Proceedings IRF2018: 6th International Conference Integrity-Reliability-Failure
Lisbon/Portugal 22-26 July 2018. Editors J.F. Silva Gomes and S.A. Meguid
Publ. INEGI/FEUP (2018); ISBN: 978-989-20-8313-1

PAPER REF: 7208

AEROFRACTURELASTIC ON WING BOX OF MULTI-PURPOSE COMMUTER AIRCRAFT UNDER GUST LOAD BY MEANS OF XFEM

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ABSTRACT

In this paper, crack behavior of an aluminum wing box under gust load is presented. The investigated wing box is based on one of the design prototypes of a multi-purpose commuter aircraft. The wing box has been tested experimentally for the vibration test and flutter test. The results of both tests are applied to verify the FEM model used in the present work. The detailed 3D FEM result is in good comparison with the experimental results. Several gust responses are plotted with the incremental of time to observe the deflection of the wing box. As the deflection under gust load resulting in developing the stress concentration at any discontinuity point, the crack has been initiated. By implementing XFEM, the crack propagations have been modelled based on the fracture toughness of the wing box material.

Keywords: gust, crack, wing box, vibration, XFEM.

INTRODUCTION

A sudden wind, called gust has widely experienced during flight. The existence of gust during flight can cause the flying stability and reduce the flight performance. However, due to certain geometry discontinuity, it has raised an issue of structural failure due to the gust interaction. During a flight, the aircraft wing will experience several modes of vibration such as bending and twisting. For instance, the deflection or torsion of the wing has triggered the stress to be concentrated at several locations. The complexity of aircraft wing such that the concentrated mass of engines or missiles can cause larger deflection or torsion. For example, Abdullah & Sulaeman (2014) performed the aeroelastic tailoring on an oscillating supersonic wing with external stores where the composite wing box skin has been implemented to replace the conventional aluminum wing. Based on their work, the flutter speed can be increased by using this approach even the attachment of the external stores has contributed to a larger inertia measurement. On the event of gust loading, the same approach of aeroelastic tailoring but considering the gust loads has been performed by Rao (1985), where the deflection of the wing under gust loads was considered. Another optimization technique by considering gust load can be explored in (Pettit and Grandhi, 2003).

For this reason, due to the stretching force that could lead to the crack development on the wing box, the aeroelastic flutter modelling is performed. Hence there is an investigation that assessed the flutter speed by varying the crack ratio (Abdullah *et al.*, 2018). For some reasons, taper geometry of the wing that was mostly designed to optimize the aerodynamic distribution on the wing might cause structural discontinuities. At this point, the stress concentration will be higher in this area due to the existence of the discontinuity. In this recent day, the wing geometry discontinuity could be improved by the designing a morphing wing mechanism (Tarnowski, 2017). However, the current issue needs to clarify when most of the wing implement sort of smart materials either to bend or twist the shape of the original wing. This has increased the manufacturing cost since the smart materials are quite expensive and still under development. For this reason, most of the airplane in the aviation industry is still using the conventional cantilever wing, which sometime could lead to the wing geometry discontinuity.

In fracture modelling approach, several numerical methods have been introduced to the world that can predict the fracture due to the geometry discontinuity. One of the techniques is XFEM, which has been introduced by Ted Belytschko and collaborators in 1999 (Belytschko and Black, 1999). This technique has benefited the fracture mechanics field of study since the structural crack propagations can be solved without continuous and require minimum remeshing. Thus, the computational time and cost have significantly reduced. There are some researches that revealed the fracture mechanics successfully modelled by means of XFEM, such that delamination of composite laminates by Curiel-Sosa and Karapurath (2012), Yazdani *et al*., (2016), microcracking and permeability by Grogan *et al*. (2015), transversal crack and delamination of laminates by Abdullah *et al*. (2017) and fracture and delamination modelling via energy release rate and interface stress by Curiel-Sosa *et al*. (2018).

In this paper, the gust load and wing box structural interaction study has been performed to evaluate the crack propagations due to the wing complexity (either due to the tapered wing or external store). To model the fracture mechanism, XFEM is used by considering the energy release rate as the damage evolution criterion.

BENCHMARKING AND VALIDATIONS

The vibration test, flutter, and gust have been experimentally and numerically performed to the presented wing box (Figure 1) depicts the numerical result of flutter response for the wing box prototype developed under the joint program of Indonesian Aerospace, National Institute of Aeronautics and Space of Indonesia and Agency for Assessment and Application of Technology of Indonesia. The computational modal analysis of the present wing box can be seen in (Abdurohman, 2015). The present flutter speed was performed via coupling between finite element and doublet lattice method, well explained by MSC Software Corporation (2009). The computational flutter speed result is compared with the experimental flutter result done by Syamsuar *et al*. (2017), which shows a good agreement as in Table 1.

Table 1 - Flutter results at altitude 10000 ft

At H=10000 ft, M=0.346			
Work	**Stick Model (Syamsuar *et al*., 2017)**	**Experiment (Syamsuar *et al*., 2017)**	**Present Work**
Flutter Speed	767 KTAS = 395 m/s	40 m/s with 1:10 scale Resulted in true scale flutter speed = 400m/s	400 m/s
Flutter Mode	Wing Torsion	Wing Torsion	Wing Torsion

Several flutter responses using the same procedure are plotted to evaluate the effect of crack existence. Figure 1 shows the flutter response mode, which is dominantly found to be in wing torsion mode.

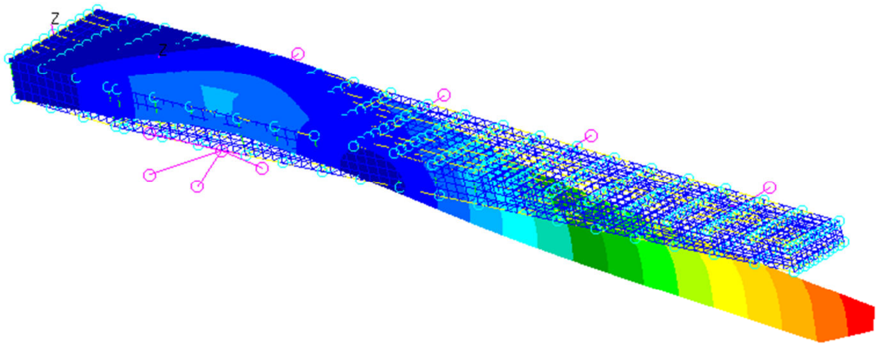


Fig. 1 - Flutter response for wing box of multi-purpose commuter aircraft

RESULTS

In this part, the gust is approximately conducted for 0.58 seconds, based on the regulation guided by CASR Part 23 derived from FAR 23 in Civil Aviation Safety Regulation (2014) at a break velocity, V_B when any disturbance such as gust encounters by the wing structure during the flight. From the gust responses in Figure 2, the wing tip deflections data are collected and intercorrelated using Fourier function series to form the whole time frame deflection function. The wing tip deflection is presented in Figure 3 as the wing tip deflected during the gust happened.

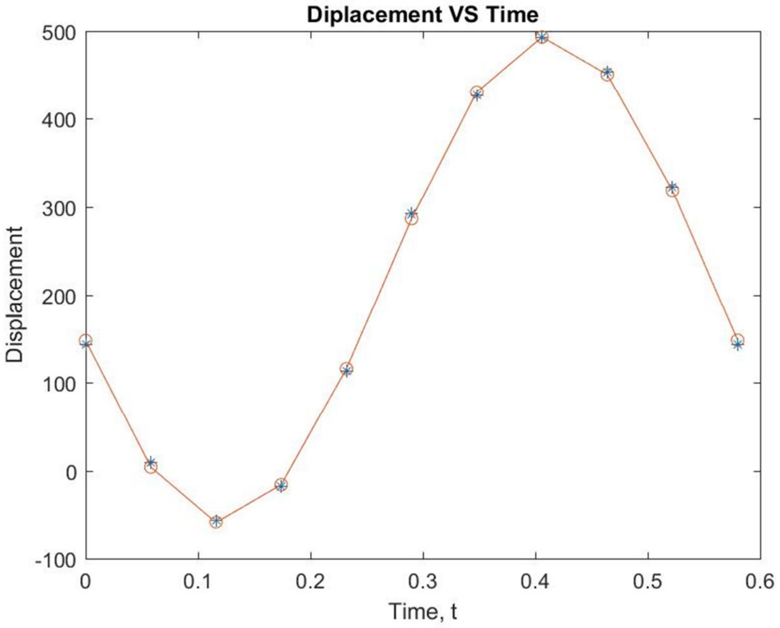
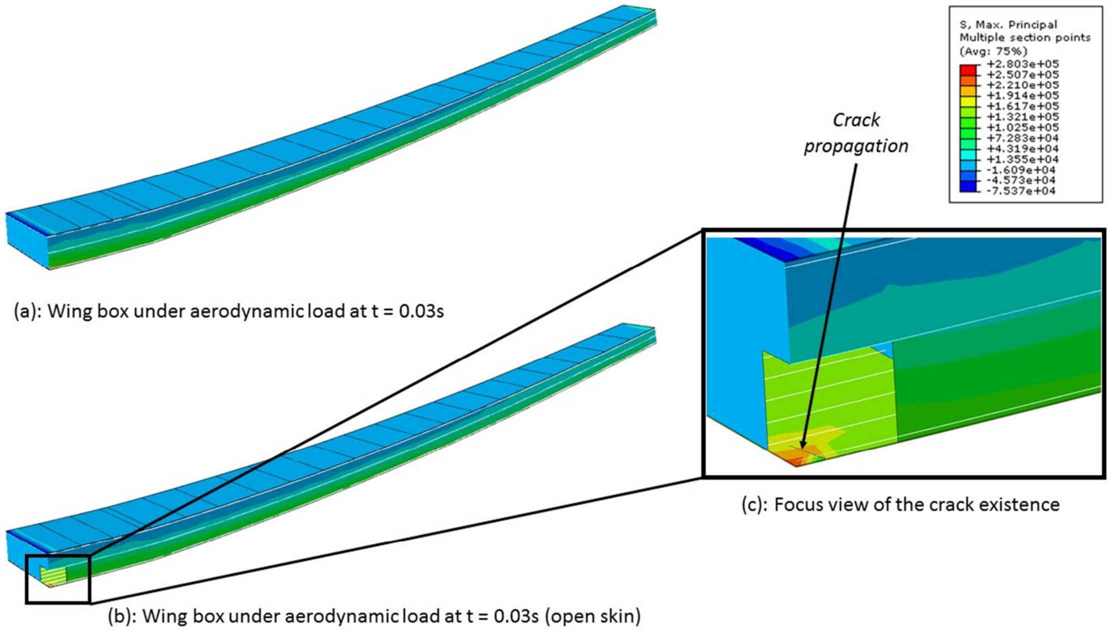


Fig. 2 - Approximate deflection correlation using Fourier function series

Since the deflection/displacement of the tip has been connected through equations, the end wing tip nodes are assigned to those equations as the boundary conditions. Since the boundary conditions for each node already assigned, XFEM is used to estimate the fracture/crack propagations location and its direction. At several time increments, the crack has emerged near to the wing root under the aerodynamic load which is demonstrated in Figure 3.



(a): Wing box under aerodynamic load at t = 0.03s

(b): Wing box under aerodynamic load at t = 0.03s (open skin)

(c): Focus view of the crack existence

Fig. 3 - Crack opening under aerodynamic load at t = 0.03s

Several wing skins modelled as solid elements have been removed as shown in Figure 3(b) to display the crack development. The crack propagations at the wing root are presented in Figure 3(c). Here, there is an inclined about 9.1° from the rear spar. The inclined crack happened due to the dihedral angle and the taper ratio of the wing box itself. The crack stops propagating as gust loads decrease with the time increment. Different results might be observed for different type of wings, considering their material properties, characteristics, and geometry.

CONCLUSION

This research presents a novel approach in predicting the crack propagations on a wing box under aeroelastic gust load, considering the flight disobeys any safety margin when the encounter the gust load. The crack location is successfully determined based on an advanced computational method called XFEM based on the energy release rate. For the present wing box, the crack propagations near to the wing root under gust load has been detected when the stress concentration is larger than the maximum material principal of stress. In future, this procedure might be performed to evaluate the crack emerging on composite wing box under the gust loads.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the funding by Ministry of Higher Education Malaysia (MOHE) and International Islamic University Malaysia (IIUM). We also acknowledge the support of National Institute of Aeronautics and Space of Indonesia, Indonesian Aerospace and Agency for Assessment and Application of Technology of Indonesia.

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