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David Upton,
Sydney Water Police,
Harris St,
Sydney

Dear David,

My report on the circumstances involving the Sword of Orion is as follows.

I spoke with you, Stuart Gray, Rob Kothe (yacht owner) and Derek Wainohau (RTA crash labs) in late December 1999. I also read transcripts of your interviews with Darren Senogles and I read the book "Fatal Storm" by Rob Mundle. From this information, the following picture emerges regarding the loss at sea of Glynn Charles.

1. Charles was seated at the steering wheel on the port side of the yacht, facing starboard, with one leg each side of the steering wheel (p12, transcript of 26.7.99). Senogles was at the entrance from the deck leading downstairs when they were hit by a huge wave (transcript of 7.1.99, p9). Senogles was the only other person above deck at the time, but he did not observe the actual events leading to Charles being swept overboard.

2. Charles had his safety harness on. The harness was connected by a lanyard to some point on the yacht nearby. The lanyard was 1.43 m long and consisted of a yellow strap very similar in construction to the safety belts used in cars. Each end of the strap passed through a steel ring and was doubled back so that it could be sewn over a length of about 150 mm to the adjacent part of the strap. This is the standard technique used to secure a steel ring at each end of a lanyard.

3. On 21.12.99 I inspected the actual lanyard used by Charles that was recovered from the yacht. The stitching had come undone at the end fastened to the harness. Stitching at the other end was partly undone but this end remained attached to the yacht after Charles was lost overboard.

4. On 21.12.99 I also inspected an identical lanyard that had been tested by Derek Wainohau of the RTA crash lab. It had been subject to a standard drop test and had failed in an identical fashion to the lanyard worn by Charles. It failed at a force of 6.7 kN and at a time of 50 ms after the force started to increase (verbal communication with Wainohau). According to Wainohau, this type of strap normally elongates by about 15% under a load of 9 kN. In fact, his tests showed that the strap failed at the stitching, between 6 and 7 kN, in both the drop test and in static pull tests on his Avery machine. From this information it is clear that (a) the lanyard used by Charles failed at a force less than the rated force (12 kN), (b) the weak point was the stitching, which appeared visually to be insufficient to hold much of a load (b) the lanyard is constructed from a relatively stiff material with only a small amount of stretch, unlike say a bungy chord, but it is more stretchy than say wire rope.

5. The drop test roughly simulates what might happen if a person is swept overboard. The test consists of dropping a mass of 132 kg from a height of 1.47 m, the top end of the lanyard being rigidly supported and the mass being attached to the bottom end. In this test, and if the lanyard does not fail, then it is easy to calculate for

a 1.43 m long lanyard that (a) the spring constant of the lanyard is about 42 kN/m (b) the mass has a speed of 5.4 m/s and kinetic energy 1.90 kJ after falling through a distance of 1.47 m, (c) the lanyard will stretch a maximum distance of 0.30 m, (d) the peak force on the lanyard is 12.6 kN and (e) the force will reach its peak value 88 ms after the lanyard first becomes taught. The identical lanyard to that used by Charles failed 50 ms into the drop when the force had reached 6.7 kN and when the elastic energy transferred from the falling mass to the lanyard was 0.53 kJ.

6. At the time the wave hit, the boom was lashed to the starboard side of the yacht, at the same end and opposite Charles. The transcript of 26.7.99 (p 11) indicates that the alloy strut normally used to hold the boom in a horizontal position had been broken, allowing the free end of the boom to rest on the deck. The boom was lashed to a point that had previously been damaged by a collision at the start of the race, but subsequently repaired by Senogles to the crew's satisfaction. About 1m height of sail was lashed to the boom, adding to its total weight.

7. The wave hit the port side of the yacht causing it to fall down the face of the wave and to roll more than 90 degrees. The tip of the mast was observed to be lying in the water and it was well below the horizontal due to the steepness of the wave as shown in Fig. 1 At this point, the lashed end of the boom would have been slightly under water and Charles would probably have been falling vertically downwards towards the boom, but held by the lanyard at the top end and hanging onto the steering wheel. If for any reason Charles was not hanging onto the steering wheel, then he could have fallen a distance vertically through the air as the yacht rolled into this position. If he fell more than about 1 m, the lanyard could have failed at that point.

8. The yacht completed a 360 degree roll in a time span of about 5 seconds. At the end of this period the mast had broken in several places and was wrapped around the yacht. The boom had become detached and took a large section of the previously damaged starboard side with it. The 6 feet diameter steering wheel was smashed, and Charles was swept overboard, the lanyard having broken.

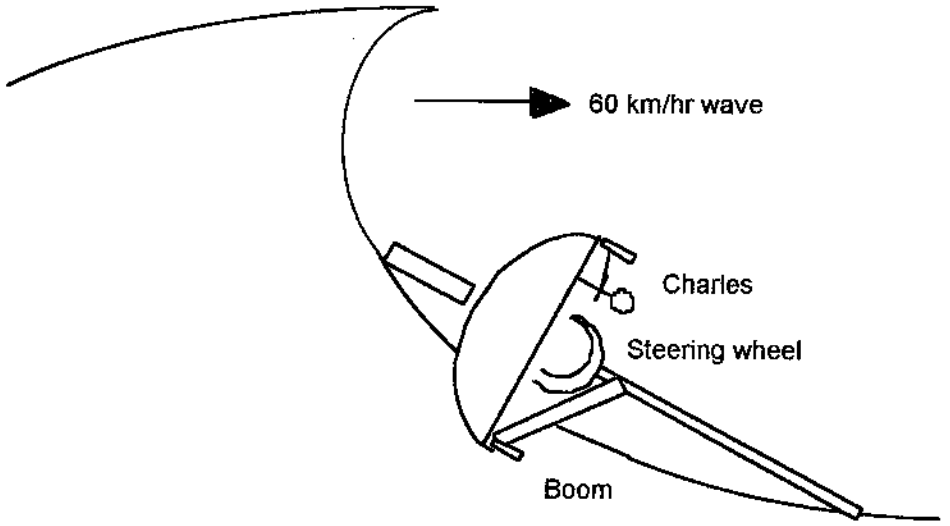

Fig. 1 Position of Sword of Orion showing location of boom and Charles. Drawn roughly to scale, where Beam = 4.17 m and wave height is about 10 m.

9. The sequence of events during the roll is impossible to determine with any precision, but it is obvious that the boom was subject to a large force, probably when it first hit the water. The force is hard to estimate but it could

well be equivalent to dropping the yacht on its side from a height of more than 2 m onto the water, given that the wave that hit the yacht was probably at least 10 m high. Waves 50 to 60 feet (15 - 18m) high were reported by many of the yachts during the storm. Some waves up to 90 feet were measured by helicopter crew.

A very similar event took place on Kingurra where the boom was lashed to the deck, the yacht rolled 360 degrees when it was hit by a large wave and the boom tore the mainsheet winch from the deck (Fatal Storm, p168-9). It is possible that other yachts experienced the same or similar events, but I have no further information on this. It can probably be found in the detailed report published by the Cruising Yacht Club of Australia. Rob Mundle suggested that maybe 7 to 10 yachts were rolled through 360 degrees by huge waves.

10. Senogles reported (statement 7.1.99, p10) that "we got hit by a big wave which we were beam onto, and it tipped the boat onto it's side, the boat slid down the wave on its side, and when the boat got to the bottom of the wave the boat continued to roll over." A more graphic description is given on p 196 of Fatal Storm. Senogles is reported to have said "All I can remember is a big roar and then an incredible bang when it hit the side of the boat. It was like being slammed in a car accident. The boat began to roll. I remember being amazed at seeing the mast on the surface of the water, yet it was angled down below the horizontal. We were way past 90 degrees. The yacht was on its side being slid down the face of the wave with the deck being pushed through the water. We crashed into the bottom of the wave and all hell broke loose. It just continued to roll the boat over. It didn't happen fast but the force was unbelievable."

11. Given that the wave speed was about 60 km/hr (16.7 m/s), it is reasonable to assume that the tip of the boom swung free at a speed of about 10 m/s. A similar result can be calculated assuming the yacht dropped 20 feet (6.1 m) onto the water. Anything dropped from this height hits the ground at 10.9 m/s and will then bounce up. The other end of the boom was pivoted at the mast. The boom was 6.385 m long, as specified by parameter E on the IMS rating certificate of Dec 1998. If one assumes that the total mass of the boom (47.0 kg), sail (25 kg) and trapped water in the sail and boom (possibly 50 kg) was about 120 kg, then the rotational energy of the boom was about 2.0 kJ. If the tip of the boom was swinging at 20 m/s, the boom energy would have been four times larger or about 8 kJ.

12. The energy required to break the lanyard, from the above test results, is about 0.53 kJ. The energy required to smash the steering wheel is unknown, but a figure of 1 or 2 kJ seems plausible. From this information, it is plausible that the boom had sufficient energy to break both the steering wheel and the lanyard, if not in one go then possibly in two separate sweeps of the boom as the yacht rolled through 360 degrees. However, while the boom was underwater, it would be difficult to accept that it could be travelling at a speed above 5 m/s, due to the drag force exerted by the water.

It is not clear that the boom did in fact hit Charles with sufficient force to break the lanyard. Fig. 1 shows the most likely orientation of the yacht when the boom broke free. If the tip travelled vertically upwards at 10 m/s, then it would first have to smash the steering wheel to reach Charles. This would reduce the tip speed to say 5 m/s, in which case the boom energy would have dropped from 2 kJ to only 0.5 kJ. Even if the tip travelled up at 20 m/s and slowed to 10 m/s after smashing the steering wheel, then the boom would have lost maybe 4 kJ in smashing the wheel, about 2 kJ was needed to raise the boom vertically to a horizontal position and the boom then had 2kJ left over. The boom would then have to hit Charles and lift him a distance of 2.9 m before the lanyard went tight. If Charles and his gear weighed 80 kg, then the energy to lift him through 2.9 m is 2.3 kJ. The energy needed to lift the boom itself is about 2.3 kJ (given that the end attached to the mast wasn't lifted and the far end would rise twice as high as the centre of mass). These figures are not consistent with the boom rising up far enough to stretch the lanyard tight.

13. It is also possible that the boom swept Charles off the yacht or that Charles was simply dragged into the water as the yacht rotated through 360 degrees, without the lanyard breaking immediately. The lanyard may have subsequently failed if the yacht lurched suddenly away from him. This scenario is somewhat diminished by the fact that 5 crew on Business Post Naiad ended up in the water after a 360 degree roll, with their lanyards and harnesses still attached. In this case, the boom remained lashed to the deck (Fatal Storm, p 244-247). It would be instructive to measure the breaking strength of the lanyards used by this crew.

14. My reading of the situation is that the lanyard most probably broke as a result of Charles falling vertically from the position shown in Fig. 1 and that this may have occured before or without the boom hitting him. If the yacht actually dropped onto the water through a height of more than 1 m, then the yacht would suddenly decelerate when it hit the water, but Charles would tend to keep going until the lanyard broke. In other words, this would be equivalent in effect to the drop test described above. Alternatively, it appears that the yacht may have been slammed into the bottom of the wave by the force of the water falling onto it from above.

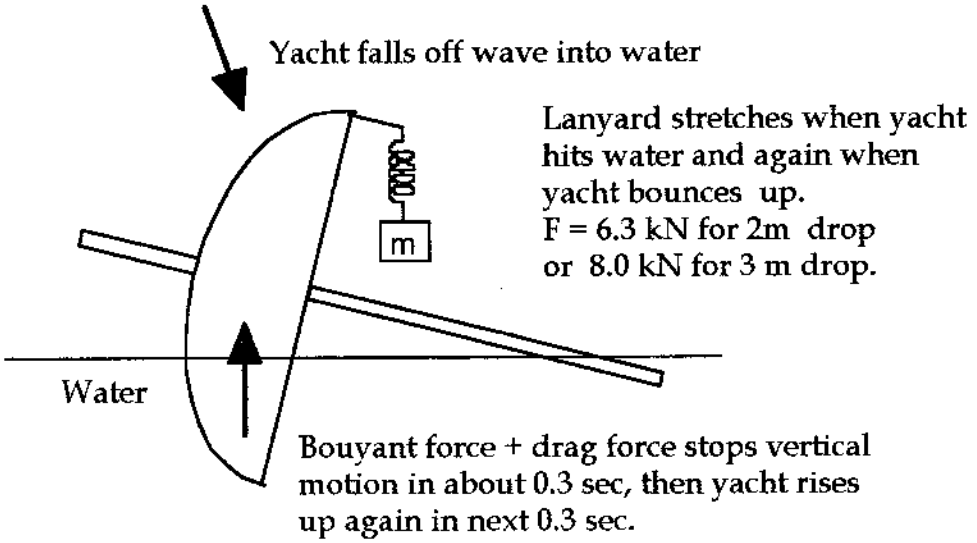

Fig. 2 Forces acting on yacht and on harness when the yacht is dropped into the water or is pushed into the water by the weight of the wave above it.

One can estimate the force on the lanyard by a simple calculation. If a boat is dropped vertically through the air onto its side, then gravity causes it to sink further into the water, but the buoyant and drag forces acting vertically upwards will slow the fall (see Fig. 2). The boat will come to a stop within about 0.3 sec, assuming the boat weighs 9 tonne and the surface area of the boat entering the water is 15 square metres (eg 15 m long x 3 m wide section). The boat will then bounce back up towards the surface of the water. The drag coefficient is about 1.0 for a cylindrical surface. I wrote a simple program to calculate the force on the lanyard, assuming a mass of 80 kg on one end, and a spring constant of 40 kN/m for the lanyard. If the boat is dropped from a height of 2 m, the peak force on the lanyard is 6.3 kN. For a 3 m drop, the peak force is 8.0 kN. The force on the lanyard rises to this peak twice in rapid succession, first when the boat slams into the water and again when it bobs back out of the water about 0.3 sec later.

However, I cannot rule out other possible scenarios. For example, the boom may have hit Charles after the yacht had completed its 360 degree roll.

15. In the 1979 Fastnet yacht race, 15 people died as a result of a heavy storm. 77 of the boats were knocked down past the horizontal position. 26 boats reported safety harness failure, and 6 deaths were attributed to failure of a safety harness. This is described in the book "The Fastnet disaster and after" by Bob Fisher (797.14/50 in Fisher library).

A/Prof Rod Cross