A NEW APPROACH TO EVALUATE DURABILITY AND DAMAGE TOLERANCE FOR AIRCRAFT COMPOSITE STRUCTURES

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Abstract

Three new approaches were made to evaluate the durability and damage tolerance of composite wing box and composite nose fuselage (cockpit) structures designed by no-growth concept. Those approaches are (1) time-temperature shift factor based on accelerated coupon test data, (2) PIF (post impact fatigue) originated from BVID (barely visible impact damage) and (3) under-threshold criteria for flawed holes or matrix crack initiation.

The PIF approach showed that there was no threshold under which BVID did not grow and that no-growth design by under-threshold criteria was not able to be done. The effectiveness of time-temperature shift factor approach and the possibility of under-threshold criteria, differently from PIF/BVID, for flawed holes and matrix crack initiation are also presented.

1 Introduction

Many composite materials are applied to new aircraft to be developed before long, e.g., EASA (Environmental Adapted Small-size Airplane) or B7E7. The percentage of composite materials is expected as over 20% of structural weight by application not only to tail and control surfaces but also to primary structures such as wing. Some new design approaches are needed to use new material instead of aluminum alloy reigning in the aircraft structures for long in order to ensure flight safety.

Authors have proposed the necessity [1] and the methodology [2] for new design approaches about durability and damage tolerance, especially predictable damage growth design, of composite primary structures. The first of the proposed approaches is time-temperature shift factor approach [3] which gives speedy estimation of long-term fatigue life. The second is PIF approach for BVID and the third is no-growth design for flaws or defects depending on the existence of threshold.

2 Structures under evaluation

Composite wing box and cockpit outer panel under development in NEDO project were evaluated for durability and damage tolerance. This project was carried out to prove the new concept of aircraft composite structures for the purpose of mass saving and part-count reduction [4]. The wing box is an integrated composite structure made by RTM/VaRTM and assembled by co-bonding . The RTM materials is T800S-24K/TR-A33 and prepreg T800S-24K/#300-2B is used for skins. The cockpit outer panels are sandwich of plastic core and prepreg UT500/#135 skin. The sandwich construction was selected to reduce part-count and mass of the structure under high internal pressure. The features of wing box and cockpit structures are shown in Figs.1 and 2.

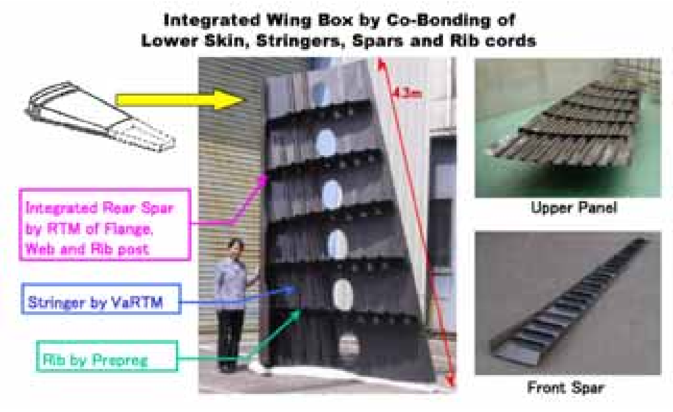


Fig 1 Co-bonded Wing Box

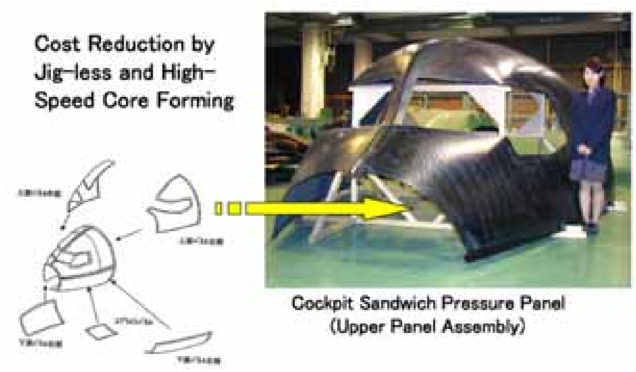


Fig.2 Cockpit Upper Sandwich Panel

3 Durability and Damage Tolerance Evaluation

3.1 Design Condition

The design conditions are 1 hour/flight, 75,000flights/20years. A standard load sequence for transport aircraft wing structures TWIST [5] was used for the wing evaluation. For the cockpit, a constant amplitude pressure is repeated each flight. The temperature is repeated each flight from +45 degree C (on ground) to –54 degree C (in flight).

3.2 Fatigue Life Estimation

(1) Fastener Joint Fatigue lives were estimated from S-N data, The B-basis fatigue life of wing root upper joint is 3.4 life. The B-basis estimated fatigue life of cockpit sandwich panel miter joint is 250 life and the endurance up to 4.8 life (not failed) was verified by fatigue test of joint specimen.

(2) Creep Creep endurances of the three materials were estimated by time- temperature shift factor approach based on accelerated coupon test data. Looking at one result in Fig.3, probability of creep rupture is extremely remote (under 10^{-14}). As the effect of repeated loading on fatigue seems to be large, the accelerated test is now continued. Evaluations by time-temperature shift factor approach will be made for repeated loading successively.

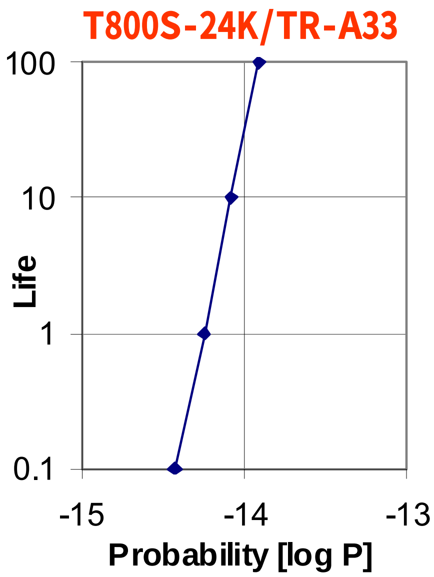


Fig.3 Creep Endurance

(3) PIF/BVID BVID grows under repeated loading and the residual strength reduces. However, the PIF lives are very long of the low working strains. The B-basis PIF life of wing upper panel stringers is 2,400 life (Fig.4) and that of nose sandwich panel is extremely long. So far, it is said that there are thresholds for PIF/BVID at about 60% of initial strength. However, recent test data such as Fig.5 show no threshold and so the no-growth design by under-threshold criteria is not applicable to PIF/BVID.

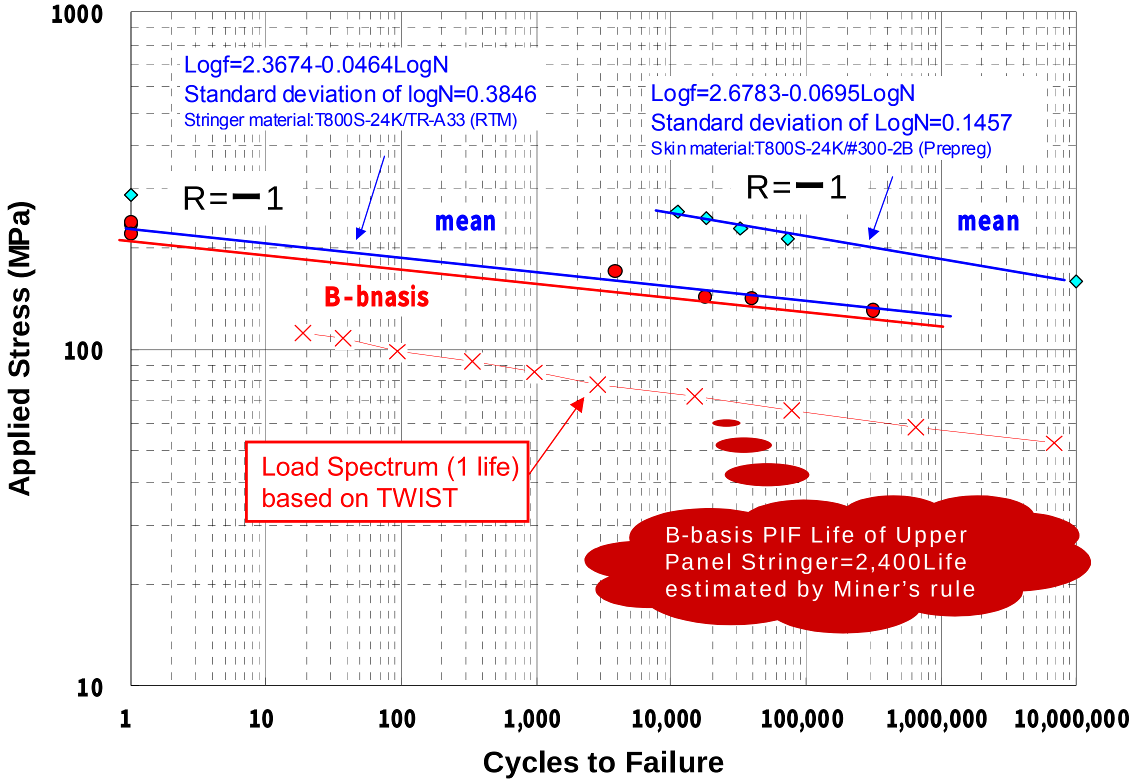
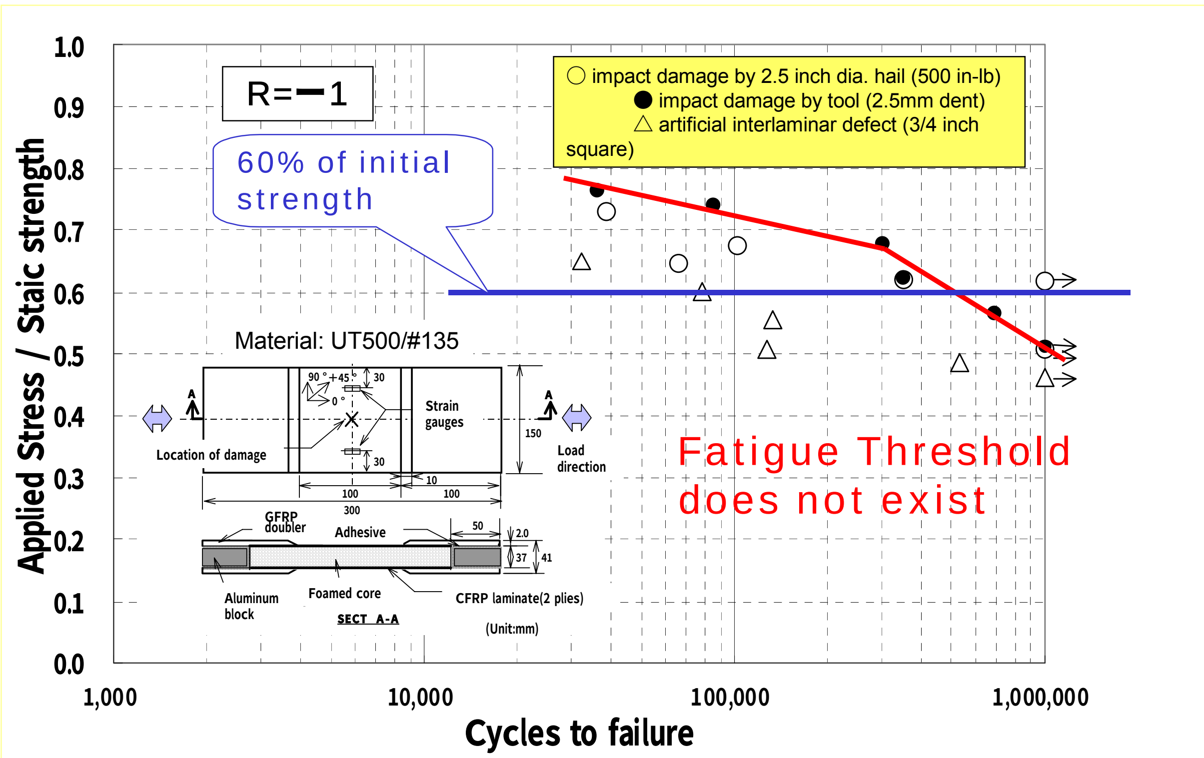


Fig.4 Post Impact Fatigue of Wing Upper Panel (PIF/BVID)



Fig,5 Recent Test Data of PIF

3.3 Damage Tolerance Evaluation

Thresholds under which damage does not grow are very high as to composite materials in comparison with aluminum alloy. Therefore, the no-growth design by under-threshold criteria can be done by setting the working strain under the threshold.

(1) Flawed Hole by Drilling The working strains of wing upper panel and spar, and nose sandwich panel are below the threshold of flawed holes specified by the hole accept or reject criteria. The threshold against working strains is showed in Fig.6 .

(2) Matrix Crack Initiation As showed in Fig.7, the working strains wing lower panel and cockpit sandwich panel are below the threshold.

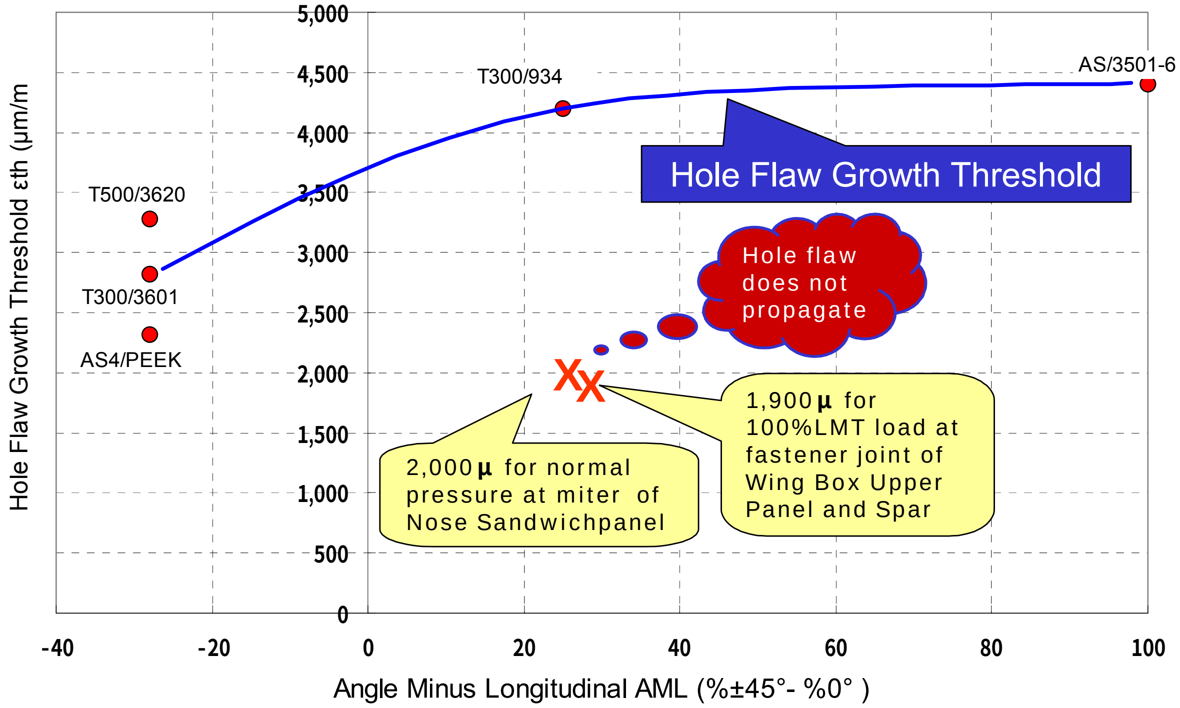
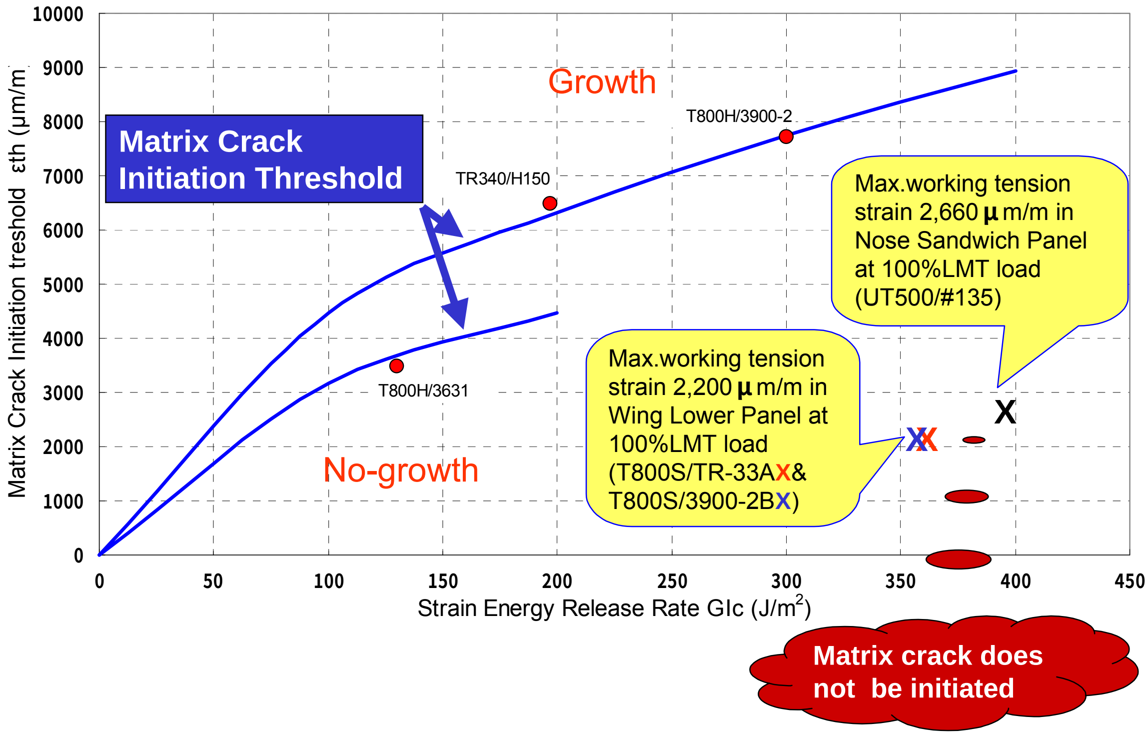


Fig.6 Hole Flaw Growth Threshold vs Working Strain



Fig,7 Matrix Crack Initiation Threshold vs Working Strain

4 Results and Discussion

4.1 Developed Composite Structures

(a) The integration technology by composite materials yielded big part-count reductions (54% - 98%) in addition to weight savings (27% - 23%). The comparison of targets of results is shown in Table 1.

(b) The strength of wing box was evaluated by ultimate static test and residual strength tests with full scale component after exposed to BVID, VID and DSD. The no-growth of BVID was proved by PIF test with a 3-stringer panel.

(c) A-SCAN and visual inspection are useful as FITs (Field Inspection Techniques) for foam core sandwich outer panels of cockpit (Fig.8). Tapping and MIA (Mechanical Impedance Analysis) gave poor performance for the foam core sandwich.

(d) The integrated composite sandwich panel can be expected to reduce remarkably the assembly cost.

(e) FAA DER (Designated Engineering Representative) reviewed our activities and gave us many good comments and effective recommendations for compliance with FAR 25.

Table 1 Comparison of Targets and Results

	Wing Box		Cockpit Outer Panel	
	Target	Result	Target	Result
Part-count Reduction	50%	54%	80%	98%
Weight Saving	20%	27%	20%	23%

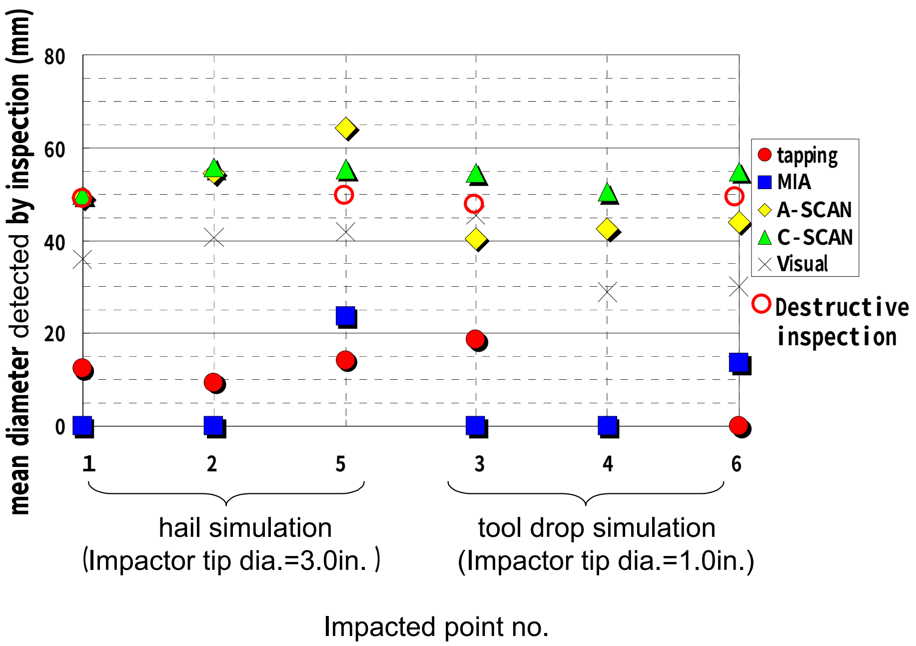


Fig.8 Comparison of NDI Detection Performance

4.2 Durability and Damage Tolerance Evaluation

(a) Recent test data in Fig.5 show no threshold and the no- growth design by under-threshold criteria is not applicable to PIF/BVID.

(b) On the other hand, no-growth design can be done as for flawed holes and matrix crack initiation (Figs.6 and 7).

(c) Fastener joints, materials itself (repeated loads, creep, moisture absorb/exhaust, cyclic temperature, etc.) have finite fatigue lives. For these items, the speedy time-temperature shift factor approach is effective to estimate.

(d) As concerns wing and cockpit structures, no-growth design was not completed, but 2-life design target is attained because of the low working strains. More mass save is expected if working strains are increased under the high threshold given by resign toughness.

5 Conclusions

(1) A fatigue life prediction method based on time-temperature shift factors obtained by accelerated coupon-test data is applied. This is a new methodology to predict fast the long-term life of composite materials under a range of temperature, times to failure and loading conditions. Applicability of this method has

already shown especially to many kinds of PAN-based carbon fiber/epoxy composites

(2) Post Impact Fatigue (PIF) test with coupon specimens is applied to evaluate damage growth characteristics from Barely Visible Impact Damage (BVID). A remarkable influence of low-velocity (low-energy) impact damage on fatigue lives is pointed out especially as to high cycle fatigue of some composite materials. This PIF test will be made to evaluate the rapid drop in residual strength over 10^5 to 10^6 cycles of loading.

(3) Some kinds of damage such as hole flaw by drilling, matrix crack initiation have the threshold under which damage dose not grow and that, the thresholds are on high level of about 40% ultimate strength. in comparison to that of aluminum alloy. Under-threshold criteria approach is effective for no-growth design.

(4) These three challenging approaches are expected to give valuable information for material selection, design optimization as well as proof testing of composite structures.

References

[1]Kikukawa,H., Tamura,H.., “Needs for Predictable Damage Growth Design of Aircraft Composite Structures ”, *Proceedings of 9th US-Japan Conference*,(2000), 125-132.

[2] Kikukawa,H., “Methodology for Predictable Damage Growth Design of Aircraft Composite Structures ”, *Proceedings of 5th DURACOSYS*, (2001), 55-60.

[3]Nakada,M., et al., “Time Temperature Dependence of Flexural Behavior of CFRP Laminates for Aircraft Use”, *Proceedings of 8th Japan International SAMPE Symposium*, (2003), 1299-1302.

[4]Kikukawa,H.,“Proof of Concept for New Composite Structures of Aircraft”, *CD ROM Proceedings of 11th European Conference on Composite Materials*, (2004), Topic: Transportation..

[8]J.B.de Jonge, et al., “A standardized load sequence for flight simulation tests on transport aircraft wing structures”, *NLR TR 73029 U*, (1973).