Same	-33.8%
WL-66-1	Wing Rear Spar, Web Attachment to Lower Chord, WS 780 – WS 790, IATP Detail #46	✓			-42.3%			Same	72.3%
WL-78-1	Stiffener S-5 Lower Flange at Lower Wing Skin Attachment, WS 899, IATP Detail # TBD				-12.2%			Same	41.1%
WL-78-2	Lower Wing Skin at S-5, WS 899				-6.6%			Same	129.3%
WL-79-1	Lower Wing S-7 Skin Attachment Flange WS 933 IATP Detail #8				-11.9%			Same	42.2%
WL-79-2	Lower Wing Skin at S-7 Attachment Flange WS 933				-8.4%			Same	120.3%
WL-101	Read Spar Web at Fitting Hole, IATP Detail #48				66.8%			Same	141.0%
WM-1A	Inboard Nacelle Strut to Link Attachment Fitting – ECP 1175-212 CX, IATP Detail #15				-76.1%			Different	-88.1%
WM-2	Inboard Nacelle Chord Angle at Rib #5 – ECP 1175-212 CX, IATP Detail #17				-64.9%			Different	-99.7%
WU-2	Wing Upper Skin Fuel Filler Hole WS 260.6, IATP Detail #50				-45.7%			Same	-55.4%

AFGROW COM

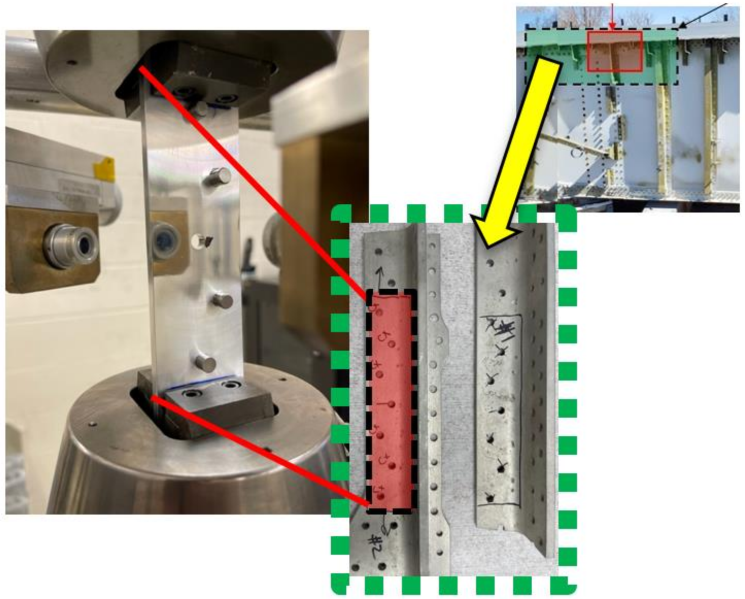
Plans for near future and implementation of the COM

- Use advanced AFGROW models instead of user-defined beta models
- Use tabular material data with the typical non-linear behavior near the threshold and fracture
- Calibrate retardation models based on spectrum crack growth testing that is in work at SwRI for several details

Manufactured coupons for several DTA locations



Some testing with excised structure



Summary

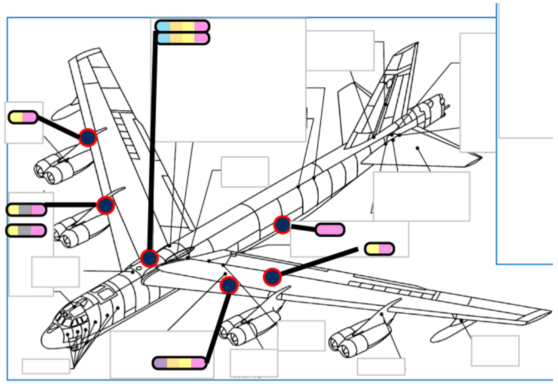
B-52 is trying to transition to using AFGROW and participating in DTA updates

Initial transition work is in progress to assess implementation in AFGROW and results relative to current DTAs from OEM

- Reproducing the current DTAs in AFGROW provides similar results for the most part, but differences were observed for some details
- Retardation may be a key factor in the differences

Effort is ongoing to assess differences and implementation with different SIF solutions, material models, and retardation

Fatigue crack growth testing is in progress and will provide useful data for correlation



View looking down