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IMPACT DAMAGE IN COMPOSITE LAMINATES

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ABSTRACT

Damage tolerance requirements have become an important consideration in the design and fabrication of composite structural components for modern aircraft. The ability of a component to contain a flaw of a given size without serious loss of its structural integrity is of prime concern. Composite laminates are particularly susceptible to damage caused by transverse impact loading.

The ongoing research program described herein is aimed, therefore, at developing experimental and analytical methods that can be used to assess damage tolerance capabilities in composite structures subjected to impulsive loading. The objective of this presentation is to outline some significant results of this work and the methodology used to obtain them, including

(1) Identification of the mechanisms that cause delamination damage initiation and growth under impact loading (Grady and Sun, 1986)

(2) Calculation of the dynamic delamination "fracture toughness" in composite laminates (Sun and Grady, 1987)

(3) Computational simulation of dynamic response and damage initiation in composite laminates (Grady, Chamis, and Aiello, 1987)

(4) Measurement of the effect that impact damage has on the structural integrity of a laminate (Grady and Chamis, 1988)

LEWIS BALLISTIC IMPACT RESEARCH

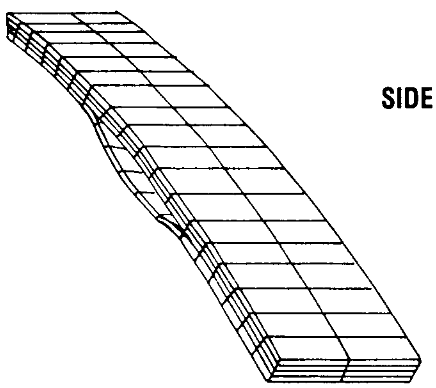
The unique ballistic impact test facility at the Lewis Research Center is used for performing a variety of instrumented impact tests. In addition to multiple channel high-speed digital data acquisition capabilities, a series of high-speed cameras can be used to record the impact event photographically. The impact cannon itself is able to accommodate impactors ranging in size from 1/2 to 6 inches in diameter. It has been used to simulate the impact of birds on engine components and is currently being used to investigate dynamic crack propagation in composite materials.

Post-impact inspections of damaged specimens can be conducted with any of the available supporting experimental facilities, which include:

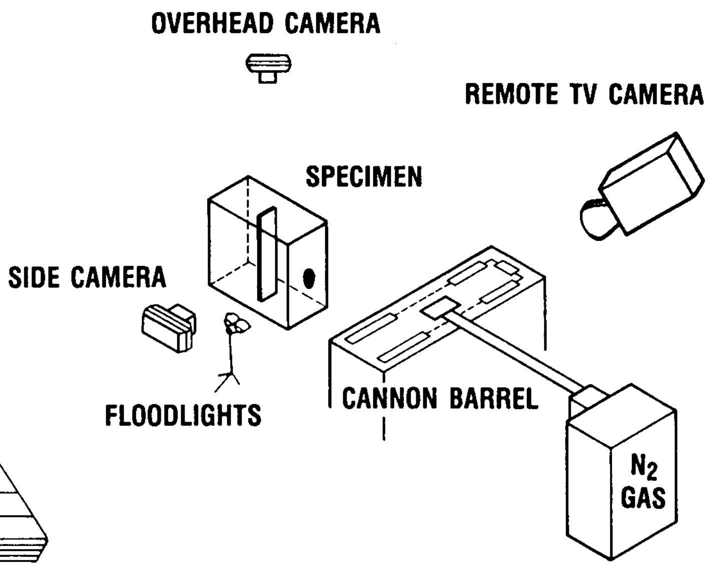
- Ultrasonic C-scan and x-ray inspection facilities, which are used to detect the type and location of impact damage

- A vibration testing facility used to measure natural frequencies and mode shapes of damaged specimens

- Static and fatigue load frames to measure the reduction in strength, stiffness, and durability of test specimens caused by impact



IMPACT SPECIMEN



BALLISTIC IMPACT FACILITY

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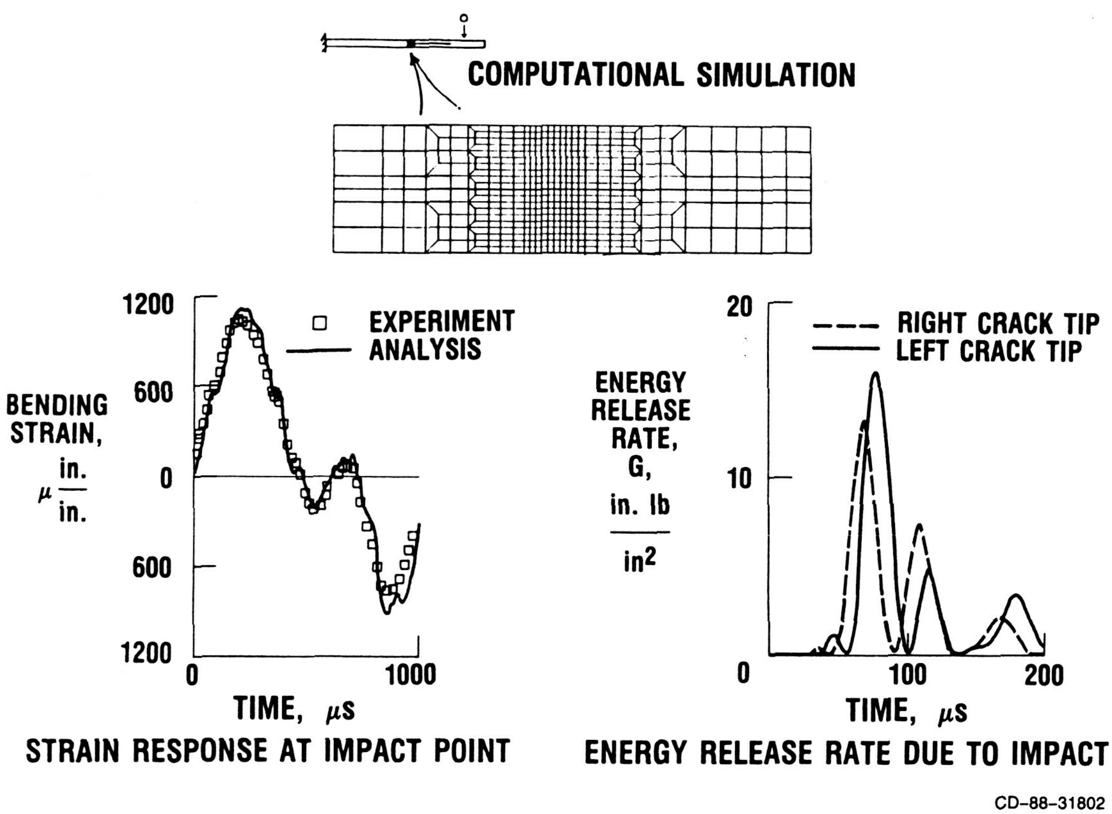
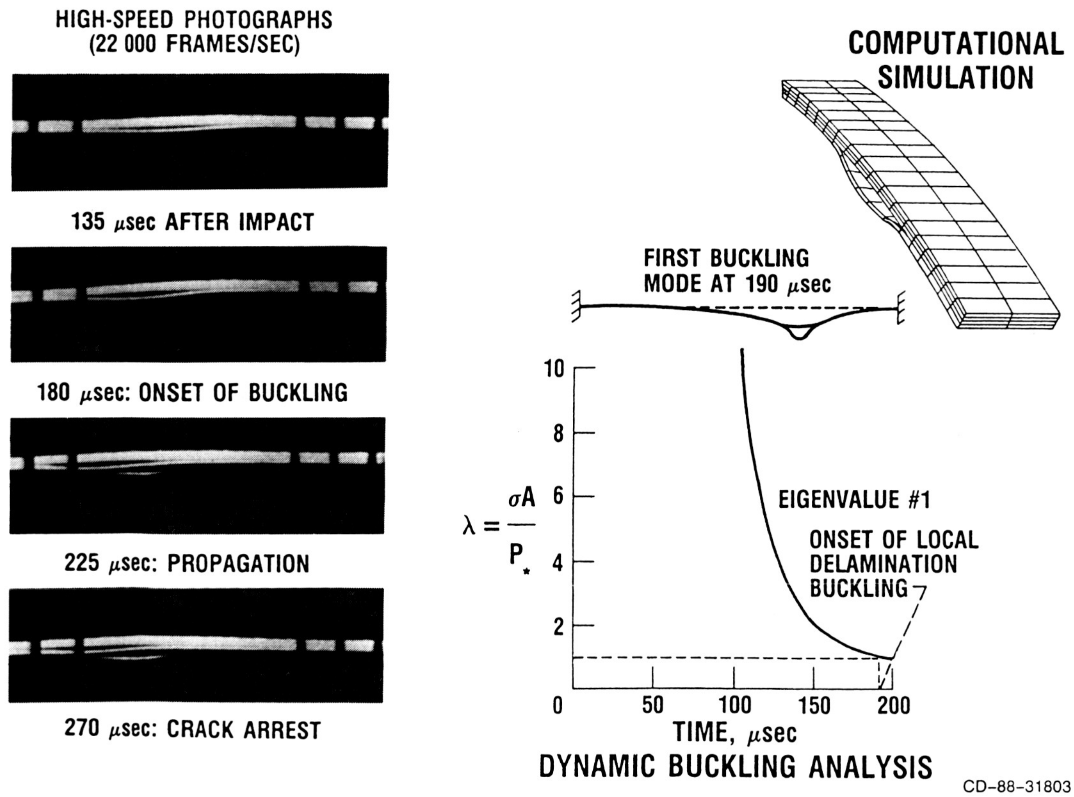
DYNAMIC FRACTURE TOUGHNESS IN COMPOSITES

A combined experimental and analytical approach was used (Grady and Sun, 1986, 1988) to predict both the dynamic response measured in a simulated engine blade and the dynamic delamination fracture toughness of the composite material. Impact tests were conducted on cantilevered graphite/epoxy laminates, and a two-dimensional finite element model was developed to computationally simulate the post-impact dynamic response. Correlations between calculated crack-tip strain energy release rates and high-speed photographs of crack initiation and propagation were used to estimate the dynamic fracture toughness of the composite material.



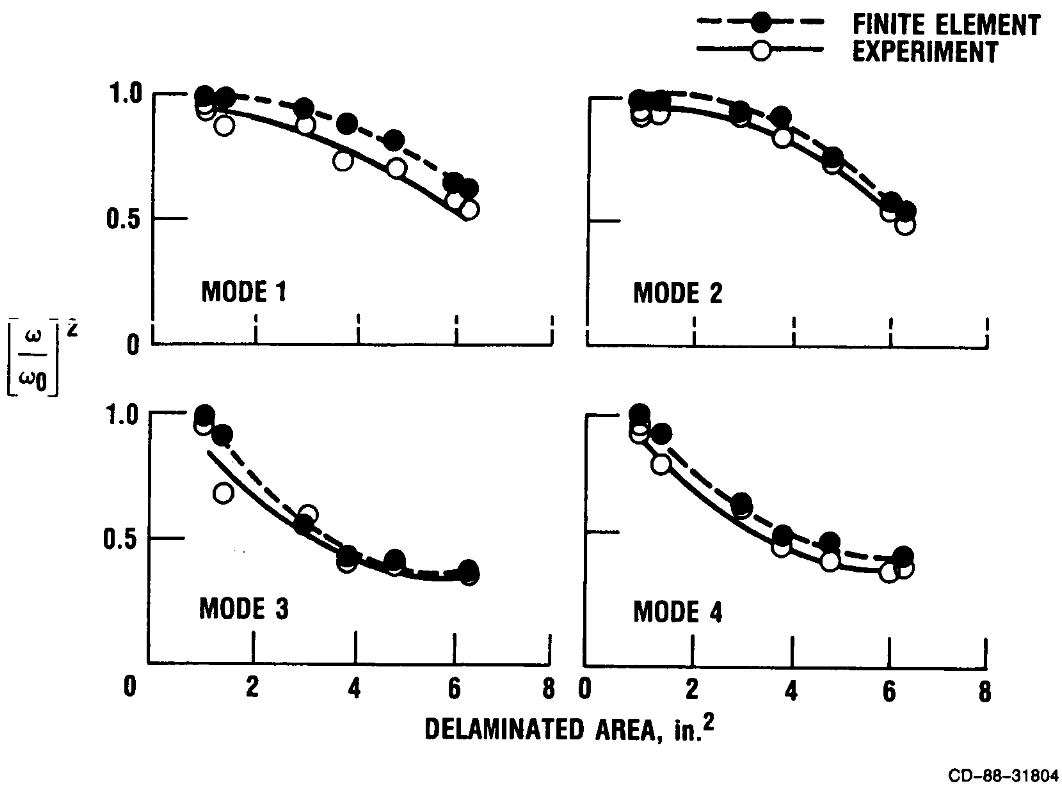
DYNAMIC DELAMINATION BUCKLING: COMPUTATIONAL SIMULATION

A unique dynamic delamination buckling and delamination propagation analysis capability has been developed and incorporated into the MSC/NASTRAN finite element analysis computer program. This capability consists of (1) a modification of the direct time integration solution sequence which provides a new analysis algorithm that can be used to predict delamination buckling in a laminate subjected to dynamic loading, and (2) a new method of modeling the composite laminate using plate-bending elements and multipoint constraints. With these modifications, NASTRAN is used to predict both impact-induced buckling in composite laminates with initial delaminations and the strain energy release rate due to extension of the delamination (Grady et al., 1987). It is shown that delaminations near the outer surface of a laminate are susceptible to local buckling and buckling-induced delamination propagation when the laminate is subjected to transverse impact loading. The capability now exists to predict the time at which the onset of dynamic delamination buckling occurs, the dynamic buckling mode shape, and the dynamic delamination strain energy release rate.



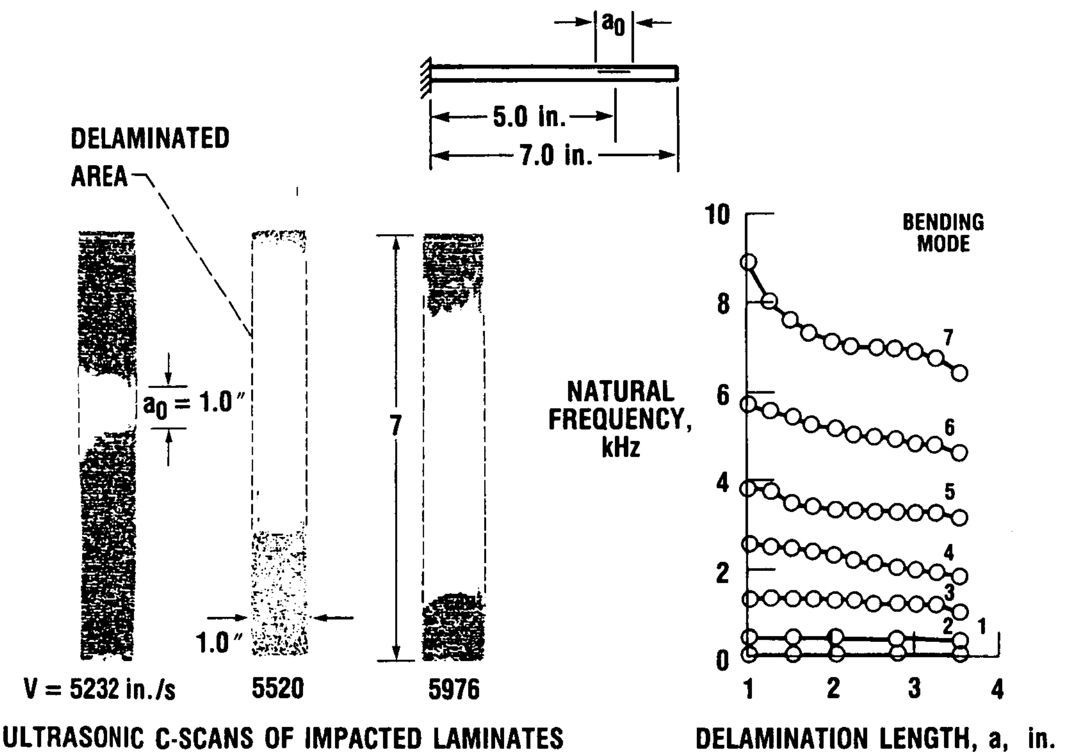
STIFFNESS LOSS DUE TO IMPACT DAMAGE

A series of additional post-impact tests were conducted on the composite impact specimens to measure the effect of impact damage on the structural integrity of the laminates. A decrease in stiffness, such as that caused by impact damage, results in a corresponding decrease in the natural frequencies of a damaged composite structure. To quantify this effect for the case of impact-induced delamination, the first four natural frequencies of a series of cantilevered composite specimens with initial embedded delaminations were measured before and after impact. The measured reduction in the natural frequencies of the first four bending modes for varying amounts of impact damage are compared with the results of a two-dimensional plane strain finite element simulation of the damaged specimens in the figures below. The difference between the two curves represents the extent to which damage other than delamination has occurred in the laminates.



DETECTING IMPACT DAMAGE

Composite laminates are particularly susceptible to damage caused by transverse impact. Ply debonding, or delamination, is the most serious type of impact damage. One method of detecting delamination in composites is by nondestructive ultrasonic C-Scan. Shown below are C-Scans of composite laminates that have been impacted at various energy levels, causing different amounts and distributions of damage. The corresponding effects of this damage on the natural frequencies of vibration are shown below. The loss of stiffness caused by delamination is most apparent in the reduction of natural frequencies for the higher modes of vibration. Since impact damage such as delamination is often undetectable visually, either of these methods can serve as a practical means of field-testing a composite structure to determine if significant amounts of internal damage exist.



ULTRASONIC C-SCANS OF IMPACTED LAMINATES

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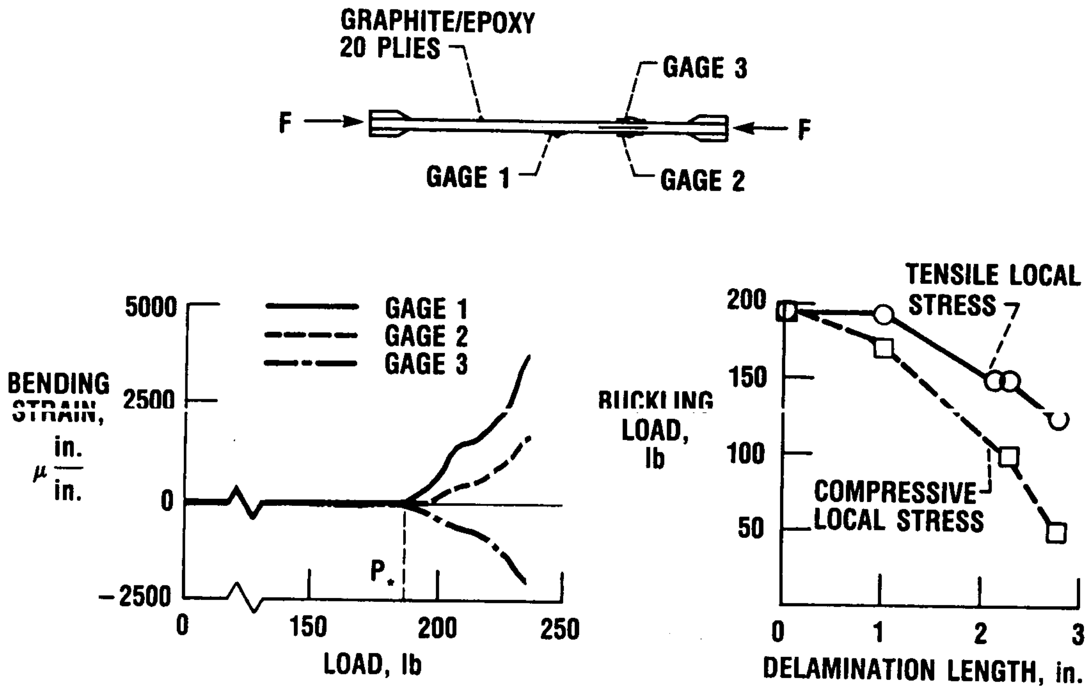
EFFECT OF DELAMINATION ON BUCKLING LOADS

Instrumented composite impact specimens were tested in compression after being impacted at velocities up to 1000 ft/s with a soft rubber projectile. Longitudinal strain measurements at three gage locations were used to identify the buckling loads. Small amounts of impact-induced delamination damage were found to cause a significant drop in the critical buckling loads, as shown in the last figure. Compressive longitudinal stress near the delaminated area can cause a secondary "local" buckling of the delamination and an increased drop in the effective load-carrying capability of the laminate.



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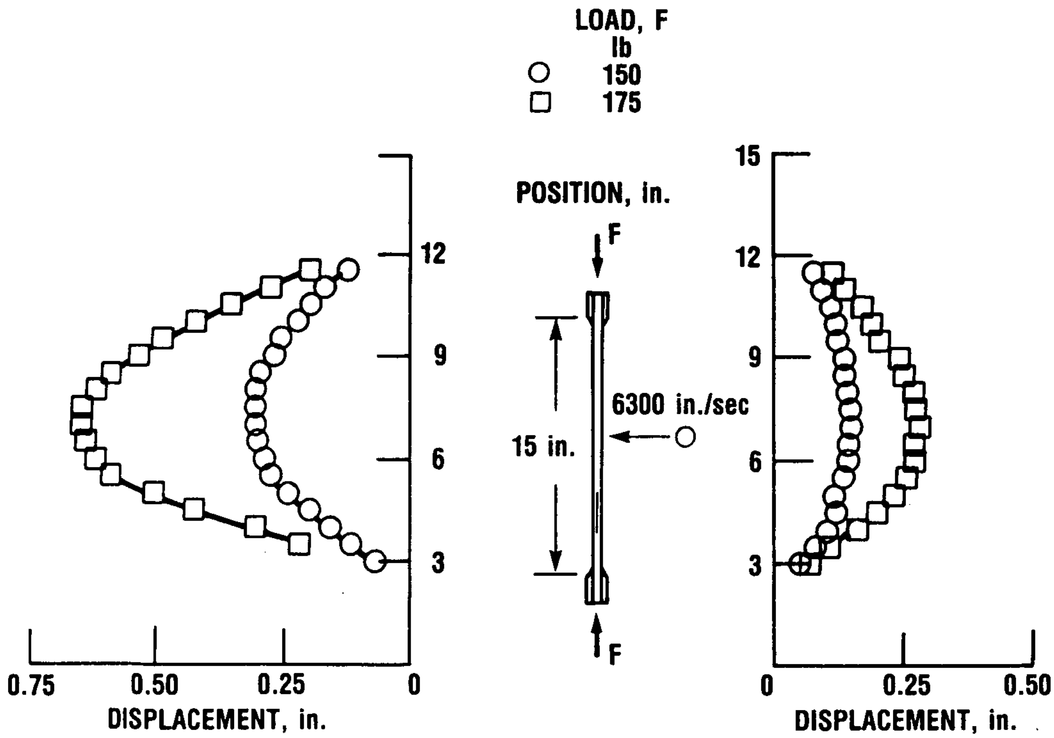
EFFECT OF IMPACT DAMAGE ON POST-BUCKLING DISPLACEMENTS

Impact damage which is not detectable by visual inspection may cause a significant loss in the structural integrity of a composite laminate. This is illustrated below, using post-impact compression tests of damaged graphite/epoxy laminates. Experimentally measured post-buckling configurations at several load levels show that internal damage caused by transverse impact can cause a large "direction-dependent" stiffness loss in composite laminates.

Under uniform compression loading, the laminate buckles in the direction of the prior impact load, as shown on the left. The measured displacement shape shows that the effective bending stiffness is significantly reduced from that of the original undamaged laminate. If lateral restraints are used to support the laminate in this direction, buckling occurs in the opposite direction, and the laminate shows a much higher post-buckling stiffness at all load levels.



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