Analytical and Numerical Investigation of the Effect of Secondary Bending in Hard-Point Joints

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Fuselage primary structural details are typically joined to each other by means of two major concepts. ***Joints (splices)*** are attachments in which the load is transferred from one member to another. Typical joints that may be found in fuselage structures are circumferential splice butt-joints and longitudinal skin lap-joints. ***Hard-points*** are attachments in which the load is jointly carried by two or more members. Typical hard-points that may be found in fuselage structures are skin-doublers attachments and skin-stringers attachments.

Due to cabin pressurization, membrane stresses are induced in the skin sheets every flight. Fastened attachments such as those described above include inherent eccentricity with respect to the load path, which induces out of plane deflections of the skin sheets. This is referred to as ***secondary bending***, and it is considered as a side effect of tensile membrane loads acting on the skin. An example of typical secondary bending effect of a lap joint structure is shown in Figure 1. It may be noted that the secondary bending effect induces tensile stresses at the vicinity of the fasteners, which reduces significantly the crack initiation and crack growth lifetime of the joint.

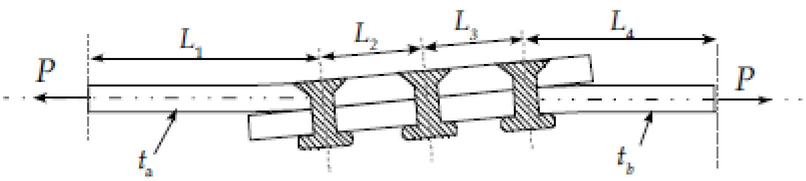

Figure 1. An example of secondary bending effect in a lap-joint attachment subjected to tensile loads.

The bending factor *k* is defined as the ratio between the bending stress and the tensile stress,

$$k = \sigma_{bending}/\sigma_{tenslie} \quad (1)$$

As discussed in [1], *k* can reach up to 3 for a case of a lap joint with a single row of rivets. This is a significantly increase of the stress level at the critical location of the joint. Indeed, the fatigue strength of riveted lap joints with two or more rivet rows, in which the bending effects are reduced, is significantly better than that with a single row of rivets. The secondary bending phenomenon is inherently different for lap-joints and hard-points attachments. Whereas the larger tensile loads are at the faying surface of a lap-joint connection, these are located at the inner skin surface for typical hard-point attachments, see Figure 2 for more details. From inspection point of view, it is understood that a lap-joint secondary bending scenario is considered as more critical than hard-point, due to the difficulty to inspect cracks at the faying surface.

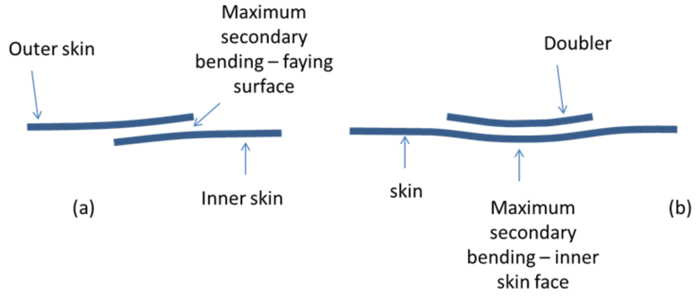

Figure 2. Illustrations of deformed shapes of (a) lap-joint and (b) hard-point attachments.

Although the effect of secondary bending was widely investigated for lap-joints attachment [1-7], both analytically/numerically and experimentally, the effect of this phenomenon on hard-point attachments is still not well established. In this study, the effect of the secondary bending on hard-point attachments is investigated analytically and numerically, and the parameter k is obtained for different geometrical combination and different hard-point scenarios (with and without skin cutout). Good agreement between analytical and numerical results is reported. The maximum ratio obtained numerically for typical fuselage configurations was derived as $\sigma_{bending}/\sigma_{tenslie}$ = 0.20 (see Table 1 for more details), which is significantly lower than that obtained for lap joint attachments (that can reach up to $\sigma_{bending}/\sigma_{tenslie}$ = 3.0). An example of an antenna installation is presented, showing significant decrease in the fatigue and crack growth lives due to the induced secondary bending effect.

Table 1. The ratio of $\sigma_{bending}/\sigma_{axial}$ for different panel and doubler thicknesses (in inches)

Sigma_B/Sigma_T

	Skin\Doubler	0.036	0.040	0.050	0.063	0.071	0.080	0.090	0.100	0.125
No Cutout	0.036	0.188	0.193							
	0.040		0.186	0.200						
	0.050			0.178	0.192					
	0.063				0.173	0.178				
	0.071					0.171	0.175			
	0.080						0.165	0.173		
	0.090							0.163	0.170	
	0.100								0.160	0.171
	0.125									0.156
With Cutout	Skin\Doubler	0.036	0.040	0.050	0.063	0.071	0.080	0.090	0.100	0.125
	0.036	0.142	0.146							
	0.040		0.141	0.145						
	0.050			0.134	0.141					
	0.063				0.131	0.134				
	0.071					0.130	0.132			
	0.080						0.128	0.131		
	0.090							0.126	0.129	
	0.100								0.125	0.130
	0.125									0.122

An example of an antenna installation is presented, showing significant decrease in the fatigue and crack growth lives due to the induced secondary bending effect.

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