PROBLEM NO. MERC-2

Title: Damage Tolerance Analysis of Critical Area on Windshield Doubler

Objective:

To illustrate the process of estimating crack growth behavior, which is necessary for setting inspection intervals.

General Description:

This problem focuses on a damage tolerance analysis of the windshield doubler at the intersection of the upper windowsill and post of an airplane. The analysis goal is to estimate the crack growth behavior of the windshield doubler. A finite element model is developed, with extensive refinement in the window area, to determine stresses in the part. A stress spectrum and β-factors are used with AFGROW to predict crack length versus flight hours.

Topics Covered: Damage tolerance analysis, finite element analysis, crack growth analysis

Type of Structure: windows, windshield doubler

Relevant Sections of Handbook: Sections 2, 5, 7, 11

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Critical Area

This problem focuses on a critical area of the windshield doubler at the intersection of the upper window sill and window post #3. The doubler is shown in Figure MERC-2.1, with the expected crack path marked. It is fabricated from 0.091" thick 7075-T6 aluminum and is 1.5" wide at the crack location. The windows are fastened to the doubler in such a way that they "float", which means that the windows transfer only bearing loads to it. The fasteners do not exert tangential loads on the windshield doubler.

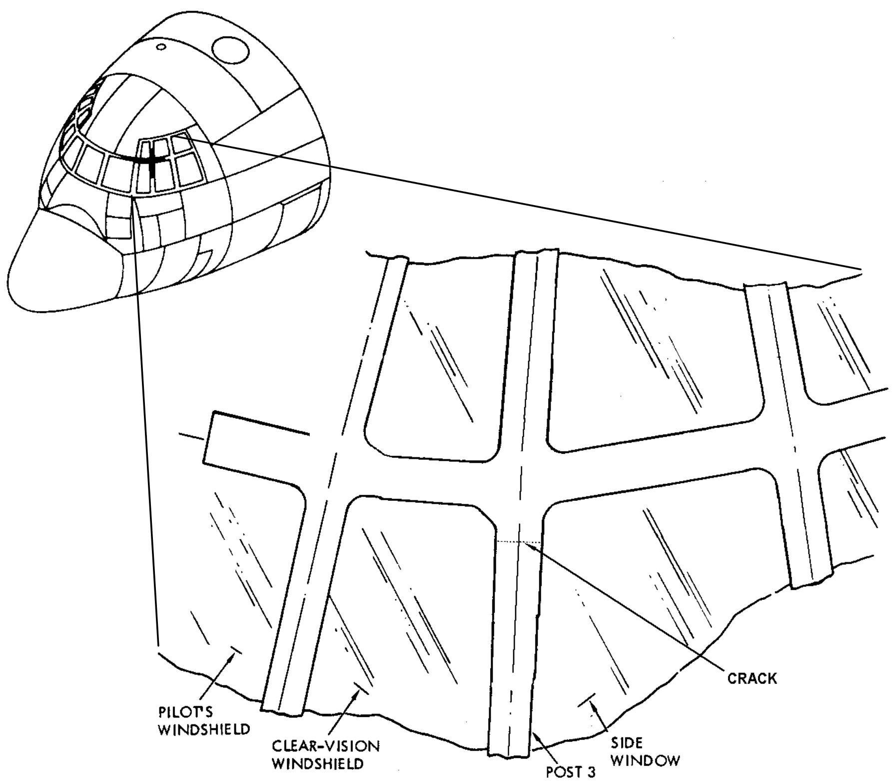

Figure MERC-2.1. Sketch of the Forward Fuselage and Windshield Doubler

Structural Finite Element Model

Geometry and Finite Element Mesh

A NASTRAN finite element model (FEM) of the forward fuselage was developed and is shown in Figure MERC-2.2. It is made up primarily of shell and beam elements. In general, joints are modeled by shared-nodes; fasteners are not explicitly modeled. However, fasteners that attach the windshield doubler to airframe structure and skin are explicitly modeled with beam elements. Rigid elements are used occasionally, such as to simulate floating windows that transfer only bearing loads to the windshield doubler.

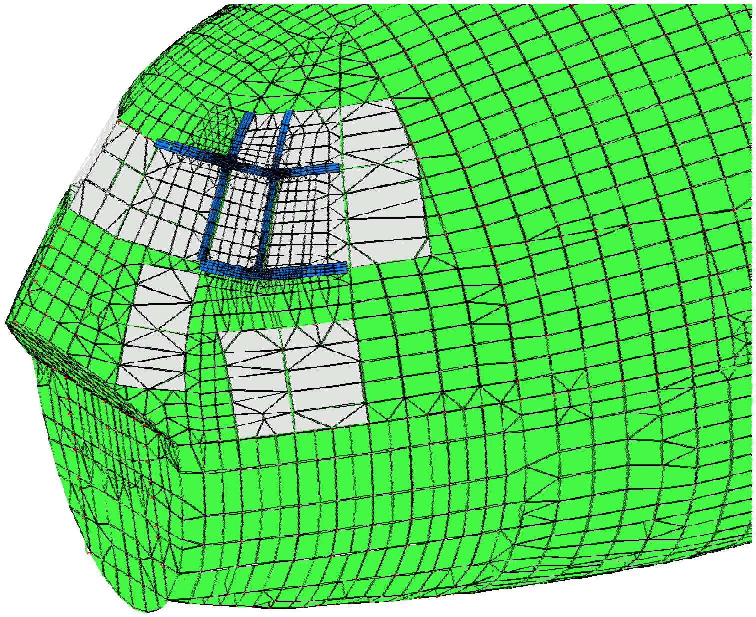

Figure MERC-2.2. Structural Finite Element Model of Forward Fuselage of the Aircraft With Mesh Refinement In Front Window Area

Loading Conditions and Stresses

Internal pressurization effects are the dominant cause of stresses in the window area. Loads due to maneuvers, landings, wind gusts, etc. are negligible in comparison. Internal pressurization actually refers to the case where the cabin is maintained at sea level pressure while flying at altitudes where atmospheric pressure is substantially less. The pressure differential is applied to the model as an internal pressure. Note that a release valve(s) in the plane prevents the pressure differential from exceeding 7.5 psi.

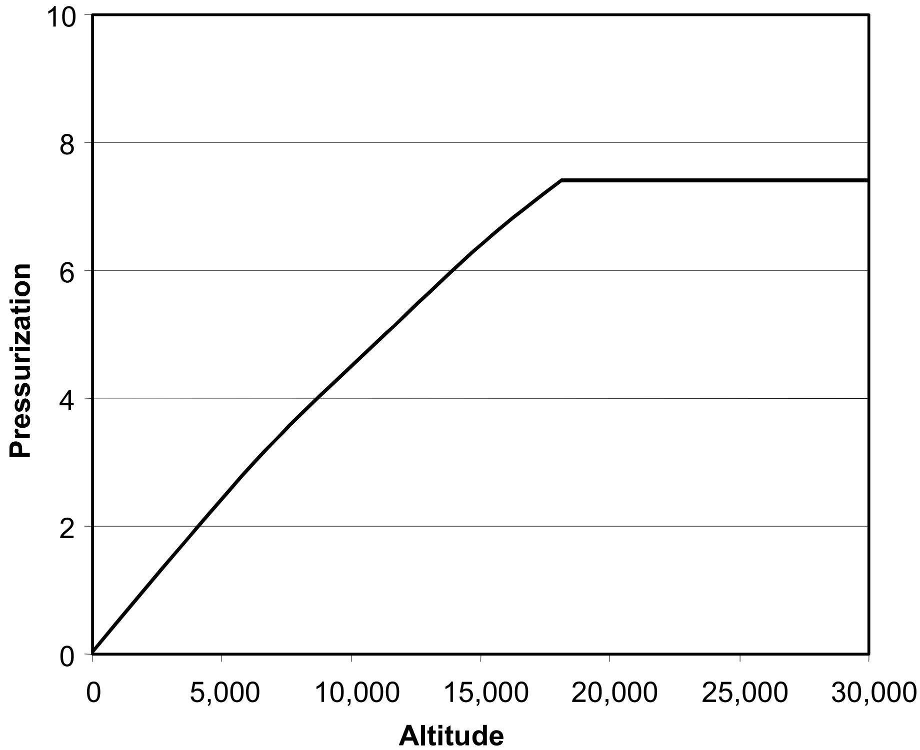

Figure MERC-2.3. Internal pressure versus altitude. A release valve prevents the pressure from exceeding 7.5 psi.

Mission profile data are combined with the pressurization information in Figure MERC-2.3 to give the frequency and amplitude of internal pressurization cycles that the plane will experience. Mission profile data consist of flight altitude data versus time. Figure MERC-2.4 shows a typical segment consisting of missions at several altitudes ranging from 1,000 ft to 25,000 ft. Combining the information in Figures MERC-2.3 and MERC-2.4 gives the internal pressurization cycles shown in Figure MERC-2.5.

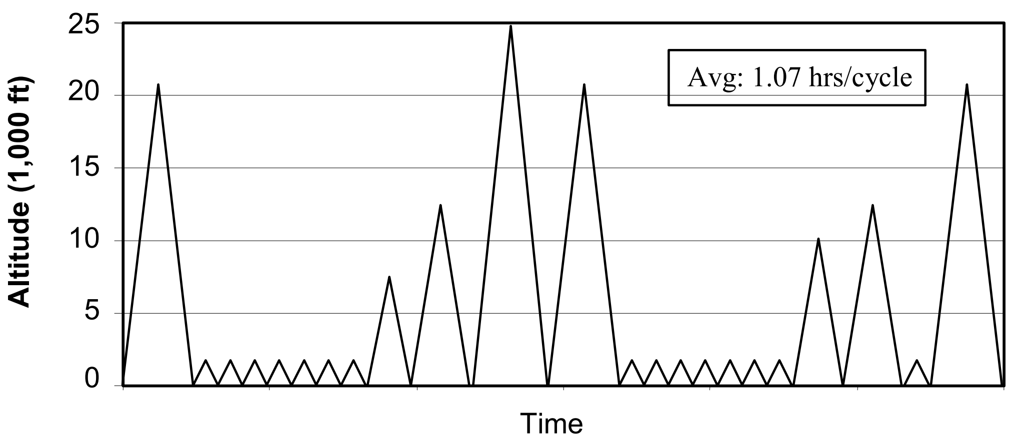

Figure MERC-2.4. Typical missions showing altitude versus time. Time spent at each altitude is not shown.

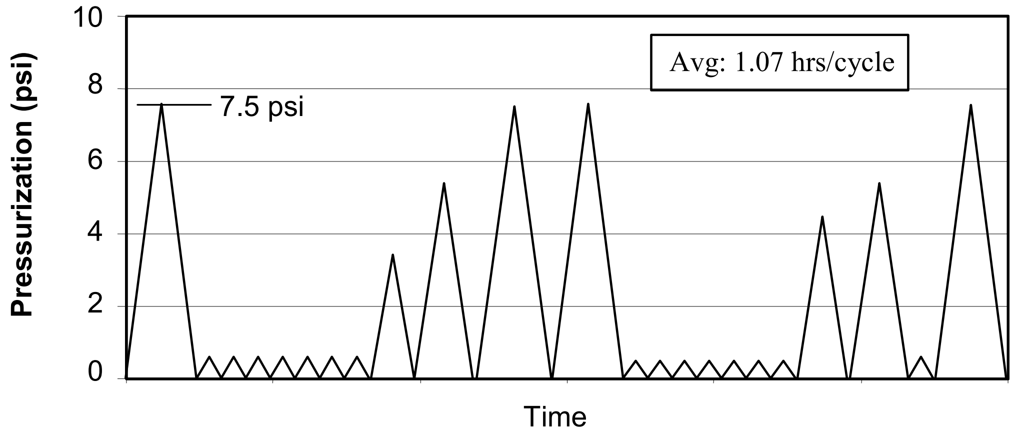

Figure MERC-2.5. Internal pressurization versus time for missions shown in Figure MERC-2.4.

Stresses in the forward fuselage and doubler for 1 psi pressurization are shown in Figure MERC-2.6 below. Stresses in the doubler are assumed to scale linearly with the imposed pressure. For example, the stress at any point in the doubler under 7.5 psi internal pressurization will be 7.5 times greater than its value in Figure MERC-2.6.

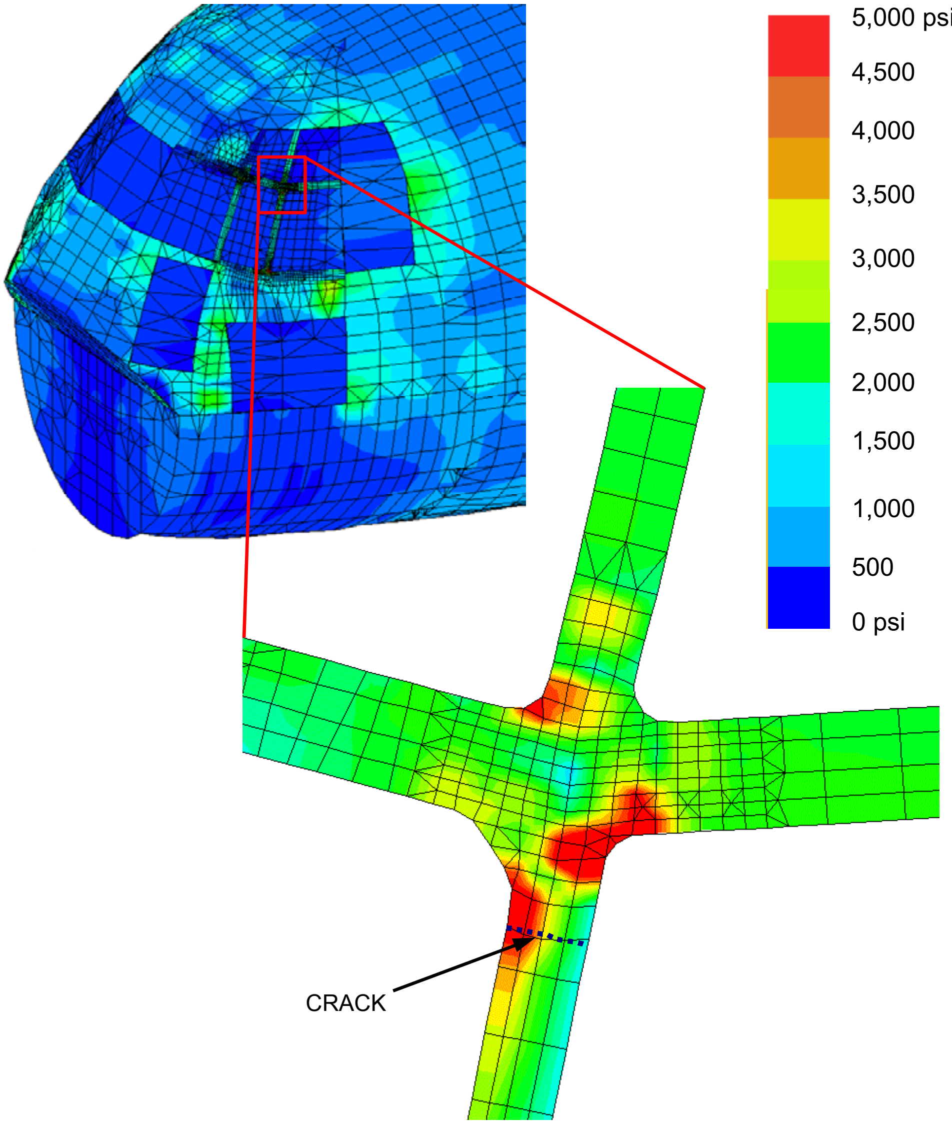

Figure MERC-2.6. Maximum principal stress in forward fuselage and window doubler due to 1 si pressurization of the fuselage. Typical crack location is shown.

Figure MERC-2.7 shows cycles of average tensile stress in the lower leg of the doubler. The values are the result of multiplying the pressure cycle data in Figure MERC-2.5 by the average tensile stress in the lower leg of the doubler predicted by the finite element analysis for 1 psi pressurization.

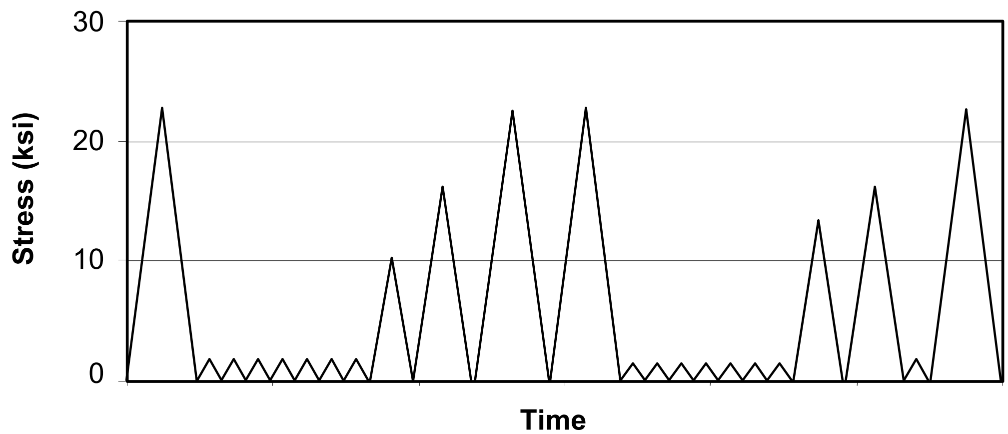

Figure MERC-2.7. Cycles of average tensile stress in lower leg of doubler. Stress cycles in the doubler are directly proportional to the pressurization cycles in Figure MERC-2.5.

Crack Growth Prediction

Critical Crack Length

Failure is defined as the time when the crack reaches a length, a_{crit}, such that further growth would be unstable under maximum loading conditions. This occurs when the stress intensity factor of the crack reaches its critical value, K_c. This value is 71 ksi√in for 0.091" thick Al 7075-T6. The tensile stress in the doubler at maximum loading conditions is σ_{limit}= 22.4 ksi. The critical crack length is determined by solving

$$K_c = \sigma_{limit} \beta \sqrt{\pi a_{crit}} \quad (1)$$

for a_{crit}. This must be solved iteratively because β is a function of crack length, a. Solving the equation gives a_{crit}=0.7". Note that β-factors for this analysis were taken from the AFGROW library.

Predicting the Crack Growth

AFGROW was used to predict crack growth in the doubler due to the fuselage pressurization cycles. The crack is assumed to start as a 0.05" radius corner crack at a fastener hole, grow to a through crack, and then grow across the doubler until failure. Stress cycles (see Figure MERC-2.7), β-factors from AFGROW, and material *da/dN* data are combined to give the crack growth prediction in Figure MERC-2.8 below. Note that Willenborg retardation is applied.

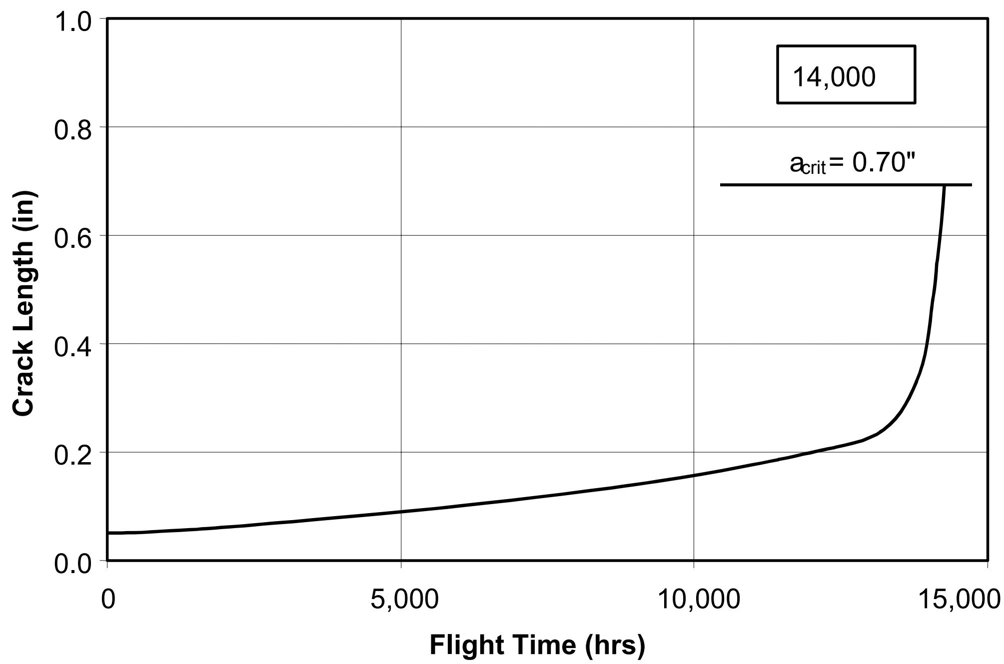

Figure MERC-2.8. Predicted crack growth versus flight hours for a crack growing across the lower leg of the doubler. Willenborg retardation is applied to the simulation.