Center for Aircraft Structural Life Extension

Providing Structural Integrity Technology to the Aerospace Community

Environmental Effects on Fatigue Crack Growth

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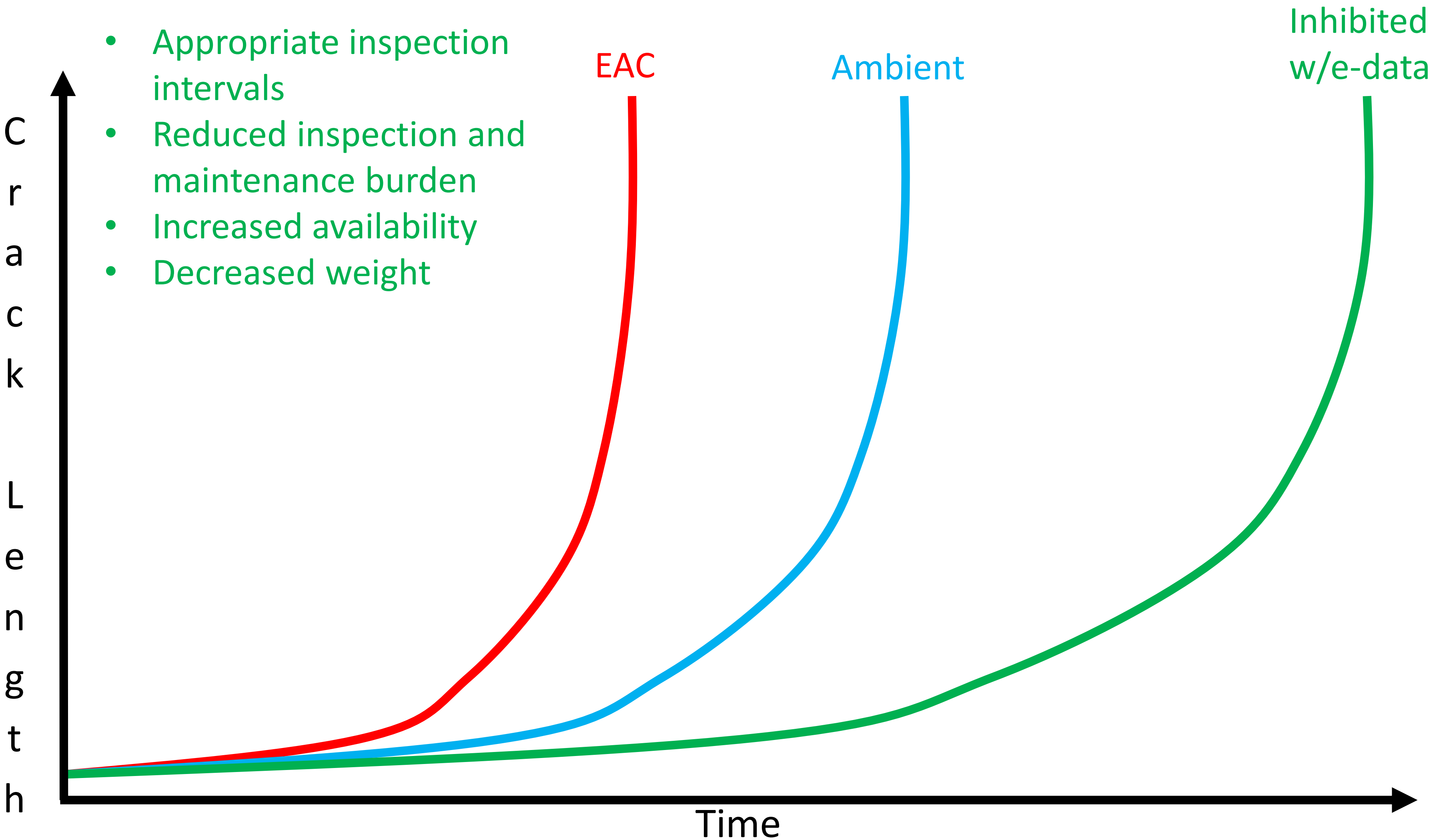
Outline

- Relevance
- Background
- Flight Environment
- Preliminary Results
- B707 Wing Detail Example
- Business Jet Wing Detail Example
- Next Steps

Relevance

- Appropriate inspection intervals
- Reduced inspection and maintenance burden
- Increased availability
- Decreased weight



Background

- How does the environment affect crack growth
  - Develop a robust database of crack growth rate data as a function of exposure (P_{H20} / f)
  - Understand the environmental fatigue process
- Can we slow the corrosion fatigue rate?
  - Standard test protocol for inhibitor evaluation
  - Effect of chromate on crack growth rate
  - Effect of ionic inhibitors on crack growth rate
  - Inhibitor leaching behavior
- Update life prediction software to
  - Use appropriate rate data for given mission segment
  - Track damage accumulation by segment
  - Include new stress intensity factor solutions

Flight Environment

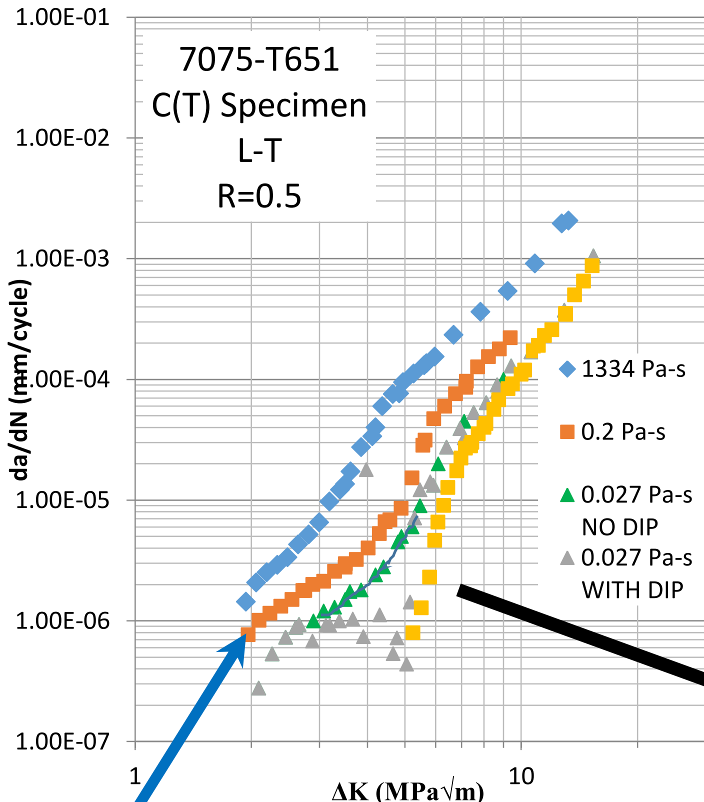
Fuselage Loads
- Pressurization
- **8,000-50,000 ft -5 to -57°C**
- *f* = 0.00003-0.001 Hz
- *Hunt; Wanhill, 2001*

Wing Loads
- Taxi/Take-off/Landing
- **Wind Gusts**
- **40% >10,000 ft; Thus < -5°C**
- *f* = 0.1-10 Hz
- *Jorge, 1979*

Primary Loading
- Aggressive Maneuvers
- **≈30,000 ft = -44°C**
- *f* = 0.005-0.2 Hz
- *Aicher, 1976; Aronstein, 1997*

Aerodynamic Loads
- Fuselage/Control Surfaces
- **0-50,000ft; Thus 0-60°C**
- *f* = 0.0003-30 Hz

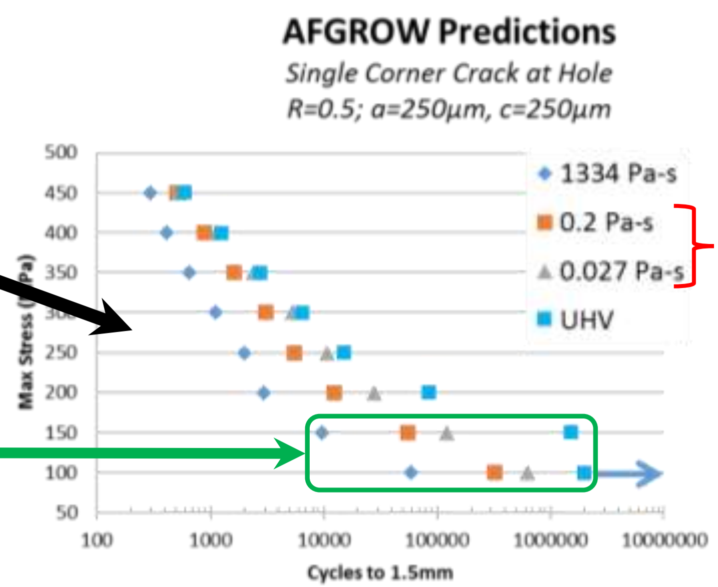
Preliminary LEFM Modeling Results



1 week per test

- Modeling Requirements
  - Environmental FCGR data
  - Defined environment by mission segment (taxi, takeoff, climb, cruise, descent, flaps, landing, etc.)
  - Known/assumed cycle frequency
- Software that can accept the above

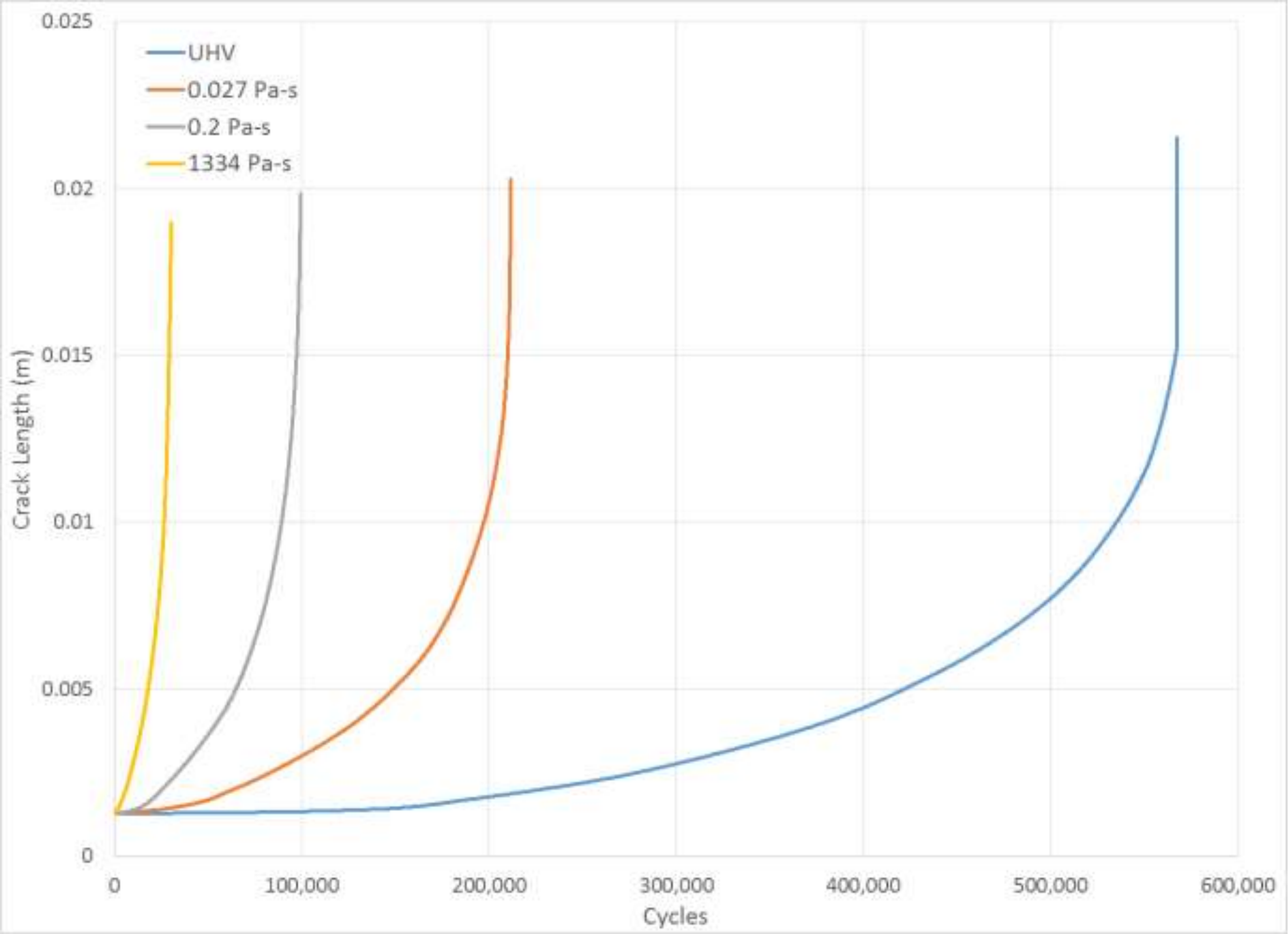
AFGROW



Cruise Altitude (40,000 – 60,000 ft)

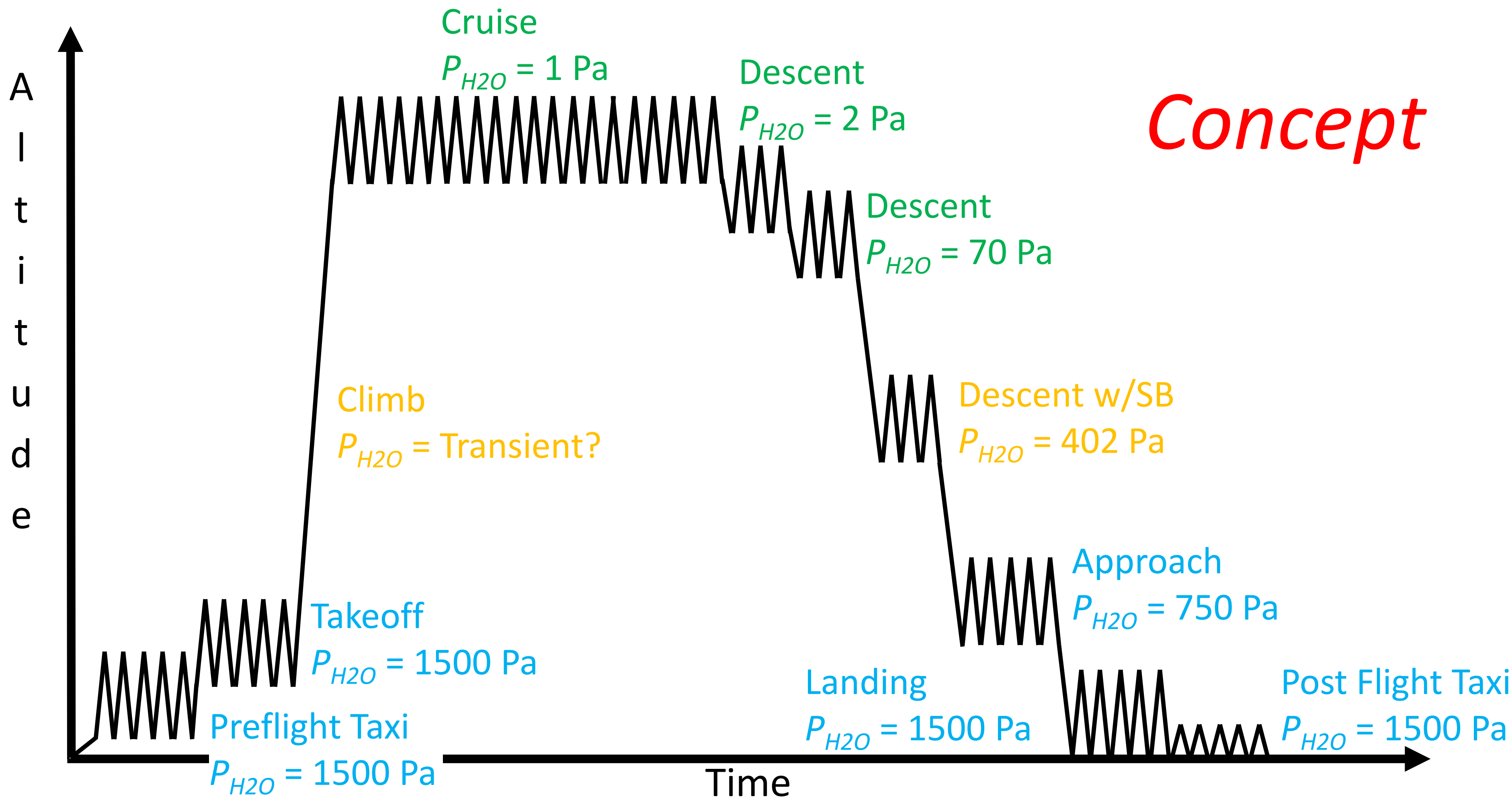
Large effect on life

Crack Growth as a Function of Exposure

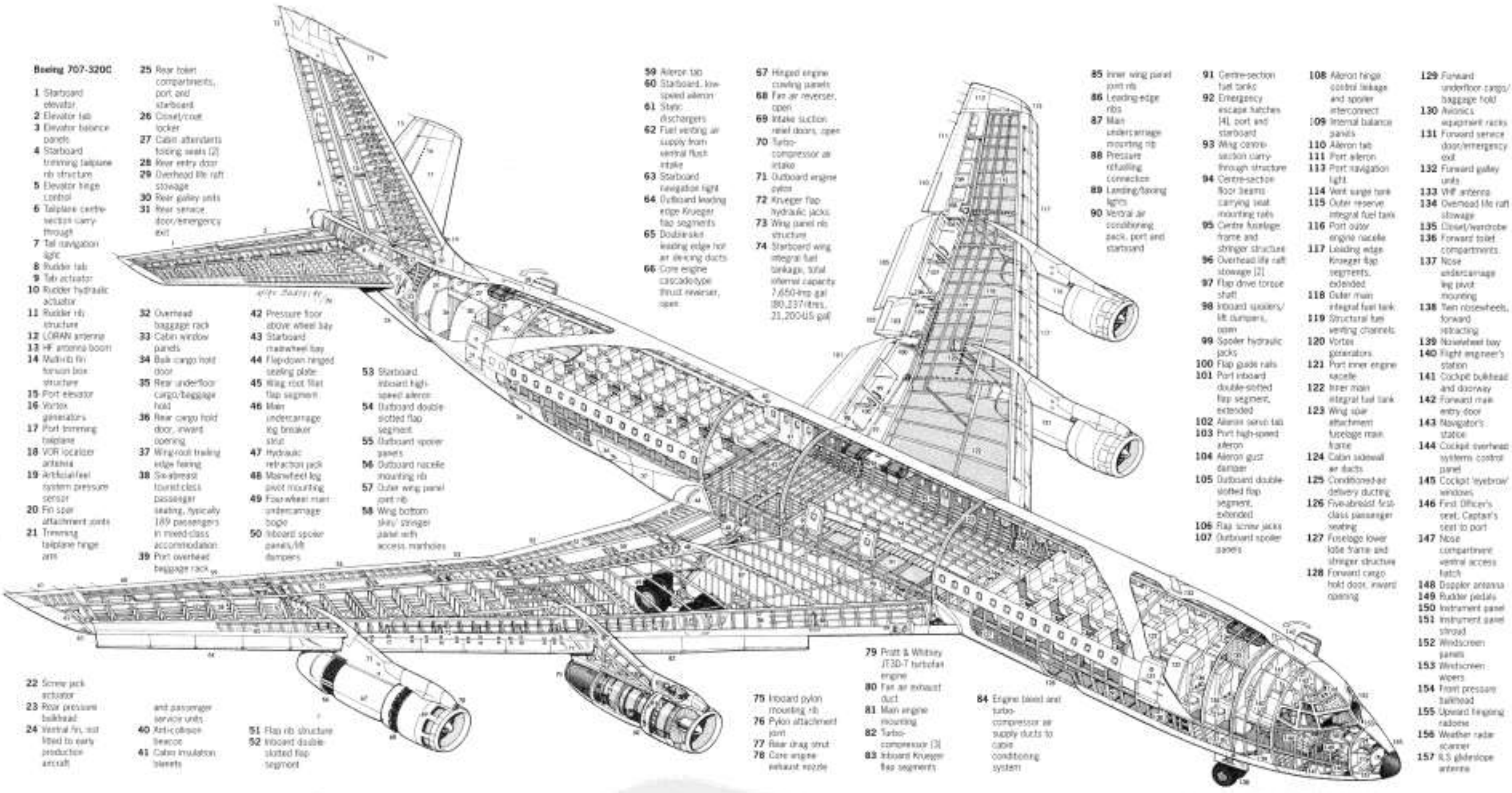


Significant effect on fatigue life and inspection intervals

Crack Growth Rate Data by Mission Segment



Boeing 707 WS360 Example



Boeing 707 WS360 Enviro-Mechanical Spectrum

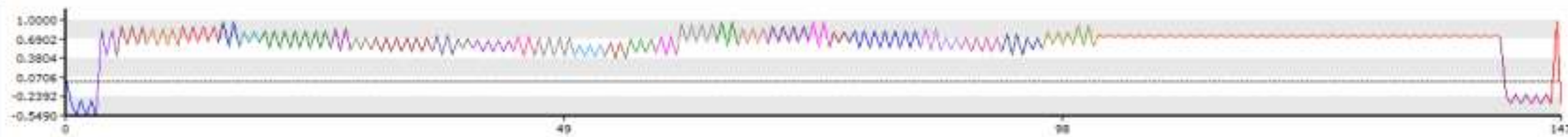
#	Segment	S_{max} (ksi)	S_{min} (ksi)	Cycles	Altitude (ft)	Actual (°C)	Binned (°C)
1	TAKEOFF	-5.55	-10.30	3	0	15.02	23
2	FLAPS DOWN DEPARTURE	15.82	7.89	2	1000	13.02	23
3	INIT CLIMB	17.12	11.57	3	3000	9.07	23
4	FINAL CLIMB	16.30	11.08	3	17000	-18.65	-15
5	CRUISE	17.17	12.16	4	34000	-52.26	-50
6	CRUISE	18.60	10.72	2	34000	-52.26	-50
7	FINAL CLIMB	15.38	12.02	2	34750	-52.26	-50
8	CRUISE	15.51	10.35	7	35500	-54.21	-57
9	CRUISE	16.37	9.50	2	35500	-54.21	-57
10	FINAL CLIMB	13.38	10.09	2	36750	-56.21	-57
11	CRUISE	13.55	9.15	6	38000	-56.48	-57
12	CRUISE	14.32	8.37	2	38000	-56.48	-57
13	FINAL CLIMB	13.06	10.43	2	39500	-56.48	-57
14	CRUISE	12.70	9.13	4	41000	-56.48	-57
15	CRUISE	13.78	8.06	2	41000	-56.48	-57
16	INIT DESCENT	13.38	7.74	4	33000	-50.26	-50
17	CRUISE	11.45	7.86	3	25000	-34.48	-37
18	CRUISE	12.01	7.30	2	25000	-34.48	-37
19	CRUISE	13.24	9.12	3	25000	-34.48	-37
20	CRUISE	13.99	8.37	2	25000	-34.48	-37
21	CRUISE	17.59	12.11	4	25000	-34.48	-37
22	CRUISE	18.76	10.94	2	25000	-34.48	-37
23	FINAL CLIMB	16.22	11.61	3	29500	-42.37	-37
24	CRUISE	17.16	12.15	4	34000	-52.26	-50
25	CRUISE	18.59	10.72	2	34000	-52.26	-50
26	FINAL CLIMB	15.38	12.05	2	34750	-52.26	-50
27	CRUISE	15.54	10.33	7	35500	-54.21	-57
28	CRUISE	16.37	9.50	2	35500	-54.21	-57
29	FINAL CLIMB	13.41	10.12	2	36750	-56.21	-57
30	CRUISE	13.38	9.41	4	38000	-56.48	-57
31	CRUISE	14.38	8.41	2	38000	-56.48	-57
32	INIT DESCENT	13.56	10.01	2	19000	-22.59	-30
33	FINAL DESCENT	15.38	11.41	3	3000	9.07	23
34	FLAPS DOWN APPROACH	17.39	10.99	2	1000	13.02	23
35	ROLL MANEUVER	14.41	13.39	40	1000	13.02	23
36	LANDING ROLLOUT	-3.54	-6.57	5	0	15.02	23
37	GAG	18.76	-10.30	1	Various	-34.28	-30

SpectrumManager Mechanical Spectrum

Exceedance Plot | R Plot | Sequence Data | Spectrum Data | Spectrum Tags

#	cycle	Max	Min	Cycles	Sub Spectrum Name
11	31	0.722	0.488	6	Training 11
12	37	0.763	0.446	2	Training 12
13	39	0.696	0.556	2	Training 13
14	41	0.677	0.487	4	Training 14
15	45	0.735	0.43	2	Training 15
16	47	0.713	0.413	4	Training 16
17	51	0.61	0.419	3	Training 17
18	54	0.64	0.389	2	Training 18
19	56	0.706	0.486	3	Training 19
20	59	0.746	0.446	2	Training 20
21	61	0.938	0.646	4	Training 21
22	65	1	0.583	2	Training 22
23	67	0.865	0.619	3	Training 23
24	70	0.915	0.648	4	Training 24
25	74	0.991	0.571	2	Training 25
26	76	0.82	0.642	2	Training 26
27	78	0.828	0.551	7	Training 27
28	85	0.873	0.506	2	Training 28
29	87	0.715	0.539	2	Training 29
30	89	0.713	0.502	4	Training 30
31	93	0.767	0.448	2	Training 31
32	95	0.723	0.534	2	Training 32
33	97	0.82	0.608	3	Training 33
34	100	0.927	0.586	2	Training 34
35	102	0.768	0.714	40	Training 35
36	142	-0.189	-0.35	5	Training 36
37	147	1	-0.549	1	Training 37

Chart



SpectrumManager Environmental Spectrum

Exceedance Plot | R Plot | Sequence Data | Spectrum Data | Spectrum Tags

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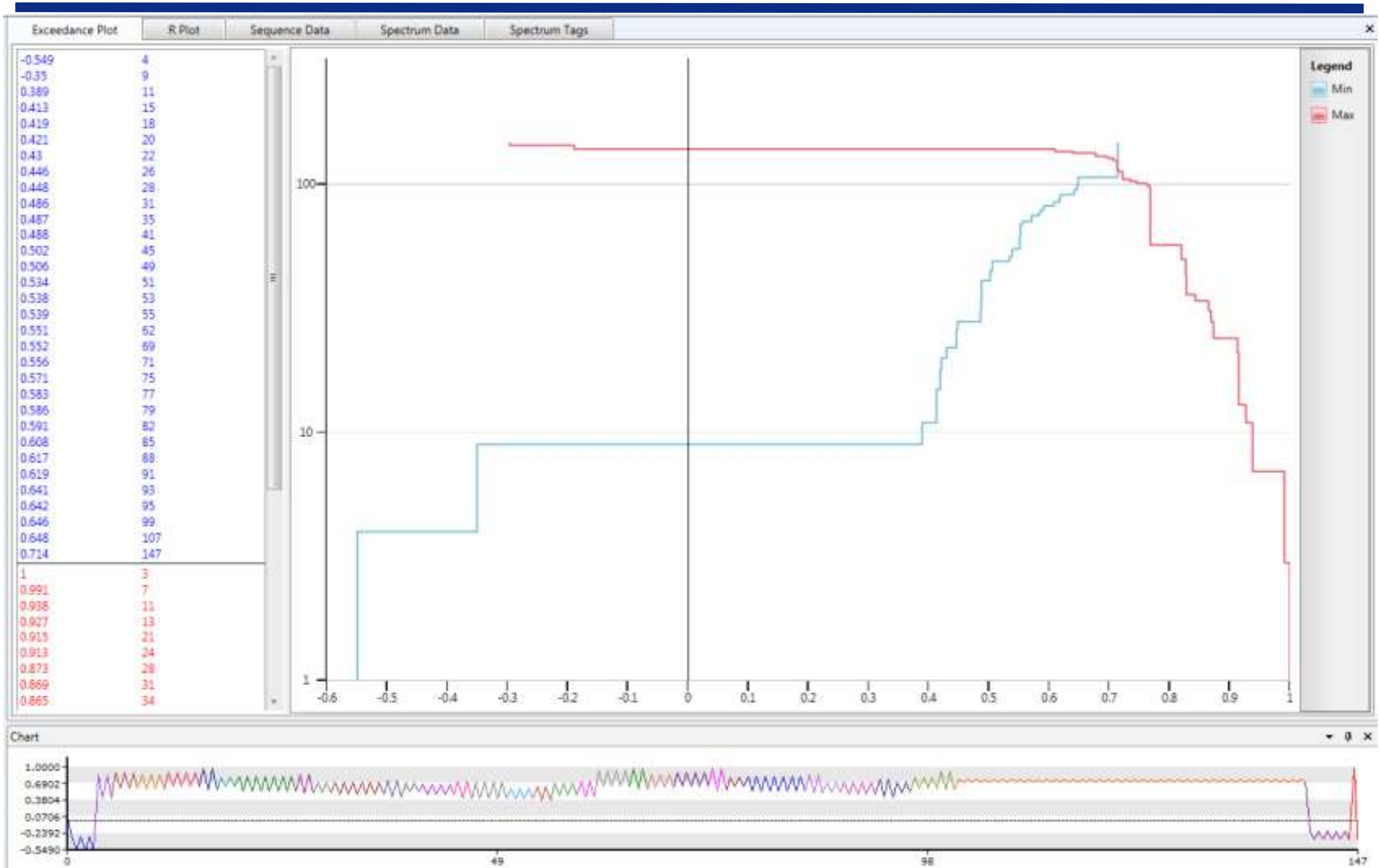
SubSpectrum	Temperature
Training 1	23
Training 2	23
Training 3	23
Training 4	-15
Training 5	-50
Training 6	-50
Training 7	-50
Training 8	-57
Training 9	-57
Training 10	-57
Training 11	-57
Training 12	-57
Training 13	-57
Training 14	-57
Training 15	-57
Training 16	-50
Training 17	-37
Training 18	-37
Training 19	-37
Training 20	-37
Training 21	-37
Training 22	-37
Training 23	-37
Training 24	-50

Chart

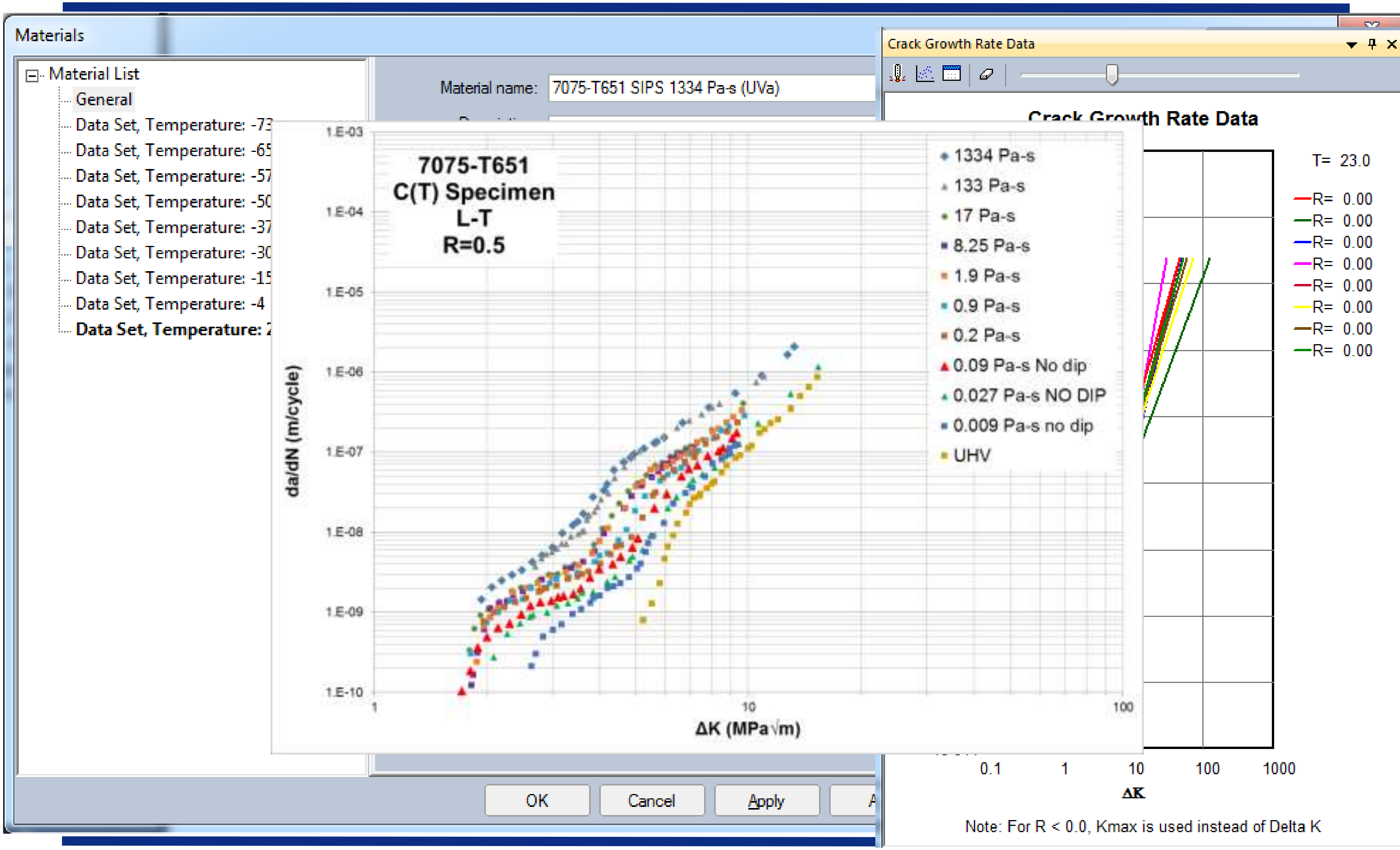
SpectrumManager Metrics
Spectrum – Exceedance Plot



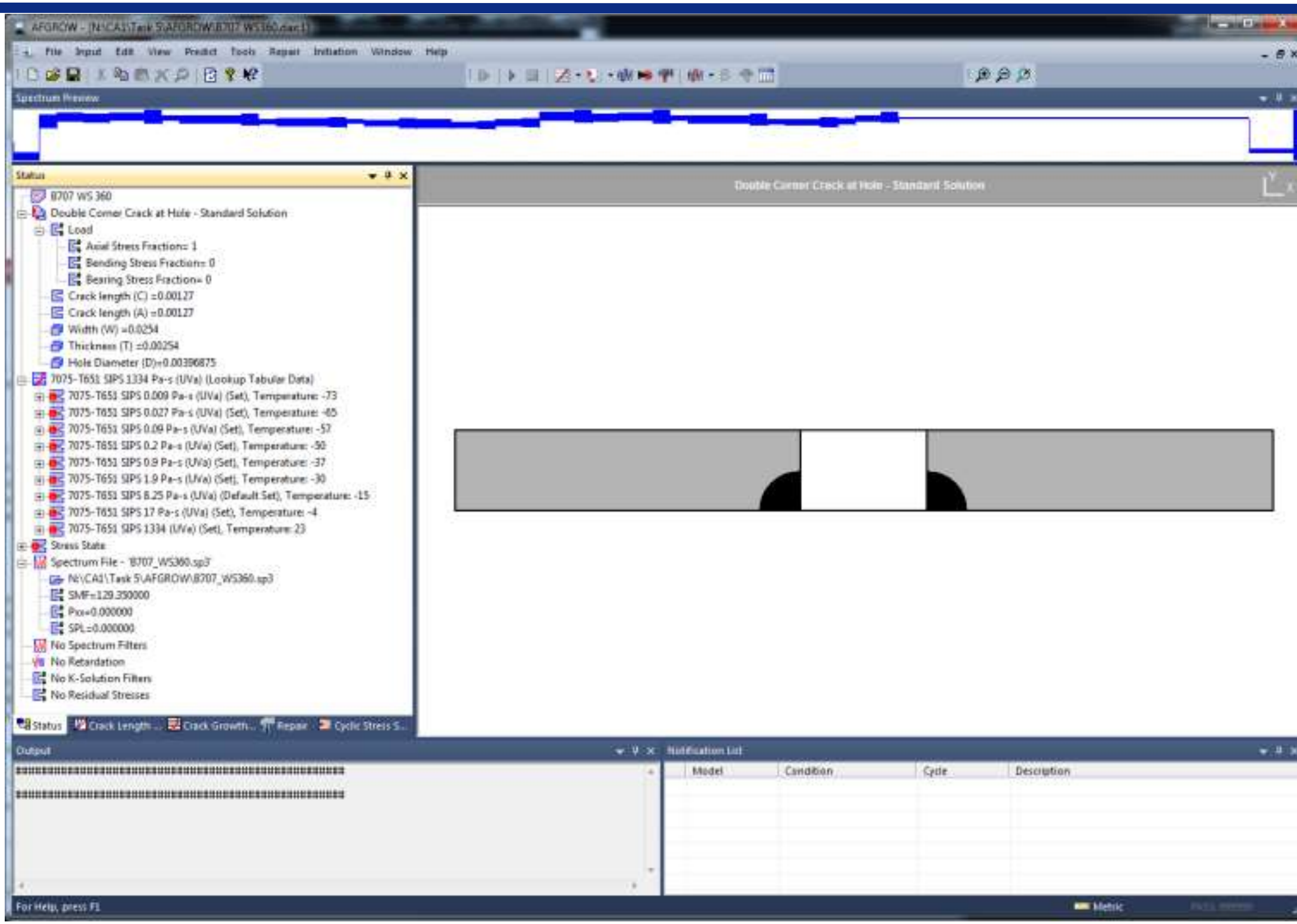
Integrity – Service – Excellence

SpectrumManager Metrics
Spectrum – R Content

AFGROW Input
Multiple Tabular Look-up Data



AFGROW Input



AFGROW $a_{90/95}$ Results

1.2 Rotary Bolt Hole Eddy Current (BHEC) IAW TO-33B-1-2 (Figure 3)

	a_{90}		$a_{90/95}$	
	Crack Length, a	Crack Depth, c	Crack Length, a	Crack Depth, c
Edge Crack				
Aluminum:	0.040 inch	0.040 inch	0.050 inch	0.050 inch
Titanium:	0.040 inch	0.040 inch	0.050 inch	0.050 inch
Steel:	TBD	TBD	TBD	TBD
	Crack Length, 2a	Crack Depth, c	Crack Length, 2a	Crack Depth, c
Mid Bore Crack				
Aluminum:	0.080 inch	0.040 inch	0.100 inch	0.050 inch
Titanium:	0.080 inch	0.040 inch	0.100 inch	0.050 inch
Steel:	TBD	TBD	TBD	TBD

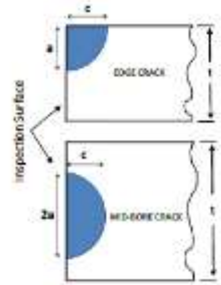
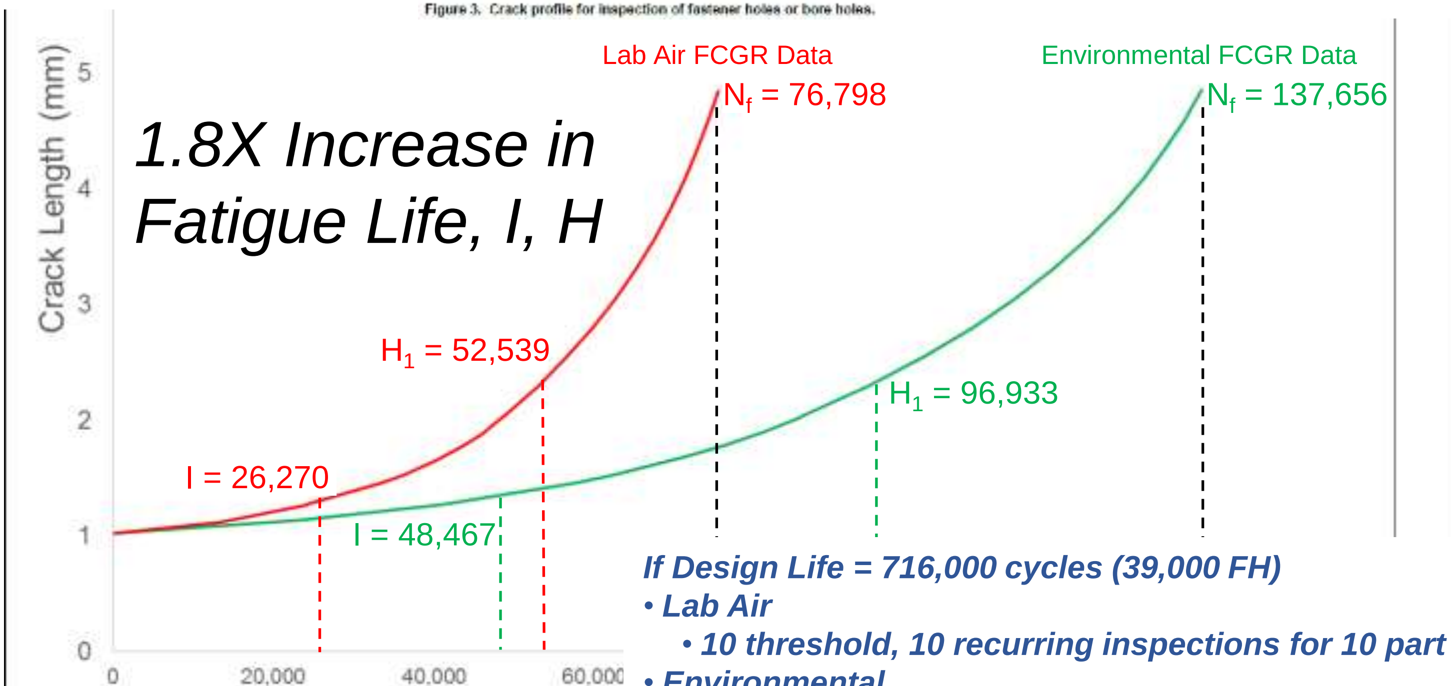


Figure 3. Crack profile for inspection of fastener holes or bore holes.

$$I = \frac{N_{a_{crit}} - N_{a_{init}}}{2}$$ Initial Inspection

$$H = \frac{N_{a_{crit}} - N_{a_{NDI}}}{2}$$ Recurring Inspection



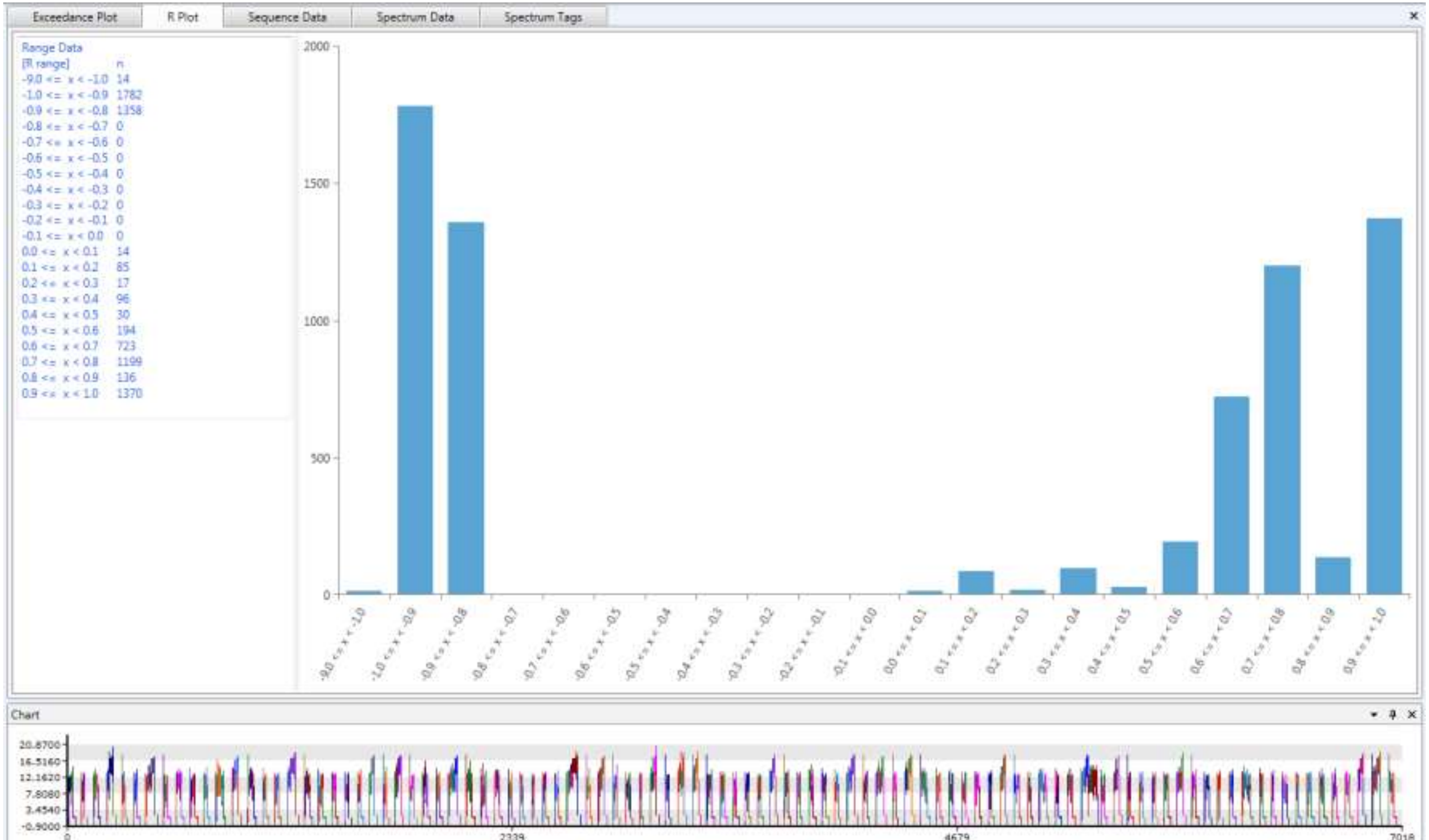
If Design Life = 716,000 cycles (39,000 FH)

- ***Lab Air***
  - ***10 threshold, 10 recurring inspections for 10 part replacements***
- ***Environmental***
  - ***5 threshold, 5 recurring inspections for 5 part replacements***

Business Jet Example

SpectrumManager Metrics
Spectrum – Exceedance Plot

SpectrumManager Metrics
Spectrum – R Content



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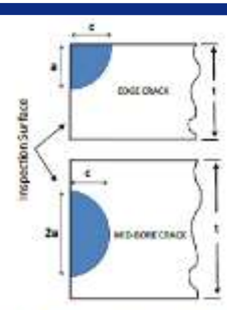
	Crack Length, 2a	Crack Depth, c	Crack Length, 2a	Crack Depth, c
Mid Bore Crack				
Aluminum:	0.080 inch	0.040 inch	0.100 inch	0.050 inch
Titanium:	0.080 inch	0.040 inch	0.100 inch	0.050 inch
Steel:	TBD	TBD	TBD	TBD



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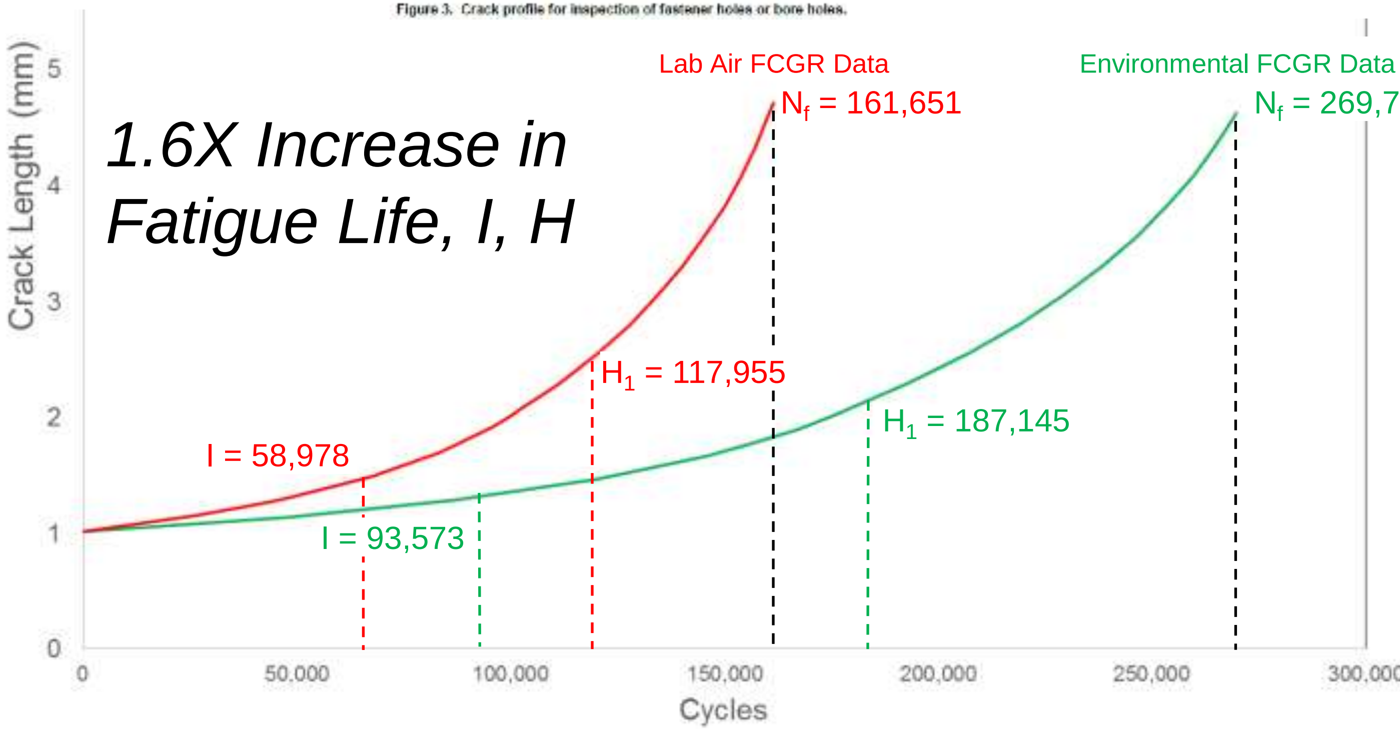

Next Steps

- LexTech Capability Enhancements
  - Spectrum Manager
    - Each mission segment in the spectrum can have environmental parameters (T, P_{H2O}, user, etc.) defined ✓
  - AFGROW
    - Accept multiple material data input ✓
- Verification - LexTech
- Validation - SAFE
  - Compare to lab test results
  - Can compare to in-service cracking results if the data is available