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Development of design charts for stress intensity factors at tips of multi-site cracks in unstiffened curved panels

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ABSTRACT

Multi-site damage need to be addressed and evaluated in order to assess the integrity of aging aircraft structures. One of the problems recognized in the recent times is the effect of interaction between two or more cracks in the close neighborhood in such structures. The present paper deals with such a problem and presents numerical estimates of stress intensity factors at a crack tip in an un-stiffened curved panel with a secondary crack in the vicinity of a primary crack. The results are presented in the form of design charts. These results should be useful in evaluation in the damage tolerance evaluation of aircraft structures with multi-site damage.

1. Introduction

The Aloha airlines Boeing-737 airplane accident in 1988, brought to focus the problems of aging airplanes to the airplane design/operating community. The failure analysis of above accident brought out clearly, the issues involved in multi-site wide spread fatigue damage in aircraft structures especially in a fuselage shell. This resulted in strong interest in the research community on aging aircraft [1–7] and a number of special conferences [8–12] were conducted on the subject. The fuselage is a major airplane component vulnerable to wide spread and multi-site damage. The major cyclic loading on the fuselage is ground–air–ground (G–A–G) cycle. These cycles contain pressurization and depressurization cycles with a biaxial stress state of 2:1 in addition to other flight loads. The effect of multi-site damage is analyzed by considering two or more cracks with one of them being larger called major (primary) crack and the others are minor (secondary) cracks. It is proposed to analyze a curved panel with multiple cracks loaded in tension and present the concept of design charts to evaluate the influence of secondary cracks on the primary crack. The stress intensity factors for the case of curved panel are obtained by applying curvature correction to the results from flat panels.

2. Problem definition

Consider a curved plate of size of $2W \times H$ with a central primary crack of size $2a_0$ and two secondary cracks of size $2a_{MSD}$ with a gap of lig1 between the two adjacent crack tips. The entire cracked region is well within the width of the panel as shown in Fig. 1. R is the radius of curvature of the curved panel.

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Nomenclature

G–A–G	ground–air–ground cycle
LEFM	Linear Elastic Fracture Mechanics
MVCCI	Modified Virtual Crack Closure Integral
MSD	multi-site damage
SERR, G	Strain Energy Release Rate
SIF	stress intensity factor
a_0	half of primary crack size
a_{MSD}	half of secondary crack size
E	Young's modulus
F_x	x-forces at the crack tip nodal point
F_y	y-forces at the crack tip nodal point
H	height of the panel
K	stress intensity factor
lig1	gap of lig1 between the two adjacent crack tips
R	radius of curvatures of the panel
t	panel thickness
U_c, V_c	nodal displacement at nodal point 'c'
W	width of the panel
Δa	length of the element at the crack front
σ	remote uniform stress

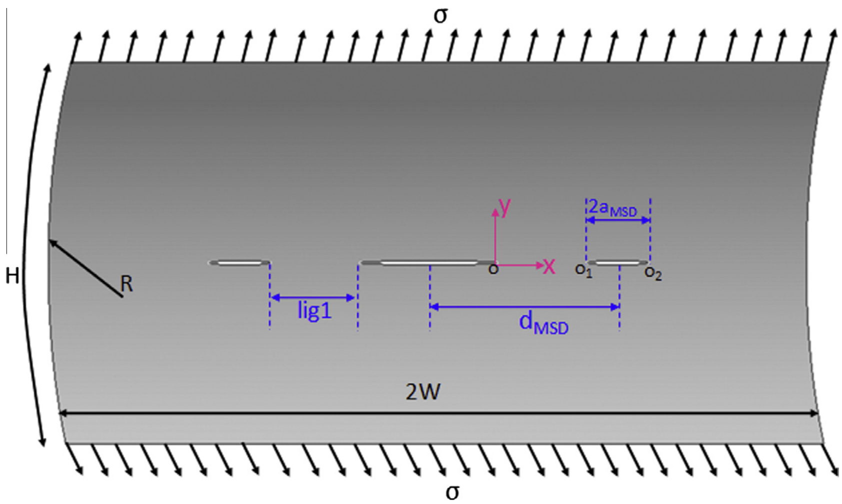

Fig. 1. Geometric details of the configuration considered.

In this paper, the analysis is confined to Linear Elastic Fracture Mechanics (LEFM). Due to the presence of two axes of symmetry in the problem it is sufficient to analyze only one quarter of the curved panel with appropriate boundary conditions. The rectangular coordinate system is used for analysis of all the problems in the panel. The **O**, $\mathbf{O_1}$, and $\mathbf{O_2}$ are the crack tips where stress intensity factors (SIF's) due to the applied loads are to be evaluated.

3. Method of analysis

The present analysis is carried out on a plate with single central crack and compared the results with those available in literature, to validate the method of analysis and adequacy of modeling. The most important parameters to be evaluated in the cracked plate are the SIF's. In the present paper only the case of far field tension on the plate perpendicular to the crack is considered, so that mode-I SIF K_I alone need be evaluated. This is because the longitudinal cracks in fuselage are primarily in mode – I. The numerical results are obtained by using conventional finite element analysis. Four noded quadrilateral elements were used in the analysis. The finite element analysis is carried out using commercially available finite element