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HLH ROTOR BOX BEAM FATIGUE TEST

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M. Hanson

September 1979

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21. ABSTRACT (Continue on reverse side if necessary and identify by block number) The purpose of this program was to evaluate the fatigue properties of a fiberglass/epoxy box beam specimen which was similar in design to the (HLH) rotor blade spar. The fiberglass/epoxy box beam was designed and fabricated by Boeing Vertol using a ply layup scheme similar to the rotor HLH blade spar but with a different preimpregnated fiberglass tape. The box beam was tested at a fatigue load level sufficient to cause failure within a reasonable number of fatigue cycles (5×10^6) to determine fatigue strength and observe failure modes and rates. Premature fatigue failure occurred in the box beam as the result of chordwise wrinkles occurring during fabrication. The Integral Spar Inspection System (ISIS), which depends on a		

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pressure differential between the sealed spar and outside ambient pressure to detect leaks resulting from cracks or flaws, indicated that a leakage had occurred at approximately the same time the failure was observed. It was concluded that the ISIS appeared to be a viable technique for signaling a structural failure of fiberglass spars. The presence of the wrinkles in the spar which resulted in premature failure, however, precluded any conclusions with regard to the fatigue strength of the preimpregnated fiberglass tape used.

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INTRODUCTION

In support of the Heavy Lift Helicopter/Advanced Technology Component (HLH/ATC) Program, a fiberglass box beam was fatigue tested on the rotor blade fatigue test machine in the Structures laboratory at the Applied Technology Laboratory of the US Army Research and Technology Laboratories. The beam was designed and fabricated to simulate the spar of the HLH rotor blade; a similar layup scheme but a different manufacturer's preimpregnated fiberglass tape were used. The box beam was tested at a fatigue load level sufficient to cause failure within a reasonable number of fatigue cycles (5×10^6) to determine beam fatigue strength and observe failure modes and rates. The beam was tested to failure on 29 April 1975.

PREPARATION OF SPECIMEN FOR TEST

The Boeing Company, Vertol Division furnished a 180-inch-long fiberglass box beam to the Structures laboratory of the Applied Technology Laboratory. The beam was uniform in cross section over its entire length with the exception of 17 inches on each end where the cross section was gradually built up with unidirectional material to provide additional end grip support (see Figure 1). The layup on the flanges of the beam was $\pm 45^\circ_3/0^\circ_{12}/90^\circ_5/\pm 45^\circ_1$ and on the vertical web was $\pm 45^\circ_3/0^\circ_1/90^\circ_5/\pm 45^\circ_1$, with 0° parallel to the longitudinal axis of the beam. This layup was similar to that used in the HLH/ATC blade spar design. Manufacturing flaws consisted primarily of dimples and wrinkles (Figures 2 and 3) and were in evidence the entire length of the beam.

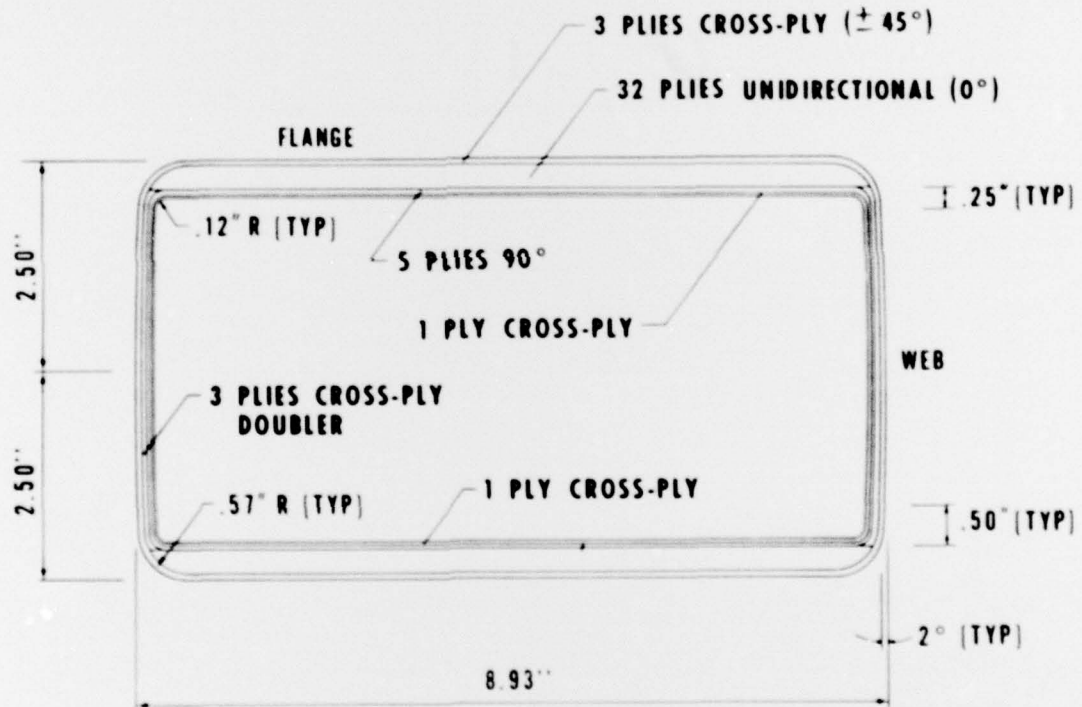


Figure 1. Cross section of box beam.



Figure 2. Manufacturing flaws (dimples) in beam.

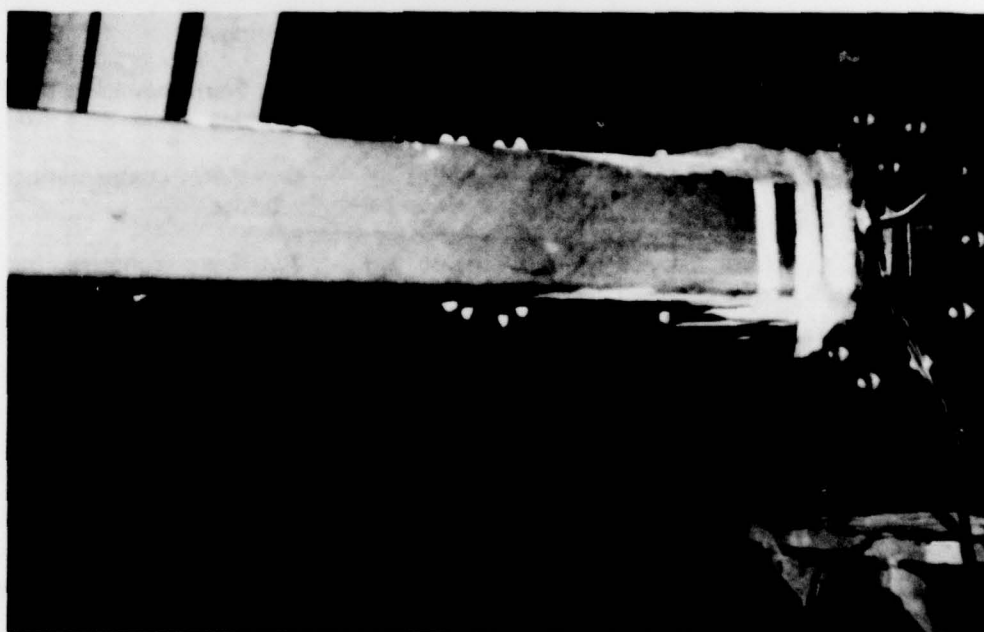


Figure 3. Manufacturing flaws (wrinkles) in beam.

Upon receipt of the beam, an aluminum bulkhead was installed 12 inches from each end to allow a failure detection system to be installed. This device, called the Integral Spar Inspection System (ISIS), monitors the differential pressure in a sealed spar whose interior has been partially evacuated. Cracks that have propagated through the wall thickness are detected by a loss of vacuum in the spar. Aluminum shims bonded with tooling epoxy were used to build up the inner surface on each end of the beam (Figure 4). This was necessary to insure that the surfaces were flat and parallel for the end grip adapter on the test machine. Aluminum doublers and a steel grip pad were then bonded on the outer surfaces of the beam. Holes were drilled through the grip pad, doublers, and box beam for a steel bushing. The bushings were installed in the holes, the grip adapter was inserted in the end of the beam, and the adapter pin was installed through the beam and adapter. The beam was pinned in this manner to allow self-aligning in the machine and to eliminate extraneous chordwise loading conditions.

Strain gages were installed at seven stations along the beam as listed in the table below and shown in Figure 5.

STRAIN GAGE LOCATIONS

Strain Gage Location	Station (Distance from Actuator End) (in.)	Type Gages	Remarks
1	12-3/4	Bending (flapwise)	Gages on doublers Two 2-arm noncompensating bridges
2	21-3/4	Bending (flapwise)	One 2-arm compensating bridge
3	55-3/4	Bending (flapwise)	One 2-arm compensating bridge
4	90	Bending (flapwise and chordwise), torsional	Two 2-arm compensating bending bridges One 4-arm torsion bridge
5	124 1/8	Bending (flapwise)	One 2-arm compensating bridge
6	158-5/16	Bending (flapwise)	One 2-arm compensating bridge
7	167-1/8	Bending (flapwise)	Gages on doublers Two 2-arm noncompensating bridges

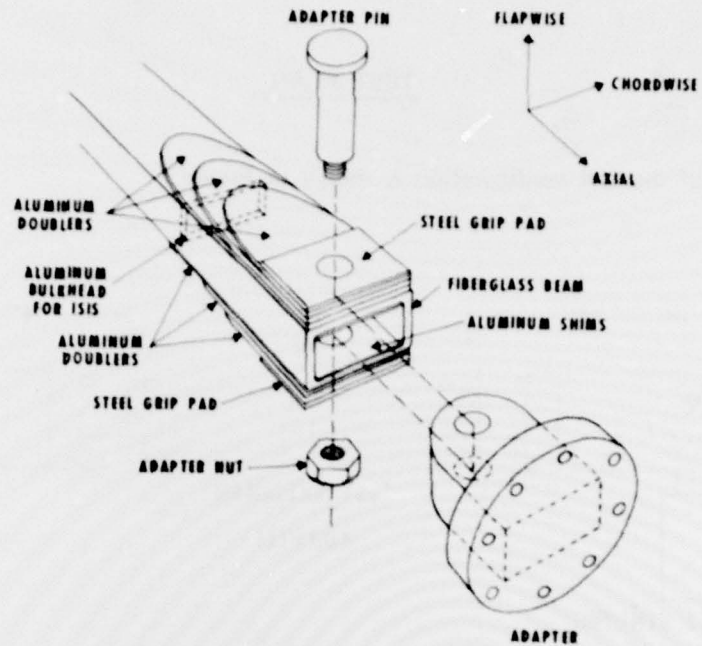


Figure 4. Beam end attachment grip buildup.

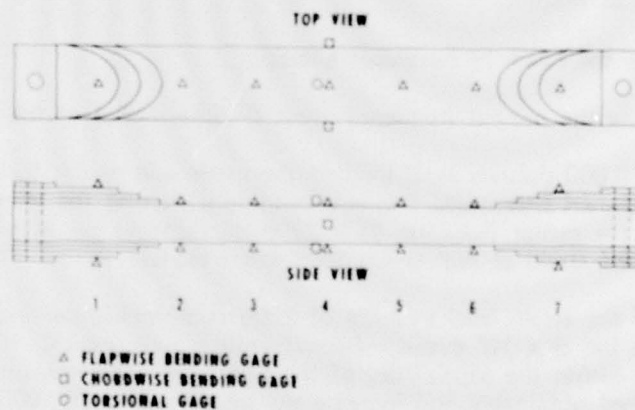


Figure 5. Strain gage locations.

TEST PLAN

A schematic of the test configuration is shown in Figure 6.

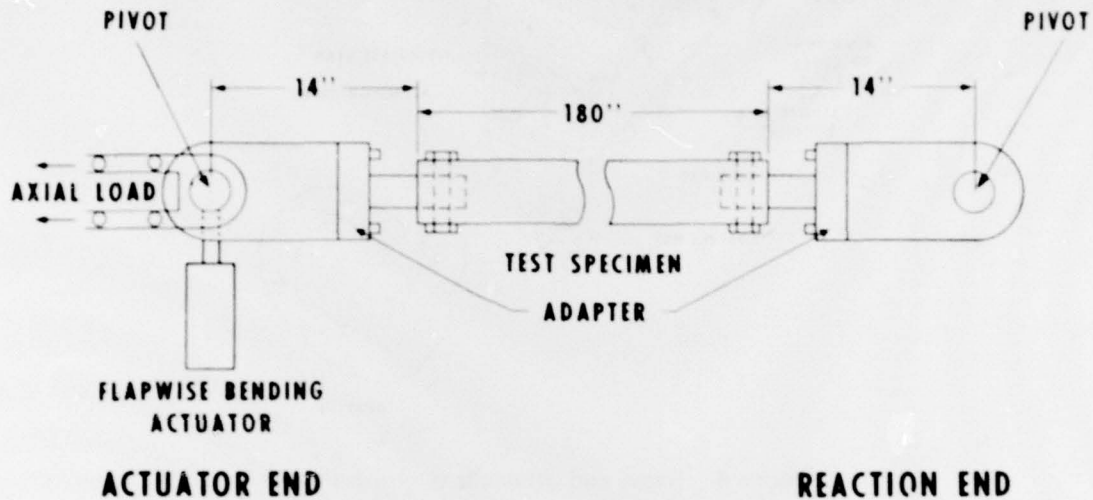


Figure 6. Test configuration.

The test plan was as follows:

1. Calibrate the beam in cantilever bending.
2. Determine the natural frequency (first flexible mode) of the beam.
3. Apply 60,000 pounds axial load to the blade and test it for 10^6 cycles in pinned-pinned first mode flapwise bending such that the alternating strain level at the center (location 4) is 2200 microinches per inch peak to peak (equivalent strain at high-speed level flight loads).
4. Increase the strain level in steps of 2200 microinches per inch peak to peak and run for $.5 \times 10^6$ cycles. Repeat until failure occurs. If failure is not reached within the capabilities of the hydraulic system, maintain the highest strain level obtainable and increase the axial load to 100,000 pounds and continue testing.

Strain readings, visual inspection, and a tactile check for localized heat buildup were made 5 minutes after each increase in strain level and every hour thereafter. Strain measurements were recorded on an oscillograph.

TESTING

The beam was cantilevered at the reaction end by installing a vertical support just in-board of the pivot location and was calibrated by applying an actuator load in the downward direction. Strain gage readings were recorded at several different load levels. The results of the calibration are shown in Figure 7.

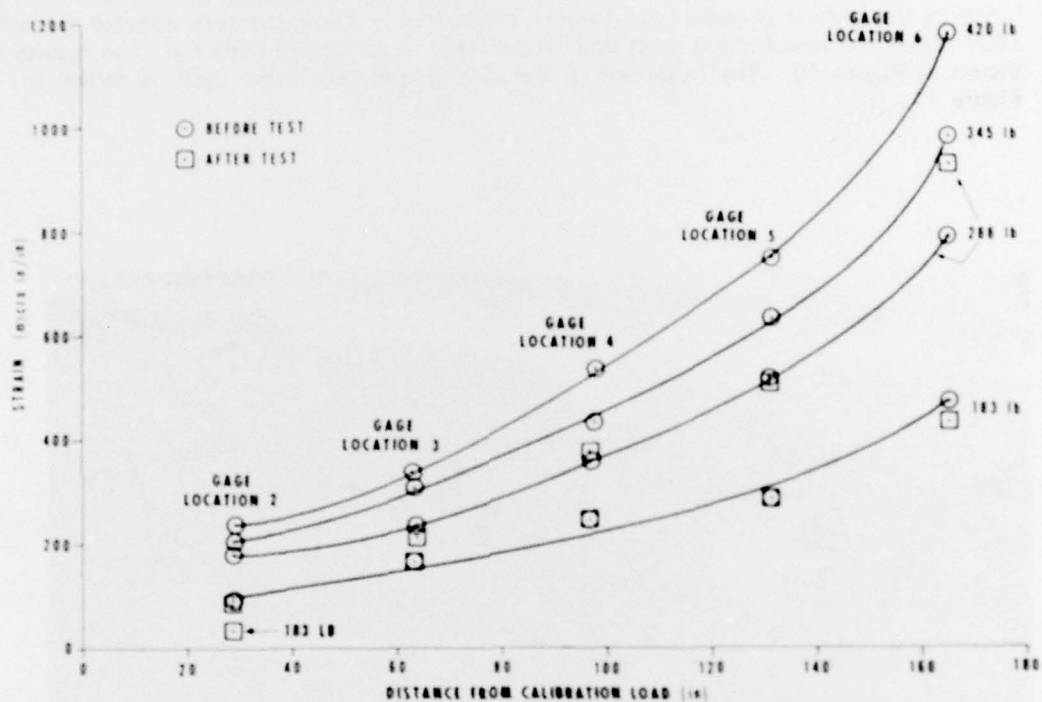


Figure 7. Calibration data for box beam.

The fatigue test was conducted at a frequency of 18.6 Hertz after the resonance point had been determined. After a total of 3600 cycles, of which approximately 600 were at the strain equivalent of high-speed flight loads (2200 microinches per inch at midspan), one set of the grip doublers at the actuator end of the test machine debonded from approximately 40 percent of its beam contact area.

The doublers were rebonded to the beam, and an aluminum bearing plate was bonded inside the beam. Bolt holes were drilled through the doublers, beam, and bearing plate, and bolts were installed. The ISIS bulkhead had to be removed for this repair, and the ISIS was inoperative after the bulkhead was replaced due to its inability to effectively seal the bolt holes or due to early blade damage caused by the fatigue failure described below.

The test resumed at the strain equivalent of high-speed flight loads, and after 6000 cycles the machine was shut down by an axial deflection limit detector. Inspection revealed a transverse fatigue crack 26 inches from the reaction end of the beam on the bottom flange in the chordwise direction. The crack area was too hot to touch. The crack originated at a manufacturing flaw (wrinkle) and extended approximately 3 inches past the end of the surface wrinkle (see Figure 8). The bending strain distributions after 3100 cycles at a low loading condition and after 6000 cycles at an equivalent flight loading condition are shown in Figure 9.

At this point it was decided to abandon the original test procedure and subject the beam to the highest possible peak-to-peak strain level. The beam was inverted (rotated 180° about the longitudinal axis) and recalibrated in cantilever bending. The results are shown in Figure 10. The hysteresis in the load-unload calibration cycle is shown in Figure 11.

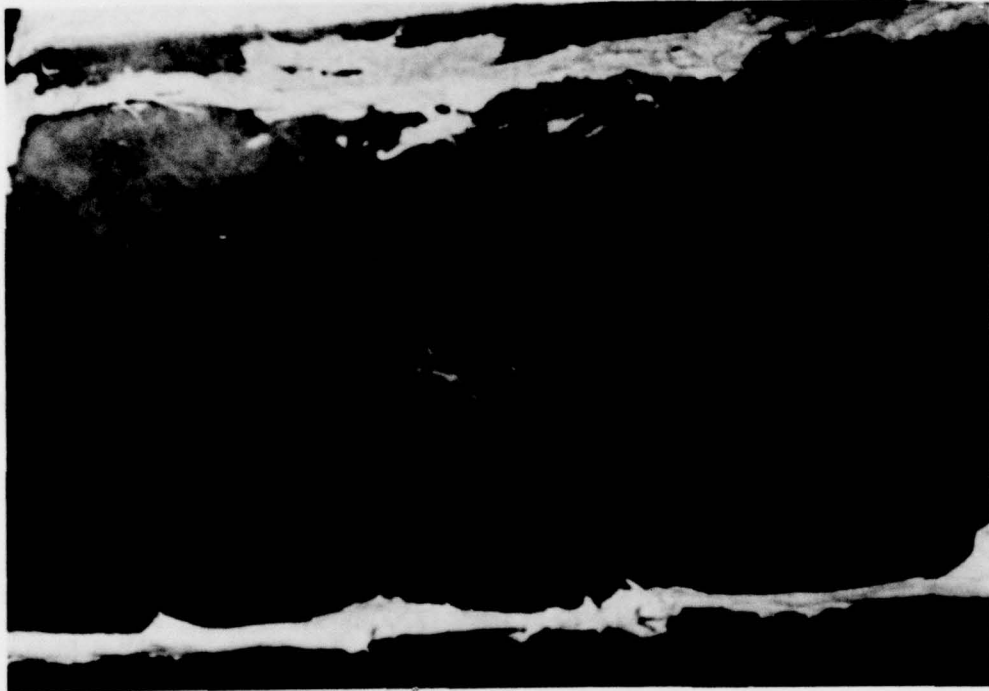


Figure 8. First failure location.

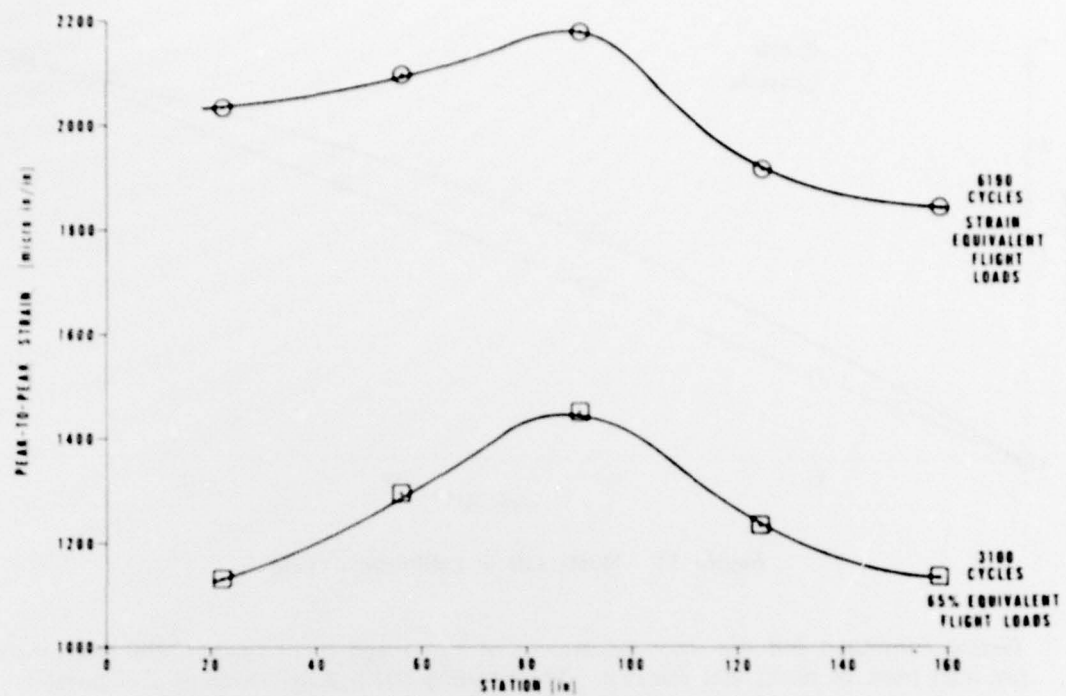


Figure 9. Bending strain distribution.

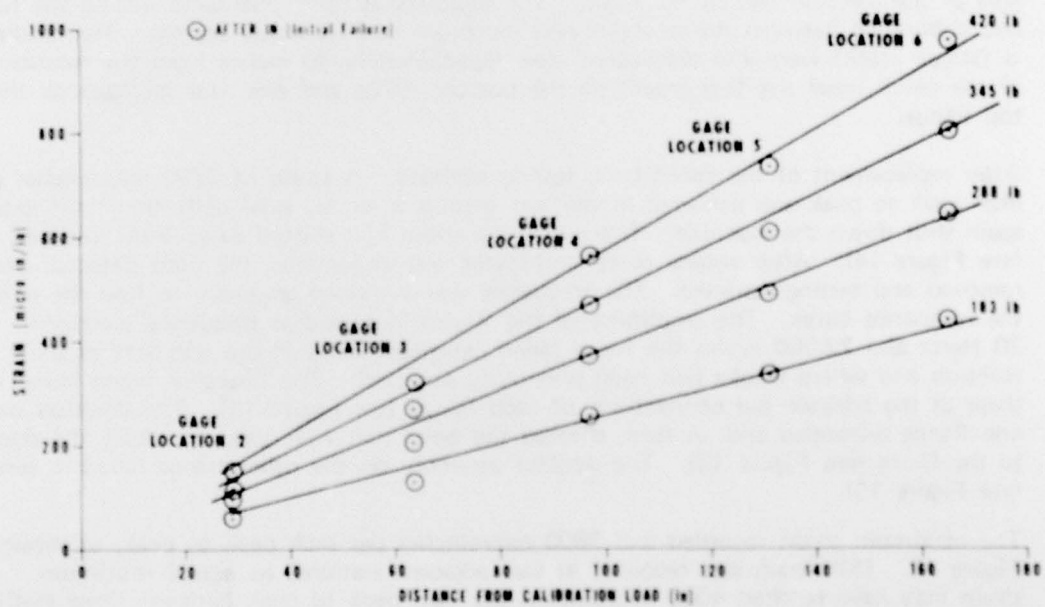


Figure 10. Recalibration data for box beam.

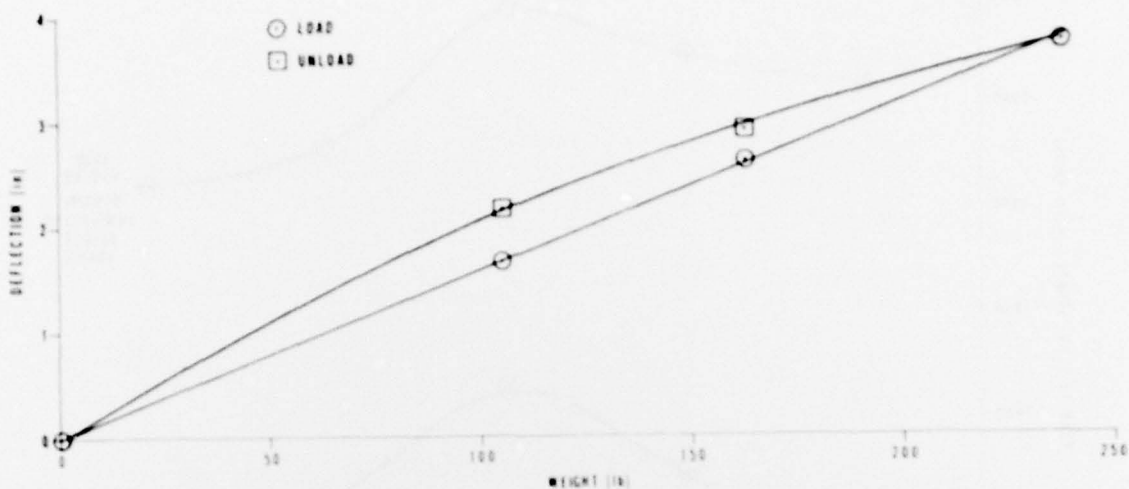


Figure 11. Hysteresis in calibration cycle.

Testing continued and the strain equivalent of high-speed flight loads (2200 microinches per inch peak to peak) was reached. The bending strain distribution at this point is shown in Figure 12. At approximately 16,000 cycles the bending amplitude was increased and a strain of 3400 microinches per inch peak to peak was recorded (see Figure 13). At this point a bolt in the test fixture failed, causing the test to be stopped. The crack previously discovered had become charred and had propagated to the corner of the beam and 2 inches up the side (web) of the beam. Smoke was also observed in the grip area at the reaction end of the beam. The doublers at both ends were hot to the touch, and debonding between the doublers and the beam had obviously started. Two additional fatigue cracks were also discovered, one approximately 40 inches from the reaction end of the beam (near the first crack) on the bottom flange and one near midspan on the top flange.

After replacement of the failed bolt, testing resumed. A strain of 3500 microinches per inch peak to peak was achieved in the test section when an axial deflection limit detector again shut down the machine. The maximum strain had shifted away from midspan (see Figure 14). After several more shutdowns and inspections, the limit detector was removed and testing resumed. The frequency was increased gradually to find the peak of the resonance curve. The amplitude of the strains increased as frequency increased. At 20 Hertz and 22,000 cycles the beam failed catastrophically in the grip area at the reaction end where smoke had been previously observed. The fiberglass beam failed in shear at the adapter pin connections of each flange (see Figure 15). The doublers on one flange debonded and, in turn, sheared the bolts that were used to secure the doublers to the beam (see Figure 16). The doubler assembly on the other flange failed in tension (see Figure 15).

The maximum strain recorded was 3800 microinches per inch peak to peak, as shown in Figure 17. This strain was recorded at two adjacent stations, so actual maximum strain may have reached 4000 microinches per inch peak to peak between those stations.

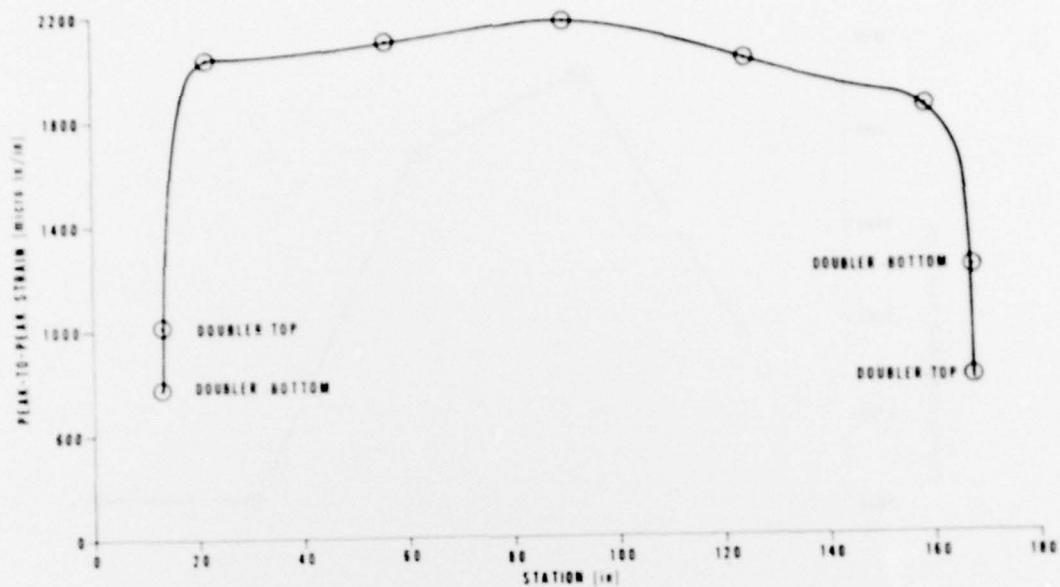


Figure 12. Bending strain distribution (9,000 cycles).

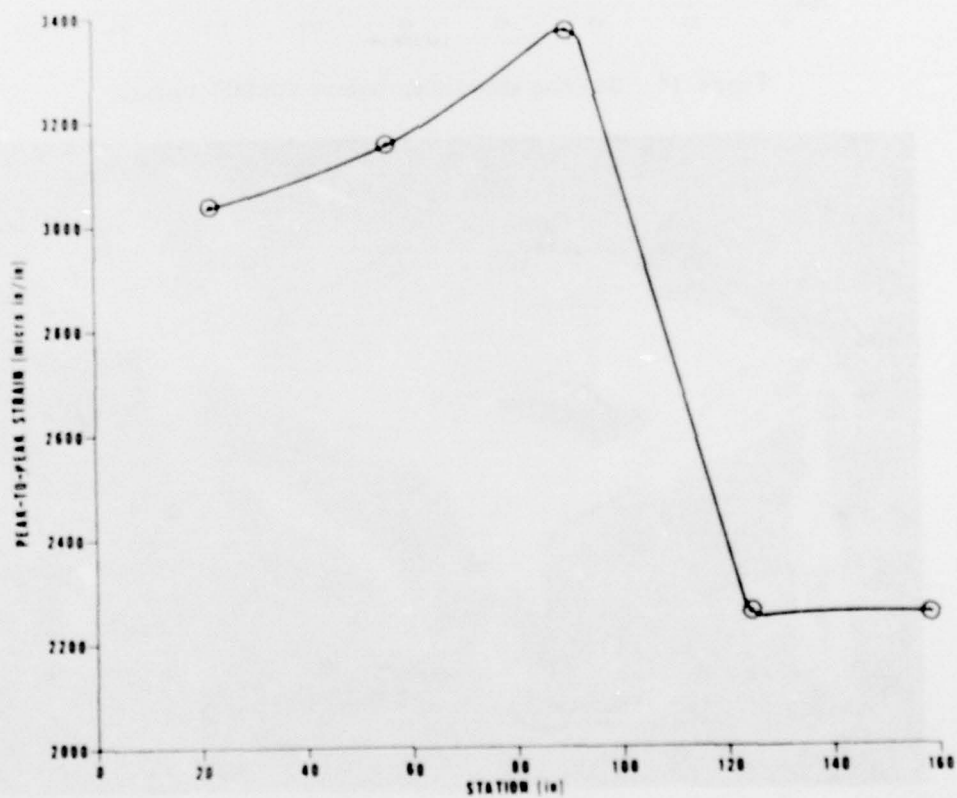


Figure 13. Bending strain distribution (16,000 cycles).

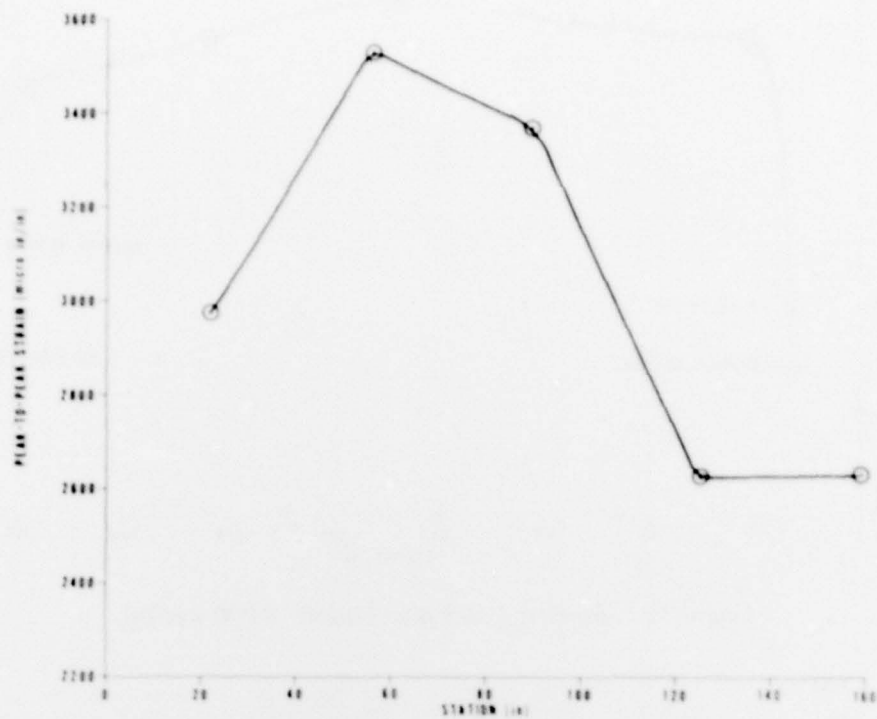


Figure 14. Bending strain distribution (18,000 cycles).

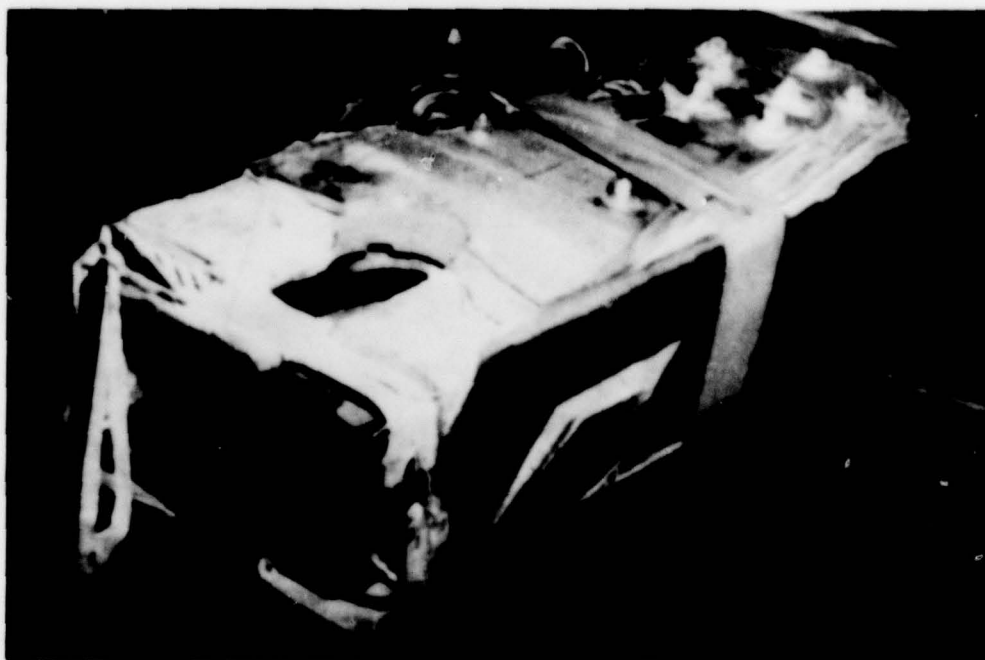


Figure 15. Tensile failure of doubler assembly.

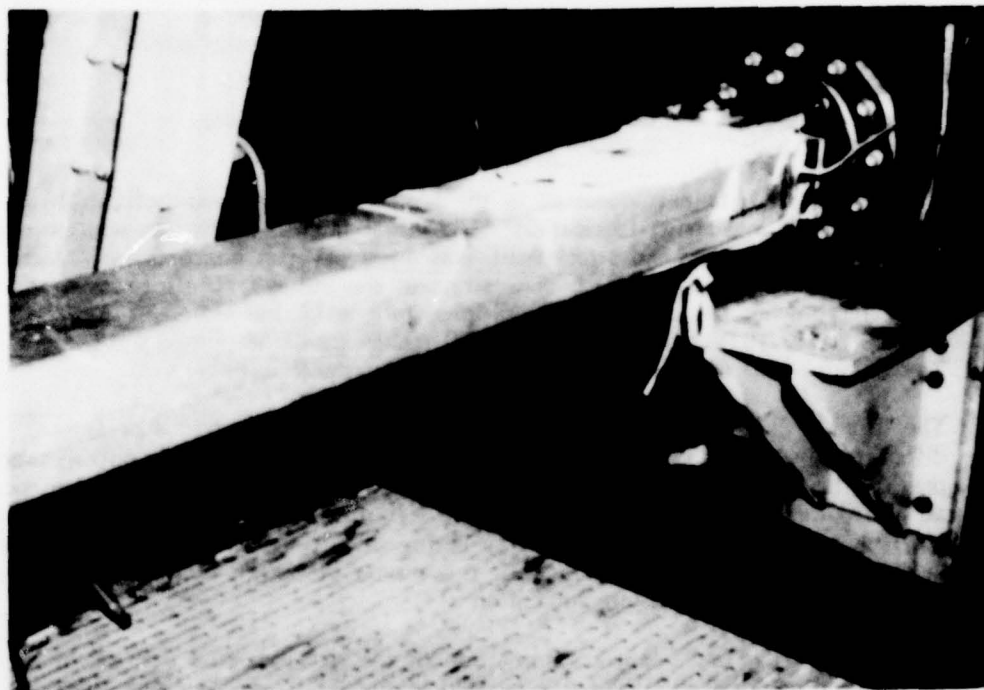


Figure 16. Shear failure of doubler assembly.

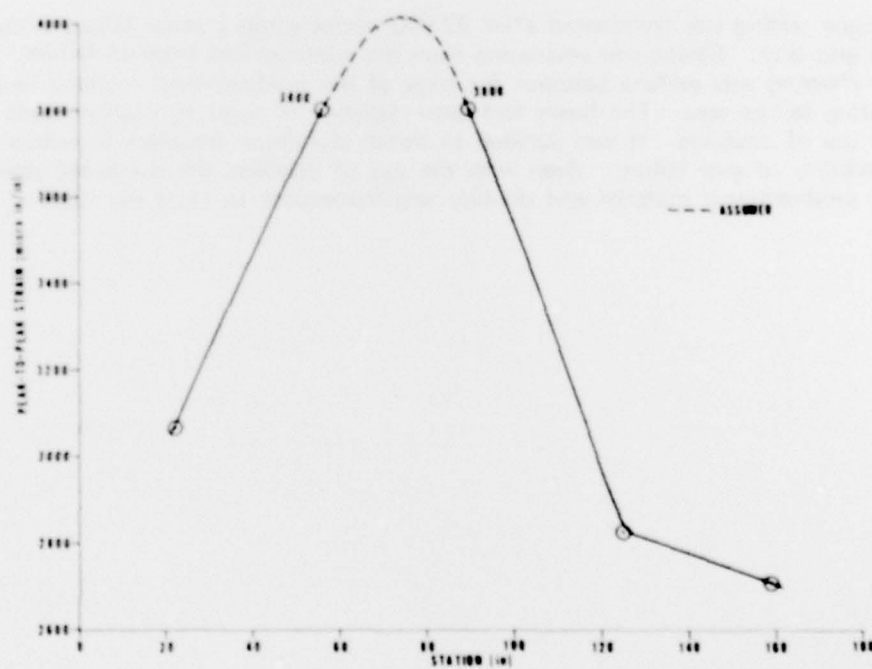


Figure 17. Bending strain distribution (22,000 cycles).

TEST RESULTS SUMMARY

1. Premature fatigue failures occurred in the box beam as the result of chordwise wrinkles occurring during fabrication. The initial failure, which was approximately 26 inches from the pinned attachment, was observed after approximately 3600 fatigue cycles had been applied. The strain at the initial failure location was ± 950 microinches per inch. Two additional fatigue failures were observed at approximately 16,000 cycles at 40 and 90 inches from the pinned attachment. The failure at 40 inches also resulted from a chordwise wrinkle.
2. The Integral Spar Inspection System (ISIS), which depends upon a pressure differential (vacuum) between the inside of the sealed spar and the outside ambient pressure to detect leaks such as cracks and flaws, indicated that leakage had occurred at approximately the same time the failure was observed. However, it is believed the leakage occurred in the failure area at the same time difficulty was experienced in sealing the doubler bolt holes. For this reason, it cannot be absolutely concluded that the ISIS provided failure indication.
3. Sectioning of the box beam at completion of the test indicated that essentially all of the unidirectional plies had delaminated in the failure area. Local charring (requiring 450° to 500°F temperature buildup) indicative of a large number of local fibers working against one another was evident in the failure area.
4. Fatigue testing was terminated after 22,000 cycles when a shear failure occurred in the grip area. Smoke was emanating from the root end just prior to failure. Interlaminar charring was evident between the plies of the unidirectional material in the bearing failure area. The beam had been designed to react to bearing loads without the use of doublers. It was decided to install aluminum doublers to reduce the possibility of grip failure. Even with the use of doublers the combined strength of the unidirectional material and doubler was inadequate to react the loads.

CONCLUSION

On the basis of the test findings reported herein, it is concluded that the Integral Spar Inspection System (ISIS), which depends upon a pressure differential (vacuum) between the inside and outside of the sealed spar to detect leaks caused by cracks, flaws, etc., appears to be a viable technique in signifying structural failure of fiberglass blade spars. A reliable sealing technique must be developed.