ENGINEERING & DEVELOPMENT GROUP
ISRAEL AEROSPACE INDUSTRIES LTD

The Use of Composite Material Strips to Extend the Damage-Tolerance Life of Integrally Stiffened Panels

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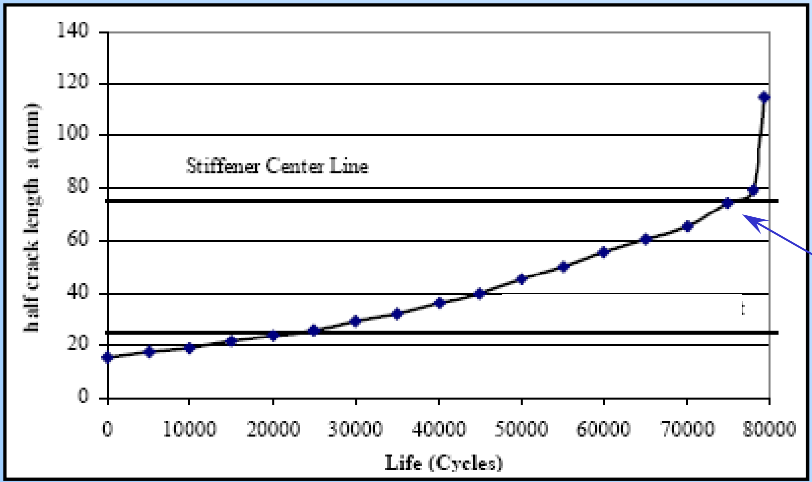
The DaToN Project

- IAI has studied the damage-tolerance behavior of integrally stiffened metallic structures as part of an international project called DaToN. *(Innovative Damage Tolerance methods for the application of New Structural Concepts).*
- DaToN was partially funded by the European Commission (EC).
- IAI has performed both analytical and experimental studies of integrally stiffened metallic structures, which confirmed our expectations that *integral structures do not possess favorable damage-tolerance characteristics.*

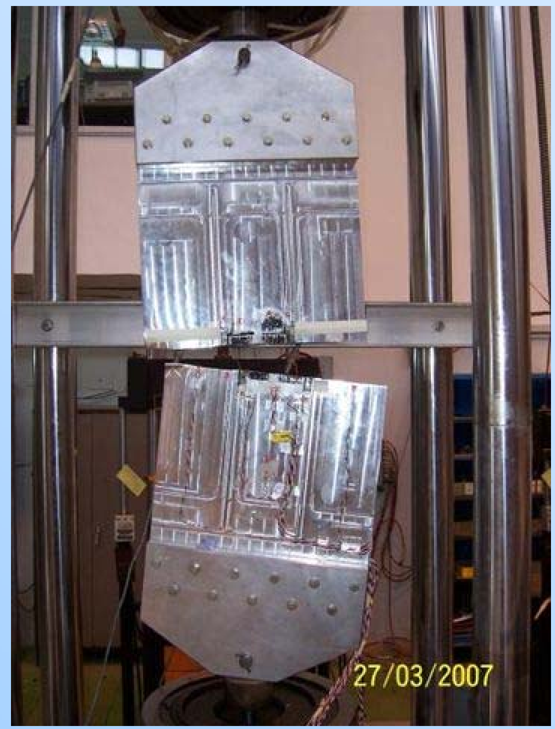


Minimal slowdown of crack at stiffener and significant acceleration after stiffener cracking

Testing of Integrally Stiffened Panels

- IAI tested six integrally stiffened (2024-T351) aluminum panels for crack growth starting from an initial crack.
- Three of these panels had carbon-epoxy or boron-epoxy reinforcements, and were tested at room-temperature and at -50°C.

Integrally Stiffened Panel in Test Rig



Test Panel After Failure

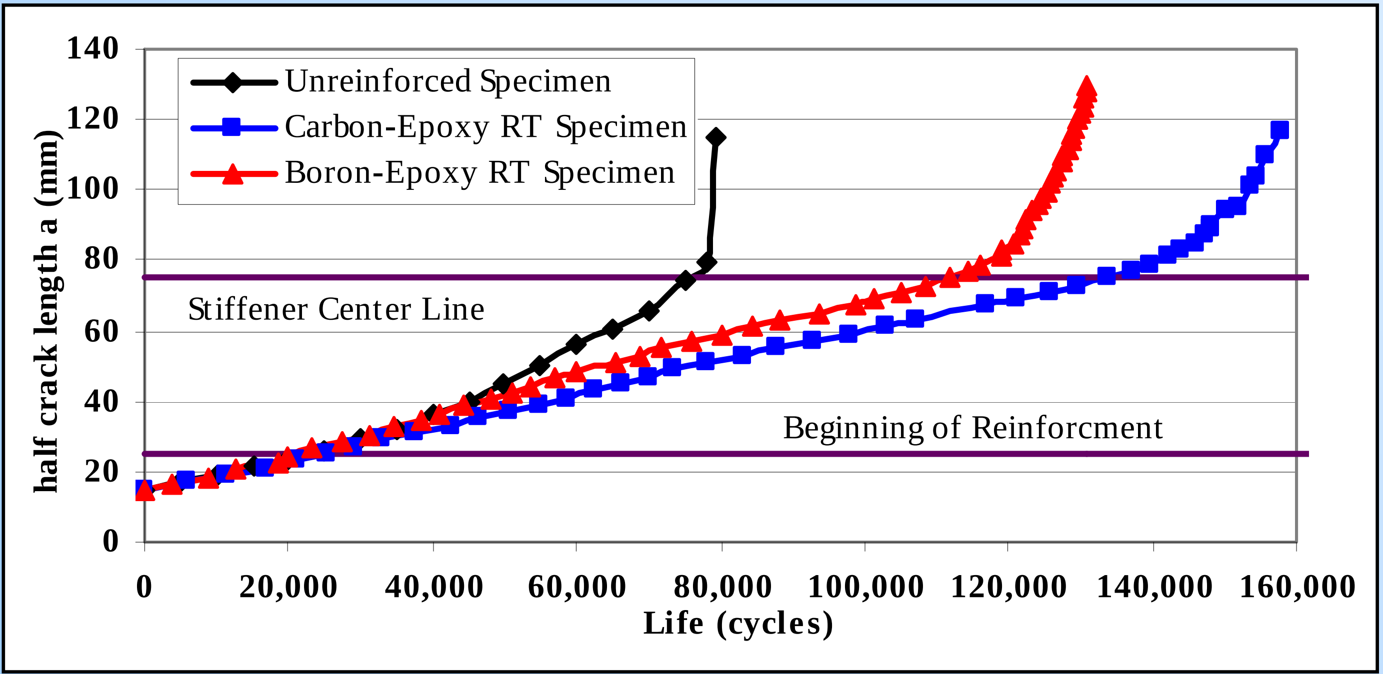
Reinforcing the Panel Using Composite Material Strips

- **In recent years there has been much discussion of the advantages of a *hybrid* stiffened panel having composite material strips bonded to the aluminum panel.**
- **The composite material stiffens the panel and serves to *bridge* any cracks that may develop in the panel.**
- **Two 35mm wide strips of Hexcel Vicotex 913 unidirectional carbon-epoxy strips were co-bonded to a two-stringer panel at 120°C. Each strip consisted of *three plies* of the carbon-epoxy laminate.**
- **On another identical panel, two 35mm wide strips of Textron 5521 F/4 boron-epoxy strips were bonded. Each strip consisted of *two plies* of the boron-epoxy laminate. For both panels, the strips were bonded only on the stringer side.**

Reinforcing the Panel Using Composite Material Strips

- **Both hybrid panel were tested at room temperature, under a 7% higher loading that was used for the unreinforced panel (80 MPa at R = 0.1).** ***The purpose of the 7% increase was to compensate for the additional EA cross-section contribution of the reinforcing strip.***
- **Crack propagation gages were bonded to the panels along the expected crack path. All the panels had artificial cracks of ±15mm length inflicted at the panel centerline.**
- **The crack growth results were compared to that of an unreinforced panel.**
- **Although both reinforced panel gave significant improvements in crack growth lives,** ***the three-layer carbon-epoxy strips gave better results than the two-layer boron-epoxy.***

Reinforcing the Panel Using Composite Material Strips

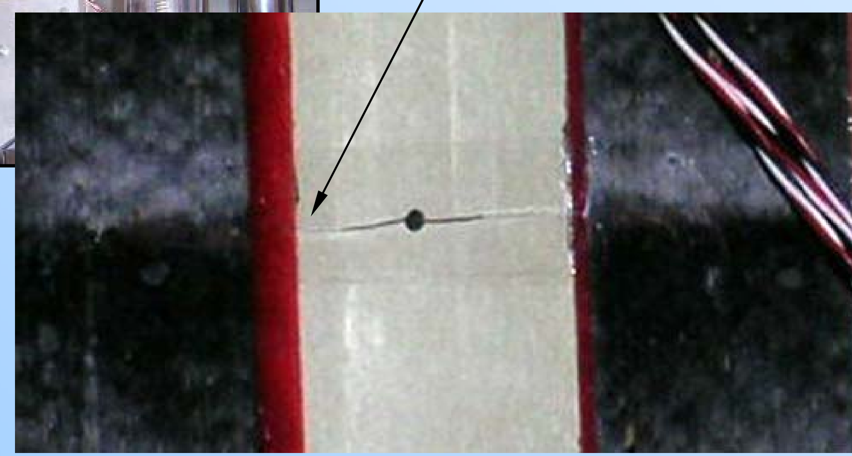


The loadings on the reinforced panels were increased by 7% relative to the unreinforced panel

Comparison of the Crack Growth of Both Reinforced Panels to the Unreinforced Panel

Reinforcing the Panel Using Composite Material Strips

Carbon-epoxy strips cause "bridging" of the loaded crack which results in closure of the crack tip



Integral Aluminum Panel Reinforced with carbon-epoxy Strips
(Before and After Failure)

Reinforcing the Panel Using Composite Material Strips

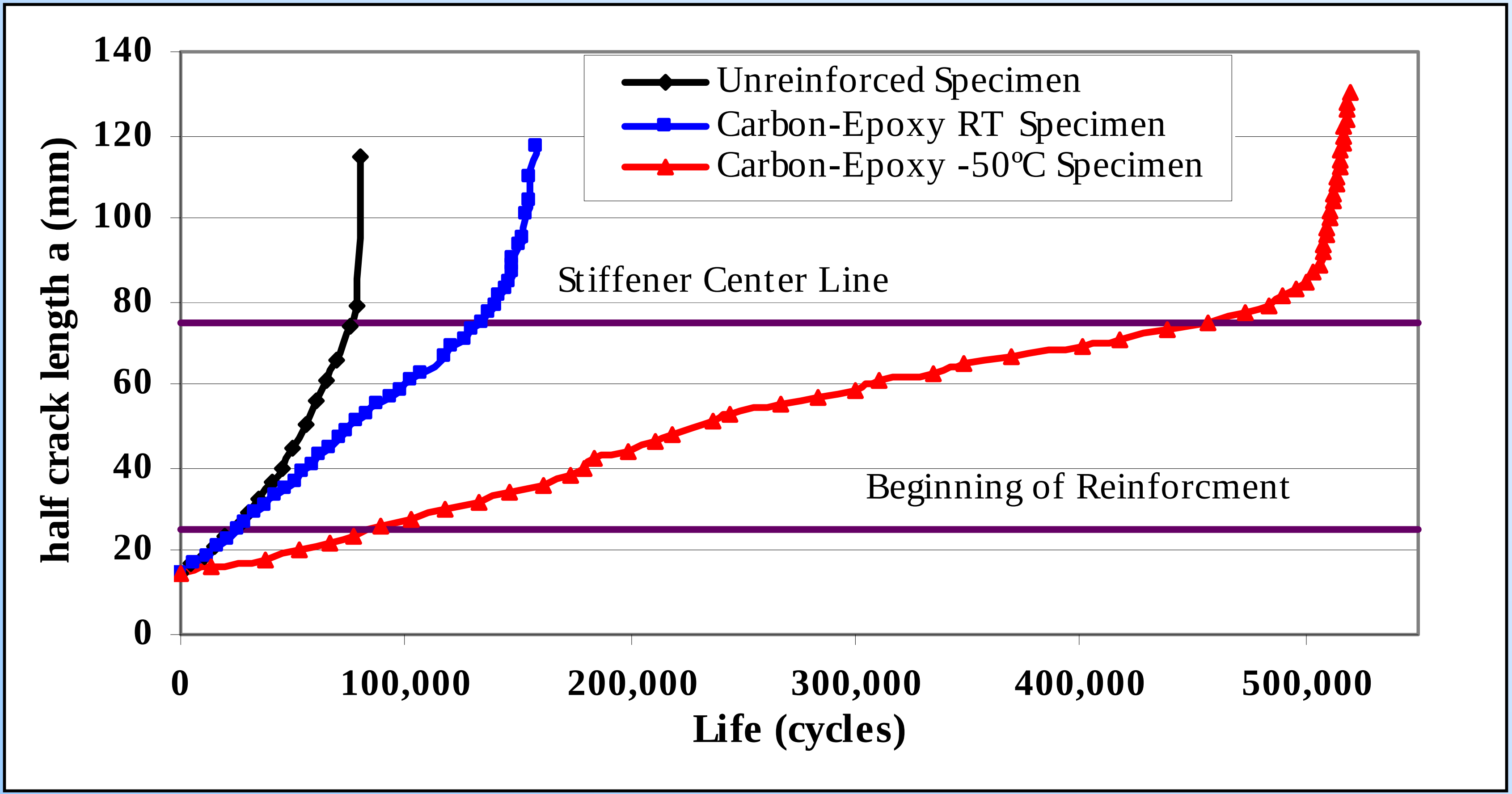
- **No debonds between the composite strips and the metal substrate, or delaminations between layers, were observed up to failure for all the panels tested.**
- **An additional carbon-epoxy reinforced panel was tested at -50°C in order to simulate operation at altitude. The test loads were identical to those of the first reinforced panel.**
- **Based on strain-gage readings and FEMs at room-temperature and at -50°C, a mean residual stress of *14 MPa* existed in the aluminum panel at -50°C. *The compressive residual stress in the carbon-epoxy strips was significantly higher than that in the aluminum plate.***
- **This tensile residual stress in the aluminum panel tended to accelerate the crack growth rate.**

Reinforcing the Panel Using Composite Material Strips

- **On the other hand, the crack growth rate in the 2024-T351 aluminum panel was found to be *much lower at -50℃ than at room temperature.***
- **The crack grew *significantly slower at -50℃ than at room temperature*, showing that the reduced crack growth rate was more decisive than the tensile residual stresses.**

Test Setup for the Carbon-Epoxy Reinforced Panel tested at -50°C

Reinforcing the Panel Using Composite Material Strips

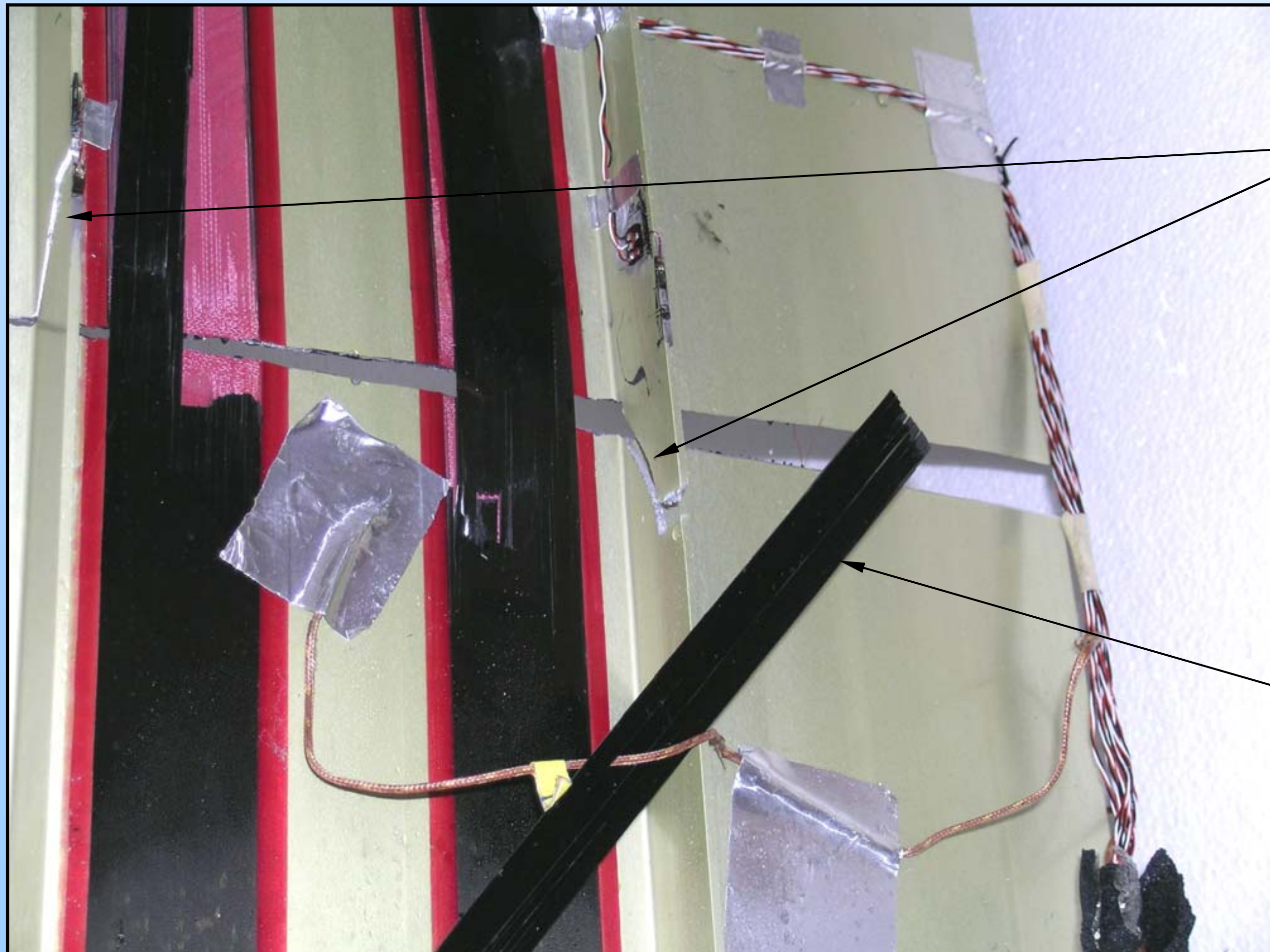


The loadings on the reinforced panels were increased by 7% relative to the unreinforced panel

Reinforcing the Panel Using Composite Material Strips

Failure of Panel at -50°C after More Than 500,000 Cycles

Reinforcing the Panel Using Composite Material Strips



Oblique Failures

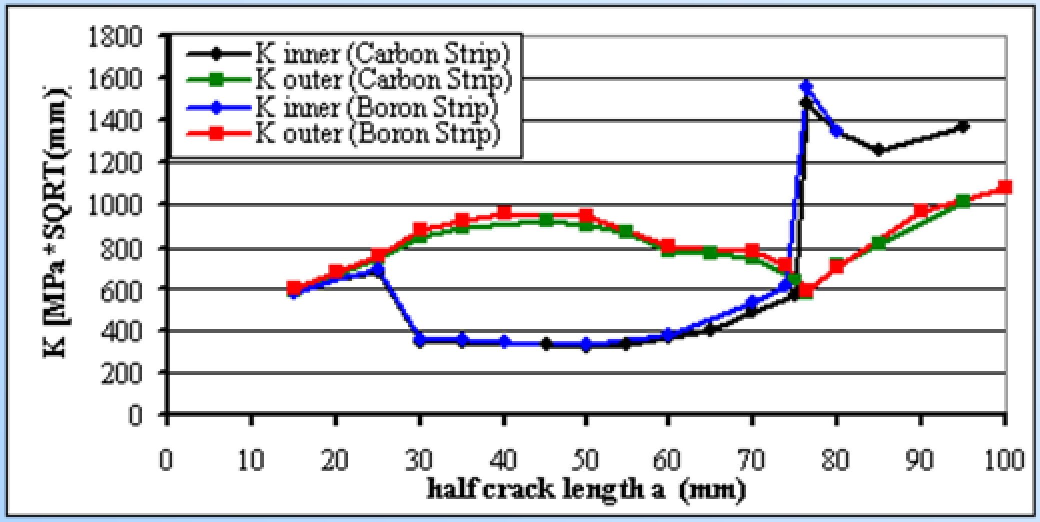
Debonded Carbon Epoxy Strip

Both the right and left stringers failed during or slightly before the final failure.

Finite-Element and Crack Growth Analysis

- **A *NASTRAN* FEM was built to study the effect of the reinforcements on the stress-intensity factor. Due to symmetry considerations, a quarter model was used.**
- **The model consisted of CQUAD4 shell elements representing the skin and reinforcement strips.**
- **3D HEXA elements were used for the adhesive.**
- **Nonlinear analyses were performed for several crack lengths, for both the unreinforced and reinforced panels.**
- **Stress-intensities were obtained for crack lengths of 15 to 100mm, using the *displacement-extrapolation* method, on both the bonding surface and free surface of the panel.**
- **Both the carbon-epoxy and boron-epoxy reinforcements were analyzed.**

Finite-Element and Crack Growth Analysis



Stress-Intensity Results for Cracked Panels *("inner" refers to the bonding surface while "outer" refers to the free surface)*

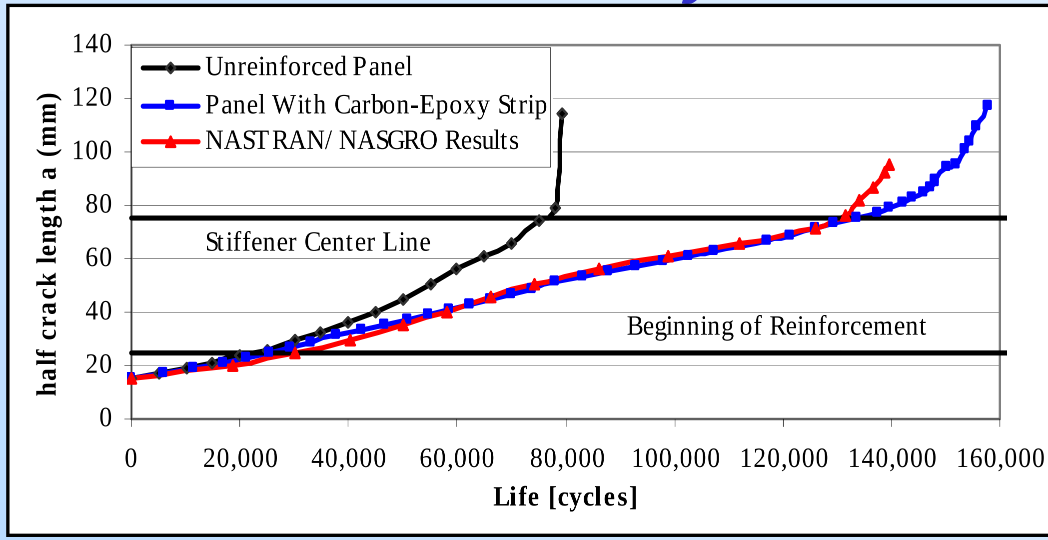
- **The stress-intensity of the cracked aluminum panel was found to be much lower at the bonding surface than at the free surface. This means that the one-sided reinforcement introduces both tension and bending.**
- **The convergence of the mean stress-intensity is nearly constant beneath the strip, as predicted by the *Rose Model*.**

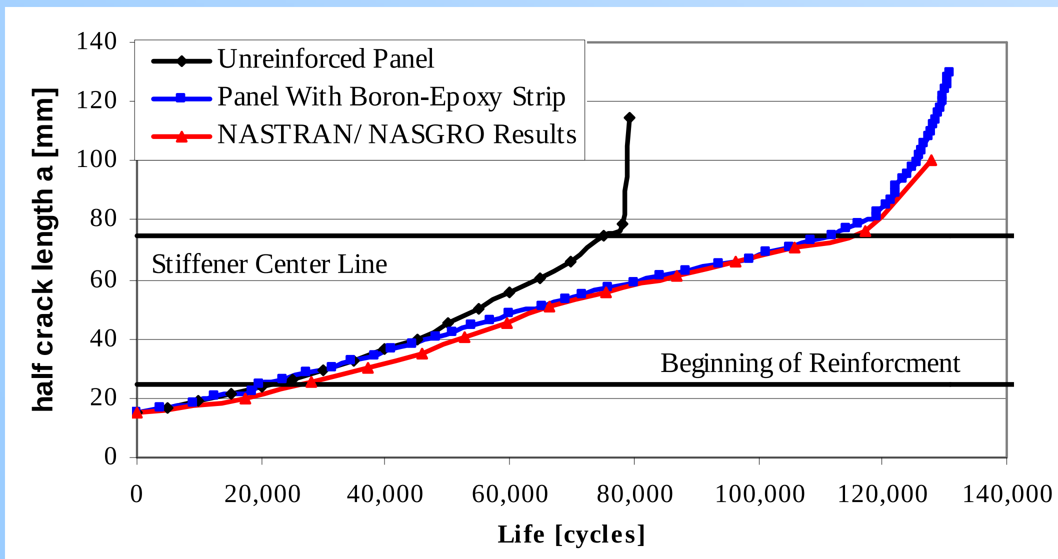
Finite-Element and Crack Growth Analysis

- **The stress-intensity factors were extracted from the FEM for the various crack lengths, at both the bonding surface and free surface of the panel.**
- **The stress-intensity factors were input into NASGRO ver. 5 crack growth software, as a data table.**
- **The effects of both the tensile loading and bending loading, induced by the composite material strips, were accounted for.**
- ***The analytical results showed very good agreement with the experimental results.***

Finite-Element and Crack Growth Analysis

Crack Growth of Carbon-Epoxy Reinforced Panel





Crack Growth of Boron-Epoxy Reinforced Panel

Summary and Conclusions

- **This experimental and analytical study demonstrated the *large potential that exists* by use of carbon-epoxy or boron-epoxy patches to increase the damage-tolerance life of integrally stiffened aluminum panels.**
- **Further testing and analysis is needed to quantitatively confirm these results.**
- **The analytical results, derived from finite-element models, *correlate very well with the test results.***

Summary and Conclusions (continued)

- **The effect of *tensile residual stresses* in the aluminum panels at low temperatures, introduced by the coefficient of thermal expansion mismatch between the aluminum and composite materials, *was not detrimental to the crack growth rate* since the reduced crack growth rate of aluminum at low temperatures more than offset the effect of the tensile residual stresses.**
- **No debonds between the composite strips and the metal substrate, or delaminations between the layers, were observed up to failure, for all the panels tested.**