Analysis, Fabrication and Testing of a Composite Bladed Propeller for a U.S. Naval Academy Yard Patrol (YP) Craft

Midshipman 1/c Christopher D. Wozniak

Advisor: Associate Professor Paul H. Miller

Opportunity

- Potential of carbon composites – current uses
- Benefits of using this technology
  - Decreased vibration and cavitation
  - Increased propeller efficiency
  - Ease of repair/replacement
  - Cost

Background

- German, British and Danish use of composite propellers
- Yard Patrol Craft
  - Almost 20 yrs. old
  - 108’ LOA/twin engines
  - Assigned to midshipman training

Objectives

- Design an effective joint between blades and hub
- Analyze prop structure and redesign for composites
- Determine worthiness of carbon fiber as propeller material through testing

Initial Full Scale Testing

- Developed test plan, instrumentation, and data analysis program
- Benchmarked existing bronze propellers
- Tested encapsulated propellers

Results

- Original bronze propellers – Inconclusive (data mismatch)
- Encapsulated propellers – Good precision and shape; calibration and weather conditions evident

Results (cont'd)

- Report of pull to starboard
- Damage to starboard encapsulation
- Burned valve on YP677 ended testing

Hub & Blade Design

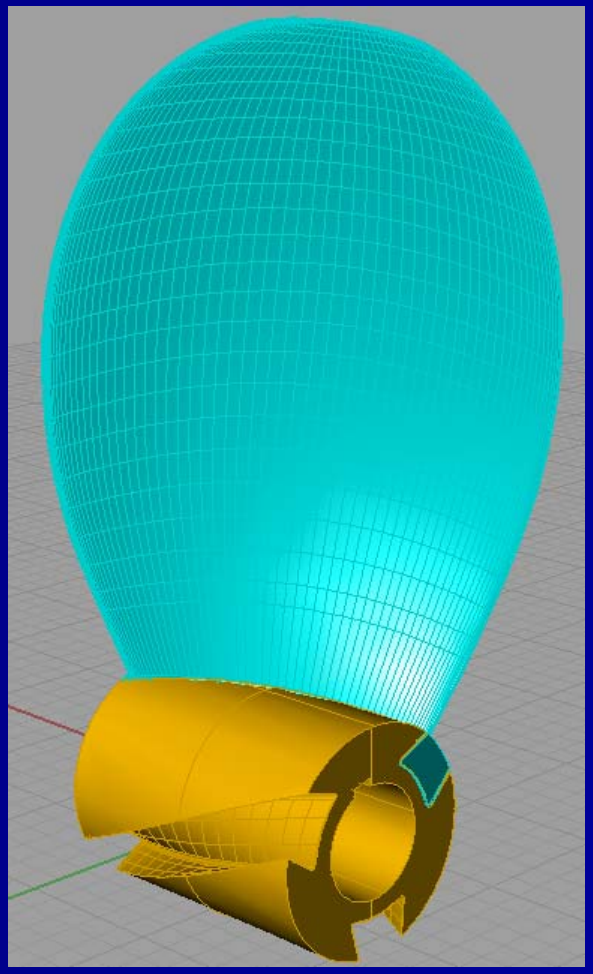
- “Dovetail” (German) vs. “Nub-Blade” (British) Designs
- Dovetail chosen for more blade continuity
- Blade design based heavily upon existing propeller

Blade Design

- Mr. Michael Harshaw at Naval Surface Warfare Center – Carderock Division mapped an existing bronze blade
- Geometry characteristics were faired for load calculation programs

Blade Design (cont'd)

- New propeller geometry was made from faired data – 3-D model
- Designed dovetail for fabrication and stress considerations
  - More bury, greater dovetail angle, close to blade surfaces

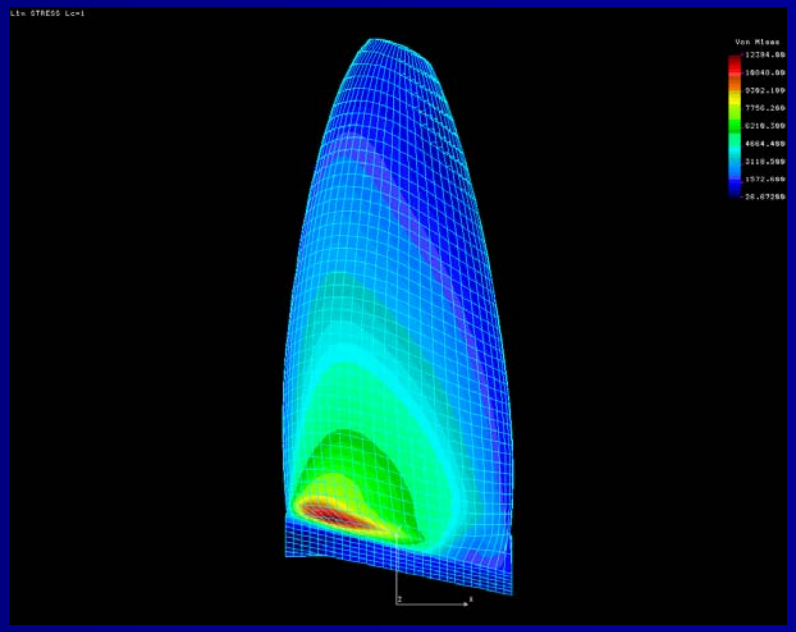


Blade Analysis

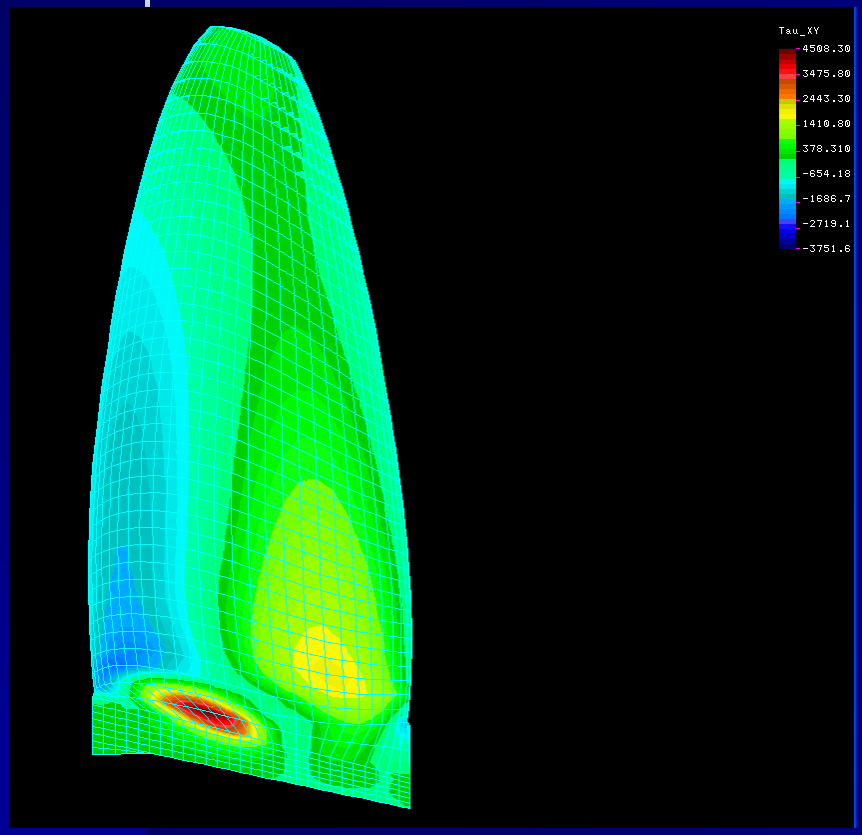
- Propeller design programs at NSWCCD calculated pressure loads based on propeller geometry and operating conditions (lifting surface/panel CFD codes)

Blade Analysis (cont'd)

- COSMOS/M finite element program
- Input pressure values over elements
- Verified "ahead full" load case with bronze model



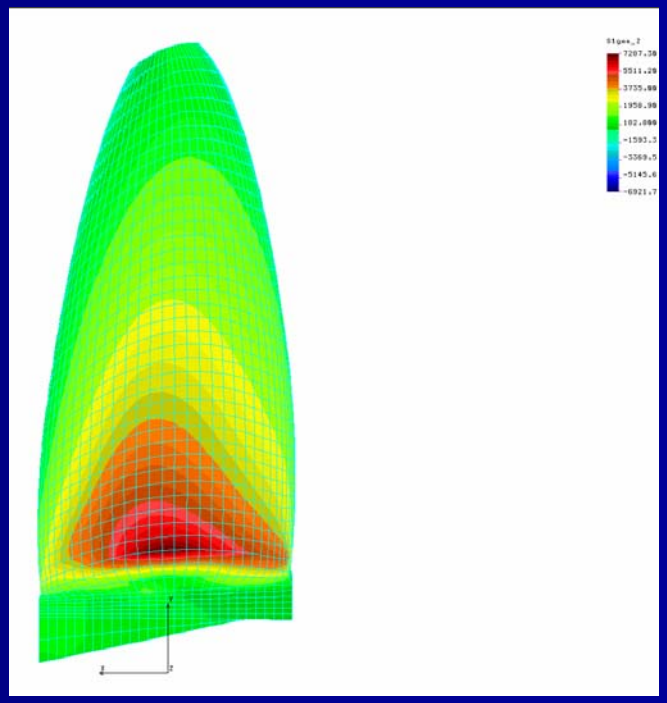
Blade Analysis (cont'd)



- Converted elements to five-layer laminates: 80% 0-90 degree weave; 20% +/- 45 degree weave
- Dovetail constrained as "elastic foundation" – derived partially by "visual" method

Blade Analysis - Results

- Stress viewed in each direction at each layer
- Acceptable factors of safety
- Limiting case – epoxy; “through the thickness” stress



Hub Design

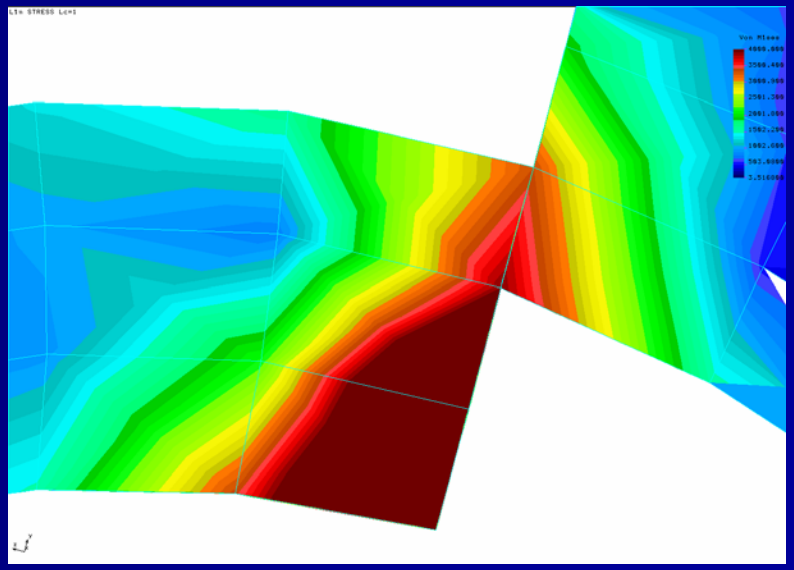
- Hub from nickel-aluminum-bronze (NAB)
- Taper and keyway designed to original prop specifications
- Complementary dovetail slot
- Shorter, but tapered to fit

Hub Design (cont'd)

- Stereolithograph (acrylic rapid prototyping) modeling used to confirm hub and blade fit and taper
- Final, full-scale blade model manufactured from rapid prototyping machine at NSWCCD

Hub Analysis

- Reaction forces applied to hub
- Worst case scenario with regard to shear
- Proved hub's ability to withstand load



Blade Fabrication

- Fiberglass molds made off model plug (two halves)
- Cut carbon layers with quilting wheel; templated to mold
- Laminated with Pro-Set 125 epoxy

Blade Fabrication (cont'd)

- Each blade half was built up (max ~105 plies)
- Edges and surfaces ground smooth for minimal gap

Blade Fabrication (cont'd)

- Thickened Cabosil/epoxy mixture used to join two halves
- Dovetail ground to fit; potted in hub

Hub Fabrication

- Used Rhinoceros-3D model to make machine code and cut bronze to dimension
- Mr. Edward Gerding and his team at the Boeing Corporation (Phantom Works, St. Louis)

Propeller Fabrication

- Capture plates were insurance structure “just in case” of blade sliding

Composite Sea Trials

- Ease of installation
- Shorter hub fit correctly
- Testing included isolating each engine for comparison

Composite Sea Trials

- Speed Over Ground vs. RPM tests for each engine indicated comparable performance
- Test included 30 minute run at flank speed (approx. 400 prop rpm) on both props
- No failures seen!

Conclusions

- Further research in the naval application of this technology
- Improvement in fabrication methods
- Crucial role of rapid prototyping
- Is this technology feasible? – YES!

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