AN ENGINEERING APPROACH FOR THE APPLICATION OF TEXTILE COMPOSITES TO A STRUCTURAL COMPONENT

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THE DEFINING OBJECTIVE: Improve impact resistance of composite fan blades by using some form of 3D reinforcement

BLADE DESIGN REQUIREMENTS:

- Correct aerodynamic shape
- Maximum life
- Aeroelastically stable
- Resistance to FOD (foreign object damage)

CONSTRAINTS:

- Budget
- Time
- Manpower

OUR MISSION STATEMENT:

Develop a cost effective, damage tolerant blade which satisfies all blade design criteria.

GOALS - TECHNICAL:

1) TEXTILE ARCHITECTURE

2) RESIN

3) PROCESSING

4) TEST METHODOLOGY

5) ANALYSIS

GOALS - NON-TECHNICAL:

- QUALITY: Build quality into the mfg. process and end product from day one.
- FOCUS: Identify key program needs and then stay focused.
- SYSTEMS APPROACH: Coordinate resources and interact frequently to provide insight and solutions to potential problems.
- TEAMWORK: Utilize all team members to their fullest extent. Know when to modify team as program evolves.
- COMMITMENT: Sustain a high level of commitment and sense of urgency.
- CHALLENGE CONVENTIONAL WISDOM: Use a "clean sheet of paper" approach within the team , and amnesty to constantly challenge both technical and non-technical paradigms alike.

CREATING THE PROJECT TEAM:

1) GE first identified their areas of expertise as well as their shortcomings.

2) GE then sought team members with the following characteristics:

- Technical expertise (in textiles, tooling, RTM, etc)
- Track record of systems approach to problem solving
- Resources and commitment of same to support the program
- Shared sense of urgency
- Open minds and a "can do" attitude

TEAM MEMBER SELECTION PROCESS

- Established basic goals and process outline
- Contacted potential suppliers
- Assessment of supplier:
  - Design
  - Manufacturing
  - Quality Issues
  - Non-technical Issues
  - Business Issues
- Final Selection
- The team identified and prioritized technical issues

GROUND RULES OF TEAM PARTICIPATION

- Fixed goals but flexible approach to getting there.
- Timing and task assignment remained flexible.
- Weekly status meetings involved all team members.
- Direct communication between specific team members encouraged.
- Technical approach was constantly challenged by all team members.
- Flexible team - technical experts were "borrowed" to solve very specific problems, then "returned".

THE TEAM WENT TO WORK...

TEXTILE

GOALS & CHALLENGES
- Fiber volume: 55 - 60 %
- High thickness: ~3 in
- Through thickness reinforcement
- Fibers straight with no crimp
- Continuously changing geometry
- Net shape
- Electronic transfer of data
- Inspection of preform

FIBERITE and 3D-Weaving

TECHNICAL ISSUES
- Translation of geometry to woven preform
- Fiber architecture design
- Ability to weave thick sections
- How to handle large number of yarns
- Adaptation of conventional loom design
- Certification of woven preform

RESIN

GOALS & CHALLENGES
- How to determine the best resin
- Toughness
- High tensile modulus, strength
- High strain-to-failure
- No microcracking, low shrinkage
- Low viscosity
- Long pot life
- Compatibility with fiber types
- Compatibility with prepreg resins
- Readily available

DOW CHEMICAL

TECHNICAL ISSUES
- How to determine wetout
- Injection equipment compatibility
- Process & tool design
- Cure cycle

PROCESSING

GOALS & CHALLENGES

- Electronic transfer of part shape data
- Uniform resin flow in mold
- Large resin injection pressures
- Equipment compatibility with resin
- No part porosity
- Inspection of injected part

GE/CORPORATE RESEARCH & DEVELOPMENT
ADVANCED TECHNOLOGY & RESEARCH
FIBERCRAFT/DESCON

TECHNICAL ISSUES

- Preform permeability
- Resin pressures
- Resin viscosity
- Cure cycle
- Tool gating for RTM mold
- Pumping equipment
- Vacuum capability
- Injection time
- Part removal

TEST METHODOLOGY

GOALS & CHALLENGES

- Provide data for design use
- Assess improvement in interlaminar properties
- Assess response to high energy impact

GEAE MATERIALS BEHAVIOR
WEST VIRGINIA UNIVERSITY
ICI/FIBERITE

TECHNICAL ISSUES

- How to measure basic mechanical properties; in particular, shear
- How to measure impact toughness
- Determine failure modes
- Correlate measurements to actual impact test results

ANALYSIS

GOALS & CHALLENGES
- Stiffness and strength models
- Failure models
- Compatibility with finite element analysis

GE/CORPORATE RESEARCH & DEVELOPMENT
NORTH CAROLINA STATE UNIVERSITY

TECHNICAL ISSUES
- Part geometry and "unit cells"
- Application of models within blade analytical methodology
- Level of detail required
- Verification of models

RESULTS - TECHNICAL:

1) TEXTILE ARCHITECTURE: Fiberite demonstrated the ability to:
   - 3D-weave thick, high fiber volume preforms to net shape;
   - handle complex part geometry;
   - adapt quickly to changing part design.

2) RESIN: Dow's resin is tough, easy to RTM, and does not microcrack.

3) PROCESSING: ATR demonstrated the ability to cleanly inject thick, high fiber volume preforms with no porosity;
   GE/CRD accurately predicted resin flow within the tool cavity.

4) TEST METHODOLOGY: Demonstrated 'ductile' behavior, interlaminar strength confirmed - very difficult to shear. Methodology requires further refinement.

5) ANALYSIS: Preliminary design tool available within GE, need further effort to achieve all goals. GE/CRD currently exploring these issues.

RESULTS - TECHNICAL: (cont)

IMPACT TESTS

- Static panel tests showed very promising results for the weave-resin combination; comparable to the standard all-prepreg panel tests

- Whirligig blade static impact tests - two blades manufactured and tested:
  - impacted by a 2.5 lb. simulated bird
  - impacted blades cycled on a shake table to 1,000,000 cycles (high amplitude in first two fundamental modes) - no damage propagation

MATERIALS AND PROCESS ARE PROVEN!

RESULTS - NON-TECHNICAL:

- The team completed the project on time and within budget.

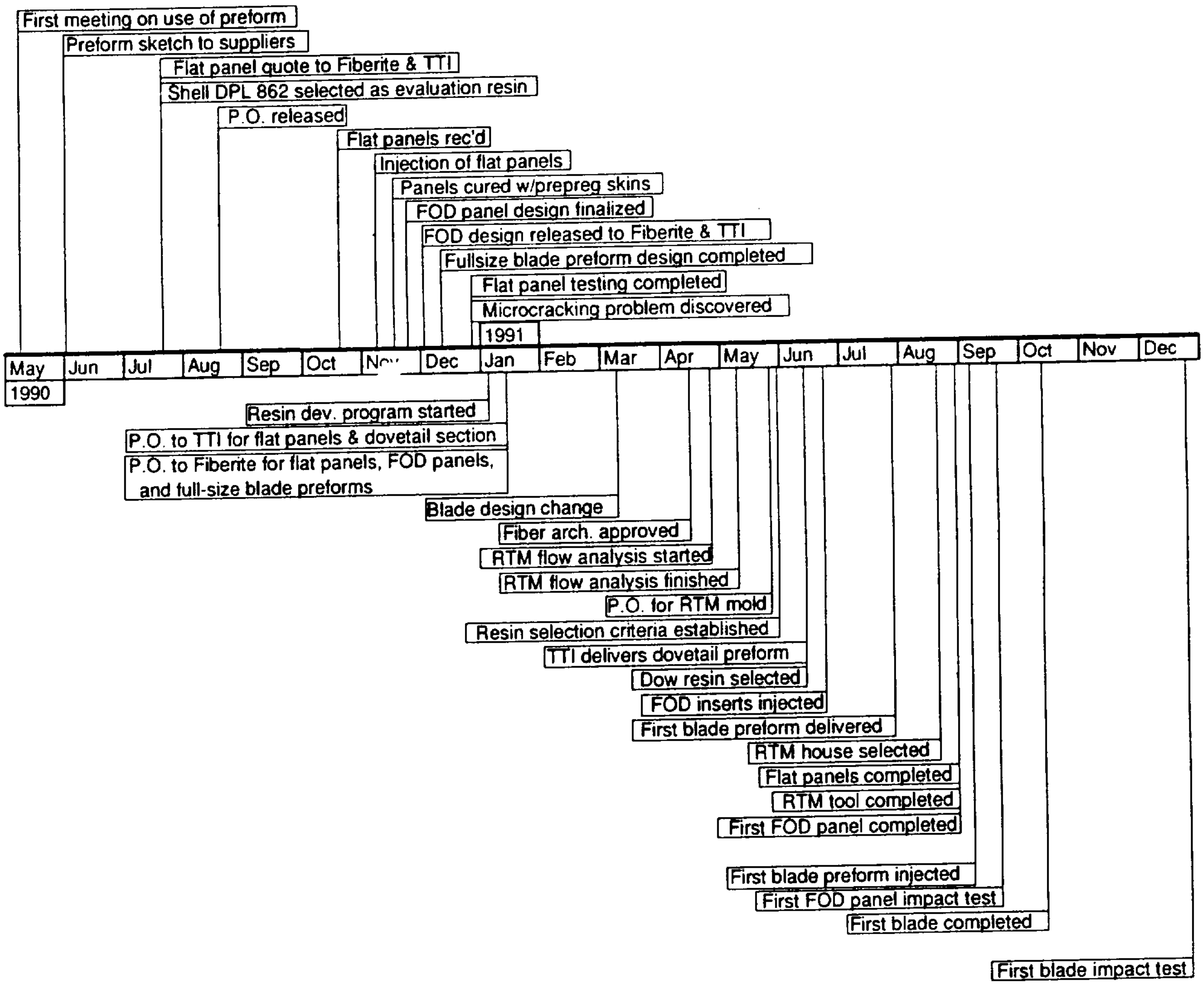
- Technology base can be applied to other engine components.

- Improved resins can find their way further into the engine (i.e. higher Tg for components in the hotter sections).

- Success of this program has expanded GEAE interest from composite prepreg laminates to also include textiles and RTM.

- Real production potential has increased resin manufacturers' interest in expanding development of truly tough RTM resins.

PROGRAM TIMELINE



CONCLUSIONS - TECHNICAL:

- 3D-woven preforms increase damage tolerance.
- Thick, complex shapes can be mass produced economically.
- Preform technology and tooling technology can be combined to provide high quality, net shape parts.
- Tough, microcrack-resistant RTM resins are available.

TEXTILE PREFORMS COMBINED WITH RTM CAN PRODUCE HIGH PERFORMANCE, COST EFFECTIVE COMPOSITE STRUCTURES WHICH MEET OR EXCEED AEROSPACE QUALITY STANDARDS.

CONCLUSIONS - NON-TECHNICAL

- Teamwork works!
- Teamwork is not always easy.
- Timeframes and budgets don't have to be limits to success.
- Open interaction between Design, Manufacturing, Quality, and Sourcing is essential.
- Technical constraints were identified and eliminated by having the entire team all working together and constantly challenging conventional wisdom.