Failure of Notched Laminates Under Out-of-plane Bending

Industrial Sponsor: Boeing Commercial Airplane Company

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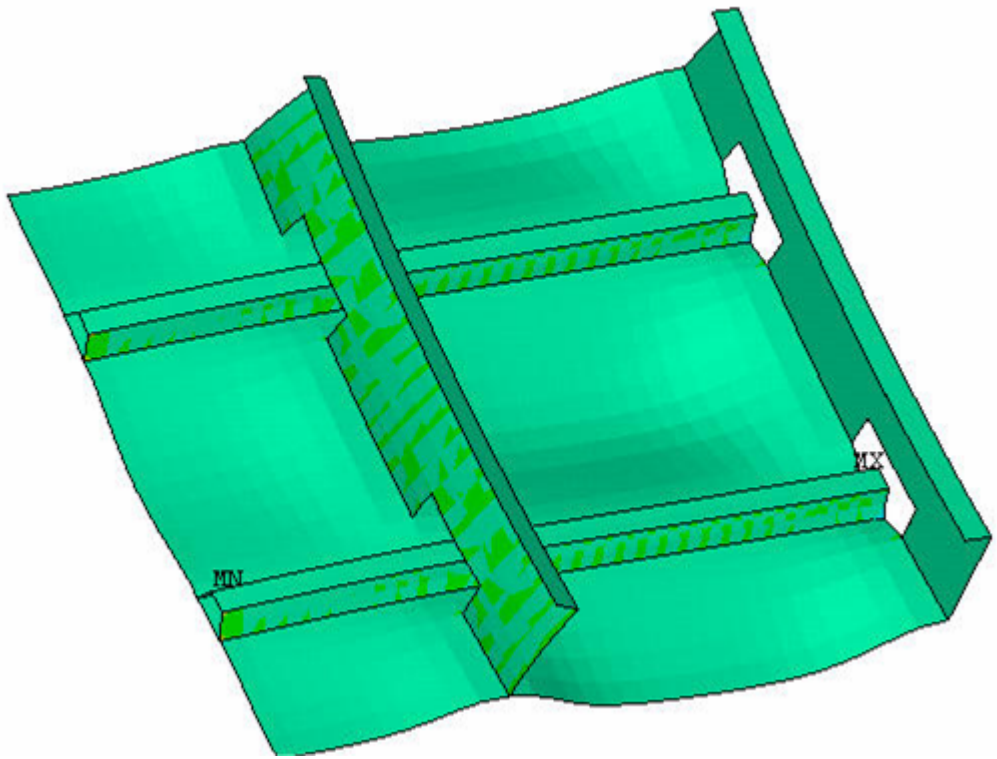
Out-of-plane Loading

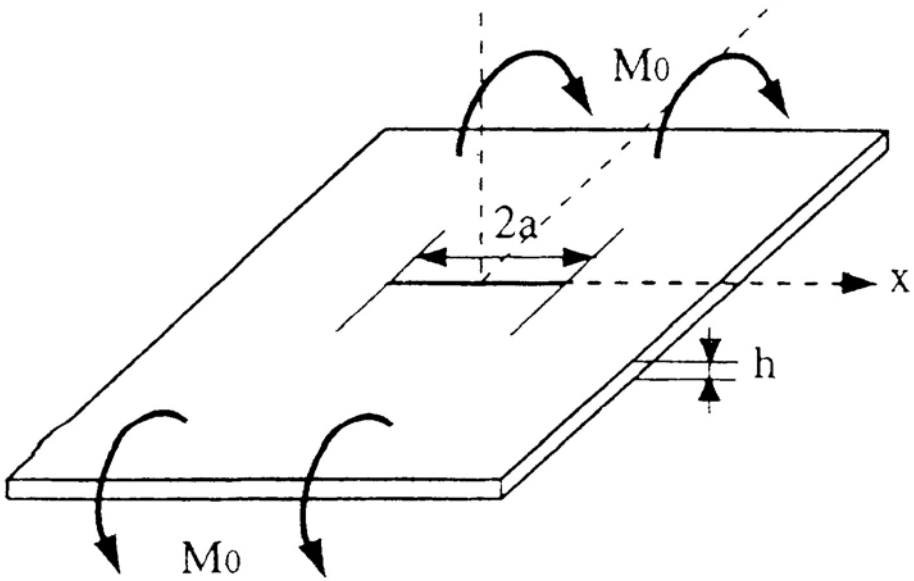


Objective: For out-of-plane bending of notched laminates, determine the modes of failure and evaluate the capability of current models to predict failure

Experiments: Four-point bending

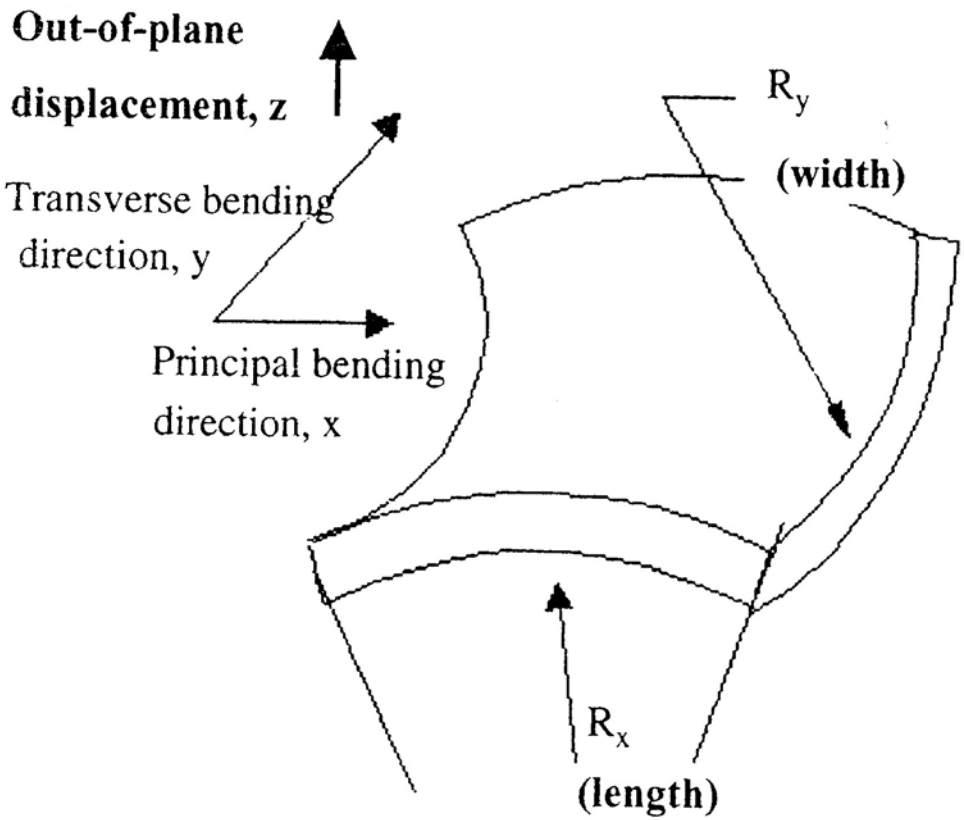
Modeling
- Stress Concentration Factors
- Progressive Damage Development

Experiments: Four-point Bending Tests



Notch Lengths: 2a = 1 inch & 2a = 4 inches

Large Deflection and Anticlastic Curvature Effects



Stress Concentrations in Notched Laminates Under Bending

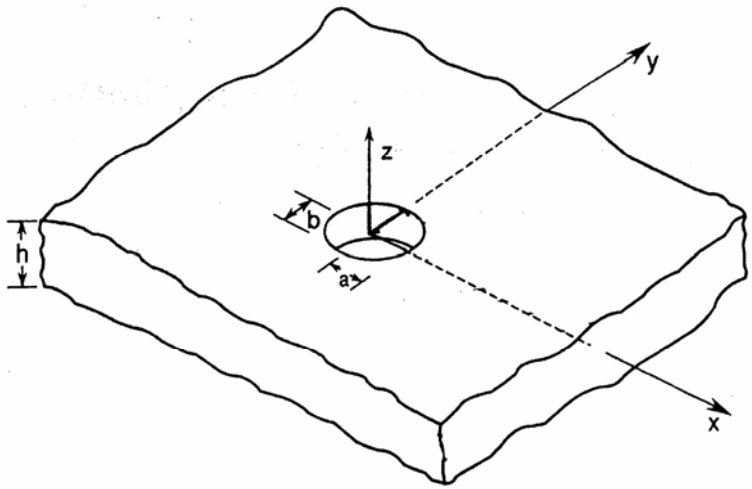
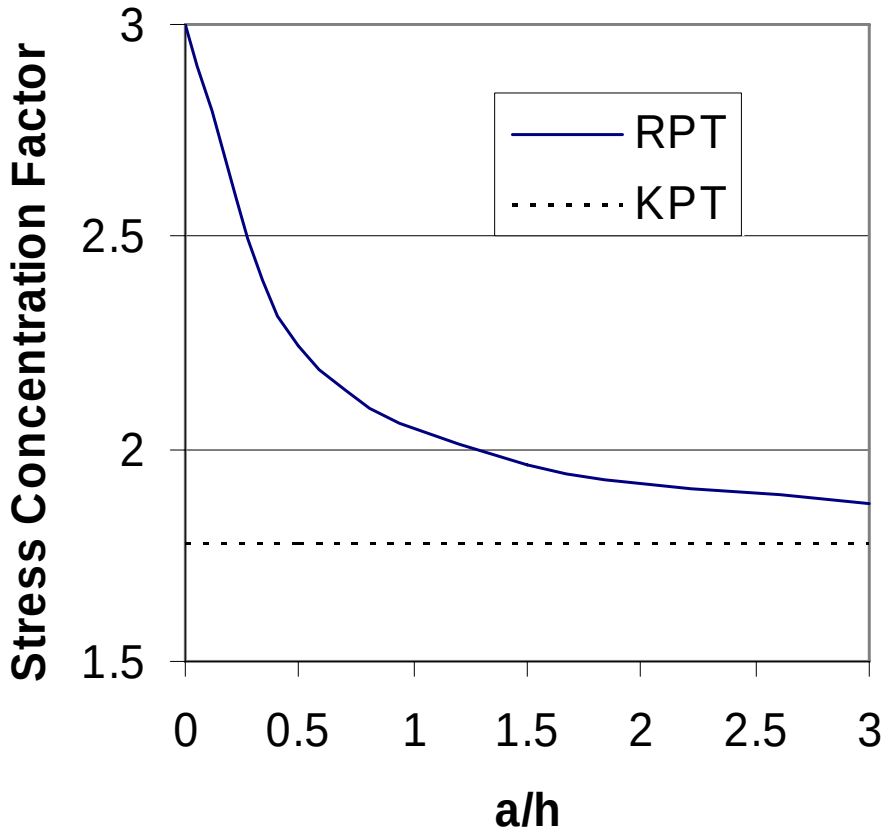
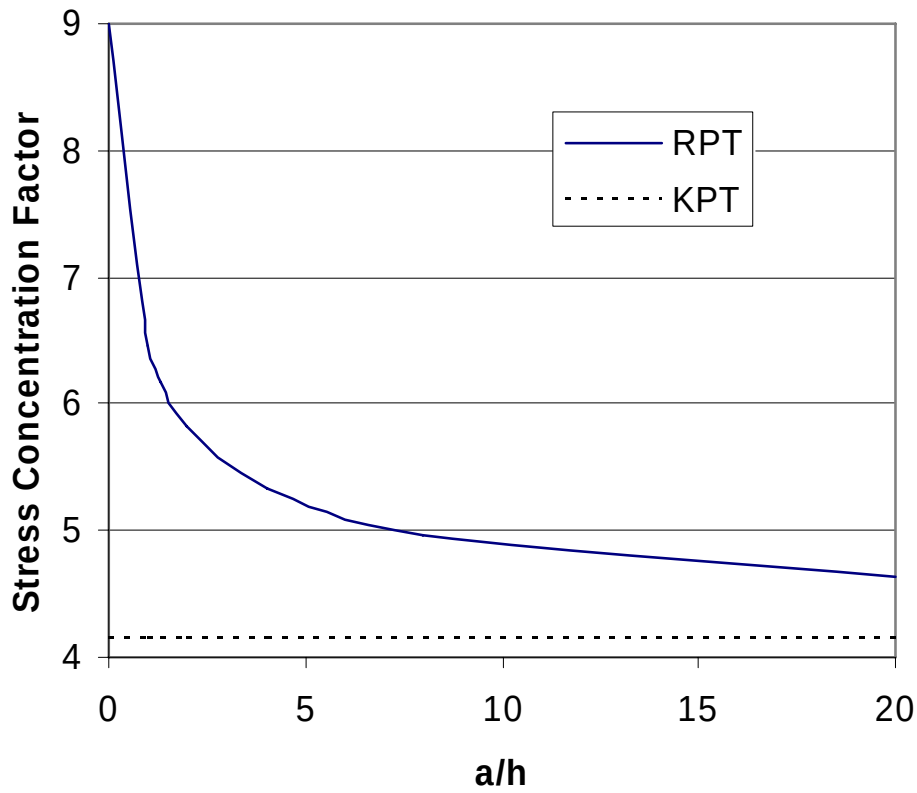


Plate Theory
- Without transverse shear effects (KPT)
- With transverse shear effects (RPT)

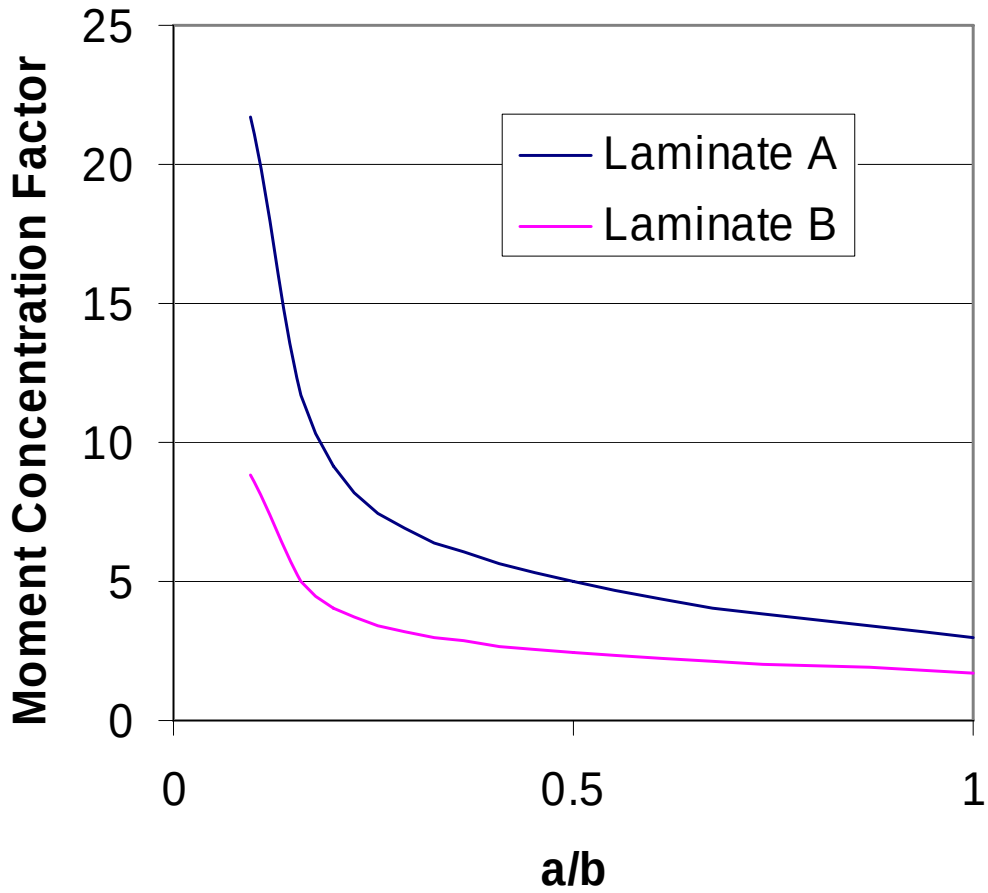
Stress Concentration for a Circular Hole – Isotropic Material



Stress Concentration for an Elliptic Hole – Isotropic Material



Moment Concentration Factor for an Elliptical Hole - Laminate



Progressive Damage Modeling

Damage Mechanics – Strain Softening

Chang Model

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \sigma_4 \\ \sigma_5 \\ \sigma_6 \end{Bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ C_{21} & C_{22} & C_{23} & 0 & 0 & 0 \\ C_{31} & C_{32} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ 2\varepsilon_4 \\ 2\varepsilon_5 \\ 2\varepsilon_6 \end{Bmatrix}$$