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13. ABSTRACT *(Maximum 200 words)*

Develop experimentally calibrated predictive computer modeling capabilities that would bridge the multiple material and structural scales and there by significantly reduce development costs. This will allow, for the first time, an integrated approach wherein structures and materials would be designed as a system. This is motivated by the fact that in an aircraft the behavior of structure is governed by both material and structural response; often these two levels are highly coupled. The pathway that will bring physical and microstructural material information into the realm of structural design will be developed.

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MULTISCALE ANALYSIS OF AEROSPACE COMPOSITES

Jacob Fish, Professor

Civil, Mechanical, Aerospace Engineering and Information Technology

Rensselaer Polytechnic Institute

Summary of Work

Developed experimentally calibrated predictive computer modeling capabilities that bridge the multiple material and structural scales and thereby significantly reduce development costs. This allows an integrated approach wherein structures and materials can be designed as a system. This goal is motivated by the fact that in an aircraft the behavior of structure is governed by both material and structural response; often these two levels are highly coupled. The pathway that will bring physical and microstructural material information into the realm of structural design has been developed.

We considered the range of length and time scales spanning more than 10 orders of magnitude with different multiphysics involved at each level. We reliably predicted evolution of progressive damage from the scale of material heterogeneity to the scale of structural components. We applied the multiscale computational technology to aircraft engines (Allison Engines AE2100, GE90) and advanced DOD airframes (HSCT, JSF).

We developed a multiscale computational technology aimed at modeling structural response at three or more different scales including: (i) the global scale (structural level), (ii) the local scale (component level), and (iii) the material scale (the level of microconstituents). Multiple scale expansion method incorporating damage (for CMCs) and eigenstrains (for polymer composites) has been developed to provide the theoretical framework for the multiscale computational model. Multilevel solution technology with mechanism-based inter-scale transfer operators has been also developed. Rapid nonlinear solution techniques which are optimal in terms of robustness and speed have been developed. The multilevel solver developed selects and monitors an optimal solution strategy based on the problem data and feedback received from the convergence of the multilevel process. Modeling error estimators aimed at quantifying the quality of the numerical and mathematical models and steering construction multiscale computational models have been also developed. Developed of system identification procedures for in-situ characterization of phases and their interfaces has just begun. This procedures are critical for calibration of multiscale models to experimental data since a direct estimation of in-situ properties is not feasible.

Accomplishments - Technology Transfer

1. Design of AE2100 Tailcone for Allison Engines

Contacts:
Dr. Durell Wildman, Allison Engines Company,
Tel: (317) 230-5670, e-mail: Durell.Wildman@aadc.com

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Dr. Allan Katz, Wright-Patterson AFB

Dr. William Coblenz, DARPA
Tel: (703) 696-2288, e-mail: wcoblenz@darpa.mil

Accomplishments: (weight savings ~20%)
1.1 Selected optimal micro-mechanical architecture (see Figure 1)
1.2 Material properties predicted were in good agreement with experimental data (see Figure 2)
1.3 Simulated progressive damage in AE2100 tailcone (in progress)
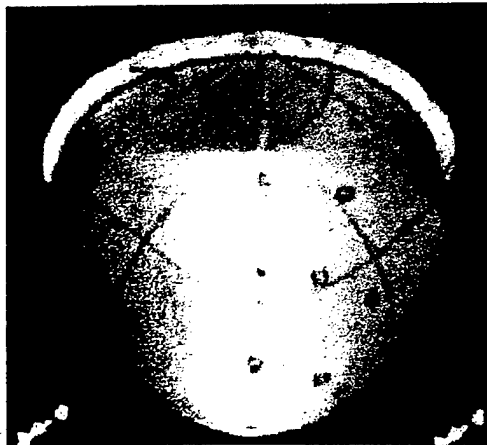
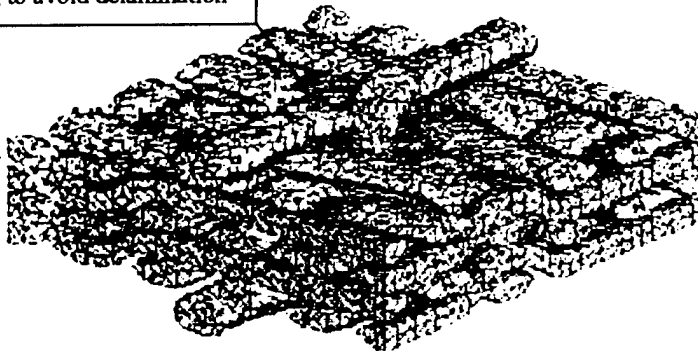

AE2100 manufactured at Northrop-Grumman
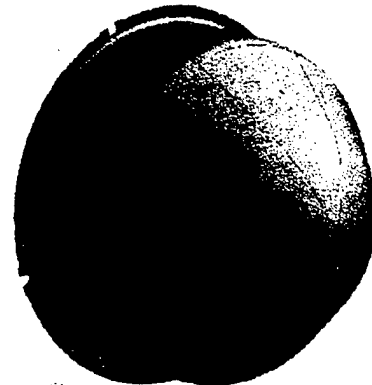
CAD model of AE2100

Stiching to avoid delamination

Optimized FE microstructure
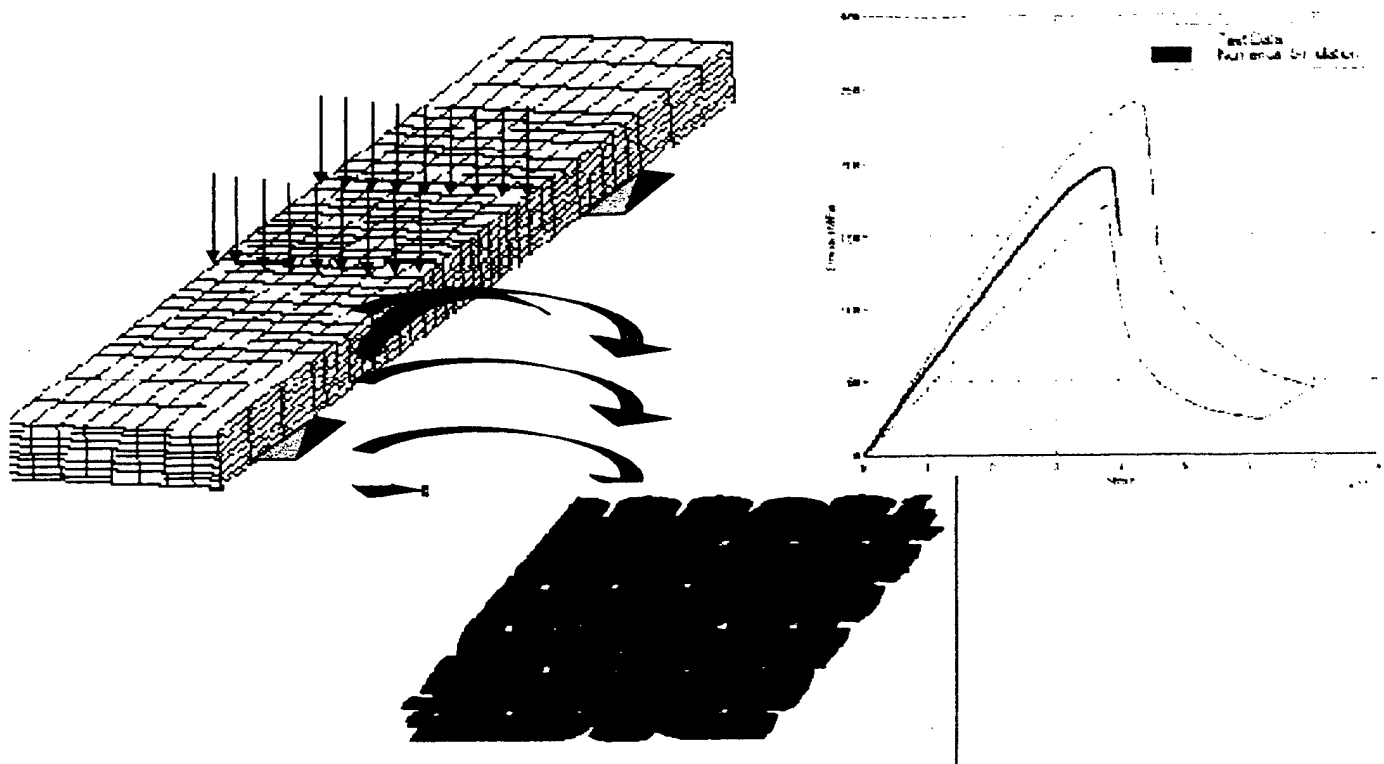

Fabricated Microstructure

Figure 1: AE2100 Design

Figure 2:   4-point bend test and comparison with test data

2.   Advanced airframe design (will start on September 18th, 1998)
Contact:
Dr. Allan Pifko, Northrop Grumman
Tel: (516) 575-1965, E-mail: allan_pifko@atdc.northgrum.com

3.   Fast solver development
Contact:
Dr. Kent Kothawala, President
Engineering Mechanics Research Corporation
Tel: (248) 689-0077, E-mail: kant@troy.emrc.com

Accomplishments
Solver implemented in EMRC commercial software package. Provided speed up of 20 and higher for some industry problems.

4.   Prediction of local effects in laminated composites
(SBIR phase I)
Contact:
Dr. N. J. Pagano, Wright Patterson AFB
Tel: (513) 255-6762

Accomplishments
Multiscale computational technology has been applied to predict local effects in laminated composites. Computational results were in good agreement with analytical solution of Pagano.

5. Thermomechanical design of GE90 fan blades

Contact: Dr. P. M. Finnigan, Program Manager, General Electric Company
Tel: (518) 387-5404

Accomplishments
Multiscale computational technology has been applied for de   n of GE90 fan blade subjected to bird impact. Numerical simulation results were found to be in good agreement with experimental data.

6. Multiscale sensitivity analysis
We developed a methodology aimed at determining the sensitivity of the global structural behavior, such deformation or vibration modes with respect to the local characteristics such as material constants of micro-constituents. An analytical gradient computation, which involves the direct differentiation of the multiple scale strong forms with respect to the design parameters has been developed. Comparison of the Multiple Scale Sensitivity Analysis (MASA) to the central finite difference (CFD) approximation in terms of accuracy and computation efficiency is carried out. We demonstrated the robustness of the MASA approach compared to the CFD approximation, which has been found to be highly sensitive to the choice of the step size, whose optimal value is problem dependent.

7. Manufacturing of fan blades

Contact: Dr. P. M. Finnigan, Program Manager, General Electric Company
Tel: (518) 387-5404

Accomplishments
Multiscale computational technology has been applied to predict wrinkling (on micromechanical level) in compression molding process. The model yielded the time of the onset of wrinkling which agreed well with the experiment conducted at GE. A new thermal/cure manufacturing cycle has been developed which yielded 30% cost savings (Figure 3).
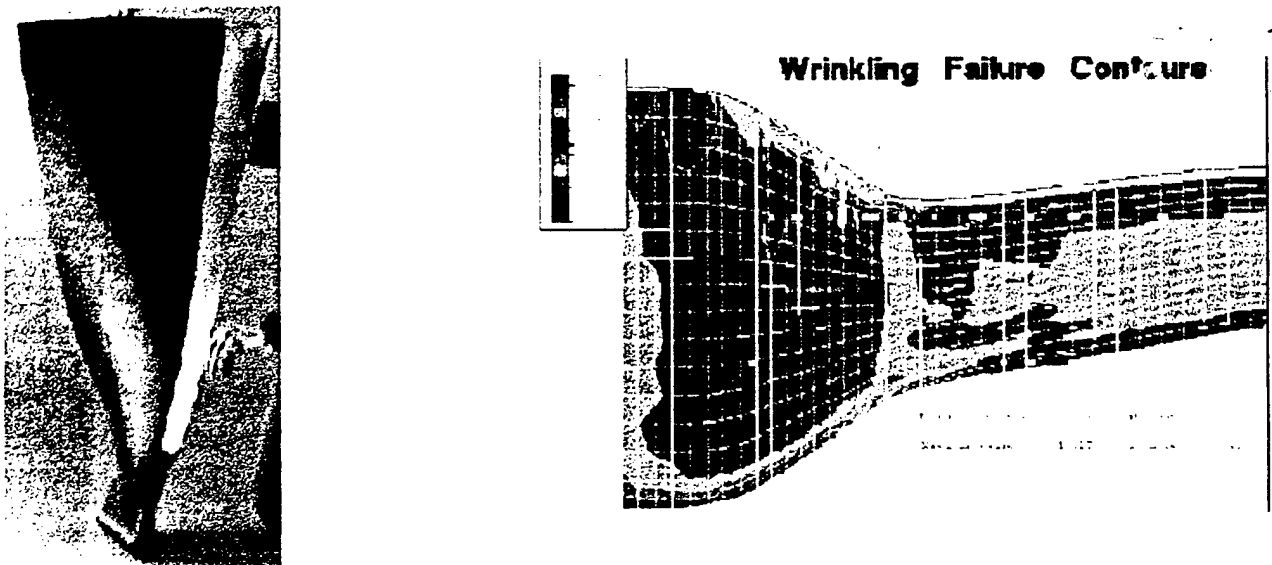

Figure 3: Typical micromechanical failure plots in a fan blade

Personnel Supported
Dr. KamLun Shek, Post-Doc
Rolf Wentorf, Research Engineer
Qing Yu, PhD student
Yong Qu, PhD Student

Publications
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Honors/Awards
Who is Who in Science and Engineering, 1998; Who is Who in America, 1998; Who is Who in the World, 1998; ASME, International Computers in Engineering Conf., Best Paper Award, 1995; USACM Travel Award, 1994; AIAA/SDM, Computational Mechanics, Best Paper, 1993; National Science Foundation Presidential Young Investigator Award, 1992.