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Mr. Peter Wiedekamm,
Paul-Löbe-Weg 18,
25337 Elmshorn,
GERMANY

By Email:

22 January 2015

Dear Mr. Wiedekamm,

Ref. sv Stormvogel Swing Keel

Thank you for your emailed instructions of 13 January 2015 with attachments.

I have now completed a study of these materials comprising the following:

1/ pdf Copy of Howells Maritime Services Survey Report No. H14-531 dated 25 July 2014;
2/ pdf Document - letter from Vero Marine to yourself dated 10 September 2014
3/ pdf Document entitled Wiedekamm vs Norsand V1.0, dated 14 September 2015

I comment as follows:

Appendix B to Ref. (1) - survey report, shows an un-dimensioned sectional view through the top of the swing keel including the aluminium keel box and the bearing support arrangements each side of the pivot shaft. For convenience this is reproduced and attached to this report as Annex B. This drawing is said to have been produced by Hutting Yachts, Netherlands who refitted Stormvogel in 2012, and presumably did some work on the swing keel at that time or, for some other reason, saw the need to produce the drawing. Appendix A to Ref. (1) is a similar, annotated section of the top of the swing keel showing an exploded view of the same components – also reproduced and attached below as Annex A. Both drawings are assumed to be an accurate representation of the arrangement as fitted on Stormvogel.

A study of the drawings and photographs shows that the central component of the lifting arrangement is a stainless steel pivot shaft (item 3), about 295mm long and Ø75mm diameter with a 12:1 taper in the centre that engages in a mating taper bore through the top of the swing keel. A parallel steel key located in keyways in the pivot shaft and the keel taper bore locks the shaft and keel together to enable the hydraulic actuator attached to a square drive spigot on the starboard end of the pivot shaft to raise and lower the keel.

On the port side of the shaft (right side of the drawing) is a threaded spigot about Ø24mm in diameter and 50mm long, of which about 35mm of thread is exposed when assembled into the bearing spigot (item 4). A pair of locking half-nuts about 17mm or less in depth engage the thread to pull the shaft and swing keel tapers together; one of these nuts fits fully within the 18mm deep recess of the bearing spigot, with the other on top but above the recess. The dimensions noted were scaled as accurately as possible from the Annex B drawing with reference to the known 8mm diameter studs attaching the seal carrier.

Watertight integrity on the port side is achieved by a gasket under the flange of the end cap (item 6) which is bolted to the keel box independently; therefore, provided the bolts and gasket remain intact, failure of other components would not cause leakage on this side.

At the opposite, starboard end, of the pivot shaft is the seal carrier, item 5, attached by four Ø8mm threaded studs into tapped, blind holes in the aluminium keel box. The sealing arrangements comprise a gasket between the seal carrier and keel box and a pair of lip seals fitted in a recess on the inboard side. A Ø6mm 'O' ring is shown in red in the Annex B drawing, but does not appear in the Annex A exploded view, and is reported to be a modification carried out by Norsand during a refit in early 2014.

There is no collar on either the starboard side of the pivot shaft or the bearing spigot i.e. the shaft is fully floating axially within the Delrin bearings (items 1 & 2). The only restraint on axial movement of the shaft is the two Delrin spacers shown in Annex A only, and three spacer pads on the outside of the swing keel seen in Ref. (1), S3.9.2 - right hand photograph.

The effect of this is that the proper function of the bearing system and particularly the integrity of the attachment of the swing keel to the pivot shaft relies solely on the compression from the half-nuts on the port side pulling the two tapers together in close contact. Any axial backlash in the security of this connection will have a number of consequences:-

- allow the pivot shaft to back out of the taper bore in the keel;
- the keel will start rocking on the shaft both laterally and fore and aft;
- wear and mechanical damage to the keyways and sides of the key will occur;
- the tapers, particularly the bore in the softer aluminium keel, will flog and wear

As with any other keyed, taper drive system, it is critical in assembling the pivot shaft and bearings that the two half-nuts are positively locked together to keep the taper bores and key/keyways in tight contact. Some difficulties are foreseen in doing this in practice. Since the first half-nut fitted is buried to approximately full depth within the recess in the bearing spigot (item 4), a special tool – cranked 'C' spanner or similar, may be required to hold it secure while fitting and torqueing up the second half-nut. When assembled, the two half-nuts should ideally be mechanically locked together with a pin or drilled and tapped to take a locking screw.

Mr. Howells' report describes the damage found on disassembling the swing keel as including, at S3.1, three of the four seal carrier studs had sheared off; and, at S3.6, the retaining *nut* on the port side was loose. Both observations raise comment:

- The photograph on page 4 of the survey report shows what looks like a threaded stud with a nut at the far left hand end. The Ref. (3) documentation refers to both studs and bolts in connection with the seal carrier. The distinction is important. At S1.4 on page 5, a possible reason for failure of the fastenings is proposed as 'the mechanics over-tighten the studs'. If these fastenings were indeed studs, as distinct from bolts, they would have been screwed into the side of the aluminium keel box using a pair of locking nuts at the end to provide a grip on the threads. Over-tightening in this case is unlikely as the lock nuts would normally be expected to slip on the thread before the yield strength of the fastening material in shear was exceeded.

  If the fastenings were bolts, the likely scenario in the event of over-tightening, is that the aluminium thread in the keel box would strip before the bolt sheared. This appears to have occurred before according to S2.3 of Mr. Howells' report.

  There is no indication from either the Annex A or B drawings as to which type of fastening is correct.

- Mr. Howells' reference to the loose 'retaining nut' (singular) suggests that there was only one nut fitted. The Annex B drawing indicates a double nut at the starboard end of the pivot shaft in the manner of paired lock nuts intended to provide security against spontaneous slackening off.

In the absence of parts to physically examine it is difficult to assign an absolute cause to the failure of the sealing system; however, after a careful study of all the documentation I consider that proximate cause and the most likely sequence of events, is that the nut or nuts under the aluminium cap on the port side of the pivot shaft came loose. This allowed the pivot shaft to move to starboard and in so doing the taper contact released, aided by lateral movement of the swing keel as the vessel rolled. The sides of the keyways would be likely to flog the key under these circumstances and cause some or all of the damage noted at S3.9 of the survey report. Similarly, the taper bore in the aluminium keel would be expected to be flogged by repeated impact against the harder material of the steel pivot pin, as had reportedly occurred when the tapers were tested with engineers' blue in Cairns to check the mating contact area.

S3.5 of the survey report describes the relative movement found between the swing keel and pivot shaft after the starboard side bearing and seal carrier had been fully refitted, but the port side had not yet been inspected. This tends to support the view that the key to the mechanical integrity of the bearing arrangement lies in the security of the lock nut(s), which were subsequently found loose.

The photograph at S3.1 of the survey report shows one of the three broken studs, with about 20mm of thread remaining to the left of the broken end. This appears to be a commercially mass produced fastening with a rolled thread as distinct from a custom made die- or machine-cut thread. Approximately 14mm of thread would have been inside the seal carrier body with the point of failure being about 6mm inside the keel box.

The photograph is of reasonably high quality and resolution and has been digitally expanded, as shown at Annex C below, to inspect the fracture face. At the top centre, within the red circle, some brown 'tea staining' is evident at the root of the thread. Below the circle are three arrows highlighting what appear to be concentric, circular beach marks, typical of bending fatigue fracture where the lines radiate out from the point of initial failure. The tea staining is most likely the result of chloride contamination initiating crevice corrosion within a small surface flaw which has propagated into a crack, ultimately leading to failure.

Increased side movement of the keel, if excessive or prolonged, may be expected to put cyclic bending moments on the seal carrier fastenings, three of which eventually sheared through unidirectional bending fatigue. At that point the seal carrier would be attached by only one stud providing a copious leakage path between itself and the keel box by-passing the lip seals.

The documentation and photographs at Ref. (3) appear to support the view that the bearing arrangements at both ends of the pivot shaft were disassembled at Norsand Boatyard in early 2014.

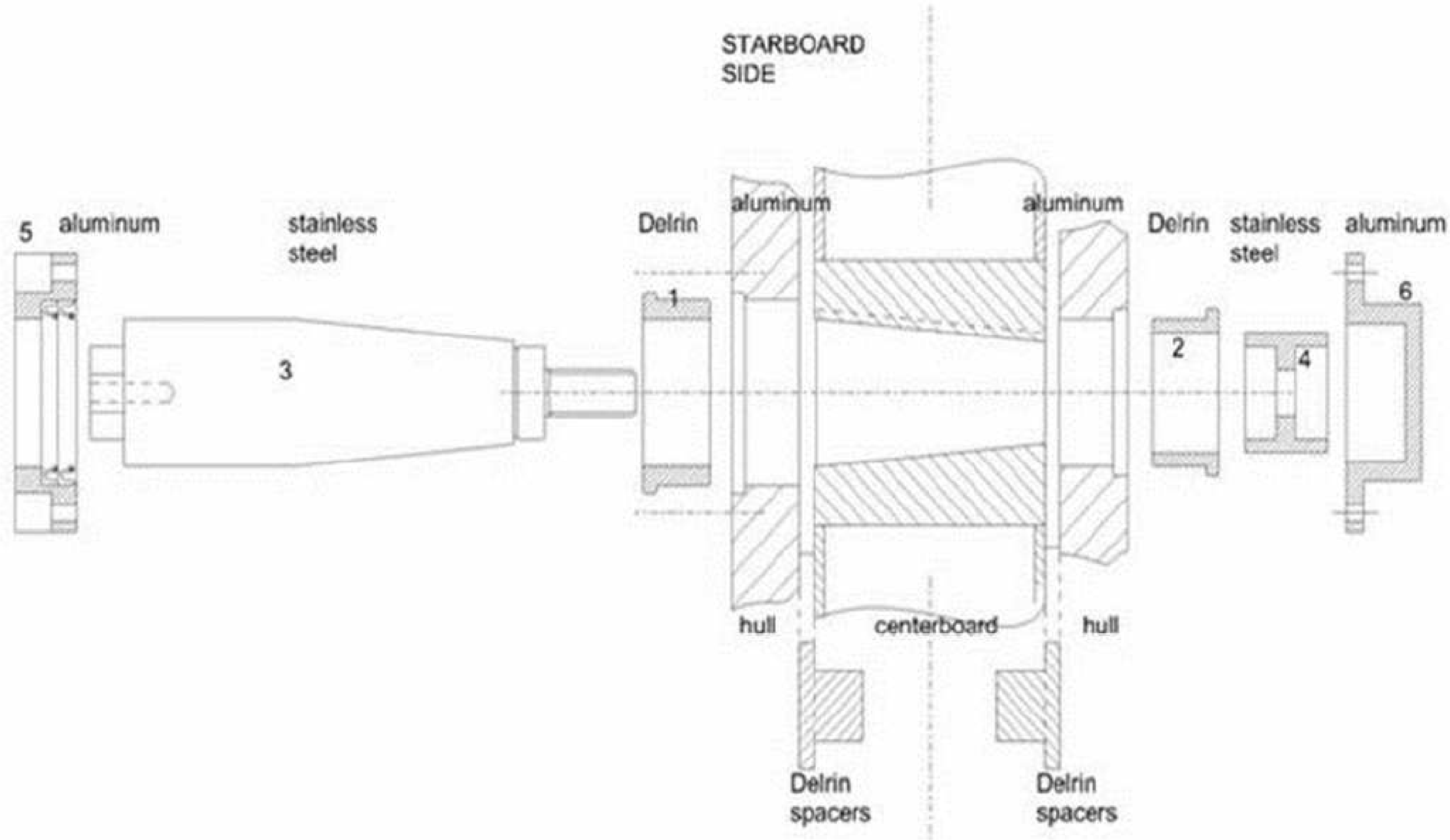
These observations are offered in good faith as to their accuracy within the limitations of the written materials examined which are assumed to be true and complete.

Sincerely,

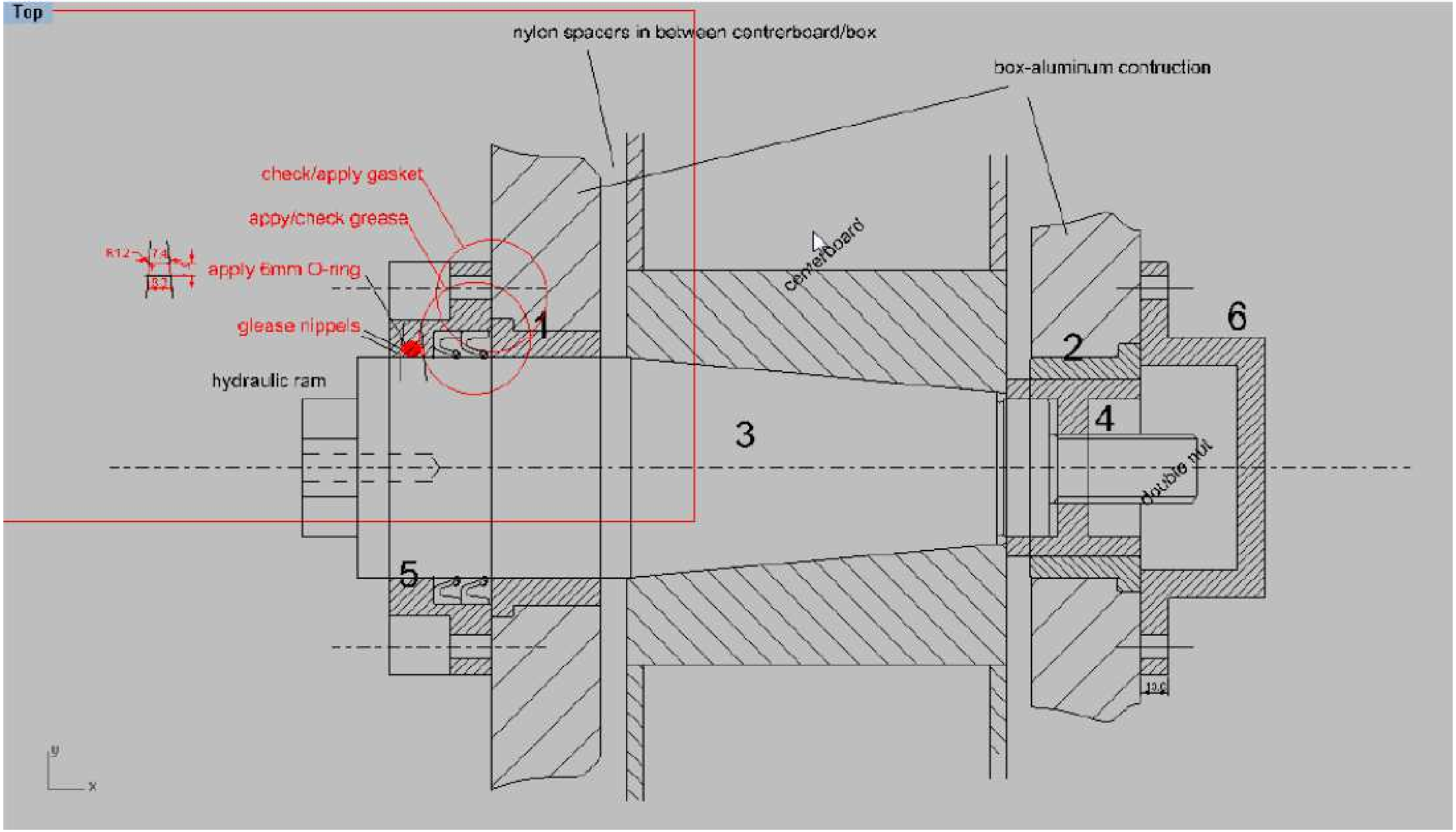
G. L. Lindberg IEng, MIMarEST, MIIMS
Engineer Surveyor

Att. Annex A – Assembled sectional drawing of swing keel components
Annex B – Exploded sectional drawing of swing keel components
Annex C – Expanded photograph of seal carrier broken stud

Annex A - Exploded sectional drawing of swing keel components



Annex B - Assembled sectional drawing of swing keel components



Annex C

Expanded close-up view of fracture face of seal carrier broken fastening, shows:-

Tea staining within circled area;
Beach marks radiating from origin point of failure