MCIB

Marine Casualty Investigation Board

REPORT OF THE INVESTIGATION INTO THE SINKING OF THE YACHT "MEGAWAT" - 25 MAY 2005

The Marine Casualty Investigation Board was established on the 25th March, 2003 under The Merchant Shipping (Investigation of Marine Casualties) Act 2000

Published by The Marine Casualty Investigation Board
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CONTENTS

1. SYNOPSIS

1.1 On the 26 May 2005 the yacht "Megawat" sank following failure of the rudderstock. The craft was sailing from Dublin to Scotland in 20/30 knots of wind when a loud bang was heard, the steering failed and the craft began to take on water. The liferaft was deployed to allow transfer to another yacht "Quite Correct" which was in the vicinity. The liferaft failed to inflate. The crew were successfully transferred using the inflatable tender belonging, to "Quite Correct". The yacht "Megawat" sank in approximately 40 minutes.

2. FACTUAL INFORMATION

2.1 Details of Yacht "Megawat"

Official Number:	403578
Port of Registry:	Dublin
Registered Owner:	Philip Watson
Builder:	Hanse Yachts, Yachtzemtrum Greifswald, Postfrack 3165, 17461 Greifswald Salinstrabe 22, 17489 Greifswald, Germany
Model:	Hanse 371
Length overall:	11.25m
Breadth:	3.59m
Draft:	1.98m
Displacement:	5959 Kg (approx.)
Crew on board:	3 persons: Mr. Philip Watson, Mr. Robert Cagney, Mr. Brian McDowell
Design:	Judel/Vrolijk & Co
Date of build:	Launched Dec 2001
History:	Sailed approx. 14,000 miles
RCD[1] Category:	Category A 'Ocean'

2.2 Details of Liferaft

Manufacturer:	Zodiac
Model:	Coaster SY6 AC
Serial No:	XDC-1CN55-L899
Original Packing Date:	Dec 1998.
Approval Authority:	MM France
Capacity:	6 persons
Emergency Pack:	RORC (Royal Ocean Racing Club)

The liferaft was on hire from SOLAS Marine Services Ltd.

2.3 Description of Hanse 371

2.3.1 The Hanse 371 is constructed using fibre-reinforced plastic (FRP). The craft complies with Category A 'Ocean' requirements of the Directive 94/25/EC of the European Parliament and of the Council of 16 June 1994 (RCD Directive), see section 4 for full details.

2.3.2 As a Category A 'Ocean' the craft is "designed for extended voyages where conditions may exceed wind force 8 (Beaufort scale) and significant wave heights of 4 m and above but excluding abnormal conditions, and vessels largely self-sufficient".

[1]EU Recreational Craft Directive

cont.

2.3.3 The rudder is of a conventional spade rudder design. The rudderstock is solid aluminium (AlMgSi 1 F32). The stock is supported by self-aligning upper and lower bearings. Appendix 7.1 contains the rudder stock construction drawing. The rudderstock was tapered over a distance of 105mm from a maximum diameter of 88mm to a diameter of 50mm. The rudder tube extends approximately 450mm above the line of the bottom shell and is fitted with a rubber gaitor to prevent water ingress. The taper and gaitor are clearly visible in the photo contained in Appendix 7.2.

3. THE INCIDENT

3.1 Location of incident: South Rock Lighthouse vessel
(off coast of Northern Ireland)
20 miles ahead bearing 14 degrees.

Weather at time of incident: 20/30 knots SSE 1.5 ~ 2m swell

Course: 20 degree Downwind under mainsail

3.2 At approximately mid-day the 25 May 2005 Philip Watson reported:

"When surfing down one of the bigger waves at about 11 kn., there was a loud bang, like a pistol-shot. Helmsman Brian McDowell felt the wheel go "limp" and watched helplessly as "Megawat" rounded up sharply. I had been sitting in the companionway & Roger was lying down below. I asked Brian had the steering failed and he showed me, by spinning the wheel, that it had."

Following the incident contact was made with the UK Coastguard.

"The Coastguard answered immediately, received our lat/lon, and the information that we were in no immediate danger".

At this stage the main sail was lowered and the crew of "Megawat" noticed that the "Quite Correct" had turned around and was heading back towards "Megawat". An hour earlier "Quiet Correct" had passed "Megawat" and was also enroute to Scotland.

Following a further inspection Philip Watson noted that:

"Water was well over the floorboards, and shoes etc, were floating about. The Coastguard was contacted again. At this stage Philip Watson spotted the rudder, with about half its stock attached, floating away from us".

"Quite Correct" was now in attendance and it was decided a yacht-to-yacht transfer was too dangerous and transfer would be undertaken using the liferaft.

"The liferaft was put into the water alongside the cockpit and sharply tugged the painter line to inflate it."

This would allow transfer to "Quite Correct" by "hanging off" "Megawat" on a long painter. The liferaft painter was pulled and the raft failed to inflate.

"Disappointment may not be quite the right word for what I was feeling when the hissing stopped after just 5 seconds, leaving about the right amount of CO2 for a life-jacket in the raft! We cut the hopelessly under-inflated raft away as it was likely to impede rescue."

cont.

The crew of "Megawat" were transferred to "Quite Correct" by using its inflatable tender, which was stored inflated on the foredeck.

A detailed narrative written by Philip Watson is reproduced in Appendix 7.3.

4. EVENTS FOLLOWING THE INCIDENT

4.1 OUTLINE OF THE INVESTIGATION

The recovery of the rudder and liferaft were key to the investigation. The yacht had sunk in approximately 80 metres of water and the Marine Casualty Investigation Board did not consider recovery of the craft viable or necessary. Towards the end of June the rudder was recovered off Cambletown, Scotland and the liferaft was recovered off the coast of Northern Ireland.

A review of the applicable legislation that applies to the craft, a review of the retrofitting of the autopilot system was undertaken and detailed technical examinations of the rudder and the liferaft were carried out.

4.2 RECREATIONAL CRAFT DIRECTIVE (RCD)

In accordance with the RCD Directive manufacturers of recreational craft have to follow the "Conformity Assessment" procedure set out in Article 8 of the RCD Directive before placing a recreational craft on the market and/or putting into service in the EU. Manufacturers can adopt alternative routes to achieve certification, which are set out in Article 8(2) of the RCD Directive. The routes are based on the length of the craft and the intended operational environment.

The Hanse 371 model was certified in accordance as category A ‘Ocean’. On the basis the craft was less than 12 meters in length the craft was certified using internal production control plus tests (module Aa) referred to in Annex VI of the RCD Directive. Copies of the Module Aa certification and EC Type Examination Certification are contained in Appendix 7.4.

The RCD Directive sets out "Essential Requirements" for recreational craft (Annex I of the RCD Directive). The requirements include:

- Owners Manual
- Structure
- Stability and freeboard
- Buoyancy and flotation
- Flooding, and
- Steering systems

For each "Essential Requirement" manufacturers are required to state the standard that has been applied to a particular "Essential Requirement". These requirements are required to be stated on the Declaration of Conformity, see Appendix 7.4 for details of the standards applied to Hanse 371.

cont.

In accordance with Annex I, A, 3.5 of the RCD Directive the craft is required to:

"be designed so as to minimize the risk of sinking. Particular attention should be paid where appropriate to:

— cockpits and wells, which should be self-draining or have other means of keeping water out of the boat interior,
— ventilation fittings
— removal of water by pumps or other means."

Due to the catastrophic failure of the rudderstock and deluge of water the electric bilge pump and manual bilge pumps fitted to the craft were insufficient capacity to control the flooding of the craft. No watertight bulkheads were fitted in the craft.

4.3 RETROFITTING OF AUTOPILOT SYSTEM

The craft was retrofitted with a Simrad (formerly Robertso) model AP21 autopilot system. Full details of the system supplied could not be obtained. The retrofitted tiller arm was designed in two halves that clamped to the rudderstock using a keyway.

Noonan Boats and Tony Brown Electronics fitted the autopilot system. The existing keyway was used as it extended a sufficient distance below the existing tiller arm and accordingly no machining of the stock was necessary, see photo in Appendix 7.2.

The steering gear system is one of the "Essential Requirements" of the RCD Directive. Referring to the manufacturers Declaration of Conformity in Appendix 7.4 any changes which "touch the essential requirements" must be agreed with the manufacturer to ensure the continued validity of the manufacturers certification. It is important to note factory fitted autopilot systems have the standard tiller arm replaced by an "L" shaped tiller arm similar to the arm in Appendix 7.5.

The European Commission were asked their opinion in relation to the retrofitting of equipment and the need for the continued validity of RCD certification. A copy of their response is contained in Appendix 7.6.

4.4 TECHNICAL ANALYSIS OF RUDDER STOCK

Hanse Yachts, in agreement with the MCIB, sent the rudderstock to Fraunhofer Gesellschaft - AGP, Rostosk, Germany for detailed technical analysis, Appendix 7.7 contains a copy of their report.

cont.

4.5 TECHNICAL EXAMINATION OF LIFERAFT

Following the recovery of the liferaft ZODIAC International were requested to examine the liferaft to establish the reason for failure. A copy of their report is contained in Appendix 7.8. Also contained in Appendix 7.8 is an extract for the Liferaft log book retrieved from the liferaft.

4.6 ANTIFOULING

"Megawat" was antifouled using the Awlgrip Gold system. The manufacturers advised the system is copper based and is not recommended on aluminium. Hanse Yachts advised similar corrosion has been found on other rudderstocks that were coated with copper based antifouling. The owners manual does not make any reference to the aluminium stock and does not contain a warning about the use of copper based antifouling.

4.7 DIAMETER OF THE RUDDERSTOCK

The rudder stock diameter was determined in accordance with the American Bureau of Shipping *Guide for Building and Classing Offshore Racing Yachts,* Appendix 7.9 contains a copy of the designers original calculations. The calculations demonstrate the diameter of the rudderstock complies with the ABS requirements.

4.8 CARRIAGE OF SAFETY EQUIPMENT

There are no regulatory requirements relating to the carriage of safety equipment on pleasure craft less than 13.7 metres overall other than the carriage of suitable "personnel flotation devices or lifejackets" in accordance with *Merchant Shipping (Pleasure Craft) (lifejackets and Operation) (Safety) Regulations 2004.*

5. CONCLUSIONS

5.1 RECREATIONAL CRAFT DIRECTIVE

5.1.1 Based on the EU Commission response it appears the owners of recreational craft that undergo modifications that relate to the "essential requirements" of the RCD Directive are required to have the modifications assessed for compliance with the RCD Directive.

5.1.2 Hanse Yachts did not produce the technical documentation described in paragraph 3 of Annex V of the RCD Directive.

5.2 RETROFITTING OF EQUIPMENT

5.2.1 The Declaration of Conformity issued by the manufacturer was invalidated as a result of the modification to the steering system.

5.3 RUDDERSTOCK FAILURE

5.3.1 The chemical composition of the rudderstock material corresponded to the specification stated.

5.3.2 The mechanical characteristics of yield point and tensile strength determined are about 10% above the upper limits of the strength class F32, which means the rudderstock had a reduced toughness leading to fast growth of any fissure present.

5.3.3 The rudderstock was roughly machined.

A surface finish of 80mm is rougher than the surface finish achieved for sand casting and flame cutting. As stated in the test report in Appendix 7.7 80mm is "considered as very rough machine work".

5.3.4 The macroscopic findings indicate a fatigue fracture due to a V-notch (approx. 0.3mm) in the circumferential direction with unsymmetrical bending stress at the notch.

It is unclear how the initial V notch defect was formed. There are two possible scenarios.

5.3.5 The defect was caused during manufacturing which resulted in a rough surface finish.

5.3.6 The retrofitted autopilot tiller arm was clamped to the rudderstock so the lower edge of the retrofitted tiller arm caught the top of the taper or a particle was present when the new tiller was clamped onto the rudderstock causing the initiating V-Notch defect.

cont.
The presence of an initial defect leads to rapid growth of a fatigue fracture. Final failure will occur when the original diameter of the rudderstock is sufficiently reduced to lead to failure. Aluminium does not have a fatigue endurance limit unlike steel.

5.3.7 The surface finish detailed on the designers drawing, see Appendix 7.1, was specified as "smooth" and the drawing specified no dimensional tolerances.

On a constructional drawing the surface finish and dimensional tolerances should be specified in accordance with best engineering practice. "Smooth" is not a recognised engineering specification.

5.3.8 The exposed part of the rudderstock between the underside of the hull and the top of the rudder blade was corroded.

The antifouling (Awlgrip Gold) was incompatible with the aluminium rudderstock. The manufacturers of Awlgrip have advised that Awlgrip Gold should not be used on aluminium components as it is copper based and causes corrosion if applied to aluminium. Hanse Yachts advised that this type of corrosion has been found on other Hanse Yachts. Continued corrosion of the rudderstock could eventually lead to failure.

5.3.9 The owners manual does not warn the owner about the use of copper based antifouling.

5.4 FAILURE OF THE LIFERAFT

5.4.1 The liferaft was on hire from SOLAS Marine Services Ltd. and was last inspected in January 2005 by SOLAS Marine Ltd.

The Liferaft logbook recovered from the liferaft indicates "periodic controls" on 15 March 2001 and 11 January 2006. The CO2 bottle was refilled March 2001 as the liferaft was accidentally deployed by the owner. The liferaft was examined by SOLAS Marine Ltd each year to replace expired items such as flares, seasick tablets etc. SOLAS Marine Services Ltd state the liferaft was test inflated each year. ZODIAC servicing instructions state the liferaft shall undergo "periodic control" yearly after the first 3 years.

5.4.2 SOLAS Marine Services Ltd are not appointed ZODIAC Agents in Ireland and they do not have any ZODIAC servicing instructions.

5.4.3 The percussion head was found not to be tight.

5.4.4 During the course of the technical examination of the liferaft by ZODIAC International a new CO2 cylinder and percussion head were fitted and the liferaft was inflated successfully.

cont.

5.5 CARRIAGE OF SAFETY EQUIPMENT

5.5.1 There are no requirements to carry any safety equipment on recreational craft less than 13.7 metres in length other than other than the carriage of suitable "personnel flotation devices or lifejackets" in accordance with Merchant Shipping (Pleasure Craft)(lifejackets and Operation) (Safety) Regulations 2004.

6. RECOMMENDATIONS

6.1 The Marine Survey Office should make a submission to the Recreational Craft Directive (RCD) standing committee:

6.1.1 To request a review of the RCD in relation to watertight arrangements in way of rudderstocks in the event of failure on category A and B recreational craft.

6.1.2 To consider an explicit statement in the RCD in relation to specification of dimensional tolerances and surface finishes for machined components.

6.1.3 To consider a requirement that Owners Manuals should clearly specify the specification of antifouling and highlight any special requirements.

6.2 The Maritime Safety Directorate should issue a Marine Notice to highlight the dangers of using copper based antifouling on craft with aluminium components.

6.3 The Maritime Safety Directorate should notify the relevant German Authority in relation to the lack of the technical documentation for the Hanse 371 model in accordance with paragraph 3 of Annex V of the RCD.

6.4 The Maritime Safety Directorate should publish a Marine Notice to clarify the situation regarding modifications to recreational craft and compliance with the RCD.

6.5 The Maritime Safety Directorate should issue a Marine Notice recommending non-SOLAS/MED Liferafts to be serviced only by authorised agents appointed by the manufacturer.

6.6 The Marine Survey Office should investigate the servicing of non-MED liferafts and introduce legislation in relation to servicing if considered necessary.

7. LIST OF APPENDICES

7.1 Rudder construction drawing

7.2 Photograph of rudder installation on sister craft

7.3 Detailed narrative

7.4 RCD certification

7.5 ‘L’ shape tiller arm

7.6 European Commission response relating to retrofitting of equipment

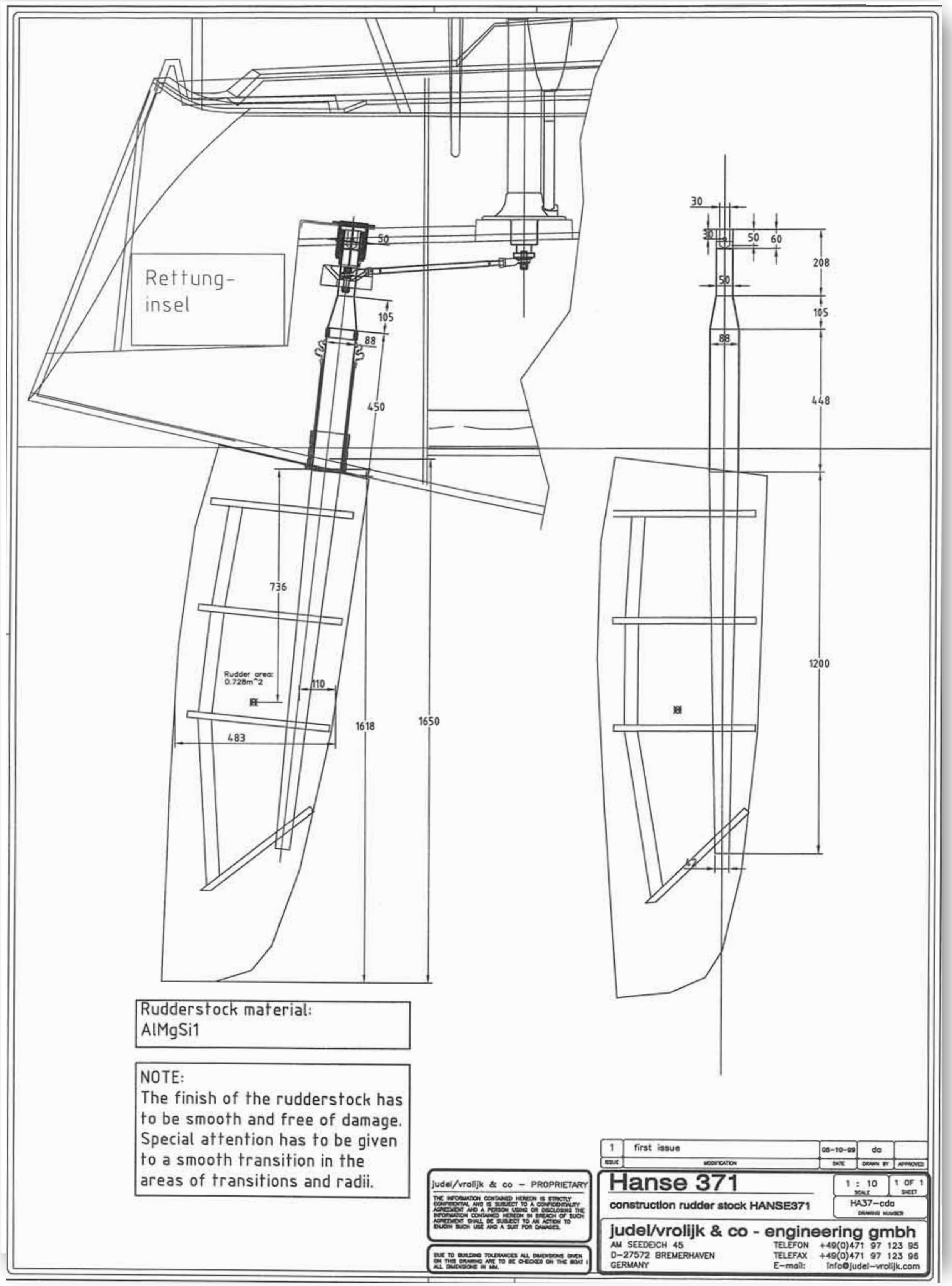
7.7 Fraunhofer Gesellschatt technical report on the rudderstock failure

7.8 Zodiac International technical report on liferaft failure

7.9 Judel/Vrolijk rudderstock design calculations

7.10 Photograph of the "Megawat"

Appendix 7.1 Rudder construction drawing



Appendix 7.2 Photograph of rudder installation on sister craft

Photographs courtesy of the RNLI at Padstow.

Appendix 7.3 Detailed Narrative

APPENDIX C – DETAILED NARRATIVE

Megawat's last hour - 28/5/05

Philip Watson describes the sinking of his boat, *Megawat*

Author: Philip Watson Posted on: 28/5/05

Photos taken from yacht *Quite Correct*

Amidst all the activity during the rescue, Peter Flynn had the presence of mind to take this sequence of pics. Peter is with the American YC Newburyport MA, USA, and was on board *Quite Correct* by invitation of crew member Tom Mulligan of the National YC.

Boat :	Hanse 371, Megawat , launched Dec 2001, ocean miles 14,000 approx.
Crew :	Philip Watson, Roger Cagney, Brian McDowell.
Date/Time :	Wed 25th May, mid-day approx., sailing to Scottish Series.
Weather :	20 - 30 Kn. SSE. Sea State:- 1.5 m - 2 m swell.
Position :	South Rock Light vessel 20 miles ahead bearing 014 degrees.
Sail :	Full main, genoa fully furled, (too broad a reach to fill it, not quite broad enough to pole it out)
Liferaft :	A hired Zodiac 6 - person. 5 years old, last serviced, Jan 2005.

When surfing down one of the bigger waves at about 11 kn., there was a loud bang, like a pistol-shot. Helmsman Brian McDowell felt the wheel go "limp" and watched helplessly as *Megawat* rounded up sharply. I had been sitting in the companionway & Roger was lying down below. I asked Brian had the steering failed and he showed me, by spinning the wheel, that it was. At this time I suspected the (Lewmar/Whitlock) rod & ball-joint steering linkage had failed.

I went below, and having checked with Roger that it was appropriate to put out a Mayday on VHF CH. 16, did just that.


Minus 60 minutes

The Coastguard answered immediately, received our lat/lon, and the info. that we were in no immediate danger.

Roger and I spent the next few minutes pulling down the main, which is difficult with a fully battened main unless you are head-to-wind. We were lying broadside. At this time we could see that the **N.Y.C. Jeanneau 54' *Quite Correct***, owned by John Roberts, and with our friends Brian Mathews and John Veale (Hammer!) aboard, was coming back towards us. An hour earlier she had passed us out so close by that we had a short and jovial conversation with them.

Appendix 7.3 cont. Detailed Narrative

Minus 11 minutes

When I next went below it was to discover an unwelcome development. Water was well over the floorboards, and shoes etc, were floating about. Time to radio the Coastguard again, and reveal the worsening situation. They confirmed having scrambled two lifeboats and a helicopter. At about this time I spotted our rudder, with about half its stock attached, floating away from us.

It was too rough when *Quite Correct* got back to us to attempt a transfer from yacht-to-yacht, without risking rig and hull damage to the rescuing yacht, and so I put the liferaft into the water alongside the cockpit and sharply tugged the painter line to inflate it. We hoped to get into it, let it away from *Megawat* on a long painter, and get aboard the 54 footer from the raft. Disappointment may not be quite the right word for what I was feeling when the hissing stopped after just 5 seconds, leaving about the right amount of CO_2 for a life-jacket in the raft! We cut the hopelessly under-inflated raft away as it was likely to impede rescue.

Minus 10 minutes

Water was now almost level with the companionway and we were eager (if at all possible) to have a dry transfer to the larger yacht, so we hailed them to launch their own dinghy, which was fully inflated on the foredeck. It's a RIB, about 11 feet long, so it took four crew to lift it over the rails, but they did it perfectly. They streamed it downwind to us on a long painter, and we were mightily relieved to get into it without the need for a spell in the cold water. We each brought a kitbag of gear, but inevitably, not the gear one would have chosen if you had an extra hour to consider it!

Minus 9 minutes

The crew of *Quite Correct*, having got us all safely aboard, radioed the Coastguard, to "stand down" the lifeboat and helicopter, adding that *Megawat* would sink very shortly and thus be no danger to shipping.

Aboard the luxurious 54', we circled for about 10 minutes, taking pictures, until she finally dropped her stern and sank in 66 m of water ... not I sight I would ever wish to see again.

We were lucky! Brian Mathews had been masterly in his handling of such a large yacht at close quarters.

To have a "disaster" you need three things to go wrong, we had two ... the sinking itself, and the lack of an inflated liferaft ... if the VHF hadn't worked ... if it was dark ... if there were no other boats about ... if, if, if ?

Minus 4 minutes

Appendix 7.3 cont. Detailed Narrative

The very next day two members of the Hanse Yachts technical team flew from Germany to meet me, together with two members of the Irish Marine Casualty Investigation Board, (M.C.I.B.) who had in recent times investigated the Debonair and Cabin Fever accidents. Together we hope to find out why our rudder-stock snapped.

At this time it is still a mystery how an 85 mm diameter solid alloy bar, as used in 600+ Hanse yachts up to 41 feet long, and in hundreds of thousands of other yachts world-wide, should fail where it failed.

When a rudderstock breaks, it is almost always at the bottom bearing, and often as a result of a previous grounding, which definitely did not happen in *Megawat's* case.

Because it broke roughly half way between the bottom bearing and the top bearing, just below the point where the quadrant is clamped around a "key", the part of the stock still attached to the blade exerted massive leverage on the bottom end of the rudder tube.

The stock probably broke the tube off the inside of the hull, leaving a hole big enough to take in a couple of hundred gallons per minute, which allowed her to sink just 40 minutes after the catastrophic stock failure.

Currently, efforts are being made to recover the rudder, which is probably on a Co. Down shore, to examine in great detail the type of break, and possibly if this isn't found the MCIB might feel it worth the resource to look at the other side of the break on the sunken yacht, which might be easier to find?

More info. later, as facts are found.

Philip

Minus 3 minutes

Minus 2 minutes

Minus 1 minute

Appendix 7.4 RCD Certification

Sailing Yacht „Hanse 371“ Yachtzentrum Greifswald GmbH & Co. KG

EC-Declaration of Conformity

corresponding to the EC- Recreational Craft Directive 94/25/EC, Annex VI

With this we declare that the design and type of the following characterised yacht as well as the carried out product that was brought into service by us is conform to the essential health and safety requirements of the European Recreational Craft Directive.
This declaration will lost its validity if anyone carries out changes on board which touch the 'essential safety requirements' and are not settled amongst ourselves.

Description of the boat:	Hanse 371
Type::	Keel yacht
Serial number of the hull:	*DE-YZG37052F101*
Category of design:	A (OCEAN)
Module of certification:	Aa
Relevant Directives:	EC Recreational Craft Directive (94/25/EC)
Used standards:	see annex
Examining authority:	Lloyd's Register Quality Assurance GmbH - Yacht Services -
Address:	Mönckebergstr. 27; D – 20095 Hamburg
Module: Aa	EC-Certificate of Conformity no.: 219/00

Date / Signature of manufacturer

Michael Schmidt
manager

Manufacturer: Yachtzentrum Greifswald GmbH & Co. KG; Salinenstraße 22; D – 17489 Greifswald

Appendix 7.4 cont. RCD Certification

Sailing Yacht „Hanse 371“ Yachtzentrum Greifswald GmbH & Co. KG

Declaration of conformity
Applied harmonised standards or drafts for standards, respectively, corresponding to the EC-Recreational Craft Directive 94/25/EG

EC-Directive	ISO-Norm
1. Principal Data	8666
2.1. Identification of hull	**10087**
2.2. Manufacturer's plate	14945
2.3. To go over the side protection	15085
2.4. Owner's manual	**10240**; 11192
3.1. Structure	12215 Teil 1
3.2. Stability and freeboard	12217 Teil 2
3.3. Buoyancy and flotation	12217 Teil 2
3.4. Openings in the hull	12216; 9093
3.5. Flooding	11812; 12217; 12216; **8849**; 15083
3.6. Manufacturer's maximum recommended load	14946
3.7. Place for liferafts	Sicherheitsrichtlinie des DSV
3.8. Emergency exit	9094 Teil 1, 12216
3.9. Anchoring, mooring and towing	15084
4. Handling characteristics	**8665**; 11592
5.1. Engine and engine spaces	**7840**; 9094; 10088; **8846**; **4585**; 11812; **4566**
5.2. Fuel system	**7840**; **8469**; 9094; 10088
5.3. Electrical system	**8846**; **8849**; **9097**;
5.4. Steering system	**8847**; **8848**; **9775**; **10592**; 13929;
5.5. Gas system	**10239**
5.6. Fire protection	9094
5.7. Navigation lights	KVR
5.8. Discharge preventation	8099

(e.g. **8847** - harmonised standards)

1. Description of the yacht
1.1 Main particulars
1.1.1 Principal dimensions

Length overall	L_{OA}		11,25 m
Length on waterline	L_{WL}		9,85 m
Breadth max.	B_{max}		3,55 m
Light weight /Displacement			6.500 kg/ 6.000 kg
Ballast			2.245 kg
Draught - normal keel	D_{max}	abt	1,98 m
Draught - flat keel	D_{max}	abt	1,69 m
Draught – drop keel	D_{max}	abt	1,08 m
Headroom **	H_D	abt	16,80 m

** The headroom can become a critical dimension when passing bridges etc. It is the height between waterline and mast top (without antennas or radar reflector, and doesn't include top lights or other attachments).
Please enter the real headroom into the owner's manual after the installation of devices.

Appendix 7.4 cont. RCD Certification

Sailing Yacht „Hanse 371" Yachtzentrum Greifswald GmbH & Co. KG

LLOYD'S REGISTER QUALITY ASSURANCE GmbH Yacht-Services

EU-Konformitätszertifikat

Lloyd's Register Quality Assurance GmbH, eine Benannte Stelle im Sinne der EG-Richtlinie 94/25/EG für die Sportschiffahrt, hat die Berechnungen des Herstellers und/oder die Kontrollen für die Stabilität und des Auftriebs entsprechend den grundlegenden Sicherheitsanforderungen 3.2 und 3.3 für die Boot-Entwurfskategorie ..A.... im Hinblick auf das Boot wie unten beschrieben überprüft, und bestätigt, daß diese grundlegenden Sicherheitsanforderungen in Übereinstimmung mit dem Modul Aa der obigen Richtlinie zufriedenstellend erfüllt wurden.
Die Benannte Stelle war nicht in Produktionskontrollen einbezogen wie evtl. angenommen werden könnte, wenn die EU-Kennummer neben dem CE-Kennzeichen erscheint.

Dieses Zertifikat ist ausgestellt für:

Antragsteller	: **Yachtzentrum Greifswald GmbH** Salinenstraße 22 **D – 17489 Greifswald**
Bootstyp	: Segelyacht mit festem Kiel „Hanse 371"
Modul	: Aa
Rumpflänge	: 11,33 m
vom Hersteller empf. max. Zuladung	: 1000 kg
max. Personenzahl	: 8
Hersteller	: **Yachtzentrum Greifswald GmbH** Salinenstraße 22 **D – 17489 Greifswald**
Spezifizierte Normen	: ISO 14945, 14946, 12217-2
Zertifikat-Nr.:	219/00
Ausstellungsdatum:	19. Januar 2000

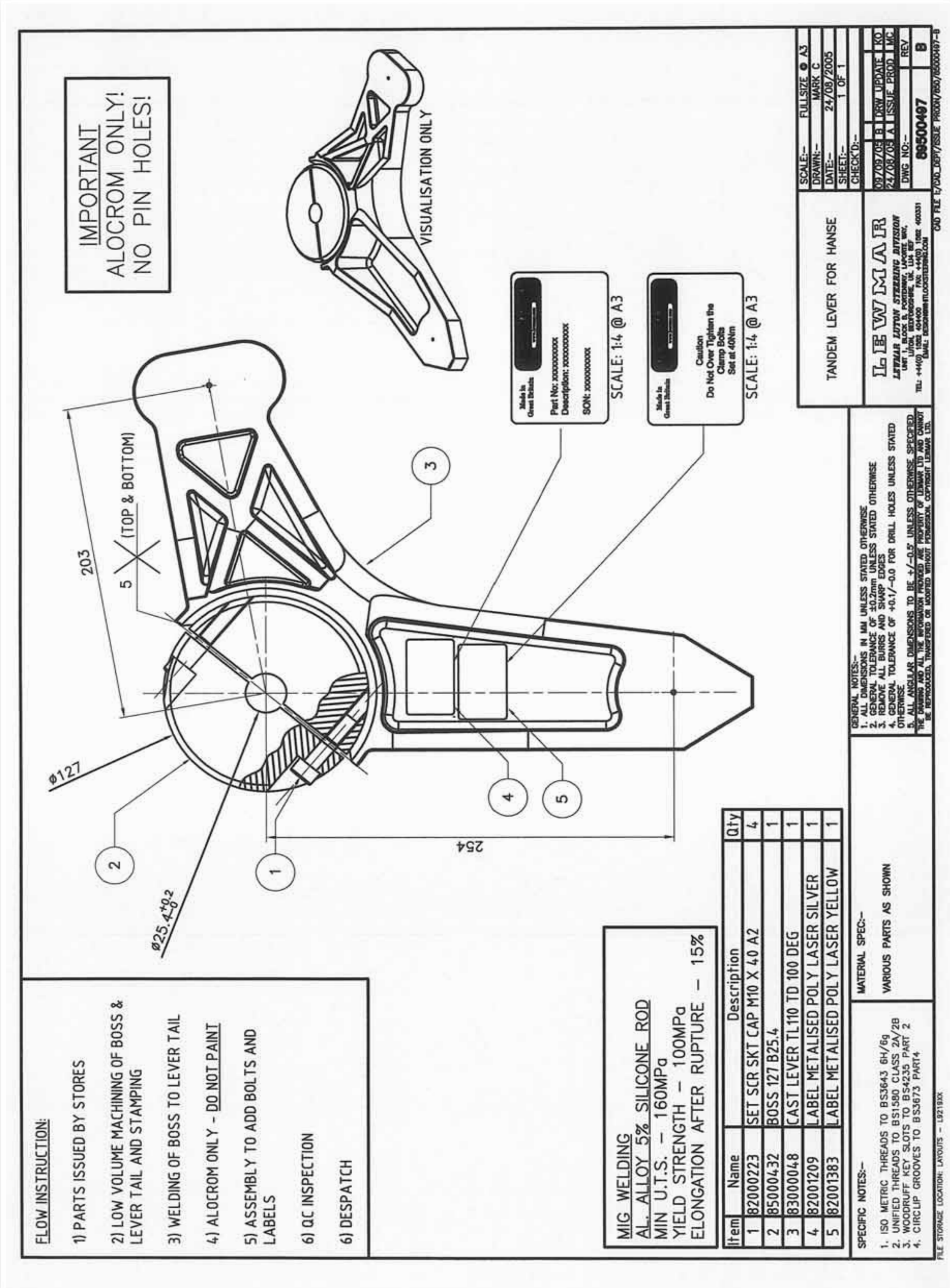
LLOYD'S REGISTER OF SHIPPING Lloyd's Register YACHT-SERVICE HAMBURG

LRQA GmbH
EU-Kennummer: 0525

Name:
Lloyd's Register Quality Assurance GmbH

Unstimmigkeiten, die Dienstleistungen der Gesellschaft LRQA GmbH betreffen, oder Verträge die diese Dienstleistungen zum Inhalt haben, unterliegen deutschem Recht mit Gerichtsstand in Hamburg.
Lloyd's Register Quality Assurance GmbH ist eine Tochtergesellschaft der internationalen Klassifikationsgesellschaft Lloyd's Register of Shipping, registered office: 71 Fenchurch Street, London EC3M 4BS

Appendix 7.5 ‘L’ shape Tiller Arm



Appendix 7.6 European Commission response relating to retrofitting of equipment

APPENDIX 7.6 – EUROPEAN COMMISSION RESPONSE RELATING TO RETROFITTING OF EQUIPMENT

Dear Mr. Russel,

The certification procedures in the Recreational Craft Directive are primarily aimed at ensuring that recreational craft are assessed on their conformity with the safety requirements **before** they are placed on the market and/or put into service. As a result the Directive does not contain requirements related to the further use and maintenance of the craft.

However it has been recognised in the context of the scope of new approach directives that products that have been subject to important changes may be considered as new products that have to comply with the provisions of the applicable directives when placed on the market and put into service. Paragraph 2.1 of the Commission Guide to the implementation of directives based on the new approach and the global approach (the "Blue Guide" – see http://europa.eu.int/comm/enterprise/newapproach/legislation/guide/document/1999_1282_en.pdf) specifies in this respect that :

A product, which has been subject to important changes that aim to modify its original performance, purpose or type after it has been put into service, may be considered as a new product. This has to be assessed on a case-by-case basis and, in particular, in view of the objective of the directive and the type of products covered by the directive in question. Where a rebuilt or modified product is considered as a new product, it must comply with the provisions of the applicable directives when it is placed on the market and put into service. This has to be verified – as deemed necessary according to the risk assessment – by applying the appropriate conformity assessment procedure laid down by the directive in question. In particular, if the risk assessment leads to the conclusion that the nature of the hazard or the level of risk has increased, then the modified product should normally be considered as a new product. The person who carries out important changes to the product is responsible for verifying whether or not it should be considered as a new product.

Likewise, the Commission's guide to the application of the recreational craft directive 95/25/EC (see http://europa.eu.int/comm/enterprise/maritime/maritime_regulatory/doc/guide_v2_94_25_en.pdf) provides similar guidance for cases where retrofitting of recreational craft could have an impact on its compliance with the requirements of the Directive (see below). Please note that this guidance is meant to be applied in the context of manufacturer responsibility and in the case that an existing CE-marked craft is rebuild or modified (outside the EU) and then placed on the market or put into service in the EU.

The "re-building" or modifying of a boat (or component) in the context of manufacturer responsibility means that the boat has been changed to such an extent that compliance considerations with the Essential Requirements are altered from those of the boat when originally assessed. This would mean, for example, that the stability and buoyancy characteristics of the boat have been changed due to the addition of new accommodation or rigging arrangement. Such modification would mean that the "new" boat presents a new overall design and with it new risks. In this respect such a modification in a third country of a boat with CE Marking or an existing boat would require compliance with the Directive if placed on the EEA market or put into service.

As to your question relating to the validity of the RCD certification when an owner modifies his craft impacting on the compliance with one of the essential requirements, it appears to me that this certification can only cover the craft's compliance with the essential requirements in the condition and state it was at the time of its placing on the market/putting into service. Any change made to the craft afterwards that would impact on its compliance with the essential

Appendix 7.6 cont. European Commission response relating to retrofitting of equipmen

requirements is obviously not covered by this certification. Continued validity of the certification can only be ensured if the changes to the craft are assessed on their conformity with the Directive and recertified accordingly. But this would be, as already mentioned in the guidance above, required in case the product were to be placed on the market and/or put into service after such modification.

I hope this information will be helpful.

Kind regards,

Johan Renders
European Commission
DG Enterprise & Industry
Maritime Industries
Recreational Craft Legislation

Appendix 7.7 Fraunhofer Gesellschatt technical report on the rudderstock failure

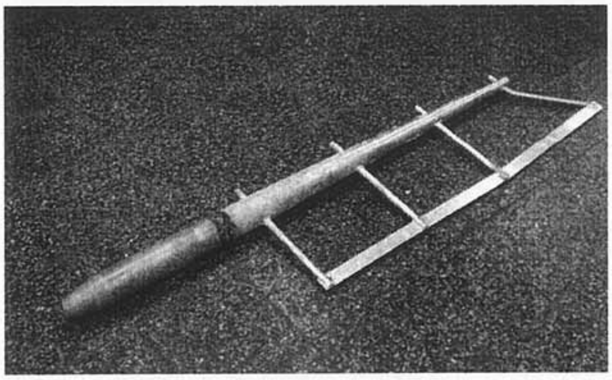
Fraunhofer Gesellschaft - AGP
J.-Jungius-Str. 9
18059 Rostock

Univ.-Prof. Dr.-Ing. M.C. Wanner

IPA
Fraunhofer Anwendungszentrum Großstrukturen in der Produktionstechnik

TEST REPORT 07/05

Damage evaluation of an Aluminium Rudder Shaft



Tests for:

HANSE YACHTS GmbH & Co. KG
Herrn Karl Dehler

Carried out/evaluated by:

Dipl.-Wirt.-Ing. Ben Becker
Dr.-Ing. Knuth-Michael Henkel
Dr.-Ing. R. Schneidenbach
Ingenieurgemeinschaft Dr. Meyer & Dr. Horn

The test report consists of 9 pages.

Rostock, 03 August 2005

Appendix 7.7 cont. Fraunhofer Gesellschatt technical report on the rudderstock failure

1 Examinations to be carried out

The company HANSE Yachts delivered a damaged rudder shaft to the Fraunhofer-Gesellschaft. The following examinations were carried out:

- Establishing and classifying the areas of fatigue fracture/ forced fracture
- Assessing the bearing value of the remaining cross-sectional remnant
- Determining the chemical properties of the material and further material characteristics (yield point, tensile strength)
- Determining notch-impact effects at the place of fracture (possibly caused by a clamping flange)
- Determining the state of corrosion holes in the lower part and assessing the effect on the burden capacity

The aim of the examinations is especially the establishment of the cause of damage. This is mainly done by examining the fractured surface and analysing the shaft material. The results gained by the Ingenieurgemeinschaft Meyer & Horn for some sub-contracted tasks were combined with the examination results yielded by the Fraunhofer Anwendungszentrum Rostock and were entered into the report.

2 Establishing and classifying the areas of fatigue fracture/ forced fracture and the effect on the burden value

The macroscopic findings indicate an fatigue fracture due to a V-notch in the circumferential direction with unsymmetrical bending stress at the notch, corresponding to a comparison of cases of damage in the specific literature (Lange: System. Beurteilung techn. Schadensfälle, Fig. 1).

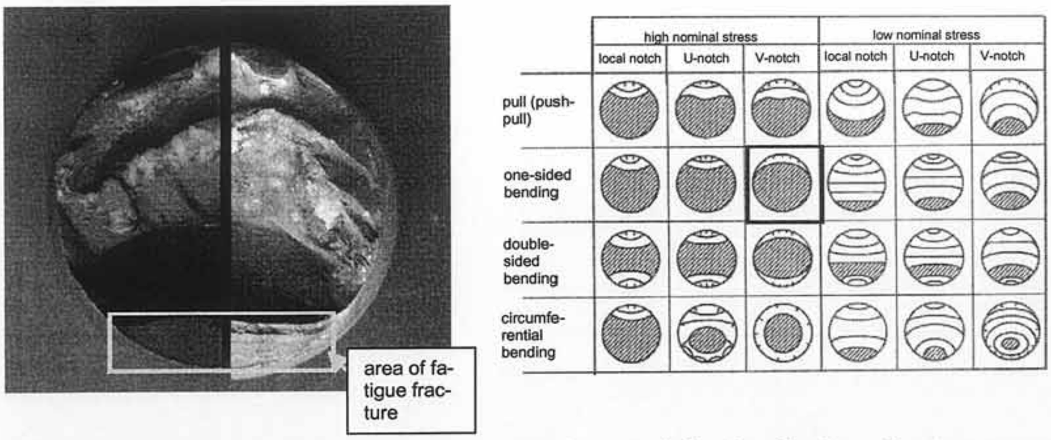


Fig. 1: Fracture area with fatigue fracture and forced fracture (left), classification of fracture areas according to the basic forms of fatigue fractures (right)

A fatigue fracture can be recognised by typical arrest lines. It amounts to about 10 per cent of the total fracture area, the part of the forced fracture, therefore, is about 90 per cent.
A V-notch could be identified as the starting point of the fatigue fracture in the crack- starting area (Fig. 2).

Appendix 7.7 cont. Fraunhofer Gesellschatt technical report on the rudderstock failure

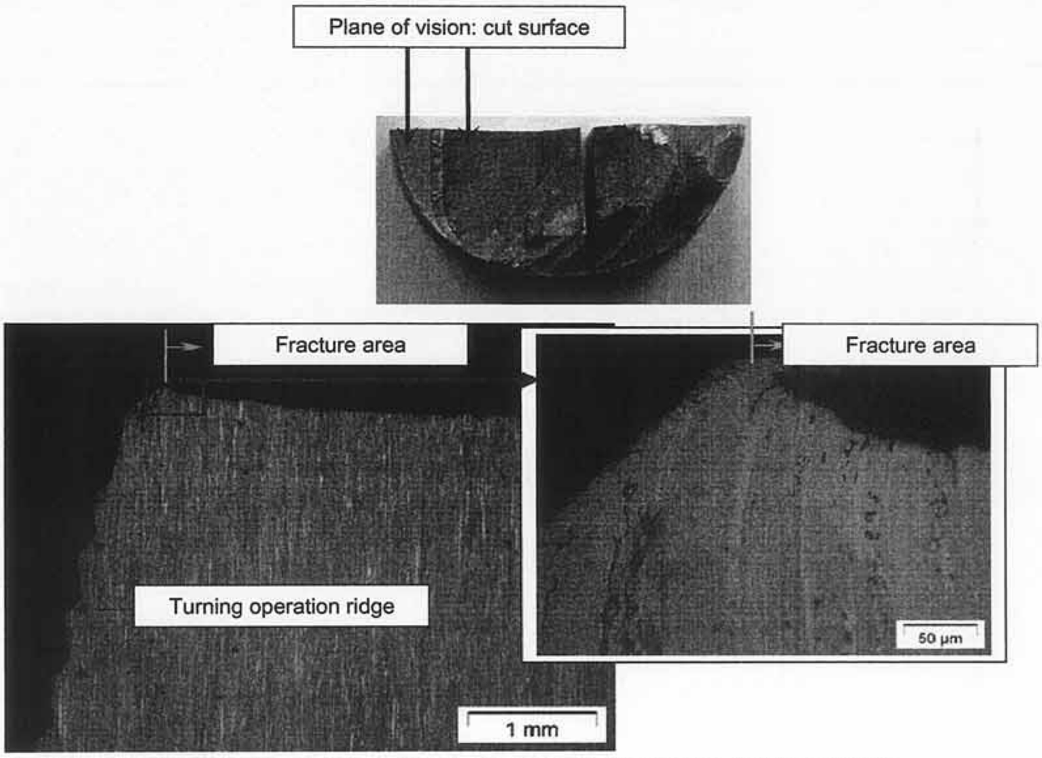


Fig. 2: Starting point of the fracture area (Source: Examination report Fa. IGHM Nr.10a/05)

Shape and position indicate that the starting point of the fatigue fracture is not a turning operation ridge in the conical area (with RZ about 80 µm), at the entrance into the cylindrical part a magnification shows areas of deformation and cracks (UB-Nr. 10a/05, p. 4) (Fig. 2, left side). The deviation from the line-structure of the material structure (Fig. 2, right side) may have been caused by a plastic deformation of the material prior to the beginning of the fatigue fracture.

3 Determining the chemical properties of the material and further material characteristics

Material of the rudder shaft according to specification AlMgSi 1 F32, i.e. characteristics of the material according to EN 754, 755/ DIN 1746, 1747:

Tensile strength R_m (MPa)	320-380
0,2%-elongation limit (yield point) $R_{p0,2}$ (MPa)	270-370
Breaking elongation	> 6%

The material is hardenable.

3.1 Chemical properties

The chemical analysis of the material was conducted by optical spark-emission spectral analysis according to DIN EN 14726. The material is an aluminium alloy AlMgSi0,7 or AlMgSi1. The results of the chemical analysis, therefore, correspond to the relevant specifications (encl. PB210-050714-01). A statement on the strength class of the present material is not possible by means of a chemical analysis, it is evaluated in a tensile strength test according to EN 10002-1.

Appendix 7.7 cont. Fraunhofer Gesellschatt technical report on the rudderstock failure

3.2 Hardness testing

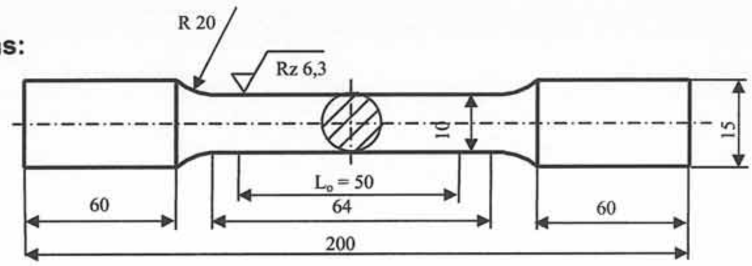
The hardness determined is 115 HB2,5/62,5 on an average. Comparative values for hardness classes up to F35 are about 90 HB2,5/62,5. Therefore it can be assumed that in the present material a certain degree of cold-forming higher than specified was used during the production of the shaft material. The low material ductility resulting from this can, in the presence of fissures, lead to a speedy growth of fissure, however, it need not be the cause of the fissure formation (UB-Nr. 10a/05).

3.3 Mechanical material characteristics (yield point, tensile strength, breaking elongation)

To analyse the broken rudder shaft, the strength parameters tensile strength R_m, 0,2, yield point $R_{p0,2,}$ and breaking elongation A were tested.
The tensile strength test was carried out according to EN 10002-1.

Production of specimens:
Shape of specimen:

Tensile test specimen
shape A



The specimens were taken from various parts of the shaft (Fig. 4).

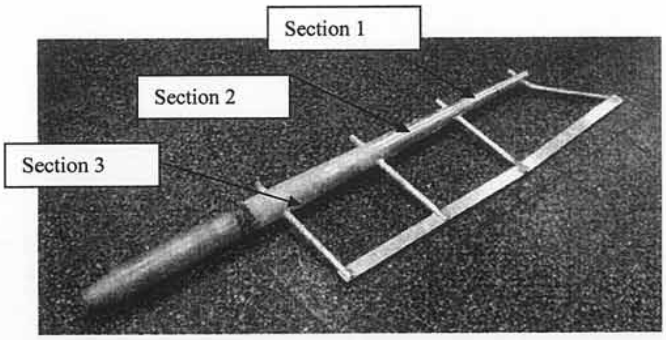
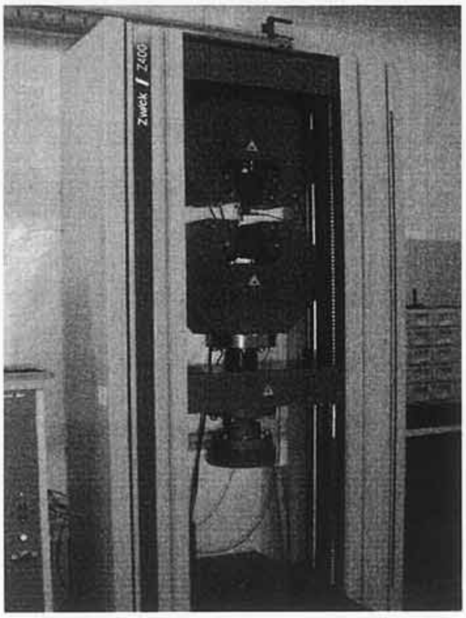


Fig. 3: Sections of the rudder shaft used for the production of the tensile test specimens

The specimens tested were taken from sections 2 and 3, the specimen production was done by quartering the sections and then cutting/turning the parts.

Appendix 7.7 cont. Fraunhofer Gesellschatt technical report on the rudderstock failure



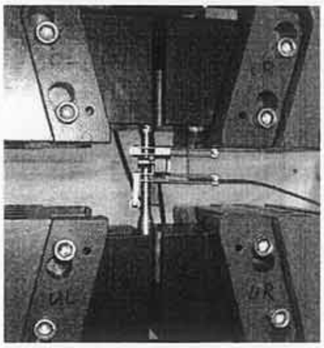


Fig. 4:
Test-machine Zwick Z400 (left) and determination of elongation of held tensile test specimen by extensometer (right)

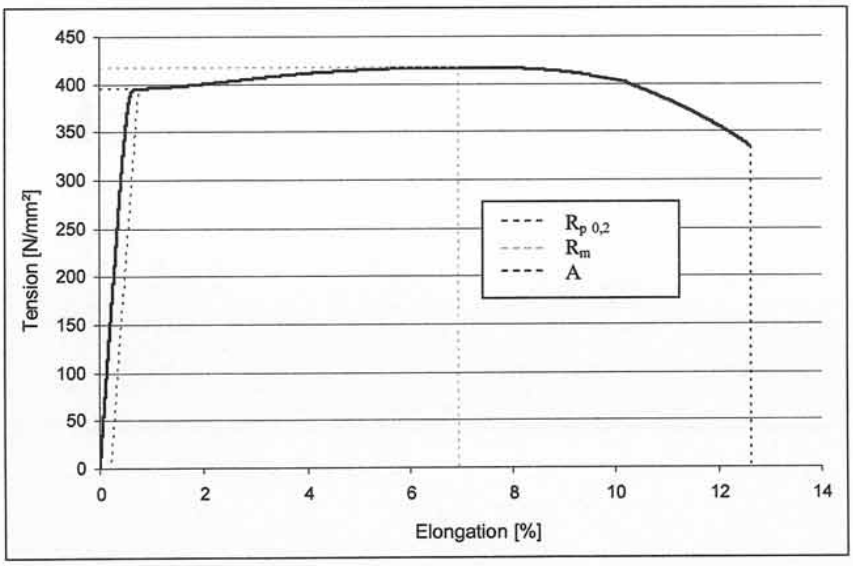


Fig. 5:
Exemplary tension-elongation diagram of a tensile strength test (left picture), aluminium round specimen after tensile strength test (right picture)

Appendix 7.7 cont. Fraunhofer Gesellschatt technical report on the rudderstock failure

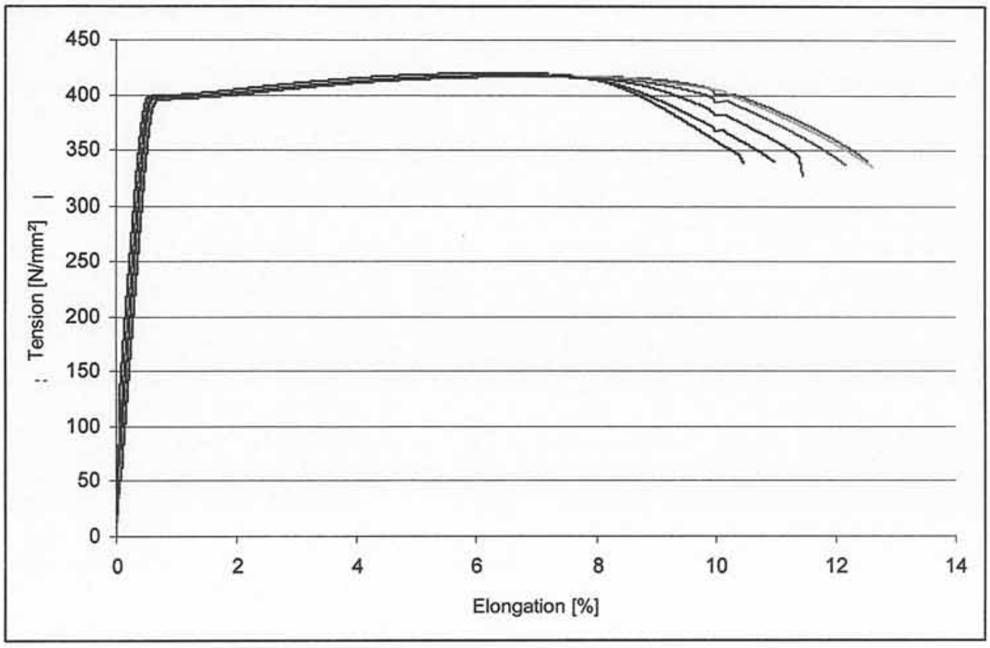


Fig. 6: Course of tension-elongation exhibited during the tensile strength test

Nr	E-Modul N/mm²	Rp0,2 N/mm²	Rm N/mm²	L bei F max mm	A %
1	70851	398,70	419,84	3,19	10,45
2	71059	396,98	417,20	3,49	12,18
3	71091	396,55	417,26	3,51	12,53
4	70464	395,66	417,50	3,50	12,62
5	69310	395,51	416,53	3,44	11,45
6	70107	397,33	417,81	3,25	10,98
average value	70480	396,79	417,69	3,40	11,70
standard deviation	686	1,18	1,14	0,14	0,88
variation coeff. in %	0,97	0,30	0,27	4,13	7,56

Table 1: Summary and statistic assessment of the test results

The results of the determination of elongation by extensometer confirm the high degree of reproducibility of the material characteristics determined. Yield point ($R_{p\ 0,2}$) and tensile strength (R_m) are about 10 per cent higher than the upper characteristic values of the specification. This is also confirmed by the results of the hardness testing, the material tested belongs to a higher hardness class than specified in the description (F32).

Appendix 7.7 cont. Fraunhofer Gesellschatt technical report on the rudderstock failure

3.4 Surface constitution

Measuring the surface roughness was carried out by means of a (scanning) test-cutter *Hommel* (measuring range ± 40 µm).

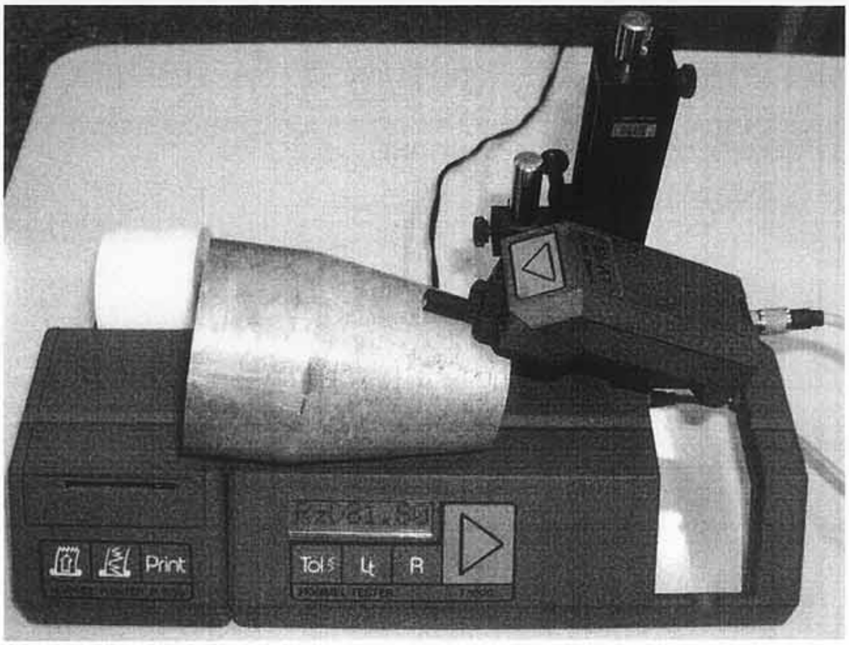


Fig. 7: Roughness testing of the conical shaft area by means of a Hommel test cutter

The profile established is shown in the following figure.

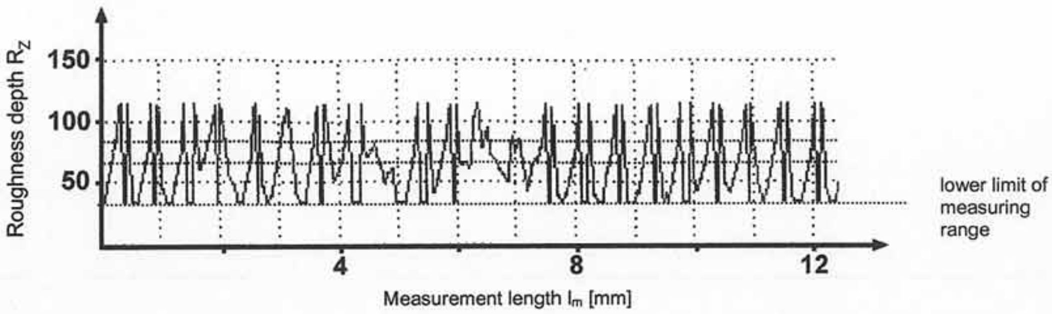


Fig. 8: Depth of roughness in the surface of the specimen $R_{Z\,DIN} \geq 80$ µm; (surpassing the lower limit of the measuring range)

The measurement shows that the medium roughness depth $R_{Z\,DIN}$ of the examined surface is in the range of ≥ 80 µm (surpassing the measuring range).
The roughness of the turned conical test body was then compared optically and by finger-nail test with several roughness standards. The test standard R_Z = 80 µm (turning) came as a minimum nearest to the present specimen surface and confirmed the values determined by the Hommel tester. The surface, therefore, has a degree of roughness of about N12 with a value of roughness of $R_a \geq 50$ µm in the standardised roughness classes of DIN ISO 1302. Several tests on possible mean positions of roughness depths R_z due to mechanical

Appendix 7.7 cont. Fraunhofer Gesellschatt technical report on the rudderstock failure

processing showed that an R_z of about 50 μm can be obtained e.g. by rough cutting, which means that the present value of about 80 μm can be considered as a very rough machining work.

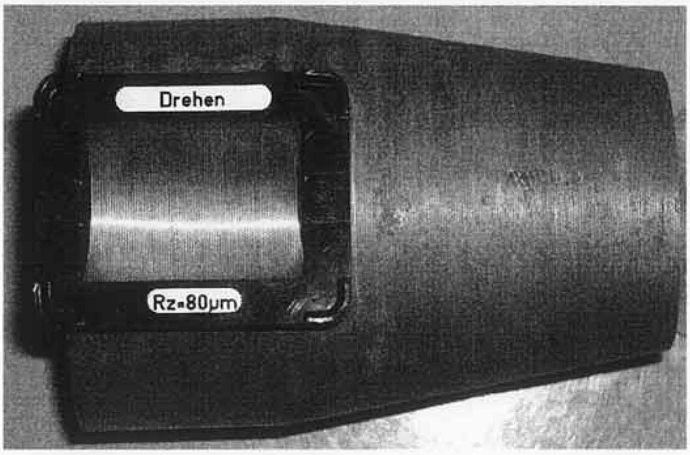


Fig. 9: Comparison of the specimen surface with the roughness standard R_Z=80 μm

4 Determing the state of the corrosion holes in the lower part and assessing their effect on the burden capacity

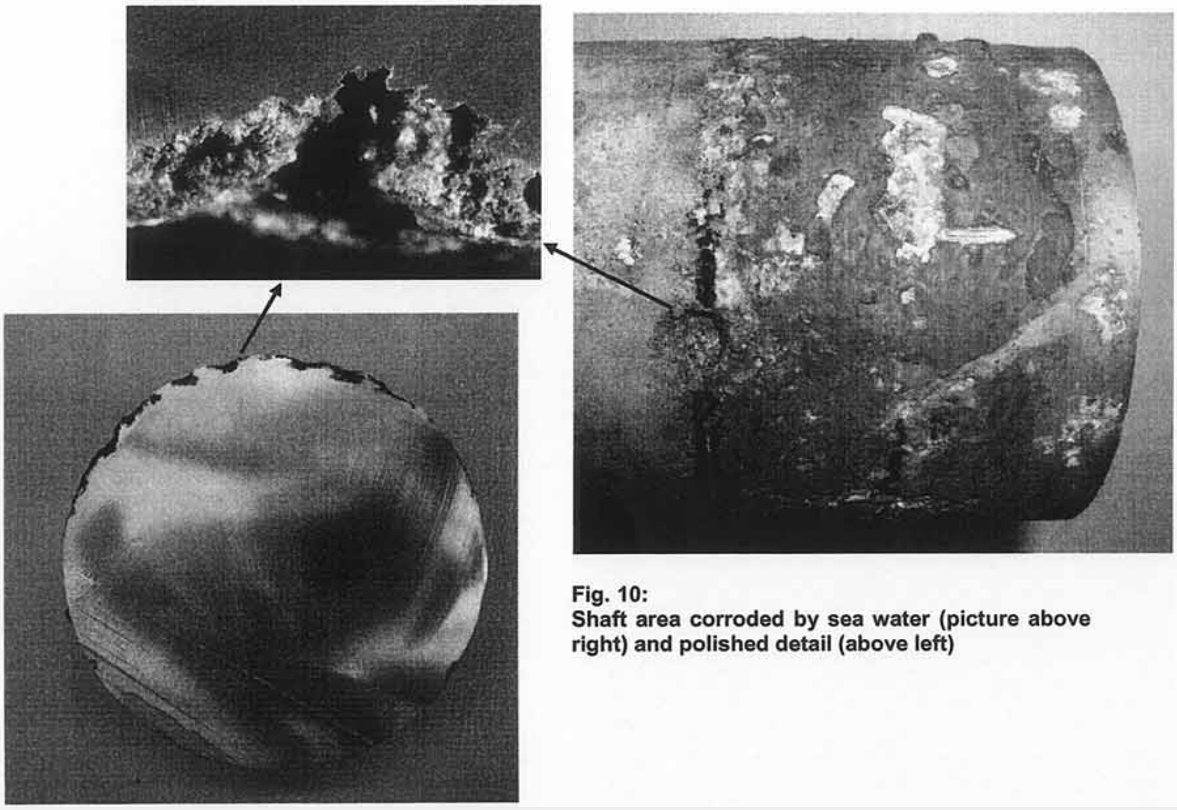


Fig. 10:
Shaft area corroded by sea water (picture above right) and polished detail (above left)

Appendix 7.7 cont. Fraunhofer Gesellschatt technical report on the rudderstock failure

Fraunhofer Gesellschaft AGP, Test Report 07/05 *p. 9*

An area of high damage in the part of the shaft that was exposed to seawater was exemplarily examined for cross-sectional weakening by corrosion. In the cross-section examined (Fig. 11) the weakening of the cross-section amounted to about 3 per cent (2 cm^2 of an overall cross-section of 60 cm^2).

5 Summary

The chemical composition of the material corresponds to the specification stated. The mechanical characteristics of yield point and tensile strength determined are about 10 % above the upper limits of the strength class F32 stated in the description. This was confirmed by the hardness measurements. The reduced toughness of the material resulting from these facts can lead to a fast growth of any fissure present, but it is considered not to be the direct cause of fissure formation. The material is assessed as having a good seawater-resistance according to DIN EN 13195-1.

Comparing the fatigue fracture with typical fracture pictures allows the following suppositions: the fracture was caused by a circumferential V-notch under one-sided bending stress. An examination of the fracture area under a light-microscope showed a clearly visible notch of a depth of about 0.3 mm in the crack-starting area, where the fatigue fracture was proven to have started.

Form and position of the starting point of the fatigue fracture do not indicate a turning-processing ridge of the conical area of an R_z of approximately 80 µm. At the entrance into the cylindrical part, areas of deformation and cracks are visible. This underlines the assumption that prior to the beginning of the fatigue fracture, the notch in the crack-starting area was caused by a plastic deformation of the material or by forcing an object into it.

Appendix 7.8 Zodiac International technical report on liferaft failure

CONTROLE PERIODIQUE N° 1 / PERIODIC CONTROL N° 1 Date : 15/3/01

N° de bouteilles/Cylinders number : 1 107780 2

Date d'épreuve/Date of the cylinder hydraulic test : 10/98

Poids initial de la bouteille pleine/
Weight of the filled cylinder mesured : 5.481

Poids de bouteille constaté/
Weight of the filled cylinder :
Variation de poids/Weight variation :
N° tête de commande/Operating head N° :

DATE DE PEREMPTION/EXPIRY DATE .

Fusée parachute/Parachute rocket : ✓
Fumigène/Smoke signal : ✓
Feux à mains/Hand flares : ✓
Cachet antinaupathique/Antiseasickness tablet : Replaced
Pharmacie/First aid : ✓
Eau/Drinking water : ✓
Ration alimentaire/Emergency ration : ✓
Pile pour éclairage/Battery for light : ✓
N° poche étanche/Airtight pouch N° :
(Concerne radeau sous poche étanche/Only for liferaft packed in airtight pouch)

Consttaations/Statements : Raft inflated By Customer

Remplacements/Replacements : SS Pills Co2 Cyl Refilled

Rapport de contrôle n°/Control report n° : ~~0125~~ 0237
Prochaine révision/Next servicing : 14/3/02

Nom vérificateur habilité / Authorized operator's name	Cachet de la station / service station's stamp	Cachet de autorités habilitées / Stamp of authorized administration
[signature]	SOLAS MARINE SERVICES LTD. Tom Whelan Managing Director The Dry Docks, Alexandra ... Tel. 01-8561320 Fax: 01 856132... Email: solasmarine...	

4

CONTROLE PERIODIQUE N° 2 / PERIODIC CONTROL N° 2 Date :

N° de bouteilles/Cylinders number : 1 107780 2

Date d'épreuve/Date of the cylinder hydraulic test : 10/98

Poids initial de la bouteille pleine/
Weight of the filled cylinder mesured : 5.481

Poids de bouteille constaté/
Weight of the filled cylinder :
Variation de poids/Weight variation :
N° tête de commande/Operating head N° :

DATE DE PEREMPTION/EXPIRY DATE .

Fusée parachute/Parachute rocket : N/A
Fumigène/Smoke signal : N/A
Feux à mains/Hand flares : 8/05
Cachet antinaupathique/Antiseasickness tablet : 10/06
Pharmacie/First aid : N/A
Eau/Drinking water : N/A
Ration alimentaire/Emergency ration : N/A
Pile pour éclairage/Battery for light : N/A
N° poche étanche/Airtight pouch N° :
(Concerne radeau sous poche étanche/Only for liferaft packed in airtight pouch)

Constatations/Statements :

Remplacements/Replacements : 4 1 Cell ... 3 ... SS Pills

Rapport de contrôle n°/Control report n° :
Prochaine révision/Next servicing : 11/1/06

Nom vérificateur habilité / Authorized operator's name	Cachet de la station / service station's stamp	Cachet de autorités habilitées / Stamp of authorized administration
	[faint stamp]	

5

Appendix 7.8 Zodiac International technical report on liferaft failure

ZODIAC INTERNATIONAL SOLAS Sector Usine de Chevanceaux	ADJUSTER'S REPORT CL5 LIFERAFT No. 1CN55J899	No. X1894 C05 Date : 14/10/2005 Page : 1/2 Issued by: M Chaillou

I) History:

During the shipwrecking of the mother vessel, the Megawat, on 25 May 2005, the life raft only inflated very partially (for 5 seconds claims the user).

It drifted for several weeks before it was found. The shipwrecked people were saved by their Avon craft. The Irish government is requesting an enquiry to try to determine the cause of the insufficient inflation.

The life raft was apparently serviced in January 2005

II) Liferaft original characteristics.

- Serial number: *1CN55J899* Type: *COASTER SY6* Approval No.: *96.09.0201.ES.PL*
- Date of folding: *12/98 in sealed pack*
- Inflation line:
  1. Cylinder: *No. 107780* Date of testing: *10/98* Weight when full = *5.479KG* CO2 load =*1.487KG* – N2 =*0.095*
  2. Striker head : *Z01A N° 41671*
  3. Life raft connection: *Floating nut Tee connection*
  4. Torque loads:

Assembly	Torque load
Base / Cylinder	*23mKg*
Head / Base	*10mKg*
Tee coupling / Head	*3.5mKg*

III) Report.

1. The life raft was not folded in a sealed pack (the sealing end was missing from the upper threaded part of the head)
2. There was no protection on the inflation couplings
3. The percussion index was not the original one
4. The cylinder was seriously corroded.
5. Presence of marking. Date of re-testing???
6. Original cylinder label
7. The percussion head was screwed in <u>loose</u> into the socket (unscrewed by hand)
8. Presence of red sealing compound on the upper part of the cylinder (base/cylinder assembly)
9. Presence of 75cl of fresh water in the cylinder
10. Oxidization of the base: Head / base threading – Base interior – Closing yoke
11. Presence of red sealing compound on threads of closing yoke
12. Presence of corrosion inside the percussion head.
13. Operating test: the life raft was equipped with a new cylinder and percussion head, after the triggering of the head, the raft inflated with ease.

IV) Conclusion.

2 possible causes of failure to operate

1) Leak from cylinder <u>and fitted accessories</u>

The failure of the life raft to operate is due to major negligence committed when the cylinder was refilled and the percussion head was assembled.

The cylinder of this life raft was renewed in theory (markings on cylinder) and refilled with gas (the closing yoke had been removed and reassembled with interposed thread lock or red liquid sealing compound).

**** The yoke that was not changed on filling is a very plausible cause of leakage.**

**** There is nothing to prove that the socket was really removed but a line of sealing compound at the start of the neck thread of the cylinder might indicate the presence of a leak that somebody tried to seal off.**

The cylinder is highly corroded (corrosion that should already exist during the previous servicing suggesting that there may have been a leak but that it was not apparent since the cylinder was not refilled for safety-related matters

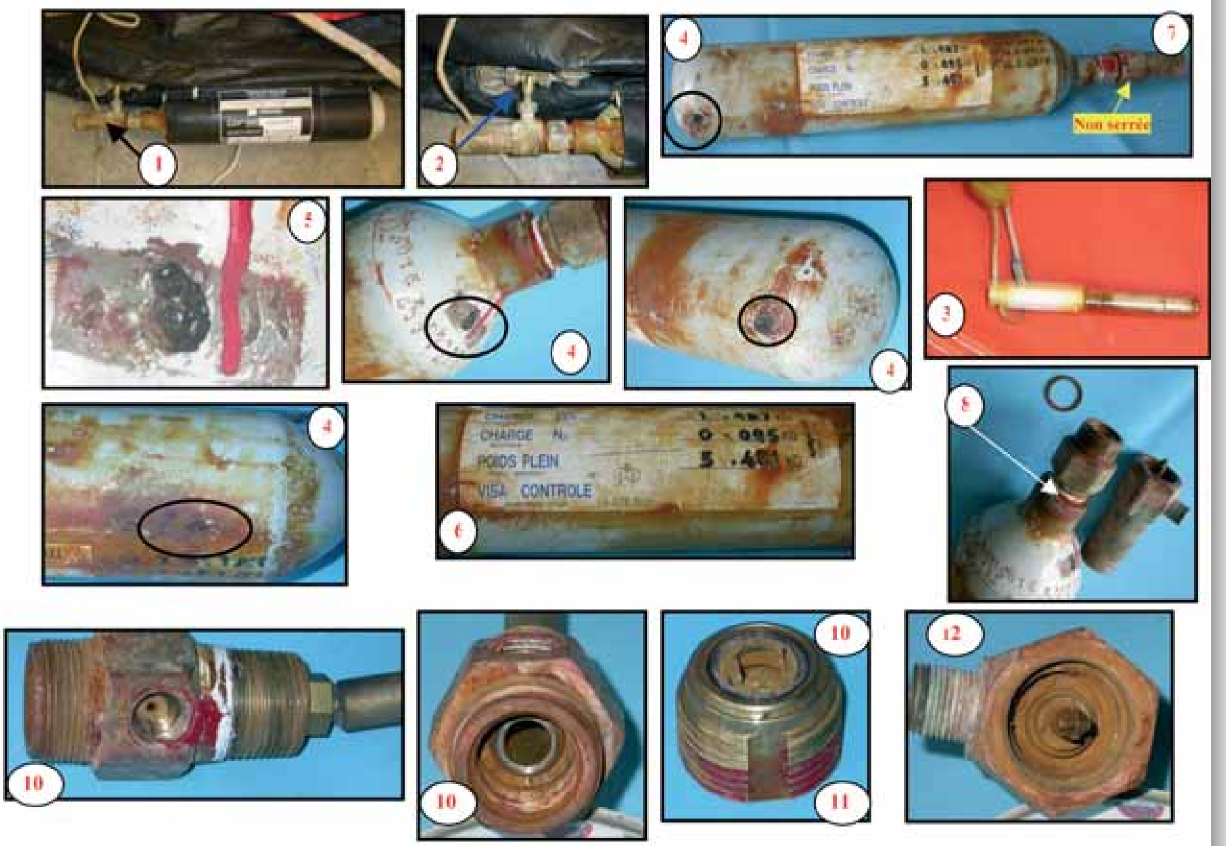
2) <u>Leak when the cylinder was emptied</u>

Further, if the cylinder was not partially empty when the raft was inflated, **the percussion head was not tight On the socket of the cylinder, meaning that the gas could have escaped from this connection.** (The filling time of this type of life raft is approximately 6s)

PV01

Appendix 7.8 Zodiac International technical report on liferaft failure

ZODIAC INTERNATIONAL	ADJUSTER'S REPORT	No. X1894 C05
SOLAS Sector Usine de Chevanceaux	CL5 LIFERAFT No. 1CN55J899	Date : 14/10/2005 Page : 2/2 Issued by: M Chaillou



PV01

Appendix 7.9 Judel/Vrolijk rudderstock design calculations

judel/vrolijk engineering

	ABS - RUDDER STOCK	**HA371**	
Rudderstock material	Yield Strength	[N/cm²]	26000
	Ultimate Tensile Strength	[N/cm²]	31000
Yacht dimensions	LWL	[m]	10,00
	Max. Displacement	[t]	7
Rudder dimensions	Rudder Area	[m²]	0,728
	Vert. height of rudder at stock	[cm]	161,8
	Vert. dist. centroid - top of rudder at stock	[cm]	73,6
	Vert. dist. centre of lower bearing - bottom of rudder	[cm]	165,0
	Chord length at centroid	[cm]	48,3
	Horiz. dist. leading edge - stock axis at centroid	[cm]	11,0
Intermediate results (for calculation only)		lc	6,0
		C	1,5
		k	984
		N	1,0
Forces, loads etc.	Rudder force	[N]	10745
	Bending moment	[Ncm]	825238
	Torque	[Ncm]	64875
	Design stress	[N/cm²]	17714
Diameters	Solid Stock Diameter @ lower bearing	[cm]	7,82
	Solid Stock Diameter @ upper bearing	[cm]	3,55

Appendix 7.10 Photograph of the "Megawat"

8. LIST OF CORRESPONDENCE RECEIVED

8. CORESPONDENCE RECEIVED

NOONAN BOATS.

"BOAT YARD" NEWCASTLE
NOONAN BOATS
Co. WICKLOW

"The Boat Yard", Sea Road, Newcastle,
Greystones, Co. Wicklow, IRELAND.
Tel & Fax (01) 281 9175.
V.A.T No. IE9536612B.

MARINE CASUALTY INVESTIGATION BOARD
IRELAND
21 MAR 2006
EIRE
An Bord Um Imscrudu Taismí Mara

20th March 2006

Marine Casualty Investigation Board
Leeson Lane
Dublin 2

Re; "MEGAWAT".

Dear Sirs,

We are in receipt of a copy of your preliminary report of the sinking of Mr. Philip Watson's yacht "MEGAWAT".

We note the contents.

Our comment would be that –
The Autohelm equipment supplied to Mr. Watson for fitting to "MEGAWAT" was supplied by a world renowned company, namely Messrs Whitlock of Luton, Bedfordshire, U.K.

This was fitted by Noonan Boats and Mr. Tony Brown of "Yachtronics", by the clamping of the tiller to the rudder stock in the manner prescribed by the Makers.

The system looked very sound and well designed, and operated well on the two crossings of the Atlantic Ocean.

We have no objections to these comments being published.

Yours sincerely,

Tony Noonan

Tony Noonan

MCIB RESPONSE

The MCIB notes the contents of this letter.

8. CORESPONDENCE RECEIVED

Megawat - sinking

Comments/Observations from Philip Watson – owner/skipper of *Megawa*t, after consultation with my two crewmembers Roger Cagney, and Brian McDowell, both of whom are structural engineers.

Causes of the failure of the rudderstock on *Megawat*

Whilst the hardness of the aluminium (10% too hard) and its rather rough machining were possibly *minor* factors in the shaft failing catastrophically, the *major* factor, which almost certainly caused the failure, is that the retrofitted "tiller", to which the Autopilot was attached, was clamped too far from the top bearing. .

This resulted in the shaft experiencing a large "bending" (rather than twisting) moment with each steering correction. This bending of the shaft occurred at the point where the taper ends, which is known as a "stress raiser". In hindsight this was the worst possible place to connect a tiller, and that is exactly where the break occurred. To be fair to the reputable experts who fitted this autopilot, we are only too aware that to use hindsight is unfair to them now, but we feel a lesson should be learned from this experience.

You have speculated that the possible inclusion of some particles or "foreign bodies" inside the clamp-on tiller bracket may have been a part cause of the failure. Our reaction is that this is possible, but highly unlikely, and really only a guess on your part. It is surely more helpful to stick to facts, and what can be proven in an instance like this.

Autopilots fitted by Hanse Yachts are connected to a *second tiller on the same quadrant,* very close to the top bearing, and thus don't bend the stock whilst twisting it. This is surely the reason why no other Hanse yachts have experienced a similar stock failure. It should also be pointed out that the Danish company Jefa, who supply Hanse with rudderstocks, also supply most of the major boat-builders in Europe & the USA. e.g. Beneteau, Dehler, Jeanneau, X-boats and J-Boats, and that they don't appear to be experiencing stock failures.

We also feel that it would be highly desirable in future yachts that the breakage of a rudderstock should never lead to the sinking. If rudderstocks were not tapered, which makes them weaker in the part between the top and bottom bearings, then the weakest point when they are overloaded for whatever reason (including a grounding) would always be exactly at the bottom bearing. A break at that location would not tear a big hole in the bottom of the boat, as happened in Megawat. Therefore prevention of a repeat is surprisingly simple.

Your report (4.6 and repeated in 5.3.8.) gives much exposure to the fact that it is not advisable to let copper based paint get in contact with an aluminium rudderstock. Whilst we obviously accept this, we feel that you should also have stated clearly that this was **not** a factor in the sinking of Megawat.

8. CORESPONDENCE RECEIVED

Liferaft - Difference of opinion.

We reported that the liferaft cylinder hissed for about 5 seconds and you have made a huge leap to the conclusion that the gas was going somewhere other than into the raft. You assume this because you learned from Zodiac that this model of raft normally inflates in about 6 seconds. You have completely misunderstood what actually happened here. The cylinder had only a tiny amount of gas in it, which came out slowly and gently. After sixteen years in the liferaft servicing business I know the difference. When you "pull the cord", on a fully charged cylinder, the rush of gas is quite dramatic, almost violent, and very loud. We, the crew of Megawat, are united in our opinion that this cylinder released only a tiny fraction of the amount of CO_2 needed to inflate a liferaft.

Facts that should be corrected in your report

The make of Megawat's Autopilot was Simrad (formerly Robertson) model AP21

The Steering system on the Hanse 371 is Lewmar (formerly Whitlock) – The tiller which was retrofitted to connect the Autopilot to the rudderstock, was bought from Lewmar.

Megawat sank in 40 minutes in 66 m of water – this is in our first-hand report written three days after the incident, which is included in your report. You have written that she sank in 30 minutes (1.1) in 80 m (4.1) of water.

MCIB RESPONSE to the letter from Mr. Philip Watson dated 20th March 2006.

MCIB RESPONSE TO THE LETTER FROM MR. PHILIP WATSON DATED 20th MARCH 2006.

As stated in the Fraunhofer Gesellschaft - AGP report the rudderstock suffered fatigue failure. The report does not state how the initial V notch defect was formed. Section 5.3 states the MCIB's opinion in relation to the most likely cause.

The rudderstock was designed by Judel/ Vrolijk in accordance with the American Bureau of Shipping Guide for Building and Classing Offshore Racing Yachts, a copy of Section 9 Rudders, Rudder Supports and Keels is attached for reference. This guide is internationally recognised and is used extensively for the structural design of yachts.

Tapering of engineering components is used extensively in engineering. Even if the shaft had not been tapered the shaft, as a result of the initial V notch defect, would have eventually suffered fatigue failure due to the fatigue characteristics of aluminium.

Recommendation 6.1.1 recommends a review of the EU Directive on Recreational craft with a view to increasing the requirements in relation to the watertight arrangements in way of rudderstocks in the event of failure on category A and B craft.

The MCIB acknowledge the use of the copper based antifouling system did not have an influence on the sinking of the yacht. However these findings are included to highlight the dangers of using a copper based system on aluminium components.

Following the recovery of the liferaft the refit was forwarded to ZODIAC for a technical examination. We note your comments regarding the level of the contents of the liferaft cylinder and the relevant bullet point in section 5.4.5 of the report has been deleted. It is important to note this does not change the ZODIAC findings and the MCIB conclusions.

The reference to the type of autopilot system fitted has been corrected in section 4.3 Retrofitting of Autopilot System.

The reference to the time taken to sink has been corrected in section 1.1.

Extract from American Bureau of Shipping Guide for Building and Classing Offshore Racing Yachts

SECTION 9

Rudders, Rudder Supports, and Keels

9.1 Rudder Stocks

9.1.1 Solid Stocks

The rudder stock diameter, d, is to be not less than required by the following equation.

$$d = \sqrt[3]{\frac{32}{\pi\sigma_r}(0.5M + 0.5\sqrt{M^2 + 4T^2})} \quad \text{cm or ins.}$$

where

$\sigma_r = \dfrac{U}{1.75}$ or Y, whichever is lesser, for metals

$= \dfrac{U}{2.33}$ or $\dfrac{Y}{1.33}$, whichever is lesser, for other accepted materials

U = the minimum ultimate tensile strength of the material in N/cm² (kgf/cm², psi)

Y = the minimum yield strength of the material in N/cm² (kgf/cm², psi)

M and T = respectively the bending moments and torques, in N-cm (kgf-cm, lbf-in) imposed on the rudder stock, determined as given in 9.1.3 and 9.1.4

Changes in rudder stock diameter are to be gradual; notches are to be avoided.

9.1.2 Tubular Stocks

Where tubular stocks are fitted, the outer and inner diameters, d_0 and d_i are to comply with the following equation.

$$d = \sqrt[3]{\frac{d_0^4 - d_i^4}{d_0}} \quad \text{cm or in.}$$

where

d = the required diameter of solid stock given in 9.1.1 in cm or in.

d_0 = the required external diameter of stock in cm or in.

d_i = the required internal diameter of stock in cm or in.

The wall thickness of tubular stock is also to provide adequate local strength for the loads imposed at the lower end of the neck bearing.

9.1.3 Spade Rudders

The bending moment and torque to be used in 9.1.1 are given by the following equation.

$M_n = P \mid h_b - h + h_c \mid$ N-cm (kgf-cm, lbf-in)

$T_n = P\ell_r$ N-cm (kgf-cm, lbf-in)

$P = k\,CL_{WL}\,AN$ N (kgf, lbf)

where

M_n = the bending moment at the neck bearing in N-cm (kgf-cm, lbf-in)

T_n = the torque at the neck bearing in N-cm (kgf-cm, lbf-in)

P = the total force on the rudder in N (kgf, lbf)

k = 984 (SI), 100.4 (metric), 6.25 (lbf-in)

ℓ_r = $0.33\ell - x_\ell$, ℓ_r is not to be taken as less than 0.125ℓ

ℓ = the horizontal length of the rudder in cm or in. at the centroid of the total projected area of the rudder, see Figures 9.1 and 9.1a

x_ℓ = the distance in cm or in. at the same position, from the leading edge of the rudder to the centerline of the rudder stock, see Figures 9.1 and 9.1a

C = the lift co-efficient of the rudder and is to be taken as 1.5 for rudders having both $\dfrac{h}{\ell}$ between 2 and 6 and $\dfrac{W}{\ell} \geq 0.06$.

h_c = the vertical distance from the top of the rudder at the center of the stock to be centroid of area of the blade. For trapezoidal profile rudders, h_c may be taken as $[h(\ell_u + 2\ell_\ell)]/[3(\ell_u + \ell_\ell)]$. See Figures 9.1 and 9.1a.

h_a, h_b, h, ℓ_u and ℓ_ℓ are the distances in cm or in. as indicated in Figures 9.1 and 9.1a

L_{WL} = is as defined in 2.1

A = the total projected area of rudder in m² or ft²

W = maximum width in cm or in. of the rudder at ℓ

$N = 1.0$; where $\dfrac{\Delta}{(0.01L_{WL})^3} \geq 4304$ SI/metric units

$\dfrac{\Delta}{(0.01L_{WL})^3} \geq 120$ inch ft units

$= \dfrac{0.0265L_{WL}^{\frac{2}{3}}}{\sqrt[3]{\Delta^2}}$; where $\dfrac{\Delta}{(0.01L_{WL})^3} < 4304$ SI/metric units

$= \dfrac{0.00243L_{WL}^{\frac{2}{3}}}{\sqrt[3]{\Delta^2}}$; where $\dfrac{\Delta}{(0.01L_{WL})^3} < 120$ inch ft units

SECTION 9 | 1 Rudders, Rudder Supports, and Keels

Δ = maximum estimated displacement, in metric tons or long tons

The required rudder stock diameter at and in the neck bearing is to be obtained from 9.1.1 using M_n and T_n for M and T respectively. Above the neck bearing the required rudder stock diameter is to be obtained using T_n and a value of M reducing linearly from M_n at the top of the neck bearing to zero at the rudder carrier bearing.

Below the neck bearing the required stock diameter may be gradually reduced but at a distance 0.2h from the bottom of the rudder it is to be no less than 0.46 times the required diameter at the neck bearing.

9.1.4 Semi-spade Rudders

The bending moment and torque to be used in 9.1.1 are given by the following equation.

$$M_p = \frac{F_2 h^2_C}{2} \quad \text{N-cm (kgf-cm, lbf-in)}$$

$$M_n = \frac{F_1(h^2_b - h^2_n)\left(\frac{1}{2} + \frac{\bar{x}}{8}\right) + F_2 h^2_C\left(\frac{1}{2} + \frac{h_b}{h_c} - \frac{\bar{x}}{4}\right)}{1 + \bar{x}\left(1 + \frac{h_a}{h_b} \times \frac{I_b}{I_a} \times \frac{E_b}{E_a}\right)}$$

N-cm (kgf-cm, lbf-in)

$$\bar{x} = \frac{h^3_b}{3 I_b E_b h_h\left(\frac{\ell^2_h}{G_h J_h} + \frac{h^2_h}{3 I_h E_h}\right)}$$

$$F_1 = \frac{P\left(A_1 + \frac{A_2}{2}\right)}{A(h - h_c)}, \quad F_2 = \frac{P\left(A_3 + \frac{A_2}{2}\right)}{A h_c}$$

$$T_n = \frac{P}{A}(A_1\ell_1 + A_2\ell_2 + A_3\ell_3) \quad \text{N-cm (kgf-cm, lbf-in)}$$

$$T_p = \frac{P}{A}(A_2\ell_2 + A_3\ell_3) \quad \text{N-cm (kgf-cm, lbf-in)}$$

where

M_p = the bending moment at the pintle, in N-cm (kgf-cm, lbf-in)

M_n = is the bending moment at the neck bearing in N-cm (kgf-cm, lbf-in)

T_n = the torque at the top of the rudder in N-cm (kgf-cm, lbf-in)

T_p = the torque at the pintle in N-cm (kgf-cm, lbf-in)

For the above locations see Figure 9.4.

ℓ_1 and ℓ_2 = $0.20\ell - x_1$ cm or in. but not to be taken as less than 0.125ℓ

ℓ_3 = $0.33\ell - x_1$ cm or in. but not to be taken as less than 0.125ℓ

ℓ = the horizontal length of the rudder in cm or in. at the centroid of areas A_1, A_2 or A_3 as appropriate and x_1 is the horizontal distance at the same position from the leading edge of the rudder to the centerline of the pintle

h, h_a, h_b, h_c, h_n and ℓ_h are the dimensions in cm or in. as shown on Figure 9.3

P and A are as defined in 9.1.3

A_1, A_2 and A_3 are the areas, in m^2 or ft^2 as shown on Figure 9.3.

I_a = is the mean moment of inertia in cm^4 or $in.^4$ of the upper rudder stock

I_b = is the mean moment of inertia in cm^4 or $in.^4$ of the rudder above the pintle

I_h = is the mean moment of inertia in cm^4 or $in.^4$ of the rudder horn

J_h = is the polar moment of inertia in cm^4 or $in.^4$ of the rudder horn at the support point

$= \frac{4\,a^2 t}{s}$ cm^4 or $in.^4$

a = is the mean horizontal area in cm^2 or $in.^2$ enclosed by the outer surface of the rudder horn plating

t = is the mean plate thickness in cm or in. of the rudder horn

s = is the median rudder horn wall circumference in cm or in.

ℓ_h = horizontal distance in cm or in. from center of stock to center of *a*.

E_a = flexural modulus of elasticity of the upper stock, in N/cm^2 (kgf/cm^2, psi)

E_b = flexural modulus of elasticity of the lower stock or rudder body, in N/cm^2 (kgf/cm^2, psi)

G_h = shear modulus of the horn in N/cm^2 (kgf/cm^2, psi)

E_h = flexural modulus of elasticity of the horn in N/cm^2 (kgf/cm^2, psi)

The required rudder stock diameter at the neck bearing is to be obtained using M_n and T_n. Above the neck bearing, the required rudder stock diameter is to be obtained using T_n and a value of M, reducing linearly from M_n at the neck bearing to zero at the rudder carrier bearing. At the pintle, the required rudder stock diameter is to be obtained using M_p and T_p. Below the pintle, the required stock diameter may be gradually reduced but at a distance $0.2h$ from the bottom of the rudder it is to be no less than 0.46 times the required diameter at the neck bearing.

9.3 Rudder Structure

Where the rudder stocks do not extend to the bottom of the rudder, the rudder structure in way of the axis of the stock is to have bending and torsional strength, and stiffness no less than required for the stock in the same location, as required in 9.1.3 and 9.1.4; below $0.2h$ from the bottom of the rudder, the strength and stiffness may be gradually

SECTION 9 | 2 Rudders, Rudder Supports, and Keels reduced until at the bottom of the rudder they correspond to that of a stock having a diameter 0.33 times the required stock diameter at the neck bearing. Where rudders are of eliptical profile, the strength and stiffness of the rudder below 0.2h from the bottom of the rudder may be gradually reduced until at a point 0.1h from the bottom of the rudder, they correspond to a stock having a diameter of 0.39 times the required diameter at the neck bearing. Strength and stiffness are to be gradually reduced below from this point to the bottom of the rudder.

Where FRP rudder is unstiffened internally, PVC foam of no less than 64 kg/m^3 (4 lbs/ft^3) is to be used.

9.5 Rudder Bearings, Pintles and Gudgeons

9.5.1 Rudder Bearings

Rudder bearings are in general to be arranged as shown in Figures 9.1 and 9.3. The neck bearing is to be fitted as near to the top of the rudder as practicable. The bearings are to be adequately supported and effectively attached to the hull.

The bearing pressure on rudder stock and rudder pintle bearings is to be not greater than obtained from the following equation.

$$p = \frac{R}{A_b} \text{ N/cm}^2 \text{ (kgf/cm}^2\text{, psi)}$$

where

p = the allowable bearing pressure in N/cm^2 (kgf/cm^2, psi) for steel against steel and for steel against bronze is 1037 N/cm^2, 105.7 kg/cm^2 or 1500 psi, and for steel against synthetic material is 677 N/cm^2, 69 kgf/cm^2 or 975 psi. Special consideration will be given to roller and similar mechanical bearings.

R for spade rudders
at the carrier bearing is $R_c = M_n/h_a$ N (kgf, lbf)
at the neck bearing is $R_n = P + R_c$ N (kgf, lbf)
R for semi-spade rudders
at the carrier bearing is $R_c = M_n/h_a$ N (kgf, lbf)
at the neck bearing is

$$R_n = R_c(1 + h_a/h_b) + \frac{F_1}{2h_b}(h_b - h_n)^2 - M_p/h_p \text{ N (kgf, lbf)}$$

at the pintle bearing is $R_p = P + R_c - R_n$ N(kgf, lbf)

A_b = the bearing area, d times the bearing length, in cm^2 or in.^{2}

d = the actual diameter of the rudder stock or pintle in the bearing, in cm or in.

P = is as defined in 9.1.3
for spade rudders, M_n and h_a are as defined in 9.1.3
for semi-spade rudders M_n, M_p, F_1, h_a, h_b and h_n are as defined in 9.1.4

In general the length of the bearing is to be not less than 1.20d nor more than 1.5d, where d is the diameter of the stock or pintle in the bearing. The bushings are to be effectively secured in the bearings. Roller bearings will be specially considered.

9.5.2 Rudder Pintles

Pintles are in general to be cast or forged steel, other bearing materials will be specially considered. In the housing, the length of the pintle is to be not less than 1.2 times the pintle diameter and in the housing, the pintle is to be tapered about 1 in 6 on the diameter. The pintle nut is to be effectively locked to the pintle.

Where sleeves are fitted, they are to be shrunk onto the pintle; other methods of efficiently securing the sleeves will be specially considered.

9.5.3 Pintles, Gudgeons and Housings

Pintles, gudgeons and housings are to have a depth not less than 1.2 times the diameter of the pintle and a thickness outside the bore of not less than 0.5 times the diameter of the pintle. Compliance with this thickness requirement for tapered pintle housings may be based on the thickness outside the bore at the half depth of the housing.

9.7 Rudder Stock Couplings

9.7.1 Bolts

Where bolted rudder stock couplings are used, each coupling bolt is to be of steel or other approved material and is to have a diameter, d_b, at the bottom of the thread not less than the following equation.

$$d_b = \sqrt{\frac{0.382d^3}{n\,r}} \text{ cm or in.}$$

where

d = the required solid rudder stock diameter in cm or in. obtained from 9.1.1 using the minimum ultimate tensile and minimum yield strengths of the bolt material,

r = the pitch circle radius of the coupling bolts in cm or in.

n = the number of coupling bolts, generally not less than four.

The coupling bolts are to be fitted and coupling bolt nuts are to be effectively locked.

9.7.2 Coupling Flanges

Where bolted rudder stock couplings are used, the flanges are to be of steel or other approved material. Where the flanges are of material having strength properties no less than those of the coupling bolts, the thickness of the coupling flanges is to be not less than d_b in cm or in. and the minimum width of flange material outside the bolt holes is to be not less than ⅔ d_b in cm or in.

9.9 Tillers

Tillers and their connections to the stocks are to have strength equivalent to that required for the rudder stock at the rudder carrier.

9.11 Rudder Horns

The rudder horn is to be of a material having a modulus of elasticity comparable to that of the material of which the rudder stock is made. Special consideration will be given where this is not the case. The rudder horn is to be an integral part of the hull with the rudder horn structure effectively developed into the canoe hull, floors are to be arranged in the hull, in line with those in the horn. The combined stress, σ_h in the rudder horn at any section as determined by the following equation is to be not more than σ_c as defined below.

$$\sigma_h = 0.5\sigma_b + 0.5\sqrt{\sigma_b^2 + 4\tau^2} \quad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, psi)}$$

where

σ_h = combined stress at any horizontal section of the rudder horn.

σ_c = allowable combined stress
= for metals, $U/2.1$ or $Y/1.2$ whichever is lesser
= for other approved materials, $U/2.8$ or $Y/1.6$ whichever is lesser

U = minimum ultimate tensile strength of the material in N/cm² (kgf/cm², psi)

Y = minimum yield strength of the material in N/cm² (kgf/cm², psi)

$\sigma_b = R_p \times h_h/SM_h$ N/cm² (kgf/cm², psi)

$\tau = R_p \times \ell_h/2ta$ N/cm² (kgf/cm², psi)

R_p = the force on the rudder pintle, in N (kgf, lbf) as given in 9.5.1

SM_h = section modulus of the rudder horn about the longitudinal axis, in cm³ or in.³ at the horizontal section being considered

t = minimum wall thickness of the rudder horn in cm or in. at the section being considered

a = area in cm² or in.² enclosed in the horizontal plane by the outside lines of the rudder horn at the section being considered

h_h = vertical distance in cm or in. from the center of the pintle bearing to the section of the rudder horn at the section being considered

ℓ_h = horizontal distance in cm or in. from the center of the pintle bearing to the center of area of the horizontal plane of the rudder horn at the section being considered

9.13 Keels

As stated in 1.5, this Guide is not intended as a substitute for the independent judgment of professional designers, which judgment covers various aspects not addressed in this Guide. This is particularly appropriate for those aspects of keels and their attachment not addressed in this subsection or elsewhere in this Guide for which the designers are solely responsible.

9.13.1 Continuity

Where fitted, floors within ballast keels and in spacer structure between the ballast keel and the underside of the hull are to be in line with the floors in the hull. Internal load carrying members within the ballast keel are to be aligned and connected with floors in adjacent structure.

9.13.2 Connections

Where fitted, bolts connecting ballast keels or spacer structure to adjacent structures are to be in accordance with 6.3.1. Other types of connections will be specially considered.

9.13.3 Structure

All keel components including spacer structure are to meet the requirements of the following paragraphs. Where lead keels are fitted with wings or bulbs, consideration is to be given to providing internal support.

a. Transverse Load

The shear and primary stresses at any location of the keel structure under the following assumed load are not to exceed the respective allowable stresses given below.

Assumed Load:

Acting Transversely	Weight of the keel below the section of the keel under consideration acting at its center of gravity.

Allowable stress:

	shear stress	primary stress
All materials	$0.5\tau_y$	$0.5\sigma_y$

where

σ_y = minimum tensile yield strength of the material but is not to be taken as greater than 70% of the ultimate tensile strength of the material. Where steel is used, σ_y is also not to be taken as greater than 390 N/mm² (40 kgf/mm², 57,000 psi).

τ_y = minimum shear yield strength of the material but is not to be taken as greater than 40% of the ultimate tensile strength of the material.

b. Grounding Conditions

The shear and primary stresses at any location of the keel structure under the following assumed loads acting separately are not to exceed the respective allowable stresses given below.

Assumed Loads:

Acting aft	Load as indicated below on the centerline of the yacht at the bottom leading edge of the keel.
	For $L_{WL} \geq 20$m (66 ft.); $3F_{\Delta}$
	For $L_{WL} \leq 10$m (33 ft.); $1.5F_{\Delta}$

	Linear interpolation is to be used to determine Grounding loads for vessels with intermediate values of L_{WL}.	
Acting upward	$1.5F_\Delta$ on the bottom of the keel.	

Allowable stress:

	shear stress	primary stress
Steel and aluminum	$0.75\tau_y$	$0.75\sigma_y$
Fiber Reinforced Plastic	$0.35\tau_u$	$0.35\sigma_u$

where

F_Δ = Force corresponding to the maximum displacement of the yacht.

τ_u = minimum ultimate shear strength of the laminate

σ_u = minimum ultimate tensile or compressive strength of the laminate as appropriate

σ_y and τ_y are as defined in 9.13.3a.

It is recommended that radii or other effective means be provided at the intersection with the canoe hull to avoid hard spots. Buckling strength is also to be considered.

9.13.4 Minimum Plate Thickness

The thickness of the keel side, end, and bottom plating is to be sufficient to meet the requirements in 9.13.3, but in no case less than required by equation 7.1 or 7.3.1a using h and F as defined below:

$h = 0.187LH$ m $\qquad 0.057LH$ ft

but not less than 1.2 times the basic head in Table 7.1.

$F = 1.0$

L = length as defined in 2.1

H = depth of the keel below the underside of the canoe hull in m or ft. see Figure 7.2.

Spade Rudder

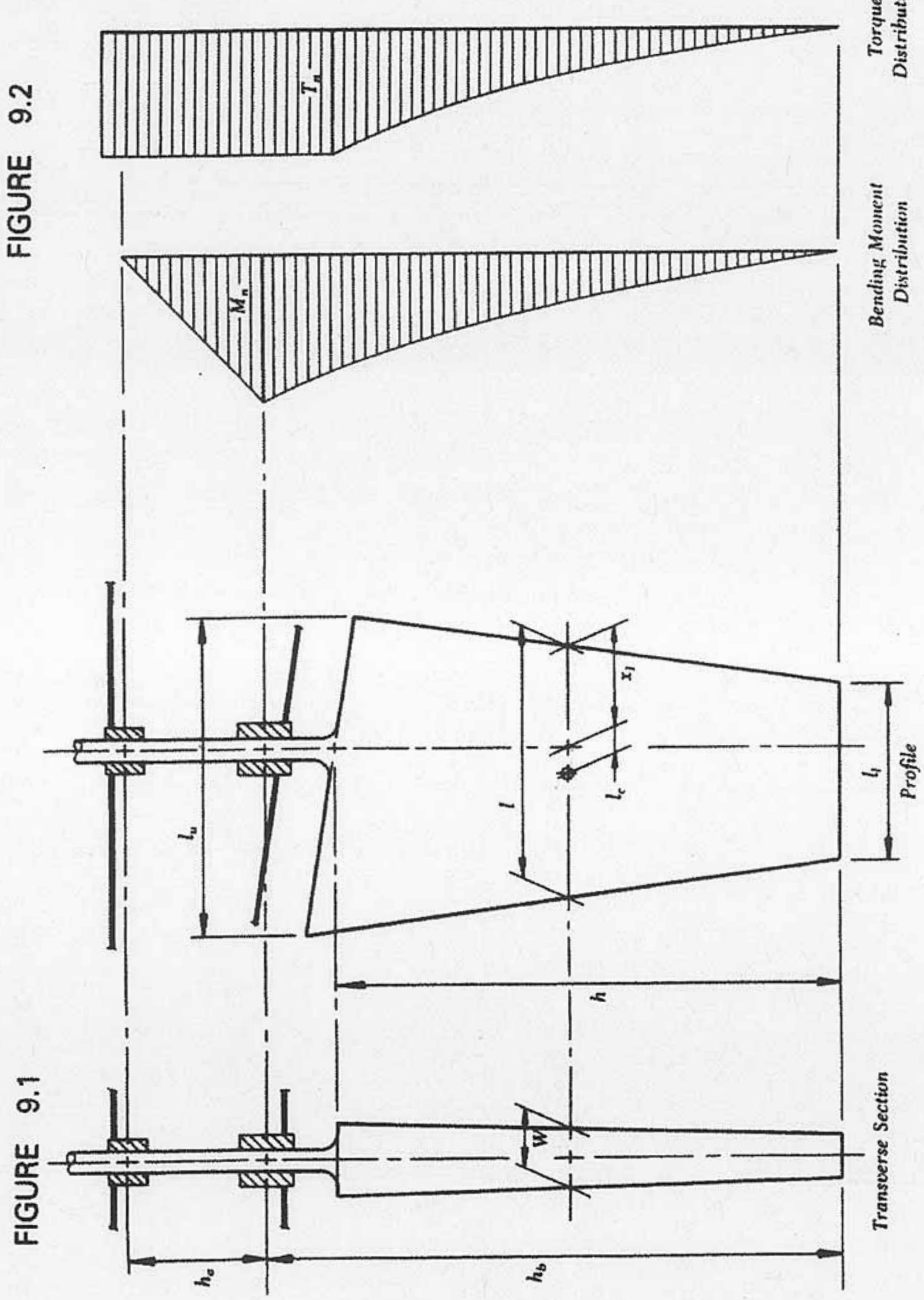
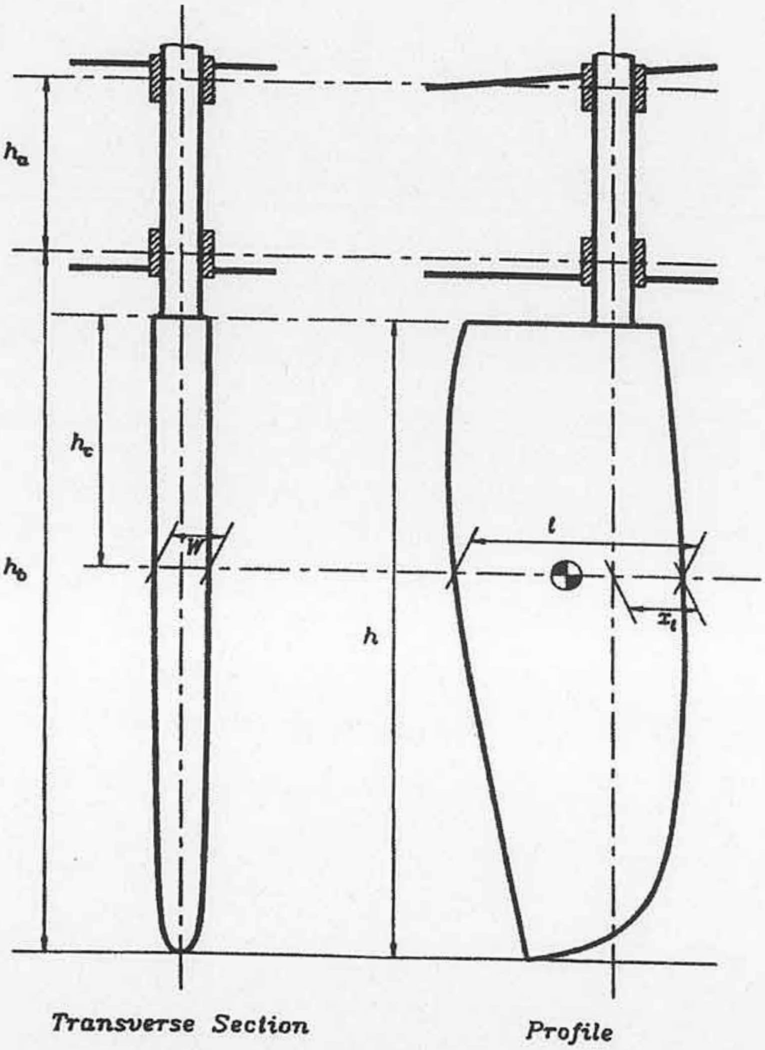
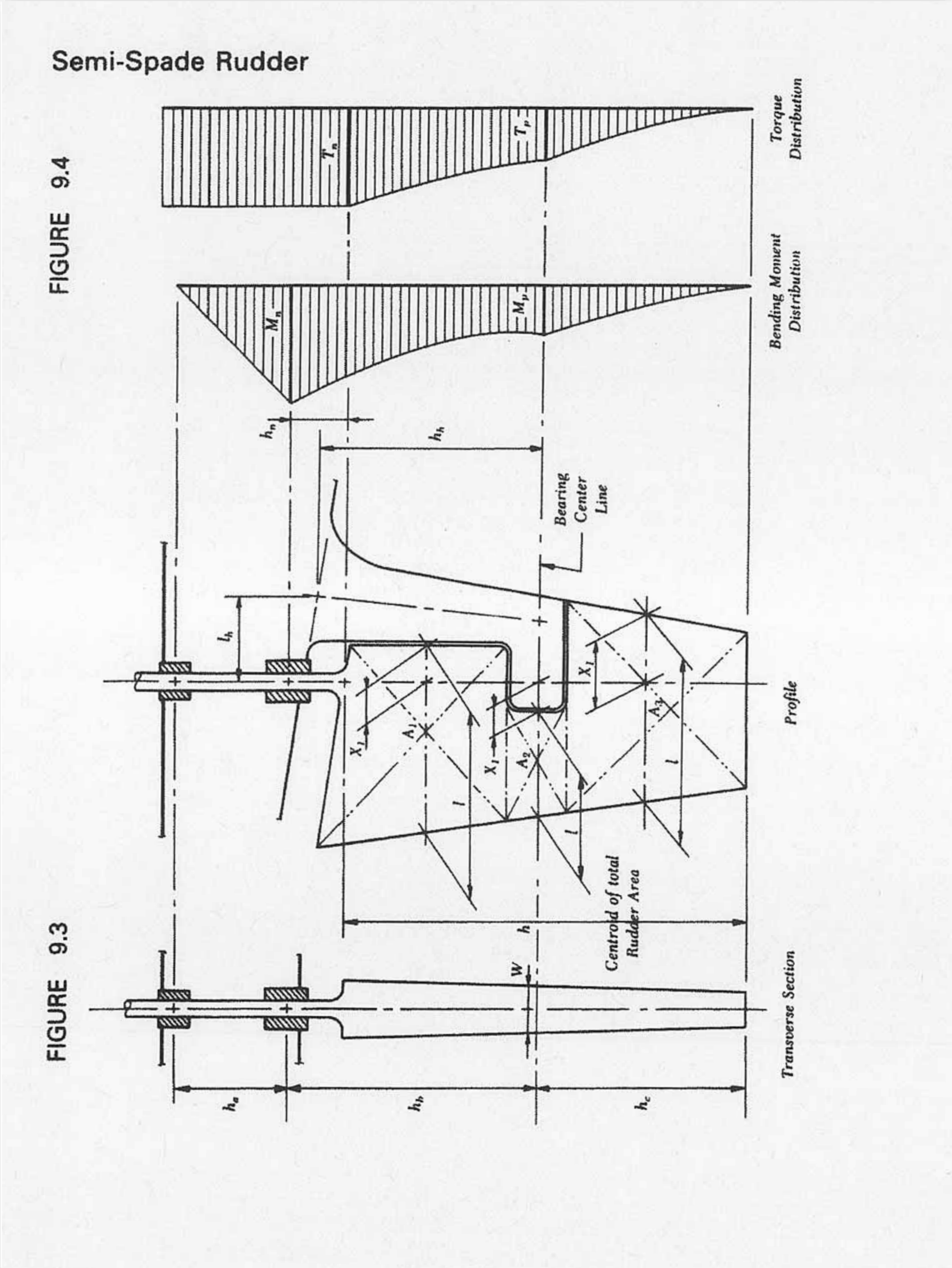


FIGURE 9.1A
Elliptical Profile Spade Rudder




Semi-Spade Rudder
FIGURE 9.3
FIGURE 9.4
Torque Distribution
Bending Moment Distribution
Bearing Center Line
Centroid of total Rudder Area
Profile
Transverse Section
T_n
T_p
M_n
M_p
h_n
h_h
l_h
h
W
h_a
h_b
h_c
A_1
A_2
A_3
X_1
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