Report on the investigation of the

keel failure, capsize, and loss of one crew member from

the Max Fun 35 yacht

Hooligan V

10 miles south of Prawle Point

on

3 February 2007

Marine Accident Investigation Branch
Carlton House
Carlton Place
Southampton
United Kingdom
SO15 2DZ

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Extract from

The United Kingdom Merchant Shipping

(Accident Reporting and Investigation)

Regulations 2005 – Regulation 5:

"The sole objective of the investigation of an accident under the Merchant Shipping (Accident Reporting and Investigation) Regulations 2005 shall be the prevention of future accidents through the ascertainment of its causes and circumstances. It shall not be the purpose of an investigation to determine liability nor, except so far as is necessary to achieve its objective, to apportion blame."

NOTE

This report is not written with litigation in mind and, pursuant to Regulation 13(9) of the Merchant Shipping (Accident Reporting and Investigation) Regulations 2005, shall be inadmissible in any judicial proceedings whose purpose, or one of whose purposes is to attribute or apportion liability or blame.

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

ABS	-	American Bureau of Shipping
BMF	-	British Marine Federation
CG	-	Coastguard
DSC	-	Digital Selective Calling
ECB	-	European Certification Bureau
EN-ISO	-	European Norm Standard
EPIRB	-	Electronic Position Indicating Radio Beacon
GPS	-	Global Positioning System
GRP	-	Glass reinforced plastic
HWYDC	-	Hugh Welbourn Yacht Design Consultants
ICOMIA	-	International Council of Marine Industry Associations
ISAF	-	International Sailing Federation
kg	-	kilogram
kW	-	kilowatt
LSA	-	Lifesaving Apparatus
m	-	metre
MIG	-	Metal Inert Gas
MPa	-	Mega Pascals
NCI	-	National Coast Watch Institution
NDE	-	Non-destructive Examination
Nm	-	Newton Metre
QAB	-	Queen Anne's Battery
RCD	-	Recreational Craft Directive
RNAS	-	Royal Navy Air Station
RNLI	-	Royal National Lifeboat Institution

RORC	-	Royal Ocean Racing Club
RSG	-	Recreational Craft Sectoral Group
SAR	-	Search and Rescue
TCC	-	Time Correction Coefficient
UTC	-	Universal Time Co-ordinated
VHF	-	Very High Frequency
YDSA	-	Yacht Designers and Surveyors Association

Chord length	The length of the side profile of the keel adjacent to the hull.
Micro balloons	Lightweight “free flowing“ powder which is mixed with polyester or epoxy resin to make a strong filler which is easy to sand.
Notified Body	A professional body which an EU Member State appoints as being suitable to assess RCD conformity requirements.

SYNOPSIS

During the late evening of 2 February 2007, the owner and four crew of the Max Fun 35 yacht *Hooligan V* sailed from Plymouth towards Southampton following out of season repair and maintenance. At about 0320 (UTC) on 3 February, the boat's keel became detached and the boat capsized, causing the loss of life of one crew member.

Hooligan V was the first of 10 yachts in a class developed by the Dutch yacht designer Maarten Voogd, for use in Recreational Craft Directive (RCD) Category B waters. The yacht was apparently designed following the American Bureau of Shipping (ABS) standards. It was built by Breehorn BV in Woudsend in The Netherlands and marketed by Max Fun Boats BV.

Unbeknown to the designer, the builder sub-contracted construction of the hollow keel to a steel fabricator who had no marine experience. The fabricator changed the design of the keel to ease manufacture and to reduce costs but without adequately assessing the stresses to which the keel would be subjected in service.

In 2005, the owner of *Hooligan V* contracted a UK yacht designer to optimise the yacht for IRM and IRC[1] racing. This involved adding a further 160kg to the keel bulb.

At the end of a successful 2006 racing season, the yacht was delivered to Queen Anne's Battery in Plymouth for repairs and maintenance. When the boat was taken out of the water, a considerable amount of detachment of the keel's epoxy filler and anti-fouling was found. There was also evidence of the likelihood of fine cracking in the steel adjacent to the fillet weld, but this went undetected. At the end of January 2007, the boat was put back into the water for the delivery voyage from Plymouth to Southampton.

In the meantime, the owner of *Hooligan V* had interviewed a number of prospective new crew for the forthcoming 2007 season. He offered places on the delivery voyage to two of the more experienced candidates.

The owner met with his crew at Southampton at 1200 on 2 February 2007 and advised them that he intended to sail at about 0700 the following day. The two nominated watch leaders were very experienced and had frequently sailed in races with the owner. The group drove by car to Plymouth, arriving at *Hooligan V*'s berth at about 1630, then set about checking the boat over for the delivery voyage. The two new crew members were briefed on the safety gear, layout of the boat, equipment and sailing procedures.

At about 1830, the group went ashore for dinner when it was agreed to sail later that evening because of the favourable weather conditions. The group returned to *Hooligan V* at about 2200, made final preparations for sea and donned their foul weather gear. The owner allocated the 3 hour watches commencing at midnight, and decided that he would assume an "on call" role.

At about 2300 *Hooligan V* motored out towards the eastern entrance of Plymouth breakwater. Visibility was good and there was an 8-10 knot wind from the north-east. At 2335 the boat passed the breakwater and the mainsail and genoa were rigged. The boat was on a port tack, heeling about 15° to starboard and making about 7-8 knots over the ground. Just before midnight the wind freshened and the first reef was put in the mainsail. At midnight, one of the watch leaders and crew went to their bunks. The owner followed at 0045 after putting the second reef in the mainsail.

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[1] These acronyms have no official meaning

By 0245 the wind had increased to 25 knots, gusting 35 knots and the boat was heeling 25º to starboard. At 0300 the relief crew arrived on deck, and after a period of handover the offgoing watch leader went below, but the crew member remained on deck with his relief. At 0315 the heel increased to 30°. The off watch leader returned on deck and preparations were made to put the third reef in the mainsail, the genoa having already been 2/3 furled.

Before the mainsail could be reefed, the list rapidly increased and at about 0320 the boat very quickly inverted, trapping the skipper inside the cabin. Once in the water, three of the crew found their way to the transom and immediately noticed that the keel was missing. As they set about cutting the liferaft lashings, the skipper managed to push the flare box and grab bag out of the cabin. These floated to the surface and the flares were set off. At the third attempt, the skipper escaped from the cabin, but there was no sign of the fourth crew member. Despite repeated shouts, there was no response from him.

Fortunately, the crew managed to release the liferaft and set off more flares. The crew were finally rescued at 0430 by a nearby ship. The body of the missing crew member was recovered by Salcombe lifeboat at 0655.

Hooligan V was salvaged and brought into Plymouth. On investigation it was found that the fabricated keel had failed just below the fillet weld connecting the fin to the taper box which was inserted into the hull. Laboratory metallurgical analysis confirmed that the keel had suffered fatigue failure in the fillet weld area, which had been subjected to high bending stresses. Defects were also found in the keel taper box welds and two of the three keel bolts had also failed.

Independent analysis of the “original” design calculations confirmed that they did not achieve the required Safety Factor. Further analysis of the keel design, as built, showed this failed to achieve the required safety factor by an even larger margin and that the subsequent addition of extra bulb weight in 2005 had exacerbated the situation. *Hooligan V*’s fabricated keel was unable to withstand the “in service” bending stresses and this led to the conditions of fatigue failure and consequent capsize of the boat.

Who Cares, a Dutch owned Max Fun 35 yacht had also suffered fracture of its keel, but in this case the cracking was noticed before the keel completely failed. The existence of this second case provided confirmatory evidence about the inadequacy of the keel design and construction.

As a result of the MAIB investigation, the Max Fun 35 yacht keel has been redesigned and now exceeds the minimum required safety factor. New keels have been fitted to 7 out of the 9 remaining boats.

Recommendations include:

- The need to ensure that the appropriate safety factor is applied to designs and that the build standard is fully documented.
- An amendment to be made to the Recreational Craft Sectoral Group Guidelines to include keel construction standards.
- The safety issues identified in this report to be promulgated to the marine industry.

Hooligan V

SECTION 1 - FACTUAL INFORMATION

1.1 PARTICULARS OF HOOLIGAN V AND ACCIDENT

Vessel details

Registered owner	:	Privately owned
Port of registry	:	Southampton
Type		Max Fun 35 yacht – Bermudian sloop
Designer	:	Simonis Voogd Yacht Design of The Netherlands
Builder and year	:	Built by Breehorn BV in Woudsend in The Netherlands on 30 May 2002
Hull Identification No	:	NL-BRW35001F202
Construction	:	GRP and PVC foam sandwich
Keel construction	:	Fin – prefabricated steel S235JR (ST 37) Bulb – lead with 2-4% antimony
Length overall	:	10.65m
Breadth	:	3.32m
Draught	:	2.2m
Weight (as measured by RORC in April 2005)	:	3813kg
Engine type and power	:	Yanmar 2GM-20 output 23.43kW
Sail wardrobe		Mainsail, No 3 and No 4 genoas, storm jib,trisail, and an asymmetric spinnaker

Accident details :

Time and date	:	Approximately 0320 (UTC) on 3 February 2007
Location of incident	:	50° 02'N 003° 45.5'W – 10 miles south of Prawle Point
Persons on board	:	Five
Injuries/fatalities	:	One fatality and one severe case of hypothermia
Damage		Capsize leading to total constructive loss

1.2 BACKGROUND

(All times are UTC)

The Max Fun 35 yacht *Hooligan V* completed build at the Breehorn BV boatyard at Woudsend in The Netherlands on 30 May 2002. The first owner purchased the boat, then named *Windemere,* on 11 June 2002, but did not sail it due to other commitments. Short term ownership transferred to the yacht broker, Tangent Yachting, from whom the present owner purchased the boat on 6 November 2002 and renamed it *Hooligan V*.

The owner established a core team of about 18 experienced yachtsmen to crew the boat in a variety of demanding races. The 2006 season was especially successful, with the boat winning Class 1 in the Shetland Round Britain and Ireland Race. Following the arduous 2006 season, the boat was sailed to Queen Anne's Battery, Plymouth for out of season maintenance and repair. On 21 November 2006 *Hooligan V* was lifted out of the water so that Fast Tack Yachts, the primary contractor, could start work.

In the meantime, the owner advertised for additional crew on the Royal Ocean Racing Club (RORC) website. A number of prospective candidates were short listed for a more detailed practical sailing assessment which was planned for March 2007. Following scrutiny of the candidates' personal profiles, and a meeting with the owner and a number of the crew, two of the candidates were invited to crew *Hooligan V* for the delivery voyage from Plymouth to her home port of Southampton.

The owner visited *Hooligan V* twice during the maintenance and repair period and was extremely satisfied with the standard of work. *Hooligan V* was put back in the water on 24 January 2007 for the mast and rigging to be fitted and to await the delivery crew.

1.3 IDENTIFICATION OF CREW MEMBERS

For the purposes of this report, the crew members are identified as: the skipper, who was also the owner; Watch Leaders 1 and 2; Jamie Butcher (Crew 1[2]) and Crew 2.

The skipper and Watch Leaders had considerable experience in sailing *Hooligan V* and other boats, and had crewed together on many occasions. Although Jamie Butcher and Crew 2 also had wide sailing experience, they had not previously sailed a Max Fun 35 yacht.

1.4 NARRATIVE

1.4.1 Pre-sailing activities

At the end of January 2007, the skipper confirmed that Fast Tack Yachts had completed all the repair and maintenance work on *Hooligan V*. He arranged for the delivery voyage to start at about 0700 on 3 February 2007, and at 1100 on 2 February, obtained weather forecasts for 3 February from the Marine Call and Theyr websites. A predominantly high pressure system with 10-25 knot north-easterly winds was predicted.

The skipper met with his 4 man crew at 1200 on 2 February 2007 at the Royal Southampton Yacht Club. After collecting stores for the voyage they travelled by car to Queen Anne's Battery in Plymouth. During the trip the skipper told the crew

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[2] Crew 1 was later to become the casualty

of the weather forecast and confirmed his intention to sail the following morning. However, Watch Leader 1 mentioned that the conditions meant that the trip would be a little unpleasant, and suggested that it may be better to sail on the evening of 2 February when the conditions were expected to be a little more favourable. The skipper acknowledged this and the group agreed to defer the decision until later that evening.

The group arrived at *Hooligan V'*s berth at 1630 and were met by a team from Fast Tack Yachts who were loading the sails and other equipment which had been kept ashore during the repair period. The crew checked the condition of the boat, re-fuelled it, took on water and connected the gas cylinders. The VHF radio, with DSC facility, GPS, the 8 auto-inflatable lifejackets, engine and battery charging system were also checked, as was the Avon Modular Super 8-man liferaft, which was lashed in its container, in a criss-cross fashion at the transom, behind the rudder stock **(Figure 1)**

Figure 1

Position of liferaft and securing arrangement

Watch Leader 2 briefed Jamie Butcher and Crew 2 on the layout of the boat, the rigging arrangements and where the first-aid kit, emergency water containers, flare box and the "grab bag"[3] were located. When opening the "grab bag" he noticed that the EPIRB was missing, but despite efforts to find it, it could not be located.

[3] The 'grag bag' contained a signalling mirror, rope, VHF hand held radio, hand held GPS, survival bags, waterproof torch, spare batteries, knife, binoculars, sunscreen, high energy cereal bars, sea sickness tablets and polythene bags

At about 1715 the port and starboard safety jack lines were fitted, the mainsail was rigged and then flaked over the boom. Soon after, the No3 genoa was also rigged and then fully furled.

The skipper then provided auto-inflation, “Crewsaver” lifejackets, and separate spray hoods which were held in individual pouches to all those onboard. However, the use of the spray hoods and method of attachment were not discussed or demonstrated. Crew 2 provided his own manual inflation lifejacket, and so declined the offer of the use of the skipper’s lifejackets, but he accepted the spray hood.

By 1800 *Hooligan V* was fully stowed and prepared for the delivery voyage.

At about 1830 the group went ashore for drinks and a meal at a nearby restaurant. During the meal, it was unanimously agreed to sail later that evening because there was only a 10 knot north-easterly wind, the sea conditions were also favourable and so the passage was likely to be more comfortable than if the departure was deferred until the following day.

The group left the restaurant at about 2115 and called at the Royal Western Yacht Club for a drink before returning on board *Hooligan V* at about 2230. By this time each of the group had consumed about three pints of beer, and two to three glasses of wine.

As the crew made final preparations to secure the boat ready for sea, the skipper plotted a course to take *Hooligan V* approximately 6 miles south of Bolt Head and then on to Southampton. The crew then donned their mid layer fleece clothing and foul weather gear. All, except Watch Leader 1, put on their lifejackets and secured their splash hood pouches to the lifejacket webbing. The skipper then allocated the watches. Watch Leader 1 and Jamie Butcher were allocated the 0001 to 0300 watch and Watch Leader 2 and Crew 2 were to take the 0300 to 0600 watch while the skipper assumed an “on call” role.

1.4.2 Subsequent events leading to the accident

With the skipper at the helm, *Hooligan V* left Queen Anne’s Battery at about 2300 and motored out towards the eastern entrance of Plymouth breakwater. There was a full moon, and although overcast, the visibility was good and there was an 8-10 knot wind from the east-north-east.

At about 2325 the boat passed through the breakwater, and the mainsail and genoa were rigged and the engine stopped. *Hooligan V* was then placed on a close hauled port tack, and as it left the lee of the land, was heeling about 15º to starboard and making 7-8 knots over the ground.

As the crew settled down to sailing, the skipper and Watch Leaders noted that the boat was much “stiffer” and more responsive to the helm than prior to the repair period. It was slamming into the 0.75 metre seas in a more purposeful manner. At about 2345 the skipper decided to put one reef in the mainsail as the wind freshened to about 15 knots.

At midnight, Watch Leader 2 and Crew 2 went below to their bunks. The wind continued to strengthen to about 20 knots, so at 0045 on 3 February the skipper agreed with Watch Leader 1 to put a second reef in the mainsail. At 0100 the skipper handed over the helm to Watch Leader 1, and went below. He took off his lifejacket and foul weather jacket and lay on the top of the port forward bunk.

Soon after, the wave height had increased to about 1.25 metres, so to make the motion more comfortable, Jamie Butcher furled the genoa by 1/3. The wind continued to gather strength and as Jamie Butcher went below to rouse the relief watch at 0245, the wind strength was 25 knots, gusting 35 knots and the boat was heeling about 25° to starboard.

Watch Leader 2 donned his lifejacket and arrived on deck at about 0300, having instructed Crew 2 to put a fix on the chart. Watch Leader 1 remained on deck until about 0310 as he pointed out shipping to Watch Leader 2 and gave him time to develop his night vision. As Watch Leader 1 went below to rest on top of his bunk, Jamie Butcher, who had decided to remain on deck with Crew 2, further reduced the genoa by another 1/3. At this point, Crew 2 had clipped his safety harness to the jack line. Watch Leader 2 was not clipped on, and it is unclear whether or not Jamie Butcher was secured to the jack line.

By about 0315, *Hooligan V* had assumed a 30º heel to starboard, although there had been no change in either the weather or sea conditions. Watch Leader 2 called Watch Leader 1 back to the deck because he wanted to put a third reef in the mainsail.

Watch Leader 1 held onto the boom as he reefed in the mainsail. In the meantime, the heel steadily increased to about 35°, and Watch Leader 1 then advised Watch Leader 2 to steer *Hooligan V* closer to the wind to reduce the heel. However, the heel to starboard continued to increase to about 70° and Jamie Butcher, seated next to Watch Leader 2, fell from the high side, into the cockpit that was partially filled with water. At this point Jamie Butcher was conscious and was spoken to by Watch Leader 2.

Watch Leader 2 was unable to get the boat to respond to the helm and the speed rapidly dropped to about 4 knots. Over the next 4-5 seconds the heel increased to about 90º, the mast head then touched the water and *Hooligan V* immediately inverted at about 0320.

1.4.3 Post-accident

As the boat capsized, Watch Leader 1 was thrown over the starboard side into the water. Crew 2, realising that the boat was not recovering from the heel, managed to unclip his safety harness and push himself off the high side into the water. On seeing the mast disappear below the water, Watch Leader 2, cogniscent that he was wearing an auto-inflate lifejacket, dived between the clearing gap created by the sea and the inverting transom guardrail. He surfaced at the upturned stern with his lifejacket inflated.

As Watch Leaders 1 and 2 and Crew 2 swam towards the boat's transom they noticed that the boat's keel was missing. As they reached the stern, they managed to cling onto the guardrail stanchions. This was very difficult as the upturned yacht was pitching in 1.5 metre seas, and they were very cold. Watch Leader 1 did not have his lifejacket on. Crew 2 pulled the manual inflation cord of his lifejacket, but it failed to operate because it had become snagged on velcro fasteners.

The group assessed the situation. Because there was no sight of either the skipper or Jamie Butcher, and there was no response to the group's calls to them, they assumed that they were likely to be in an air pocket inside the boat's cabin area.

Watch Leader 1 then set about trying to cut the lashings securing the liferaft using a knife he had with him. In the meantime, the skipper, who had been thrown out of his bunk, swam out of the cabin, but he became entangled in the ropes in the cockpit, so he returned to the air pocket in the cabin. At this point he managed to collect the flare box and grab bag and forced them out of the cabin. They surfaced about 15 metres from the upturned hull. Crew 2 immediately swam after them and brought them both back to the transom. The skipper by now was making his second attempt to leave the cabin, but once again he became entangled in ropes and returned to the cabin space.

By now, Watch Leader 2 and Crew 2 had managed to release the flare box lid and fire off a parachute distress flare. Unfortunately it was released horizontally and disappeared below the surface of the water. However, two others were successfully fired before the flare box sank and the grab bag drifted away. Knowing that shipping was nearby, Watch Leader 2 was confident that the flares would be seen and rescue would soon follow. Crew 2 was then able to hang on to a horseshoe life buoy that had been released from the transom.

The skipper was now making his third - and this time successful - attempt to escape from the cabin. After disentangling himself from the ropes in the cockpit, he surfaced close to the stern of the boat. Watch Leader 2, the only one with an inflated lifejacket, immediately grabbed him, and kept him afloat. Further calls were made by the group to Jamie Butcher, but there was no response.

Watch Leader 1 was suffering from the cold, but fought to cut the liferaft lashings. He dropped his knife once but managed to catch the lanyard it was attached to, and persevered in trying to release the liferaft. By that time, the skipper, suffering from hypothermia, was shivering violently and was beginning to slip in and out of consciousness.

Watch Leader 1 was unable to keep a grasp of his knife and it fell from his grip. Luckily, a couple of minutes later, at about 0345, the liferaft floated to the surface, but it drifted away because the painter, attaching the liferaft to the boat, had been cut. Once again, Crew 2 swam the 5 metres to collect the liferaft. He managed to get it back to the transom of the boat, where Watch Leader 1 attached the painter to a guardrail while Watch Leader 2 struggled to keep the skipper's head above water.

The group were becoming very tired and cold. They had swallowed a lot of sea water and their ability to think clearly was becoming impaired. Crew 2 had still not attempted to inflate his lifejacket, and none of the group attempted to don their spray hoods to help prevent them swallowing water. Despite this, Watch Leader 1 managed to pull the painter which inflated the liferaft. Both Watch Leader 1 and Crew 2 were able to swim to the liferaft and pull themselves inboard. Watch Leader 2 was now finding it very difficult to keep hold of the skipper and was unable to swim the 50 metres to the liferaft. Watch Leader 1 pointed out the liferaft's drogue to Watch Leader 2, who managed to grasp it and haul himself, and the skipper towards the liferaft. At about 0357, Watch Leader 1 and Crew 2 hauled the skipper, and soon afterwards, Watch Leader 2 on board the liferaft.

As the group set about bailing the liferaft out, the painter snapped allowing the lilferaft to float free from *Hooligan V.* As no-one had cut or released the painter, the group assumed that *Hooligan V* had sunk, causing the painter to break. In the meantime Watch Leader 2 located the flares in the liferaft and fired off a parachute distress flare and two pinpoint distress flares. The group then set about trying to warm up the skipper and keep him out of the water that was in the liferaft.

1.4.4 Recovery

At 0402 the container vessel *Gerd Sibum* reported to Brixham Coastguard that red flares had been sighted in position 50º02'N 003º 45.5'W. A short time later, the general cargo vessel *RMS Laar* reported sighting a liferaft and that she was closing it. On seeing the searchlight from the vessel, Watch Leader 2 fired off a further parachute and 2 pinpoint distress flares.

In the meantime, Brixham Coastguard transmitted a "mayday" relay to which *HMS Portland*, *RFA Wave Knight* and *MV Happy Lady* responded. The SAR helicopter R169 from RAF Chivenor and Salcombe Lifeboat were also activated.

At 0423 *RMS Laar* recovered the group from *Hooligan V*'s liferaft. The group were initially taken to the bridge, where Watch Leader 1 spoke to Brixham Coastguard and advised them that Jamie Butcher was missing, that the skipper appeared to be suffering from severe hypothermia, that *Hooligan V* had capsized and that her keel was missing. The group then took the skipper to a cabin where his temperature was recorded as 30º C. *RMS Laar*'s crew wanted to place him in a shower to deal with the hypothermic symptoms. *Hooligan V*'s crew were aware of the potential risk to rapid re-warming and objected to this. They persuaded two of *RMS Laar*'s crew to get into a bunk with the skipper to carry out safe passive re-warming of the skipper.

By that time, Brixham Coastguard had tasked the SAR helicopter R193 from RNAS Culdrose and Torbay lifeboat to assist in the search for Jamie Butcher. *RFA Wave Knight* was also requested to proceed to the scene. At 0535 a medical technician from *RFA Wave Knight* was transferred by seaboat, to *RMS Laar,* to attend to the hypothermic skipper.

At 0700, R193 winched the crew and medical technician on board. The medical technician was transferred to *RFA Wave Knight* before the helicopter landed at Plymouth's Roborough Airport where the crew were transferred to Derriford Hospital in Plymouth for treatment and observation.

MV Gerd Sibum was involved in the search for Jamie Butcher and, at 0630, her crew spotted reflective tape in the water. Salcombe lifeboat was directed to the area, and at 0655 recovered the body of Jamie Butcher in position 50° 04.7'N, 003° 43.9'W. He was wearing an inflated lifejacket which did not have a light attached, his lifejacket anti-spray hood was still in its pouch secured to his waist. He was later landed at Salcombe and then taken to Derriford Hospital. The subsequent postmortem showed that death was due to "immersion".

Brixham Coastguard released all vessels from the scene at 0717.

1.4.5 Salvage

As *RFA Wave Knight* proceeded towards Plymouth, the upturned hull of *Hooligan V* was spotted by the bridge lookout. At 0745 the sighting was reported to Brixham Coastguard who requested Torbay lifeboat to proceed to the scene to assess the feasibility of towing the boat into port and so remove the risk of any future collision. The lifeboat arrived on scene at 0815. The coxswain of the lifeboat was able to confirm that the keel had sheared off but that there were no signs of any hull damage or other signs of contact with an underwater object **(Figures 2 and 3)**.

Figure 2

Hull condition on arrival of Torbay lifeboat - port side

Figure 3

Hull condition on arrival of Torbay lifeboat - starboard side

Photographs courtesy of RNLI

The lifeboat was unable to manoeuvre close enough to connect a tow line. However, *RFA Wave Knight* agreed to launch her RIB in support and managed to connect a line **(Figure 4)** which was then passed to the lifeboat. At 0945 the Torbay lifeboat had *Hooligan V* under tow and was making 2 knots towards Salcombe. The tow parted twice before Brixham Coastguard instructed Torbay lifeboat to abandon the effort. Torbay lifeboat was released at 1108.

The National Coast Watch Institution (NCI) lookout at Prawle Point kept *Hooligan V* under observation until 1250 when it disappeared from view. A number of sightings were made over the next 24 hours. *Hooligan V* was finally salvaged by Marine Contract Divers Ltd of Plymouth, who had been contracted by the owner's insurers. The boat was brought into Victoria Wharves on 6 February 2007, where it was craned onto the dockside and examined by MAIB inspectors and representatives of the Devon and Cornwall Police.

Photograph courtesy of *RFA Wave Knight*

Figure 4

RIB from RFA *Wave Knight* connecting tow line

1.5 ENVIRONMENTAL CONDITIONS

At the time of the accident, the wind was north-easterly at 25 knots, gusting 35 knots. There was a full moon and visibility was good with 4/8ths cloud cover. There was an approximately 1.5 metre swell and the tide had just started to ebb. The air temperature was 9.1°C and the sea water temperature 10.8°C.

1.6 INITIAL FINDINGS

Initial investigations identified that the hull had been severely damaged by the salvor's ropes and those secured by *RFA Wave Knight*. These had cut through the GRP foam sandwich layers as *Hooligan V* was being towed by the Torbay lifeboat, and later by the salvor **(Figures 5 and 6)**.

Figure 5

Rope damage - starboard side of cockpit

Photograph courtesy of Mark Hill, Marine Contract Divers Ltd

Figure 6

Rope damage to hull under port side of cockpit

There was also evidence of paint markings, some minor impact damage and circumferential and longitudinal scratch marks down the port and starboard sides caused during connection of the towing ropes by *RFA Wave Knight*'s RIB, Torbay lifeboat and the salvor. These were predominantly on the antifouling surfaces **(Figures 7 and 8)**. The stem was badly damaged below the waterline, resulting in full penetration through the hull **(Figure 9)**. The rudder was also bent, but the engine sail drive unit was intact.

The keel was found to have been detached just below the fillet weld which had secured the fin to the taper box **(Figure 10)**. The presence of "beach marks" **(Figure 11)** on the fracture surface suggested that the fin had become detached through a mechanism of fatigue failure. There was also evidence of corrosion around the area of the weld.

With the exception of the rope induced hull splits, the internal structure was sound. The substantial GRP, cruciform structure supporting the keel was visually examined. There was no evidence of cracking, deformation or de-lamination. The keel bolt cover was removed and, although the three keel bolts showed signs of light corrosion, they were in place **(Figure 12)**. No attempt was made to check the tightness of the bolts as this was intended to be done under controlled laboratory conditions.

On completion of the examination, the remains of the keel, together with its supporting structure, were cut from the hull **(Figure 13)** so that a detailed metallurgical examination could be conducted to determine the cause of the keel material failure.

Figure 7

Paint and scratch marks on starboard side

Figure 8

Paint and scratch marks on port side

Figure 9

Stem damage showing full penetration of the hull

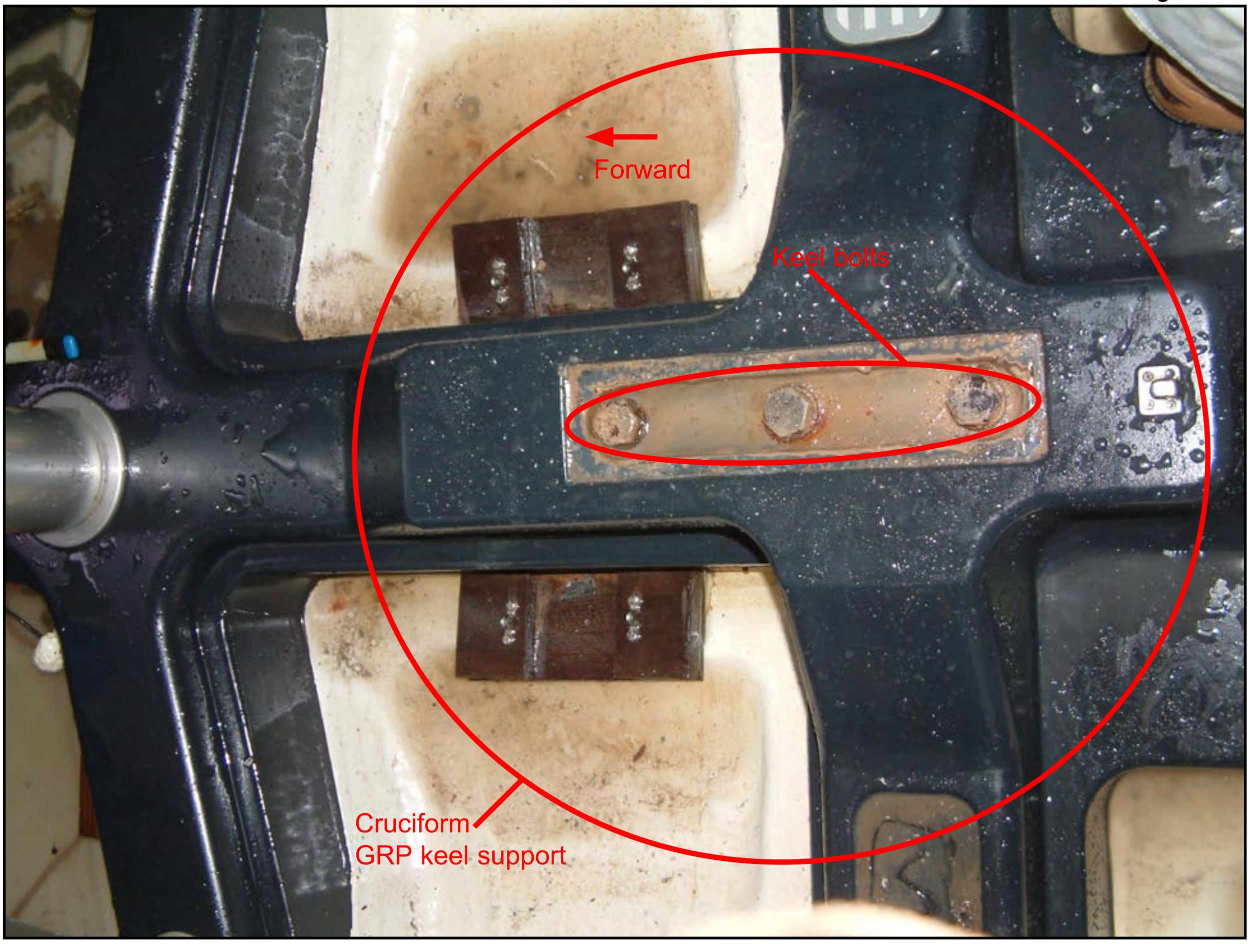
Figure 10

Remains of fin, showing point of detatchment

Figure 11

Remains of fin, showing 'beach marks'

Figure 12



Keel GRP supporting structure and keel bolts

Figure 13

Removed keel remains and supporting structure

1.7 THE MAX FUN 35 CLASS OF YACHTS

1.7.1 Background to the Max Fun 35

The Max Fun 35 was designed (Design No 150) in 2001 by Dutch based, Maarten Voogd of the South African/Dutch partnership of Simonis-Voogd Design BV. The design, which was stated to fulfil the Recreactional Craft Directive (RCD) Category "B" requirements, followed on from the smaller, very successful, Max Fun 25 Class. The Max Fun 35 won the Dutch Boat of the Year in 2003.

Max Fun Boats BV of Enkhuizen in The Netherlands was formed to manufacture and market the Max Fun 35s. The company owners comprised Maarten Voogd, his brother, and the director and owner of the well known boat builders, Breehorn BV, based in Woudsend, also in The Netherlands. The partnership was dissolved in 2005, leaving Maarten Voogd as the sole owner of Max Fun Boats BV.

Breehorn BV was selected to build the Max Fun 35s. The day to day oversight and the inevitable design changes identified during the build were largely left to the owner of Breehorn BV. To date, 10 of the class have been built and these are based in the UK, Netherlands, France and Germany. *Hooligan V* was the first of the class, and completed build in May 2002. The last Max Fun 35 to be built was delivered in 2005. Although the moulds are still held, there have been no firm orders for Max Fun 35s since 2005.

1.7.2 General description

The Max Fun 35 was described in the owners' manual as a "seagoing sailing yacht, with a built in engine". It was a Bermudian sloop with a 7/8 fractional rig. The GRP hull has a foam core for panel stiffness and the one piece internal structure, comprising space frames, avoids the need for internal bulkheads. The boat was originally designed to displace about 3000kgs, about half of which is accounted for by the keel fin and bulb.

The carbon fibre mast was fitted with an aluminium boom and two sets of aft-swept spreaders and discontinuous rod rigging. *Hooligan V* had a conventional stainless steel rod forestay, but a Spectra backstay had recently been replaced with an uprated Kevlar one with a breaking strain of 10 tonnes, which was tensioned via a cascade pulley system.

The mainsail had three reefing points, and the genoa could be reefed or furled using standard roller-reefing gear. When sailing downwind, an asymmetric spinnaker could be set from a carbon fibre retractable bowsprit.

This type of yacht will sail comfortably up to an angle of heel of around 25º. As the wind increases, the mainsail can either be reefed to reduce its size, or trimmed by flattening and/or feathering to reduce its power. With the genoa on a furler this can also be reefed, or alternatively changed for a smaller genoa or jib. All controls are fed over the coachroof and back to the cockpit.

Although not fitted as standard, *Hooligan V* was equipped with an Avon Modular Super 8 man liferaft secured at the transom.

As a lightweight, high powered yacht, to be sailed to its potential this design requires a skilled crew. Crew weight distribution is also important, to provide additional stiffness and fore and aft trim.

1.8 RECREATIONAL CRAFT DIRECTIVE

1.8.1 Background

The Recreational Craft Directive (RCD) - Directive 94/25/EC, was laid before the European Parliament on 16 June 1994, and application to Member States came into force on 16 June 1996. In the UK, Statutory Instrument (SI) – 1996 No. 1353, Consumer Protection, Recreational Craft Regulations 1996, mandates the requirement[4]. The regulations had a transition period until 16 June 1998, when they became mandatory.

The purpose of the RCD is to promote the free trade of recreational craft within the Member States of the European Union. The Directive applies to recreational vessels between 2.5m and 24m in length overall, and provides buyers with the confidence that vessels are built to a required, safe standard.

1.8.2 RCD guidance

To aid the interpretation of the RCD, the EU has produced updated guidance in the second edition of a publication entitled the "Recreational Craft Directive and Comments to the Directive Combined". For the purposes of this report, the publication is from hereon in referred to as the RCD Guidelines.

1.8.3 Recreational Craft Sectoral Group

A more comprehensive technical guidance, which includes lists of European Norm (EN) Standards, is provided by the EU's Recreational Craft Sectoral Group (RSG). The RSG Guidelines 2006 have been developed by EU Member States' Notified Bodies and other parties to assist with the conformity of assessment procedures undertaken by Notified Bodies on craft between 2.5m and 24m.

1.8.4 Build module choice

Manufacturers are required to prove RCD conformity. They are able to do this by selecting an appropriate build module designator as laid out in the table at Chapter 2 of the RCD Guidelines. A compilation of these instructions is detailed in the table at **Annex A**.

Module selection is based on the length of the vessel and the physical conditions that might be encountered. This is known as the Design Category as set out in Table 1 below.

Table 1

Design Category	Wind force (Beaufort scale)	Significant wave height (m)
A – "Ocean"	Exceeding 8	Exceeding 4
B – "Offshore"	Up to, and including, 8	Up to, and including, 4
C – "Inshore"	Up to, and including, 6	Up to, and including, 2
D – "Sheltered waters"	Up to, and including, 4	Up to, and including, 0.5

Modules range from Module A (Internal production control and self assessment by the manufacturer), to Module H (Full quality assurance with the intervention of a notified body to approve and control the manufacturer's quality system).

[4] The regulations had a transition period until 16 June 1998 when they become mandatory. SI 1996 No 1353 has since been superseded by SI 2004 No 1464 – The Recreational Craft Regulations 2004. These came into force in two stages, the first stage on 30 June 2004 and the second stage on 1 January 2005.

A fundamental element of the quality assurance self assessment system is the maintenance of accurate technical documentation. This should include system drawings, results of tests and examinations, and design calculations as required by Annex XIII of the RCD.

The Max Fun 35s were built to Design Category "B". They are under 12m length overall and therefore fall under build Module "Aa" as laid out at **Annex A**. The criteria for build Module Aa is defined in Table 2 below.

Table 2

Design Category	Module	Title	Description
B	A	Internal production control	Internal conformity assessment and production control by the manufacturer who draws up a written declaration of conformity in accordance with Annex XV of the RCD.
	Aa	Internal production control plus tests	This is Module A, plus tests of stability and buoyancy carried out on the responsibility of the notified body, which issues an examination report.

1.8.5 Essential Safety Requirements

Annex I to the RCD Guidelines **(Annex B)** sets out the Essential Safety Requirements for the design and construction of recreational craft. The Annex also identifies appropriate EN Standards, where these have been developed and ratified, against each requirement. Builders are not obliged to use these, but they must demonstrate that an equivalent standard, or other method of compliance, has been used and achieved. For the Max Fun 35, the designer confirmed in writing to the owner that the American Bureau of Shipping (ABS) guide for yacht design had been followed.

1.8.6 Declaration of Conformity

The RCD Annex XV requires a written declaration of conformity to be provided by the manufacturer, which is unique to each vessel. This should accompany the owner's manual and should include a list of the harmonised standards and national technical standards the manufacturer has complied with. In this case, the owner of *Hooligan V* did not have a copy of the owner's manual as this had not been passed on by the previous owner.

1.8.7 Builder's plate and CE marking

Annex I of the RCD specifies that a Builder's Plate be permanently affixed to the boat, which details the:

- Manufacturer's name
- CE marking
- Boat design category
- Manufacturer's maximum recommended load
- Number of persons recommended by the manufacturer for which the boat was deigned to carry when underway.

Annex III of the RCD requires that all vessels which are regarded as meeting the RCD Essential Safety Requirements must bear the CE marking of conformity. The marking symbolises conformity to all of the obligations incumbent on manufacturers in respect of the product covered by the RCD.

Further details of the requirements for the CE marking and Builder's Plate are contained in the RCD Guidelines at Annex I, Section 2.2 and Chapter 3, Article 10, a copy of which is respectively at **Annexes B and C**.

There was no evidence of CE markings on any of the six Max Fun 35s seen by MAIB inspectors.

1.8.8 Manufacturer's responsibility

Chapter 1, Article 4 (iv) of the RCD Guidelines states that:

> *"The manufacturer is the person or persons:*
>
> *- responsible for the design and construction of the product covered by the directive with a view of placing it on the EEA market on his/their behalf"*

The article goes on to describe the manufacturer's responsibility with regard to subcontracting elements of manufacture. It states that:

> *"The manufacturer may subcontract some operations within the manufacture, including the design, if he physically manufactures the product, or the manufacture if he designs the product. However, in both cases he must retain overall control and responsibility..."*

In this case Max Fun Boats BV was the boat's manufacturer.

1.8.9 Notified Body – testing of buoyancy and stability

Notified Bodies are organisations that are approved by EU Member States to carry out specific tasks in support of certain requirements as set out in the build module choice.

In the case of the Max Fun 35s, there was a requirement under build module "Aa" for a Notified Body to check the boat's buoyancy and stability. This was conducted by Bureau Veritas, who certified that the design was compliant. At the time of evaluation, the Bureau Veritas surveyor also offered to check the design scantlings in accordance with their normal business practice. Because the RCD does not require Notified Body involvement in this area the designer declined the offer.

1.9 STATEMENT OF ABS AND IRM CONFORMITY

1.9.1 ABS conformity

While an RCD Declaration of Conformity could not be provided (paragraph 1.8.5), the designer did declare, in a letter to the owner, that he had followed the ABS Guide for Yacht Design **(Annex D)**. The statement was requested by the owner in order to satisfy the International Sailing Federation's (ISAF) Offshore Special Regulations for construction standards.

Compliance with the ISAF Regulations was required for *HooliganV* so that the owner could compete in Category 1 and 2 races such as the Shetland Round Britain and Ireland Race. A copy of Section 3.03 of the Regulations – Hull Construction Standards – is at **Annex E**.

1.9.2 IRM conformity

The Royal Ocean Racing Club's (RORC) Rating Office requires a designer to declare that a boat's design satisfies a number of IRM rules so that the boat can be given a rating for racing purposes.

Rule 40.2 states that:

> *"For structural design of steel and steel alloys used in hull and appendages, sizing shall be with ABS or RCD factors of safety applied"*

The designer completed the IRM Designer Declaration on 5 December 2002 stating that Rule 40.2 had been complied with, i.e. that a Safety Factor of 2 had been applied to the hull appendages, which included the keel.

1.10 INTERNATIONAL STANDARDS ORGANISATION SPECIFICATION FOR SCANTLINGS

Although there was an ISO covering scantling sizes for keels at the time the Max Fun 35s were designed, work at developing a standard is now at an advanced stage. ISO 12215 Part 9 – Small Craft - Hull Construction Scantlings – Sailing Boats – Appendages and Rig Attachment is currently in Draft International Standard form awaiting formal ratification. The ISO covers the standards to be applied to the design of keels in boats between 2.5m and 24m. The standard follows the logic of the ABS Offshore Racing Yacht Guide 1994 in terms of matching loads and stress factors to give a similar margin of safety i.e. a Safety Factor of 2.

The draft ISO, which will eventually mature into an EN Standard, includes a requirement to check the strength of the ballast keel, and implies by the provision of equations for both solid and hollow sections, that the calculation is applicable to both fabricated and cast fins.

While there is no formal requirement for designers to comply with the Standards, the Introduction to the RSG Guidelines 2006 states that:

> *"RSG urges the industry and Notified Bodies to use EN Standards*"

1.11 KEEL CONSTRUCTION

1.11.1 Changes to the keel construction during build

The keel fitted to all of the Max Fun 35 boats was at variance with the "original" design. Breehorn BV, the boat builder, contracted Konstruktiebedrijf De Jong BV, a small steel fabricating company based at Oudega Gaast Sleat in The Netherlands, to construct the keels. While the company was well known to the boat builder for its industrial fabrication work, this was the first time the company had been involved in boat component construction. The original design was forwarded to the fabricator but he wanted to change the design to ease manufacture, enable more thorough hot dip galvanising, and in his view, to strengthen the fin connection to the taper box.

1.11.2 Original design

Hooligan V was originally designed with a narrow profile, fabricated steel fin with a chord length of 552mm. The top of the 1585mm long fin was welded to a steel taper box that was inserted into a matching female GRP taper located in a cruciform support that was integral to the hull. The hollow internal area of the fin was stiffened using 3 webs which extended from the base of the fin to the top of the taper where the webs were to be welded. Three M20 nuts were welded to the underside of the top plate of the taper box. Three, M20 stainless steel 316, Class 70 bolts mated with the nuts to secure the keel into the female taper. There was no specification for the torque setting for the keel bolts.

A 1325kg lead bulb, with between 2% and 4% antimony content to increase its strength, was fitted to the bottom of the fin. The designer's technical drawing of the keel fin and bulb is at **Figure 14**. The original design did not have any welds in the critical stress areas where the fin is attached to the taper box and is seen externally at the hull juncture.

The fin steel grade was specified as S235JR (ST 37). A copy of the steel's properties is at **Annex F**. Of particular note is the yield strength of 235 MPa and the ultimate tensile strength range of 360 – 510 MPa. The importance of these readings is discussed at Section 2. Definitions of yield, and ultimate tensile strengths is given at **Annex G**.

1.11.3 Original keel design calculations

The original keel design calculations to resist keel fin bending were based on the ABS Yacht Design criteria. The calculations showing the bending stress under normal sailing and in the worst case "knockdown" condition, i.e. when the boat has heeled through 90° and the keel fin and bulb are parallel to the surface of the water, are at **Annex H**. It should be noted that the designer correctly identified the minimum Safety Factor in the knockdown case as 2.0 or more, and this is discussed in more detail at Section 2.

The ABS standards also require that a boat's grounding loads be assessed as well as the suitability of the keel bolts to withstand grounding and tension loads. Neither of these requirements was covered in the original design calculations.

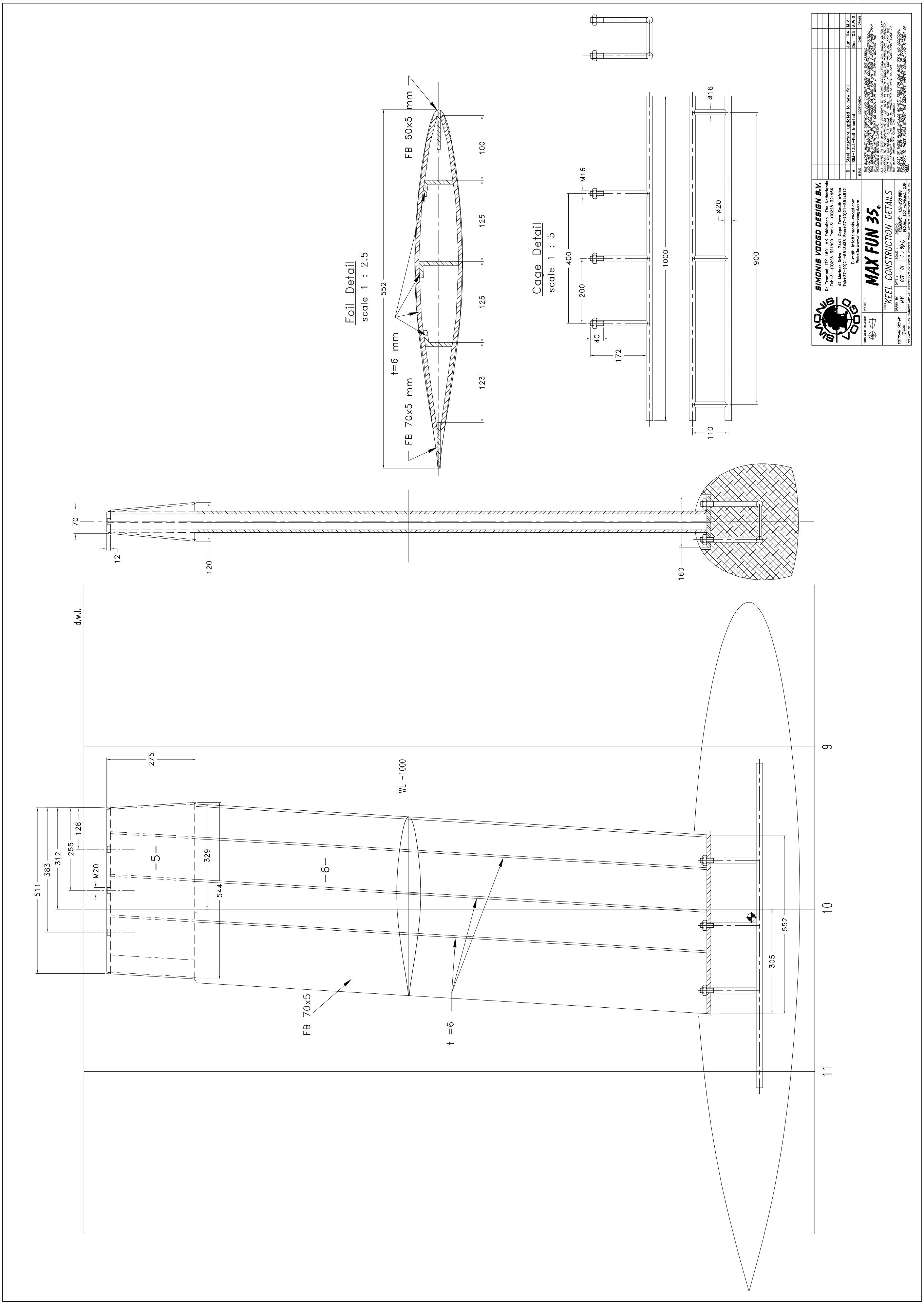
1.11.4 Modified design

Although the keel fabricator made design changes to the keel construction, the overall dimensions of the keel, taper and bulb, and the fin material specification, were consistent with the "original" design. Photographs of the "as built" keel, which externally is identical to the original design keel, are at **Figures 15 and 16**.

The main changes made by the fabricator were that the keel's internal stiffening webs were terminated short of the underside of the bottom plate of the taper box and also that they were not welded to the plate. Additionally, a critical fillet weld was introduced in the highly stressed area of the fin attachment to the taper box. The fabricator also specified that the fin was to be hot dip galvanised to give a degree of corrosion protection. A technical drawing of the changed, "as built" design is at **Figure 17**. A schematic showing the comparisons of the "original" and the "as built" designs is at **Figure 18**. A schematic of the configuration for the connection of the keel fin taper to the hull is at **Figure 19**.

The bolts and fin bulb were provided from a separate source and fitted by Breehorn BV.

Figure 14



Original keel design

Figure 15

After perspective

Figure 16

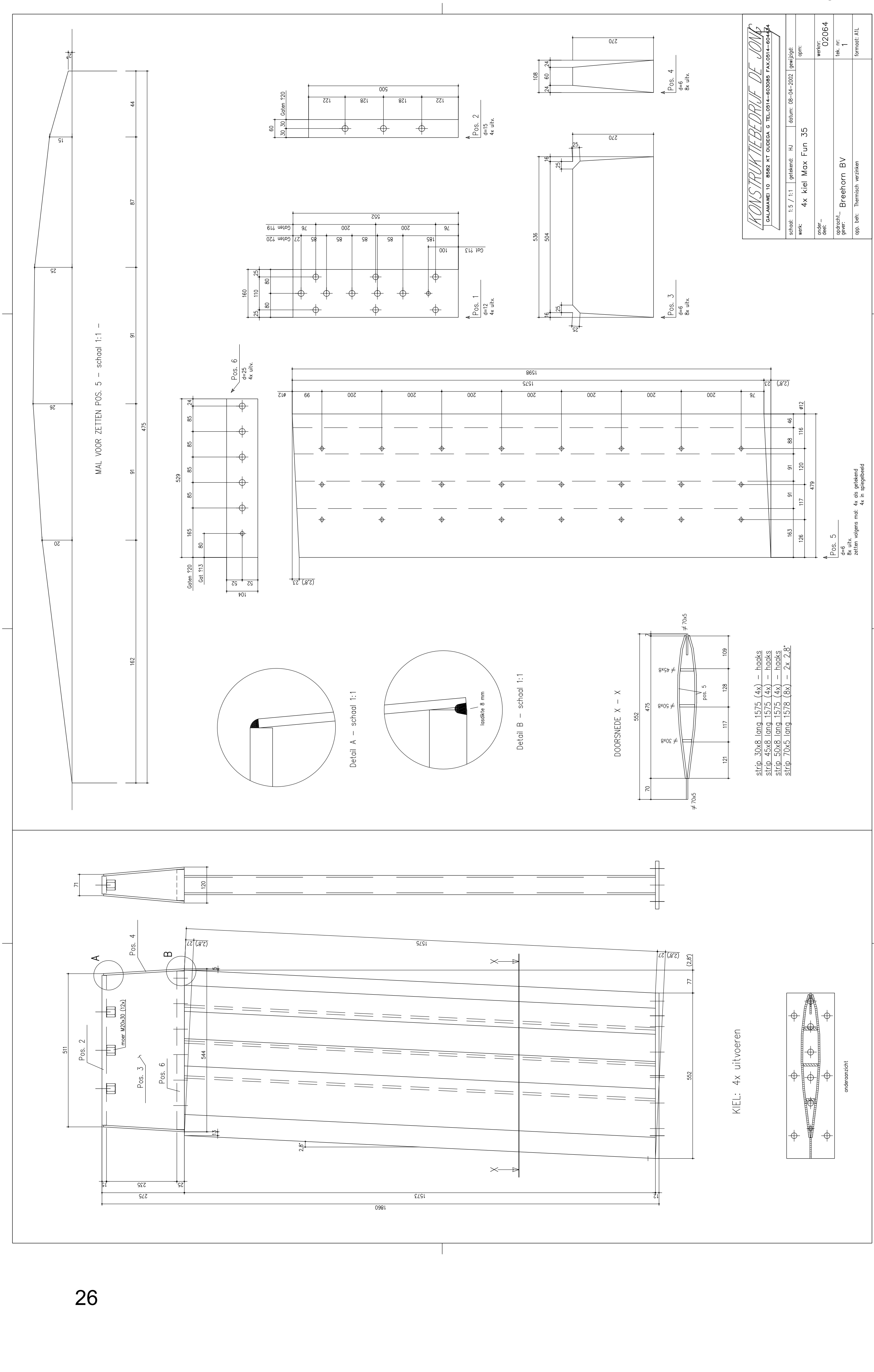
Starboard perspective

Views of the "as built" keel arrangement

1.11.5 Modified design calculations

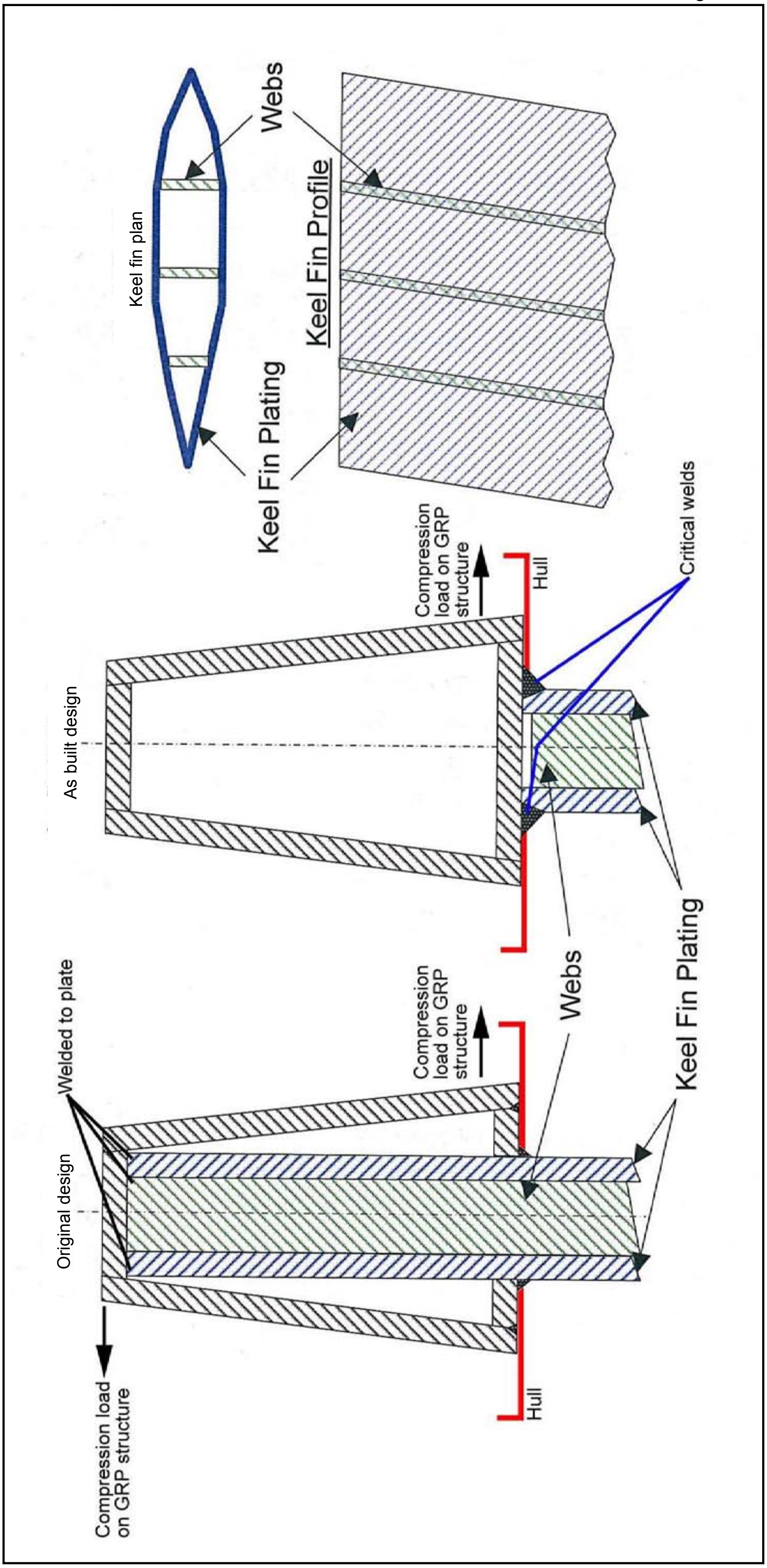
The steel fabricator did carry out some rudimentary design calculations but these were based on assessing the suitability of the taper box insert into the hull. The calculations did not check the structure in way of the keel fin root or its welded attachment. A copy of the calculations, translated from Dutch to English is at **Annex I**.

Figure 17



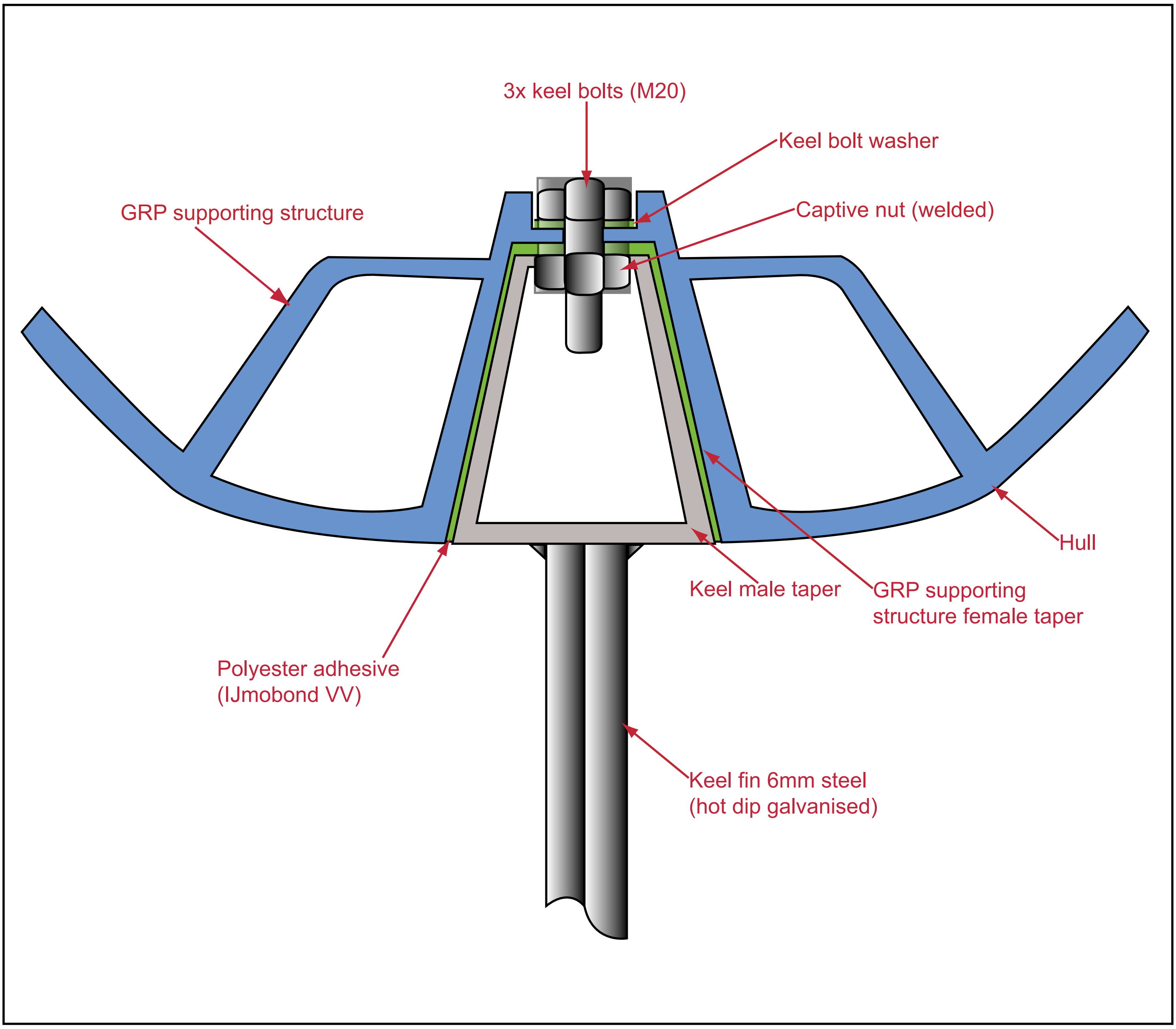
"As built" keel design

Figure 18



Schematic comparison of 'original' and 'as built' designs

Figure 19



Schematic of the connection of the keel fin taper to the hull

1.12 KONSTRUKTIEBEDRIJF DE JONG BV

1.12.1 Modified design – fabricator's quality assessment measures

Founded in 1976, Konstruktiebedrijf De Jong BV employed 5 multi skilled fabricators and one draughtsman. None of the staff, or the owner had any formal welding training or held any welding qualifications. Their skills had been developed through "on the job training" and experience.

In the case of the keel production, engineering drawings had been developed. However, there was no formal weld specification, except for the taper box construction. Neither was there any post-weld treatment or pressure test specified, other than instructing the use of the (Metal Inert Gas) MIG process. A number of staff worked on the keel plate and carried out the welding. Keel manufacture quality assessment comprised an occasional visual check of the welds and plate work by the owner.

1.13 POST-BUILD KEEL MODIFICATIONS

1.13.1 Re-profiling of the keel fin

Having gained 18 months racing experience with *Hooligan V,* the owner approached the original designer at the end of the 2003 racing season and sought his advice on re-profiling the keel fin to give the boat more lift. The designer provided a modified keel template giving a slightly increased aero foil section. The re-profiling work was carried out in Southampton in February and March 2004 using micro balloons mixed with epoxy.

1.13.2 Proposed keel bulb changes for IRC and IRM racing optimisation

Boats racing under IRC and IRM rules can be modified for optimisation purposes and thus reduce their racing handicap to make them more competitive. A full explanation of the rationale of optimisation is at **Annex J**. There are a number of methods of optimising a boat and these can include changing the waterline length, changes in ballast and changes to the sail wardrobe.

At the end of the 2004 racing season the owner approached the original designer with a view to increasing the keel bulb weight by up to 200kg to trim the boat slightly by the bow and also for IRC and IRM racing optimisation purposes. There is evidence to suggest the designer confirmed during telephone conversations, that the existing keel design could accept the additional weight. However, the designer was unable to recollect this. The designer subsequently contacted the owner in February 2005. He proposed building a new keel which would have been 200kg heavier and 200mm deeper than the original. It was calculated that the boat would then trim 0.035 degrees by the bow instead of 0.3 degrees by the stern. No detailed stress-related calculations had been made at this stage because the owner had not formally agreed to the proposal.

In the meantime, the owner had also approached Hugh Welbourn Yacht Design Consultants (HWYDC) of Torquay, to offer an opinion on adding weight to the keel bulb for optimisation purposes, and to increase the boat's upwind speed. Having examined the boat's general arrangement drawings, HWYDC suggested to the owner that the addition of 150 + kg to the bulb would improve the boats trim and stability. This could be achieved by fitting a new bulb cone and by adding lead sheet to the bulb immediately behind the fin connection to the bulb.

On the basis that the designer had already indicated that 200kg could be added to the keel, the owner agreed with the HWYDC proposal. Arrangements were made for a new bulb front end to be cast of lead with 3% antimony. The owner then contracted Marine Solutions of Southampton to carry out the modification work.

1.13.3 Fitting the modified bulb cone and lead sheeting

Work to modify the bulb was carried out at Saxon Wharf in Southampton in March and April 2005.

The front of the original bulb, weighing approximately 85kg was removed **(Figure 20)**, and the new 210kg section fitted using 2 x 400mm long stainless steel pins, and a high quality propriety underwater adhesive. Approximately 35kg of lead sheeting was also secured to the lower 2/3 of the bulb immediately behind the after end of the fin connection to the bulb **(Figure 21)**. The bulb net weight gain was approximately 160kg.

Figure 20

Face of the removed section from the front of the fin bulb

Figure 21

Removed and new section of bulb, lead sheeting and stainless steel fixing pins

Photographs courtesy of Marine Solutions

1.14 END OF 2006 RACING SEASON MAINTENANCE

1.14.1 Arrangements

After a successful 2006 racing season, and having completed 19800 miles of sailing in the boat, the owner arranged for *Hooligan V* to be taken into Queen Anne's Battery (QAB) in Plymouth on 19 November 2006 for routine maintenance, repairs and modifications. Fast Tack Yachts, based at QAB was selected as the prime contractor. The small, 4-man company had previously worked on *Hooligan V* in June 2006, when it carried out repairs following the Shetland Round Britain and Ireland Race.

On 3 December 2006, while *Hooligan V* was out of the water **(Figure 22)**, Plymouth experienced winds in excess of 100 knots. At QAB the wind strength was recorded at 74 knots. A large number of yachts were destroyed, and the owner of Fast Tack Yachts noticed that *Hooligan V* was oscillating about the keel bulb during the period of high winds. Fast Tack Yachts completed work on 24 January 2007 and the boat was then put back into the water.

Photograph courtesy of Fast Tack Yachts

Figure 22

Hooligan V at Queen Anne's Battery, Plymouth, December 2006

1.14.2 Keel repairs

On taking the boat out of the water, significant damage was found to the keel fin's port **(Figure 23)** and starboard side **(Figure 24)** epoxy filler and anti-fouling surfaces near the hull juncture. The amount of detachment was most severe on the port side of the keel fin and, in this case, bare steel and corrosion products were clearly evident. There were also corrosion products and detachment of the epoxy coating and primer on both the leading and trailing edges of the fin.

Figure 23

Condition of port side of the keel - November 2006

Figure 24

Condition of starboard side of the keel - November 2006

Photographs courtesy of Fast Tack Yachts

Fast Tack Yachts' staff wire brushed the surfaces to remove the corrosion products and immediately primed the surfaces to prevent the onset of corrosion. Unfortunately the staff did not critically examine the reason for the surface and filler detachment. The implications of this oversight are discussed at Section 2.

1.14.3 Modifications

During the maintenance period a number of modifications were carried out to "stiffen up" the boat. These included:

- Resealing the hull/deck interface joint which had previously allowed water to enter the cabin.
- Lengthening the fore and aft tabs of the chainplates.
- Fitting six carbon fibre tubes at 45 degrees between the hull and underside of the deck to stiffen the hull and deck.
- Replacement of the rudder.
- Mast backstay replaced by an uprated Kevlar design.

1.15 CONDITION OF OTHER MAX FUN 35 KEELS

Team Heiner is a yachting school based in Lelystad on the Ijselmeer in The Netherlands. The company owns 3 Max Fun 35 boats which are predominantly used for corporate events, in the mainly benign conditions of the Ijselmeer. Each of the boats has sailed about 4000 miles since new, and there have been no alterations made to the keel.

In March 2007 the owner was concerned that one of these boats, *Who Cares,* was not in an upright position when alongside the pontoon. The boat was taken out of the water and it was found that the keel fin had suffered a 370mm fracture along the port side directly under the fillet weld connecting the fin to the taper box **(Figures 25 and 26)**.

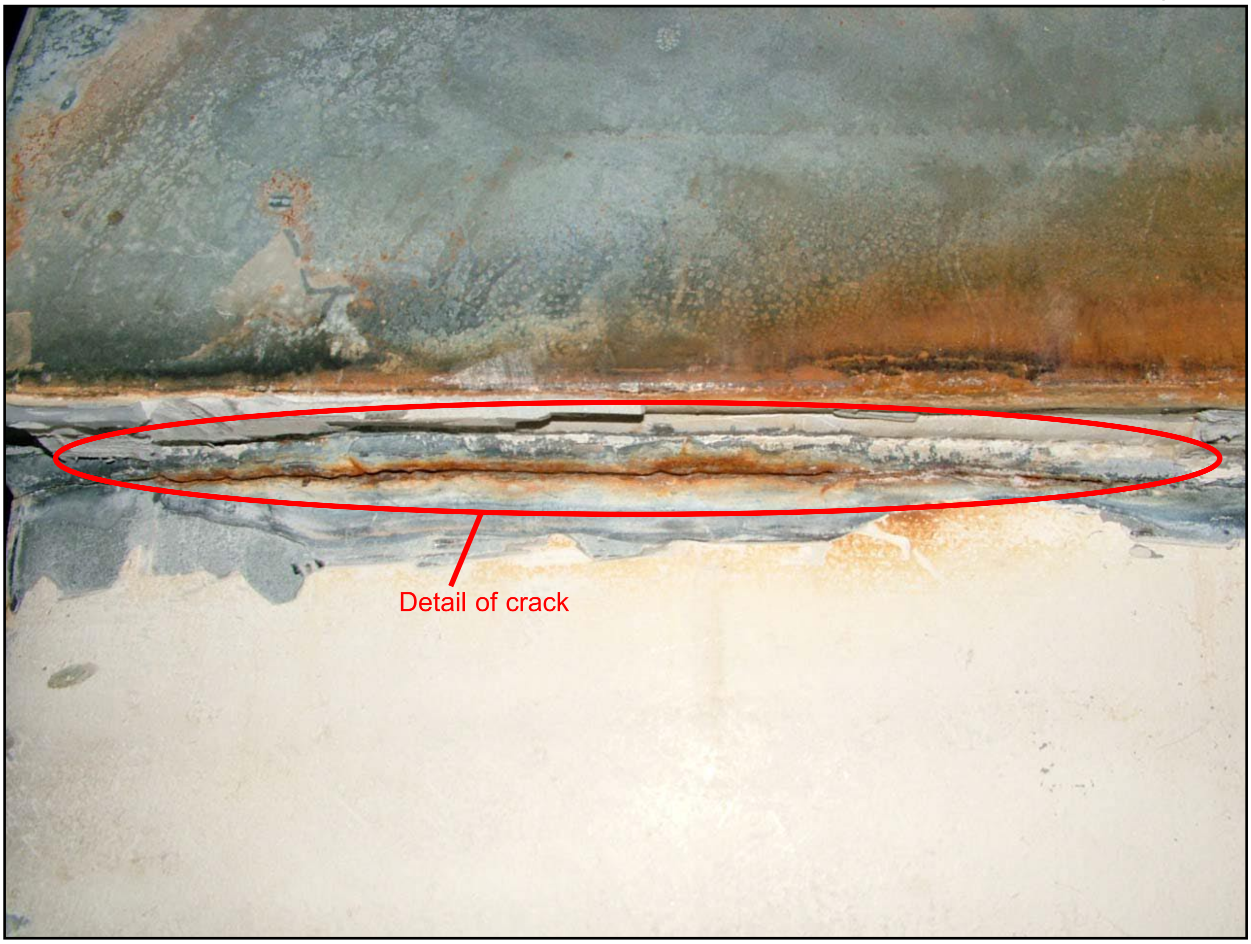
The failure had occurred in an identical position to that of *Hooligan V.* The fin was removed from *Who Cares* and returned to the fabricator. MAIB inspectors examined the GRP female taper **(Figure 27)** on board *Who Cares* and found it to be defect free. They also examined the failed keel.

The keels of two other Max Fun 35s, *Mad Max* and *Guts "n" Glory* **(Figures 28 and 29)** were also visually examined. Both exhibited movement of the keel, evidenced by cracking of the epoxy fillers and anti-fouling surfaces. The condition of the steel keel structures has not been determined.

Figure 25

Fracture of the port side of the keel fitted to *Who Cares*

Figure 26



Detail of the fracture to the port side of the keel fitted to *Who Cares*

Figure 27

Female GRP fin taper fitted to *Who Cares*

Figure 28

Keel of *Mad Max* showing cracking of the epoxy fillers and anti-fouling

Figure 29

Keel of *Guts "n" Glory* showing cracking of the epoxy filler and anti-fouling

1.16 INDEPENDENT LABORATORY METALLURGICAL TESTING AND ANALYSIS AND DESIGN CALCULATION VALIDATION

The preliminary findings of the MAIB investigation indicated there was a need to determine the:

- Failure mechanism of the keel.
- Torque settings and condition of the keel securing bolts.
- Condition and suitability of the keel attachment welds and whether they contributed to the failure.
- Properties of the materials used in the keel construction and, where possible, the comparison of these against the specification and design.
- Condition of the GRP keel supporting structure.

The Test House (Cambridge) was contracted to conduct the detailed laboratory metallurgical testing analysis. A copy of The Test House report's Section 6 – Summary, and Chapter 7 – Conclusions, Discussion and Opinion, together with a selection of images is at **Annex K**.

In addition, it was necessary to ascertain the suitability of the keel "original design" calculations and those related to the "as built" design. There was also a need to assess the impact on the keel bending stresses of the 160kg of added bulb weight to both designs. Southampton University's Wolfson Unit for Marine Technology and Industrial Aerodynamics was contracted to carry out this work. A copy of the resultant report is at **Annex L**.

The findings of both reports are endorsed by the MAIB, and are further discussed at Section 2.

1.17 ORGANISATIONS ASSOCIATED WITH YACHT DESIGN

1.17.1 International Council of Marine Industry Associations

The International Council of Marine Industry Associations (ICOMIA) - was formed in 1965 to bring together, in one global organisation, all the national boating federations and other bodies involved in the recreational marine industry, and to represent them at international level. Its aim is to:

- Promote awareness of the recreational marine industry's requirements and objectives, including safety.
- Maintain close dialogue with international bodies, national governments and other regulatory authorities.
- Provide recommendations and guidance on compliance with new international standards and regulations.
- Publish its opinions and recommendations, and formulate draft international standards and codes of practice.

1.17.2 British Marine Federation

The British Marine Federation (BMF) is the trade association for the British boating industry, and its 1500 members account for about 90% of the marine industry manufacturers. The Federation offers its membership a wide range of marine related services including seminars, workshops and full training courses. In relation to this accident, the BMF was able to offer comprehensive and pragmatic advice on all aspects of the RCD requirements; it also sits on the ISO Working Groups.

1.17.3 Yacht Designers and Surveyors Association

The Yacht Designers and Surveyors Association (YDSA) offers a variety of professional services within the marine industry, including the registration, coding and certifying of vessels for commercial use. The Association also promulgates best practice and runs courses and seminars to help members keep abreast of new technologies and law.

SECTION 2 - ANALYSIS

2.1 AIM

The purpose of the analysis is to determine the contributory causes and circumstances of the accident as a basis for making recommendations to prevent similar accidents occurring in the future.

2.2 SEQUENCE OF EVENTS CAUSING KEEL FAILURE

The catastrophic keel failure occurred in weather conditions of force 6 and seas of up to 1.5m. These conditions were well within the capability of the boat and her crew, and within the RCD, Category B criteria to which the boat was apparently designed and built.

Just before the accident, at about 0245, the wind strength was about 25 knots, the mainsail had two reefs in, and the genoa was 1/3 furled. The boat at this time was heeling 25° to starboard. The experienced crew were unconcerned as this was considered to be normal under those conditions.

However, soon after the change of watch at 0300, Watch Leader 2 instructed the genoa to be 2/3 furled and preparations to be made to put a third reef in the mainsail. He did this because the heel had steadily increased, although the weather conditions had not changed. In hindsight, Watch Leader 2 recalled that at this point, the boat's handling characteristics had indeed changed. The boat's speed reduced, the heel increased and it became more difficult to 'point'[5] the yacht. He did not recognise the significance of this at the time. It is likely that the heel increase and changes in the boat's handling were due to the propagation of the material failure to the port side of the keel. This would have caused the keel to adopt a more vertical position under the influence of the bulb weight. Without the righting moments to correct the boat's attitude, the heel increased. At some point, just before the mast head touched the water the material on the starboard side of the keel failed and the keel finally became detached, causing the boat to capsize.

The sequence of events is shown at **Figure 30**.

2.3 POSSIBLE CAUSES OF KEEL FAILURE - OPERATIONAL

2.3.1 Possible causes of keel failure

The initial survey of the remains of the keel fin suggested that the failure was due to fatigue of the keel fin plating. However, it was necessary to consider whether the operation of the boat contributed to the failure.

2.3.2 Contact with an underwater object

On 18 January 2007, the container vessel *MSC Napoli* suffered a hull failure resulting in her intentional beaching in Branscombe Bay 2 days later. During this period, up to 90 steel containers were lost overboard. There had been considerable speculation that the keel of *Hooligan V* had become detached after making contact with one of the submerged or semi-submerged containers.

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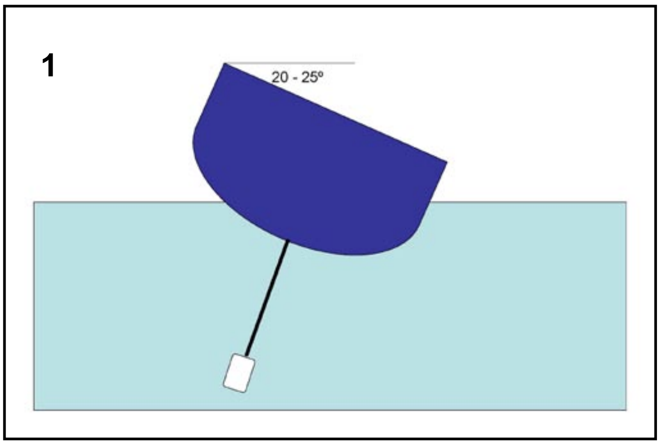
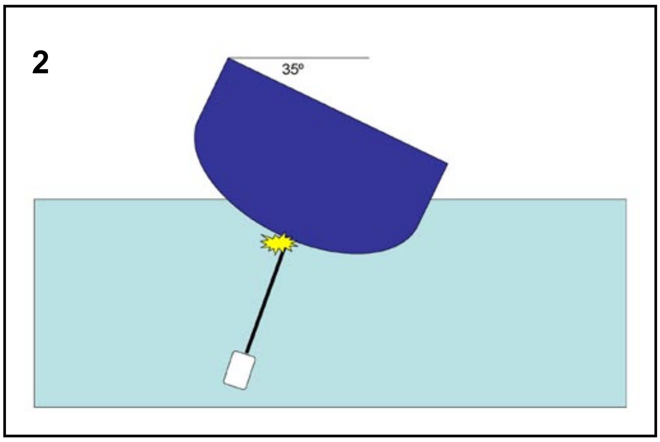
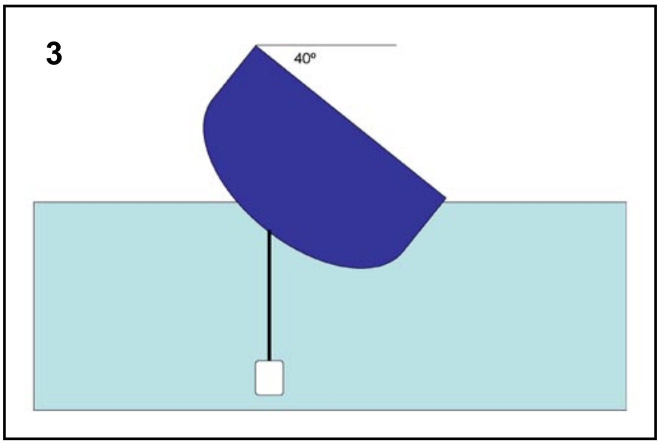
[5] To Point - to be able to steer a sailing boat close to the wind: typically around 45 degrees to the true wind direction



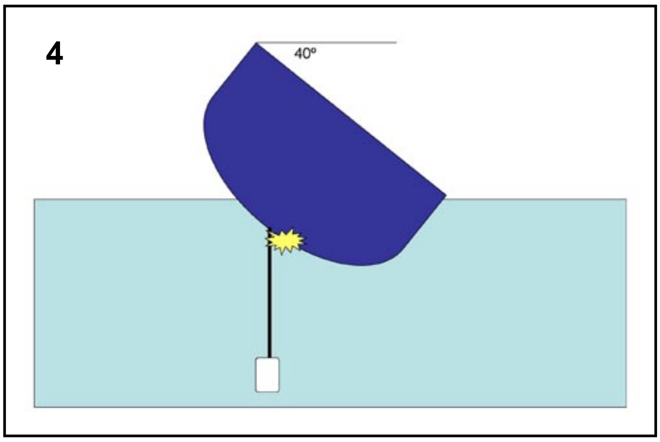
Normal upwind sailing angle



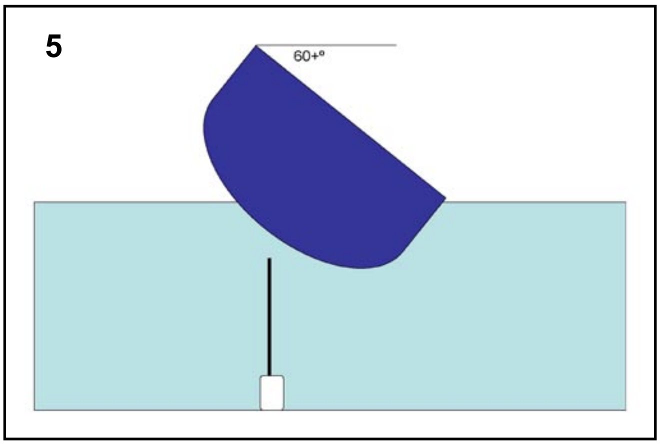
Keel fin fractures on port side



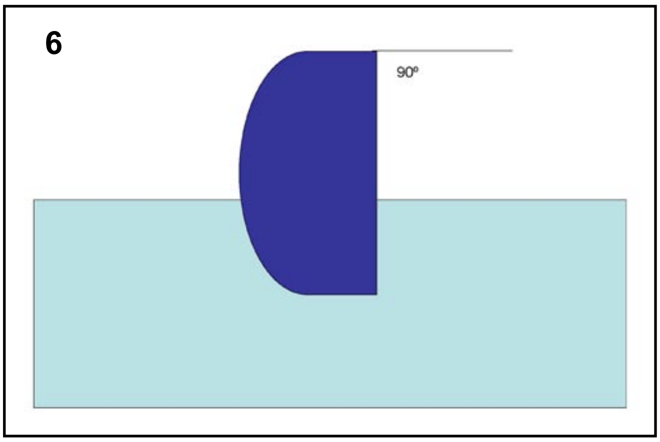
Angle of heel increases - boat slows down and feels less responsive on helm



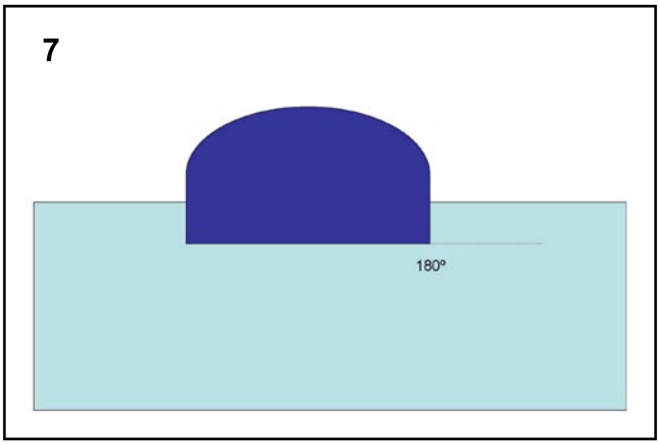
Keel fin fractures on starboard side



Keel falls away



Yacht capsizes with mast in water



Total inversion

Sequence of events leading to the keel failure

There is no evidence to support this argument. At the time of the keel failure the crew were fully alert, and confirmed there was no impact noise or vibration which would have occurred had contact been made. Additionally, photographic and video evidence taken by Torbay lifeboat, and by the crew from *RFA Wave Knight* a short time after the accident, confirmed that the hull was blemish free, with no evidence of any contact being made.

2.3.3 Groundings

The risk of grounding is an everyday hazard to those who use the water for trade or leisure. To mitigate this risk, yacht designers take into account the additional loadings experienced by keels and keel bolts in the event of grounding.

The owner reported that the boat had touched bottom on two occasions during his ownership. The first happened during the Royal Southampton Winter Race in November 2005. *Hooligan V* touched a mud bank at about 4 knots while off Netley in the Solent. The boat was immediately tacked off the bank and resumed her race. The second happened in early 2006 when the boat was manoeuvring at about 2.5 knots, under engine power, from her berth in Ocean Village at Southampton. The boat slowed gently as it touched a build up of silt and was immediately taken off using minimum astern power.

Both the “original” and “as-built” keel designs satisfied the ABS requirement for grounding loads as confirmed at Table 3 of **Annex L**. There is nothing to suggest that these slow speed groundings contributed to the keel failure.

2.3.4 Boat handling

Hooligan V was only skippered by the owner and a long standing, very experienced colleague. The boat had seen considerable racing success and there is no doubt that the owner was a serious and competitive offshore racer, who fully explored the boat’s capabilities. *Hooligan V* was marketed as being compliant with RCD Category B, and thus deemed suitable for use in winds up to force 8 and in 4m significant wave heights. During offshore races it is impossible to avoid the risk of using the boat outside this RCD specified operating envelope. However, the skippers were able to recall only a couple of occasions when winds stronger than force 8 had been experienced, and the boat had never been in seas exceeding 4m.

Both skippers had a reputation for placing crew and boat safety as their highest priorities, and had a full appreciation of their duty of care responsibilities. There is no evidence to suggest that either would have placed the crew or boat in danger by taking unwarranted handling risks. The owner’s training regime[6], maintenance programme and administration procedures all serve to confirm a conscientious attitude to safety.

Despite this evidence, *Hooligan V* was the most used of the 10 Max Fun 35 boats built. The boat had sailed about 19800 miles at the time of the failure, and in more arduous conditions than any of the others in the class. However, the identical keel failure to *Who Cares* in The Netherlands (paragraph 1.15) occurred after only some 4000 miles of use, in the benign conditions of the Ijselmeer, and always within the RCD Category B operating criteria.

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[6] At the 2006 Annual General Meeting the owner mandated that all crew were to have completed the Basic Sea Survival and First-Aid Courses and the ISAF Racing Crew Courses by May 2007.

2.3.5 Summary

There was no evidence to suggest that the keel failure to either *Hooligan V* or *Who Cares* was related to the operation of the boats. This suggested that the failures were due to one or more factors common to both *Hooligan V* and *Who Cares* such as inadequate design, poor fabrication procedures, material defects or post-build changes.

2.4 KEEL FAILURE – GRP SUPPORTING STRUCTURE, KEEL DESIGN, FABRICATION AND MODIFICATIONS

2.4.1 GRP supporting structure

There have been examples where keel failures have occurred because the design of GRP supporting structures has been inadequate to support the "in service" loads. Poor "lay up" procedures during manufacture can cause GRP de-lamination, leading ultimately to keel failure.

No defects were found in *Hooligan V'*s GRP supporting structure, either during the on site survey, or during later laboratory examinations. Examination of *Who Cares'* keel supporting structure also showed it to be defect free.

It is concluded that the GRP keel supporting structure was adequate for its intended purpose and did not contribute to the keel failures.

2.4.2 Original design calculation considerations

The designer had declared that the ABS guide had been followed in his design work. The ABS guide include requirements for keels and their supporting structure and for keel bolts. The keel arrangement has to be designed to withstand the worst sailing transverse loading conditions of keel fin bending and keel fin shear as seen in the "knockdown" case. In satisfying this requirement it is considered that a design will be suitable for all other sailing conditions. In addition, the keels also have to withstand the grounding loads.

The designer recognised that in the "knockdown case" the minimum keel fin bending Safety Factor of 2 had to be applied. Indeed, his calculations **(Annex H)** specifically state that the Safety Factor:

"Must be 2.0 or more"

The calculations record that the design achieved a Safety Factor of 2.01, but this was when applied against the ultimate tensile strength of the materials. However, and most importantly, the ABS guide require that material yield strength be used in the calculations and that yield strength is not to be taken as greater than 70% of the ultimate tensile strength of the material, and in any case not greater than 390 MPa where steel is used. In this case the maximum ultimate tensile strength of the materials used was 510 MPa and therefore the ABS rule for yield strength is 357 MPa. When applying the Safety Factor of 2, this reduces to an allowable bending stress of 178.5 MPa.

The keel steel strength range was recorded by the manufacturer as between 360 MPa and 510 MPa.

The designer used the upper strength value of 510 MPa for the steel throughout his calculations. Without testing, it would not have been possible to ascertain the exact strength of the steel and so it would have been prudent to use the lower value for safety calculation purposes. The designer was unable to explain why he had not done so.

The Wolfson Unit, who provided specialised support to this investigation, calculated that the actual Safety Factor for the original design was only 1.38 when using the same material values as the designer.

It is notable that in discussions with other yacht designers, a Safety Factor of 2.5 – 3.5 is commonly used.

As the "original" keel design was never incorporated in any boats of the class, it is not possible to state categorically whether the design would have been adequate. It is nevertheless clear that the design did not satisfy the minimum ABS Safety Factor of 2.

2.4.3 "As built" design calculation considerations

The fabricator of the keel had no previous boat building, and specifically, no keel fabrication experience. He produced some calculations which assumed a maximum stress in the fin of 150 MPa. The calculations do not appear to check the structure in way of the fin root or its welded attachment, but only concentrate on the taper box insert into the hull. There is no evidence that the keel bulb weight, moment arm, or material properties have been considered and therefore it has not been possible to reconcile how the 150 MPa has been derived.

Furthermore, the fabricator was not aware of the existence of the ABS guide or the need to comply with any specific design criteria. He was not aware of the need to consider the stresses imposed by either the "knockdown case", or the grounding situation. Neither was he aware of the existence, and therefore the requirements, of the RCD, or the operational limitations specified for the boat's designated usage under RCD Design Category B.

Without suitable calculations, it would have been impossible to assess through steel fabrication experience alone, that the keel was suitable for its intended purpose. The Wolfson Unit calculated that the Safety Factor for the "as built" design as 1.23, well short of the required 2.0.

2.4.4 Construction

Even though a Safety Factor of 2.0 was not achieved, there is no doubt that the "original design" of the keel **(Figure 14)** was more satisfactory to accept the "in service" loads than the "as built" version **(Figure 17)**. There were no critical welds in the area of the fin attachment to the taper box, and the internal supporting frames extended to the underside of the top of the taper box where they would have been welded, and so stiffening the structure.

In the "as built" design, the position of the fillet welds at the fin to taper box connection, and the shortened support frames which were not welded to the underside of the taper box, meant that the fin flexing was taken up in the vicinity of the weld and not satisfactorily transferred through to the internal GRP supporting structure.

It is well known that areas of local fatigue in the vicinity of welds can be relieved using procedures such as weld dressing, hammer peening and toe grinding. None of these were considered. It is impossible to state whether these procedures, had they been followed, would have prevented the accident, but they would have mitigated the risk.

2.4.5 Decisions

The fabricator did contact the director of Breehorn BV, the boat builder, and informed him of his intention to change the design to ease manufacture. The designer was not informed of the change until some time after the keel and boat production had started. No formal discussions were held between the designer, director of Breehorn BV or the keel fabricator, and so there was no proper consideration given to the implications of the changes to the original keel design. The designer was alerted to this, but seems to have accepted the decision without proper consideration of the full implications of the changes to his original design. It appears that the designer left the decision to agree the design changes to the director of Breehorn BV, who was also one of the co-owners of Max Fun Boats BV, and was therefore empowered to make the decision.

Had the designer taken the opportunity to evaluate the changes, it is probable that he would have identified the high risks associated with the revised design, especially those related to the critical fillet weld at the fin root, and would have not agreed to the proposal.

2.4.6 Keel modification

Weight addition modifications to keels, especially those to highly stressed fabricated keels, need to be very carefully considered to ensure that the structure is able to accommodate the additional stresses.

HWYDC's addition of approximately 160kg to the keel for racing optimisation purposes would have inevitably increased the stresses experienced by the keel.

HWYDC justified the addition because it was aware from the owner, that the designer had at the end of 2004, verbally confirmed that the existing keel could accept a 200kg weight addition. However, the designer was unable to recollect this. HWYDC was not aware that the designer subsequently proposed a completely new keel which was 200kg heavier than the original keel.

What is clear is that HWYDC did not have any detailed keel construction drawings, other than a general arrangement drawing of the boat, on which to base its decisions. HWYDC was unable to produce any calculations to support the suitability of the fabricated keel to cope with the additional bending stresses imposed by the added weight. Furthermore, there was no attempt made to obtain original design data, or to contact the designer directly to discuss the suitability of the modification to ensure that the Safety Factor would not be adversely affected.

What was also unknown to the owner and to HWYDC was that the keel fitted to *Hooligan V* was not that which was originally designed. The Wolfson Unit calculated that the added weight reduced the "original" and "as built" keel Safety Factors to 1.26 and 1.12 respectively, almost 50% lower than the requirement.

2.5 DESIGN REVIEW BY WOLFSON UNIT

The Wolfson Unit design validation report **(Annex L)** concludes that:

- Neither the "original" nor "as built" designs conformed to the bending stress or keel fin shear criteria of the ABS Guide under the keel bulb unmodified or keel bulb modified configurations.
- The keel fin and keel bolts both passed the ABS requirement for the grounding case.
- The "as built" design is considered to be below acceptable Safety Factors. The arrangement of the "as built" specification increases the risk of fatigue failure greatly over that originally designed. This combined with the addition of the extra bulb weight, lower fin section mechanical properties and the low Safety Factor over the allowable stress contributed to the failure of the keel at the keel fin root.

Section 7.3 of the report also highlights that if the keel fin contains water, the added weight would further reduce the Safety Factors as it would increase the bending moment and hence reduce the design bending stress. It was confirmed during the inspection of the fin taper box by The Test House (Cambridge) that there was firm evidence that water had been in the box for a considerable time. It therefore follows that the fin must also have been full of water, which in turn reduced the Safety Factor, making failure more likely.

2.6 THE TEST HOUSE (CAMBRIDGE) - LABORATORY EXAMINATION AND METALLURGICAL ANALYSIS

2.6.1 Keel bolts

The examination found that the three keel bolts were uniformly covered with iron and zinc corrosion products, with no evidence that they had recently been tightened. The bolt material, although not in accordance with the "original" design[7], exceeded the original specification which was ABS compliant. The release torque for the bolts was:

- Forward bolt - 220 Nm
- Middle bolt - 33 Nm
- Aft bolt - 5 Nm.

It was also found that the after and middle bolts had suffered from cyclic reverse bending stresses in the transverse port and starboard directions. This caused the bolts to fail at their juncture with the captured nuts fixed to the underside of the keel taper top plate **(Figures 17 and 19)**. The report goes on to state that the bolt failures predated the keel failure and the refit, and were most unlikely to have had an influence on the final failure of the keel.

Neither the Owner's Manual nor the "original" design specifies a bolt torque setting or a recommended interval for bolt tightness checks. Breehorn BV, the boat building yard, did not have any torque settings either, and it became apparent during the investigation that torque settings are seldom specified. It is custom and practice among owners, boat builders and repairers to fit, and periodically check the bolts and tighten them using a socket and extension bar until they can be pulled up no further.

[7] The "As Built" design did not specify the bolt material.

The tightness of the keel boats was checked every 6 months in accordance with the boat's maintenance schedule which had been developed by the owner and his crew. The owner of *Hooligan V* personally tightened the bolts in June 2006. He also stated that he verbally asked Fast Tack Yachts to check the bolts during the refit, which was just before the accident. The contractor could not recall this, and there are no records to reflect the owner's request. The contractor confirmed that the bolts had not been checked. Had they been, then the two bolt failures would probably have been identified and would have been replaced, and this might well have led to more extensive examinations.

It is likely that the bolt failures occurred through slight, transverse flexing of the keel and supporting structure during the 2006 racing season. It was also noted that none of the bolts securing *Who Cares'* keel had failed.

2.6.2 Materials used for construction

The materials used in the construction of the keel, including the taper box, were confirmed to meet the "original" design specification. The "as built" design also used this specification, and therefore the possibility of material manufacturing defects contributing to the failure can be ruled out

2.6.3 Welds

A number of weld defects were found. These were predominantly in the taper box seam butt welds, but they had not grown during service. The weld defects were not judged to be significant to the casualty.

The examination confirmed that a fillet weld had been placed in the critical stress location where the fin joined the taper box. There was no evidence that any measures were taken to negate or reduce the local fatigue sensitivity by using well established, weld dressing, hammer peening or weld toe grinding techniques. Had this been done then the risk of failure would have been reduced.

2.6.4 Impact of high winds during refit

The report concludes that it was technically feasible for the oscillations caused by the high winds during the refit to have been a source of damaging cyclic stresses. However, the keel bulb was rested on thick rubber matting which would have had a significant anti-resonance damping effect.

While the wind-generated resonance cannot be fully discounted, its contribution to the keel failure is considered very slight. This is especially so as *Who Cares* never experienced such oscillations and yet the boat's keel also failed.

2.6.5 Keel fin examination – cause of failure

The laboratory examination found that there was evidence of long standing corrosion along the underside edge of the keel taper, suggesting that there had been flexing in this area and this had destroyed the protective coatings.

A distinct water mark inside the taper box confirmed that the fin had been full of water for a considerable time, and that the level had extended to about halfway up the taper box causing breakdown of the protective galvanised coating.

Paragraph 6.8 of the report **(Annex K)** concludes that:

> *"The keel blade had fractured due to a mechanism of reversed bending fatigue cracking. Fatigue cracks had initiated at stress concentration sites in the toes of the fillet welds joining the keel blade to the underside face of the tapered steel box. The keel also contained secondary fatigue cracks propagating outwards from the inner blade face and from the roots of the fillet welds."*

The predominant fracture types are illustrated at **Figure 31**.

2.7 REFIT – KEEL DEFECTS

Regular out of water inspections provide an opportunity to identify underwater defects. This is especially important where boats are sailed hard, or where potentially vulnerable fittings, such as hollow keels, are fitted.

The owner of *Hooligan V* had a regular maintenance programme which included the November 2006 – January 2007 end of season refit. Fast Tack Yachts of Plymouth, the prime contractor, addressed the keel defects, and corrosion **(Figures 23 and 24)** by rubbing back, and wire brushing the damaged areas of the fin chord root and fin surfaces prior to priming them to prevent further corrosion.

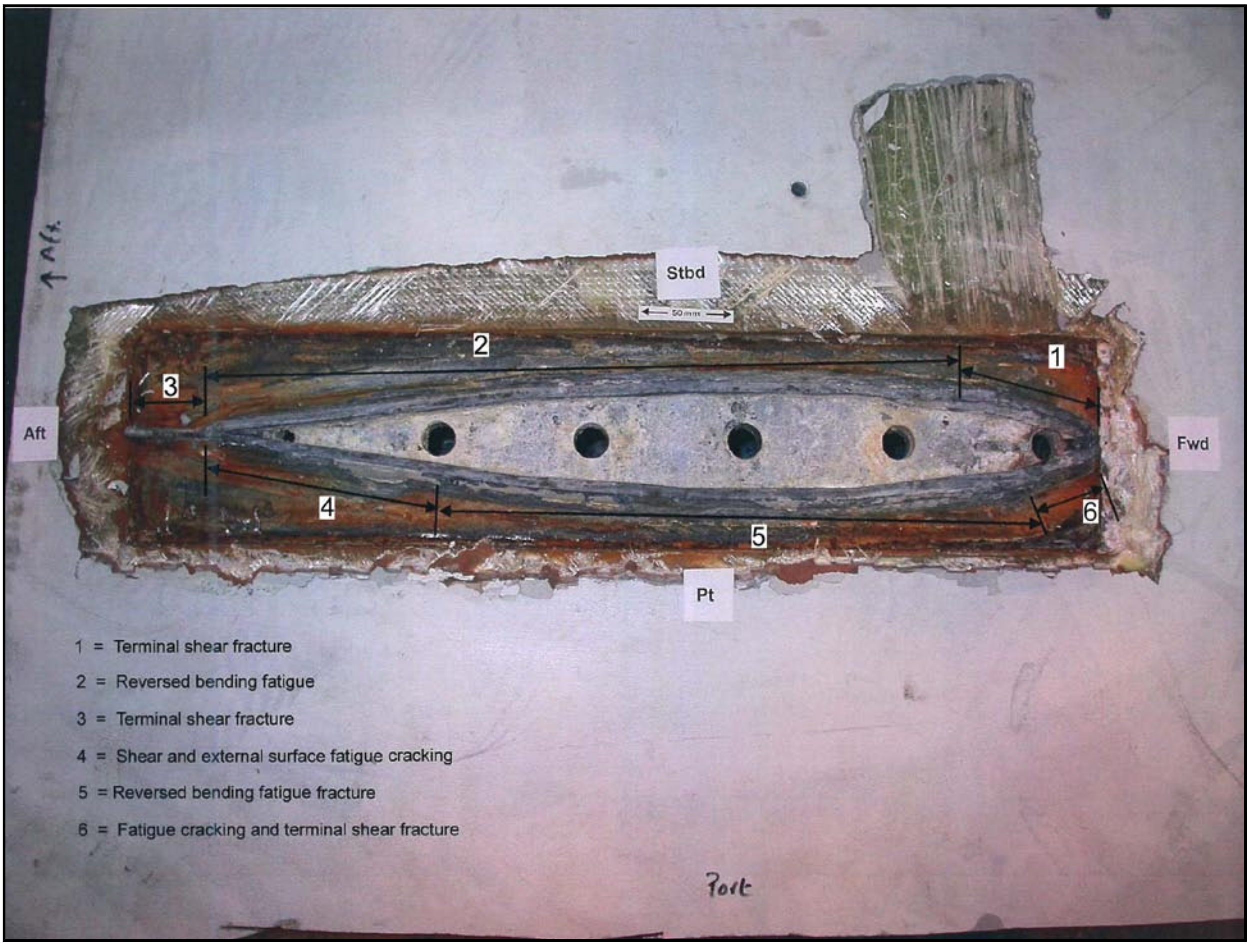
The contractor had very little experience in dealing with hollow fabricated keels, so the significance of the epoxy filler and paint detachment in the area of the fin chord was not recognised. The detachment and corrosion was indicative of flexing of the fin, which was the first visible sign of the impending keel failure. **Figure 23** shows the epoxy and paint detachment to the port side of the keel. A close up of the photograph **(Figure 32)** shows an area of possible cracking at the fin chord root, which matches with "area 5" in **Figure 31**. The area is identified as the port side of the keel that had suffered a reverse bending fatigue fracture.

Although the likely hairline crack would have been difficult to see, had it been identified, the contractor is likely to have then carried out a more detailed examination. This would have shown up the parlous condition of the keel, and expert advice could then have been sought to help identify the extent and cause of the defect.

This was the last opportunity to prevent the accident. Unfortunately, due to lack of experience, the indicators had been missed.

In the case of highly stressed, fabricated keels it is good practice to carry out a detailed periodic visual check of the integrity of the keel. Wherever there is any doubt about the condition of the keel the use of Non-destructive Examination (NDE) techniques will confirm whether cracks are present. There is a wide range of techniques available, from the relatively cheap, dye penetrant and Magnetic Particle Indicator to the more expensive radiography and ultrasonic procedures.

Figure 31



Predominant fracture types

Photograph courtesy of Fast Tack Yachts

Figure 32

Site of possible crack - port side of keel phtographed at Queen Anne's battery, November/December 2006

2.8 DESIGN STANDARDS

Paragraph 1.10 discussed the content of ISO 12215 Part 9, which will become the recognised standard for sailing boat appendage scantlings. The ISO groups the design Safety Factors for RCD Category A and B boats and Category C and D boats.

Article 5 of the RCD states that compliance with the RCD's Essential Safety Requirements will be presumed if products meet national and harmonised standards. ISO 12215 Part 9 will fall under this definition. While designers are not obliged to follow the ISO standards, the RSG urges the industry and Notified Bodies to use them as they represent an internationally agreed standard. Designers should be encouraged to adopt this approach in order to avoid the risk of any misunderstanding regarding the Safety Factors or standards which should be applied.

A designer or builder who is subject to self-certification procedures may, at any time, seek the intervention of a Notified Body to check the design or build standard of a boat. In this case, the Notified Body would refer to the RSG Guidelines for the appropriate information and standards. Section E.A.3.1.d, currently refers only to keel attachments, and not to the keel construction itself. This omission implies that keel construction need not be considered, when ISO 12215 Part 9 clearly covers the subject.

2.9 RCD COMPLIANCE

A manufacturer's statement that a boat has been built in compliance with the appropriate RCD category should provide owners with a high degree of assurance regarding the safety of the product.

Max Fun Boats BV, as the manufacturer (paragraph 1.8.8), had the responsibility to ensure that the Max Fun 35s complied with the RCD requirements. This included a responsibility to ensure that fitted components, including the keel, met the required standard.

Despite repeated requests to the designer for a copy of the Declaration of Conformity, it has not been provided. As a result, it has not been possible to determine whether any standards in addition to those stated in the ABS guide have been followed.

None of the six boats inspected showed any evidence of a CE marking confirming RCD compliance, and none had the required Builder's Plate fixed to the boat. The boat builders should have complied with these RCD Essential Safety Requirements, and Max Fun Boats BV, who placed the boats on the market, should have ensured that the CE marking and Builder's Plates were in place.

With the exception of Bureau Veritas, as the notified body, to confirm that stability and buoyancy requirements were satisfied, there was no other external validation of the Max Fun 35s. The market surveillance in the UK for new boats built under the RCD rests with the local Trading Standards organisations. They have the responsibility and authority to check that the product meets the required standards. None of the Max Fun 35 yachts when brought into the UK as new boats, had been subjected to RCD compliance checks.

Without an assurance of RCD compliance by means of external validation, it is essential that self-certification procedures are robust.

2.10 DEFECTS NOTED ON OTHER YACHTS OF THE CLASS

To date, there have been keel fracture failures affecting 20% of the Max Fun 35 Class. The keel "as built" design and resultant fabrication are considered unfit for purpose, and pose a serious risk to users in their current configuration.

A further two Max Fun 35 boats, *Mad Max* and *Guts "n" Glory* have also suffered from epoxy and paint cracking in the area of the fin to taper box fillet weld, bringing into doubt the condition of these keels.

There is a need for a full design review of the Max Fun 35 keel arrangement. Either a modification to the existing keel is required, or the manufacture of a completely new design of keel which fully satisfies the RCD requirement.

2.11 ACTIONS POST-ACCIDENT

There is no doubt that being unexpectedly thrown into cold seas in the middle of the night, in winter, is an extremely traumatic experience. This is especially so when the skipper and one of the crew are missing, and not all those in the water are wearing inflated lifejackets.

2.11.1 Teamwork

The whole crew of *Hooligan V* pulled together and worked well as a team. It was this teamwork that undoubtedly ensured the survival of four of the crew. The skipper kept a clear head when inside the upturned hull, in firstly pushing out the flare box and grab bag. This served two purposes. It confirmed to those clinging to the hull that the skipper was likely to be still alive, and that there was an opportunity to raise the alarm using the flares from the box.

Once the skipper finally escaped from the cabin, Watch Leader 2 did remarkably well in keeping the skipper afloat. This was especially so as the skipper's own ability to assist was badly affected by the onset of hypothermia, as he slipped in and out of consciousness.

Watch Leader 1's perseverance at cutting the liferaft lashings was key to the group's survival. The group had assumed that the flares fired from those taken from the flare box had been seen by nearby shipping, and that help would soon arrive. However, the flares fired from the flare box were not reported. The first recorded sighting of flares was reported after the group had got into the liferaft, and had set off the flares stowed in the liferaft. Had the liferaft not been released, survival of the group would have been severely jeopardised.

The owner of the Hooligan V required his crew to undertake a wide range of safety related courses. It is clear that many aspects of the ISAF Racing crew, and the RYA's Basic Sea Survival and First Aid training courses were utilised. These were significant in focussing the crew's actions and helping in their survival.

2.12 LIFESAVING APPARATUS

2.12.1 Liferaft lashings

Ready access to a boat's liferaft can often mean the difference between survival and loss of crew. This is especially so in cold conditions where the onset of hypothermia is a real risk and confusion sets in.

*Hooligan V'*s liferaft was secured to a frame at the transom using criss-cross lashings. The skipper had considered stowing the liferaft on the coachroof, but this was impractical because of the need for unimpeded access to this area. He had also considered fitting the liferaft with an automatic hydrostatic release unit, but once again this was unsuitable as the boat regularly shipped water and so there was a good chance of the unit operating when unintended.

Because of space limitations, many skippers stow liferafts below decks or in a dedicated locker on the deck. While there are no absolute guidelines on stowage, the RNLI recommends that liferafts should be stowed in a position ready for immediate launching, and not between decks or under other equipment.

In *Hooligan V'*s case, the stowage position was a sensible and well considered compromise. The use of quick release knots would have helped to expedite the release of the liferaft and is worthy of future consideration.

2.12.2 Use of lifejackets

There is much debate about the merits of self and manual inflating lifejackets. If a self-inflating lifejacket is worn, and the wearer becomes trapped under the hull or inside a cabin, it makes escape extremely difficult because the buoyancy of the lifejacket forces the individual up against the obstruction. On the other hand, if an individual is knocked unconscious, and falls over into the water, a self-inflating lifejacket is clearly a better option.

Had Watch Leader 2 not worn a lifejacket, it would have been unlikely that he could have supported the skipper until they accessed the liferaft. Crew 2 wore his own manually inflating lifejacket, but he was unable to inflate it because the operating cord was trapped between the Velcro fasteners. He stated that he was not overly concerned by this because air had become trapped in his oilskins, and this aided his buoyancy. His lifejacket did eventually inflate when the operating cord was accidentally pulled while in the liferaft. Crew 2 was a fit young man; even so, it would have been wise for him to have persevered with inflating his lifejacket, or by using the oral inflation tube. Watch Leader 1 did not don his lifejacket when he went to the deck to help put the third reef in the mainsail. He, too, managed to survive without the aid of a lifejacket, but he became extremely tired, and was losing his grip on the transom by the time he managed to cut the liferaft free.

The selection of the type of lifejacket to wear is a matter of personal choice. Nevertheless, it is always best practice to wear one when on deck so that crew are prepared for the unexpected, as this case serves to illustrate.

2.12.3 Spray hoods

Spray hoods help prevent water and spray entering the airways, and improve the chances of survival. They can be integral to a lifejacket, or as in this case, can be held in a separate pouch attached to the lifejacket's webbing straps.

While the skipper and Watch Leaders 1 and 2 were familiar with the equipment, Crew 2 was not, and it is unclear if Jamie Butcher had previously fitted the hood. Despite the hoods being carried, none of the crew attempted to fit them despite ingesting a good deal of sea water into their airways.

Skippers should ensure that the crew are familiar with the LSA carried on board and, where appropriate, a safety brief and demonstration should be given. In this case, spray hoods were issued to the crew but no instruction was given on their use.

2.13 FATAL CASUALTY

Jamie Butcher was described as a very fit young man. Despite having Type 1 diabetes, he enjoyed a wide range of demanding sports including power boating, free-fall parachuting and rock climbing. He had 5 years sailing experience, was clear thinking and would have been familiar with the actions to take in the event of a capsize; notably, to ensure his lifejacket had inflated, and of the need to make his way back towards the boat.

The toxicology report states that Jamie Butcher's blood sugar levels were raised. This could possibly have mildly impaired his judgment. However, each individual will be affected differently, and it is not possible to ascertain to what degree, or if at all, Jamie Butcher was affected by this. The report also records that Jamie Butcher's blood/alcohol level was well below the legal limit required to be in charge of a vehicle, and therefore alcohol is not considered to be a contributory factor.

Just before the capsize, Jamie Butcher slipped down to the starboard side of the transom. It is unclear if he had a safety line attached at this time. As the boat continued to heel to starboard and became inverted, it is possible that he became trapped under the transom, and his immediate escape would have been obstructed by the transom guard wires. By that time, his auto-inflation lifejacket would have operated, forcing him up against the transom, making escape even more difficult. It is possible that he remained trapped under the boat for some time before eventually being released by the pitching of the hull.

The postmortem report records an abrasion on Jamie Butcher's forehead, and it is also possible that he was knocked unconscious during the capsize and drifted away from the boat as the remainder of the crew assembled at the yacht's transom.

Had Jamie Butcher managed to get clear of the boat, and was conscious, then it is most likely that he would have instinctively responded to the repeated calls by the crew in the water and made his way back to the boat. The fact that he did not do so suggests that he was either trapped under the boat or was unconscious.

2.14 FATIGUE

The skipper and crew had all been well rested during the night prior to the accident. At the time of the accident, the group had been awake for between 15 and 20 hours. Although it could be argued that it would have been more appropriate to sail after a full night's rest, none reported feeling overly tired or felt unable to fulfil the watchkeeping requirements.

Fatigue is not considered to have contributed to this accident.

2.15 OTHER CASES OF FABRICATED KEEL FAILURES

The MAIB accident database does not contain any references to fabricated keel failures.

Section 7.6 of The Wolfson Unit report at **Annex L** refers to a relevant case involving the prefabricated keel of the Open 60 class ocean racing yacht *Ecover.* The report states:

> *"…The Open 60, Ecover, had a keel failure at 40000 miles in service. The Open 60s Kingfisher and Hexagon had no keel failure and lasted 60,000 miles. All keels were built by the same manufacturer…Kingfisher and Hexagon were designed with a stress Safety Factor of 20% more than Ecover, this is significant in terms of the failure of Hooligan V as the as built modified bulb had a Safety Factor of 20% less than the as designed, original bulb."*

The report goes on to say that:

> "*...the crack that caused the keel failure of Ecover propagated from a weld that did not exist in the Kingfisher or Hexagon design".*

SECTION 3 - CONCLUSIONS

3.1 SAFETY ISSUES DIRECTLY CONTRIBUTING TO THE ACCIDENT WHICH HAVE RESULTED IN RECOMMENDATIONS

Factors relating to the "as built" design

1. The keel fabricator was not aware of the RCD or ABS requirements for keel strength, resulting in the "as built" design not satisfying the minimum ABS Safety Factor of 2. [2.2.4.3], [2.4.3]

2. The "as built" keel design increased the risk of fatigue greatly over that of the "original" keel design, thereby further reducing the keel's ability to cope with normal "in service" stresses. [2.4.4], [2.5]

3. The keel fabricator did not support his design with keel fin bending calculations, and he was unaware of the requirement to consider the knockdown and grounding cases. [2.4.3]

4. The keel fabricator did not consider using fatigue relief procedures such as weld dressing, hammer peening, or toe grinding in areas of the critical welds. [2.4.4], [2.6.3]

5. The designer did not properly evaluate the changes to his design, thereby removing the probability of him identifying the high risks associated with the fabricator's revised design. [2.4.5]

6. Other than in respect of stability and buoyancy requirements, the RCD does not require Design Category B compliance to be externally validated, thereby relying on the manufacturer having robust self-certification procedures in place. [2.9]

Factors relating to the keel modification:

7. The contractor had no calculations to support his keel bulb modification. He based his decisions on a general arrangement drawing of the boat, and made no attempt to obtain original design data or to contact the designer directly to discuss the suitability of the modification, resulting in the Safety Factor being adversely affected. [2.4.6]

Factors relating to the 2006/2007 refit

8. The contractor had very little experience in dealing with hollow fabricated keels, resulting in his not recognising the significance of the epoxy filler and paint detachment in the area of the fin chord. [2.7]

9. The contractor did not carry out a detailed visual check of the integrity of the keel and did not consider using NDE techniques to confirm whether cracks were present, resulting in his not identifying an area of probable cracking at the fin chord root. [2.7]

3.2 OTHER SAFETY ISSUES IDENTIFIED DURING THE INVESTIGATION ALSO LEADING TO RECOMMENDATIONS

Factors relating to documentation

1. The RSG Guidelines refer only to keel attachments and not to the keel construction itself, implying that the keel construction need not be considered. [2.8]

Factors relating to the "original" design

2. Max Fun Boats BV's procedures did not include meeting the Declaration of Conformity, Builder's Plate and CE marking requirements to indicate and confirm RCD compliance. [2.9]

3.3 SAFETY ISSUES IDENTIFIED DURING THE INVESTIGATION WHICH HAVE RESULTED IN ACTIONS TAKEN

Factors relating to the "original" design

1. The keel failure occurred in conditions well within RCD Category B defined waters, to which the boat was apparently designed. [2.2]

2. The designer used the maximum material ultimate tensile strength rather than the material yield strength in his stress calculations, resulting in the "original" keel design not satisfying the minimum ABS Safety Factor of 2. [2.4.2]

3.4 SAFETY ISSUES IDENTIFIED DURING THE INVESTIGATION WHICH HAVE NOT RESULTED IN RECOMMENDATIONS

Factors relating to the 2006/2007 refit

1. The aft and middle keel bolts had fractured through reverse bending stress in the transverse directions and were not checked during the refit, and it is not usual for tightening torques to be specified. [2.6.1]

Factors relating to lifesaving apparatus

2. The liferaft was secured without a means of quick release, resulting in difficulty in releasing it after the boat had capsized. [2.12.1]

3. One of the crew working on deck was not wearing a lifejacket when the boat capsized, resulting in his becoming extremely tired while in the water and attempting to cut free the liferaft. [2.12.2]

4. The skipper did not discuss or demonstrate the use of spray hoods and method of attachment, contributing to none of the crew attempting to fit them after the boat had capsized. [2.12.3]

SECTION 4 - ACTION TAKEN

4.1 MAX FUN BOATS BV

On 6 February 2007, the yacht designer informed all owners of Max Fun 35s of the accident occurring to *Hooligan V.* He also advised them that their Max Fun 35 yachts should remain in port pending the outcome of the MAIB accident investigation report **(Annex M)**.

A replacement keel design has been developed for the Max Fun 35 class. The design has been verified by the Dutch Notified Body, European Certification Bureau (ECB) Nederland (Notified Body No 0614). Their report confirms that the design exceeds the safety factors detailed in the ABS guide and fulfils the RCD requirements.

The replacement keel design has been fitted to 7 out of the 9 boats remaining.

Max Fun Boats BV has yet to finalise arrangements for fitting new keels to the outstanding two boats.

4.2 MARINE ACCIDENT INVESTIGATION BRANCH

At the time of final publication of this report, the Marine Accident Investigation Branch will circulate a 2-page account of this accident and the principal lessons to be learned from it. Among the issues the MAIB will stress is the importance of designers complying with required Safety Factors and the need to consult with the original designer, where possible, when considering modifications. The importance of owners and boat repairers/maintainers in recognising the early signs of failure of fabricated steel keels, and the need to seek professional advice, will also be emphasised.

SECTION 5 - RECOMMENDATIONS

Max Fun Boats BV is recommended to:

2007/169 Review its obligations and procedures as a manufacturer to ensure that the following RCD requirements are met:

- Declarations of Conformity are provided for each boat.
- Boats declared to meet the RCD requirements are identified by the CE marking of conformity.
- A Builder's Plate is permanently affixed to boat.
- Processes - including those of sub-contractors - are sufficiently robust to ensure that the design of the Max Fun 35 meets the appropriate standards.

2007/170 Ensure that the appropriate Safety Factor is applied to designs,and that the standard to which the boat is built is fully documented.

Konstruktiebedrijf De Jong BV is recommended to:

2007/171 Revise its manufacturing procedures to:

- Ensure that components manufactured for fitting to boats built under RCD criteria fully meet the RCD requirements, are supported by calculations and have the appropriate Safety Factor applied.
- Refer to component designers when considering changes to a design to ensure that safety is not compromised, especially by the addition of welds in stress critical areas.
- Where appropriate, specify weld fatigue procedures to relieve stresses in critical weld areas.

The International Council of Marine Industry Associations is recommended to:

2007/172 Propose the following amendment to the Recreational Craft Sectoral Group Guidelines 2006:

- Add the term ***"keel construction"*** to Section E.A.3 Part 5.d

The Yacht Designers and Surveyors Association, Royal Yachting Association, Royal Ocean Racing Club, British Marine Federation, Royal Institution of Naval Architects, International Council of Marine Industry Associations and Institute of Marine Engineers and Science and Technology are recommended to:

M2007/173 Promulgate to their membership, owners, surveyors, and repairers/maintainers where appropriate, the following safety issues, which have been identified in this investigation report:

- The need to rigorously follow the standards selected for design criteria, especially where these include Safety Factors.
- The importance of referring to original and revised drawings when considering modifications to ensure that proposals will not compromise safety.
- The need for quality systems to be in place to properly check the product against the design criteria.
- The importance of examining keels for signs of fatigue cracking, especially where hollow fabricated steel keels are fitted, and to consider using non-destructive examination techniques whenever there is doubt about the integrity of the appendage.

M2007/174 Promulgate, where appropriate, the following comment at page 7 of the RSG Guidelines 2006:

- *"RSG urges the industry and Notified Bodies to use EN Standards".*

Marine Accident Investigation Branch
August 2007

Safety recommendations shall in no case create a presumption of blame or liability