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Incorporation of a Progressive Failure Analysis Method in the CSM Testbed Software System

by

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Development of graphite-epoxy composites for aircraft primary structure has been the focus of research for many years. Analysis of the postbuckling behavior of composite shell structures pose many difficult and challenging problems in the field of structural mechanics. Current analysis methods perform well for most cases in predicting the postbuckling response of undamaged components. To predict component behavior accurately at higher load levels, the analysis must include the effects of local material failures. Consider the example in Fig. 1 where the end-shortening results for a blade-stiffened panel with a central cut-out are presented. Good agreement between the test results and the analytical predictions are observed for loads up to the point where local failures were first observed, however, beyond this point the analysis begins to deviate significantly from the experimental data. In order to predict the structural response beyond the point of local material failures, the analysis must reflect the change in stiffness due to local material failures. In response to this need, current research efforts are in progress to incorporate a progressive failure model into the geometrically nonlinear solution procedure in the CSM Testbed software system.

The CSM Testbed software system is a highly modular structural analysis system currently under development at the NASA Langley Research Center[1]. One of the primary goals of the CSM Testbed is to provide a software environment for the development of advanced structural analysis methods and modern numerical methods which will exploit advanced computer architecture such as parallel-vector processors. The CSM Testbed is composed of three major components: functional processors, a command language and a data manager. The fundamental program tasks or functions are organized into independent Fortran programs called processors. Examples of tasks commonly performed by processors include computing stiffness matrices, equation solving and eigenvalue extraction. The command language provides the mechanism for invoking the various processors in order to perform specific analysis tasks. The command language features a high-level, structured programming capability including DO, IF, WHILE and PROCEDURE constructs. Data exchange between functional processors is not performed directly with each other, instead the processors share data stored in a common database under the control of the data manager.

Development of a progressive failure analysis method consists of the design and implementation of a processor which will perform the ply-level progressive failure analysis and the development of a geometrically nonlinear analysis procedure which incorporates the progressive failure processor. An overview of the nonlinear analysis procedure showing a typical load step is presented in Fig. 2. At each load step, after a converged solution is obtained, the progressive failure analysis processor is executed. In the progressive failure analysis processor, all plies within the elements are analyzed for possible failures, see Fig. 3. If a ply failure is detected, as indicated by the failure criteria, the ply properties are then modified according to a particular degradation model. In the event ply failures are detected, the structure is reanalyzed utilizing the modified ply properties at the current load level. This process is continued until either no additional ply failures are detected or additional ply failures continue to progress resulting in total collapse of the structure.

Regarding the development of the progressive failure processor, two components are required: failure criteria and a degradation model. For the initial implementation, the failure criteria of Hashin [2] will be used, see Fig. 4. A major advantage of these criteria is identification of the failure mode which is essential information for the material degradation model. The function of the degradation model is to provide the progressive failure processor with the reduced ply properties in response to the various detected failure modes. For a matrix failure which typically indicates the development of transverse matrix cracks, the ply properties will be degraded following the suggestion of Tsai [3]. Tsai proposed that the properties of the cracked ply should be replaced by material properties of an uncracked material with a reduced matrix modulus. The new ply properties are then easily obtained using micromechanics relations. For a fiber failure, the ply is unable to carry any load, as a result the ply properties are effectively reduced to zero. In the future, it is anticipated that a variety of failure theories and degradation models will be examined. In response to this need provisions have been made in the software design which will allow the incorporation of other models into the progressive failure analysis processor with minimal effort.

Work to date includes the design of the progressive failure analysis processor and initial plans for the controlling geometrically nonlinear analysis procedure. The implementation of the progressive failure analysis has begun. Access to the model database and the Hashin failure criteria have been completed. Work is in progress on the input/output operations for the processor related data and the finite element model updating procedures. In total the progressive failure processor is approximately one-third complete.

References

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2. Hashin, Z., "Failure Criteria for Unidirectional Fiber Composites", J. Appl. Mech., Vol. 47, 1980, pp. 329-334.
3. Tsai, S. W., Composites Design, 3rd edition, Think Composites, Dayton, Ohio, 1987.

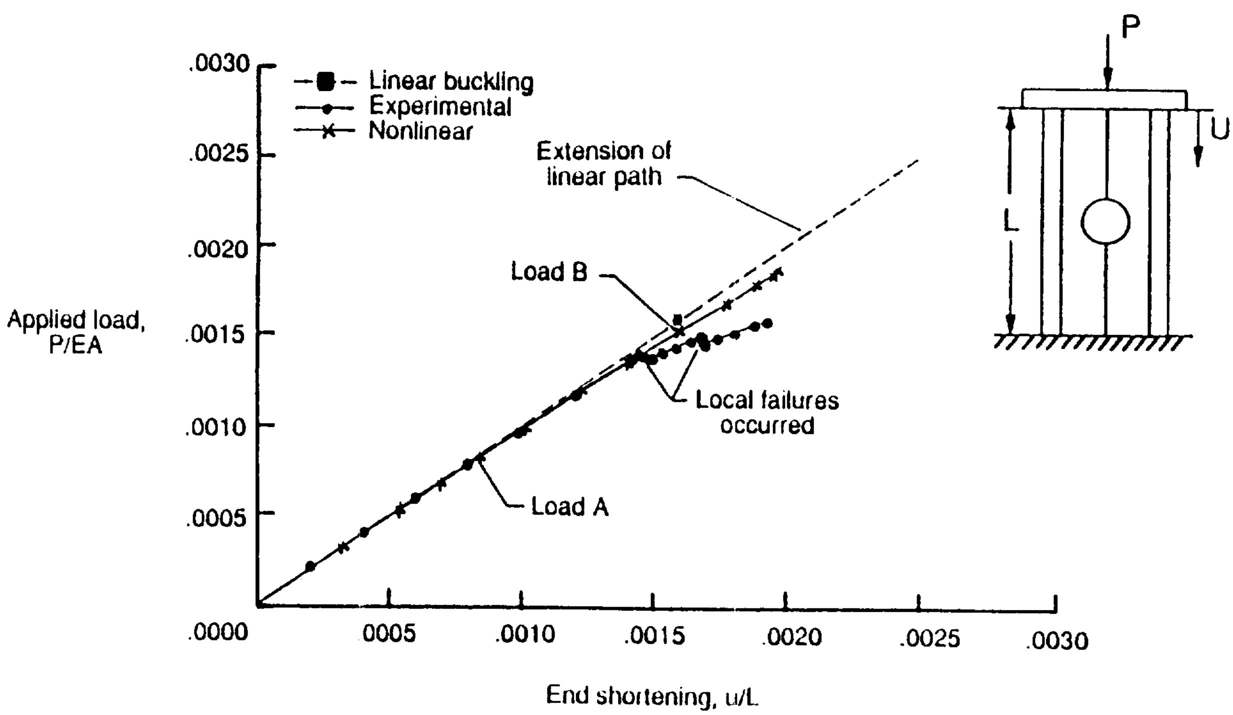

Figure 1. Blade-Stiffened Panel with Discontinuous Stiffener

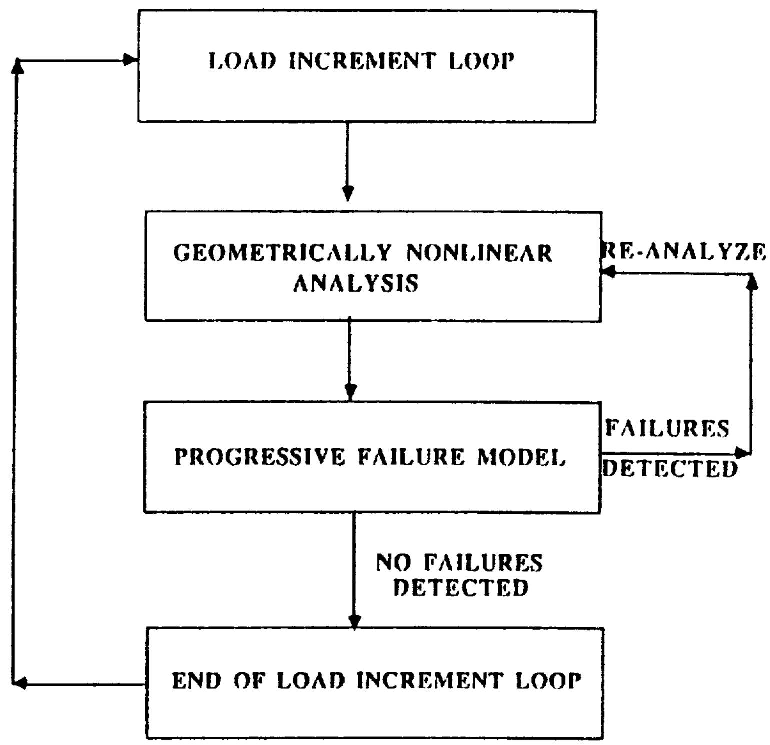

Figure 2. Progressive Failure Analysis Solution Procedure

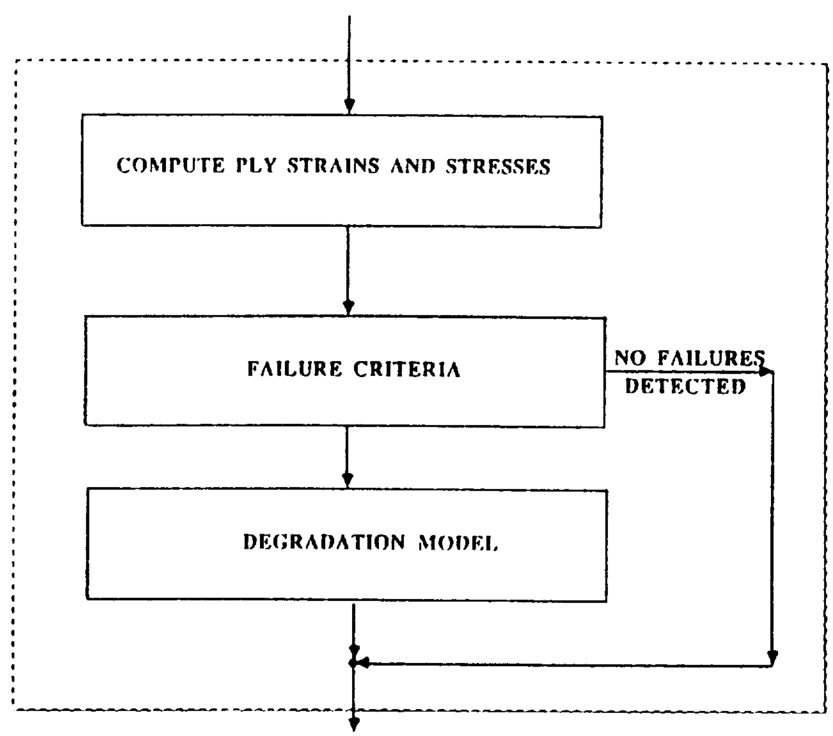

Figure 3. Progressive Failure Analysis Processor

- Tensile Matrix Failure, $\sigma_{22} + \sigma_{33} > 0$

$$\left(\frac{\sigma_{22} + \sigma_{33}}{Y_T}\right)^2 + \frac{1}{S_{23}^2}\left(\sigma_{23}^2 - \sigma_{22}\sigma_{33}\right) + \frac{1}{S_{12}^2}\left(\sigma_{12}^2 + \sigma_{13}^2\right) = 1$$

- Compressive Matrix Failure, $\sigma_{22} + \sigma_{33} < 0$

$$\frac{1}{Y_c}\left[\left(\frac{Y_c}{2S_{23}}\right)^2 - 1\right](\sigma_{22} + \sigma_{33}) + \frac{1}{4S_{23}^2}(\sigma_{22} + \sigma_{33})^2 + \frac{1}{S_{23}^2}(\sigma_{23}^2 - \sigma_{22}\sigma_{33}) + \frac{1}{S_{12}^2}(\sigma_{12}^2 + \sigma_{13}^2) = 1$$

- Tensile Fiber Failure, $\sigma_{11} > 0$

$$\left(\frac{\sigma_{11}}{X_T}\right)^2 + \frac{1}{S_{12}^2}\left(\sigma_{12}^2 + \sigma_{13}^2\right) = 1$$

- Compressive Fiber Failure, $\sigma_{11} < 0$

$$\frac{\sigma_{11}}{X_c} = 1$$

Figure 4. Hashin Failure Criteria