U.S. AIR FORCE

B-52 Spectrum Development and Validation for Organic DTA Support

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13 Sept 2022

Outline

- Goal of task
- Data Delivery from Boeing
- Spectrum development
- AFGROW model creation
- Spectrum comparison
- Next Steps

B-52 Support Task

- The B-52 SPO provided funding to the A-10 to enhance organic capability and provide third party engineering support
- Program includes
  - Testing (FCGR, SCG, K1)
  - Detailed analysis (BAMpF)
  - FEM technical support
  - Data collection
  - Organic Analysis Development

Spectrum Development Goal

- When A-10 support started, B-52 SPO had no spectrum files for use in AFGROW
  - Boeing performed all crack growth predictions for ASIP/repairs
- B-52 SPO wants to perform DADTA independent of Boeing
  - DADTA report provides information for
    - Geometry
    - Material model
    - Retardation model
    - Y-factors (equivalent to betas in AFGROW)
    - Crack growth curves
    - Stress equation
  - B-52 SPO does not have input for stress equation
- B-52 SPO desires the spectrum for their DTA locations to complete the dataset for their crack growth models

Data from Boeing

- Spectrum request = no
- Did provide mission stress sequences
- DADTA report provides two different mission mixes
  - Mix 1 from early 2000s and Mix 2 from 2010s
- Data provided was sufficient to assemble a spectrum in spectrum manager

MISSION: 1 MSN A		
load levels	flight hours	
77	6	
Max stress per		
10 flights	100 flights	200 flights
14.9	16.4	16.8
Smax	**Smin**	**Cycles**
-8.14	-10.641	3
13.5	-11.25	1
11.5	8.984	14
12	8.511	5
12.5	8.013	2
13	7.514	1
13.5	6.995	1
13	7.514	1
12.5	8.013	2
12	8.511	5
11.5	8.984	14
11.9	9.37	12
12.4	8.921	3
12.9	8.377	1
13.4	7.882	1
12.9	8.377	1

# of independent stress cycles

Length of mission

Varying peak stresses per number of flights of mission

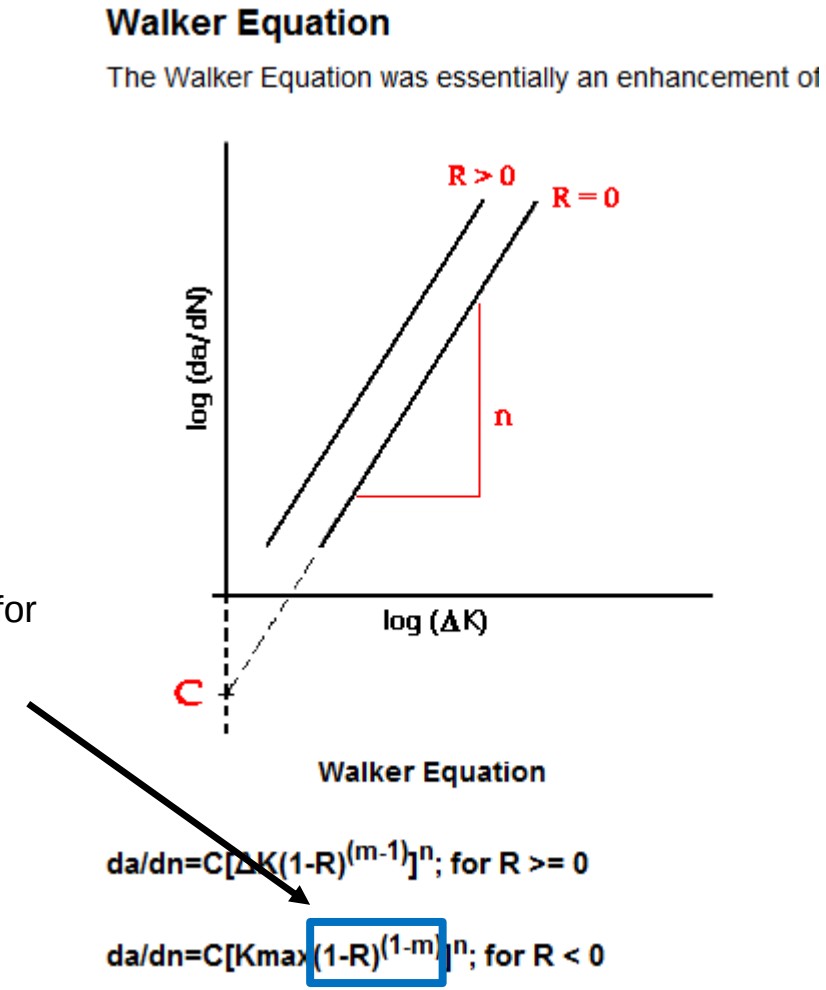
Independent cycles

# of occurences of each stress cycle

AFGROW Model - Material

- Boeing uses Walker Equation for material da/dn curves
- AFGROW and Boeing's implementation of Walker for negative R is different
- Tabular lookup for R = -1 to .99 using Boeing Walker equation used to simulate Boeing implementation results.
  - Potential source of error

Different factor for negative R



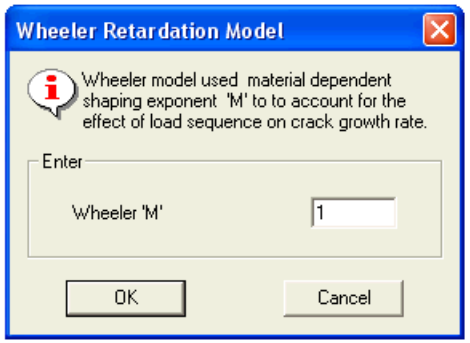
Tabular Lookup Example

			R	-1	-0.7	-0.5	-0.3	0	0.2	0.4	0.6	0.8	0.95
			da/dn										
			1.00E-09	0.895063	0.920158	0.937685	0.955892	0.984569	0.950037	0.907299	0.850307	0.761046	0.609651
M	70		3.00E-09	1.344513	1.38221	1.408538	1.435888	1.478965	1.427093	1.362894	1.277284	1.143201	0.915784
p	2.7		1.00E-08	2.100022	2.158901	2.200023	2.242742	2.310024	2.229005	2.128731	1.995015	1.785588	1.430381
u	0.1		2.00E-08	2.714666	2.790779	2.843936	2.899158	2.986133	2.8814	2.751778	2.578925	2.308203	1.849032
q	0.84		4.00E-08	3.509208	3.607597	3.676313	3.747697	3.860128	3.724742	3.557181	3.333737	2.983778	2.390215
			6.00E-08	4.07782	4.192151	4.272002	4.354953	4.485602	4.328278	4.133566	3.873917	3.467253	2.777512
			1.00E-07	4.927133	5.065276	5.161758	5.261986	5.419846	5.229755	4.99449	4.680762	4.189399	3.356001
			2.00E-07	6.369229	6.547805	6.672525	6.802089	7.006151	6.760424	6.4563	6.050749	5.415572	4.338251
			3.00E-07	7.401263	7.608775	7.753704	7.904261	8.141389	7.855845	7.502443	7.031178	6.293081	5.041197
			4.00E-07	8.233404	8.464247	8.625471	8.792956	9.056744	8.739096	8.34596	7.82171	7.000627	5.607991
			6.00E-07	9.567499	9.835746	10.02309	10.21772	10.52425	10.15513	9.698293	9.089096	8.134969	6.516679
			1.00E-06	11.56018	11.8843	12.11067	12.34582	12.7162	12.2702	11.71822	10.98214	9.829289	7.873947
			2.00E-06	14.94367	15.36265	15.65527	15.95926	16.43803	15.8615	15.14796	14.19644	12.70617	10.17853
			4.00E-06	19.31745	19.85906	20.23733	20.63029	21.24919	20.50392	19.58153	18.35152	16.42507	13.15763
			1.00E-05	27.12283	27.88328	28.41439	28.96613	29.83511	28.7887	27.49362	25.76661	23.06176	18.47408
			2.00E-05	35.06126	36.04429	36.73085	37.44407	38.56739	37.21471	35.54058	33.3081	29.81158	23.88116
			4.00E-05	45.32316	46.5939	47.4814	48.40337	49.85547	48.10689	45.94276	43.05687	38.53698	30.87081
			1.00E-04	63.63636	65.42056	66.66667	67.96117	70	67.54488	64.50632	60.45436	54.10817	43.34442
			2.00E-04	82.26175	84.56815	86.17898	87.85235	90.48793	87.31423	83.38632	78.14842	69.9448	56.03067
			4.00E-04	106.3385	109.32	111.4022	113.5654	116.9724	112.8698	107.7922	101.0213	90.41657	72.42999
			6.00E-04	123.569	127.0335	129.4532	131.9669	135.9259	131.1585	125.2583	117.3902	105.0672	84.16614
			8.00E-04	137.4621	141.3162	144.008	146.8042	151.2084	145.905	139.3413	130.5886	116.8801	93.62914
			2.00E-03	193.0049	198.4162	202.1956	206.1217	212.3054	204.8592	195.6434	183.3541	164.1065	131.4608
			4.00E-03	249.4945	256.4896	261.3751	266.4504	274.4439	264.8183	252.9052	237.019	212.138	169.9373
			1.00E-02	350.3048	360.1264	366.986	374.1119	385.3353	371.8204	355.0937	332.7886	297.8541	238.6019
			3.00E-02	526.2083	540.9618	551.2658	561.97	578.8291	558.5277	533.4019	499.8963	447.4198	358.4145
			1.00E-01	821.8952	844.939	861.0331	877.7522	904.0848	872.3757	833.1311	780.7981	698.8339	559.8148

Retardation

- Boeing currently using Wheeler retardation model with m = 1
- AFGROW and Boeing implementation is the same
- Side note: part of A-10 support is spectrum crack growth testing to update m for important locations

Wheeler Retardation Model



The Wheeler retardation model is one of the most empirical load interaction models in use in Fractur on the ratio of the current yield zone size to the difference between the effective crack length of an c

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 yi maximum stress (or load) exceeds a previous maximum, or when the current yield zone size (**Ry**) gro

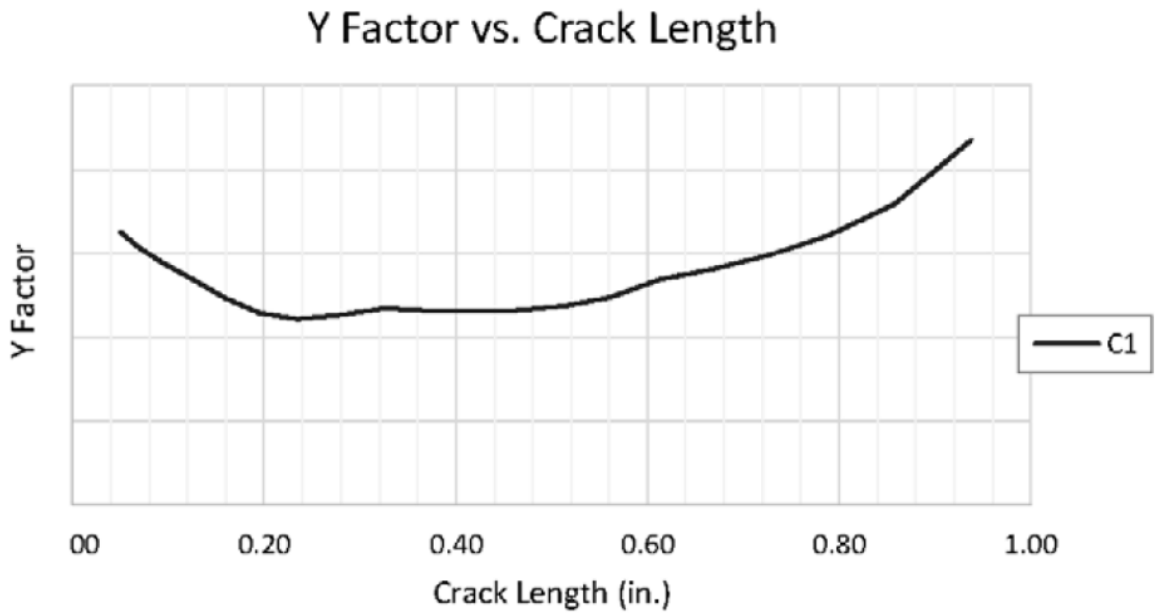
Retardation Parameter:

m : Wheeler exponent

The value of m is determined from test data for a given material, spectrum, stress level, etc. As ment has been known to be dependent on MANY test parameters. Users should use this model with cautic

Betas/Y-Factors

- AFGROW betas = Boeing Y-factors
- Boeing provides Y-factors for all locations
- Used as input data into a user-defined beta model to capture Boeing's influence of edge distance, bearing, crack type, etc
- Useful for spectrum validation. Not possible to modify for repair conditions



Spectrum Creation

- Performed in Spectrum Manager version 1.1.1.3
- Excel used to expand out stress cycles to create individual cycles repeated the prescribed number of times.
- Each mission was input into Spectrum Manager as a sub-spectrum
- Example mission sequence below
  - Note: randomized sequences and mission-representative sequences built: generally very small difference (<1%)

MISSION: 1 MSN A		
load levels	flight hours	
77	6	
Max stress per		
10 flights	100 flights	200 flights
14.9	16.4	16.8
Smax	**Smin**	**Cycles**
-8.14	-10.641	3
[illegible]	-11.25	1
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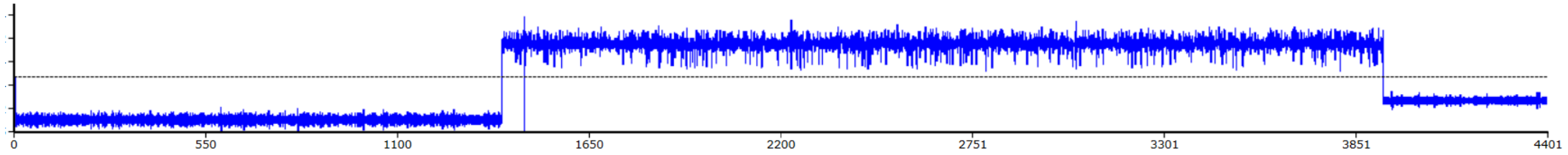
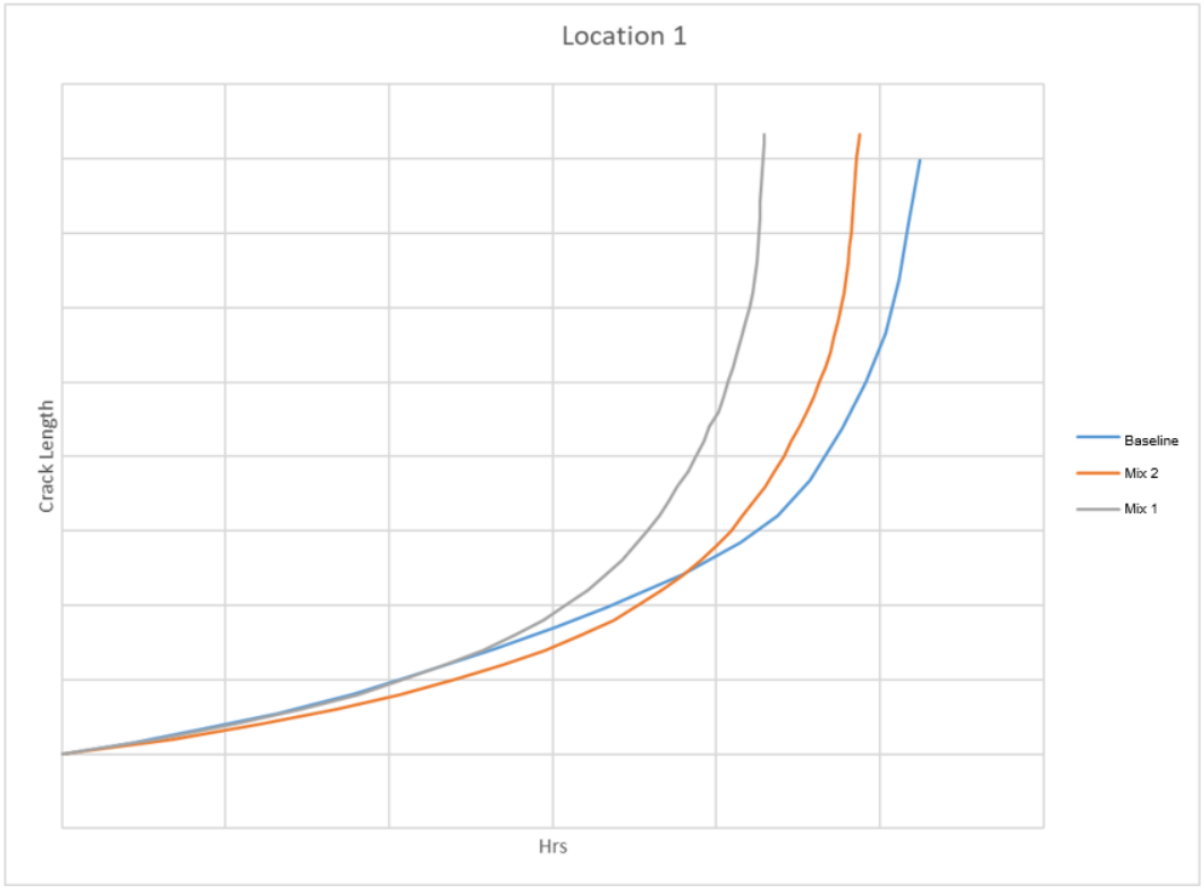


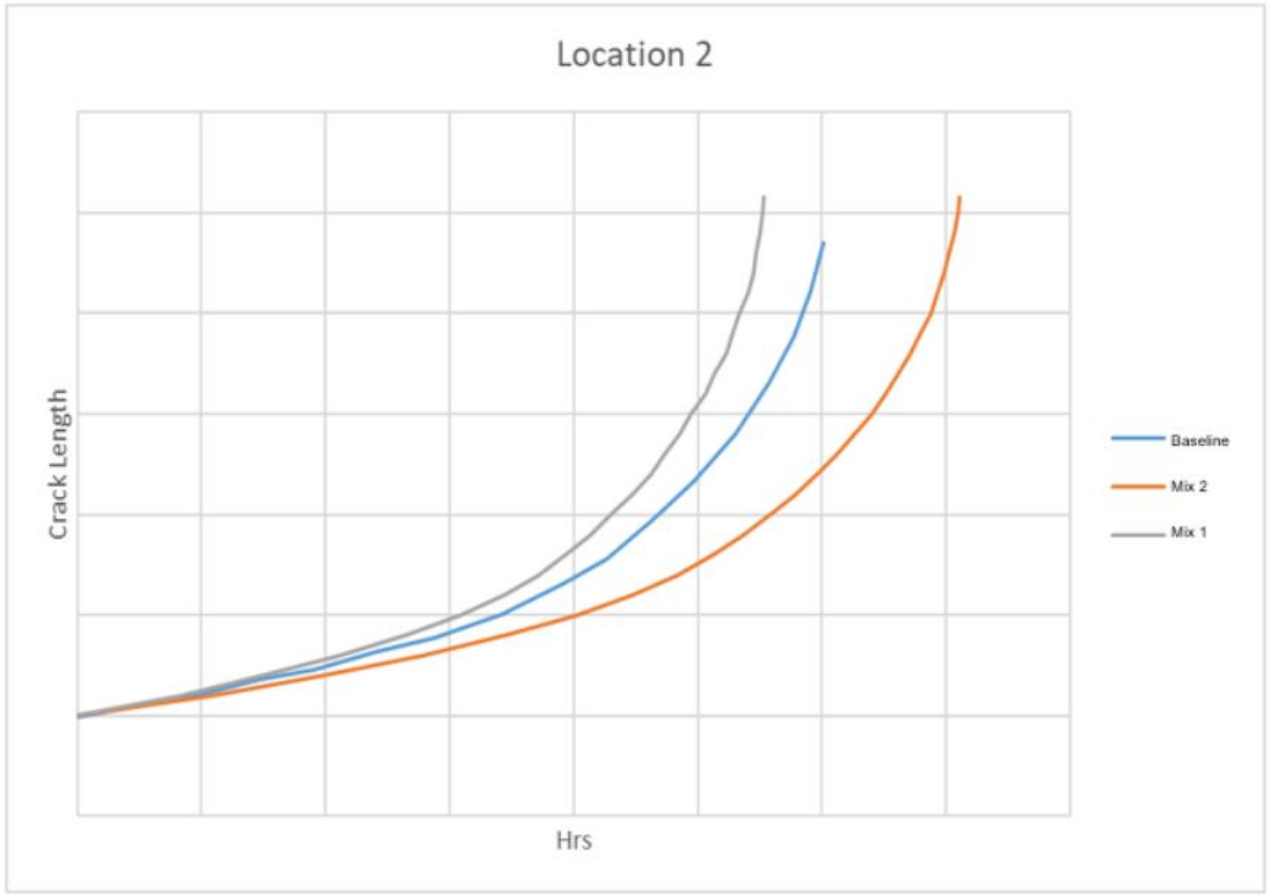
Mission Mix

- The sub-spectra in Spectrum Manager sequenced in a random order to achieve full AFGROW spectrum
  - 1000 hr target
  - Two possible mission mixes used
    - Been an issue of discussion for B-52 program – potential for error
- Spectra made using both mission mixes and results compared
- Overloads also incorporated in spectrum: 10% of missions have a 10th flight overload included
  - Potential for inconsistency with Boeing

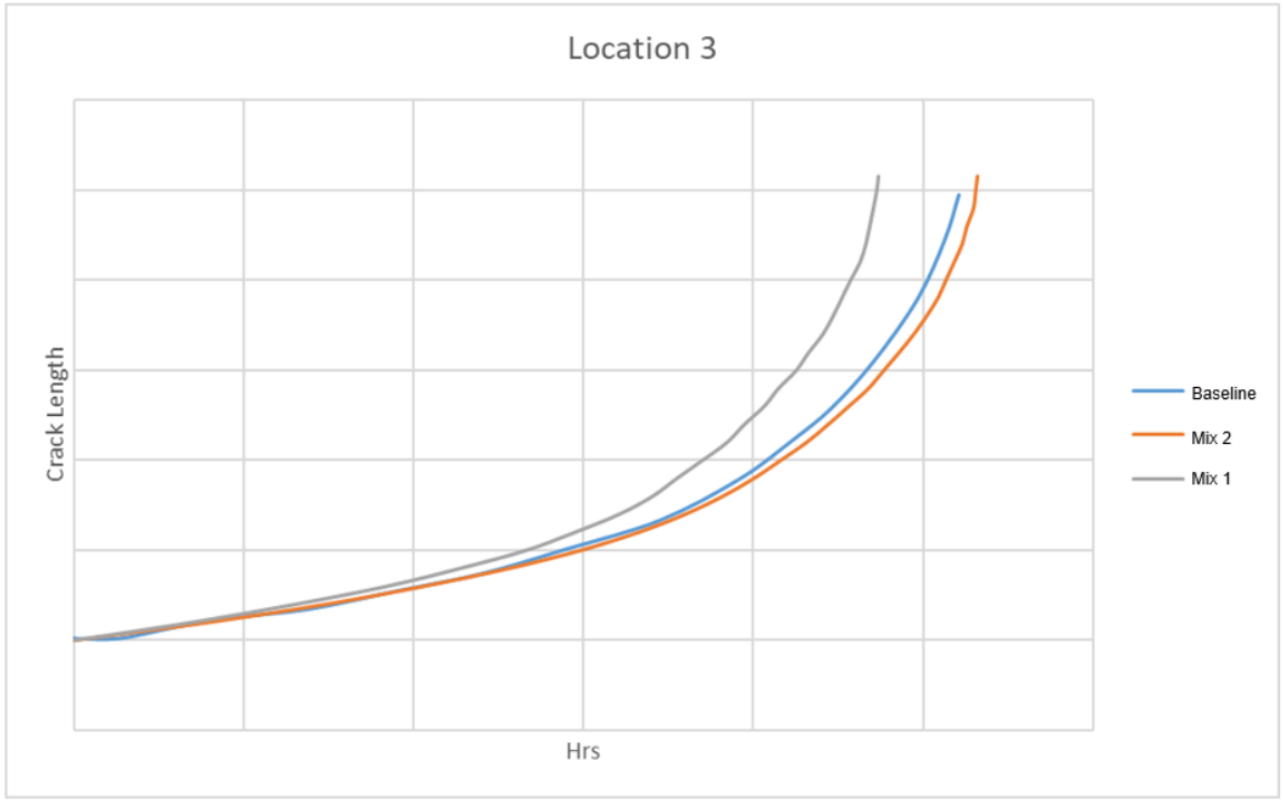
DADTA Mission ID	Mix 1		Mix 2	
	Duration (Hrs)	Freq.* (%)	Duration (Hrs)	Freq.* (%)
A	6.4	3.0	6.75	4.46
B	6.7	4.0	8.39	4.06
C	5.7	29.0	4.78	39.36
D	10.5	2.0	11.25	4.84
E	6.8	39.0	5.77	33.38
F	14.1	1.0	11.73	5.59
G	3.1	2.0	1.87	1.76
H	7.8	2.0	7.65	1.42
I	16.6	4.0	11.82	1.32
J	15.0	11.0	15.91	0.31
K	15.2	3.0	13.03	3.47
	Total:	100%	Total:	100%

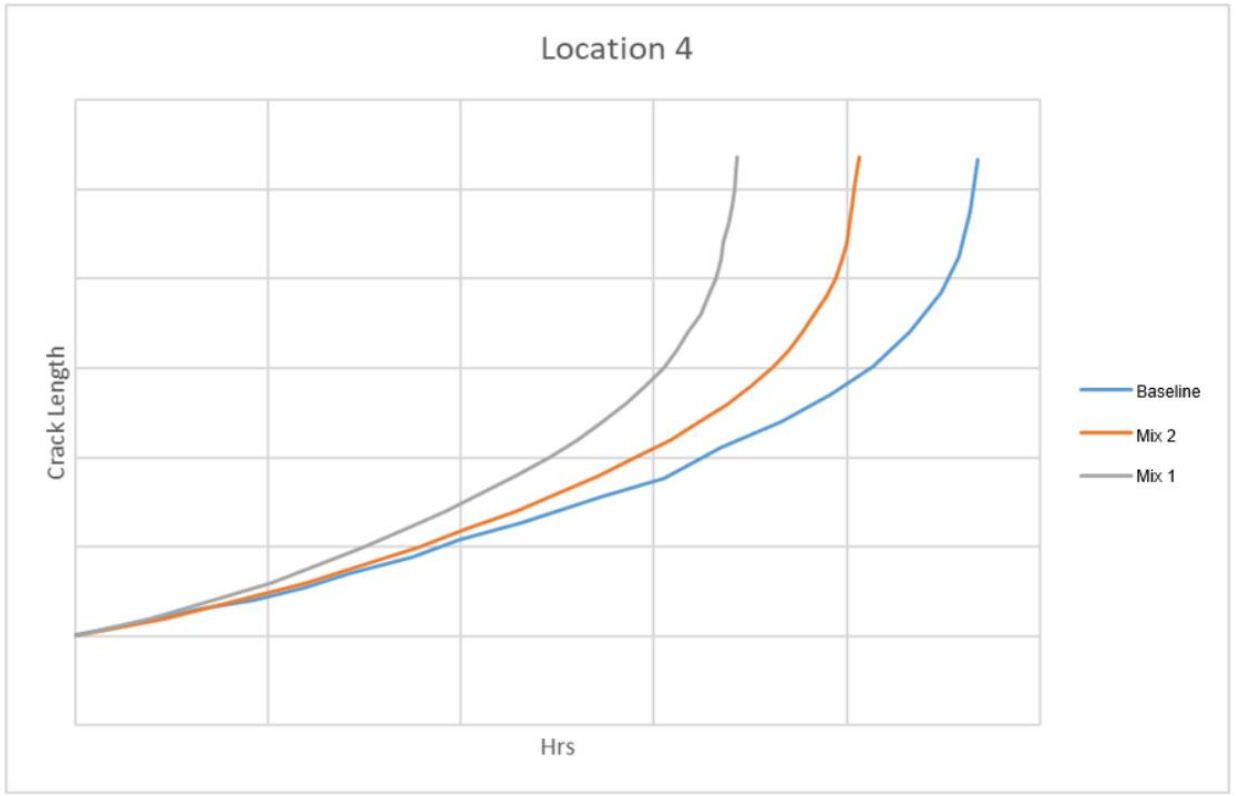
Result Comparison





Result Comparison





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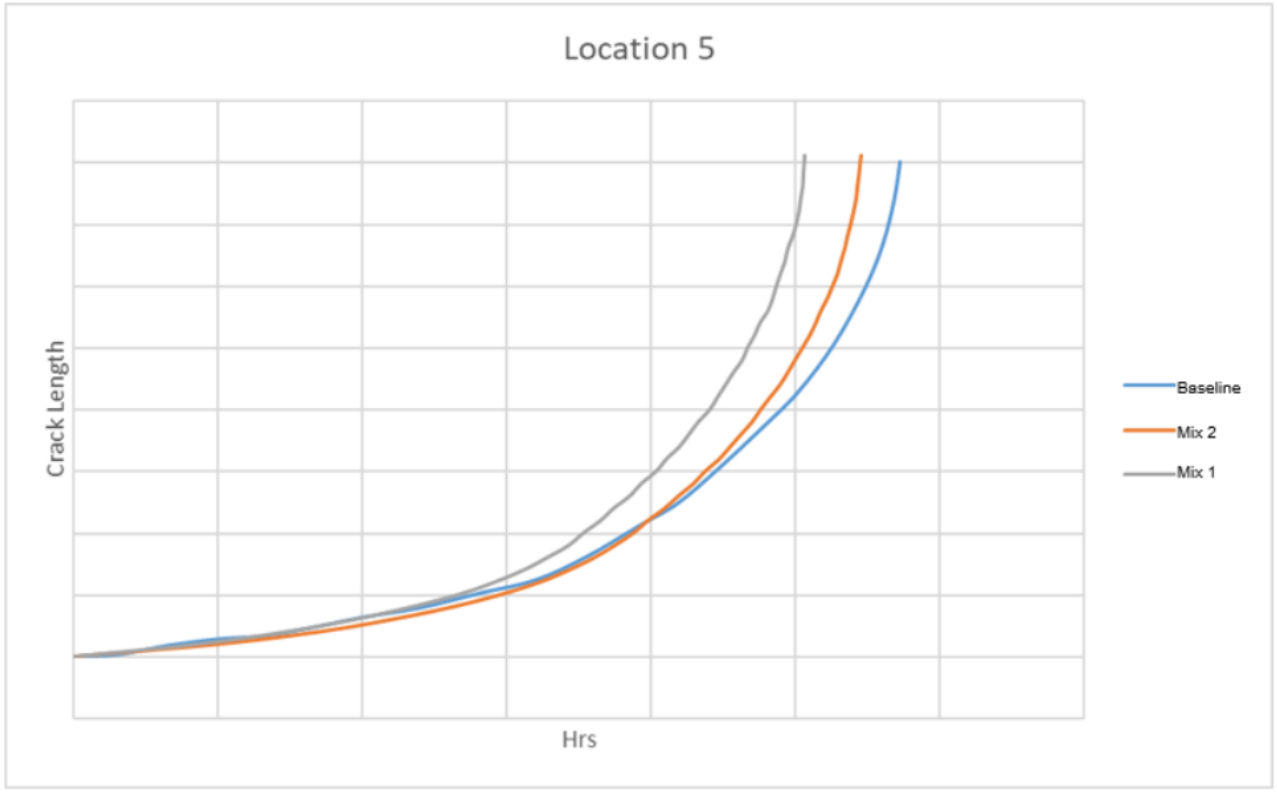
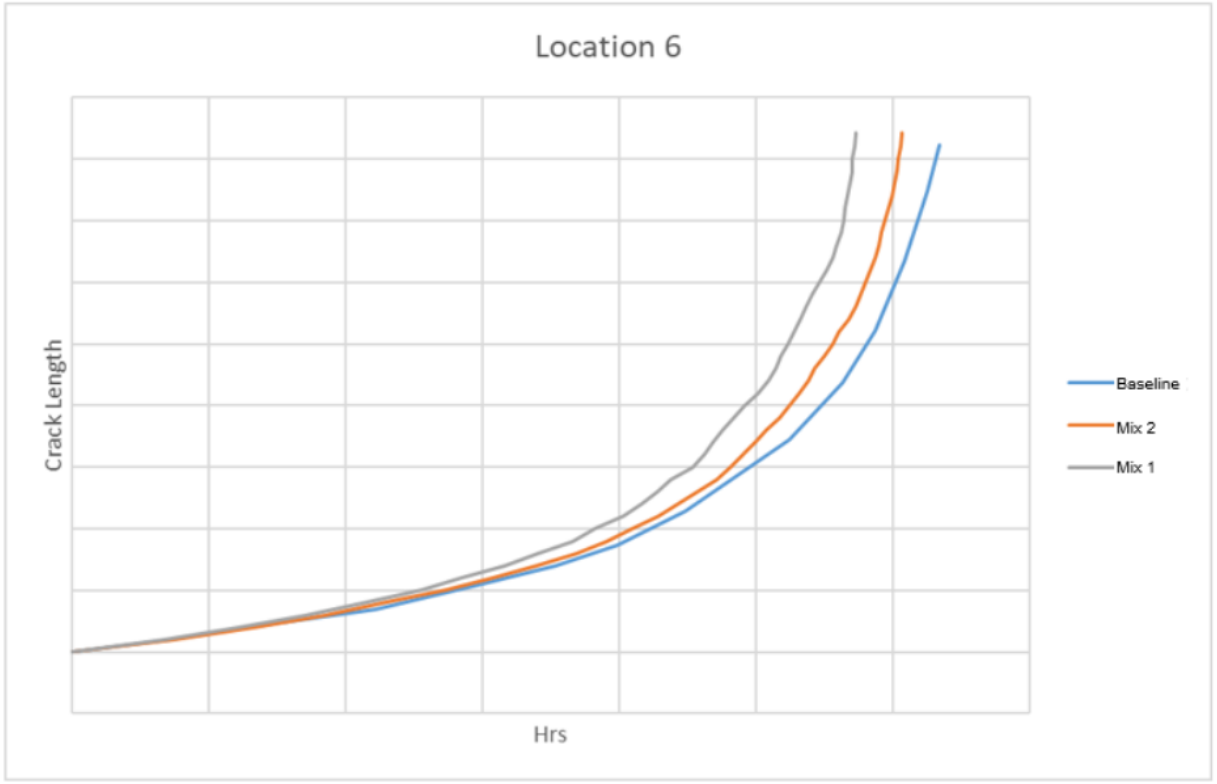


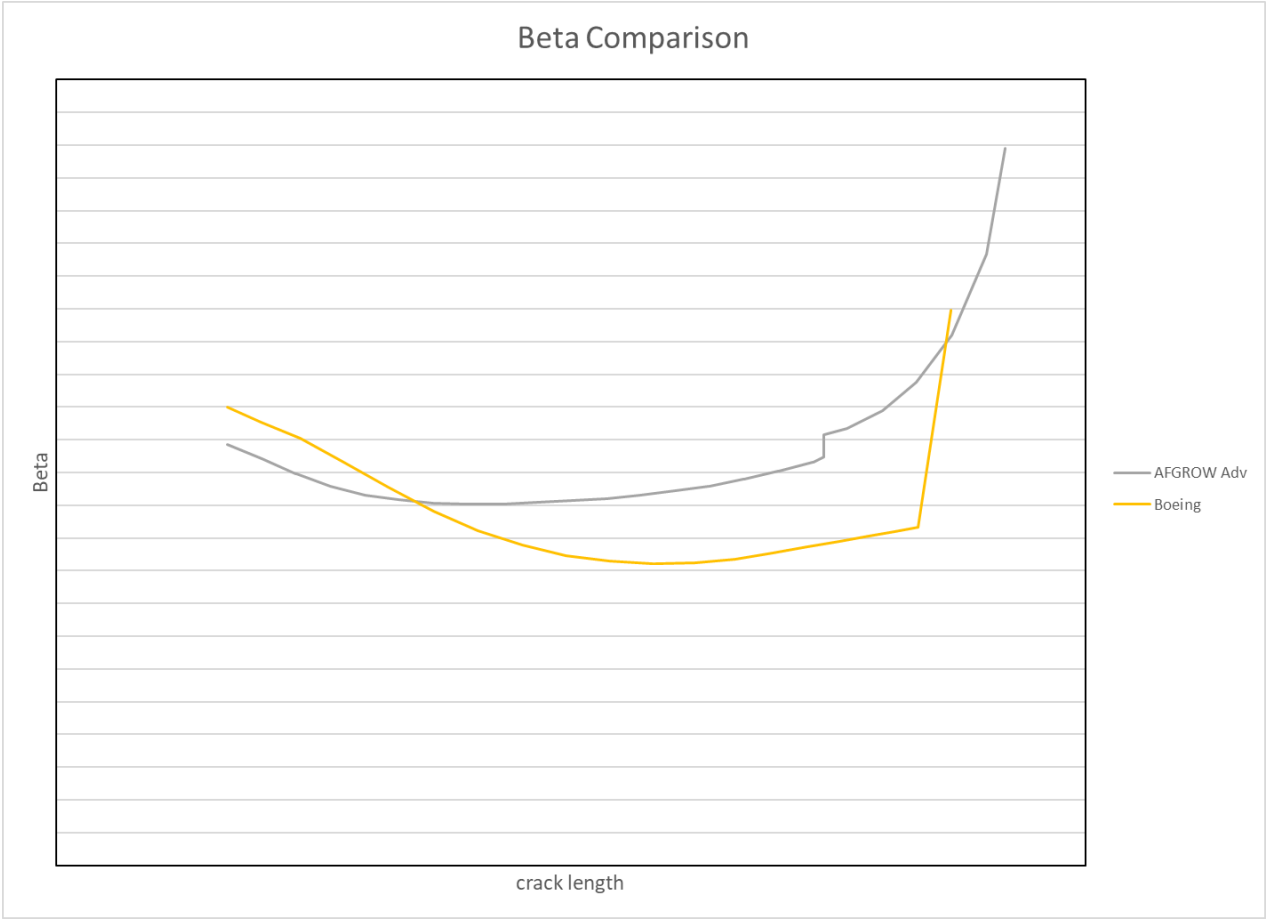


Result Comparison Summary

- 17 locations completed
  - 12 locations performed better with Mix 2
  - 5 locations performed better with Mix 1
- Very few matched the baseline curve exactly
  - Why?
    - Potential issues
      - Boeing provided stress sequences and Y-factors don’t align.
      - Difference in tabular lookup and walker equation in interpolated R-values
    - Is there is difference in basic equations between Boeing code and AFGROW?
    - Do the overloads need a different implementation method?

Next Steps

- Work with Boeing to look for additional differences in crack growth model setup.
- Convert locations from Boeing models to AFGROW models for the same geometry
  - Most information provided in DTA report
- Investigate differences in betas for seemingly the same solution
- Generalize spectra for other locations on the aircraft



Questions?