Bundesstelle für Seeunfalluntersuchung
Federal Bureau of Maritime Casualty Investigation
Federal Higher Authority subordinated to the Ministry of Transport,
Building and Urban Development

Report

Investigation Report 56/09

Very serious marine casualty

Collision between Motor Vessel CHRISTA and Pleasure Craft ODIN off Timmendorf/Poel on 28 February 2009

15 April 2010

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The investigation was conducted in conformity with the law to improve safety of shipping by investigating marine casualties and other incidents (Maritime Safety Investigation Law - SUG) of 16 June 2002.

According to this the sole objective of the investigation is to prevent future accidents and malfunctions. The investigation does not serve to ascertain fault, liability or claims.

The present report should not be used in court proceedings or proceedings of the Maritime Board. Reference is made to art. 19 para. 4 SUG.

The German text shall prevail in the interpretation of the Investigation Report.

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1 Summary of the marine casualty

On 28 February 2009, 35 passengers were on board the CHRISTA, a sport fishing vessel, for a deep sea fishing trip. The skipper and a deckhand had prepared the vessel accordingly. The trip began at about 0700[1] in the Westhafen in Wismar. The CHRISTA followed the fairway and was to then pass through the Flaggtief to reach the open sea. The Timmendorf/Poel approach buoy was also situated on this route. The skipper was alone on the bridge and used a radar device.

Earlier, two people had also set off for a fishing trip on the ODIN, a pleasure craft. When the ODIN was situated in the vicinity of the Timmendorf/Poel port approach buoy, the crew detected water inside the boat. In order to clarify the cause, the boat was stopped and the engine switched off. Shortly after that, the crew began to make a temporary repair. During this period, only the passenger noticed a distant vessel. The crew of the ODIN only became aware of this vessel again when it was on a collision course at a distance of between approx. 100 m and 200 m. They attempted to draw attention to themselves by shouting, waving and sounding a signal horn. However, they were unsuccessful and the CHRISTA collided with the pleasure craft. The crew of ODIN had removed themselves from the danger area prior to this happening by jumping into the water.

On board the CHRISTA, the ODIN remained unnoticed until she was only approx. 30 m away and therefore it was no longer possible to avoid the collision. Prior to that, the pleasure craft was reportedly neither detected visually nor by radar.

The ODIN was heavily damaged during the collision. The stern sank immediately afterwards. The CHRISTA was only slightly damaged.

The two crew members of the ODIN were taken on board the CHRISTA and cared for. Some time after, a search and rescue boat took the two individuals ashore, where they were initially treated by an emergency doctor and later taken to a hospital.

[1] All times shown in this report are Central European Time (CET) = UTC + 1.

2 Scene of the accident

Type of event:	Very serious marine casualty. Collision between the CHRISTA, a sport fishing vessel, and the ODIN, a pleasure craft, with the subsequent foundering of the ODIN
Date/Time:	28 February 2009/0750
Location:	Baltic Sea, Wismar Bay, off Timmendorf
Latitude/Longitude:	φ 53° 59.47'N λ 011°21.95'E

Excerpt from Nautical Chart 1641, Federal Maritime and Hydrographic Agency (BSH)

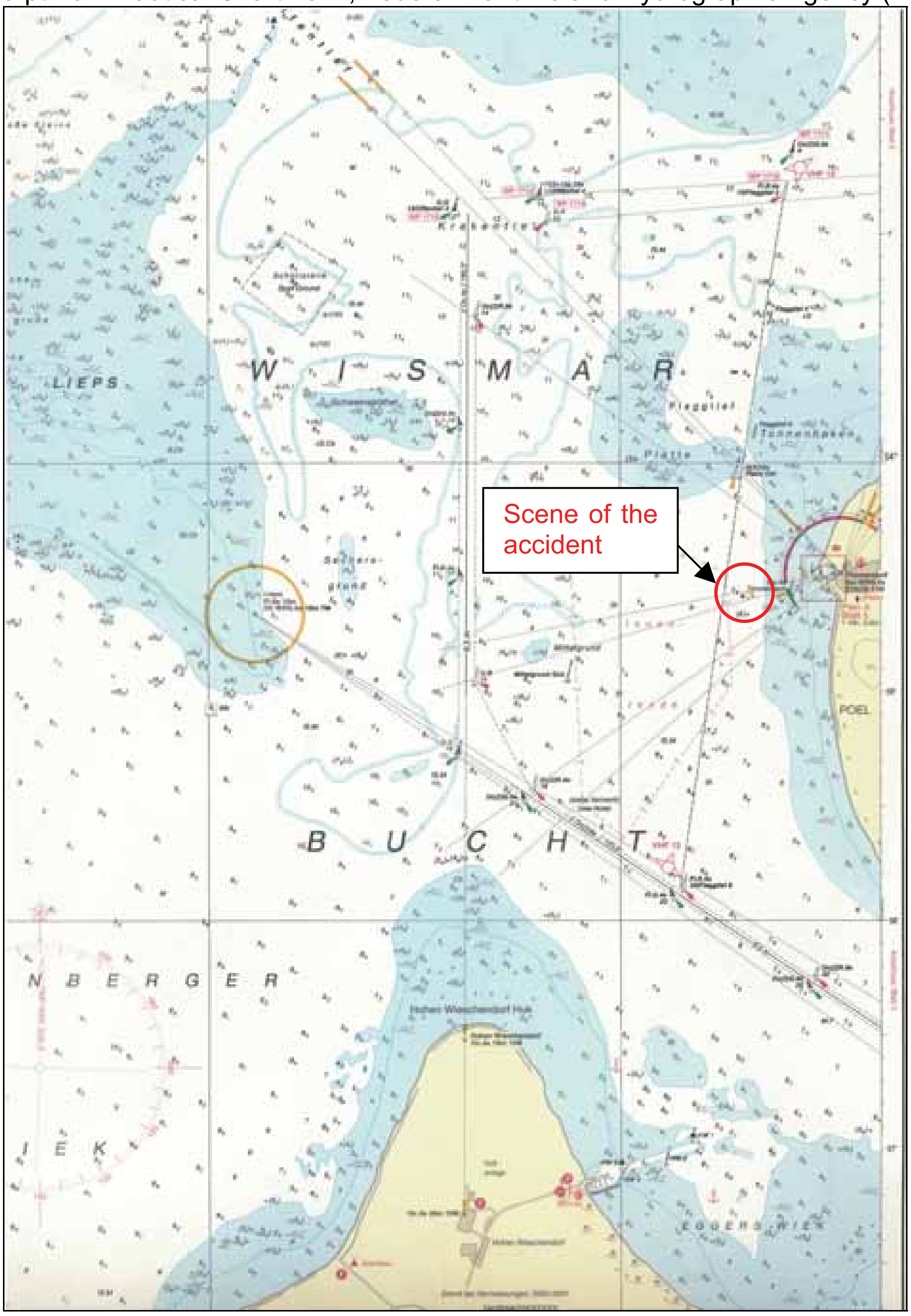

Figure 1: Nautical chart showing the scene of the accident

3 Ship particulars

3.1 CHRISTA

3.1.1 Photo

Figure 2: Photo CHRISTA

3.1.2 Particulars

Name of the vessel:	CHRISTA
Type of vessel:	Sport fishing vessel
Flag:	Federal Republic of Germany
Port of registry:	Wismar
Call sign:	DJYI
Owner:	MS "Christa" Seetouristik GbR
Year built:	1954
Shipyard:	Laan en Kooy, Den Oever
Length overall:	23.00 m
Breadth overall:	5.64 m
Gross tonnage:	66
Draught at time of accident:	2.70 m
Engine rating:	220 kW
Main engine:	Brons Diesel
(Service) Speed:	8.2 kts
Hull material:	Steel
Number of crew:	2
Number of passengers:	35

3.2 ODIN

3.2.1 Photo

Figure 3: Photo ODIN

3.2.2 Particulars

Name of the vessel:	ODIN
Type of vessel:	Pleasure craft
Flag:	Federal Republic of Germany
Port of registry:	Wismar
Year built:	Unknown
Shipyard/yard number:	Unknown
Length overall:	8.40 m
Breadth overall:	2.35 m
Draught at time of accident:	0.80 m
Engine rating:	20 kW
Main engine:	Installed engine, Farymann Diesel
(Service) Speed:	5 kts
Hull material:	Wooden, hull covered with GRP
Number of crew:	2

4 Course of the accident

4.1 Course of the voyage – CHRISTA

On 28 February 2009, the CHRISTA, a German sport fishing vessel[2], was manned by the skipper and a permanently employed sailor deck[3]. The vessel was taking 35 passengers on a deep sea fishing trip.
The trip reportedly began at about 0700 in the Westhafen in Wismar. By all accounts, the CHRISTA then followed the course of the fairway.
The speed was reported to be approx. 8 kts. She reportedly left the fairway at buoy number 20 and steered a course of 360° in order to pass through the Flaggtief.
It was reported that the vessel was steered by the skipper. He reportedly used the radar for collision avoidance and navigation. He reportedly did not leave the bridge until the collision took place. The deckhand reportedly cleared up the deck after casting off and subsequently assumed the task of lookout on the bridge. While doing so, it was claimed that he also used the radar sporadically in order to obtain an overview. However, by all accounts no other vessels were identifiable.
After some time, the deckhand reportedly went to the galley to fetch coffee for the skipper. After a very short stay there, calls by the passengers reportedly made him aware of a particular situation. By all accounts, he initially kept watch on the port side; therefore, the collision was reportedly not seen by him.
It was claimed that the skipper first noticed the ODIN ahead on the starboard side at a distance of about 30 m from the stem. Therefore, the only option was reportedly to disengage the engine. It was reportedly not possible to change course. Both vessels reportedly collided shortly thereafter.
The collision occurred at about 0750.

4.2 Course of the voyage – ODIN

One of the two owners of the German pleasure craft ODIN and one other person intended to go fishing on the day of the accident. It was claimed that the trip began at about 0645 at the vessel's berth in Wismar. The reported intention was to sail via the Flaggtief in close proximity to the buoy that marks the beginning of the eastern fairway to the port of Wismar. By all accounts, the voyage initially passed without any irregularities. While in the vicinity of the Timmendorf/Poel port approach buoy, the skipper reportedly noticed the automatic bilge pump in operation. It was claimed that this was unusual and therefore the skipper reportedly decided to stop the vessel. During the inspection of the engine compartment, it was reportedly found that the nozzle of the cooling water hose was broken and therefore cooling water had reportedly leaked into the vessel. It was claimed that an attempt was then made to repair the damage temporarily. Both people were reportedly situated in the vicinity of the engine compartment for the repair. The engine was reportedly not in operation.

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[2] According to the Sailing Permit of the See-Berufsgenossenschaft, which was renamed the Ship Safety Division (BG Verkehr) on 1 January 2010.
[3] According to the Minimum Safe Manning Certificate issued by the See-Berufsgenossenschaft. referred to as deckhand throughout the remainder of the document.

At this point, it was reported that the ODIN was located about 100 m from the Timmendorf approach buoy.
The other vessel involved in the subsequent collision was reportedly noticed by the passenger for the first time just before the engine was switched off. At that point, the still unidentified vessel was reportedly situated near buoy number 22 of the fairway to Wismar. It was thus about 1.7 nm away. By all accounts, this observation was not passed on to the skipper by the passenger and further monitoring was reportedly dispensed with due to the large distance.

While work was still being carried out on the engine, the passenger reportedly went to the stern. While doing so, it was reported that he saw the vessel on a collision course at a distance of 100 m to 200 m because the tarpaulin cover was open there. He reportedly called the skipper immediately and made him aware of the imminent risk of a collision and then started to wave. The skipper reportedly sounded a signal horn. By all accounts, they both jumped into the water when the CHRISTA was reportedly 0.5 m away from the vessel. The CHRISTA reportedly collided with the stern section of the ODIN at right angles to the port side.

4.3 Subsequent events

After the collision, the skipper of the CHRISTA turned a circle over port and reported the incident to the Vessel Traffic Service (VTS) over VHF.
In the meantime, passengers threw a lifebuoy, which the two people in the water held on to. The deckhand threw another lifebuoy. The CHRISTA was then brought to a halt close to the two people in the water and they were able to swim to the vessel. Since the cast lifebuoys were not equipped with a line, assistance in reaching the side of the vessel was provided using a gaff[4]. Several people then took part in helping the swimmers to board the CHRISTA, where they were provided with dry clothing. At 0806, the skipper reported over VHF that the crew of the ODIN had been rescued. The GÜNTER SCHÖPS, a DGzRS[5] search and rescue boat stationed at Timmendorf/Poel, arrived at the scene of the accident shortly afterwards. Assistance by the crew of the rescue boat was reportedly initially not necessary because the survivors felt comfortable and wanted to stay on board the CHRISTA. However, the condition of one of the survivors deteriorated after the search and rescue boat went back to port. The search and rescue boat returned to the CHRISTA and took both people ashore to a waiting emergency doctor, who later transferred the two individuals to a hospital.
The CHRISTA was unable to enter the port due to her draught.

At 0830, the HOBEN, a coastal patrol boat of Waterway Police Wismar, arrived and the police officers began the investigation.

The hull of the ODIN was split in two due to the collision. The aft section along with the engine and fuel tank sunk at the scene of the accident. The HOBEN towed the larger fore section, which was still floating upside down, to Timmendorf, where it was initially cordoned off with an oil barrier by the fire brigade and subsequently lifted

[4] Gaff – a long rod with a pointed hook for landing fish.
[5] DGzRS – Deutsche Gesellschaft zur Rettung Schiffbrüchiger (German Maritime Search and Rescue Service).

ashore (Figure 3). The fore section was secured and stored onshore in accordance with an order issued by the BSU.
The SCHARHÖRN, a multi-purpose vessel, placed an isolated danger buoy at the position that the aft section sank. On 3 March 2009, the aft section was salvaged by a vessel from Waterways and Shipping Office (WSA) Lübeck and put in a yard of the WSA, where it was also secured.

5 Investigation

The CHRISTA and the wreck of the ODIN were surveyed by a team from the BSU on 29 April 2009. The investigators examined the investigation file of the waterway police during the course of the investigation and thus gained knowledge of the statements of the parties involved in the accident and witnesses.

5.1 CHRISTA

The CHRISTA was acquired by her present owner in 2000. She was also used as a sport fishing vessel prior to that. The necessary certificates could be displayed and were valid.

At the time of accident, both skipper and deckhand possessed the required licences and documents according to the Minimum Safe Manning Certificate. The vessel's nautical equipment was complete.

At the time of the accident, the skipper was using a Furuno FR-1505-MKIII-IIB radar. It was reportedly set to a range of 1.5-nm and operated off-centre. Accordingly, at the stated speed an area of at least 2 nm or 15 minutes of the path ahead was covered. The radar image is stabilized with the support of a satellite compass. Guard zones[6] were not used or configured. The radar image was overlaid with an electronic nautical chart. Two more screens also facilitated the display of an electronic nautical chart. The electronic nautical charts in use were not approved. The devices next to the radar unit used for displaying the electronic nautical chart were also not approved. Therefore, paper nautical charts had to be used for navigation.
Nautical charts 1641 of the BSH (issue stamp 19/2001) and 36 (issued in 2007) were used to navigate the sea area in which she was sailing.

The AIS signal[7] of the CHRISTA was not visible on the corresponding record of VTS Wismar until 0900 onwards. The CHRISTA is not required to carry such a device.

The CHRISTA was steered with the assistance of an autopilot.

The view ahead from the bridge of the CHRISTA is only marginally restricted due to the structural parts of the forward mast. The forecastle only obstructs the view of the water immediately in front of the bow (see Figures 4 and 5).

[6] Fixed automatic detection zone for radar echoes, with alarm.
[7] AIS – Automatic Identification System.

Figure 4: View ahead from the bridge of the CHRISTA; the colour of the image is due to the tinted windscreens

Figure 5: Bridge of the CHRISTA, looking ahead

The BSU investigation team inspected the life-saving appliances relevant to the case. There were two lifebuoys on board with a signal lamp and two lifebuoys with a floating line. A pilot ladder and a rescue net were also displayed.

The logbook indicated that the vessel was prepared for the journey on the basis of checklists. The content of the checklists was examined by the investigators.

The CHRISTA was only marginally damaged by the collision with slight dents and paint abrasions in the bow area. None of the passengers were injured.

Figure 6: View of the main deck of the CHRISTA

Figure 7: Sport fishing vessel CHRISTA

5.2 ODIN

The co-owner of the ODIN, who was also the skipper when the accident occurred, displayed a Pleasure Craft Skipper's Licence (Power/Sail) Sea, issued on 28 July 2009, at the request of the BSU. The licence was issued on the basis of art. 5.2 of the implementing directive[8]. This means that the issuing body was satisfied that the skipper had acquired a corresponding pleasure craft skipper's licence in the former GDR, but that this is no longer in his possession.
The passenger stated that he was also in possession of a Pleasure Craft Skipper's Licence (Power/Sail) Sea.

The investigators were unable to detect any indication of a navigation device. However, it was claimed that a GPS device was on board. A compass was fitted at the helm. A fixed radar reflector was not mounted on the pleasure craft. She was equipped with a CB radio set, but not a VHF marine radio. At least one mobile phone was carried.
Life jackets were reportedly on board. However, they were not worn at the time of the accident.
Type approved navigation lights were installed. Statements as regards operation of the navigation lights varied. The passenger thought that they were still on at the time of the accident because they were turned on when they set sail. Witnesses on board the CHRISTA did not see navigation lights in operation. The investigation by the waterway police found that the bulbs were intact.

The BSH tested navigation lights of various manufacturers on behalf of the BSU. In doing so the illuminates, under operating state temperature (burning-in time 2 hours), were not destroyed while immersed in cold salt water (- 1° C).

The BSU investigation team gathered the following additional data on the vessel:
- Depth of the hull from the waterline at the stern: 0.65 m
- Depth of the hull from the waterline at the bow: 0.75 m
- Height above deck of the forward part of the cabin superstructure: 0.50 m
- Height above deck of the helm: 1.15 m

The visible side area was thus approx. 7.5 m². An additional area of approx. 3 m² was created by the tarpaulin, which ran to the stern. An inspection from exactly in front of the bow or exactly behind the stern resulted in an area of approx. 4.2 m².

Part of the hull, i.e. the port side, floor area and transom, was torn off during the collision. That led to massive water ingress and the vessel foundered. In addition, the superstructures tore off or were destroyed.

[8] Directive of 15 September 2005 for the German Motor Yacht Association and the German Sailing Association on the implementation of the requirements of art. 4 of the German Maritime Pleasure Yachting Navigating Licences Ordinance (implementing directive SpbootFüV-See).

Figure 8: Stern of the ODIN

Figure 9: View into the rear of the ODIN and of the installed engine

Figure 10: Wheelhouse of the ODIN

Figure 11: View of the helm and parts of the ODIN's hull from aft; helm wall stood up by the BSU; blue trailer in the foreground

5.3 Witness accounts

The waterway police contacted all those involved in the voyage of the CHRISTA in writing and requested an account of the course of the accident from their perspective. The majority of the passengers did not observe the accident directly. Amongst other things, this is due to the high forecastle of the CHRISTA, which only permits limited forward visibility from the main deck (see Fig. 6). It was not until shortly before the collision that the anglers on deck became aware of the close proximity of the two vessels, at which they began to wave and shout in order to alert the bridge. One of the witnesses confirmed that a signal horn was used on board the ODIN. However, it was reportedly barely audible. No signal was reportedly sounded by the CHRISTA.

5.4 Environment

According to the expertise prepared by Germany's National Meteorological Service (DWD), the weather was as follows:
On the morning of 28 February 2009, the western Baltic Sea was situated in the area of a high-pressure system with a core pressure of 1021 hPa over the Alps. A wedge extended northward to southern Scandinavia. The warm front of a low pressure system near Iceland (995 hPa) ran from the North Sea to central Europe.
The weather conditions were described as follows:
Wind: during the period under consideration, there was a south-easterly wind with a strength of 2 to 3 Bft.
Sea conditions: swell measurements and observations from the scene of the accident are not available. It can be assumed that the wave heights were below 0.5 m.
Visibility: at the time of the accident, visibility was 3 to 4 km according to the measurements and observations of Pelzerhaken, Boltenhagen and Rostock.
Air temperature: the air temperature was 2 degrees C.

At 0800, VTS Travemünde estimated visibility to be 6 km in its area.

The entries for the weather in the logbook of the CHRISTA were as follows: air pressure: 1010 hPa; air temperature: 4°C; water temperature: 2°C; wind: light. Visibility at the time of the collision was measured at 300 m.

Various witnesses estimated that visibility was between 500 m and 4 km. By all accounts, it was cloudy but there was reportedly no fog. Some witnesses reported that the Hohen Wieschendorfer Huk, which is located some 2.2 nm away from the scene of the accident, was visible.

In this area, dawn began at 0549. Sunrise was at 0705.

6 Analysis

6.1 CHRISTA

The CHRISTA was prepared for the forthcoming voyage. The number of passengers on board was within the permitted limit.

After clearing up which followed the casting off manoeuvre, the deckhand went to the bridge and assumed the role of lookout. Since the skipper of the CHRISTA did not complete the Weather (ww)[9] column in his first logbook entry at 0700 or record the visibility explicitly, a statement as to the actual visibility in Wismar is not possible in retrospect.
The BSU views the problem of manning the role of lookout critically. Employing the deckhand as lookout would not have been absolutely necessary as long as the visibility of up to 4 km as reported by witnesses prevailed. During daylight, it is legally permissible for the skipper/officer on watch to perform the role of lookout; however, certain criteria must be considered in advance. One criterion is the prevailing visibility. However, since about 9 minutes elapsed from passing buoy number 20 up to the collision, and visibility at the time of the accident was 300 m according to the logbook, this criterion would not have been met. We are therefore unable to understand the decision of the skipper to release the deckhand from his task after passing buoy number 20.

In addition to the requirements for a lookout under regulation 5 COLREGs[10], regulations 6 and 7 also apply for all levels of visibility. Regulation 6 deals with safe speed and states, inter alia, that in the case of vessels with an operable radar, the following should be considered:

> (...) *the possibility that small vessels (...) may not be detected by radar at an adequate range.*

Regulation 7 deals with the potential risk of a collision, according to which every skipper :

> *(…) shall use all available means appropriate to the prevailing circumstances and conditions to determine if risk of collision exists.*
> *Proper use shall be made of radar equipment if fitted and operational to obtain early warning of risk of collision (…).*

In addition to the COLREGs, the STCW Code[11] contains further regulations. Regardless of the presence of an additional lookout, it is a basic duty of the skipper to keep a lookout.

[9] Weather (ww) – Used to record the weather condition, coded in number groups.
[10] COLREGs – International Rules of 1972 for the Prevention of Collisions at Sea.
[11] Code on standards of training, certification and watchkeeping for seafarers (STCW Code), section A-VIII/2 part 3-1, implemented in German law by the Ordinance for the International Convention of 7 July 1978 on standards of training, certification and watchkeeping for seafarers.

This lookout should[12]:

13.1 maintain a continuous state of vigilance by sight and hearings as well as by all other available means with regard to any significant change in the operating environment;
13.2 fully apprising the situation and the risk of collision, stranding and other dangers to navigation; and
13.3 detecting ships or aircraft in distress, shipwrecked persons, wrecks, debris and other hazards to safe navigation.

Other obligations apply for the master/nautical watch officer:

37 The officer in charge of the navigational watch shall use the radar whenever restricted visibility is encountered or expected (...) having due regard to its limitations.

38 The officer in charge of the navigational watch shall ensure that range scales employed are changed at sufficiently frequent intervals so that echoes are detected as early as possible. It shall be borne in mind that small or poor echoes my escape detection.

44 In clear weather, whenever possible, the officer in charge of the navigational watch shall carry out radar practice.

45 When restricted visibility is encountered or expected, the first responsibility of the officer in charge of the navigational watch is to comply with the relevant rules[13] with particular regard to the sounding of fog signals, proceeding at a safe speed and having the engines ready for immediate manoeuvre. In addition, the officer in charge of the navigational watch shall.
.1 (...)
.2 post a proper lookout;
.3 exhibit navigational lights; and
.4 operate and use the radar.

The CHRISTA followed the fairway and according to a statement by the skipper changed to a northerly course at buoy number 20. In the process, a course of 360° was reportedly steered. However, this course does not lead to the passage through the Flaggtief (see Figure 12). To navigate the recommended course through the Flaggtief from buoy number 20, a true course of 008.5° would have had to be steered. However, a course over ground of 013° must have been steered to get to the accident position from buoy number 20.

[12] STCW Code, section A-VIII/2 part 3-1 (13)
[13] Of the COLREGs.

It is possible that the course had already been changed between buoy numbers 20 and 22. In that respect, if the course was changed at a point at which it would have been possible to pass through the Flaggtief at 360°, this course would lead directly past the subsequent accident position.
Due to insufficient logbook entries concerning the time at which buoys were passed or changes in course were made, it is not possible to trace the course exactly. VTS Wismar does not monitor this area by radar. The CHRISTA's AIS signal was not logged at this time.

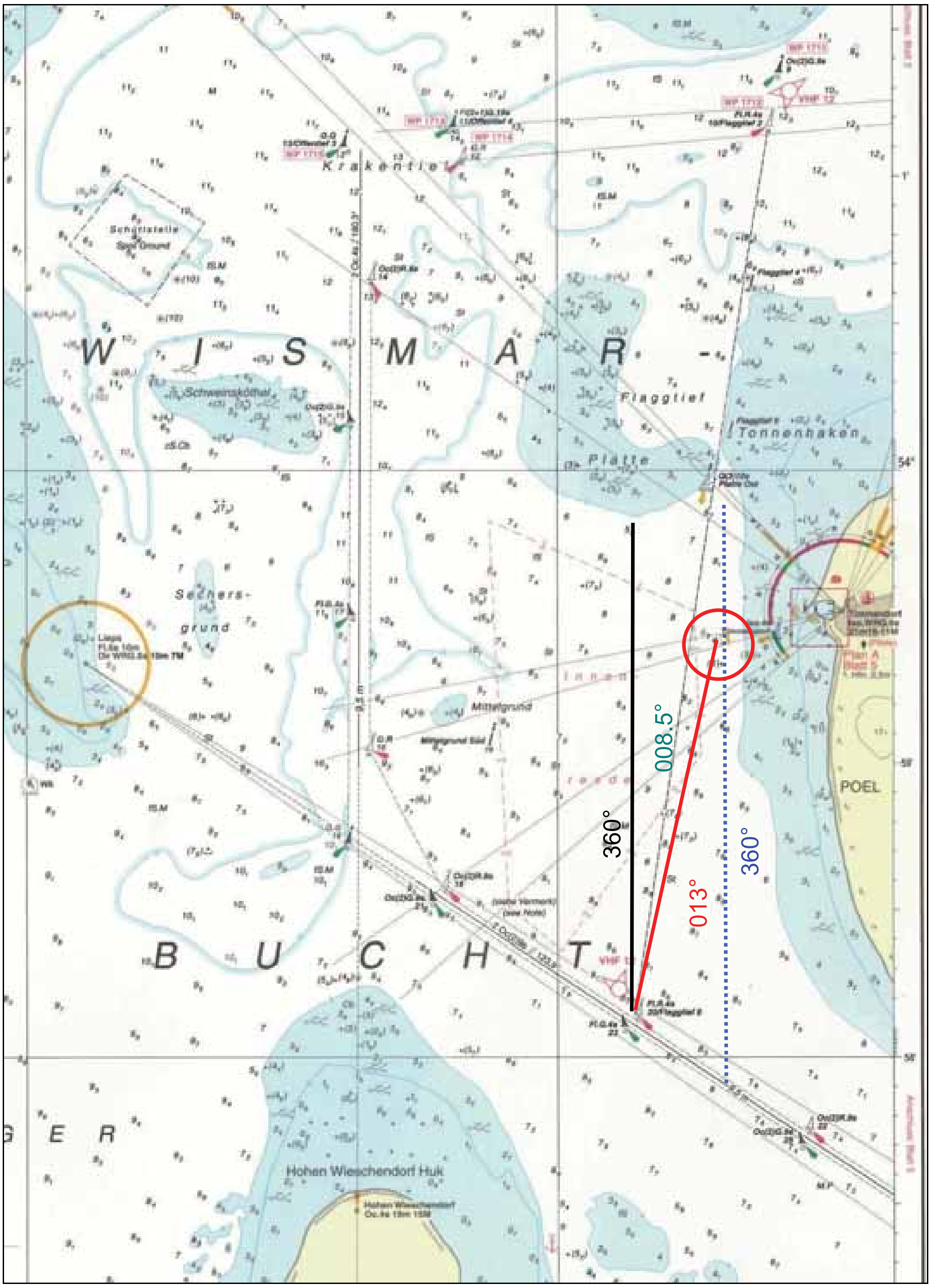

Figure 12: Course to the scene of the accident

The nautical charts on board the ODIN did not meet the requirement of art. 13 para. 1 (2a) SchSV[14] in conjunction with section C.I.4 of Annex 1 No. 3, according to which the latest editions of official nautical charts are to be carried.

6.2 ODIN

The provisions of the Rules for Preventing Collisions at Sea also applied to the skipper of the ODIN at the time of the accident. The fact that his vessel was not under command did not absolve him from his obligations. Although he did not have radar at his disposal, he was also required to keep a lookout and switch on navigation lights.

6.3 Radar reflector

The ODIN was not equipped with a radar reflector. However, it is precisely a reflector which may have improved the visibility of the pleasure craft on the radar screen of the CHRISTA and thus prevented the collision.

The thinking behind using a radar reflector is based on the fact that the visible area of an object is not equal to the reflection area. This is illustrated with a very simplified diagram in Figure 13.

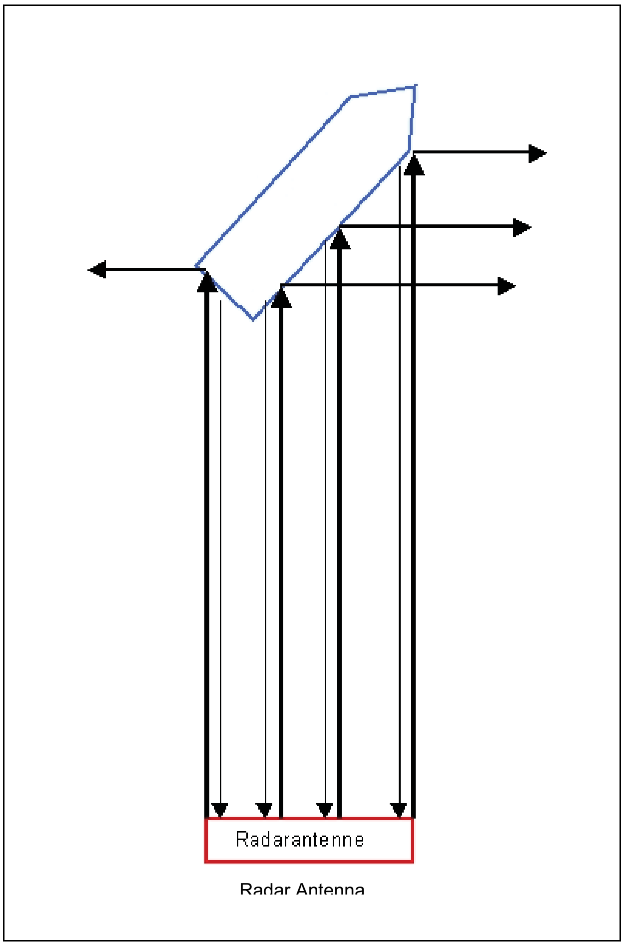

Figure 13: Illustration of the reflection of radar beams on a vessel

[14] SchSV – Schiffssicherheitsverordnung (Ordinance for Shipping Safety)

It is apparent that at the position of each vessel in relation to the other a large percentage of the radiated energy is not returned to the antenna. However, the percentage of energy returned is of critical importance to the way in which the vessel is displayed on the screen of a radar device. This percentage makes the difference between 'invisible', 'faint' or 'visible'.
The visibility of a vessel can be improved by using a good radar reflector.

6.3.1 Legal bases for equipment

SOLAS chapter V regulation 1 states that the regulations of this chapter fundamentally apply to all ships on all voyages. However, paragraph 4 permits the administrations of individual member states to grant exemptions to ships of less than 150 GT.

SOLAS chapter V regulation 3 enables an administration to grant further exemptions to ships without mechanical propulsion. However, the radar reflector under regulation 19 paragraph 2.1.7 is excluded from this possibility.

SOLAS chapter V regulation 19 prescribes the carriage requirements for shipborne navigational systems and equipment. A distinction is made between ships built before 1 July 2002 and those built after that date.

According to SOLAS chapter V regulation 19 paragraph 1.2.1, the carriage requirements prescribed in the SOLAS Convention in force before 1 July 2002 remain applicable for ships built before 1 July 2002. However, retrofitting requirements have been established for certain systems and equipment.

Ships built before 1 July 2002 are not required to carry radar reflectors under SOLAS because the version of SOLAS in force before 1 July 2002 did not contain a corresponding provision. Moreover, the new version of SOLAS does not prescribe that these ships should be retrofitted with a radar reflector at a later date. Furthermore, no other statutory provisions exist under which retrofitting would be required.

For ships built on or after 1 July 2002, regulation 19 paragraph 2 applies to the fitting of a radar reflector:

> *2.1 All ship, irrespective of size, shall have (...)*
> *2.1.7 if less than 150 gross tonnage and if practicable, a radar reflector, or other means, to enable detection by ships navigating by radar at both 9 and 3 GHz;*
> *(...)*

Therefore, ships built on or after 1 July 2002 only need to be fitted if it is practicable to do so. Other technical devices may also be used if they work on both radar wavebands. If the installation of these devices is practicable, the fitting thereof is mandatory.

Section C.I.4. of Annex 1 to article 5 SchSV[15] deals specifically with SOLAS chapter V. The following is stated in paragraph 1.2:

> *Pleasure craft with a gross tonnage of less than 150 shall:*
> *On large pleasure craft[16] within the meaning of article 2 (2) of the Maritime Pleasure Yachting Ordinance Sea of 29 August 2002 (BGBl. [Federal Law Gazette] I p. 3457), regulation V/18 only applies if its application is prescribed in this ordinance, a directive pursuant to article 6 paragraph 1 of this ordinance or in a Community directive set out in section D of the annex to the Ship Safety Act (SchSG[17]) or in a Community regulation.*

Section C.I.4. (2) of Annex 1 to the SchSV goes on to state:

> *Navigation equipment requirements for pleasure craft*
> *On large pleasure craft within the meaning of art. 2 (2) of the Maritime Pleasure Yachting Ordinance Sea of 29 August 2002 (BGBl. I p. 3457) with a gross tonnage of less than 150, which are exclusively not used commercially for sports and recreational purposes, regulation V/18 applies for the navigation equipment carried in accordance with paras. 2.1.1, 2.1.4, 2.1.5 and 2.1.7 of regulation V/19 of the annex to the SOLAS Convention.*

SOLAS chapter V regulation 18 paragraph 1 states that in principle all systems and equipment pursuant to regulation 19 must be type approved.
Paragraph 2 states that systems or equipment installed on or after 1 July 2002 must at minimum meet the performance standards of the IMO. This means that systems and equipment that were type approved at the time of installation must also meet higher performance standards that may come into force subsequently.
Paragraph 3 specifies that vessels built before 1 July 2002 must be fitted with equipment or systems that comply with the requirements of paragraph 2 in the event of replacement or refitting if doing so is reasonable and practicable. Accordingly, the BSU is the view that a specific retrofitting requirement for pleasure craft built before the above date does not exist, since paragraph 3 is to be seen only in connection with paragraph 1 and 2 and in conjunction with regulation 19 paragraph 1.2.1.

Therefore, in summary pleasure craft built on or after 1 July 2002 must be fitted with an approved radar reflector in principle; in contrast, pleasure craft built before that date do not have to be fitted with a radar reflector.
In the opinion of the BSU, a violation of this policy is not an administrative offence within the meaning of the Ship Safety Act.

[15] National exemption for vessels of less than 150 GT within the meaning of SOLAS chapter V regulation 1 paragraph 4.
[16] Pleasure craft with a cabin and sleeping accommodation which are suitable and intended for voyages seaward of the baseline (territorial waters, coastal marine waters, high seas), in particular, sailing and motor yachts. The ODIN corresponded to the definition of a large pleasure craft.
[17] SchSG - Schiffssicherheitsgesetz

6.3.2 Ordinary practice of seamen

Articles 3 paragraph 1 (1 and 2) of the VO-KVR[18] and the SeeSchStrO[19] are identical. These state:

> *The conduct of every person taking part in shipping traffic shall be such as to ensure the safety and easy flow of shipping traffic and to avoid any other person to be exposed to any damage or detriment, to be put at risk, or to be impeded or molested any more than is inevitable in the circumstances prevailing. Every person taking part in shipping traffic shall, in particular, take any precaution as may be required by the practice of good seamanship or by the special circumstances of the case.*

Hence, the ordinary practice of seamen comprises complying with traffic regulations, but also the observance of seaman's custom, i.e. compliance with written and unwritten practices and duty of care, which may increase safety on board and also be referred to as 'good seamanship'.
To clarify whether and what ordinary practices of seamen arise as regards the use of radar reflectors, the relevant, generally accessible directives and equipment recommendations can be referred to.

In its section on equipment, the 'Sicherheit auf dem Wasser (Safety on the Water)'[20] brochure states that a minimum carriage requirement exists for marine waters and that this is regulated internationally. The radar reflector is included in the list. In addition, there are also other items of safety equipment, which according to the ordinary practice of seamen should also be carried on board. An active or passive radar reflector is also listed there.
The section of the brochure that deals with travel preparation addresses measures for which a check is to be made or that should be performed before casting off. It states the following: "Mount a radar reflector if possible." This is repeated in another section. For conduct in restricted visibility, it states amongst other things that a radar reflector should be fitted.

The Cruiser Section[21] makes information material available in an info-pool on its website. Some of this is also accessible to non-members. The generally accessible paper on 'SOLAS for Pleasure Craft' contains a general statement, without limitation with respect to the year of construction, to the effect that compliance with the provisions of SOLAS chapter V regulation 19 is mandatory for large pleasure craft. That also includes paragraph 2.1.7 (radar reflectors).

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[18] VO-KVR - Verordnung zu den Internationalen Regeln von 1972 zur Verhütung von Zusammenstößen auf See (Ordinance pertaining to the International Rules of 1972 for the Prevention of Collisions at Sea)

[19] SeeSchStrO – Seeschiffahrtsstraßen-Ordnung (German Traffic Regulations for Navigable Waterways)

[20] Sicherheit auf dem Wasser – Wichtige Regeln und Tipps für Wassersportler (Safety on the Water – Important Rules and Tips for Water Sport Enthusiasts), published by the Federal Ministry of Transport, Building and Urban Development (BMVBS).

[21] Cruiser Section of the German Sailing Association e.V.; www.kreuz-abteilung.org.

A helpful overview of the recommended equipment continues to be the safety regulations[22] of the Cruiser Section. Under 9.7, and valid for all territories other than inland waters, the following is stated:

> *Radar reflector. Note ISO 8729. Octagonal radar reflectors must have a minimum diameter of 457 mm (...); non-octagonal reflectors must have a radar cross-section of > 10 m², which is documented by the manufacturer (...) spherical projection surface (standard definition). The minimum effective height above water is 4 m.*

In summary it should be noted that the use of radar reflectors is recommended in the brochures and papers of the authorities and organisations.
Similarly, German trade journals such as 'Palstek', 'Segeln' or 'Yacht' have been reporting on the need to use radar reflectors for some time now. Comparison tests established the performance level of different types of radar reflector (see also para. 6.3.4).
Moreover, the radar reflector has been a topic of training for the Pleasure Craft Skipper's Licence (Power/Sail) Sea for many years.
For this reason, it can be assumed that it is common knowledge that a radar reflector facilitates or enhances a vessel's capability to be detected by radar. The fitting of a vessel with a radar reflector and subsequent use thereof therefore conforms to good seamanship and is thus part of the ordinary practice of seamen.

Non-use, i.e. not mounting a passive radar reflector or failing to switch on an active radar reflector, is partly regarded to be a breach of good seamanship if another party is damaged, endangered or impeded or bothered more than is unavoidably necessary due to such non-use. That would mean, for example, that one's own vessel is either not or not sufficiently visible to others on a radar screen and that a hazardous traffic situation is caused because of this. Non-use is equal to using a non-approved radar reflector because of the potentially limited capability to be detected.
However, the BSU is of the opinion that in the case of pleasure craft built before 1 July 2002, carriage requirements can neither be derived from article 3 of the ordinance pertaining to the COLREGs or article 3 of the German Traffic Regulations for Navigable Waterways (SeeSchStrO), nor can non-use, non-installation or installation of a non-approved item be penalised under the aforementioned articles on the grounds of not displaying good seamanship. The equipping of a vessel is conclusively regulated in the Ordinance for the Shipping Safety, having regard to SOLAS. Since older vessels, as indicated above, are not subject to a carriage requirement, it is also not possible to derive an administrative offence[23] from the requirement of good seamanship. However, since a carriage requirement exists for pleasure craft built on or after 1 July 2002 in principle, non-use on these vessels could represent a violation of the requirement of good seamanship.

[22] Safety Guidelines – Equipment and Safety of Sailing Yachts/Multi-hull Boats, 2000/2002 version, based on the ORC Guidelines (1999).
[23] See also art. 3 German Administrative Offences Act (OWiG) – principle of clarity.

6.3.3 Technical provisions

Irrespective of SOLAS, in Resolution A.384(X) the IMO, or its Maritime Safety Committee (MSC), recommended as early as in 1977 that vessels of less than 100 GT should be fitted with radar reflectors if practicable.
The recommended minimum standards were defined in the resolution and should apply to detection by radar systems with an operating frequency of 9 GHz. The minimum standards include:

- Use of a tested type with a radar cross section of at least 10 m² and a minimum height above the water surface of 4 m or a radar cross section of 40 m² and a minimum height above the water surface of 2 m.
- An absorption area on an azimuth of 360°.

The above resolution was replaced in 2004 by MSC Resolution 164(78)[24]. The recommended performance standards now apply for radar reflectors which are to be detectable for radar systems operating in the 9 GHz (X-Band) and 3 GHz (S-Band) range. It was established that the minimum requirements should be met by passive or active reflectors. The points below include some of the minimum requirement:

- With an installation height of at least 4 m above the water surface, the Stated Performance Level (SPL)[25] for X-Band should be at least 7.5 m² and for S-Band at least 0.5 m².
- The reflector is to achieve this performance at minimum on an azimuth of 280°.
- For power-driven vessels and sailing vessels with a low heel (multi-hull), the performance of the reflector should also be achievable with a lateral heel in either direction of 10°. For other sailing vessels, the performance of the reflector should also be achievable with a heel of 20°.

The current technical standard for passive radar reflectors for shipping[26] entered into force in 1998. The performance standards laid down apply for X-Band frequencies and are similar to the requirements in the MSC Resolution.
The technical standard for active radar reflectors[27] was published in June 2009[28]. The requirements laid down for reflectivity conform to the MSC resolution, i.e. active radar reflectors must operate on both frequency bands.

A radar reflector that has been successfully type approved[29] and thus met the technical standards valid at the time of the approval procedure is marked with the steering wheel symbol.

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[24] Annex 28, Resolution MSC.164(78), adopted on 17 May 2004 – Revised performance standards for radar reflectors.
[25] Stated Performance Level – A value determined using a specific procedure, which facilitates the comparability of reflectors. Defined in m²-Radar Cross Section (RCS).
[26] EN ISO 8729: 1997 – Marine Radar Reflectors. The replacement standard ISO 8729-1 - Marine radar Reflectors - Part 1: Passive Type - is being drawn up.
[27] Also known as a Radar Target Enhancer (RTE).
[28] ISO 8729-2 Ships and marine technology – Marine radar reflectors – Active type.
[29] Procedure under Council Directive 96/98/EC on marine equipment (EC Marine Equipment Directive (MED)).

6.3.4 Radar reflector types

Passive radar reflectors can be divided into two basic types. Firstly, simple reflectors. These are designed so that the radar beam is returned to the antenna using two or three reflection areas. The reflectors on the market differ in the arrangement and number of corner arrays as well as in the length of the inner edge of the corner array. Some providers combine a number of corner arrays with a low edge length in one reflector. The actual construction cannot be seen in some reflectors, since the structure is enclosed in plastic. The second type is the Luneberg lens. This is a spherical reflector and the radar beam is reflected from inside. This type is not widely used by shipping.

Active radar reflectors function differently. If such a radar reflector *"(...) is hit by the radar beam of a vessel, (it) returns a signal in the same frequency as the incoming pulse. This then produces a correspondingly strong echo on the radar of the vessel that transmitted the pulse. However, as opposed to Racon, RTE does not transmit coded signals (ID), but only returns the incoming signal under amplification (...). This results in considerably more energy being received by the transmitting vessel than a passive reflector of the same size as a standard yacht would return. Accordingly, a significantly larger reflection area is simulated (more than 60 m²)."*[30]
For a detailed explanation of the functioning of the different reflectors and an overview of the types available on the market, see the corresponding references in Sources.

6.3.5 Performance level

The performance level of passive reflectors depends on the length of the inner edge of the corner array. It represents the critical size for the reflectivity of a passive radar reflector. The reflectivity of a reflector improves only slightly when a number of reflection areas are combined to form a reflector. To receive a reflection area of approx. 11 m² under ideal conditions, the length of the inner edge should be 21 cm. However, passive radar reflectors are rarely optimally aligned on a pleasure craft. Furthermore, they possess certain return beam characteristics which prevent reflectors from returning evenly over the entire azimuth of 360°. The return beam characteristics depend on the position of the reflector, i.e. the position of the reflection areas and the corners which form.
For motor yachts, the 'catch rain' position is generally recommended since an almost uniform all-round radar cross pattern is achieved. In this position, one corner points directly upwards ('catch rain') and the opposite one directly downwards. However, after a thorough test[31] it was concluded that the 'double catch rain' position achieves better results in the event of heeling movements.

[30] Rutter, Sven M.: Radar Reflectors. In: Palstek, Issue 5/2006, p. 70.
[31] Corenman, Jim et al: Radar Reflectors. 1995.
URL: www.ussailing.org/safety/Studies/radar_reflector_test.htm, (03/09/2009).

For sailing yachts, it is assumed that seen from the side the rig possesses certain reflection properties, which do not exist when seen from fore or aft. Therefore, on sailing yachts it is recommended that radar reflectors are used in the 'yacht position'. This means that one corner points forward and the opposite corner to aft.

In recent years, German sailing publications have regularly reported on the various radar reflector types and their level of performance. However, the reflectors were tested while under favourable conditions, i.e. with no heel. The reflection properties are strongly dependent on the 'heel' of the reflector. Therefore, the current directive (see para. 6.3.3) requires that the minimum values are also achievable if the heel of the reflector carrier is 10° or 20°.

The British Marine Accident Investigation Branch (MAIB) published a report [32] on the loss of the sailing yacht OUZO and the death of her three crew members in April 2007. The MAIB assumes that the PRIDE OF BILBAO, a ferry, collided or at least nearly collided with the OUZO and that this led to the yacht sinking. In connection with the investigation of this accident, the MAIB contracted the company QinetiQ to prepare two expertises. Firstly, the probability of detecting a small yacht with the radar of the PRIDE OF BILBAO[33] was investigated. Secondly, the effectiveness of the radar reflectors available on the market[34] was assessed. The outcome of both tests is summarised[35] below.

For the first test, a sister vessel of the yacht was initially examined to assess her reflection properties. In the process, it was found that this yacht possesses few sections that come close to being perpendicular to the surface of the water. She is therefore typical of most yachts. It should be noted that modern warship designs also possess this property to reduce the risk of being detected on a radar device. In addition, the OUZO was built using GRP, a material that possesses poorer reflection properties than steel. The following values (without radar reflector) were determined for the OUZO's radar cross section (RCS):

- Precisely abeam, about 8 m², considerable and immediate drop at low deviation
- From fore, approx. 2 m²
- From aft, approx. 3 m²

The large RCS of 8 m² from abeam needs to be restricted in the sense that it should be assumed that this value is only achievable when the mast is upright.

[32] MAIB: Report on the investigation of the loss of the sailing yacht Ouzo and her three crew South of the Isle of Wight during the night of 20/21 August 2006. 2007.
URL: http://www.maib.gov.uk/sites/maib/cms_resources/Ouzo_.pdf.

[33] MAIB: Annex 4: Investigation into the likelihood of the Pride of Bilbao's radars detecting a small yacht. URL: http://www.maib.gov.uk/cms_resources.cfm?file=/Ouzo_Annexes.pdf.

[34] MAIB: Performance Investigation of Marine Radar Reflectors on the Market. URL: http://www.maib.gov.uk/cms_resources.cfm?file=/Radar%20reflectors%20report.pdf.

[35] The full report of the test on the effectiveness of radar reflectors is published in English in the annex with the kind permission of the MAIB.

The testers applied an RCS of 4.5 m² with an azimuth of 360° for the collapsible radar reflector that was carried by the OUZO and possibly mounted.
For the computer simulation using a special program, the influence of the swell (height 1.5m) and wind (4 Bft) was taken into account. This is important because in rising seas vessels with a low side height are increasingly concealed by wave crests.
In each case, the probability of detecting the yacht with and without mounted radar reflector using X-Band radar and S-Band radar was calculated. The following probabilities were determined:

- S-Band without reflector: 50% probability at 1.4 km, then decreases more or less evenly to 0% at 10 km,
- S-Band with reflector: small peak of 70% at 2 km, 0% at 3 km, 100% between 3.5 km and 8 km, then decreases to 0% at 18 km,
- X-Band without reflector: less than 5% probability of detection at a range from 3 km to 13 km, before 0%
- X-Band reflector: many peaks of 40% to 60% from 0 km to 4 km, broad peak of about 85% with maximum at 6.5 km, over 90% between 10.5 km and 19 km.

For the second test, radar reflectors that are generally available on the market were examined in a controlled environment. The following models were tested.

1. Plastimo 16'' octahedral reflector, in the upright and in the 'catch rain' position, length of inner edge = 30 cm
2. Plastimo 4" (10 cm dia.) tube reflector
3. Davis Echomaster 16'' octahedral reflector, in the 'catch rain' position, 32 cm diameter
4. Viking Large Tri-Lens, three Luneberg lenses at an angle of 120° to each other, enclosed in a plastic case
5. Viking Standard Tri-Lens, as above but with smaller dimensions
6. Echomax 230, vertical stack of three corner arrays encased in plastic, the only reflector which has been type approved to ISO8729
7. Firdell Blipper 210-7, spiral array of corners encased in plastic
8. Sea-me Radar Target Enhancer (active radar reflector)
9. POLARef 11, Luneberg lens, for calibration

The test involved the performance of the reflectors being assessed at X-Band. All the reflectors were tested in an upright position and with increasing heeling angles. Firstly, the results were compared to the performance standards of ISO8729 (1999). Amongst other things:

a) The total angle should not be less than 2.5 m² on an azimuth of at least 240°[36].
b) In the case of a heel, total angle should not be less than 0.652 m² on an azimuth of at least 240°.

Secondly, a comparison was made with the performance standards of MSC.164(78) and the future ISO 8729-1, according to which:

c) The SPL should be > 7.5 m².

[36] That also meets the requirements for radar reflectors for non-SOLAS vessels from the future ISO 8729-1 (passive radar reflectors).

Abridged results are shown below:

1) The Plastimo 16" octahedral reflector, which was not prepared for use in the 'catch rain' position by the manufacturer, met the requirements of a) only in an upright position and without a heeling angle. The requirements of b) were satisfied for almost all heeling angles. It fell far short of the requirements of c).

2) The Plastimo 4" tube reflector did not meet the requirements of a). The requirements of b) and c) were met only in the upright position. There was a significant drop in performance at a heel of just 1°.

3) The Davis Echo Master did not meet the requirements of a) and c). The requirements of b) were met only up to a heel of 5°.

4) The Viking Large Tri-Lens met the requirements of a) and b). It achieved relatively high, but not sufficient values for c).

5) The Viking Standard Tri-Lens only met the requirements of b).

6) During the test, the Echomax 230 was inclined/heeled towards (+) and away (-) from the radar antenna. This led to different results. The requirements of a) were met only in the upright position. The requirements of b) were met up to a heeling angle of + 10°.

7) The Firdell Blipper 210-7 was also inclined in two directions. The requirements of a) were met only in the upright position. The requirements of b) were met up to a heeling angle of - 5° to + 15°. It failed to meet the requirements of c).

8) The Sea-me RTE met the requirements of a) and b) over 360°. The requirements of c) were met only up to a heel of 15°.

9) The POLARef 11 met the requirements of a) and b) over 360°. With respect to the requirements of c), it was close to or above the required value for all heeling angles.

In summary it should be noted that the commonly used passive radar reflectors do not come close to meeting the requirements of MSC.164(78) or the future ISO 8729-1. However, Test 1 shows that almost every radar reflector is better than no reflector at all because the probability of detection is increased significantly.
The Sea-me RTE tested would not have met the requirements of ISO 8729-2 because it only functioned in the 9 GHz band. An RTE has now been introduced on the website of the manufacturer that works in both required frequency ranges.

An overview of the current type approval situation for radar reflectors is provided by the MarED database established in connection with the EC Marine Equipment Directive.

This does not include the passive or active radar reflectors intended for use on lifeboats and life rafts or as part of the navigation equipment. This evidently means that there are currently no type approved radar reflectors.

6.3.6 Summary

In connection with the investigation of this case, the BSU has again found that the existing regulatory gap for pleasure craft built before 1 July 2002 is critical. This situation was already established during the investigation of the marine casualty involving the ALLMIN[37] and addressed in a letter to the Ministry of Transport, which made reference to the pending changes to the sea traffic regulations. It is the opinion of the BSU that the regulatory gap still persists. The investigators assume that the majority of pleasure craft on German navigable maritime waterways were built before 1 July 2002. This means that for a large percentage of German pleasure craft, fewer or less specific requirements and obligations pertaining to equipment exist since the legislator has hitherto not grasped the opportunities it has at its disposal to establish a uniform system of requirements or recommendations. It remains open to the BSU whether the maximum requirements of SOLAS are introduced for all pleasure craft or whether by applying a sense of proportion and in coordination with government agencies and associations regulations are found, which could apply equally to all pleasure craft.

The existing literature, i.e. the brochure of the BMVBS, but also the papers of the associations, is lacking in terms of helping individual pleasure craft operators establish what equipment is presently mandatory for their particular vessel. In many cases, the literature neither clearly distinguishes between mandatory and recommended equipment nor differentiates according to year built. Guidance on the basis of existing laws and regulations is made very difficult due to many references and may lead to wrong conclusions.

Regardless of the foregoing, it is self-evident that all pleasure craft should carry an appropriate radar reflector on board. This is especially true if the voyage involves sailing in particular sea areas, during darkness or in poor weather.

[37] BSU 203/04 – Foundering of SY ALLMIN and drowning of two sailors on 29 June 2004 east of Rügen.

7 Safety Recommendations

The following safety recommendations do not attribute a presumption of blame or liability in respect of type, number or sequence.

7.1 Operators and skippers

The Federal Bureau of Maritime Casualty Investigation recommends that operators and skippers of sea-going pleasure craft equip their vessel with an active or passive radar reflector. Passive radar reflectors should be such that they provide the largest possible radar cross section. Their mounting on a vessel should be such that a good return characteristic is achieved.

7.2 Federal Ministry of Transport, Building and Urban Development

The Federal Bureau of Maritime Casualty Investigation recommends that the Federal Ministry of Transport, Building and Urban Development revise the legal bases for the equipping of pleasure craft. The 'Sicherheit auf dem Wasser' brochure published by the Ministry should be improved so that mandatory and recommended equipment in relation to the year the vessel was built is more easily determined.

8 Sources

- Findings of Waterway Police Inspectorate Wismar
- Written statements
- Witness accounts
- Nautical chart, Federal Maritime and Hydrographic Agency (BSH)
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9 Annex

An investigation of the performance of radar reflectors conducted by QinetiQ has been reprinted in the Annex. The reprint is courtesy of the British Marine Accident Investigation Branch (MAIB), which commissioned this test in connection with the investigation of the loss of the sailing yacht OUZO and the death of her three crew members (Report 7/2007).

Report by QinetiQ: “Performance Investigation of Marine Radar Reflectors on the Market”

This study was commissioned by MAIB as a result of the loss of the yacht *Ouzo* (see investigation report www.MAIB.gov.UK). The work, which has been carried out by **QinetiQ, Funtington,** is designed to better inform yachtsmen of the most appropriate choice of radar reflector for their craft from among those currently being produced. The quality of the study has been independently assessed for MAIB by two other experts in the field.

The QinetiQ tests have measured the radar cross section of the reflectors in a controlled environment. While this gives a very good comparison, it is not a comprehensive set of measurements, in that it cannot take into account different radar parameters, clutter, target RCS/range/aspect etc.

There are other studies that have been carried out in the past, the results of which have been widely published in the yachting press and other public fora.

Yachtsmen are offered the following advice:

- You are urged to carefully consider the findings of this study (along with other relevant research and studies) and then to fit the most effective and appropriate radar reflector for your circumstances.
- You may also like to bear in mind that, if fitting a passive reflector, a simple but effective rule might be to fit the largest reflector that your boat can sensibly display.
- Ensure your reflector is properly installed

Finally, it is essential for yachtsmen to be aware that, notwithstanding the type of radar reflector fitted, in certain circumstances their craft may still not be readily visible on ships’ radars and thus they should always navigate with caution.

Performance investigation of marine radar reflectors on the market

Steve Luke
QINETIQ/D&TS/SEA/CR0704527/2.0
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1 Introduction

1.1 General

This report has been written to compare a selection of radar reflector types in terms of their free space radar cross section (RCS) performance. It will allow yachtsmen and small boat owners to make an informed judgement regarding the type and size of reflector to fit in order to have the best chance of being detected by the radar of other ships.

The report describes free space radar cross section (RCS) measurements carried out on 9 radar reflectors and compares the results both graphically and statistically.

The report covers measurements taken at X-Band (9.41GHz) only. SOLAS Chapter 5 requires that all vessels over 300 tonnes carry an X Band radar and all ships over 3000 tonnes to also carry an S Band radar as well. All commercial shipping should be at least using X Band radar. For this reason all of the reflectors available are designed to operate at X Band. It should be noted however that passive reflectors will offer some performance at other frequencies including S Band. All the testing and the modelling presented in this report has been performed at X Band.

To assist with quantifying the performance the results have been compared to the RCS performance aspects of ISO8729 [1] and to its draft replacement [2], this was carried over a limited set of elevation angles. ISO8729 also covers environmental testing of radar reflectors which has not been covered by this report.

This report also includes a brief section dealing with radar propagation effects of target detection at sea relating to a commercial vessels ability to detect radar reflector of various sizes (RCS) carried by a yacht.

1.2 Effect of RCS on the probability of detection

Computer modelling of radar detection in an overwater environment was carried out to demonstrate the effect of altering a radar reflectors RCS will do to its probability of being detected on a typical navigational radar as fitted to SOLAS vessels and highlight the importance of a radar reflector with good performance.

The predictions were made using QinetiQ's naval electromagnetic environment simulation suite (NEMESiS). NEMESiS is an advanced propagation tool that simulates how microwave energy propagates through the atmosphere and interacts with the terrain.

These predictions are only valid for the specific case shown below; different radar antenna heights, sea conditions and target heights will affect the probability of detection against ranges shown.

Table 1 shows the modelling parameters for the radar.

Parameter	X-Band radar
Peak power (kW)	25
Pulse Duration (μs)	0.75
Transmit gain (dB)	26
Receive gain (dB)	26
Noise (W/Hz)	2.006e-20
Loss (dB)	5
Polarisation	HH
Azi Bw (deg)	2
Radar	Bridgemaster
CFAR	0.0001
Antenna height (m)	30

Table 1 Modelled radar parameters

The probability of detection at close ranges deteriorates as the incident sea state increases due to an effect known as sea clutter where radar returns are made by wave crests or other parts of a broken sea surface. These are presented on screen as random returns which can mask the presence of true target reflections. The clutter responses can have a significant RCS but do not have any consistency of location so modern radar does have anti clutter techniques to improve discrimination but these will always work better if the true target has an RCS above a certain threshold.

The parameters shown in table 2 were used to model the reflector and the seas state for this scenario.

Parameter	Value
Target RCS (m^2)	$1m^2$, $2m^2$, $4m^2$ & $10m^2$
Target height (m)	4m
Swerling	1
Wind speed (knots)	16
Land clutter	Necaps
Sea Clutter	GIT [3]

Table 2 Modelled target and scenario parameters

The Naval Environmental Clutter, Attenuation and Propagation Specification (NECAPS) describes a 5ft swell as a moderate to rough sea state, which is created by a wind speed of approximately 16 knots. This parameter has been used to simulate the 5ft swell in the model.

Figure 1 shows the results of this modelling. It is generally accepted that a competent radar operator will recognise a true target (as apposed to clutter returns) if it paints in the same place for at least 5 out of 10 radar scans (50% paint). This definition of detection is also used by an ARPA (automatic radar plotting aid) to both detect and maintain track of a target.

The graph in figure 1 shows the effects of the clutter field as the highly variable response to each target RCS in the region up to 4nm, this is actually caused by both clutter and multipath (another phenomena of overwater propagation), further explanation can be found in ref [4].

The modelling shows that when using a radar reflector with an RCS of 1m^2, 50% probability of detection is only achieved between 2.6 and 3.1nm and again between 4.6 to 9.1nm. More importantly it clearly illustrates the beneficial effects of increased RCS and consistency of return, particularly at close range.

For radar reflectors with an RCS of 2m^2 and above the probability of being tracked inside 2nm increases significantly.

With a radar reflector of RCS of at least 4m^2 50% probability of detection is achieved beyond 10nm from 4.5nm.

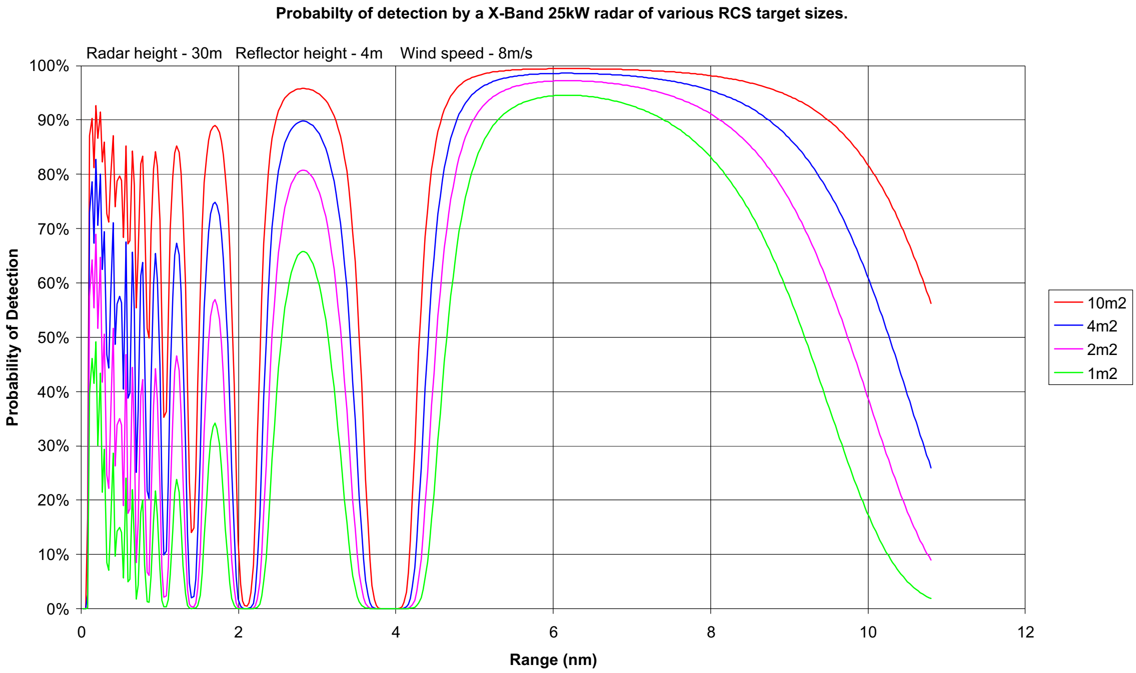

Figure 1 Plot showing the probability of detection when tracking targets of different RCS vs. range.

2 Description of Test

2.1 Items for test

9 reflectors were chosen for the testing and comparison to represent a cross section of radar reflectors available in the UK. These reflectors were generally sourced from local chandlers and offer a typical performance. Where it was difficult to source a reflector, data has been taken from a previous MCA report produced in 2003 and the results used for comparison.

These targets are described in the table below, table 3, and the following sections;

Reflector	**Dimensions**	**Weight**	**Price**
Plastimo 16" Octahedral	300 x 300 x 415mm	0.65kg	£16
Plastimo 4" Tube	590 (L) x 100mm (D)	0.9kg	£40
Davis Echomaster	320mm diameter		£60
Viking Large Tri-Lens	160 x 160 x 80mm	5.5kg	£300
Viking Standard Tri-Lens	120 x 120 x 60mm	2.5kg	£130
Echomax 230	610 (L) x 248mm (D)	2.4kg	£130
Firdell Blipper 210-7	595 (L) x 240mm (D)	1.8kg	£130
Sea-Me	416 (L) x 50mm (D)	0.4kg	£500
POLARef 11	279mm (D)	≈5kg	≈£2000

Table 3 Radar Reflectors supplied for the testing regime.

The data presented above was sourced from manufacturers and chandlers websites; the prices should be taken as approximate at the time of report issue.

2.1.1 Plastimo 16” octahedral reflector

Plastimo 16” is a push fit octahedral reflector constructed from three aluminium diamonds slotted together, these panels are locked in placed by plastic corners pieces. This reflector only had mounting holes for an upright position (not the generally recommended “catch rain” position). The Plastimo 16” Octahedral reflector is pictured in this mounting position in figure 2.

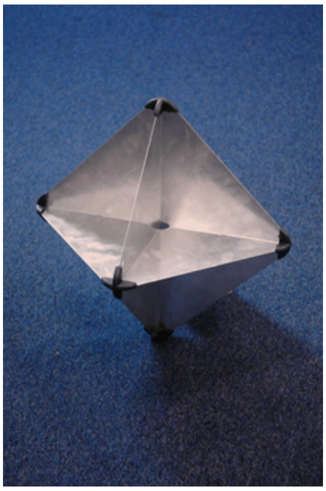

Figure 2 Photo of the Plastimo 16” Octahedral reflector

2.1.2 4” Plastimo tube reflector

4” tube is the larger of the two tube reflectors currently on the market; it consists of an array of dihedrals stacked in the vertical plane which are encompassed within a clear plastic body. Manufacturers instructions show it vertically mounted. A Plastimo tube reflector is shown in figure 3.

Figure 3 Photo of the Plastimo Tube reflector.

2.1.3 Davis Echomaster

The Davis Echomaster is a push fit octahedral reflector constructed from three aluminium circular panels which are slotted together, these panels are locked in placed by plastic corners pieces. This octahedral is designed to be mounted in the catch rain position, and is shown below in this position in figure 4.

Figure 4 Davis Echomaster radar reflector

2.1.4 Viking Large Tri-Lens

The Viking Large Tri-Lens is the largest of the Viking (also marketed as Rozendal) Tri-Lens range of radar reflectors, it uses three luneberg type lens reflectors spaced 120° apart and is encompassed by a moulded plastic case. At 5.5kg it is the heaviest reflector currently on the market. The large Tri-lens is pictured below in figure 5.

Figure 5 Photo of the Large Tri-Lens reflector

2.1.5 Viking Standard Tri-Lens

The Viking Standard Tri-Lens is the medium sized Tri-Lens, it utilises three luneberg type lens reflectors spaced 120° apart and is encompassed by a moulded plastic case. The Standard Tri-lens is pictured below in figure 6.

Figure 6 Photo of the standard Tri-Lens.

2.1.6 Echomax 230

The Echomax 230 reflector comprises a vertical stack of three aluminium corner arrays enclosed in a plastic case. It relies upon interactions between each of the arrays to produce large peak responses. This reflector is only one supplied which has been type approved to ISO8729 [1]. The Echomax 230 reflector is pictured in figure 7.

Figure 7 Photo of Echomax 230 reflector

2.1.7 Firdell Blipper 210-7

The Firdell Blipper is outwardly of a similar design to that of the Echomax 230 but it uses a vertical spiral array of 7 corners. It relies upon interactions between each of the corners to produce large peak responses. The reflector is encompassed within a plastic case. The Blipper 210-7 reflector is pictured in figure 8.

Figure 8 Photo of a Firdell 210-7 reflector

2.1.8 Sea-me Radar Target Enhancer (RTE)

The Sea-me RTE is an active system, which receives a radar pulse, amplifies it and re-transmits it. It contains a receive antenna, amplifier and transmit antenna contained within a plastic case/radome. This transponder will only perform against X-Band radars; unlike the passive reflectors it will not offer any performance in S-Band. The Sea-me RTE is shown below in figure 9.

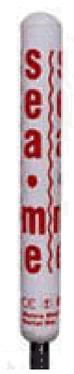

Figure 9 Photograph of the Sea-me RTE.

2.1.9 POLARef 11 radar reflector

The POLARef 11 reflector is a precision radar target generally used for the calibration of radars. It is a luneberg lens which operates over its complete azimuth range. This reflector is usually made to order but has been included as a baseline to demonstrate what is achievable from a passive reflector. The POLARef 11 reflector is shown in figure 11.

Figure 10 Photograph of the POLARef 11 reflector.

2.2 Measurement set-up

2.2.1 Anechoic chamber

RCS measurements were carried out on the radar reflectors in the anechoic chamber at QinetiQ Funtington (figure 11). The chamber is a 15m long, 6m wide and 5m high screened room clad with radar absorbent material (RAM). The radar transmit and receive horns are mounted side by side and are positioned in the middle of the wall at one end of the chamber. At the other end, the reflector is positioned at the same height as the horns on a radar invisible mount (polystyrene cone) fitted to an azimuth-over-elevation positioner which is screened by a small RAM wall.

The facility uses a HP8530 vector network analyser with a HP8511A frequency converter unit as the calibrated radar. The system is computer controlled and the positioner data is synchronised with the measured RCS, which is plotted in real time. The RCS system is calibrated using a 300mm-diameter sphere with an RCS of $0.039m^2$. The background clutter from the chamber is removed using an automated background subtraction method measured when the chamber is empty.

The equipment used for these measurements are calibrated annually, they were last calibrated on the 7^{th} of August 2006. Within this facility, over this frequency range, RCS measurements can be made to an accuracy of $\pm 0.5dB$.

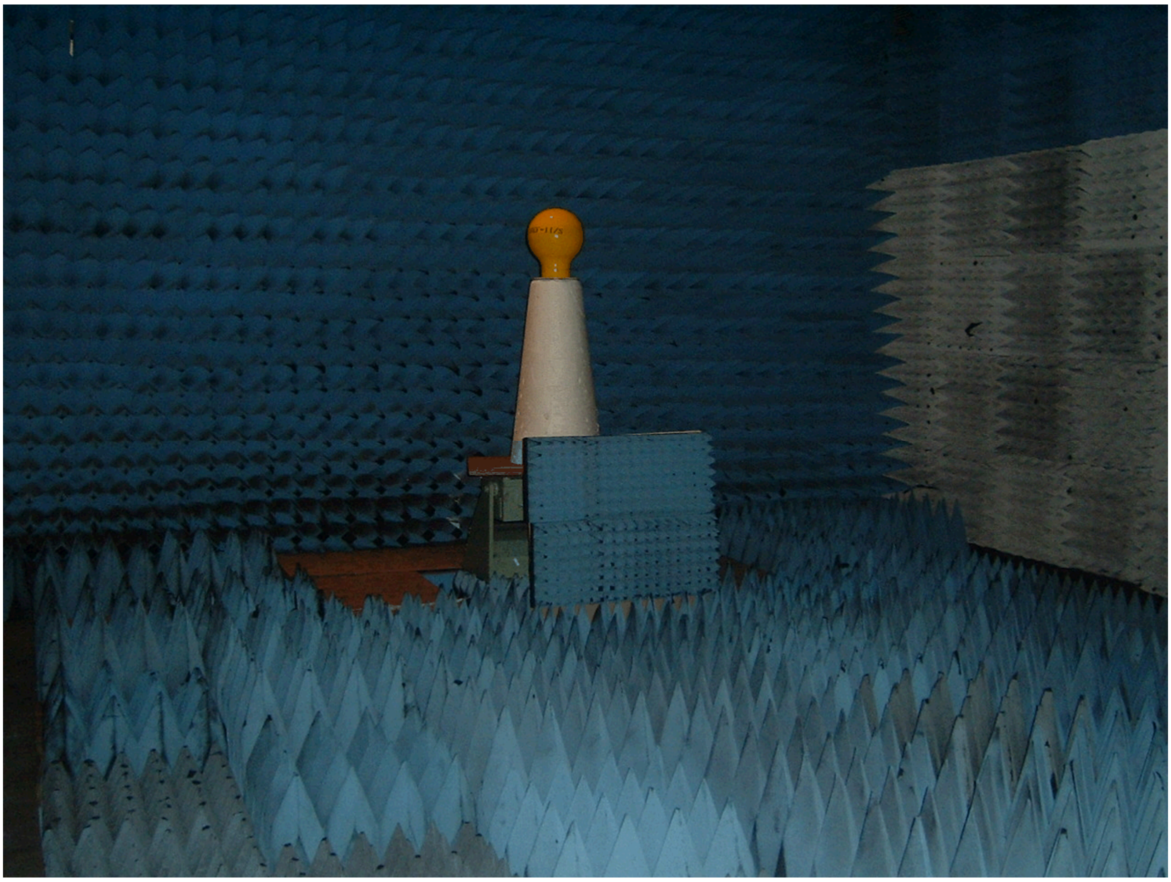

Figure 11 Picture of a POLARef in the Anechoic Chamber at QinetiQ Funtington

2.3 Test matrix

The typical test parameters used for this measurement program were;

- Azimuth angles = 0˚ to 360˚ recorded every 1˚
- Frequency = 9.41GHz (centre of maritime X-Band frequency band)
- Polarisation = Horizontal
- Elevation angles = minimum of 0˚, 5˚, 10˚ & 15˚

For the stacked array radar reflectors (Echomax and Firdell) additional tests were carried out over ±3° in accordance with ISO8729[1], this data was combined to produce the 0° plot.

3 Description of Results

3.1 General

In order to compare the reflectors, azimuth RCS measurements were taken over a number of elevation angles. Based on these measurements, RCS graphs and statistics have been produced showing:

- maximum RCS in m^2
- average RCS in m^2
- total angle above $2.5m^2$ (at 0˚ elevation ISO8729 [2] requires this to be >240˚)
- total angle above $0.625m^2$ (for all other elevation angles, ISO8729 [2] requires this to be >240˚)
- Stated performance level – this is the lowest level which a 10˚ null width occurs (for the replacement [3] to ISO 8729 this is required to be $>7.5m^2$ up to 10˚ elevation for motor cruisers and sailing vessels such as catamarans which are designed for small angles of heel and 20˚ elevation for all other sailing vessels)

These statistics are based around the performance requirements of the current ISO8729 specification [1] and the future ISO 8729 Ed. 2. The draft revision is based on IMO Resolution MSC.164(78) which provides the concept and level for the Stated Performance Level (SPL) [2].

3.2 Plastimo 16" Octahedral reflector

The RCS of the Plastimo 16" radar reflector over the elevation angles 0˚, 5˚, 10˚, 15˚ & 20˚ is shown in figures 12 and 13 below. They show the RCS of the reflector when mounted in the upright and the catch rain positions.

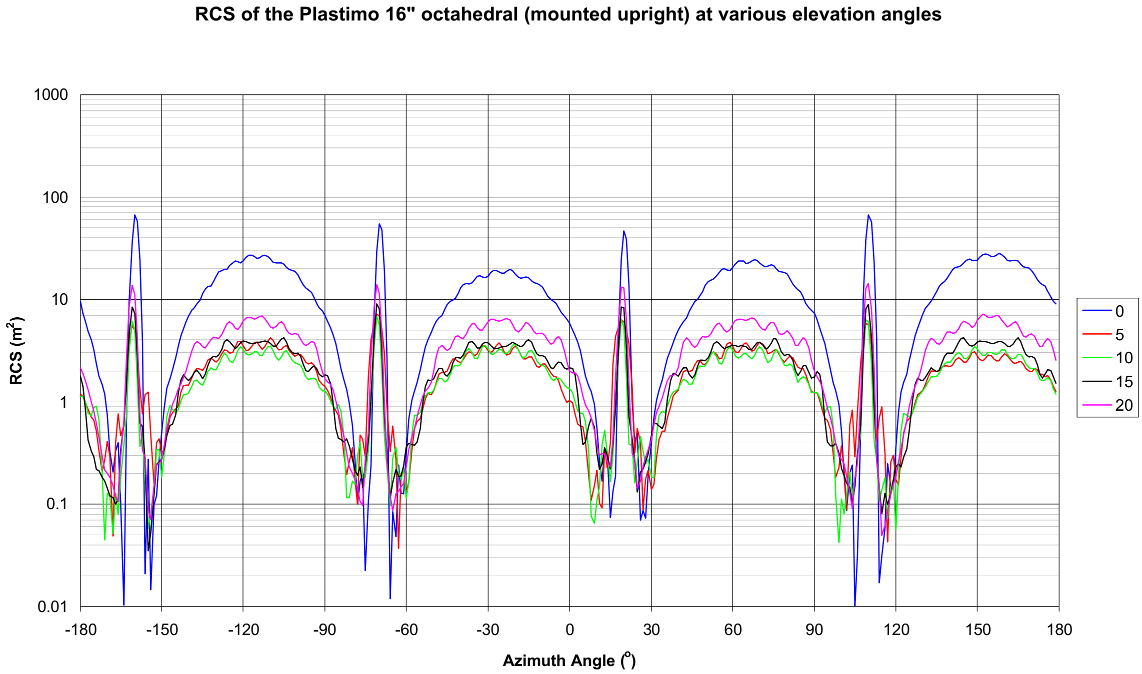

Figure 12 Plot of linear RCS of the Plastimo 16" Octahedral reflector when mounted in the upright position.

In the upright position (as designed) the peaks are very large for a small reflector and reach an RCS of $66m^2$ at 0˚ elevation and the shape is very regular. The drawback with this reflector mounted in this fashion is the very large nulls between the peaks. At 0˚ elevation the stated performance level (taken from table 4) is $1.29m^2$, this value gets worse as the elevation angle is increased.

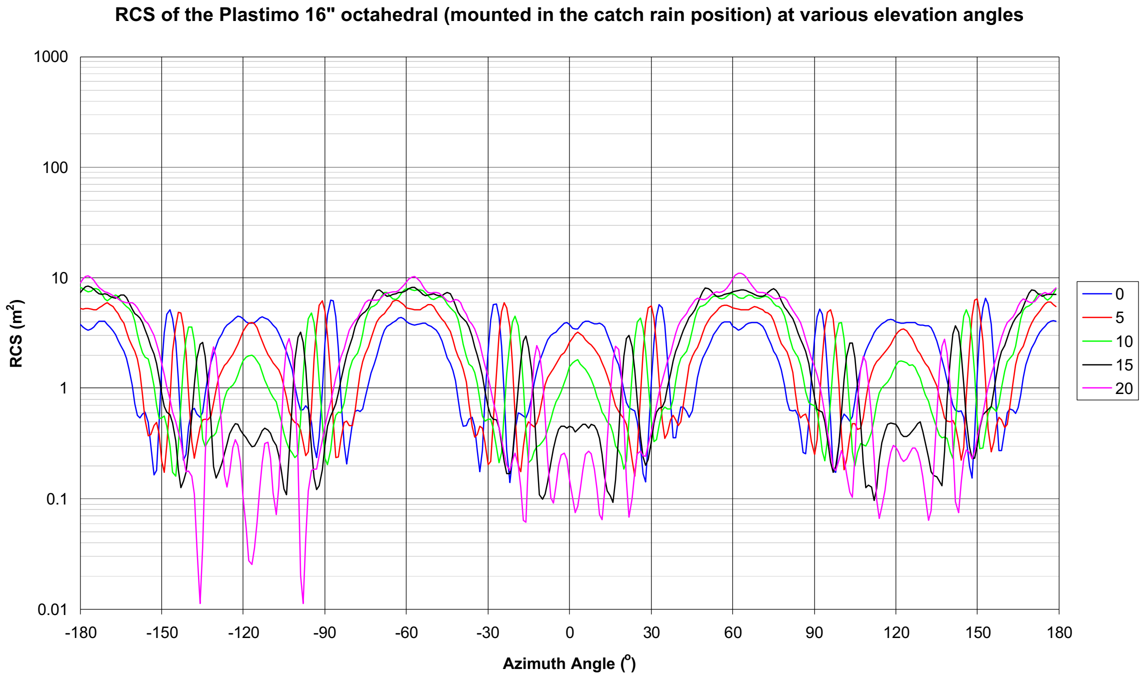

Figure 13 Plot of linear RCS of the Plastimo 16" Octahedral reflector when mounted in the catch rain position.

When in the catch rain position the RCS has lower peaks but is more balanced with azimuth angle variation, it has six peaks each having an RCS of 4m^2 at 0° elevation. As the elevation angle increases it is noticeable that three of the six lobes increase in RCS to 10m^2, whereas the other three decrease to levels around 0.5m^2. The average RCS is more consistent over the elevation range in the catch rain position.

Reflector	Elevation Angle	Maximum RCS (m^2)	Average RCS (m^2)	Total angle > 2.5m^2	Total angle > 0.625m^2	Stated Performance Level (m^2)
Plastimo 16 inch Octahedral	0	66.76	11.92	264	302	1.29
Plastimo 16 inch Octahedral	5	25.53	1.97	132	280	0.54
Plastimo 16 inch Octahedral	10	7.17	1.75	117	277	0.47
Plastimo 16 inch Octahedral	15	4.40	2.17	153	258	0.30
Plastimo 16 inch Octahedral	20	6.79	3.41	212	280	0.47
Plastimo 16 inch Octahedral in catch rain position	0	6.50	2.32	171	279	0.81
Plastimo 16 inch Octahedral in catch rain position	5	6.38	2.44	148	258	0.82
Plastimo 16 inch Octahedral in catch rain position	10	8.15	2.77	138	263	0.61
Plastimo 16 inch Octahedral in catch rain position	15	8.42	2.87	149	215	0.43
Plastimo 16 inch Octahedral in catch rain position	20	11.07	3.07	152	214	0.26

Table 4 Statistics of the Plastimo 16" Octahedral reflector in its 2 mounting positions.

3.3 Plastimo 4" Tube reflector

The RCS of the Plastimo tube radar reflector over the elevation angles 0˚, 1˚, 5˚, 10˚ & 15˚ is shown in figure 14. At 0˚ the RCS response looks fair with 8 lobes achieving between 6m^2 and 9m^2, but as soon as the reflector is tilted even to as little as 1˚ these maxima fall away to levels of between 0.4^2 and 4m^2. As the elevation angle increases the performance degrades even more, at 5˚ and 10˚ the stated performance level is 0.03m^2 and there is only 1˚ of azimuth where both plots exceed 0.625m^2. The statistics for the Plastimo 4" Tube reflector are shown in table 5.

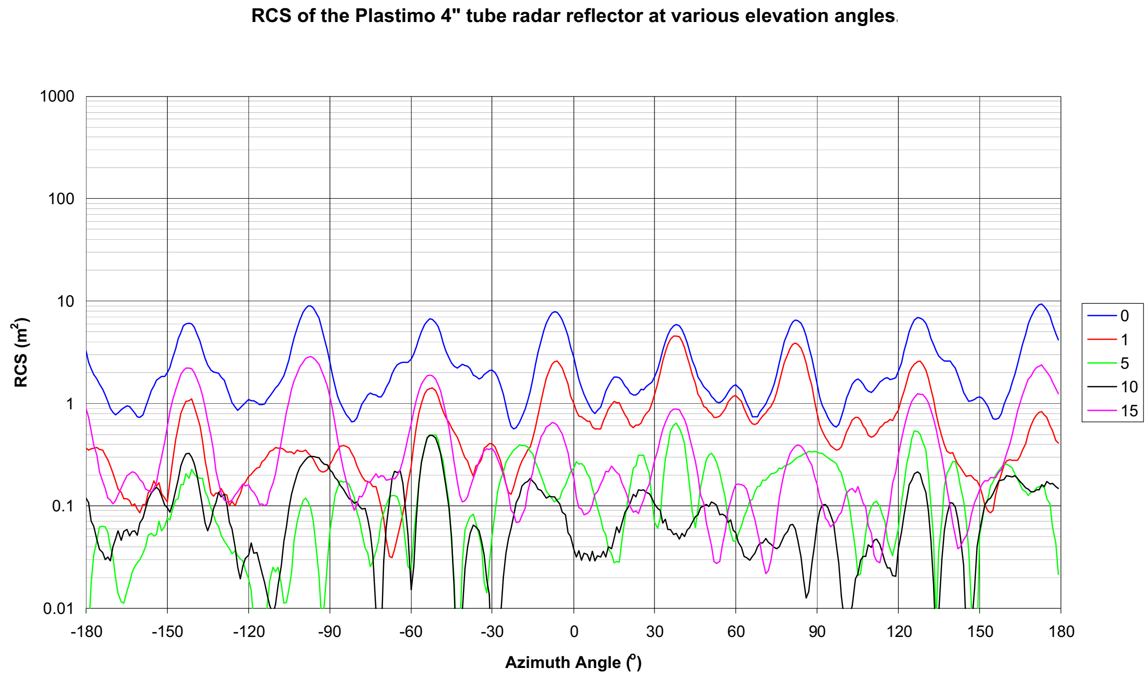

Figure 14 Plot of linear RCS of the Plastimo 4" Tube.

Reflector	Elevation Angle	Maximum RCS (m^2)	Average RCS (m^2)	Total angle > 2.5m^2	Total angle > 0.625m^2	Stated Performance Level (m^2)
Plastimo 4 inch Tube	0	9.30	2.62	121	354	0.95
Plastimo 4 inch Tube	1	4.58	0.76	22	144	0.12
Plastimo 4 inch Tube	5	0.64	0.15	0	1	0.03
Plastimo 4 inch Tube	10	0.49	0.10	0	0	0.03
Plastimo 4 inch Tube	15	2.86	0.50	6	88	0.11

Table 5 Statistics of the Plastimo 4" Tube reflector.

3.4 Davis Echomaster Reflector

The RCS of the Davis Echomaster octahedral radar reflector over the elevation angles 0˚, 5˚, 10˚ & 15˚ is shown in figure 15. At 0˚ the RCS response shows 6 lobes achieving between 2.5m^2 and 5m^2. As the reflector is elevated it is noticeable that three of the six lobes increase in RCS to 7m^2, whereas the other three decrease to levels around 0.5m^2. The stated performance level is around 0.4m^2 until the reflector is heeled over to 15˚ where it drops to 0.2m^2. The statistics for the Davis Echomaster are shown in table 6 below

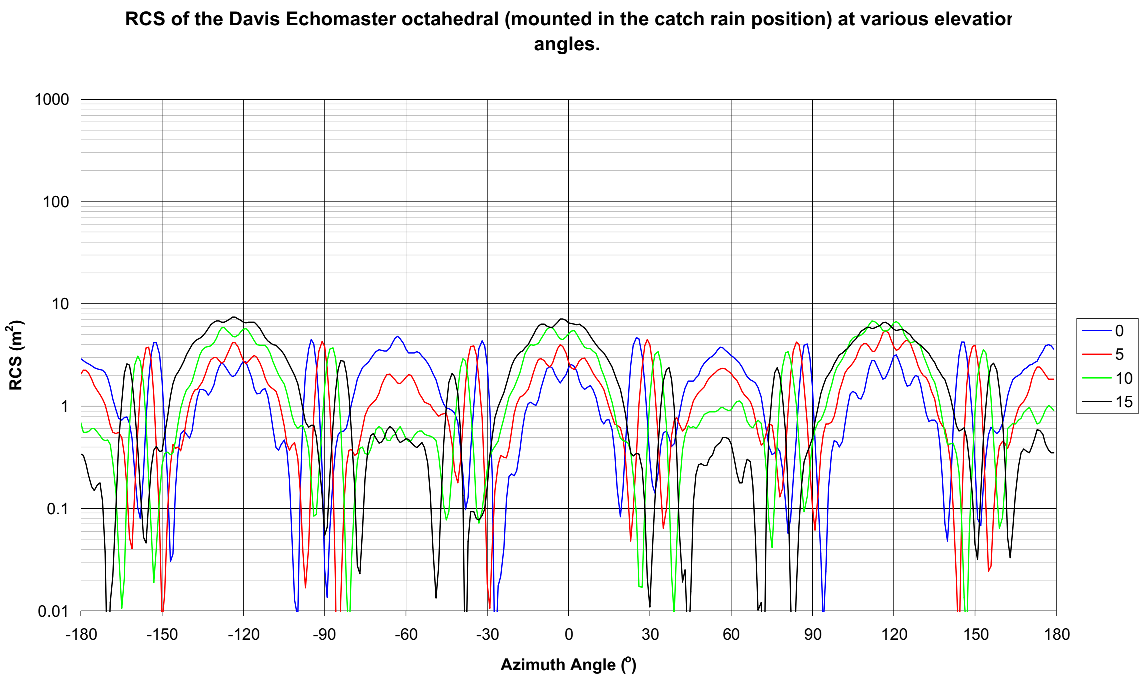

Figure 15 Plot of linear RCS of the Davis Echomaster octahedral radar reflector.

Reflector	Elevation Angle	Maximum RCS (m^2)	Average RCS (m^2)	Total angle > 2.5m^2	Total angle > 0.625m^2	Stated Performance Level (m^2)
Davis Echomaster	0	4.82	1.60	88	252	0.37
Davis Echomaster	5	5.47	1.57	82	252	0.45
Davis Echomaster	10	6.74	1.81	109	223	0.40
Davis Echomaster	15	7.47	2.08	119	193	0.21

Table 6 Statistics of the Davis Echomaster radar reflector.

3.5 Large Tri-Lens Reflector

The RCS of the Large Tri-Lens radar reflector over the elevation angles 0˚, 5˚, 10˚, 15˚ & 20˚ is shown in figure 16. This plot shows the RCS to be consistent with elevation, there are three very wide lobes with an RCS of between 8m^2 and 9m^2.

The average RCS and stated performance level are both high around 5m^2 and 4m^2 respectively also the reflector has most of its returns over 2.5m^2. The statistics are shown in table 7.

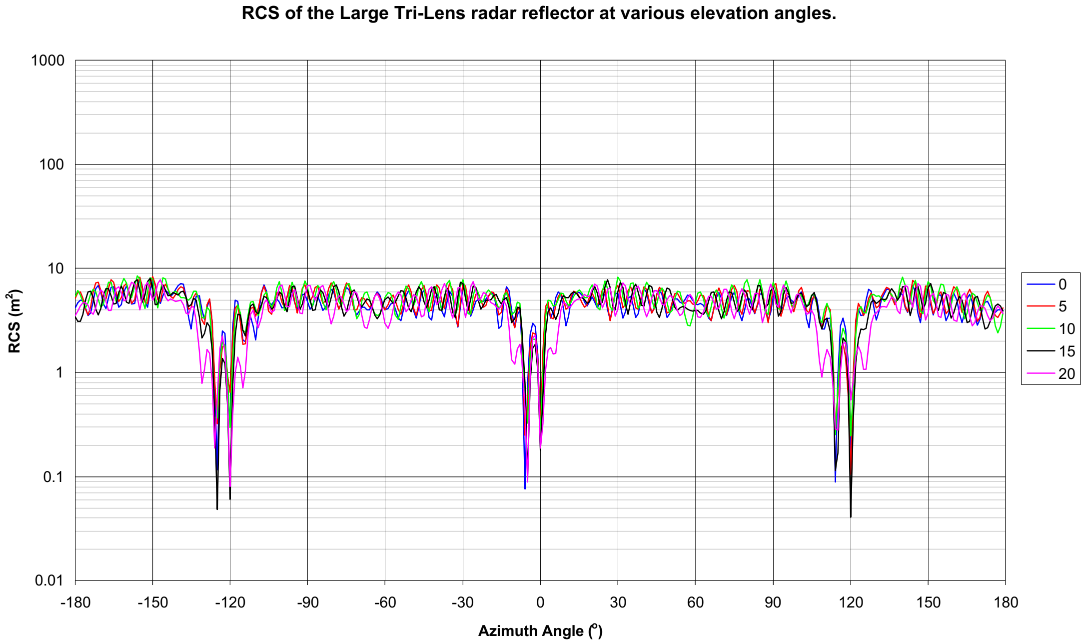

Figure 16 RCS of the Large Tri-Lens radar reflector.

Reflector	Elevation Angle	Maximum RCS (m^2)	Average RCS (m^2)	Total angle > 2.5m^2	Total angle > 0.625m^2	Stated Performance Level (m^2)
Large Tri Lens	0	7.94	4.49	338	354	3.36
Large Tri Lens	5	8.42	4.81	332	353	4.04
Large Tri Lens	10	8.53	4.97	331	352	3.72
Large Tri Lens	15	8.00	4.59	326	349	2.16
Large Tri Lens	20	7.85	4.26	300	348	1.95

Table 7 Statistics of the Large Tri-Lens radar reflector

3.6 Standard Tri-Lens Reflector

The RCS of the Standard Tri-Lens radar over the elevation angles 0˚, 5˚, 10˚, 15˚ & 20˚ is shown in figure 17. The RCS level remains fairly consistent with changes of elevation angle, there are three very wide lobes with an RCS of between 2m^2 and 4m^2.

The average RCS and stated performance level are both high around 2m^2; the reflector has most of its returns over 0.625m^2. The statistics are shown in table 8.

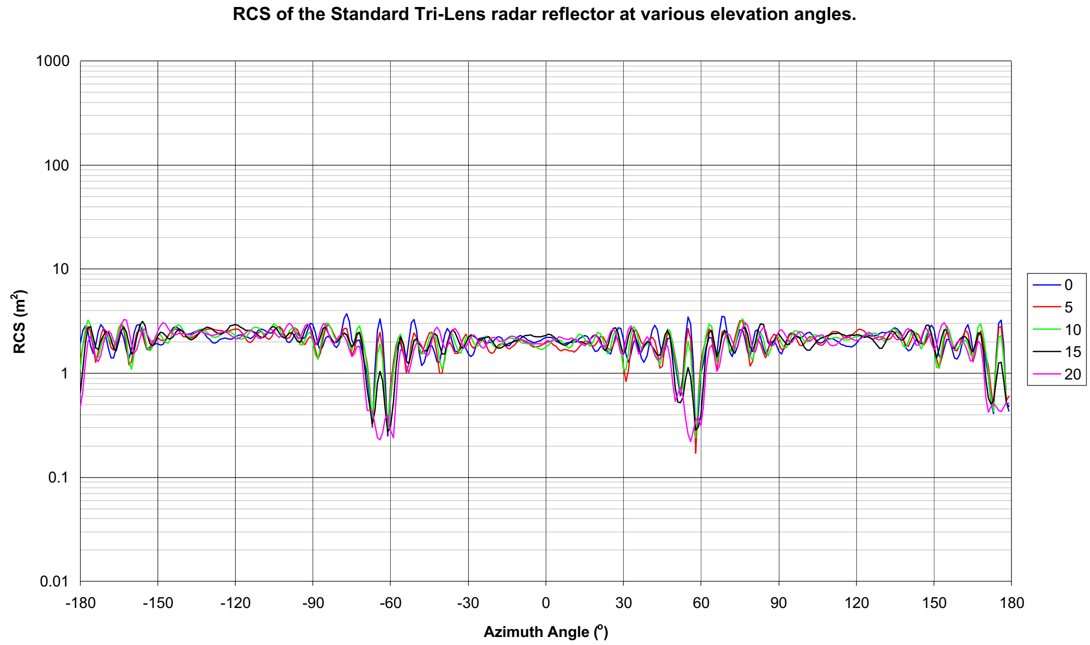

Figure 17 RCS of the Standard Tri-Lens radar reflector.

Reflector	Elevation Angle	Maximum RCS (m^2)	Average RCS (m^2)	Total angle > 2.5m^2	Total angle > 0.625m^2	Stated Performance Level (m^2)
Tri Lens Standard	0	3.76	2.04	63	349	2.13
Tri Lens Standard	5	3.20	2.00	59	352	1.86
Tri Lens Standard	10	3.32	2.03	59	350	1.93
Tri Lens Standard	15	3.15	2.03	59	341	1.04
Tri Lens Standard	20	3.31	1.97	57	327	0.44

Table 8 Statistics of the Standard Tri-Lens radar reflector

3.7 Echomax 230 Reflector

The RCS of the Echomax 230 radar reflector is shown below in figure 18. The plot shows some peaks up to 24m^2, but as the elevation angle increases, gaps appear in the performance of the reflector. These gaps only seem to appear in random areas of the patterns and do not appear as a gradual drop off in performance.

The statistical information on the Echomax 230 reflector shown in table 9.

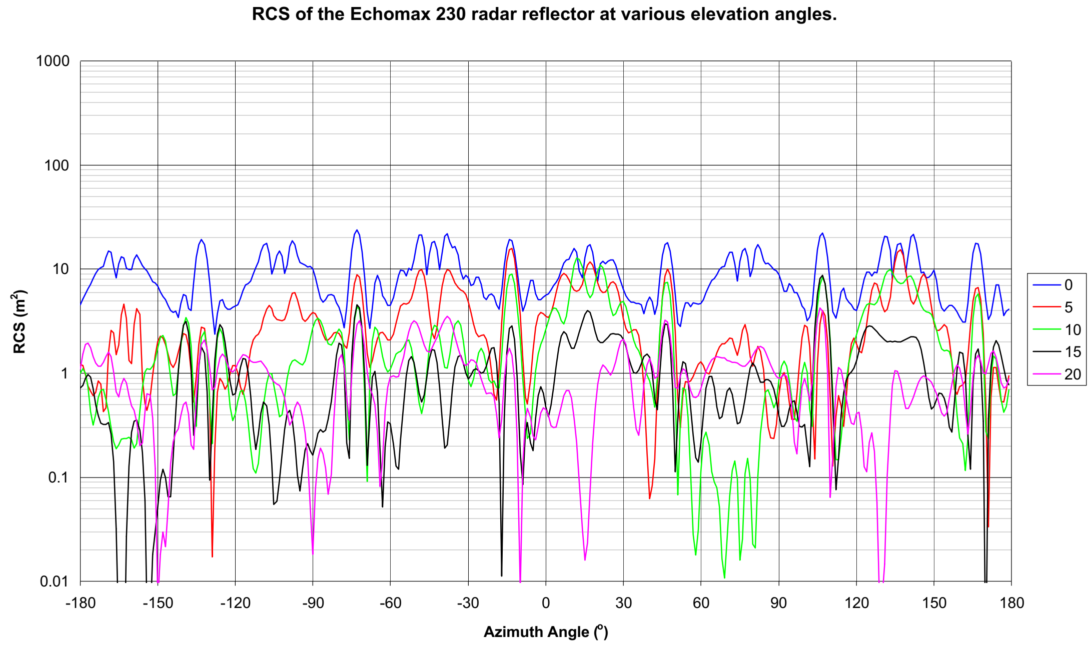

Figure 18 RCS of the Echomax 230 radar reflector.

Reflector	Elevation Angle	Maximum RCS (m^2)	Average RCS (m^2)	Total angle > 2.5m^2	Total angle > 0.625m^2	Stated Performance Level (m^2)
Echomax 230	-20	4.66	0.76	13	159	0.13
Echomax 230	-15	5.97	1.06	38	215	0.33
Echomax 230	-10	7.42	1.49	75	233	0.22
Echomax 230	-5	7.42	1.42	71	175	0.06
Echomax 230	0	23.95	9.29	359	360	4.70
Echomax 230	5	15.81	3.34	163	318	1.01
Echomax 230	10	12.88	2.24	108	254	0.14
Echomax 230	15	8.76	1.11	30	206	0.12
Echomax 230	20	4.25	0.98	21	228	0.27

Table 9 Statistics of the Echomax 230 radar reflector

3.8 Firdell Blipper 210-7 Reflector

Figure 19 below shows the RCS of the Firdell Blipper 210-7 radar reflector over the elevation angles 0˚, 5˚, 10˚, 15° and 20˚. This plot shows a good response at 0˚ with a peak over 11m², but as the elevation angle increases the performance degrades. To demonstrate this the statistics shown in table 10 show that although the maximum RCS stays above 5m² the stated performance level drops to 0.09m² as the reflector elevation angle increases.

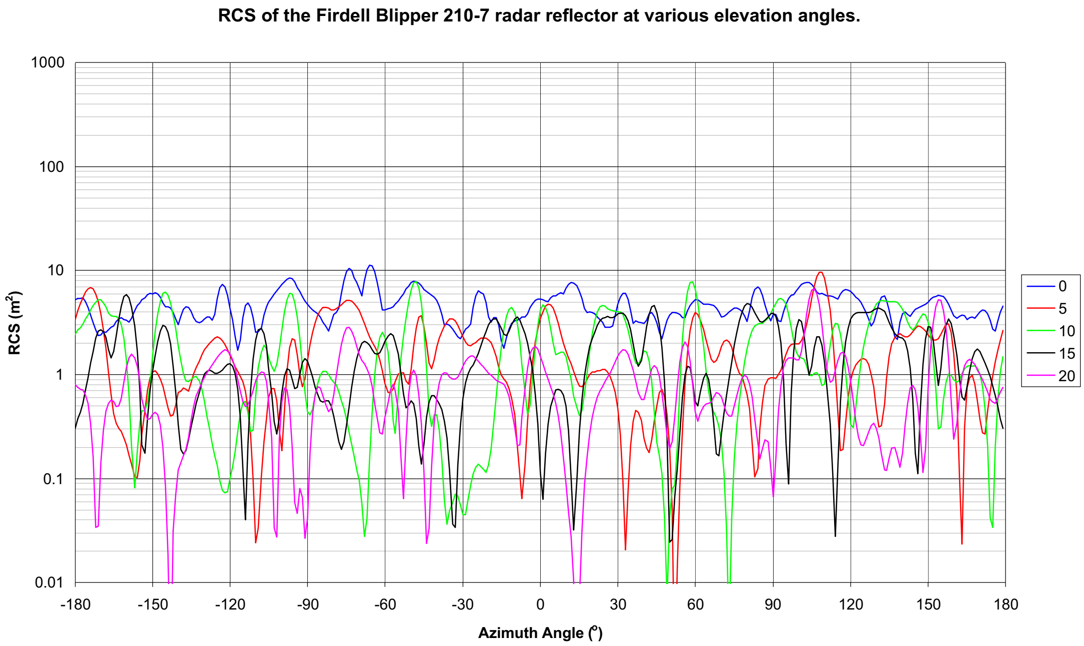

Figure 19 RCS of the Firdell Blipper 210-7 radar reflector.

Reflector	Elevation Angle	Maximum RCS (m²)	Average RCS (m²)	Total angle > 2.5m²	Total angle > 0.625m²	Stated Performance Level (m²)
Firdell Blipper 210	-20	2.81	0.73	5	179	0.24
Firdell Blipper 210	-15	4.46	0.80	16	175	0.11
Firdell Blipper 210	-10	3.44	0.97	36	179	0.13
Firdell Blipper 210	-5	3.62	1.24	52	240	0.14
Firdell Blipper 210-7	0	11.26	4.72	346	360	3.07
Firdell Blipper 210-7	5	9.71	1.78	82	275	0.34
Firdell Blipper 210-7	10	7.86	1.94	119	246	0.09
Firdell Blipper 210-7	15	5.88	1.65	93	259	0.56
Firdell Blipper 210-7	20	6.72	0.90	16	196	0.25

Table 10 Statistics of the Firdell Blipper 210-7 radar reflector

3.9 Sea-me RTE

The RCS of the Sea-Me RTE is shown in figure 20, it shows the peak at elevation angle of 0° is over 300m^2 and the pattern is very smooth with gradual variations in RCS as the reflector is rotated. When the elevation angle is increased the RCS does show degradation although at 15° the RCS is still almost always above 10m^2 which is the required peak for ISO8729 [1]. At 20° the RCS is all above 3.5m^2.

The statistics for this reflector are shown in table 11. The table shows that the Sea-Me RTE doesn't drop below 2.5m^2 at any part of this testing. However, when the elevation angle is increased to 20°, the stated performance level drops below the specified stated performance level for the replacement to ISO8729[2] which is 7.5m^2.

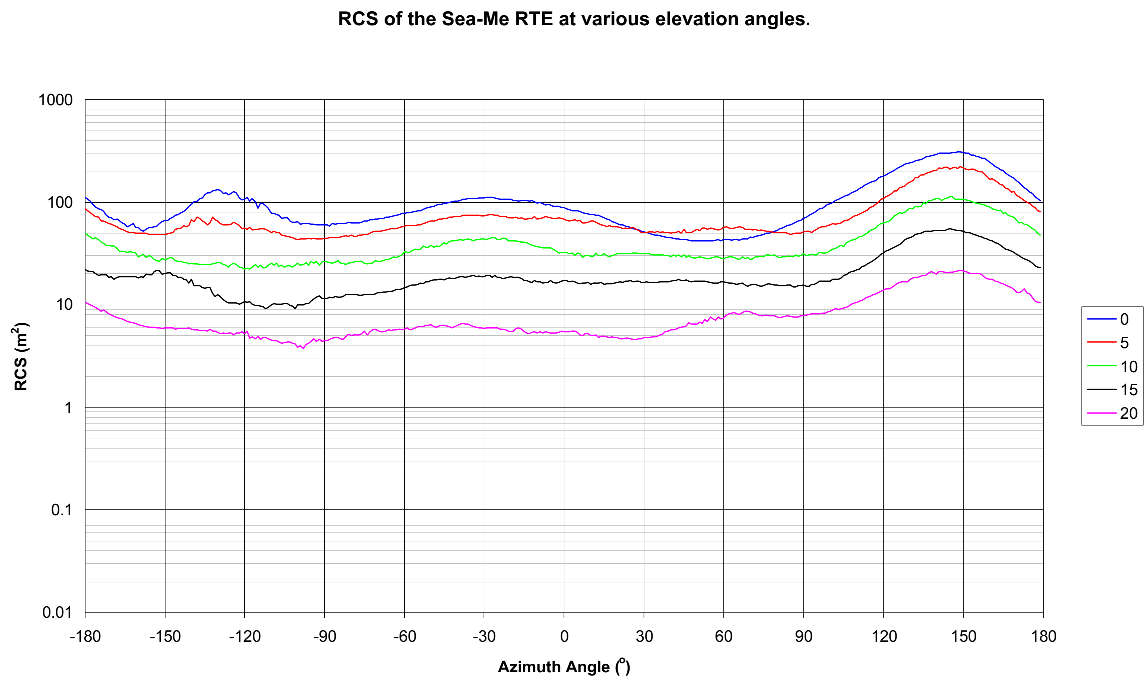

Figure 20 RCS of the Sea-Me RTE.

Reflector	Elevation Angle	Maximum RCS (m^2)	Average RCS (m^2)	Total angle > 2.5m^2	Total angle > 0.625m^2	Stated Performance Level (m^2)
Sea-Me	0	308.27	104.63	360	360	42.57
Sea-Me	5	219.97	76.05	360	360	44.17
Sea-Me	10	112.89	40.92	360	360	24.87
Sea-Me	15	55.16	20.46	360	360	10.15
Sea-Me	20	21.62	8.16	360	360	4.35

Table 11 Statistics for the Sea-Me RTE

3.10 POLARef Reflector

The RCS of the POLARef radar reflector is shown below in figure 21. This chart shows that the RCS of this reflector is both high and consistent with angle. The peak RCS is very close to 10m^2 with the minimum stated performance over all of the elevation angles being greater than 6m^2.

The statistics shown in table 12 highlight the reflectors consistency with a minimum stated performance level of 6m^2.

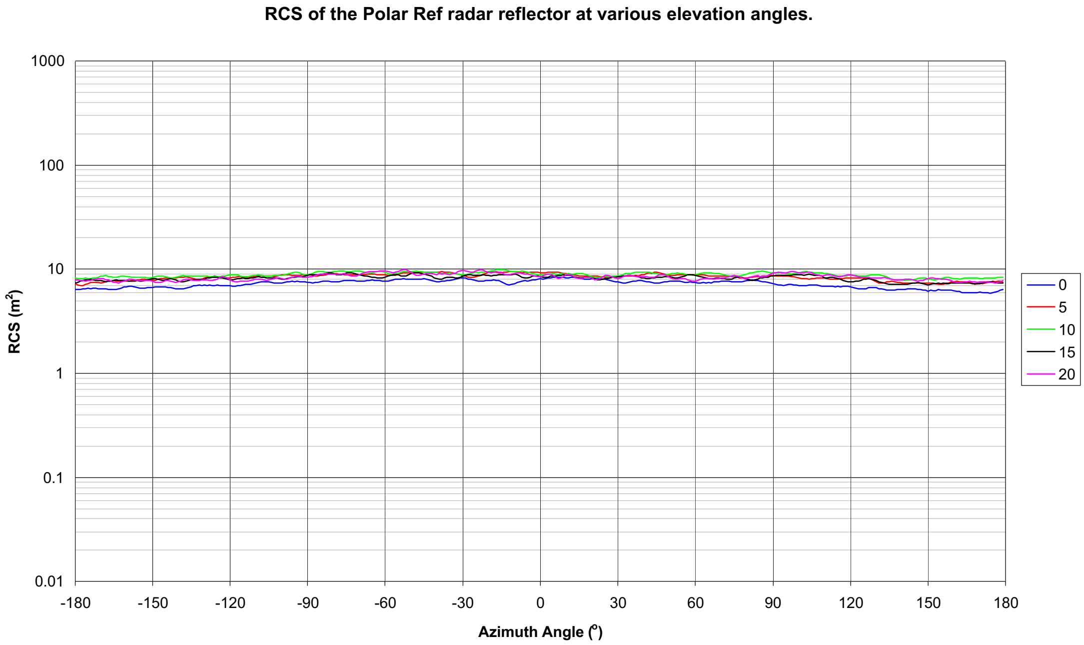

Figure 21 RCS of the POLARef radar reflector.

Reflector	Elevation Angle	Maximum RCS (m^2)	Average RCS (m^2)	Total angle > 2.5m^2	Total angle > 0.625m^2	Stated Performance Level (m^2)
POLARef	0	8.44	7.25	360	360	6.06
POLARef	5	9.50	8.45	360	360	7.42
POLARef	10	9.97	8.87	360	360	8.14
POLARef	15	9.29	8.22	360	360	7.33
POLARef	20	9.92	8.45	360	360	7.62

Table 12 Statistics for the POLARef radar reflector

4 Discussion of Results

4.1 Comparison of reflectors

To enable easy comparison between each of the radar reflectors, graphs have been produced showing the statistical data taken from the tables in section 3. The maximum RCS, average RCS and stated performance level are shown in figures 22 to 24 respectively.

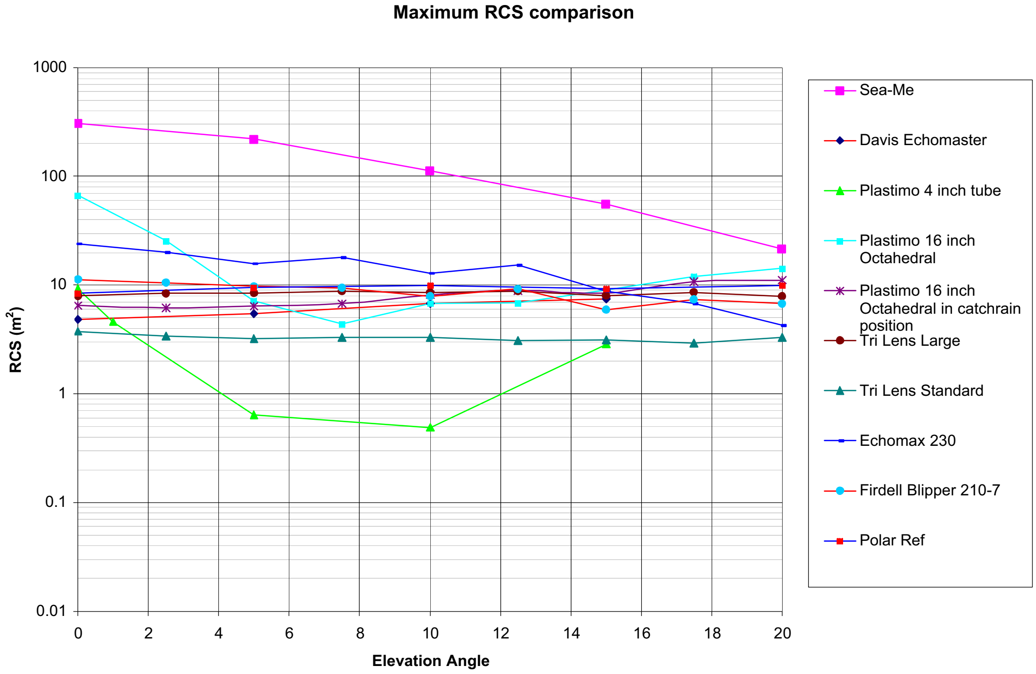

Figure 22 Comparison of each of the radar reflector's maximum RCS level.

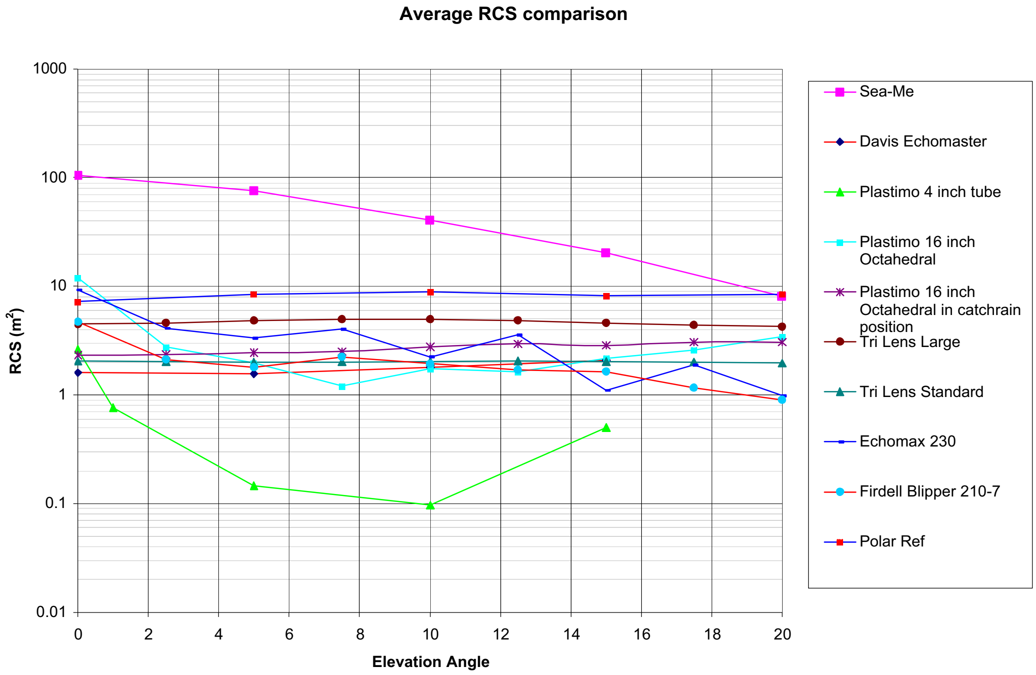

Figure 23 Comparison of each of the radar reflector's average RCS.

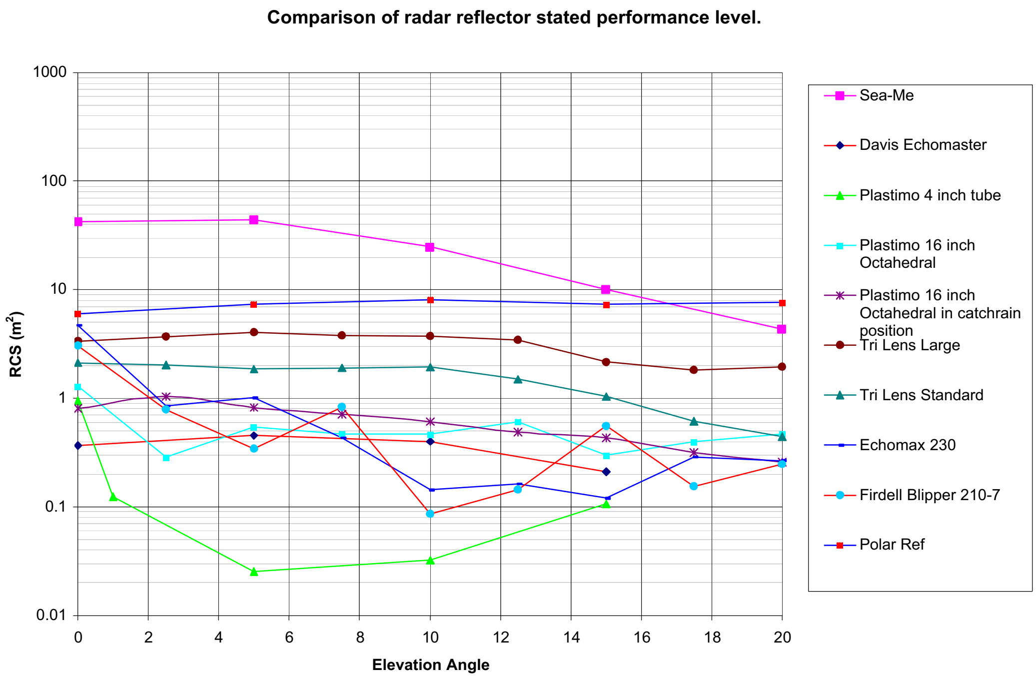

Figure 24 Comparison of each of the radar reflector's stated performance level.

As expected the active Sea-Me outperforms all of its competitors, although at an elevation angle of 20° its stated performance level is exceeded by the POLARef.

The POLARef performs very consistently and is the best performing passive radar reflector with maximums, averages and stated performance levels all falling between $6m^2$ and $10m^2$.

The Large Tri-Lens performs well with a good consistent RCS, it lacks the peak RCS value of some of its competitors at 0° but as the elevation angle increases the Tri-Lens performance doesn't fall away as dramatically as some of the others.

The Echomax 230 shows good peak and average RCS performance compared to its competitors but its stated performance level falls to around 0.2m^2 above an elevation angle of 10°.

The Firdell Blipper 210-7 is slightly down on the Echomax 230 in terms of peak and average RCS performance but has a very similar stated performance level.

The Standard Tri Lens shows average performance. The peak RCS was quite low at 4m^2, but as the elevation angle increased the relative performance of this reflector increased. Above 15° it out performed the Blipper and Echomax in terms of average RCS.

The Plastimo 16" octahedral has a good peak and average performance when mounted in its upright position although the large nulls shown in its azimuth patterns (figure 11) bring the stated performance level down. In the catch rain position the reflector is more consistent but has a lower peak RCS.

The Davis Echomaster performed least well out of the octahedrals, it had a peak RCS of 7.5m^2, but its average RCS and stated performance levels were only 2m^2 and 0.45m^2 respectively.

The 4" Tube reflector performed very poorly especially beyond 1° and is well behind the others in performance having an average RCS of approximately 0.1m^2 at 5° and 10°.

4.2 General summary of results

The Sea-Me RTE has a peak RCS that is very high in comparison to the passive reflectors described in this report. On the basis of these results it is the only reflector tested that would fully satisfy the performance requirements of ISO8729 [1] and the proposed specification for ISO8729 Ed.2 [2] (only up to an elevation angle of 10° or Category 1).

The POLARef reflector narrowly fails the current and future ISO8729 specifications [1] [2] having a peak RCS of 8.44m^2 at 0° elevation. Although the performance is exceptionally good having a very consistent RCS over the elevation angles tested.

The Large Tri-Lens performs consistently over the elevation angles tested with very little variation in its peak and average RCS, its stated performance level is between 1.95m^2 and 4.04m^2 at all elevation angles tested.

The Echomax 230 demonstrates good peak and average RCS performance compared to its competitors but its stated performance level drops significantly beyond an elevation angle of 5°. The Echomax 230 tested fails to meet the total angle >0.625m^2 aspect of ISO8729 [1].

The Firdell Blipper 210-7 peak RCS figures are good but the average and stated performance levels reduce when the reflector goes past an elevation angle of 5°. The Firdell Blipper 210-7 tested fails to meet the total angle >0.625m^2 aspect of ISO8729 [1] at -10 and 15° elevation

The Standard Tri Lens performs similarly to the Large Tri-Lens although the peak RCS is low at about 3.75m^2. It is very consistent up to an elevation angle of 20° with the average RCS only varying by 0.07m^2.

The Plastimo 16" octahedral has a good peak and average performance when mounted in its upright position although the large nulls (>12° wide at 2.5m^2 at 0°

elevation) shown in its azimuth patterns (figure 11) bring the stated performance level down. In the catch rain position the reflector is more consistent although it has a lower peak RCS. It fails to meet ISO8729[1] in both orientations due to it null widths at 0˚ and the total angle >0.625m^2.

The Davis Echomaster has a reasonable peak and average RCS but is too small to meet the performance requirements of ISO 8729[1].

The 4" Tube reflector had a good peak RCS of 9.3m^2 at 0˚. However, as the elevation angle increased the RCS rapidly decreased. Even at 1˚ the stated performance level had dropped to 0.12m^2.

5 Conclusions

The following is concluded;

- The Sea-Me is a good example of an active reflector (RTE) exceeding the requirements of the current and future ISO 8729 at heel/elevation angles of up to 15˚, it is also very small and light. Drawbacks are that it requires power to operate (which on a yacht is at a premium), it will only operate at X-Band and will offer no performance at S-Band.
- The POLARef shows excellence is possible but at a price, technically it just fails meet current ISO8729 [1] or its replacement [2]. The main drawbacks are it is very costly at £2000 and its quite heavy at around 5kg. It is currently used as a radar measurement standard although it could possibly be re-engineering for commercial production which could reduce the price.
- The Large Tri-Lens performs well especially at larger angles of heel and elevation, it just falls short of ISO8729 [1] having a peak RCS of 8.5m^2 but otherwise performs well. It is the heaviest reflector supplied for test at 5.5kg and costs around £300.
- The Echomax 230 narrowly failed to meet ISO8729 during this testing, but showed good peak and average RCS performance. The reflector is reasonably priced at £130 and weighs 2.4kg; the main drawback was a RCS drop-off above an elevation angle of 10˚.
- The Firdell Blipper 210-7 narrowly failed to meet ISO8729 during this testing, but showed good peak and average RCS performance. The Blipper is priced at £130 and weighs 1.8kg; the main drawback was a RCS drop-off above an elevation angle of 10˚.
- The Standard Tri Lens does not meet ISO8729 as the peak RCS was too low at 4m^2. However its consistent RCS response outperformed most of the other reflectors when heeled over beyond 10˚; it is reasonably priced at £130 and weighs 2.5kg.
- The Plastimo 16" octahedral is inexpensive at £16 and lightweight at 0.65kg but failed to meet ISO8729 in either tested position. It had reasonable peak and average performance averaging around 2m^2 but had wide nulls which kept its stated performance level down. Other drawbacks are that its mounting arrangement is by suspension only (often in an unfavourable position) and could be subject to damage.
- The Davis Echomaster failed to get close to ISO8729 during this testing. Its peak RCS is too low at 7.5m^2 and its average performance is only 1.75m^2. This reflector is priced at £60 and is lightweight; it can be mounted on a rod as well as by suspension (in the correct catch-rain position).
- The 4" tube reflector performed very poorly.
- It is concluded that either the active Sea-Me, POLARef and the Standard or Large Tri-Lens radar reflectors are the best reflectors at heel and elevation angles of over 10˚.

6 Recommendations

- Based on the results of this report it is recommended that yachtsmen always fit a radar reflector that offers the largest RCS practicable for their vessel.
- The RCS of the radar reflector should have a minimum consistent RCS of $2m^{2.}$
- The Sea-Me is the recommended product if power is available
- If power is not available then the passive Large Tri-Lens reflector is recommended
- The 4” tube reflector is not considered suitable due to its poor performance. It is also recommended that the 2” tube reflector is not suitable since the performance of this target will be even lower.
- It is recommended that poorly performing radar reflectors are not fitted as it is possible that the user could be lulled into a false sense of security believing that their chances of detection has been enhanced.

7 References

[1] BS EN ISO 8729:1999 - Ships and marine technology. Marine radar reflectors

[2] Future ISO 8729 Ed. 2, currently in draft is based on IMO Resolution MSC.164(78) provides the concept and level for the Stated Performance Level (SPL).

[3] Method for modelling sea surface clutter in complicated propagation environments. IEE proceedings. Volume 137, Issue 2, April 1990 - GD Dockery

[4] Introduction to Radar Systems - second edition– M.I. Skolnik chapter 12.2, 1980

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Abstract This report has been written to compare and contrast a selection of radar reflector types in terms of their radar cross section (RCS) performance. It will inform yachtsman and owners of small craft which reflector has the best performance and therefore which reflector to fit in order to give the best possible chance of being seen on radar by commercial shipping. This task has followed on from investigative work carried out by QinetiQ Funtington into the loss of the yacht Ouzo over the period 20th to the 21st of August 2006.			
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