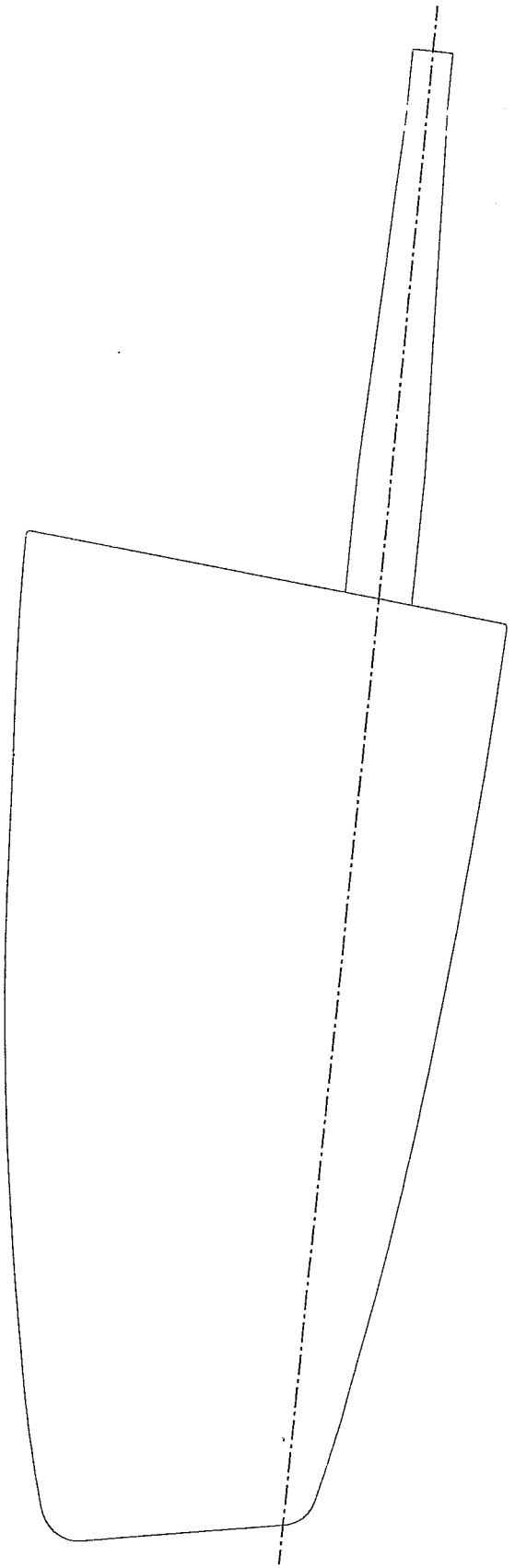
TIDES MARINE RUDDER SYSTEM

BENETEAU 411



SUMMARY REPORT ON THE TIDES MARINE CARBON FIBER RUDDER SYSTEM

for

BENETEAU USA INC.
Marion, SC

on behalf of

TIDES MARINE INC.
Deerfield Beach, FL

by

SPONBERG YACHT DESIGN INC.
Newport, RI

INTRODUCTION

Tides Marine INC. manufactures the carbon fiber rudder system for Beneteau's Oceanis 411 sailboat, replacing Beneteau's own fiberglass rudder and other steering components from blade to quadrant. Beneteau is now also installing the Tides system in their Oceanis 381 sailboat, and they intend to put it into a new 36' model. This report reviews the technical highlights and advantages of the Tides carbon rudder system.

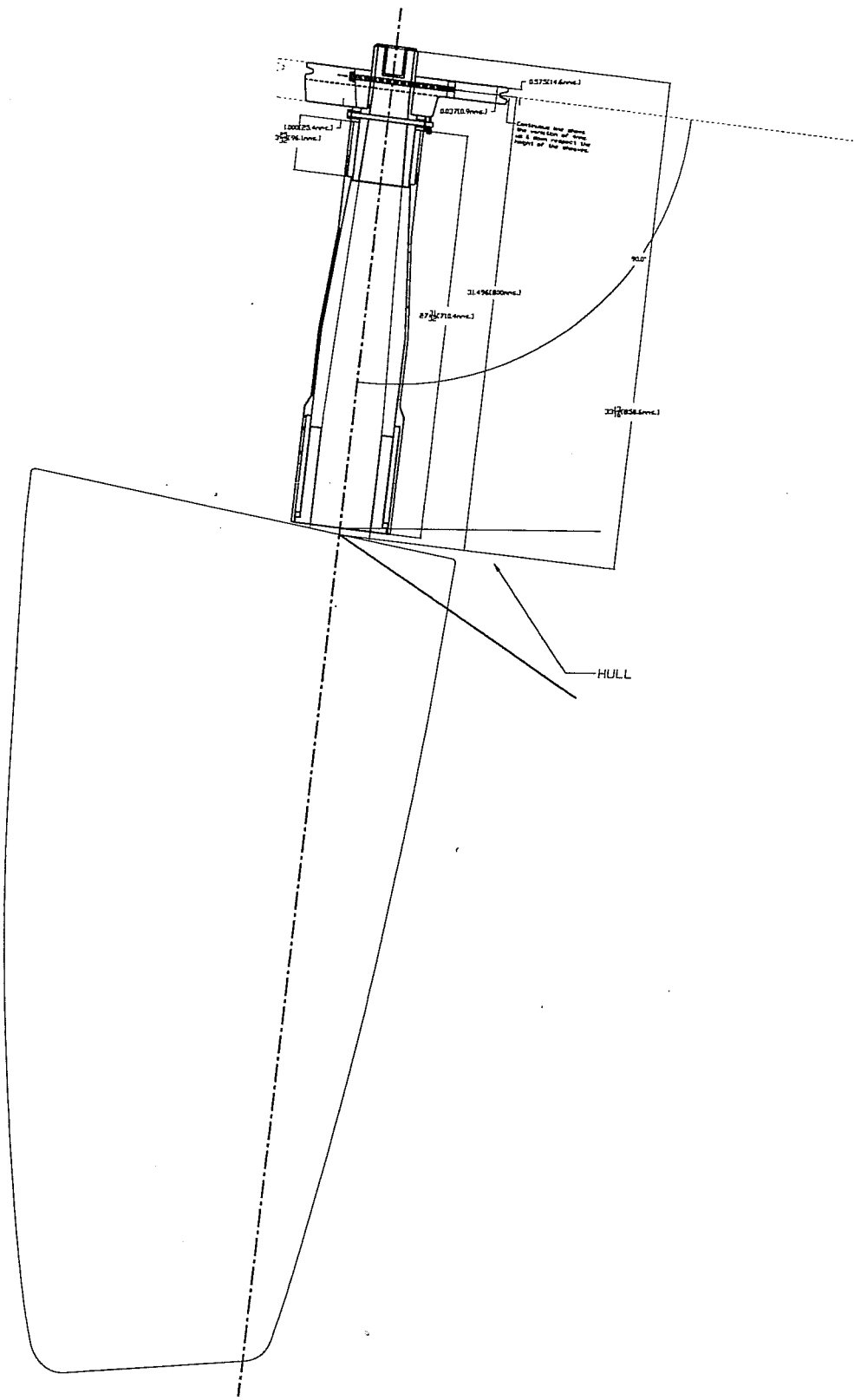
DESIGN AND MANUFACTURING OVERVIEW

The Tides carbon rudder system is comprised of the following parts:

* Integral molded carbon fiber rudder blade and stock
* Square rudder stock cross-section, not round
* Ultra High Molecular Weight plastic (UHMW) neck and carrier bearings
* Carbon fiber bearing sleeves
* Fiberglass tube casing
* UHMW lock collar
* Carbon fiber steering quadrant
* Fiberglass emergency tiller connection

[SEE DRAWING #1]

The rudder blade and stock, bearing sleeves, steering quadrant, and emergency tiller connection are all molded in matched metal molds by resin transfer molding (RTM) using as SP Systems (Cowes, England) epoxy laminating resin. The RTM process means laminate structural properties are more uniform from part to part, and laminate construction is better, with fewer imperfections, than is possible with conventional contact molding techniques. Tides' entire manufacturing process allows extensive quality control and inspection inside the rudder so that the separate parts, as assembled, are ensured to be of top quality materials through and through.


90.0°
HULL

The Ultra-High Molecular Weight (UHMW) plastic used in the bearings and lock collar has built-in lubricating properties that ensure superior low-friction performance under load compared to conventional bearings. Altogether, the primary components of the rudder system are molded and made in plastics, so that the only metal parts are two locking pins and two steering anchor blots, and these are all made of stainless steel. This makes the system strong, stiff, light in weight, and virtually free from metal corrosion.

With rudder geometry supplied by Beneteau, Tides Marine developed the architectural concept of the carbon rudder system and the manufacturing techniques for the various parts. Under a confidentiality agreement, Tides Marine contracted with Sponberg Yacht Design Inc. to develop the laminate engineering and specific part design for the carbon fiber rudder, stock, and quadrant. With Sponberg Yacht Design's design and laminate specifications, Tides Marine built a number of prototype rudder stocks, blades, bearings and quadrants and had them all tested for strength and stiffness by Sigma Labs (Pinellas Park, FL), an independent laboratory specializing in composites testing. Continuing analysis of each test result by Tides Marine and Sponberg Yacht Design, with commensurate improvements in part design, laminate construction, and the manufacturing process, assured that the final production model of the Tides carbon rudder system well exceeds industry design and manufacturing standards.

The Tides carbon fiber rudder is stronger and stiffer than, about half the weight of, and more securely built than Beneteau's original fiberglass rudder. Tides Marine packages and ships the carbon rudder system, complete with assembly jigs, for direct installation into Beneteau's boats. The total system is simpler and faster to install because all but one of the parts (the quadrant) are pre-assembled in perfect alignment, saving valuable boatbuilding production time and labor cost. Tides Marine's carbon fiber rudder system's strong, secure, low-friction design makes Beneteau's boats safer and easier to steer.

INDIVIDUAL PARTS

Rudder blade and stock

Construction: Tides Marine molds the rudder blade and stock as an integral unit in carbon fiber, E-glass fiberglass, polyurethane foam, and epoxy resin. The foam cores for the blade and stock have a minimum density of 8 lb./cu.ft. and are cast separately in closed-shell female molds. Out of the mold, they trim the foam stock to shape, and make a cavity in the region of the neck bearing for a transverse internal fiberglass shear web. Tides then cuts the foam blade into three sections- leading edge and trailing edge parts, and a "stock section" that they discard. Molding the foam cores separately allows Tides to inspect them, even inside at the surfaces of the various cuts, for voids, imperfections, and completeness of cure. This cannot be done in conventional rudder construction where the foam is injected directly into the rudder and cannot be inspected at all.

[SEE DRAWING #2]

To laminate the integral carbon fiber rudder blade and stock, Tides wraps the blade and stock foam cores with dry carbon fiber and fiberglass, according to

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RUDDER AND BEARING SYSTEM FOR BENETEAU 411

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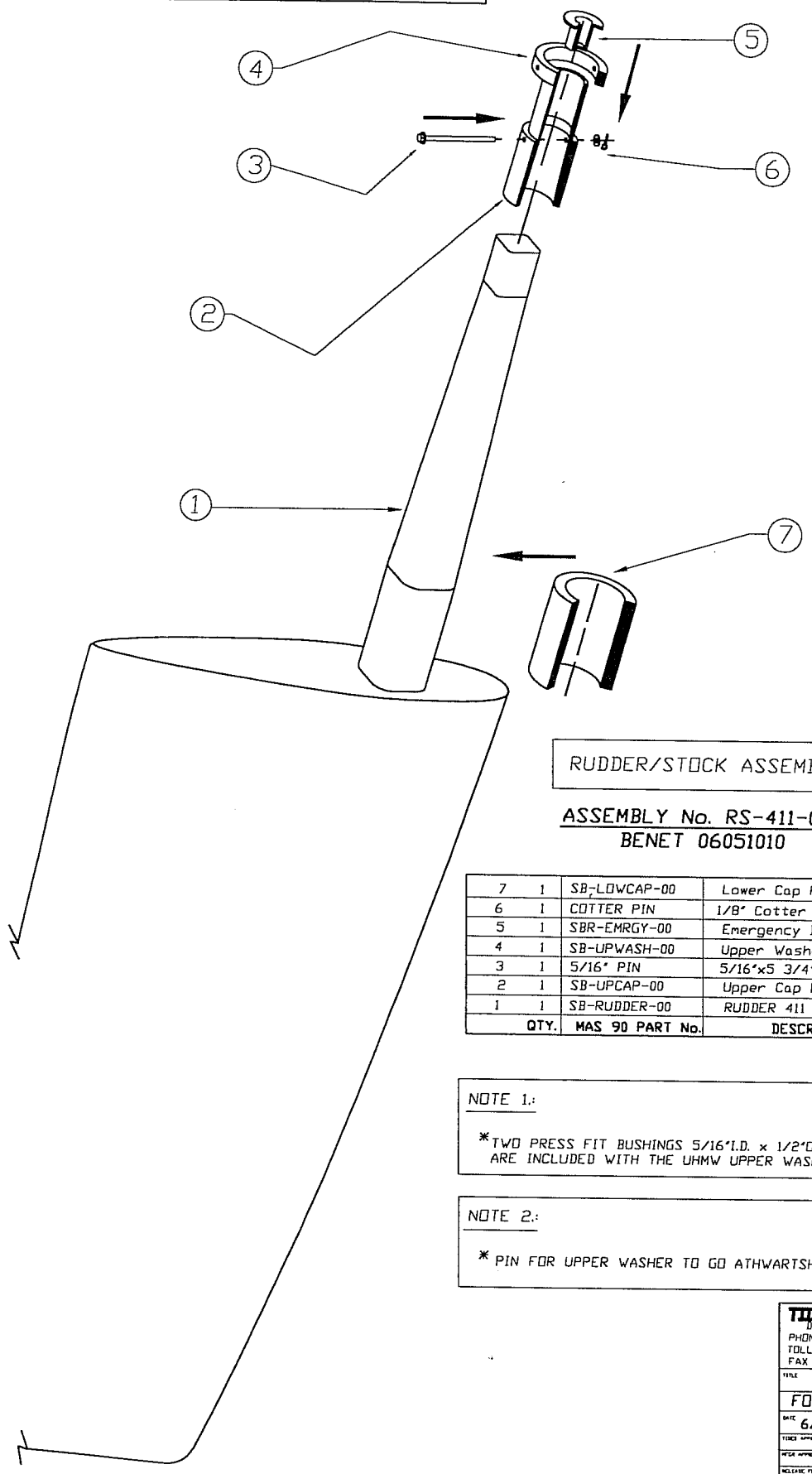

RUDDER/STOCK ASSEMBLY:

ASSEMBLY No. RS-411-00
BENET 06051010

QTY.	MAS 90 PART No.	DESCRIPTION
1	SB-LOWCAP-00	Lower Cap FRP
1	COTTER PIN	1/8" Cotter Pin, S.S.
1	SBR-EMRGY-00	Emergency Insert FRP
1	SB-UPWASH-00	Upper Washer UHMW *
1	5/16" PIN	5/16"x5 3/4" Pin, S.S.*
1	SB-UPCAP-00	Upper Cap FRP
1	SB-RUDDER-00	RUDDER 411
7	1	7
6	1	6
5	1	5
4	1	4
3	1	3
2	1	2
1	1	1

NOTE 1.:

* TWO PRESS FIT BUSHINGS 5/16"I.D. x 1/2"O.D. x 9/16", S.S. ARE INCLUDED WITH THE UHMW UPPER WASHER.

NOTE 2.:

* PIN FOR UPPER WASHER TO GO ATHWARTSHIP.

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TITLE	ASSEMBLY 00
	FOR BENETEAU-411
DATE	6/30/98
SCALE	N.A.
TIDES APPROVAL	DATE
MFGR APPROVAL	DATE
RELEASE FOR MFGR	DATE
DR. BY	LUIS EDERY
MATERIAL	AS SPCD.
DRAWING NUMBER-CAD FILE	RS-411-00
PART NUMBER	AS SPCD.

the pre-determined laminate schedule, and are placed into the rudder mold. They close the mold, and inject epoxy resin into the mold under low pressure to fully impregnate the fiber. The mold has a built-in water circulation system that controls cure temperature by removing the heat of exotherm created by the resin cure chemical reaction.

This process has a number of advantages. First, all of the carbon fiber and fiberglass is laid into the mold dry, so that there is no restrictive "working time" trying to laminate with wet resin. This makes it much easier for the laminator to use care in orienting all the fibers perfectly. Second, when the resin is injected into the mold, all of the fiber all around and through the blade and stock is impregnated and cured as an integral part. Tides adds extra reinforcing material along the blade's trailing edge and in its tip for superior strength and toughness in these areas of more frequent impact and abrasion. All of the material in the blade and stock are cured together in a primary bond; there are no secondary bonds inside the blade. Third, once out of the mold, the rudder does not require any gap filling, joint taping or secondary fairing. Besides eliminating a considerable amount of labor, this also means that water cannot get into the rudder blade while the boat is in service, because there are not joints or crevices for water to get in. And finally, the laminate has no gelcoat on the outside so that the surface of the both the blade and stock laminates can be inspected for any voids or misaligned fibers created as a result of the resin injection. Tides' RTM process produces the best quality laminate in the least amount of manufacturing labor time with virtually no flaws or later stage rework. Final molded weight of the Oceanis 411 rudder and stock is 57 lbs., just 52% of Beneteau's conventional rudder design which weighed 110 lbs.

Emergency tiller fitting: Tides fabricates this socket fitting with fiberglass and epoxy resin using RTM in matched metal tooling. They then bond it into the top of the rudder stock. This construction gives the socket a stronger, more precise fit to the emergency tiller on each and every rudder and boat, making emergency steering more reliable, and therefore, safer. Also, being in a "catch water" orientation at the top of the rudder stock, the socket fitting's composite construction eliminates any corrosion problems such as would be present with a metal fitting. Lifetime emergency safety goes up while lifetime maintenance goes down.

Strength and stiffness: The strength criteria, as required by Beneteau, was that the rudder stock and blade had to withstand twice the bending load defined by the American Bureau of Shipping's (ABS) *Guide for Building and Classing Offshore Racing Yachts*. The ABS *Guide* defines the magnitudes of the bending and torsional moment loads based on the size of the rudder and the boat. Using basic engineering principles, the bending and torsional moments can be calculated into a single equivalent "bending-only" moment, which is convenient for testing. The ABS combined bending moment for the Beneteau Oceanis 411 rudder is 106,338 in-lbs (122,625 kg-cm). Twice the ABS requirement, therefore, is 212,676 in-lbs (245,250 kg-cm).

The ABS *Guide* does not have any stiffness requirement for stocks and blades. That is, the rudder and stock can bend and twist any amount so long as they do not break. Beneteau's own stiffness criterion, however, is that the rudder tip

should not bend to one side more than 10.63" (270 mm) to either side. This is based on their previous fiberglass rudder designs.

[SEE TEST #1 & # 2]

Tides Marine arranged for destructive bending tests to be carried out by Sigma Labs. Over the course of some months, Tides built approximately half a dozen prototype rudder stocks and blades with different laminate constructions until the required bending strength was met. In fact, at Tides' and Sponberg Yacht Design's direction, Sigma Labs built a special test fixture to simulate the actual arrangement of the rudder and stock in a boat, complete with stock sleeves and bearings. Ultimately, the production model rudder stock and blade reached a bending moment of 246,552 in-lbs (284,314 kg-cm) when a tension failure occurred in the stock just above the root of the blade. This load was 232% of the ABS required bending load. The deflection of the rudder tip under this load was 5.935" (151 mm), just 56% of Beneteau's allowable limit. At exactly 2.0 times the ABS load, the tip deflection would be 5.120" (130 mm), or 48% of Beneteau's allowable limit.

Beneteau's previous production rudder was made using S-2 fiberglass and E-glass in a round-section rudder stock design. The rudder stock was molded first, and then machined more perfectly round in way of the bearings for close-fitting stainless steel sleeves. The fiberglass blade skins were then laid up in a two-part female mold, and the stock was set into place in the mold with extra fiberglass and bonding material where it contacted the blade skins. The mold was then closed, injected with foam, and the whole allowed to cure.

Fiberglass is neither as strong nor as stiff as carbon fiber. Also, a round section shape is neither as strong nor as stiff as the square section shape of the same overall dimensions, such as that which Tides Marine uses for its rudder stock design. Nevertheless, it is not too difficult to design and build a round, fiberglass rudder stock that is *strong* enough to meet twice the ABS allowable limit; however, it won't be very *stiff*. ABS has no criterion as to how stiff a rudder should be, nor is there any other independent standard anywhere for rudder stiffness. Unfortunately, fiberglass is such a bendy material that the deflection of the rudder tip at twice the ABS load is unacceptable. The rudder bends way off to one side. Installed in a boat, such a rudder would be difficult to steer because of unusual hydrodynamic flow and loadings caused by the rudder bending, and because the stock would bind in the bearings, unless more expensive self-aligning bearings are used. Short of making the rudder and its stock very much fatter and gaining stiffness by virtue of increased geometry, the only other solution to making a fiberglass rudder stock stiffer is to add more fiberglass into the laminate, and this makes the stock unnecessarily strong and overly heavy.

This was borne out by Beneteau's own test on an Oceanis 411 fiberglass rudder conducted in France. The test showed that the stock was capable of withstanding a bending moment of 297,801 in-lbs (343,842 kg-cm), equal to 2.8 times the required ABS load, which is exceedingly high, and the tip deflection was 10.63" (270 mm). The tip deflection limit criterion described above-this

same value-was based on this test, the best deflection result that Beneteau could achieve with their fiberglass construction.

Tides Marine had a Beneteau Oceanis 381 rudder tested at Sigma Labs. The rudder blade for the Oceanis 381 is longer and narrower than the Oceanis 411 design, but the test set-up was the same. The rudder stock broke at a bending moment of 270,180 in-lbs (311,561 kg-cm), 254% of the ABS limit. However, the deflection of the rudder tip was 9.80" (249 mm). For a direct comparison to the shorter Tides carbon Oceanis 411 rudder, the deflection at the same depth would be a 8.84" (225 mm). At exactly 2.0 times the ABS load, the deflection at this depth would be 6.96" (177 mm), or 65% of Beneteau's allowable limit. Therefore, Tides' tip deflection of 5.120" at 2.0 times ABS on the Oceanis 411 rudder is just 74% of Beneteau's 6.96" equivalent deflection on its Oceanis 381 rudder.

Rudder sleeves

The rudder sleeves are circular cylinders that Tides epoxy-bonds onto the rudder stock in way of the neck (lower) and carrier (upper) bearings in order to make the stock's square cross-sectional shape round. They make the sleeves of fiberglass and carbon fiber using the RTM process in matched metal tooling. When the Beneteau carbon rudder system is completely assembled, the sleeves, bonded onto the stock, are located inside the UHMW neck and carrier bearings. The sleeves' outside surfaces provide the sliding fit inside the bearings. The sleeves' carbon fiber construction and precision molded fit make them strong enough to withstand the primary bending loads and bearing pressures of the working rudder without any misalignments and excessive wear problems common to conventional rudder bearing installations.

Bearings

By virtue of the stiffer carbon fiber stock, the Tides fits the carbon rudder with simple sleeve bearings rather than more expensive and complex multi-axis spherical bearings. They machine the sleeve bearings out of UHMW plastic and freeze-fit them into the fiberglass tube casing. Tides sizes the lengths of the bearings so that the bearing pressure and compression load on the UHMW is very low. UHMW has a very low coefficient of friction, about 0.10, and excellent low-abrasion and low-wear characteristics so that steering feels particularly smooth, positive, and secure. UHMW is an ideal material for rudder bearings-much harder and longer wearing than metal-rubber or metal-plastic bearings.

Tube casing, lock collar, and thrust washer

The tube casing, hand-laid in fiberglass, is one of the most important parts in the Tides carbon rudder system. It houses the rudder bearings and keeps them in perfect position and alignment. Without the tube casing, Beneteau would have to establish bearing position and alignment on each and every boat on its production line. This is a meticulous, time-consuming process, and sure to come out slightly different each time. Tides' tube casing establishes bearing position and alignment at the Tides factory so that it is always exactly the same from rudder-to-rudder, boat-to-boat. Beneteau's installation and fit-up work is much less rigorous, requiring much less labor and cost to install.

[SEE DRAWING #3]

Another important function of the tube casing is to carry the vertical thrust loads of the rudder. The weight of the rudder is borne by the UHMW lock collar located at the top of the carrier bearing sleeve through which it is pinned. The collar bears against the top edge of the UHMW carrier bearing which itself sits in a shouldered socket at the top of the tube casing. The weight of the rudder, therefore, carries through the collar, to the carrier bearing, to the tube casing.

Similarly, the upward thrust of the rudder, such as from a grounding, is borne by a thrust washer. This is also made of UHMW, and it sits above the neck bearing at the top of the shouldered socket inside the lower end of the tube casing. The thrust washer bears against the top edge of both the neck bearing and the neck bearing sleeve on the rudder stock. A grounding load, therefore, carries through the rudder stock, to the neck bearing sleeve, to the thrust washer, to the tube casing.

By designing the Tides carbon rudder system to withstand vertical thrust loading, the loads are necessarily removed from direct bearing onto the hull and deck. This simplifies the fit of the system into the hull because the rudder does not have to the precisely positioned and fitted with its own thrust washer between its root surface and the hull. This also greatly reduces the potential for damage between the rudder blade and the hull during groundings.

Quadrant

After the rudder and its stock, the quadrant is typically the next heaviest piece of equipment in a boat's steering system. Therefore, the attraction of making the quadrant out of lightweight carbon fiber is high. However, the steering loads pass directly through the quadrant, and the American Boat and Yacht Council (ABYC) recommends that all steering components, including quadrants, withstand steering cable loadings of up to 2,000 lbs. pull. The Tides carbon fiber quadrant design was tested at Sigma Labs to ensure that it meets this requirement.

[SEE DRAWING #4]

Tides' RTM-molded carbon fiber quadrant is lightweight and strong enough for the task. Its most significant features are its flat disc design and square rudder stock hole. Most metal quadrants have a spoke design in order to reduce their normally heavy weight. Spokes are extremely difficult to mold with composites, but composites are so lightweight anyway that spokes are not required. The flat-disk design is much easier to manufacture, and Tides molds it with a carbon fiber, fiberglass and epoxy laminate over an 8 lb./cu.ft. polyurethane foam core. Test results show that it has more than enough strength to withstand the ABYC 2,000-lb. pull at any point on its perimeter.

The square rudder stock hole, molded to fit the stock precisely, allows the steering loads to transfer directly from the stock to the quadrant and into the steering cables without relying on an overly strong metal locking pin. The locking security and strength of a square peg in a square hole transfers the

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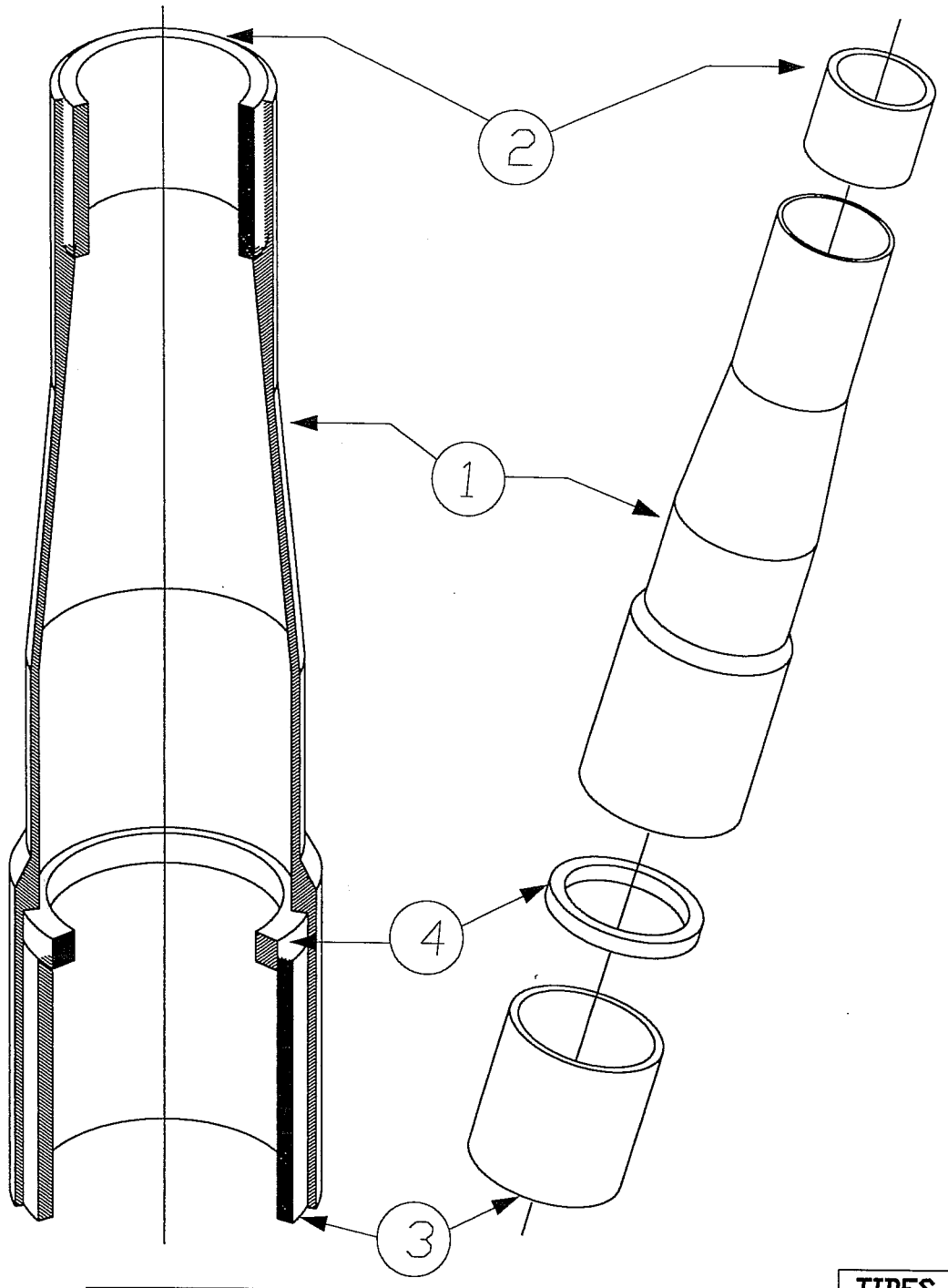

RUDDER/STOCK ASSEMBLY:

Part No. RS-411-01 & Part No. BENET 06051000

ID No.	QTY.	MAS 90 PART No.	DESCRIPTION
4	1	SB-LOWWASH-00	Washer UHMW
3	1	SB-LOWBEAR-00	Lower Bearing UHMW
2	1	SB-UPBEAR-00	Upper Bearing UHMW
1	1	SBR-TUBE-00	Tube FRP

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TITLE	ASSEMBLY 01 FOR BENETEAU-411
DATE 6/25/98	SCALE
TIDES APPROVAL	DATE
MFGR APPROVAL	DATE
RELEASE FOR PROD.	DATE
DR. BY	LUIS EDERY
MATERIAL	AS SPCD
DRAWING NUMBER-CAD FILE	RS-411-11
PART NUMBER	AS SPCD

steering loads. There are no appreciable steering loads directly on the pin that is, however, provided.

A lightweight lock pin is necessary to lock the quadrant in the appropriate vertical position on the rudder stock. Tides pre-drills the pin hole in the quadrant and provides a drill jig which Beneteau uses to drill the mating pin hole in the rudder stock. The height of the quadrant is dependent on the height of the deck molding as it sits on the hull, and the height of the steering cable sheaves where they are installed inside the boat. These dimensions vary slightly from boat to boat, which is why final positioning and drilling of the pin hole in the rudder stock is accomplished on board.

SYSTEM INSTALLATION

Tides' completes its manufacturing of the carbon rudder system by priming the blade with anti-fouling primer and assembling all the parts together, except for the quadrant. The system is bubble-wrapped and packaged in foam and a stable shipping box.

Beneteau has only to unpack the rudder system, set it in place in the hull, line it up vertically, and fiberglass all around the base of the tube casing to bond it permanently into the hull. This can be done before the deck is installed, early in the production line. After the deck is fitted, Beneteau bonds the upper end of the tube casing to the deck, which completes the structural installation. Finally, they drill the pin hole for the exact position of the quadrant, attach the steering cables, and the system is complete.

As mentioned earlier, one of the best features of the Tides carbon rudder, besides its superior strength and stiffness, is that its overall construction and assembly significantly reduces installation time over a conventional rudder design. In conventional rudders, both the neck and carrier bearings are usually installed separately, each with its own structural connections and/or fiberglass build-up, all while they are kept in alignment with each other. The rudder usually has to go into the boat a few times to make sure the bearings are lined up, and likewise removed a few times so that it stays clean while the bearings are fixed in place. This all usually takes place after the deck is mounted onto the hull, so that the installers are hampered by working in a very confined space. Such a process consumes a lot of labor time and is fraught with misalignment errors. The Tides carbon rudder system greatly simplifies this whole process, producing a better installation at a lower cost of production time and labor.

QUALITY CONTROL

Some quality control steps have already been mentioned-inspection of the foam inside the rudder blade and stock; inspection of the carbon fiber laminate through the clear resin, etc. All of the molded parts are made in a similar manner, allowing similar inspection steps throughout the manufacturing process. Tides inspects the UHMW parts for fit and finish at every stage throughout the production line.

The Tides carbon rudder is one of the few production rudder designs that has been physically tested to destruction to assure that the strength that was *designed* into the system is actually *built* into the system. Prototype

#4

QUADRANT FOR BENETEAU 411

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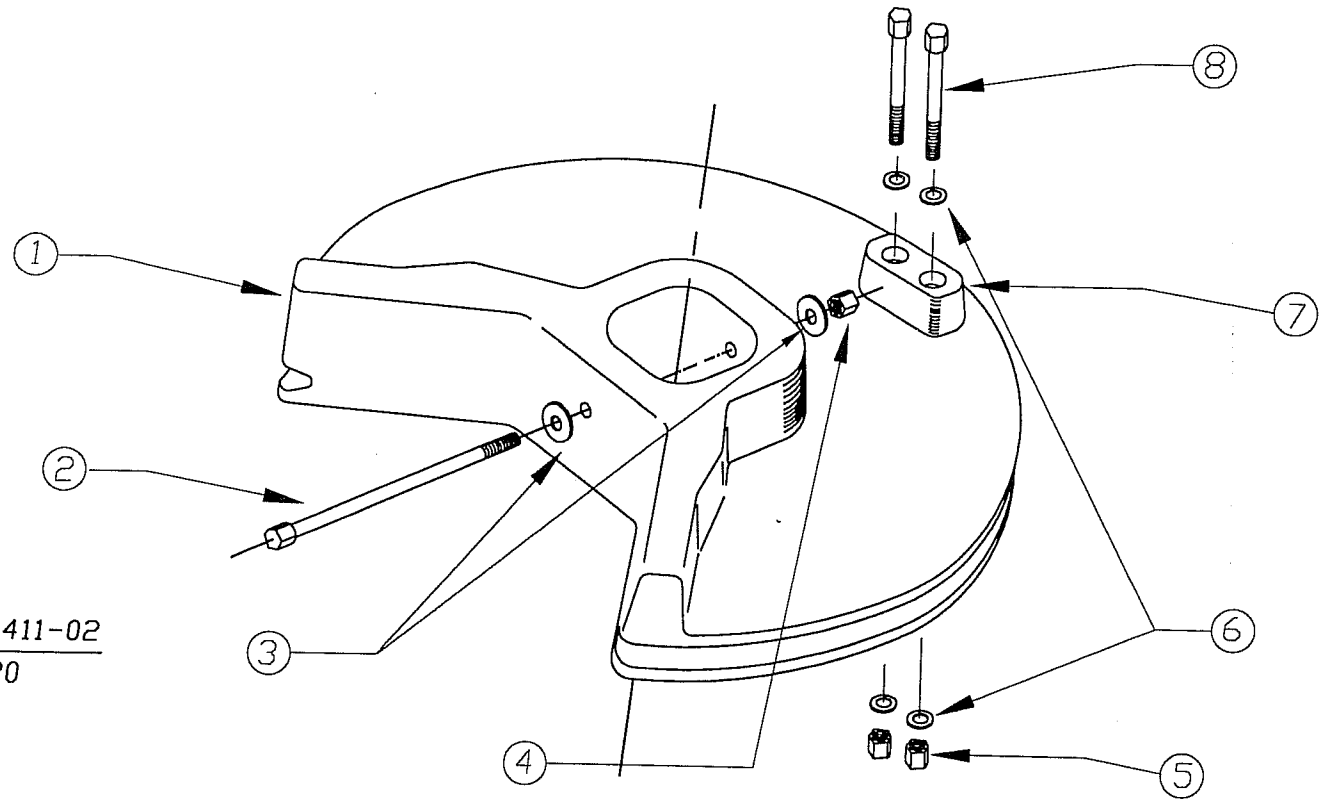

ASSEMBLY No. RS-411-02

BENET 06051020

ID No.	QTY.	MAS 90 PART No.	DESCRIPTION
8	2	3/8" BOLT	3/8"(9.5mms)-16 NC-2A, 2 3/4"(70mms) LONG, S.S.
7	1	SB-QDSTOP-00	UHMW STOPPER 1.570" x 1.750" x 3.750"
6	4	3/8 WASHER	Plain washer 3/8- S.S.
5	2	3/8 NUT	3/8" (9.5mms)-16 Hex. Nylon Nut, S.S.
4	1	5/16 NYLOC NUT	5/16(8mms)-18 Hex. Nylon Lock Nut, S.S. , S.S.
3	2	5/16 WASHER	Plain Washer 5/16- S.S.
2	1	5/16" BOLT	5/16"(8mms)-18 UNC-2A 5"(127mms.) LONG, S.S.
1	1	SB-QUAD-00	16"(406.4mms.)Dia. Quadrant for Rudder 411 (FRP, Carbon).

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MATERIAL	AS SPCD.
DRAWING NUMBER-CAD FILE	RS-411-02

development and testing brought to light various features of the system design and material processing that found their way in to the quality control inspection process so that Tides can assure that the quality, strength, and stiffness are indeed there. Tides also retains in its inventory a small section off the top of each rudder stock in order to keep a structural record of every rudder made. This stub verifies the rudder stock laminate and the completeness of its resin saturation and cure.

SUMMARY

There is no other sailboat rudder system, carbon or otherwise, built in the US today that is quite like the Tides carbon rudder system. All of the molded parts are built with the most advanced composite materials using ahead-of-the-art RTM technology. The integral blade-and-stock design is the only production carbon fiber rudder available today. All other carbon rudders have been expensive, custom, on-off designs. The Tides carbon rudder is verifiably strong, stiff, and simple to install. It is also the lightest production rudder available, being nearly half the weight of the rudder it replaced. The Tides carbon rudder system is the result of Tides Marine's commitment to superior design, manufacturing innovation, and a philosophical outlook to make a better product that is easier for its customers to install and use, and all at a much lower, and more beneficial, manufacturing cost.

Respectfully submitted,

Eric W. Sponberg
Naval Architect
Tides Marine Design Consultant
Sponberg Yacht Design Inc.
Newport, RI

15 September, 1998