Assessment of aircraft structural service life using generalized correction methodology

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Aircraft structural service life assessment methodology with high accuracy is one of the key techniques of Individual Aircraft Tracking (IAT) Program and Structural Prognosis and Health Management (SPHM). At present, there doesn't exist one common model or approach that can completely cover all stages and influence effects of fatigue life. In the state-of-the-art IAT programs, fatigue damage models and methodologies used by different countries and different aircrafts vary from each other. Due to the large derivation of life prediction from the actual life, classical fatigue damage models can't be applied directly but by calibration or correction with experimental data.

The uncalibrated classical models provide poor predictions of the general fatigue and crack growth behavior, yet provide a reasonable prediction for the relative difference between two variable amplitude (VA) spectra. This research proposes a generalized correction methodology based on representative coupon test data which can be applied to all critical structural locations and can provide reliable service life assessment for decisions on Force Structural Maintenance Plan (FSMP).

Generalized correction methodology is divided into fatigue life correction method and crack growth rate (CGR) correction method. The former is the scaling of initiation life used for crack initiation modeling, assuming that the ratio of actual lifes between two VA spectra is approximate to the ratio of lifes predicted by an uncalibrated crack initiation model. The latter is the scaling of CGR used for Effective Block Approach (EBA), a characteristic block type approach, assuming that the ratio of true CGRs between two VA spectra is approximate to the ratio of CGRs estimated by an uncalibrated LEFM model.

For each critical location, due to different management philosophies, structural service life is categorized as durability life (from EIFS to economic size a_e) and damage tolerance life (from rogue initial size a_0 to critical size a_{cr}), referring to maintenance (repair or replacement) life and inspection interval in FSMP, respectively. Based on representative coupon test data, durability and damage tolerance (DADT) optimal approach is each selected where the former is chosen from crack initiation models as well as linear elastic fracture mechanics (LEFM) models implicitly in the EBA approach, and the latter is chosen from LEFM models. Crack initiation models are commonly stress-life (S–N) approach and strain-life (ε–N) approach, and LEFM models are usually the combination of various CGR relationships and retardation models.

Flowchart of application of generalized correction methodology in structural service life assessment is shown in Figure 1.

Case study of some bulkhead representative coupon data under four test spectra at different stress levels (as shown in Figure 2 and Table 1) is reviewed where the implementation of generalized correction methodology has been comprehensively examined and validated, in addition, $\varepsilon-N$ approach and Walker+Closure model in the EBA approach are chosen as the optimal DADT models, respectively, of which the prediction accuracy is generally the best for different comparison combinations (as shown in Figure 3 and Figure 4).

Keywords: service life assessment; generalized correction methodology; crack initiation models; effective block approach; durability and damage tolerance; linear elastic fracture mechanics models

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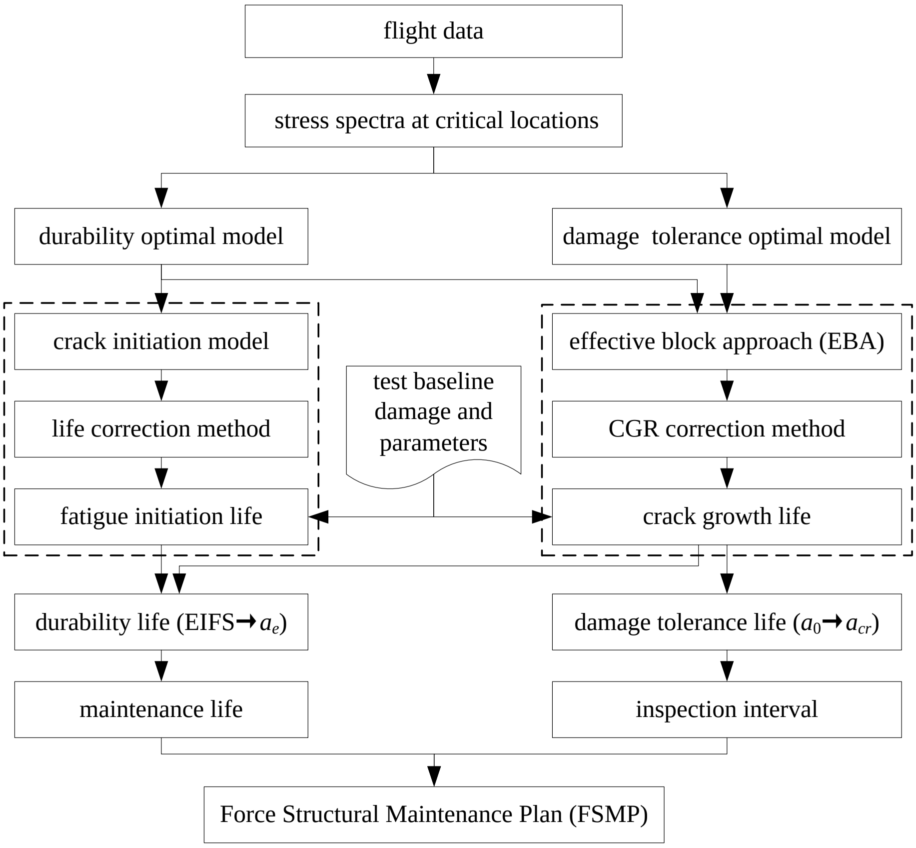


Figure 1.Flowchart of application of generalized correction methodology.

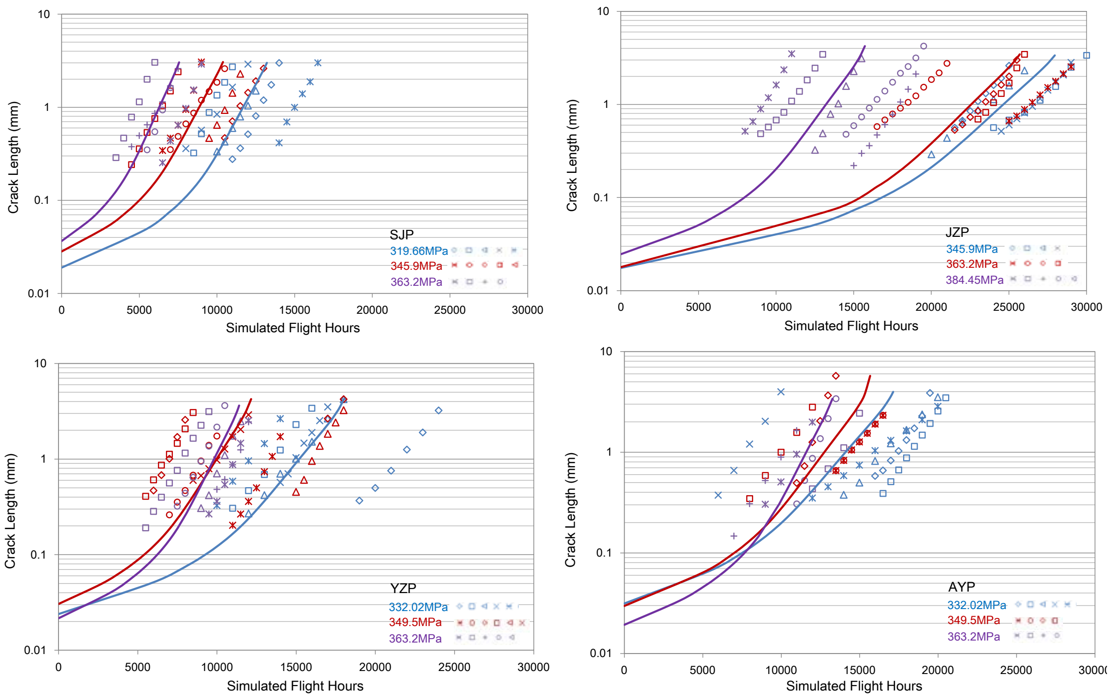
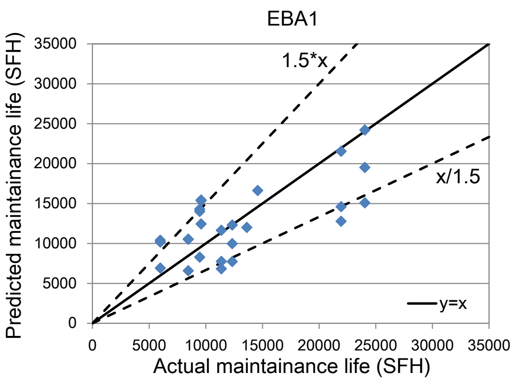


Figure 2. Bulkhead representative coupon data and EBA predictions.

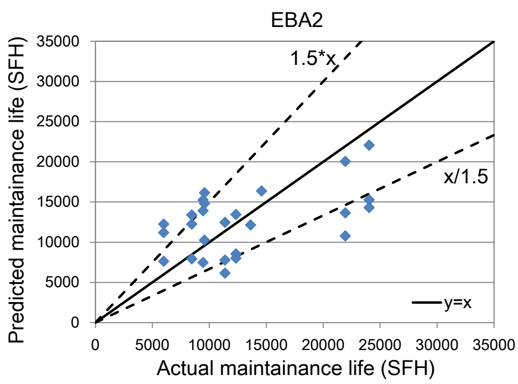
Table 1. Fatigue damage and CGR fit of test spectra by different modeling.

Test Spectra	Stress (MPa)	Fatigue Damage		CGR fit to test data		CGR fit to predictions by LEFM models							
						LEFM 1*		LEFM 2*		LEFM 3*		LEFM 4*	
		S–N	*ε–N*	C	m	C	m	C	m	C	m	C	m
SJP	318.66	0.313	0.029	9.78 E-14	3.4	3.07 E-13	3.4	2.05 E-13	3.4	7.47 E-11	2.5	1.88 E-11	2.7
	349.5	0.412	0.046	7.25 E-14	3.4	3.15 E-13	3.4	2.03 E-13	3.4	7.48 E-11	2.5	1.86 E-11	2.7
	363.2	0.462	0.055	7.57 E-14	3.4	3.03 E-13	3.4	2.07 E-13	3.4	7.37 E-11	2.5	1.88 E-11	2.7
JZP	349.5	0.186	0.011	3.57 E-14	3.4	1.39 E-13	3.4	1.14 E-13	3.4	3.76 E-11	2.5	9.24 E-12	2.7
	363.2	0.208	0.014	3.37 E-14	3.4	1.43 E-13	3.4	1.15 E-13	3.4	3.64 E-11	2.5	9.05 E-12	2.7
	384.45	0.247	0.019	3.84 E-14	3.4	1.37 E-13	3.4	1.14 E-13	3.4	3.63 E-11	2.5	9.21 E-12	2.7
YZP	332.02	0.253	0.021	5.61 E-14	3.4	2.19 E-13	3.4	1.72 E-13	3.4	6.13 E-11	2.5	1.44 E-11	2.7
	349.5	0.294	0.028	6.12 E-14	3.4	2.17 E-13	3.4	1.69 E-13	3.4	6.10 E-11	2.5	1.43 E-11	2.7
	363.2	0.330	0.035	6.84 E-14	3.4	2.19 E-13	3.4	1.65 E-13	3.4	6.10 E-11	2.5	1.44 E-11	2.7
AYP	332.02	0.301	0.020	5.05 E-14	3.4	2.70 E-13	3.4	2.10 E-13	3.4	5.41 E-11	2.5	1.69 E-11	2.7
	349.5	0.351	0.026	4.87 E-14	3.4	2.72 E-13	3.4	2.04 E-13	3.4	5.34 E-11	2.5	1.67 E-11	2.7
	363.2	0.393	0.032	6.24 E-14	3.4	2.73 E-13	3.4	2.05 E-13	3.4	5.34 E-11	2.5	1.64 E-11	2.7

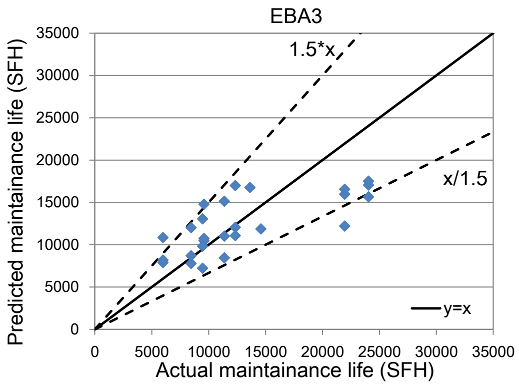
* LEFM 1 refers to Nasgro model, LEFM 2 refers to Nasgro+Generalized Willenborg model, LEFM 3 refers to Walker+Closure model, LEFM 4 refers to Ncode model.



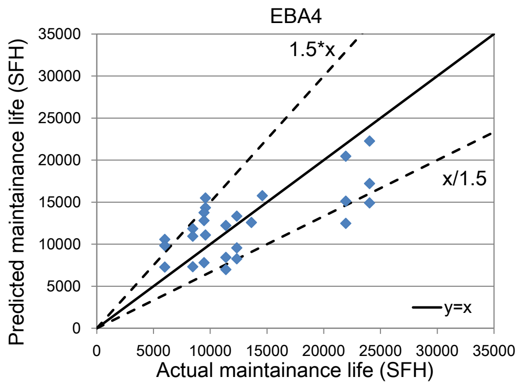
(a) LEFM model 1



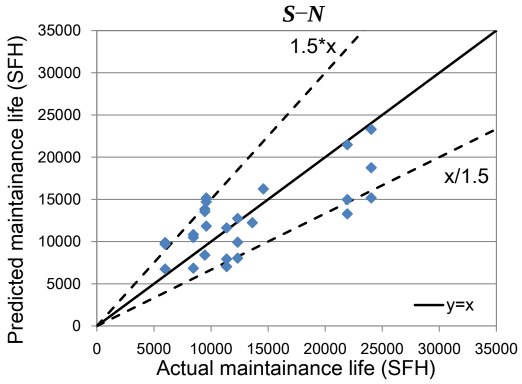
(b) LEFM model 2

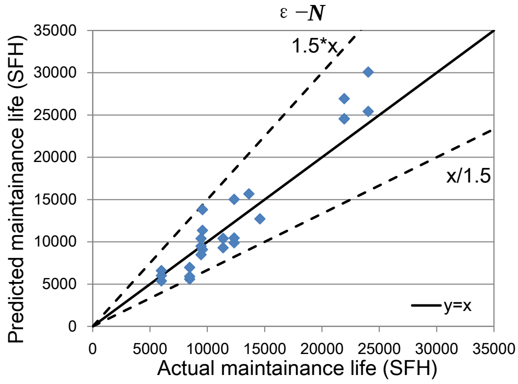


(c) LEFM model 3



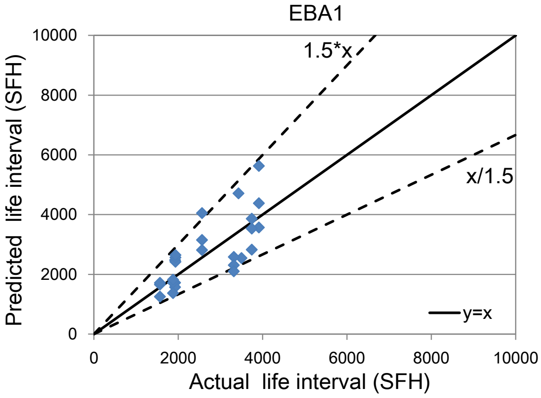
(d) LEFM model 4

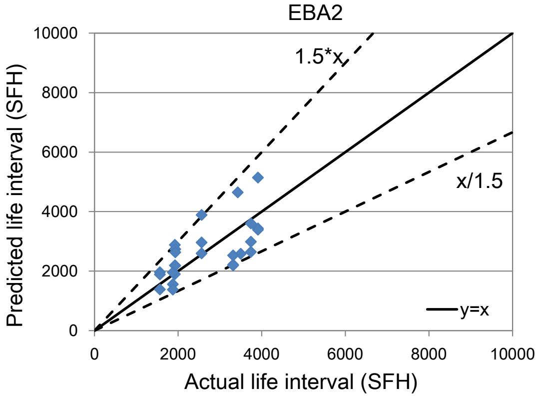




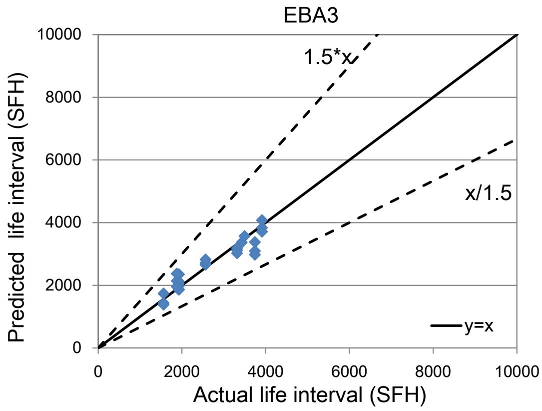
(e) *S*–*N* approach (f) *ε*–*N* approach

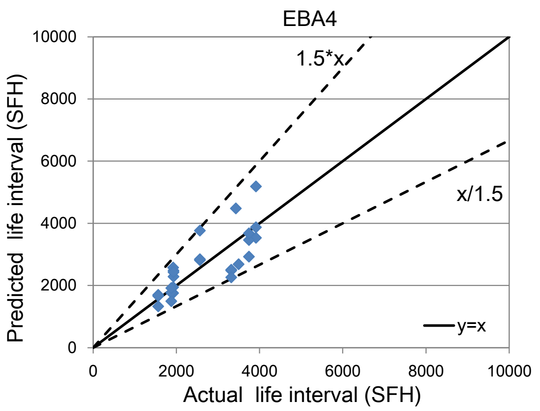
Figure 3. Maintenance life predictions using generalized correction method compared to test result.





(a) LEFM model 1 (b) LEFM model 2





(c) LEFM model 3 (d) LEFM model 4

Figure 4. Interval predictions using generalized correction method compared to test result.