EFFECT OF MATERIAL PROPERTIES AND LOAD PARAMETERS ON THE CRACK GROWTH PROPAGATION

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Abstract. The paper deals with a crack propagation evaluation. A few approaches to crack growth evaluation have been studied in the Aeronautical Research and Test Institute, Prague. The cycle-by-cycle crack growth calculation based on the crack closure concept was chosen to final applications. An original PREDIKCE computational code was developed using the concept and its modification resulting from „black-box" analysis of loading sequence parameters. The ratio of a maximum stress to a mean stress for particular loading flight sequences is used as a nondimensional parameter in the PREDIKCE. The computational code has been verified for typical loading spectra including the MINITWIST and FALSTAFF. Especially for loading sequences of transport airplanes the errors are less than 20%. Two practical applications are presented for example. A stress intensity factor as a function of the crack lengths was developed by the finite elements stress analysis. The attention was given to study loading frequency effect on the crack growth rate evaluation under normal laboratory test conditions. Extensive testing has been performed to verify the effect which is not unique for each aluminium alloy. The cause of this event is not explained satisfactory till this time.

Introduction

The design concept evaluation from a safe life design of aircraft structures to a damage tolerance design philosophy has been respect in Czech aircraft industry as well. From the historical point of view, the L-410 transport airplane widely used in East Europe countries has been on a safe life basis designed as well as the L-39 military jet-trainer and the Z-50 acrobatic airplane for example. The L-610 advanced transport airplane being under a certificate process at this time is fully designed under damage tolerance concept.
The damage tolerance design of a structure is intended to ensure that even when serious damage occurs within the operational life of the aeroplane, the remaining structure can withstand specified service loads without critical failure until the damage is detected. Damage tolerance requirements are specified in various categories as a functions of design concept and degree of inspectability. Generally, the damage tolerance evaluation of an aeroplane should encompass the design objectives:
- life to crack initiation,
- crack propagation period,
- residual strength.

On the airworthiness standard base it should be determined by analysis, supported by test evidence, that the structure reaches design parameters of objectives the above. The paper deals with a crack growth evaluation.

Crack growth model modification

Many crack propagation models were carried out by their authors using the deterministic methods. They all demonstrated that it is possible to predict the propagation of a crack but they are different in their ability to respect a complex mechanism of the crack propagation in a real structure under miscellaneous conditions expected in service. Really, only a limit set of parameters can be take into consideration to keep the crack growth model to easy using with reasonable results.
When the L-610 airplane development on the damage tolerance base was started no commercial software to crack propagation evaluating was disposable. Thus a few approaches to crack growth evaluation have been studied [(1),(2)] in the Aeronautical Research and Test Institute (ARTI), Prague. Although each model was evaluated on the published principles, these models are likely different from their patterns because complete information was not published for each one [(3),(4),(5)].
The cycle-by-cycle crack growth calculation based on the crack closure concept was chosen to a final application. An original PREDIKCE computational code was developed in ARTI using the concept.
The computational code has been verified for typical loading spectra including the MINITWIST and FALSTAFF standardized loading sequences. A close attention was given to the crack growth model testing under loading sequences which respect the

operational usage specified for conventional commercial transport airplanes. Although the initially designed version of the PREDIKCE crack growth model was mostly in a good agreement with test results. Crack growth calculation differences more then 20% from experimental data were observed. The effect of particular parameters of loading sequences was analyzed on the base of "black-box" approach to explain these events. The analysis results in the model modification. The ratio of a maximum stress to a mean stress for particular loading flight sequences was used as a nondimensional parameter in the PREDIKCE crack growth model. It should be note the parameter is typical for the loading spectra of transport airplanes only.

Fatigue crack growth data bases

Considerable effort during the recent three years has been dedicate to damage tolerance material properties testing on the MIL-HDBK-5 [6] methodology base. The most of aerospace aluminium alloys and their semiproducts used by Czech aircraft industry was tested to evaluate their fatigue crack growth behavior. The material characteristics are evaluated from experimental data acquired by laboratory tests which are mostly performed on electrodynamic resonance test machines. Since the tests are very fast, the ones are economically profitable. A resonance machine loading frequency is, however, typically about two orders higher then a real loading frequency in service.

The loading frequency is one of the most important variables when environmental effects are tested but rarely is taken into consideration when the test is running under normal laboratory test conditions. While crack growth tests are standardized, little is known about loading frequency effect on the crack growth rate. A view of the 2124 typical aluminium alloy crack growth performance presented in MIL-HDBK-5 shows no loading frequency effect. Extensive test performed [7] in ARTI to verify this effect results in a statement that the loading frequency effect on the crack growth rate is not unique for each aluminium alloy.

The Figure 1 and 2 show crack growth performance for the ONZ 424206.61 forging and the 50-mm-thick ONZ 424201.61 plate respectively. Both of them are aluminium alloys. Those alloys are destined for a main wing attachment frame and different fittings respectively. The ONZ 424206.61 crack growth rate is independent of loading frequency, the ONZ 424201.61 depends on loading frequency very expressively.

The Figure 3 presents loading frequency effect on the threshold stress intensity value for the 3-mm-thick D16č-ATV aluminium alloy sheet destined for a lower skin of a wing. Especially the growth of short cracks is strongly influenced by threshold stress intensity value because the stress intensity is low even if the stress level is high.

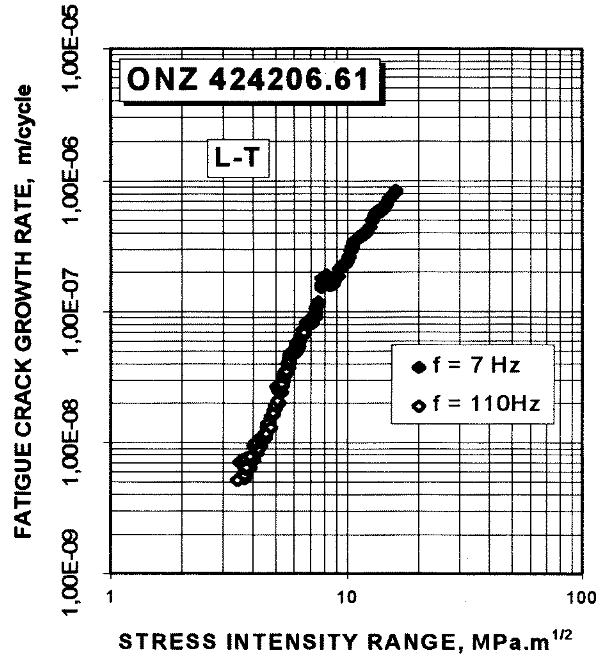

FIGURE 1 - Crack Growth Behaviour without Loading Frequency Effect

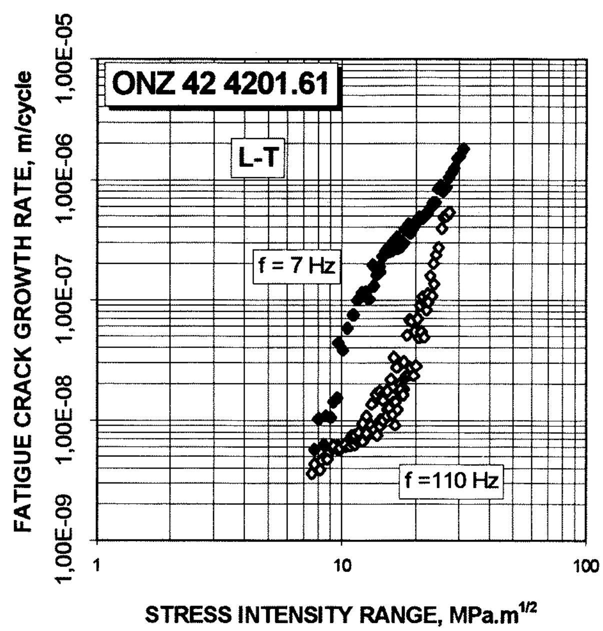

FIGURE 2 - Loading Frequency Effect on Crack Growth Behaviour

Verification of crack growth prediction technique

The full-scale loading process should

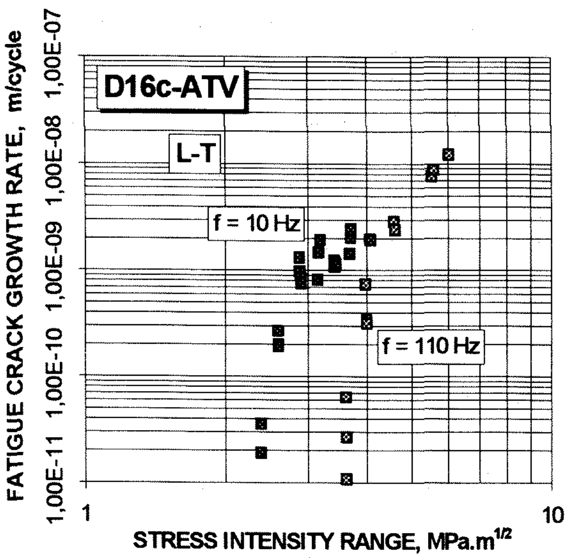

FIGURE 3 - Loading Frequency Effect on Threshold Stress Intensity Factor

include the different flight types expected in service. All loads in the spectrum must be initially considered but their effect on the crack growth rate in individual structure parts is not the same because the stress levels and material properties are different. On the base of a crack closure hypothesis used by the PREDIKCE computational code is possible to state that not all cycles which may be applied to a structure part in service need to be considered. Thus the spectrum may be simplified in this case by eliminating loads which are not damaging. It is recognized from an economic standpoint that the full-scale test will be less time-consuming.
The preliminary test on the CCT specimen was performed to develope the stress range truncation level [8] for the airplane under developing. The part of the original loading sequence is shown in Figure 4. The crack growth curves evaluated by the PREDIKCE computational code are presented in comparison with experimental data, see Figure 5. The evaluated parameters are the omitted stress levels of the loading spectrum.
The fatigue crack propagation in a real structure represents a complex problem. A crack propagation in one structure element causes a stress increasing in an adjacent structure element and a crack initiation in it as well. The period between primary and secondary crack initiation depends on the structural and technological parameters of the critical area and more tests should be performed to evaluate the scatter of damage tolerance characteristics of a single critical area. Unfortunately, full-scale tests are much expensive and usually only one configuration of primary and secondary cracks is tested. The damage tolerance analyses including stress and crack growth prediction techniques are necessary in these cases.

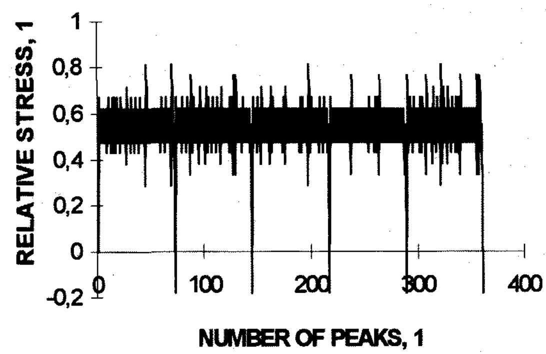

FIGURE 4 - Record of Random Loading Sequence

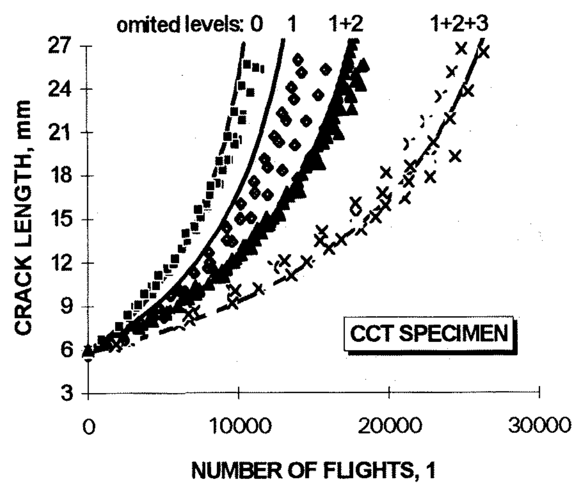

FIGURE 5 - Predicted/Experimental Effect of Stress Range Truncation of Spectrum on Crack Growth

The crack growth in a rear spar and adjacent skin of a wing of a transport airplane is presented for example. The test load sequence, see Figure 6, was designed in the form of blocks of cycles at various stress levels. The draw of a critical area is shown in Figure 7. The skin and spar crack lengths at the given moments are depicted. It should be note the

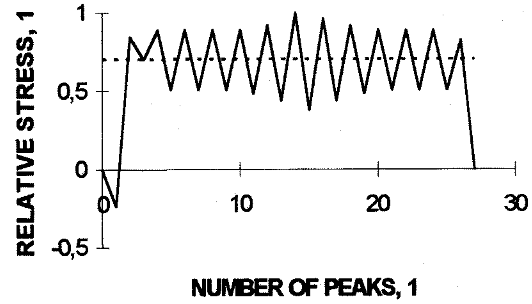

FIGURE 6 - Deterministic Loading Sequence

cracks has been initiated from sawcuts. The crack growth was monitored visually.
A stress intensity factor as a function of the crack lengths was developed on the strain energy release base by the finite element stress analysis [9] supported by NASTRAN software. Consequently the crack growth curves were evaluated by the PREDIKCE computational code using this stress intensity function. The crack growth curve in the skin, see Figure 8.

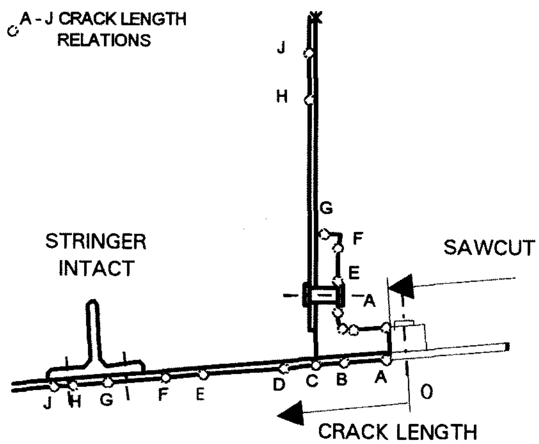

FIGURE 7 - Details of Wing-box Critical Area

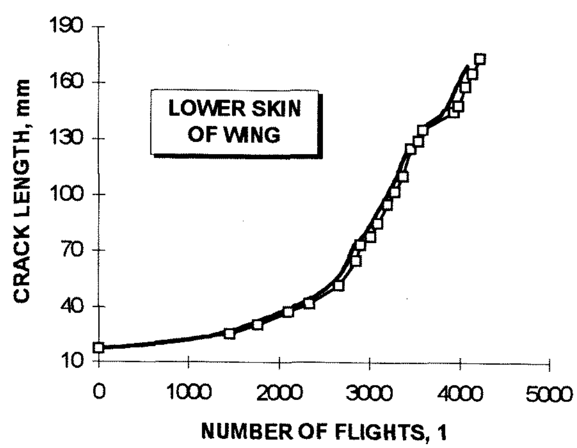

FIGURE 8 - Predicted/Experimental Crack Propagation in Skin of Wing

Finally, when the crack growth analysis has been validated, the different crack configurations expected in service can be evaluated.

Conclusions

The PREDIKCE computational code presented here has been verified for typical loading spectra and it is acceptable for calculating the crack growth under service airplane loading in industrial applications. The model requires only

- PARIS or FORMAN crack growth material characteristics including the threshold stress intensity factor,
- stress intensity factor as a function of crack length,
- loading sequence data.

Especially for transport airplanes is possible to obtain crack growth curves fitted to experimental data more better then by other crack growth computing commercial software which was in Czech aircraft industry tested during two recent years. The attention must be given to study of loading frequency effect mentioned here. The aluminium alloy sensitivity to loading frequency under normal laboratory test conditions is not explained satisfactory till now. More tests must be carried out to determine this material property.

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