Final Investigation Report

on the

*S/V CYNTTHIA WOODS*

*Prepared by:*

The Office of General Counsel and the Internal Audit Department of The Texas A&M University System

July 17, 2009
Statement of Purpose

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On June 6, 2008 the *S/V Cynthia Woods* capsized in the Gulf of Mexico when it suddenly and unexpectedly lost its keel, resulting in the loss of one crew member, Safety Officer Roger Stone. The vessel was owned by Texas A&M University at Galveston (TAMUG), a member of The Texas A&M University System. Within days following the accident, the Chancellor of the A&M System ordered the commission of a complete and thorough investigation into the cause of the accident and requested recommendations, as appropriate, on necessary operational changes to the TAMUG’s Offshore Sailing Program. The investigation and preparation of this report were performed by the Office of General Counsel and the Internal Audit Department of the A&M System.

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# TABLE OF CONTENTS

Executive Summary ........................................................................................................... 1

Glossary of Abbreviations and Acronyms..................................................................... 4

Definitions of Key Technical Terms .............................................................................. 5

1.0 Incident Summary ....................................................................................................... 7

2.0 Timeline of Events ..................................................................................................... 9

3.0 A&M System Investigation ...................................................................................... 11
  3.1 Investigation Overview .......................................................................................... 11
  3.2 Secured Evidence .................................................................................................. 11
  3.3 Analyzed Documents and Conducted Interviews .............................................. 12
  3.4 Obtained Key Investigative Reports ................................................................... 14
  3.5 Summary of Investigation Findings .................................................................... 15
     3.5.1 Scientific Findings ...................................................................................... 15
     3.5.2 Operational Findings ................................................................................. 27

4.0 Conclusions ................................................................................................................ 30

5.0 Recommendations ..................................................................................................... 31

6.0 Actions Taken by Management ................................................................................. 32

Appendices
Appendix A – Vita of Brendon Dobroth, Dobroth Design, Inc.
Appendix B – Operating Procedures for the Offshore Sailing Program
Appendix C – K.W. Diers & Associates’ Report
Appendix D – United States Coast Guard Investigation Report
Appendix E – Dobroth Design, Inc. Scientific Report

**NOTE:** This report and all appendices can be viewed at:
[http://tamus.edu/offices/communications/cynthiawoods/index.html](http://tamus.edu/offices/communications/cynthiawoods/index.html)
EXECUTIVE SUMMARY

Background Facts

The S/V Cynthia Woods departed from Galveston, Texas on Friday, June 6, 2008, one of more than 20 teams competing in the Regata de Amigos to Vera Cruz, Mexico. The vessel was crewed by the Texas A&M University at Galveston’s (TAMUG) sailing team, which consisted of four student crew members and two Safety Officers.

Between 11:30 p.m. and 11:45 p.m. on the night of the departure, the vessel began taking on water, and within approximately 45 seconds, the vessel turned completely upside down. The topside crew entered the water and one of the Safety Officers, Roger Stone, assisted two student crew members out of the cabin. Stone never surfaced.

When the crew failed to make a scheduled satellite telephone check-in the following Saturday morning (June 7, 2008), TAMUG officials contacted the United States Coast Guard (USCG) and a search was launched. On Sunday (June 8, 2008), after 26 hours in the water, the four student crew members and Safety Officer Conway were rescued approximately five miles from the wreckage. That afternoon, it was learned that Safety Officer Stone had not survived the accident.

A&M System Investigation Conclusion

Shortly after the accident, the Office of General Counsel and the Internal Audit Department of the Texas A&M University System (A&M System) were asked to conduct an investigation into the cause of the accident and to assess the adequacy of the current operational procedures in place at TAMUG. This report is the culmination of that investigation and operations assessment.

We concluded in this report that the cause of the June 6, 2008 S/V Cynthia Woods accident was the result of an inadequate design and construction of the vessel’s hull and the keel-to-hull connection. In performing our investigation and reaching our conclusion as to the cause of the accident, we relied heavily on the scientific analysis conducted by Mr. Brendon Dobroth of Dobroth Design, Inc. (Dobroth), a well-known and highly regarded marine architect and engineer. Dobroth was retained by the A&M System to provide technical expertise in determining the cause of the accident. Our conclusions
regarding the accident and other operational issues at TAMUG were also informed by numerous interviews and the review of hundreds of documents, including documents related to the TAMUG Offshore Sailing Program.

Dobroth concluded that the 4,870 pound keel failed because the hull’s fiberglass laminate was too thin to support the weight of and forces upon the keel, thereby resulting in insufficient shear load capacity. In addition, the use of backing plates that were too narrow exacerbated the problem. Significantly, the vessel failed five design requirements set forth in the American Bureau of Shipping Guide for Building and Classing Offshore Racing Yachts (1994) (the ABS Guide) and three criteria in *Principles of Yacht Design* (Larsson & Eliasson). Finally, Dobroth performed a computational design analysis – Nastran Finite Element Analysis – and confirmed the inadequacy of the design.

The thickness of the hull’s fiberglass laminate was one-third of the minimum thickness specified in the ABS Guide. The vessel manufacturer used only 1/2” to 9/16” of fiberglass laminate to construct the hull, when the ABS Guide required a minimum of 1½” of fiberglass laminate. ABS Guide section 7.3 requires that the thickness of the hull at the point where it connects to the keel (the “keel-to-hull” connection) should not be less than the diameter of the keel bolts. The vessel manufacturer used bolts as large as 1½” to attach the keel to the hull. This configuration, combined with extremely narrow backing plates, caused the front-left corner of the middle backing plate to cut through the hull, causing the keel to fall off.

The keel-to-hull connection of the *S/V Cynthia Woods* also fell short of the ABS Guide’s safety factor criteria. The ABS Guide uses 0.50 as a fatigue value for fiberglass laminate in the keel area. So when the hull of a vessel is properly designed and manufactured according to ABS standards, it has a safety factor of 2.0 (1.0/.50=2). In other words, the hull should be constructed two times thicker than necessary to accommodate for fatigue that occurs during the expected service period of the vessel.

Using the ABS Guide standard, the hull fiberglass laminate for the *S/V Cynthia Woods* should have been at least 3.11” thick. This number is very large due to the narrow backing plates. Instead, the *S/V Cynthia Woods* only had 1/2” to 9/16” of fiberglass laminate in the hull, which corresponds to a 0.32 safety factor.
In addition to the design issues identified, we also noted management and operational issues related to the Offshore Sailing Program. While we have concluded that these issues did not contribute to the cause of the accident, TAMUG should address them to strengthen the control systems over this program.
Glossary of Abbreviations and Acronyms


A&M System – The Texas A&M University System

EPIRB – Emergency Position Indicating Radio Beacon

FOIA – Freedom of Information Act

Investigation Team – A&M System Investigation Team

LUC – Latent unsafe condition (a United States Coast Guard term)

TAMU – Texas A&M University (College Station campus)

TAMUG – Texas A&M University at Galveston

USCG – United States Coast Guard
Definitions of Key Technical Terms

**Bow** - The forward most or front part of the vessel. Bow is the opposite of stern.

**Close Hauled** - A point of sail where the vessel is sailing as close to the wind (as directly into the wind) as possible; sails are pulled in tight, enabling the vessel to point as high as possible to the direction the wind is coming from.

**Fatigue** - (1) The tendency of a material to break under repeated stress. (2) The phenomenon leading to fracture under repeated or fluctuating stresses having maximum value less than the ultimate strength of the material.

**Heel** - To lean over to one side, due to wind pressure on the sails or crew on the side. The amount that a vessel is tipped over side-to-side, relative to its normal horizontal position.

**Hull** - The main structural body or shell of the vessel, not including the deck, keel, mast, or cabin.

**Keel** - An air foil shaped structure attached to the bottom of a sailboat to create ballast (to keep the boat upright) and prevent side-slipping when sailing towards the wind. There are several types of keels, the keel on the *S/V Cynthia Woods* was a bulb keel with a teardrop shaped ballast-filled bulb at the bottom. The purpose of the bulb keel is to place the ballast as low as possible, therefore gaining the maximum possible amount of leverage and thus the most righting moment. The *S/V Cynthia Woods*’ keel weighed 4,870 pounds.

**Keel bolt** – The bolt that holds the keel to the hull.

**Laminate** – (1) To roll or compress into a thin plate. (2) To unite layers of material (for example fiberglass) by an adhesive or other means. (3) A material constructed by uniting two or more layers of material together.
Load – The forces to which a given object is subjected.

Port - The left side of the vessel when facing forward; originally called larboard. Port is the opposite of starboard.

Port Tack - Sailing with the wind coming from the port side, with the boom on the starboard side.

Safety Factor - The ratio of the breaking stress of a structure to the estimated maximum stress in ordinary use.

Shear Force - External force that acts parallel (same direction) to a plane. In the case of the S/V Cynthia Woods, the plane was through the hull laminate where the failure of the keel started; cutting and then tearing through the vessel’s hull laminate.

Starboard - The right side of the vessel when facing forward.

Starboard Tack - A sailboat sailing on a tack with the wind coming from starboard and the boom on the port side. If two vessels under sail are approaching, the one on port tack must give way to the vessel on starboard tack.

Stern - The back (aftermost) part of a vessel.

Strain – To stretch beyond a proper limit.

Stress – Constraining force or influence.
1.0 INCIDENT SUMMARY

The S/V Cynthia Woods departed from Galveston, Texas on Friday, June 6, 2008, one of more than 20 teams competing in the Regata de Amigos to Vera Cruz, Mexico. The race, which is conducted every even-numbered year, is approximately 630 nautical miles or 725 miles. The TAMUG sailing team for the regatta consisted of four student crew members (Ross Busby, Steven Guy, Joseph Savana and Travis Wright) and two Safety Officers (Steve Conway and Roger Stone).

Photo 1. The crew of the S/V Cynthia Woods prior to the start of the Regata de Amigos, June 6, 2008. Included in the photo is the former coach of the team, who did not participate in this regata.

Safety Officer (SO) Conway’s watch began at 8:00 p.m. on June 6, 2008, at which time SO Stone, Wright, and Guy went below to sleep. SO Stone did not advise SO Conway of any problems prior to going below. SO Conway, Busby and Savana settled in for their watch which was uneventful for the next 3.5 hours. SO Conway took the helm at approximately 10:30 p.m. During the time he was at the helm they were close-hauled on a port (left) tack and making approximately 6.3 knots. Apparent wind was 17 to 20 knots and seas were running 4’ to 6’ out of the southeast. Sometime between 11:30 p.m. and 11:45 p.m., the vessel began taking on water. Within approximately 45 seconds, the
vessel shifted sharply to the right (starboard) and turned completely upside down. The topside crew unhooked their safety tethers and entered the water. SO Stone assisted Guy and Wright out of the hatch of the cabin. SO Stone never surfaced.

When the crew did not make its scheduled satellite telephone check-in at 8:00 a.m. on Saturday, June 7, TAMUG officials contacted the United States Coast Guard (USCG) and a search for the vessel was immediately launched. At approximately 5:00 p.m. that day, the USCG notified TAMUG officials that the hull of a vessel had been spotted 27 miles southeast of Freeport, Texas. The initial reports indicated that the keel appeared to have been torn from the vessel.

Around 2:00 a.m. Sunday, June 8, after 26 hours in the water, the four student crew members and SO Conway were rescued approximately five miles from the wreckage. That afternoon, divers hired by TAMUG explored the submerged vessel wreckage and discovered SO Stone, who had not survived the accident.

On June 10, with the assistance of T&T Marine Salvage, Inc. of Galveston, Texas (“T&T Marine”), the S/V Cynthia Woods was recovered and placed on a dock in Freeport, Texas until arrangements for more suitable storage could be made. T&T Marine recovered the keel on June 19 at approximately 11:00 a.m. Both the keel and S/V Cynthia Woods were transferred to a secure T&T Marine warehouse on June 20, 2008. On July 14, 2008, the S/V George Phydia, the sister vessel to the S/V Cynthia Woods, which was designed and constructed by the same vessel manufacturer, was moved to this warehouse. The vessels are currently being stored on the TAMUG campus.
# 2.0 TIMELINE OF EVENTS

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
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<tbody>
<tr>
<td>Friday, June 6, 2008</td>
<td>Race starts in Galveston, Texas</td>
</tr>
<tr>
<td>Saturday, June 7, 2008</td>
<td><strong>S/V Cynthia Woods</strong> misses planned call-in; USCG contacted and search begins</td>
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<tr>
<td>Saturday, June 7, 2008</td>
<td>USCG reports locating the vessel</td>
</tr>
<tr>
<td>Sunday, June 8, 2008</td>
<td>USCG locates five crew members</td>
</tr>
<tr>
<td>Sunday, June 8, 2008 (afternoon)</td>
<td>Divers explore submerged vessel and discover Roger Stone, who had not survived the accident</td>
</tr>
<tr>
<td>June 10, 2008</td>
<td>A&amp;M System Investigation Team formed and commissioned; <strong>S/V Cynthia Woods</strong> recovered and moved to Freeport, Texas</td>
</tr>
<tr>
<td>June 19, 2008</td>
<td>Keel from <strong>S/V Cynthia Woods</strong> recovered and taken to Galveston, Texas</td>
</tr>
<tr>
<td>June 20, 2008</td>
<td><strong>S/V Cynthia Woods</strong> and keel moved to secure warehouse in Galveston, Texas</td>
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<tr>
<td>July 1, 2008</td>
<td>Core samples taken from <strong>S/V Cynthia Woods</strong> and shipped to Structural Composites for laboratory analysis</td>
</tr>
<tr>
<td>July 14, 2008</td>
<td><strong>S/V George Phydias</strong> (sister vessel) moved to secure warehouse in Galveston, TX</td>
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<tr>
<td>Date</td>
<td>Event</td>
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<tr>
<td>August 1, 2008</td>
<td>A&amp;M System Investigation Team presents preliminary status report to A&amp;M System Board of Regents in College Station, Texas</td>
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<tr>
<td>September 10, 2008</td>
<td>Lab results from Structural Composites are published to USCG’s Tiger Team (Ancon Marine Consultants, Inc.)</td>
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<tr>
<td>November 16, 2008</td>
<td>Tiger Team submits report to USCG</td>
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<tr>
<td>December 18, 2008</td>
<td>USCG releases partial report to the public; A&amp;M System Investigation Team submits FOIA requests to USCG for the full report and appendices</td>
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<tr>
<td>February 21, 2009</td>
<td>A&amp;M System Investigation Team receives full USCG report</td>
</tr>
<tr>
<td>July 17, 2009</td>
<td>A&amp;M System Investigation Team publishes final investigation report and presents findings to the A&amp;M System Board of Regents in College Station, Texas</td>
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3.0 A&M SYSTEM INVESTIGATION

3.1 Investigation Overview

Upon receiving a request for an internal investigation of the incident, Chancellor Michael McKinney directed that an investigation into the cause of the accident be conducted. The A&M System’s principal investigation team members (Investigation Team) consisted of the following individuals:

- Jerry Brown, Assistant General Counsel
- Amanda Dotson, Internal Audit Manager
- Robin Woods, Manager of Investigative Audit Services

In addition, the Investigation Team retained the services of Mr. Brendon Dobroth of Dobroth Design, Inc. (Dobroth), a marine architect and engineer, to conduct the scientific analysis to determine the cause of the keel failure. Mr. Dobroth’s resume is provided at Appendix A.

The investigation included securing all physical and documentary evidence, conducting interviews of involved employees and external parties as deemed necessary, conducting scientific analysis and analyzing all pertinent external reports of the incident.

3.2 Secured Evidence

The Investigation Team’s initial task was to work closely with all interested parties (see listing below) to secure all physical and documentary evidence related to the incident. On June 10, 2008, the USCG and T&T Marine recovered the S/V Cynthia Woods and placed it on a dock in Freeport, Texas until arrangements could be made for more suitable storage. On June 19, 2008, at approximately 11:00 a.m., T&T Marine recovered the keel. The vessel and keel were transferred to a secure warehouse on June 20, 2008. On July 14, 2008, the S/V George Phydias, the sister vessel, was transferred to this same warehouse. Both vessels are currently being stored on the TAMUG campus.
The Investigation Team secured agreement among the following interested parties as to the methodology for obtaining and testing core samples from the *S/V Cynthia Woods*.

- USCG
- Texas Parks & Wildlife Department
- The Roger Stone Family
- TAMUG
- Cape Fear Yacht Works, the vessel manufacturer
- Payco Marine/Galveston Yacht Service (ship repair yard)

Once the methodology was established, it was agreed that the core sample testing would be conducted by Structural Composites, Inc.

The Investigation Team obtained and secured approximately 2,800 documents related to the *S/V Cynthia Woods*, the *S/V George Phydias* and the TAMUG Offshore Sailing Program. The principal documents obtained and analyzed included:

- Correspondence (both written and electronic) associated with the receipt, operation and maintenance of both vessels;
- Expenditures for maintenance, repairs and equipment for both vessels from December 2005 to June 2008;
- Operating Procedures for the Offshore Sailing Program; and
- USCG Boating Rules for Boats 26’ to Under 40’.

The vessel’s log book was lost at sea at the time of the accident. TAMUG had not retained a copy of the log book and as a result, the Investigation Team was unable to review the information recorded in the log book.

### 3.3 Analyzed Documents and Conducted Interviews

The Investigation Team analyzed the documents and information collected. The review of the financial records indicated that the university incurred expenses totaling
$71,964 for the *S/V Cynthia Woods* from December 2005 (when the vessel was received by TAMUG) to June 2008. These expenses included:

- Outfitting/Equipment - $20,850
- Maintenance/Repairs - $16,348 (of which $6,178 was paid to Payco Marine)
- Equipment Inspections/Fees - $12,674
- Insurance - $22,092

Included in the maintenance and repair costs paid to Payco Marine, $1,862 was for work performed on the keel as a result of a grounding that occurred in March 2007.

A review of the USCG Boating Rules for Boats 26’ to Under 40’ ([uscgboating.org/regulations/fedreg.htm](http://uscgboating.org/regulations/fedreg.htm)) indicated that recreational vessels have no prescribed inspection or maintenance requirements. Additionally, recreational vessels have only limited safety equipment requirements, which the *S/V Cynthia Woods* exceeded during the Regata de Amigos by having two satellite tracking devices and a satellite telephone. The sailing team was also required to contact TAUMG officials each morning at a designated time. This equipment and the call-in process provided an additional level of safety for the team during the regatta.

The review of the TAMUG Operating Procedures for the Offshore Sailing Program identified several weaknesses, as well as inconsistencies, in the team’s compliance with the procedures (see Appendix B). These issues are discussed in more detail in Section 3.5, Summary of Investigation Findings. While we have concluded that these management and operational issues did not contribute to the cause of the accident, TAMUG should address them to strengthen the control systems in place.

The Investigation Team also conducted interviews to obtain detailed information about the incident, in addition to obtaining a general understanding of the TAMUG Offshore Sailing Program. The Investigation Team interviewed the following:

- Four TAMUG administrators;
- Eight physical plant/marine terminal employees;
- Four Regata de Amigos student crew members;
- Thirteen TAMUG sailing team members;
• One TAMU sailing team student skipper;
• One former TAMU sailing coach; and
• One former TAMUG safety officer.

3.4 Obtained Key Investigative Reports

The Investigation Team obtained and analyzed the following external documents and/or reports during the course of the investigation:

• K.W. Diers & Associates’ (Diers) Report (see Appendix C)
• United States Coast Guard Investigation Report (see Appendix D), which includes the following:
  ➢ Executive Summary
  ➢ Tiger Team Report
  ➢ Ancon Marine Exhibits
  ➢ Structural Composites, Inc. Reports

The Investigation Team and Dobroth reviewed the analyses, results and conclusions for each of these reports. The Diers’ Report states that “It is the opinion of the undersigned surveyor(s) that the damages cited was [sic] the result of the sudden and catastrophic loss of the keel which was due to an inadequate and unacceptable keel-to-vessel mounting system.” (See page 11 of the Diers’ Report at Appendix C). Diers is a marine surveyor, adjuster and appraiser retained by TAMUG’s property insurer to determine the loss and adjust the property damage claim for the vessel.

In its report, the USCG concluded that the accident occurred as a result of improper operation and inadequate maintenance. The USCG identified operational deficiencies involving multiple groundings and improper storage of the vessel in the university’s marina in shallow waters. In addition, the USCG concluded that the vessel’s maintenance was inadequate because the potentially damaged vessel was not examined and surveyed by professionals, students made repairs to the vessel, and an unqualified employee determined the safety and integrity of the students’ repairs.
While we recognize the conflicting conclusions between the United States Coast Guard’s Report and this report, we have not attempted herein to reconcile the differences. For reasons stated herein and in Dobroth’s Report (see Appendix E), however, we do not believe that the groundings noted by the USCG Report contributed to the June 6, 2008 S/V Cynthia Woods accident.

3.5 Summary of Investigation Findings

3.5.1 Scientific Findings

As previously mentioned, Brendon Dobroth was retained to conduct a scientific evaluation as to the cause of the keel failure. In completing his evaluation, Dobroth performed the following:

- Conducted a visual inspection of the S/V Cynthia Woods and the S/V George Phydias;
- Performed mathematical calculations to test the structural integrity of the design and construction of the S/V Cynthia Woods;
- Reviewed the USCG report, including the Tiger Team report and the Structural Composites, Inc. report;
- Consulted the American Bureau of Shipping Guide for Building and Classing Offshore Racing Yachts (1994);
- Consulted Principles of Yacht Design by Larsson and Eliasson; and
- Conducted a Nastran Finite Element Analysis.

Attempts to obtain the “as designed” and “as built” plans and the build process photographs for the S/V Cynthia Woods from the vessel’s manufacturer were unsuccessful.

All offshore production sailboats are required to meet the International Sailing Federation (ISF) standards. ISF standards require all designers and manufacturers to meet the American Bureau of Shipping Guide for Building and Classing Offshore Racing Yachts (1994). Dobroth concluded that the vessel’s design failed the following five criteria in the ABS Guide:
- Single-skin Laminate - minimum hull thickness (Rule 7.3.1)
- Structure - shear loading-heeling (Rule 9.13.3)
- Fiber Reinforced Plastic - sides of framing (Rule 6.1.3)
- Structure – Transverse Load (Rule 9.13.3)
- Structure - Grounding Conditions (Rule 9.13.3).

Dobroth identified two of these five failures – minimum hull thickness and shear loading-heeling – as the cause of the keel separating from the hull. Dobroth also conducted a Nastran Finite Element Analysis, which confirmed these design and construction deficiencies. Finally, Dobroth reviewed the repairs made by Payco and the students and concluded that these repairs did not play a part in the ultimate keel failure on June 6, 2008. Each of these items is addressed in greater detail below. A copy of Dobroth’s full report is provided at Appendix E.

In order to understand the manner in which the keel was attached to the S/V Cynthia Woods, Photos 2 through 4 on the following pages provide pictures of the vessel when it was dry docked before the accident, inside the cabin of the S/V George Phydias (sister vessel made by the same manufacturer) at the point where the keel connects to the hull, and inside the cabin of the S/V Cynthia Woods where the keel was connected to the hull.
Photo 2. Photograph of *S/V Cynthia Woods* before the June 6, 2008 accident. Note the keel (weighing almost 2.5 tons) attached to the center of the hull.

Photo 3. Photograph of *S/V George Phydias*, the sister vessel to the *S/V Cynthia Woods*, from inside the cabin looking down on the location where the keel connects to the hull. Note the backing plates and bolts that connect the keel through the hull.
Photo 4. Photograph of S/V Cynthia Woods from inside cabin after the June 6, 2008 accident. This is a picture of the location where the keel tore away from the hull. For comparison to what it looked like before the accident, see Photo 3. On this photo, the stern is to the left and bow to the right.

Minimum hull thickness

Dobroth concluded that the S/V Cynthia Woods’ hull fiberglass laminate was too thin to support the weight of and forces upon the keel. In fact, the thickness of the hull’s fiberglass laminate was one-third of the minimum thickness specified in the ABS Guide (see Appendix F). The vessel manufacturer used only 1/2” to 9/16” of fiberglass to construct the hull when the ABS Guide required a minimum of 1½” of fiberglass. The weight of the keel alone was just less than 2.5 tons. The ABS Guide requires that the thickness of the hull where it connects to the keel not be less than the diameter of the keel bolts. The vessel manufacturer used bolts as large as 1½” to attach the keel to the hull.

Figure 1 below provides a graphic example of the S/V Cynthia Woods hull thickness in comparison to one that meets the ABS Guide minimum requirements. Simply put, the additional thickness in the hull required by the ABS Guide strengthens the ability of the hull to withstand the loading and forces imposed upon it when the vessel is heeling.
Figure 1. Forward keel bolt (backing plate no. 1)

Photo 5 provides a picture from the side of the recovered S/V Cynthia Woods’ keel. It shows a 1½” bolt through 1/2” to 9/16” of hull laminate. For comparison, the backing plate is 3/8”. The pink colored material is the fiberglass laminate, which is a little thicker than the backing plate. The backing plate does not add strength, but is used to distribute load.

Photo 5. Hull thickness at keel connection point.
The use of a layer of fiberglass in the hull area that is too thin (i.e., does not meet the ABS Guide minimum requirements) results in the bolts being stronger than the hull. Consequently, Dobroth concluded that it was this configuration on the *S/V Cynthia Woods* that when combined with extremely narrow backing plates, caused the front-left corner of the middle backing plate to act as an old-fashioned can opener when exposed to heel forces, cutting through the hull and causing the keel to fall off.

**Shear loading–heeling**

Dobroth also concluded that the hull of the *S/V Cynthia Woods* had insufficient shear load capacity when heeling. This was a result of the vessel being built with a deficient safety factor, which was, again, exacerbated by the use of backing plates that were too narrow. All materials fatigue (weaken) over time when they are exposed to stress or force. The condition of a sailboat heeling (the lean or tilt caused by the wind’s force on the sails) over many hours of use places tremendous force on the hull at the keel-to-hull connection. Shear force occurs when an object (the hull) incurs force (load or stress) from both sides. If sufficient force is applied to the object from both sides, the object will fail. The hull of a sailboat incurs shear force at the keel-to-hull connection point. An example of this occurrence is depicted in **Figure 2** on the following page.
Figure 2. Shearing Force. This diagram is drawn as if you were looking from the bow (front) of the vessel to the stern (back)—as if the vessel were sailing towards you. The hull incurs shear force on both sides of the keel-to-hull connection point. For this incident, the shear load on the hull at the keel connection point was greatest on the port (left) side of the vessel that is elevated in the water (the right side of this diagram).

At the time the keel failed, the S/V Cynthia Woods was on a port tack, meaning that the port side (left side when looking forward from the helm) of the vessel was elevated in the water. The stress at the connection point was unnecessarily exacerbated by the backing plates being too narrow as they were only as wide as the top of the keel (See Photo 6). For backing plates to be effective they should be much wider than the keel. This design flaw caused the backing plate to act like an old-style can opener; tearing through the hull on the port side, beginning at the front-left corner of the middle backing plate (See Photos 7 and 8).
Photo 6. Top of keel, middle backing plate.

Photo 7. Point of failure on the keel, middle backing plate. The arrow shows the front-left corner of the middle backing plate. This is the place where shear failure began. It has a straight vertical side like the fiberglass was cut with a knife or scissors (shears).
The application of a “safety factor” is common in engineering to minimize the adverse affect of a material’s exposure to fatigue. The factor is generally applied as a multiplier of the minimum fatigue load a design engineer picks to increase the design strength of a structure. Safety factors usually start at around 2 and go as high as 10. The ABS Guide uses 0.50 as a fatigue value for fiberglass in the keel area. When a vessel hull is properly designed and manufactured according to ABS Guide standards, it has a safety factor of $2.0 \ (1.0/0.50=2)$. In other words, the hull should be constructed two times stronger than necessary to accommodate for fatigue that occurs during the expected service period of the vessel.

As built, the keel-to-hull connection of the *S/V Cynthia Woods* did not satisfy the ABS Guide safety factor criteria. The vessel had a 0.32 safety factor as built. Following the ABS Guide would have resulted in a hull fiberglass thickness of over 3.11” in the center backing plate area. Wider backing plates would help reduce that thickness number.

**Photo 8.** Hull of the vessel where the failure started. When the hull failed this side was elevated in the water because the vessel was on a port (left) tack, the left side of the vessel was elevated in the water.
**Nastran Finite Element Analysis**

The Nastran Finite Element Analysis is a computational tool relied on by major industry groups to simulate and analyze linear and nonlinear stress, dynamics, and heat transfer characteristics of structures and mechanical components, including composites. This software is the industry structural standard for NASA, Sikorsky Helicopter, the Air Force, and nearly all other major industry structural builders. Using this software, a computer model was developed by Dobroth using the as-built dimensions for the *S/V Cynthia Woods*.

In the case of the *S/V Cynthia Woods*, a 50” x 72” grid was located on a section of the hull where the keel is attached to the hull. The grid is made up of a point at every one-inch interval. This grid contains 3,628 points. Each point is related, or tied, to the points next to it. As one point is loaded or moves, the points right next to that point are loaded, and move in relationship to it. See Figures 3 and 4.

![Image of grid location in hull](image-url)

**Figure 3.** Grid location in hull
All of the plots on the Nastran Finite Element Analysis show that the hull is significantly under built. **Figure 5** below shows the mode of hull failure. The maximum load the ABS Guide allows is 50% of the material’s ultimate shear strength. That number is 14,000 psi x 50% = 7,000 psi. The ABS Guide requires a safety factor of 4.0 for ultimate and 2.0 for the keel bolt structure. The figure below has yellow, orange, and black showing on the tip of the middle backing plate. The backing plates for the keel are seen on the plot as the three rectangles and the front bolt is on the left side of the diagram. Reading from the scale on the right of the diagram shows that black equates to $1.22 \times 10^4 = 12,200$ pounds on a broach load, or 90 degrees of heel. This equates to

$$(12,200 \text{ lbs./}0.56 \text{ in.}^2) = 21,785 \text{ psi}$$

as a peak load at the corner. This gives a required ABS design hull thickness of 3.11”. This number would change significantly with wider backing plates.
Repairs by Payco Marine and TAMUG Students

Dobroth concluded that frame repairs by Payco Marine and the students following a March 2007 grounding did not play a part in the failure of the keel-to-hull joint. As a result of this grounding, the *S/V Cynthia Woods* received small hairline cracks in two frames at the intersection of the hull/frame joint. The vessel showed typical grounding damage to the leading and trailing edges of the lead keel.

As previously discussed, the university paid Payco Marine $1,862 for repairs related to the March 2007 grounding. It appears supplies costing $148 were also purchased from Payco Marine at the same time. Payco Marine did most of the keel repair work (*i.e.* removed the keel and old caulking, resealed and reattached the keel). It is documented that TAMUG students repaired the small cracks and replaced the laminate to a similar thickness as what had been built originally in the vessel. The students also did laminate work around the keel-to-hull connection point. The workmanship was more
than sufficient and was done to industry standards; the material used to make the repairs was equivalent to or better than, the original material.

The post-incident inspection photographs indicated that all of the students’ repairs were still intact, even after the significant trauma of the recovery operation, so the repairs did not play a part in the keel failure. The keel frame sides as designed and initially built did not meet ABS Guide standards or standard engineering practice; however, this was not a proximate cause of the keel failure. As discussed previously, the proximate cause of the keel failure was the manufacturer’s failure to meet the ABS Guide’s hull thickness and shear loading-heeling criteria.

Photo 9. Frame repairs by students are represented by the yellow coloring. The hull failed just to the left of the #8 referenced in the photo. This area was isolated from the frame repairs made by the students.

3.5.2 Operational Findings

The Offshore Sailing Program is not adequately defined as to its organizational placement, structure or purpose within the university. It is neither a student organization nor a varsity sport. The Program was the responsibility of the marine terminal manager, although not part of his documented job responsibilities. In addition, the marine terminal
manager served as the TAMUG offshore sailing coach although his experience with offshore racing was very limited.

The Offshore Sailing Program has written procedures, although the sailing team is not consistently in compliance with them. For example:

- The procedures indicate that all team members must complete a one credit hour Offshore Sailing class in order to participate on the team. We determined that not all of the Galveston team members and none of the College Station team members had taken the required class. There are no processes in place to ensure this requirement is met.

- The procedures indicate that all team members are required to pass a swim test. Although most of the team members interviewed indicated that they had taken the test, there was no documentation to support the fact that the students had done so.

- One of the student crew members participating in the Regata de Amigos graduated in May 2008. There are no procedures in place addressing non-student participants on the offshore sailing team. Because few of the offshore sailing events are intercollegiate, the event organizers do not regulate team participation requirements.

Only one copy of the vessel’s log book was maintained. As a result, when the log book was lost during the accident it was impossible to reconstruct trips, maintenance or other incidences involving the *S/V Cynthia Woods*.

There is no formal process or specific criteria for selecting the students who participate as crew members in the various regattas. The marine terminal manager was solely responsible for selecting the crews and based these selections upon his observations and experiences with the students.

Student workers performed structural repairs to the *S/V Cynthia Woods* under the supervision of the marine terminal manager. There are no processes in place for assessing the students’ skills to determine if they are qualified to be performing these types of repairs.
TAMUG has 14 vessels for which the Marine Terminal staff had no oversight responsibilities. Twelve of these vessels were research vessels for which various university researchers have responsibility and two of these vessels were the responsibility of the Maritime Academy. It should be noted that the university lost several vessels during Hurricane Ike, but will need to consider this issue as the number of vessels owned increases in the future.

One of the safety officers is a full-time university employee in a department unrelated to the Sailing Program. His position description, last reviewed in May 2004, does not specifically address his service or responsibilities as a safety officer nor does he receive additional compensation for this work. However, the other safety officer participating in the Regata de Amigos was a part-time safety officer and received compensation for this work.

The TAMU offshore sailing team does not have a coach. The TAMUG marine terminal manager and one of the safety officers have coordinated weekly practice sessions for the TAMU team since January 2008. The TAMU offshore sailing team is a student organization and the responsibility of the Department of Recreational Sports. It is unclear as to whether the team’s advisor was aware that a College Station team member was participating in the Regata de Amigos.

The intra-university cooperation agreement between TAMUG and the TAMU Department of Recreational Sports regarding mooring, maintenance, security, use and administration for the S/V George Phydias sailboat was not signed by a TAMUG official and expired April 30, 2007.
4.0 CONCLUSIONS

Based on the review of the information obtained during the investigation and consideration of the conclusions by Dobroth, the Investigation Team has concluded that the *S/V Cynthia Woods*’ keel failure occurred as a result of inadequate design and construction of the vessel. The Dobroth report states, and we concur, that the vessel’s design failed five criteria promulgated by the ABS Guide and that two of these five failures – minimum hull thickness and shear loading-heeling – were the cause of the keel separating from the hull on June 6, 2008. This conclusion is affirmed by the computational design analysis (NastranFinite Element Analysis) performed by Dobroth.

While not contributing to the keel failure, the Investigation Team also identified several management and operational weaknesses that should be corrected. Since the accident occurred, management has been working to address many of these issues.
5.0 RECOMMENDATIONS

Management should define the organizational structure and purpose of the Offshore Sailing Program. TAMUG needs to determine whether the program will be classified as a varsity sport, a student organization or a sport club. Management should develop a governance structure for the Offshore Sailing Program that includes, but is not limited to, leadership, training, and documentation processes. In addition, oversight and monitoring processes should be established to ensure that the university is in compliance with all applicable guidelines and internal procedures.

Management should formalize the required information, documentation and retention requirements for the log books that are maintained in the vessels. As noted previously, the S/V Cynthia Woods had only one copy of the log book, which was lost when the vessel capsized. A back-up copy of the information contained in the log book would have been beneficial.

Management should centralize oversight and accountability for all university vessels to ensure they are all equipped and maintained appropriately and in compliance with the applicable standards.
6.0 ACTIONS TAKEN BY MANAGEMENT

Immediately following the accident, TAMUG placed a hold on all vessel operations. The university retained the services of a marine surveyor to perform inspections of all university vessels (power boats, rowing boats and sailing boats). The vessels were released for use as the individual inspections were completed. Only minor issues were identified during the inspections and these issues were primarily isolated to the power boats. Reports are on file with the university.

Dr. R. Bowen Loftin, CEO of TAMUG (currently the Interim President of TAMU), and Dr. Rodney McClendon, Executive Associate Vice President and COO of TAMUG (currently the Acting Vice President and CEO of TAMUG) conducted meetings with staff involved with all university water activities (swimming, rowing, sailing, marine research, etc.) and discussed any improvements that could be made in the areas of communication, safety, equipment and personnel. As a result, the university has:

- Upgraded the position of diesel mechanic, requiring more extensive experience.

- Established a Waterfront Committee that will be responsible for reviewing and managing waterfront operations. Two senior members of this committee visited the California Maritime Academy (Vallejo, CA) and the Virginia Institute of Marine Science (Gloucester Point, VA) to review their operating procedures and to obtain information regarding best practices.

- Developed a Total Vessel Operations Program, which includes new positions for a waterfront director and a safety advisor. The waterfront director will report directly to Dr. McClendon and the safety advisor will report directly to Dr. Loftin. The safety advisor will work closely with the university’s existing safety officer. The committee will develop waterfront policy and the waterfront director will implement the policy. This separation of responsibilities should result in a more rigorous and objective approach to waterfront management that will result in a safer operational environment.
• Decided that in all future offshore sailing events every crew member will be equipped with a personal Emergency Position Indicating Radio Beacon to be worn on the lifejacket.
APPENDICES

Appendix A – Vita of Brendon Dobroth, Dobroth Design, Inc.

Appendix B – Operating Procedures for the Offshore Sailing Program

Appendix C – K.W. Diers & Associates’ Report

Appendix D – United States Coast Guard Investigation Report

Appendix E – Dobroth Design, Inc. Scientific Report


The report and all appendices can be viewed at:
http://tamus.edu/offices/communications/cynthiawoods/index.html