An Objective Forensic Analysis of the Collision Between *Stockholm* and *Andrea Doria*

By Samuel Halpern

FOREWORD

Mr. Halpern has done an excellent job of documenting the causes of the *Andrea Doria/Stockholm* collision. By careful analysis of the course recorder traces, Mr. Halpern points out the role that the helmsman of the *Stockholm* played in the collision. The analysis of the course recorder traces seems to lay to rest the theory that the wrong radar range scale was used by the 3rd Mate of the *Stockholm* just prior to the collision. In addition, the collision dynamics calculations and "what if" scenarios were also quite interesting in that they illustrate for the reader what might have been. Mr. Halpern's list of contributing factors spell out the major causes of the collision. All in all, this is a very well researched paper that should be part of any *Andrea Doria/Stockholm* collision buff's reading on the subject.

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INTRODUCTION

On the night of July 25, 1956 the eastbound Swedish passenger liner *Stockholm* collided with the westbound Italian luxury liner *Andrea Doria* in what was to be described as the world's first major radar assisted collision at sea. The collision happened approximately 180 nautical miles east of the Ambrose Lightship at 11:11 p.m. local time. The *Andrea Doria* was struck just aft and below the starboard bridge wing and almost immediately took on a severe list of almost 20 degrees to starboard leaving half of her lifeboats unusable. Less than 10 minutes from time she was struck, the *Andrea Doria* transmitted an SOS calling for immediate assistance at Lat. 40° 30' N, Lon. 69° 53' W. The loss of her port-side lifeboats might have resulted in a significant loss of life if not for the relatively rapid response of several nearby ships, and by the relative stability of the fatally wounded luxury liner despite carrying a worsening list throughout the night.[1] Unlike the *Titanic* disaster of 1912, the total loss of life was relatively small. Only 46 passengers from *Andrea Doria* died as a consequence of the collision. A total of 1660 passengers and crew were rescued and survived. On *Stockholm,* five crew members, who were in the area of the bow at the time, also died as result of the collision.

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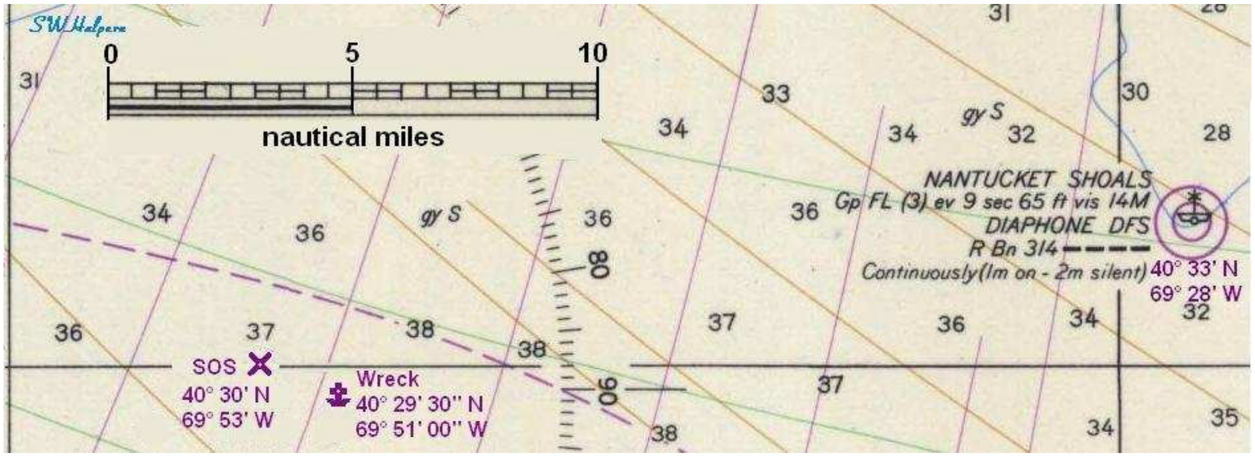
[1] The *Andrea Doria* developed a list of about 18 degrees within minutes of impact. By 10 minutes after impact the list had increased to about 25 degrees. It then took about 10 hours for the list to double to about 50 degrees before the ship started to capsize more rapidly, going from 50 to 90 degrees in half an hour just a few minutes before it disappeared from sight. (Information from a plot of list Vs. time by Capt. Charles Weeks of the Maine Maritime Academy.)



Andrea Doria capsized and sank at 10:09 a.m. the following morning at 40° 29′ 30″ N, 69° 51′ 00″ W, just 17.8 nautical miles west by south of the Nantucket Shoals lightship, having stayed afloat for almost 11 hours after being struck. In comparison, the *Titanic* lasted for only 2 hours and 40 minutes after colliding with an iceberg back in April 1912. The escorted *Stockholm* returned to New York with a severely damaged bow carrying all of her 534 passengers, 208 surviving crewmembers, as well as 545 survivors picked up from *Andrea Doria*. The rest of the survivors from *Andrea Doria* reached New York in other vessels. They included the luxury liner *Ile de France*, the freighter *Cape Ann*, the US Navy transport *Pvt. William H. Thomas*, and the US Navy destroyer escort *Edward H. Allen*.

Many books and papers have been written about the collision and the subsequent rescue over the years. Like many controversial subjects, it is hard to find a truly objective analysis of how this tragic event happened or why it happened. What we know for certain is that both ships were heading in approximately opposite directions towards each other at relatively high speed. The *Andrea Doria* was enveloped in dense fog since around 3 p.m. that afternoon. The *Stockhlom* was mostly in the clear up until the last minute before the collision. Both ships had picked up the other on their respective radars early on, and officers on both vessels monitored the rapid approach of the other vessel until visual contact was established. At that point in time it was too late. There was plenty of time and distance before any visual contact was made for either ship to take positive and decisive action to easily avoid an accident from happening. Yet both ships managed to eventually find themselves in a position where a collision became unavoidable.

So much has been written on the subject that one would think that there is little left to be told. Yet the actual detailed movements of each ship, and the whereabouts of each with respect to the other, remain shrouded in controversy. What we were told happened from those who were there and in charge are conflicting and, for the most part, mutually exclusive. It has been stated that there is no room for compromise. That the testimony of only one of the two men in charge of their respective bridges at the time of collision was correct and the other was incorrect.[2] As we shall see from the forensic evidence, neither was correct.

[2] John C. Carrothers, "The *Andrea Doria–Stockholm* Disaster: Accidents Don't Happen," US Naval Institute Proceedings, August 1971.

In this article I will reexamine the known facts and data that are available to us. I will first examine the claims of those who were responsible for the safe navigation of each vessel that foggy night in July 1956. I will show what each side said they saw on their respective radars and also visually during the minutes leading up to the collision. Using course recorder data taken from both ships, and using the speed that each ship was known to be going at, I will not only show how this terrible accident actually happened, but how it compared to those conflicting claims. I will demonstrate that the details in the stories given by both sides during the pretrial hearings that took place in New York after the accident cannot hold up when the movements of both ships are reconstructed from the available data. Not only will I show where each ship had to be with respect to the other, I will also show how the dynamics of the collision itself affected the movements of both vessels immediately following the impact. In addition, I will quantify the energies involved both before and immediately after the collision, and explain how the change in energies due to the collision itself affected the subsequent movements of each vessel. Finally, I will look at a few "what if" scenarios, and address the question as to why the accident happened by looking at the choices available and the decisions that were taken by both parties involved that led to this terrible accident.

THE EARLY STAGES

Much of what we know about events leading up to the collision comes from testimony given at the pretrial hearings in New York in the months following the disaster. The Italian Liner *Andrea Doria* was on her 101st Atlantic crossing, having departed Genoa on July 17, 1956 under the command of Captain Piero Calamai. By late evening of July 25, the last night of her voyage to New York, *Andrea Doria* was proceeding in fog at a slightly reduced speed of 21.8 knots on a heading of 267° true as she approached the Nantucket Shoals lightship located a little over 45 miles south and east of Nantucket Island. Her fog whistle was sounding 6 second blasts every 100 seconds. Captain Calamai was on the bridge in direct command for most of the time since 3 p.m. that afternoon All preparations for running in fog had been taken. All hydraulically activated watertight doors were closed. A lookout was specifically positioned at the peak of the bow with telephone contact with the bridge, and extra men positioned in the engine rooms and put on standby. Two radar screens were on and monitored. The watch officer on the bridge since 8 p.m. was Senior Second Officer Curzio Franchini who was assisted by Junior Third Officer Eugenio Giannini who manned the Raytheon radarscope.

The Swedish-American Liner *Stockholm* left New York Pier 97 at 11:31 a.m. that same Wednesday, July 25, 1956, on her 103rd eastward crossing under the command of Captain Gunnar Nordenson. She was bound for Gothenburg, Sweden and then on to Copenhagen, Denmark. At 1:32 p.m. the pilot was discharged off Staten Island, and when she passed the Ambrose Channel lightship, her course was set for 090° true, due east, heading toward the Nantucket Shoals lightship. For most eastbound ships, the accepted course from Ambrose would take them to a point 20 miles south of the Nantucket lightship to avoid the heavy traffic converging on that spot heading westbound.[3] The relatively congested waters around Nantucket were known as the "Times Square of the Atlantic." The rationale given by Capt. Nordenson for

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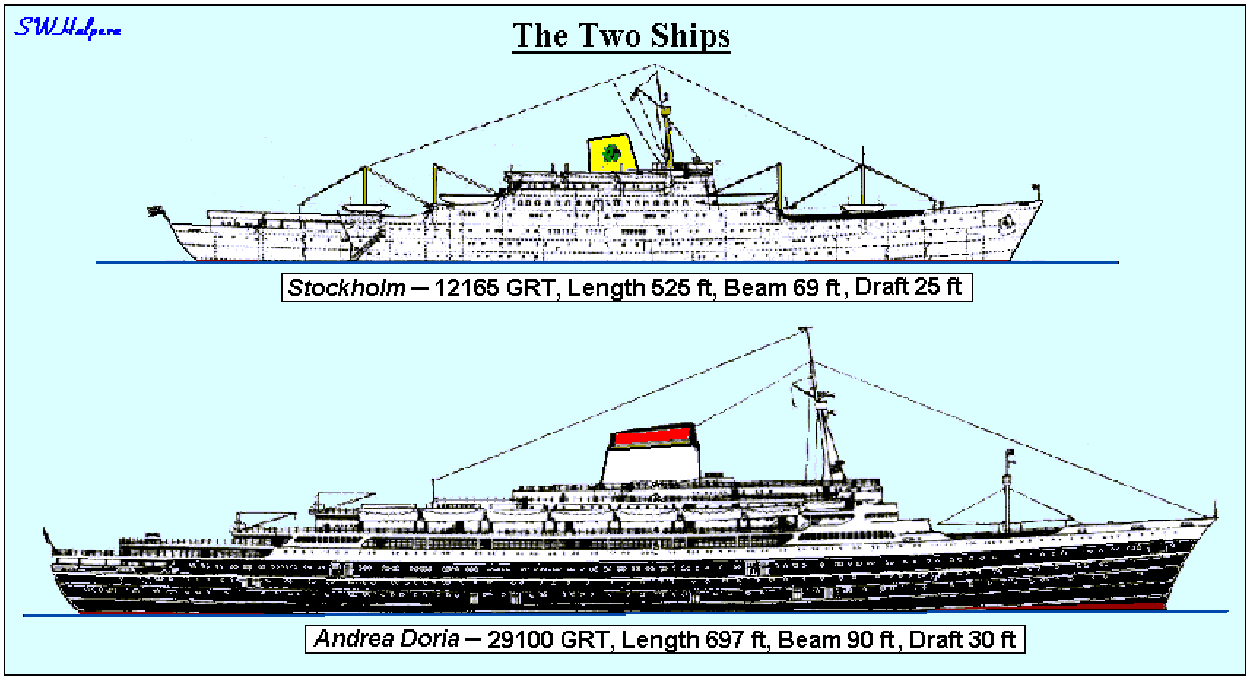
[3] The routes recommended by the US Coast and Geodetic Survey were 20 miles apart in the vicinity of Nantucket. The westbound ships were on the northern more direct route, while eastbound ships were to the south.

taking his ship on a course that would meet westbound traffic head on was that he believed it was safer than crossing the westbound lanes when he had to turn northward heading toward Nova Scotia and Scotland on his way to Scandinavia.[4] The ensuing collision was to prove Nordenson wrong.



At 3:11 p.m. *Stockholm* passed the Fire Island buoy, and by 7:11 p.m., Block Island was picked up on her radar when it was 41 nautical miles away. Senior Second Officer Lars Enestrom attributed this to a mirage effect caused by warm air over colder waters, because the radar usually did not pick up the island more than 30 miles away. At 8:30 p.m., 26 year old Third Officer Johan-Ernst Carstens-Johannsen took over the watch from Enestrom. It was a half hour past the usual change of watch time since Carstens (as he was called) had previously relieved Enestrom for a ½ hour dinner break earlier that evening. At about 9:00 p.m., Capt. Nordenson came up to the bridge for a final check of things. The *Stockholm* was running at 18.5 knots, full speed ahead. The sea was smooth with an irregular swell. The air temperature was about 70° F with a gentle breeze out of the southwest. An almost full moon could be seen off their starboard bow. Visibility was estimated at 5 to 6 nautical miles with a hazy horizon.

About 9:20 p.m. on *Andrea Doria,* Third Officer Giannini picked up the Nantucket Shoals lightship on radar, dead ahead at a distance of about 17 miles.

At the same time, 9:20 p.m. on *Stockholm*, the helmsman was changed in accordance with a pre-planned rotation between the three sailors who took turns manning the helm, the lookout station up in the crow's nest, and the standby lookout positions. This rotation took place at the end of each third of every 4-hour watch period.

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[4] Alvin Moscow, *Collision Course*, Grosser & Dunlap, 1959.

At 9:40 p.m. Capt. Calamai ordered *Andrea Doria's* course be changed from 267° to 261° when the Nantucket lightship was about 14 miles ahead on radar. The intent was to pass about a mile and a half to the south of the stationary lightship.

At the same time, 9:40 p.m., Capt. Nordenson ordered a course change for *Stockholm* from 090° to 087° so his ship would also pass within 1 to 2 miles south of the Nantucket lightship, his last fix position before heading northward. Before returning to his cabin about 10 p.m., Capt. Nordenson left Carstens-Johannsen in charge of the bridge with standing orders that he be called at once if fog or any other significant weather conditions were encountered. It was well known that advection fog usually formed in the waters off Nantucket that time of the year. Nordenson also left word that he be called before the *Stockholm* reached the Nantucket lightship, the point where he was to turn northward to 066° to put his ship on course toward Sable Island, Nova Scotia, then to Cape Race Newfoundland, and then on the great circle route to Scotland and the North Sea to Scandinavia.

At 10:04 p.m., Carstens-Johannsen decided to fix his ship's position by taking radio direction finder (RDF) bearings off radio beacons from Block Island and the Nantucket lightship. The fix he obtained showed his ship was being set more northerly than what Capt. Nordenson desired. Although he checked the radio identifiers of these beacons, he was not aware that he could receive Morse code messages from the lightship itself that showed that she was enveloped in a very dense fog at the time.

At 10:10 p.m., the eastbound *Stockholm's* course was changed by Carstens from 087° to 089° to compensate for the current that was bringing his ship more northward than the course line laid out on the chart by Capt. Nordenson. Later, Carstens was to claim that this course correction was made about 10:30 p.m.,[5] but course recorder data from *Stockholm* clearly shows this 2-degree change came at 10:10 p.m.

By 10:20 p.m., the westbound *Andrea Doria* had the Nantucket Shoals lightship approximately 1 mile off her starboard beam. Capt. Calamai then ordered a course change from 261° to 268° to put his ship on a heading for the Ambrose Channel lightship and the entrance to New York harbor.

At 10:40 p.m., after 2/3 of the 4-hour 8-to-12 watch had gone by, the *Stockholm's* helmsman was changed once again in accordance with their planned rotation. It also appears from course recorder data that a second 2-degree course correction, from 089° to 091°, was ordered by Carstens at this time. Carstens was to claim that this second correction was the result of taking a second RDF fix about a quarter hour after the first correction was made.[6] The course recorder data shows that between 10:10 and 10:40 p.m. the ship's mean heading did not change. Only after the change of helmsman at 10:40 p.m. was a small change in average heading noticeable on the recorder print. But the most outstanding item that showed up in the data from the course

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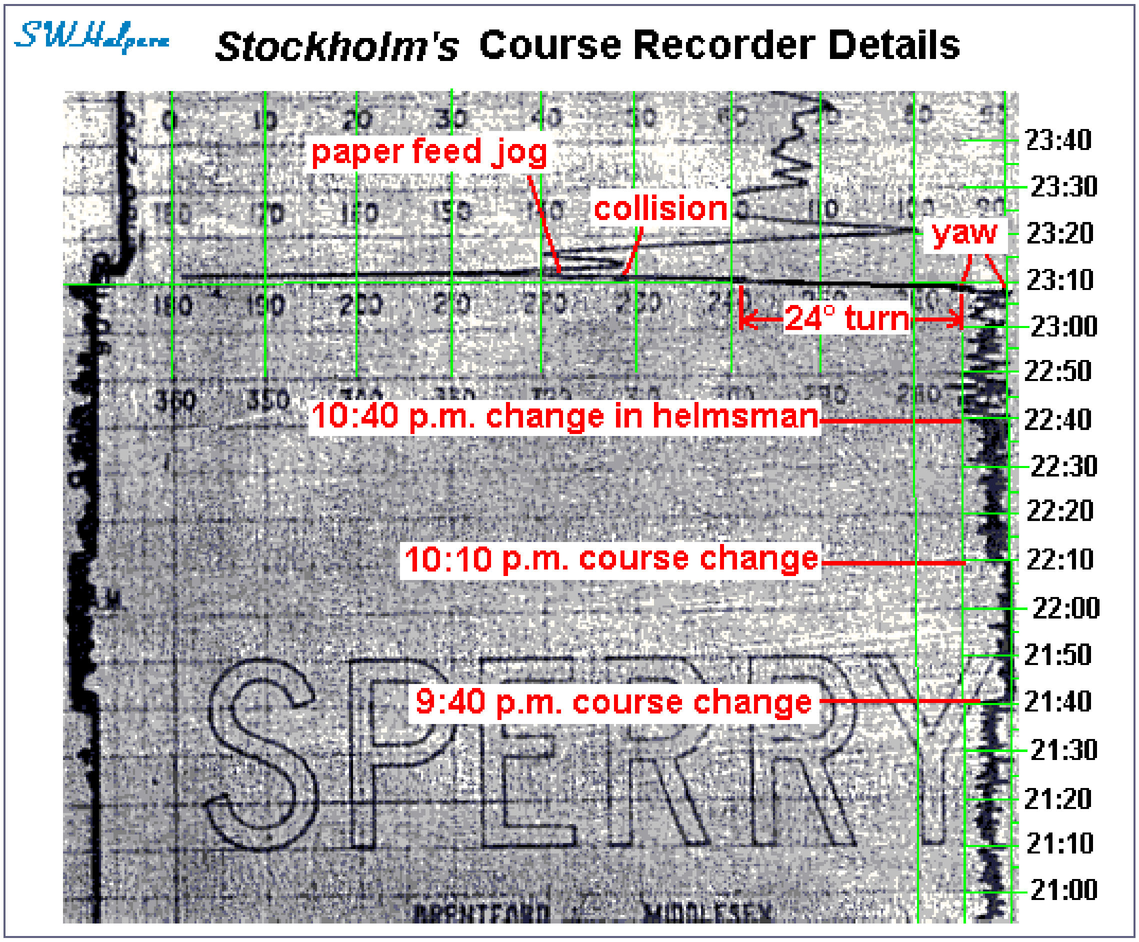
[5] Algot Mattsson, *Out of the Fog*, Cornell Maritime Press, 2003, pp. 36-37.

[6] Ibid.

recorder was the lack of concentration on the part of the new helmsman, Peder Larsen, who allowed his ship's head to yaw several degrees to either side of the mean course line. This lack of concentration was something that also came up during the pretrial hearings in NY.

Shown below are the relevant segments taken from the course recorders of both ships between 9 p.m. and 11:40 p.m. local time.[7] The changes in course headings mentioned above are identified, as well as other detail surrounding the minutes before and immediately following the collision. The relatively wide yaw variations on *Stockholm* after Larsen took over the wheel at 10:40 p.m. (22:40) are easily noticed.



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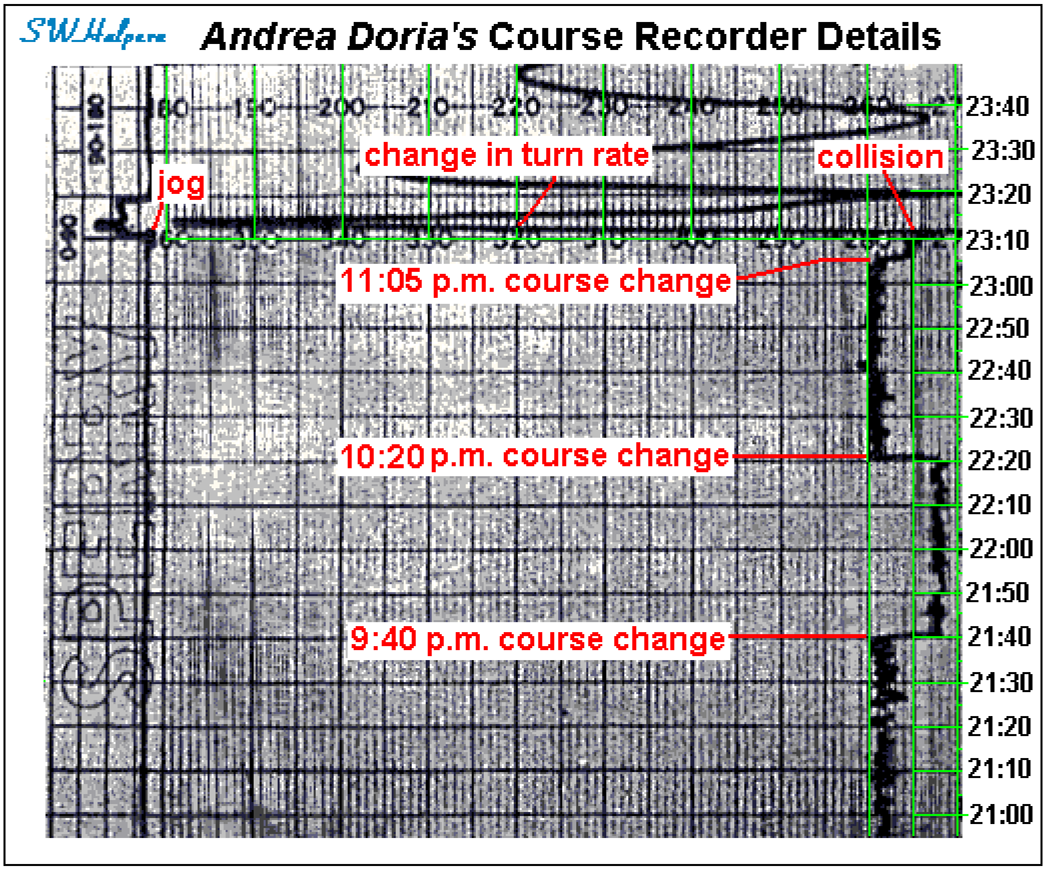
[7] 24 hour time notation is shown on these prints and in the spreadsheet analysis that was later done. To get the p.m. time of an event, you simply subtract 12 from the listed hour; e.g., 22:30 = 10:30 p.m.



For an explanation of a course recorder graph and the need for calibration, please refer to Appendix A.[8]

17 MILES AND CLOSING FAST

Just before 10:46 p.m. local time, about 26 minutes before the collision, the *Stockholm* was picked up on *Andrea Doria's* radar at a distance of about 17 nautical miles and bearing 4 degrees to starboard according to testimony presented at the pretrial hearings. *Andrea Doria* was then heading 268° true in heavy fog at the slightly reduced speed of 21.8 knots.[9] Seven minutes later, at 10:53 p.m. local time, just 18 minutes before the collision, the *Andrea Doria* was picked up on

[8] To get the true gyro heading for *Andrea Doria* from her course recorder data, a -11° correction must be applied. We can easily see this in the data where *Andrea Doria* was on a heading of 267° and the mean course recorder heading reads 278°. The reason for such a big difference between the two is that the day before the collision, First Officer Oneto moved the recorder pen about 10° ahead to avoid recording near the edge of the paper. To get the true gyro heading for *Stockholm* from her course recorder data, a -2.5° correction must be applied. We can easily see this in the data when *Stockholm* was on a heading of 090° and the mean course recorder heading reads 092.5°.

[9] All times given here are in relation to a course recorder collision time of 23:11:00 EDT and derived from the reported distances provided in pretrial hearing testimony. Since we know the speeds that both ships were making leading up to the collision, as well as the true course headings for both ships, we can easily derived the separation distance between them as a function of time. When a time presented here differs from the reported time given by a ship's officer in testimony, that difference will be duly noted.

Stockholm's radar at a distance of about 12 miles. *Stockholm's* heading was then averaging close to 090° true with relatively wide variations in yaw as previously noted. Shortly after the collision, *Stockholm's* third officer was to write in a rough deck log that he first saw the radar echo from *Andrea Doria* at 11:00 p.m. This issue came up during the pretrial hearings where it was demonstrated to him that it was impossible for two ships closing at a combined rate of 2 miles every 3 minutes to be as far away as 12 miles at 11:00 p.m. Carstens then explained that the time he put down was only an approximation, and that the real time was somewhat earlier than what he wrote down.[10]

Soon after *Andrea Doria* first appearing on his radar, Carstens-Johannsen decided to plot the approach of this fast vessel on a radar plotting board. The first point plotted was at a distance of 10 miles bearing 2 degrees to port according to what was claimed. The time would be 10:56. A second point was put down at 6 miles bearing 4 degrees to port. The time of this observation would be 11:02. Connecting the two points, he saw that the approaching ship should pass his own ship at a distance of about ½ mile, somewhat closer than what Capt. Nordenson would allow. But what really concerned the young third officer is why he was not able to see the lights of the oncoming ship as the distance between them continued to close. The *Stockholm*, with a bright moon shining from about 20 degrees off his starboard bow, was running in what appeared to be clear visibility. Unfortunately, it never crossed young Carstens' mind that the other ship may be hidden by an unseen fog bank up ahead, something that is usually deduced by those with years of experience crossing those waters.

It has been suggested that when Carstens first picked up the *Andrea Doria* on his radar the range of his set was unknowingly left on the 5 mile scale instead of the 15 mile scale as claimed. This is an interesting theory first put forth by John Carrothers in the paper he wrote back in 1971 (and previous referenced). This theory was endorsed by Capt. Robert Meurn of the US Merchant Marine Academy as well as by the late David Bright. This theory also shows up in Pierette Domenica Simpson's book, *Alive on the Andrea Doria*, and also appears on the 'andreadoria.org' website of the late Anthony Grillo.

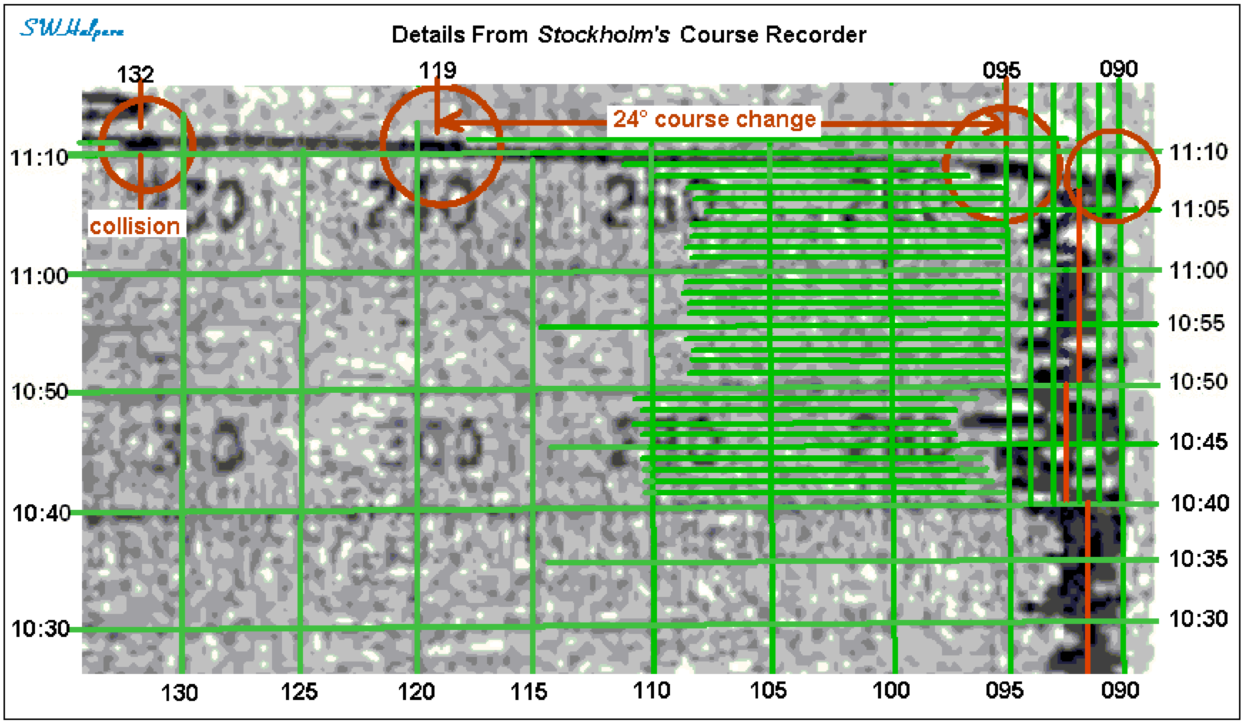
In developing his theory, John Carrothers stated that the course recorder graph from *Stockholm* shows a three-degree change in *Stockholm*'s heading which started at 11:06 p.m. He said this came in response to an order given by Carstens at 11:05 p.m., just six minute before the collision which took place at 11:11 p.m. Carrothers reasoned that Carstens gave the order for that course change to further compensate for the northward drift of his ship after taking a fix at 11:00 p.m. It was just after ordering this course correction that Carrothers believes that Carstens first picked up the *Andrea Doria* on his radar at what he thought to be a distance of 12 miles, but in reality, according to this theory, was only 4 miles away.

To make this theory work, Carrothers has to put Carstens' initial radar observation as late as 11:05 p.m. We know this because it takes six minutes to cover a distance of 4 miles with a combined closing speed of about 40 knots between the two ships. Then, according to Carrothers, when Carstens thought the approaching ship was 6 miles away, it was really 1/3 that distance, or just 2 miles away. The time of that later observation would be 11:08 p.m., just 3 minutes before

[10] Moscow, Ch. 13.

the collision, the time that Carrothers says Carstens ordered a second course change of more than 20 degrees to starboard which was to prove fatal.

Unfortunately, close examination of the course recorder data from *Stockholm* does not quite bear this scenario out as shown below in the expanded view of the relevant portion taken from the recorder print. (Time lines and course lines have been overlaid to help interpret the detail in the data.)



Despite some relatively wide yaw variations, the detail in the course recorder shows that *Stockholm* was on a mean recorder heading (highlighted by a red vertical line) of about 091.5° (089° true)[11] until 10:40 p.m., the time when Peder Larsen took over the helm. From 10:40 until 10:50 the mean recorder heading of *Stockholm* was about 092.5° (090° true), and from 10:50 to 11:07 the mean recorder heading was about 092° (089.5° true). Also notice the variations in yaw significantly increased after 10:40 p.m. showing the lack of concentration on part of the new helmsman. The apparent 3-degree course change that Carrothers talked about is the one circled under 095°, the second circled item from the right. It is very clear that this took place at 11:08 p.m., not at 11:06 p.m. The detail also shows that this mean recorder heading of 095° lasted for one full minute until 11:09 p.m. when a change of 24 degrees to starboard, from 095° to 119°, first began. The end of this 24 degree course change is identified by the circled item second from the left. The collision itself, at 11:11 p.m., is seen by the jog in the recorder course pen at 132° (129.5° true) and identified by the circled item on the far left..

[11] As explained in Appendix A, course recorder readings from *Stockholm* need to be adjusted by subtracting 2 ½ degrees if one wishes to get the true course headings on the gyro compass.

The significance of this detail is that it does not lend support to Carrother's theory that Carstens first picked up the *Andrea Doria* on his radar as late as 11:05 p.m. The 095° heading on *Stockholm's* course recorder between 11:08-11:09 was explained by Carstens as a yaw in *Stockholm's* heading, not a deliberate course change. Notice that there was a similar yaw in heading but to the opposite side of the mean course line that took place between 11:07-11:08 and marked by the circled item on the far right. It is very apparent from the recorded data that the helmsman, Peder Larsen, allowed Stockholm's head to yaw a significant number of degrees to either side of the mean course line during his trick at the wheel. As we shall see, this lack of concentration by the helmsman may have contributed to the accident because Carstens depended on Larsen to report the ship's exact heading each time he put down a point on the radar plotting board.

In my opinion, a misreading error such as what Carrothers proposed was very unlikely for another reason. If the radar range scale had been accidentally set for 5 miles instead of 15 miles, Carstens would have easily spotted the problem. Knowing his own ship was doing just over 18 knots, it would have become obvious to him, or anyone else for that matter, that the scale on the radar was set wrong because the time separation between the two observations that he claimed he plotted, 10 miles and 6 miles, respectively, would have been separated by only 2 minutes in time instead of the 6 minutes that it actually was.[12] It would have been quite obvious to Carstens that there was no possible way a distance of 4 miles can be closed in 2 minutes unless the two ships were approaching each other at a combined speed of about 120 knots, which is obviously ridiculous. He would have immediately realized that his radar was on the shorter range scale, and that the approaching ship had to be much closer than what he may at first have thought. It should be noted that Carstens-Johannsen has always denied that such an error had ever taken place.

PLOTTING THE RADAR PICTURES

Taking the information provided by the officers on *Andrea Doria* and *Stockholm* we can create a picture of what was allegedly seen on the bridge of each ship that night as they approached each other. We have seen that *Andrea Doria* picked up *Stockholm* at 17 miles bearing 4 degrees to starboard around 10:46 p.m. It was reported that as the two ships came closer the relative bearing to the other ship started to increase. This is very important, because a collision situation would obviously result if the bearing line to an approaching target on the radar screen does not change as the range continues to decrease. Bearings that are changing mean that the two ship are *not* on a direct collision course. A bearing line that was increasing to the right suggested that the oncoming vessel would pass *Andrea Doria* on her starboard side instead of coming across her bow. All this assumes of course that neither vessel changes course or speed.

The next useful data point we have for *Andrea Doria* is somewhat conflicting. Capt. Calamai wrote in a report to the Italian Line, prepared while he was on the destroyer escort *Edward H. Allen*, that he ordered a turn to port of 4 degrees to open the passing distance between the two

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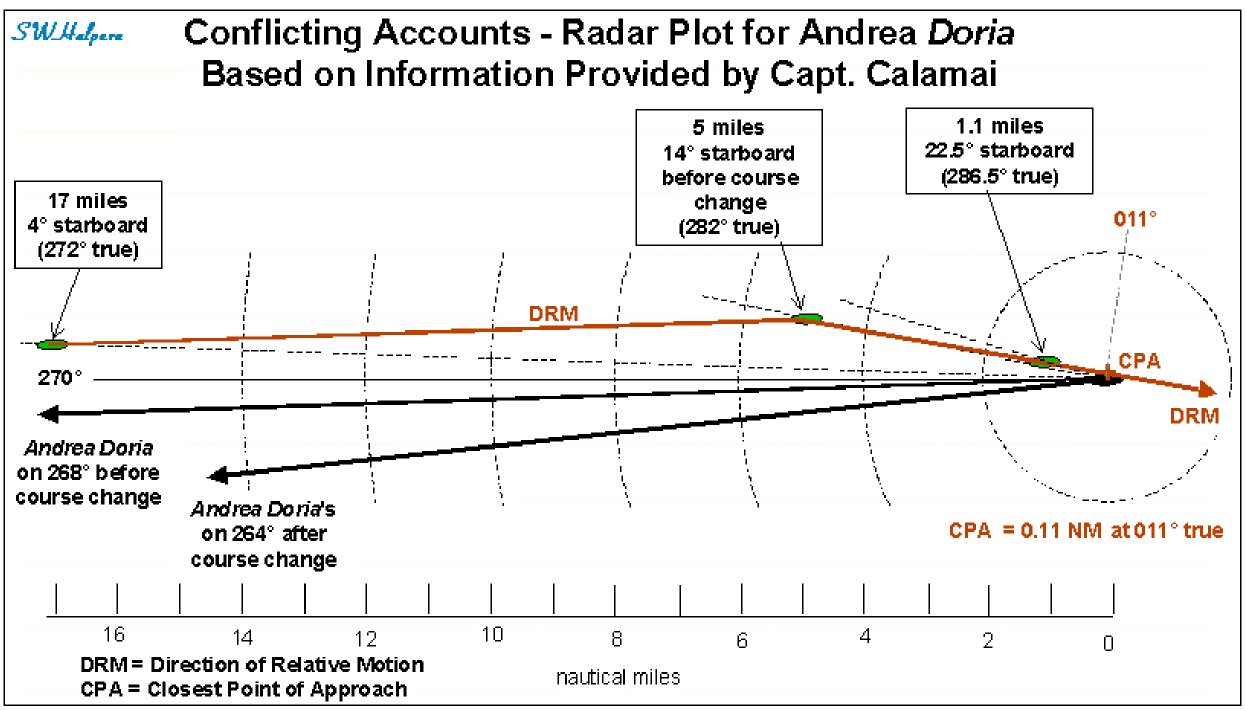
[12] At a combined closure rate of just over 40 knots, the time it takes to close the distance from 10 miles to 6 miles, a difference of 4 miles, is 1/10 of an hour, or 6 minutes. If the radar was really on the 5 mile scale instead of the 15 mile scale, and those distances were really 1/3 what Carstens believed they were, then the time difference between when those two observations were taken would have been only 2 minutes.

ships when the approaching target was 5 miles away bearing 14° to starboard. Second Officer Franchini, on the bridge with Calamai at the time, claimed that the approaching vessel was at a distance of about 3.5 miles bearing 15° to starboard when that 4° course change was ordered.[13] Capt. Calamai at the pretrial hearings said that he later agreed with his second and third officers that the distance was 3.5 miles despite remembering a distance of 5 miles.

In addition to the reported distances and bearings before that 4° course change was ordered, we also have a few data points for after that course change was ordered. From Third Officer Giannini, a glance of the radar showed the *Stockholm* at a distance of about 1.5 miles bearing 30° to 35° to starboard shortly before her lights were visually sighted to starboard. According to Capt. Calamai, the glow of *Stockholm's* lights were sighted at a distance of 1.1 miles bearing 20° to 25° to starboard, while Second Officer Franchini estimated *Stockholm* was about 1 mile away bearing 35° to 40° to starboard when her lights were first spotted. It should also be noted that Franchini left the radar when he heard Capt. Calamai and Third Officer Giannini talk about seeing a faint glow of lights out on the starboard bridge wing. As he was walking out to see for himself, Franchini went to answer a phone call from the lookout out on the bow who called to report that he was seeing lights to starboard. At this critical time, nobody was left to man the radar.[14]

Knowing the course *Andrea Doria* was on before and after the course change, as well as the specific observations reported, we can create a radar plot of the situation that was described. The first plot, shown below, is based on Capt. Calamai's reported observations.



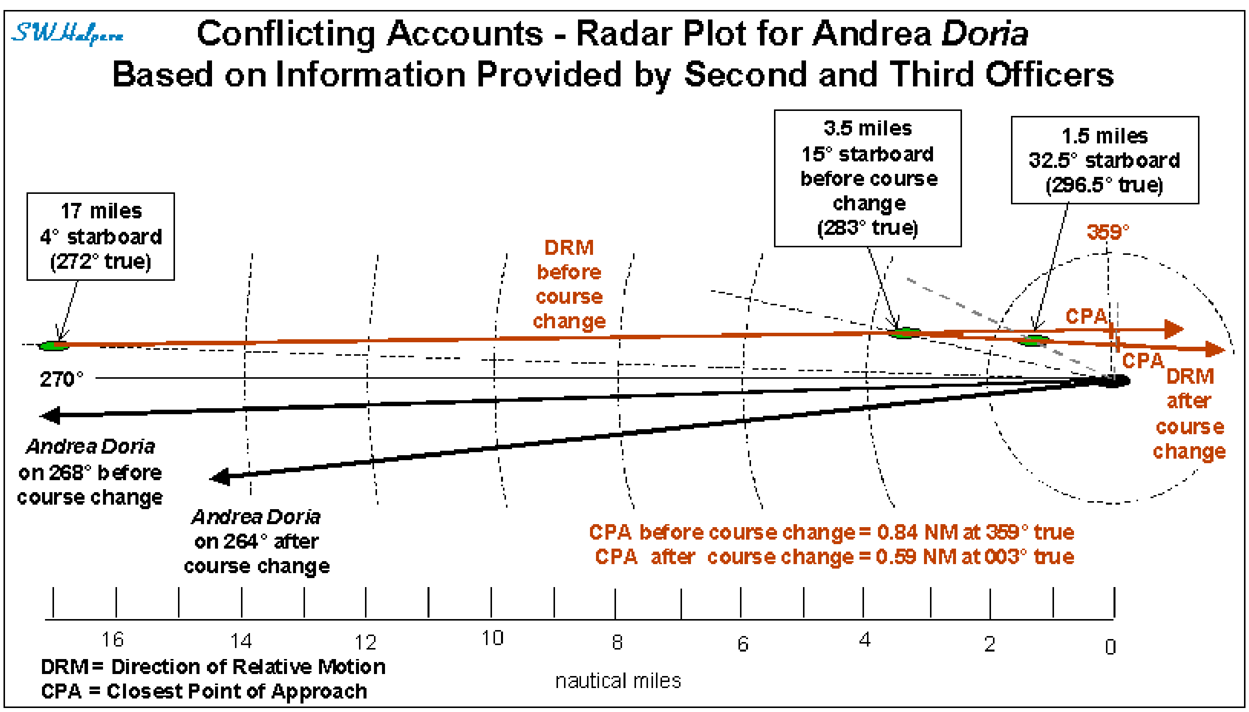
[13] William Hoffer, *Saved!*, Summit Books, 1979, p. 13.

[14] Moscow, Ch. 3.

The course for *Andrea Doria* before the course change is marked by the heading line 268° true; that for after the course change by the heading line 264° true. The relative bearing to the radar pip at 17 miles was 4 degrees to starboard of the 268° heading line, or bearing 272° true. The relative bearing to the pip at 5 miles is 14 degrees to starboard of the 268° heading line, or bearing 282° true. The line that connects through those two reported positions shows the Direction of Relative Motion (DRM) of *Stockholm* with respect to the *Andrea Doria*. After the that 4° course change, the relative bearing to the target shifts to 18° to starboard of the new 264° heading line, but its true bearing shown on the radar plot would remain essentially unchanged in the short time it took to change course by just 4 degrees. The visual contact point of Capt. Calamai at 1.1 miles is about 22.5° to starboard of the 264° heading line, or bearing 286.5° true from *Andrea Doria*. The Closest Point of Approach, the CPA on the new DRM line calculates to 0.11 miles bearing 011° true. This says the ships are now on an obvious collision course, and that the target ship must have also made a course change at some point in time which resulted in the distance between the two ships closing instead of opening up.

It must be stated that those responsible for the safe navigation of *Andrea Doria* did not do any radar plotting that night. They only made estimates of the developing situation that was being observed. During the pretrial hearings, Capt. Calamai conceded that the only way to determine the course and speed of another ship on radar was to plot two or more successive observations. He then was forced to plot the radar situation from the data he put in his report to the Italian Line, as we have done above, and was asked if "in fact the *Stockholm* was *not* on a course parallel [and opposite] to the course of the *Doria*?" Capt. Calamai then answered, "I can see it now from the maneuvering board."

A similar radar plot can be drawn based on the reported observations of *Andrea Doria's* officers Franchini and Giannini. This is shown below.



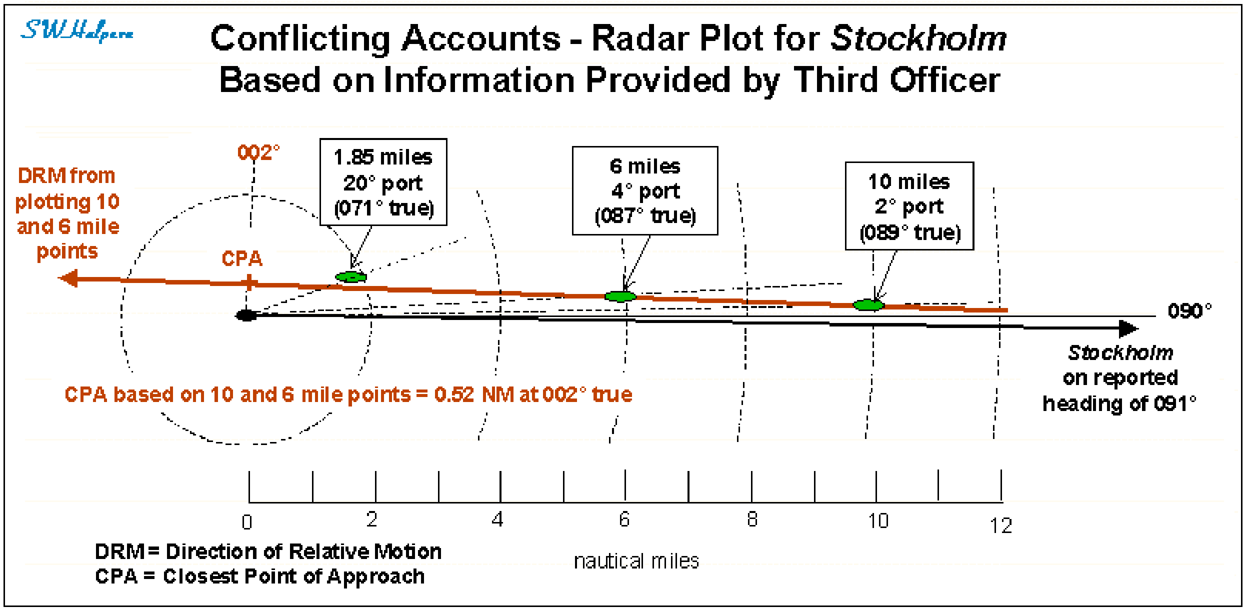
As before, the course for *Andrea Doria* before the course change is marked by the heading line 268° true; that for after the course change by the heading line 264° true. The bearing to the pip at 17 miles was as before, 272° true, or 4 degrees to starboard of the 268° heading line. The bearing to the pip at 3.5 miles is 283° true, or 15 degrees to starboard of the 268° heading line. Assuming the data was accurate, if neither ship changed course or speed, the DRM line based on those two positions says that both ships should pass each other safely at a CPA of 0.84 nautical miles bearing 359° true from *Andrea Doria*.

After the 4° change in course to port, the relative bearing to the target at 3.5 miles becomes 19° to starboard of the 264° heading line, but its true bearing, 283°, remains essentially unchanged. Giannini's radar position at 1.5 miles is about 32.5° to starboard of the 264° heading line, or at a bearing of 286.5° true from *Andrea Doria*. The new CPA then calculates to 0.59 miles bearing 003° true from *Andrea Doria*, which says the ships should still pass each other starboard-to-starboard, but the target ship had also made a course change at some point in time which closed the distance between the two ships rather than it opening up as expected.

Although we have created a radar plot for *Andrea Doria* based on information provided by her officers, it must be emphasized once again that they did not do any radar plotting that night. To those monitoring the radar, it appeared as if the oncoming ship was on an opposite but parallel track, and that the two ships should pass each other starboard-to-starboard (on the right side of each other) about a mile away if no sudden changes took place. In fact, we can see from plotting the reported developing radar situation that the oncoming *Stockholm* was not exactly on a parallel but opposite track to *Andrea Doria*. The radar plot shows a slightly converging situation. Even though the casual interpretation of the radar suggested that the two ships would pass starboard-to-starboard of each other, the greatest failure on part of those on the bridge of *Andrea Doria* was not to allow for some change in course by the oncoming vessel. They made the fatal mistake of assuming that the oncoming vessel would continue on a heading that would result in a starboard-to-starboard passage as opposed to the possibility of it turning to pass port-to-port (to the left side of each other) as required by the rules of the road for vessels in sight of each other and approaching each other almost head on.

On *Stockholm* the *Andrea Doria* was first spotted on radar at a distance of about 12 miles away. Her third officer, Carstens-Johannsen, said that he plotted the oncoming ship at a distance of 10 miles bearing 2 degrees to port, and then again at 6 miles bearing 4 degrees to port. He also said he saw the oncoming ship on his radar screen when it was between 1.8 and 1.9 miles away bearing about 20 degrees to port, the same time when her lights first became visible. As in the case of what was reported on the bridge of *Andrea Doria*, the relative bearings of the oncoming vessel were said to be increasing. However, the difference is that the alleged increasing bearings taken from the *Stockholm* were off to the port side of the vessel, while the alleged bearings taken from *Andrea Doria* were off to the starboard side of that vessel. Both cannot be right.

As we did for *Andrea Doria*, we can create a radar plot for *Stockholm* from the information provided by her third officer who was left in sole charge of the bridge at the time. This radar plot is shown below.



The course ordered for *Stockholm*, 091°, is marked by the heading line. The relative bearing to the pip at 10 miles was 2 degrees to port of the heading line, or bearing 089° true. The relative bearing to the pip at 6 miles is 4 degrees to port of the heading line, or bearing 087° true. The relative bearing to the pip at 1.85 miles is 20 degrees to port of the heading line, or bearing 071° true. The Direction of Relative Motion with respect to the *Stockholm* based on the 10 and 6 mile plotted positions indicates a divergent track line for the oncoming ship. Assuming this data was accurate, if neither ship changed course or speed they would pass each other safely, port-to-port, at a CPA of 0.52 nautical miles bearing 002° true from *Stockholm* as shown.

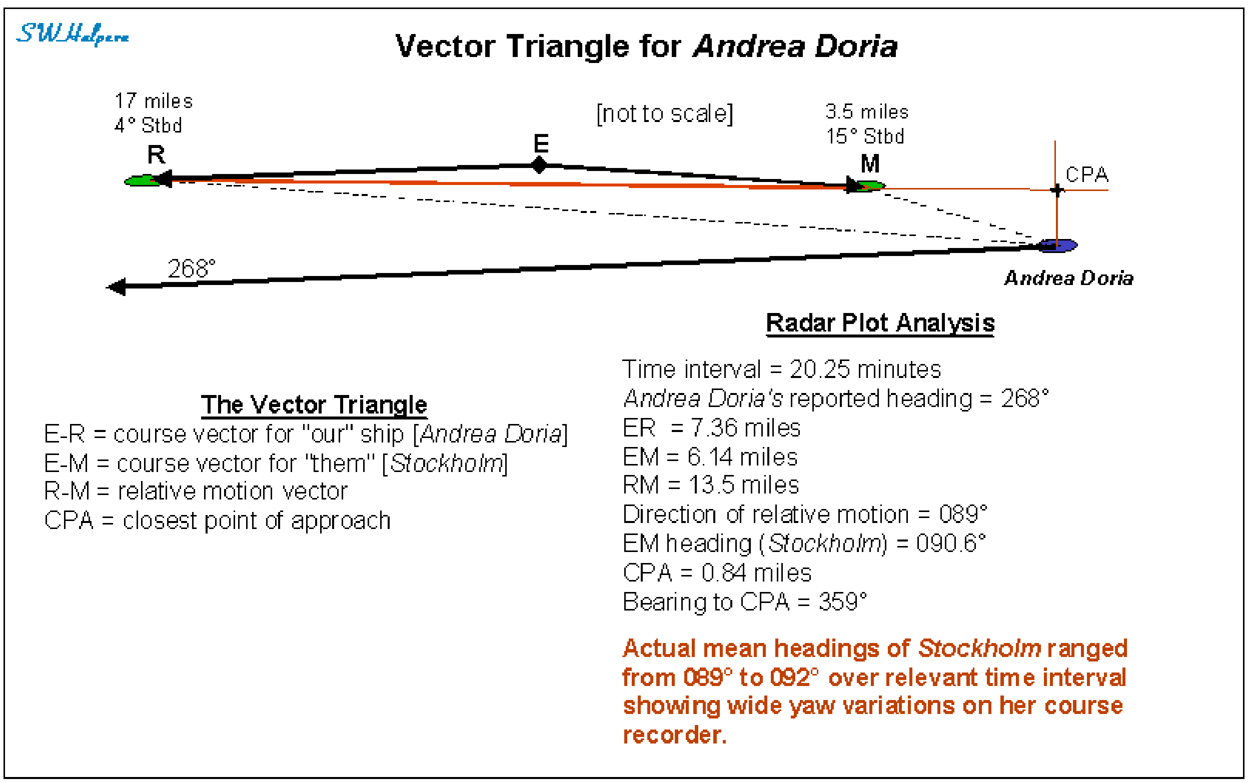
Stockholm's third officer said he used the radar plotting board located next to the radar screen. Yet he depended on the helmsman to give him the actual course heading whenever he wanted to put down a position on the board. This is because there was no gyro repeater in *Stockholm's* radar for him to check the ship's instantaneous heading. If the reported course angle from the helmsman was off a degree or two, then so to would be the position on the radar plot. And we have seen that the helmsman at the wheel at that time was somewhat erratic in keeping to the ordered course.

These radar plots derived for *Andrea Doria* and *Stockholm* tell very different stories. For the *Andrea Doria*, the oncoming ship should pass close on her starboard side; while for the *Stockholm*, the oncoming ship should pass close on her port side. They both present a contradictory situation, and one or both cannot be right.

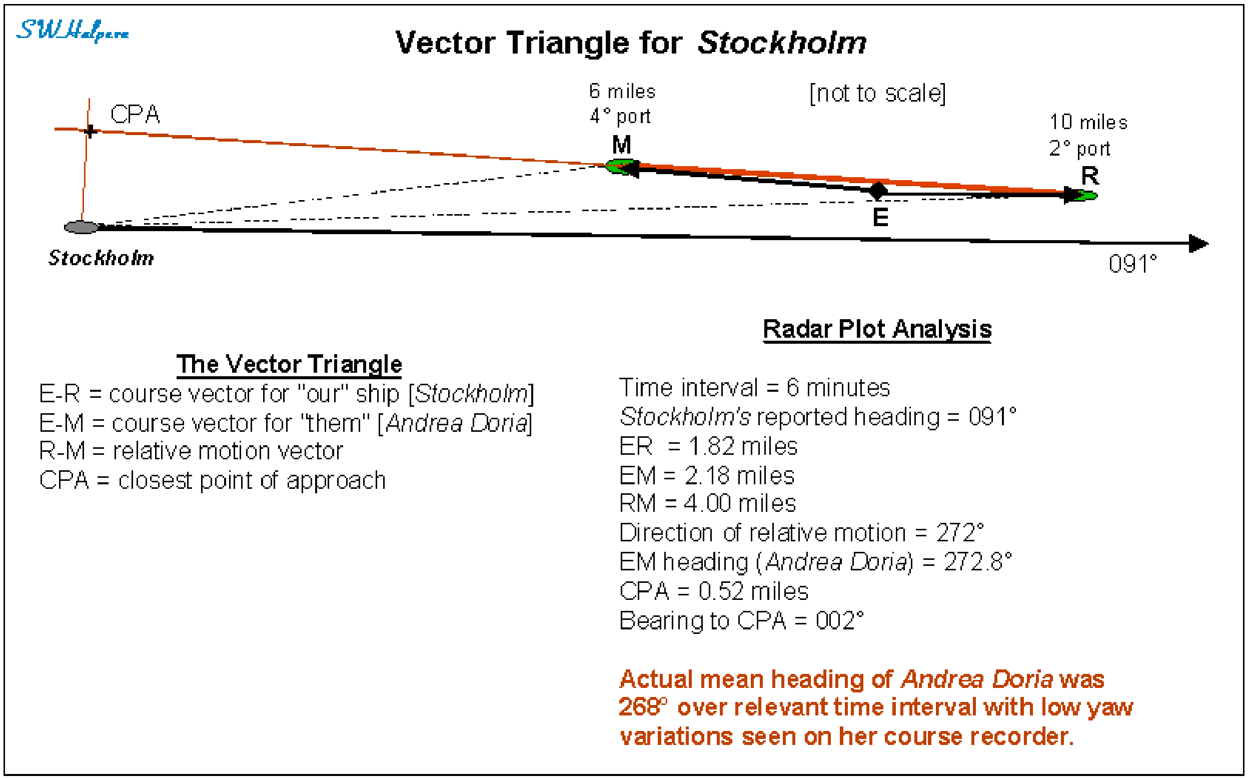
Before we leave the topic of radar plots, one other piece of relevant information can be obtained from the reported radar data. That information is the derived course heading of the oncoming vessel. In other words, we should be able to get *Stockholm's* average course heading from the radar data taken from *Andrea Doria*, and get *Andrea Doria's* average heading from the radar data taken from *Stockholm*. We can then check this against the known course headings that each ship was on, and verify it by data from their respective course recorders after the appropriate compensation adjustments are made.

The process used to derive the heading of the "other" ship is to draw what is called a Vector Triangle. Simply put, creating a vector triangle enables a ship's officer to determine the course and speed of an unknown ship seen on radar from data taken from a radar plot and using the known course and speed of your own vessel.

The vector triangle produced for *Andrea Doria* based on the information provided by her officers for the time from the initial 17 mile contact point to the 3.5 mile point is shown below. The derived heading for *Stockholm* based on this reported radar data implies that *Stockholm* was approaching *Andrea Doria* on an average course heading of 090.6° true. That actual average heading of *Stockholm* based on course recorder data was about 090° true and showing some large variations to either side over the 20 minute interval being considered. Although the heading derived from the *Andrea Doria* data appears to agree nicely with *Stockholm's* overall average heading for the given time interval, it does not mean that the radar bearings that were reported from *Andrea Doria* were necessarily accurate. We will come back to this later on.



The vector triangle produced for *Stockholm* based on the information provided by her third officer for the 10 and 6 mile contact points is shown below.



The derived heading for *Andrea Doria* based on the reported *Stockholm* radar data implies that *Andrea Doria* was approaching on an average course heading of almost 273° true. That actual average heading of *Andrea Doria* was 268° true with variations of only about 1 degree to either side of the mean course line over the 6 minute interval considered. In this case it is quite clear that the radar bearings reported from *Stockholm* could *not* have been accurate since they produced a very wrong result for *Andrea Doria*.

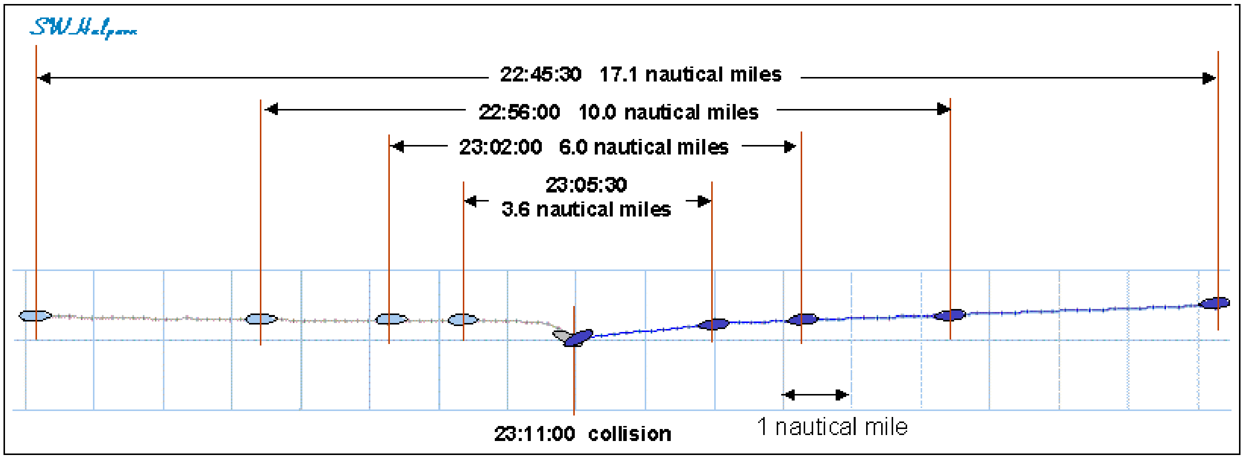
THE REALITY OF THE APPROACH

The actual approach of these two ships can be reproduced from the known speed of each ship and data taken from their course recorders after the appropriate adjustment errors are taken into account.[15] The procedure for doing this is explained in Appendix B, and the results were presented in a spreadsheet. The spreadsheet lists as a function of time the true mean course headings of both ships, the separation distance in nautical miles between the two ships, their positions north/south and east/west in nautical miles with respect to the collision point, and the relative bearings that should have been seen on the radar scopes of both ships if the equipment

[15] It should be noted that a failure to properly correct for these adjustments can lead to some slightly erroneous results. An example is the work done by John Carrothers. In his recreation of the movements of both ships he put in a correction of 10 degrees for *Andrea Doria* based on testimony given at the pretrial hearings that the recorder pen was set about 10° ahead of the gyro compass the day before. Comparing the recorder data to the known courses called for prior to the accident, a correction of 11 degrees should have been used. Similarly, an adjustment of 2 ½ degrees was needed in the course recorder data from *Stockholm*. These adjustments were not applied in Carrothers' work.

was working perfectly and accurate measurements were taken. The data was run in 30 second increments with the time of collision taken at 23:11:00 EDT.

Results from this detailed analysis are presented below. The first diagram shows the approach of both ships from 17 nautical miles. (The scale shown is 1 nautical mile per division.)



The table below lists some of the highlighted details from the spreadsheet. Included are the details for the 17 mile separation when *Stockholm* allegedly first appeared on *Andrea Doria's* radar, the 10 and 6 mile separation details when *Andrea Doria's* position on radar were allegedly plotted on *Stockholm*, and the 4.0 and 3.6 mile separation details when *Andrea Doria* changed course from 268° to 264° to open the distance that the two ships were to pass each other. (All distances listed are rounded to the nearest 1/10 mile; all headings and bearings listed are rounded to the nearest whole degree.)

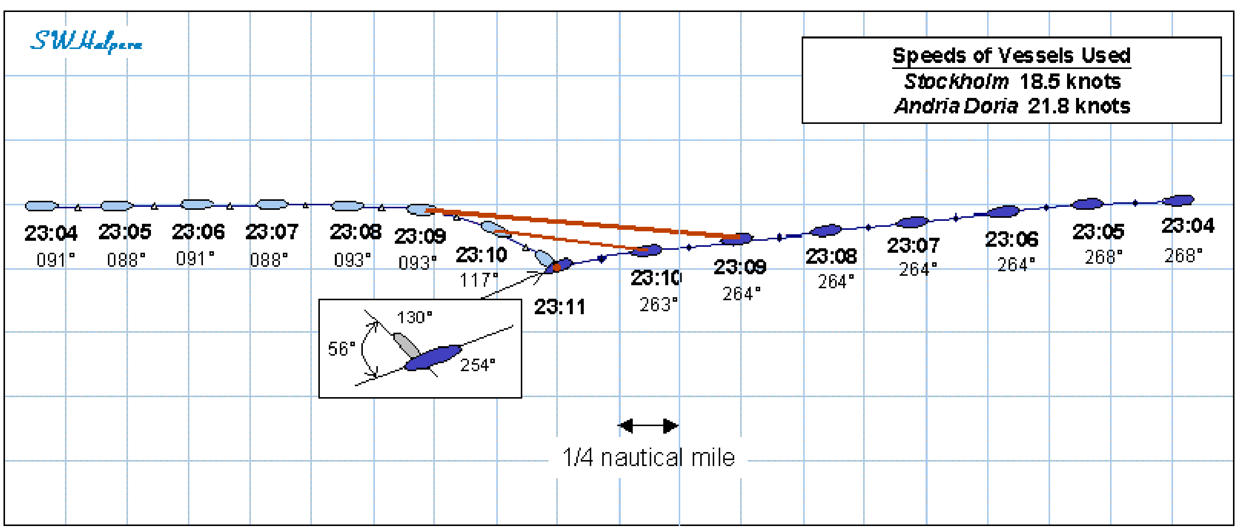
Time	Range (NMs)	Mean Heading of *Stockholm*	Mean Heading of *Andrea Doria*	Rel. Bearing of *Andrea Doria* from *Stockholm*	Rel. Bearing of *Stockholm* from *Andrea Doria*
22:45:30	17.1	090°	268°	1° port	1° stbd
22:56:00	10.0	090°	268°	dead ahead	1° stbd
23:02:00	6.0	092°	268°	2° port	2° stbd
23:05:00	4.0	088°	268°	2° stbd	2° stbd
23:05:30	3.6	090°	264°	1° stbd	6° stbd
23:11:00	0.0	130°	254°	n/a	n/a

What we see from the data is that when *Stockholm* first appeared on *Andrea Doria's* radar at 17 miles it would have been at a relative mean bearing of about 1 degree to starboard, not 4 degrees to starboard as reported. Similarly, at the 10 and 6 mile separation distances, the relative bearing of *Andrea Doria* on *Stockholm's* radar should have showed her nearly dead ahead and 2 degrees to port, respectively, not 2 degrees and 4 degrees to port as reported. At 11:05 p.m. (23:05:00), a half minute before *Andrea Doria* changed course from 268° to 264°, the two ships were 4 miles apart and *Stockholm* should have been seen on radar about 2 degrees to starboard of *Andrea*

Doria, not 14-15 degrees at 3.5 miles as reported by her captain and officers.[16] After completing that 4-degree course change, the relative bearing of *Stockholm* would have been about 6 degrees to starboard.

The reader must be cautioned before jumping to premature conclusions about the reported radar readings given by the officers from both ships. According to Captain Raoul De Beaudean of the rescue ship *Ile de France,* radar readings on scopes in the1950's had an uncertainty of about 4 to 5 degrees.[17] This can explain some of the reporting error in *Stockhlom's* radar bearings, especially when coupled with the fact that the third officer depended on his helmsman to give him his ship's precise course heading, a helmsman who was not very reliable in keeping to a steady course. However, in the case of *Andrea Doria's* reported radar bearings for distances under 5 miles, the angle of approach between the two ships was not nearly as wide as the bearings estimated by her officers despite them being correct in projecting that the two ships would have passed each other starboard-to-starboard if neither ship changed course. According to Richard Goldstein, this was also noted by Carl O. Nordling, former professor at the Royal Institute of Technology in Sweden, who also analyzed the course recorder data.[18]

More insight into what really happened can be seen in the detailed results for the last seven minutes before the collision. This is shown in the following diagram generated from the spreadsheet analysis. The location of each ship is shown along with their mean course heading at each location. (The scale now is ¼ nautical mile per division.)



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[16] Captain Calamai at first said that the other ship was about 5 miles and 14° starboard when he ordered a 4 degree course change to port to widen the passing distance. However, two of his officers, Franchini and Giannini, said the other ship was only about 3 ½ miles away and 15° to starboard when that course change was ordered. Captain Calamai later agreed with his officers.

[17] Richard Goldstein, *Desperate Hours*, Chapter 33.

[18] Ibid.

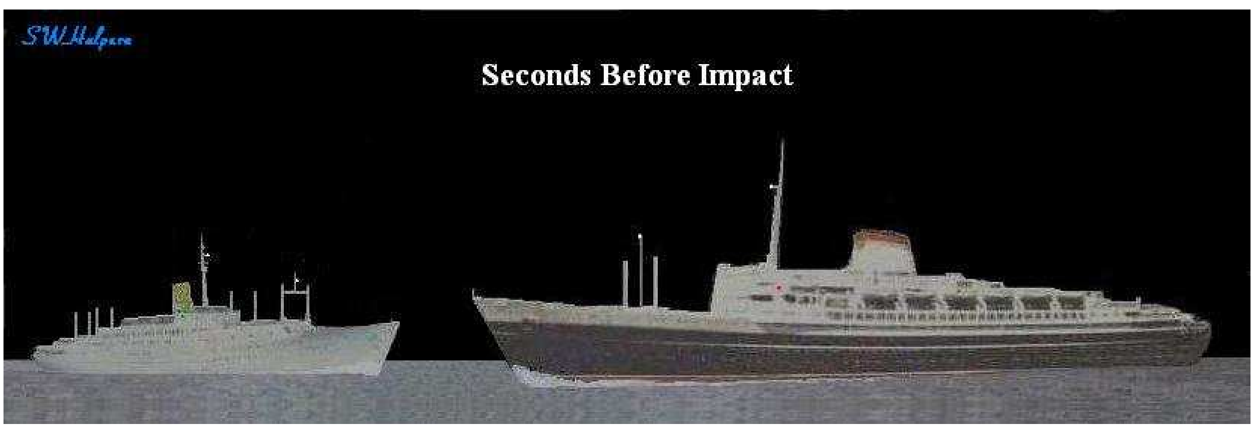
Below is a list of details from the spreadsheet for the last 2 minutes of the approach. (Again, angles are presented to the nearest whole degree and distances to the nearest 1/10 nautical mile.)

SWHelper The Final Two Minutes of the Approach (all headings and bearings rounded to the nearest degree)						
Time	**Visual Observations and Actions Taken**	**Range (NMs)**	**Heading of *Stockholm***	**Heading of *Andrea Doria***	**Rel. Bearing of *Andrea Doria* from *Stockholm***	**Rel. Bearing of *Stockholm* from *Andrea Doria***
23:09:00	Ships not yet visible	1.3	093°	264°	3° stbd	12° stbd
23:09:30	*Stockholm* turning stbd	1.0	105°	264°	8° port	13° stbd
23:10:00	Diffuse lights seen	0.6	117°	263°	18° port	15° stbd
23:10:30	Ships take evasive actions	0.3	117°	262°	18° port	17° stbd
23:11:00	Collision	0.0	130°	254°	n/a	n/a

Much can be learned from this analysis. For example, at two minutes before the collision, 11:09 p.m. (23:09:00), the ships were 1.3 miles apart and not yet visible to each other considering the density of the fog reported at that time from the *Andrea Doria*. According to the course recorder data, it was then that *Stockholm* started a turn of 24° to starboard. At one minute before the collision (23:10:00) the range between the ships decreased to 6/10 of a mile. This is about the time when the lights of the two ships would have started to become visible through the fog. At that time *Andrea Doria* was heading 263° and *Stockholm* had just come onto a heading of 117°. *Andrea Doria* would have appeared coming out of the fog bearing 18° on *Stockholm's* port side, and displaying her green sidelight to *Stockholm. Stockholm* would have appeared out of the fog bearing 15° on *Andrea Doria's* starboard side, and displaying her red sidelight to *Andrea Doria*. *Stockholm* would have first seen *Andrea Doria's* lights to port; *Andrea Doria* would have first seen *Stockholm's* lights to starboard. They were now on an unavoidable collision course.

It is clear from the details on the course recorder graph of *Stockholm* presented earlier, and from the spreadsheet data shown here, that the turn to starboard ordered by Carstens to open the passing distance between ships began at 11:09 p.m. and ended at 11:10 p.m. Just before that turn started, *Stockholm* was on a true heading of 093° as a result of the helmsman allowing the ship's head to yaw about 2 degrees to the right of the desired course line of 091°. The ordered turn itself ended when *Stockholm* came on a heading of 117° true. Carstens claimed that he ordered that turn to starboard after seeing lights from the *Andrea Doria* bearing about 20 degrees to port. He also said that the radar showed the oncoming vessel was between 1.8 and 1.9 nautical miles away on that relative bearing at that time. Despite what was claimed by *Stockholm's* third officer, the lights of the *Andrea Doria* were not visible until the ships came under a mile apart. When Carstens ordered that turn, the range between ships was only 1.3 miles, but more importantly, *Andrea Doria* was bearing about 3° on her starboard side, not her port side. *Andrea Doria* first came on the port side of *Stockholm* as that turn was taking place. One minute later, at 11:10 p.m., when the ships were 0.6 miles apart at the completion of that slow turn, diffuse lights would be seen bearing 18° off *Stockholm's* port bow. It was at this time that Sten Johannson, the lookout in the crow's nest, also noticed lights to port and went to the phone to ring the bridge to report that he sees lights of a ship to port bearing about 20 degrees. Distracted by the ringing of the phone, Carstens goes to answer the call from the crow's nest. When Carstens gets off the phone and goes out to his port bridge wing, he sees the *Andrea Doria* about to cross his bow from left to right showing him a green sidelight and her forward masthead light to the right of her higher aft masthead light. It is now about 11:10:30, and Carstens immediately orders the wheel be put hard astarboard and runs to the engine telegraphs to ring full astern on the engines. A half minute later, after turning only 13 degrees into that hard astarboard turn, and before the now reversing starboard engine could have any real affect, the bow of *Stockholm* plowed into the starboard side of *Andrea Doria* just aft of the bridge wing.

At 11:05 p.m. on *Andrea Doria*, Capt, Calamai ordered a change in course, "4 degrees to the left, and nothing to the right" to increase the passing distance between the two ships. The helmsman, Giulio Visciano, put the helm to port and watched the gyro compass tick off the 4-degree heading change. In keeping with the order "nothing to the right," *Andrea Doria* was only allowed to move slightly off the desired 264° course line to the left, the helmsman was required not to let any drift to the right of the new course line. This can be seen in the course recorder data which shows a very slight drift of 1 to 2 degrees to the left of the 264° true line in the last minute just before radical evasive action was ordered. At ½ minute before the collision, when the lights of *Stockholm* came out of the fog and could be seen more clearly, Calamai and his officers saw the oncoming ship showing a red sidelight and the forward masthead light to the left of the higher aft masthead light indicating the oncoming ship on their starboard side was turning into them. Immediately Capt. Calamai calls out for the wheel to be put hard aport. It was too late to take any effective action with steam turbine engines. About a half minutes later, only after getting about 10 degrees into that hard aport turn, *Andrea Doria* was struck just aft and below her starboard bridge wing.[19]

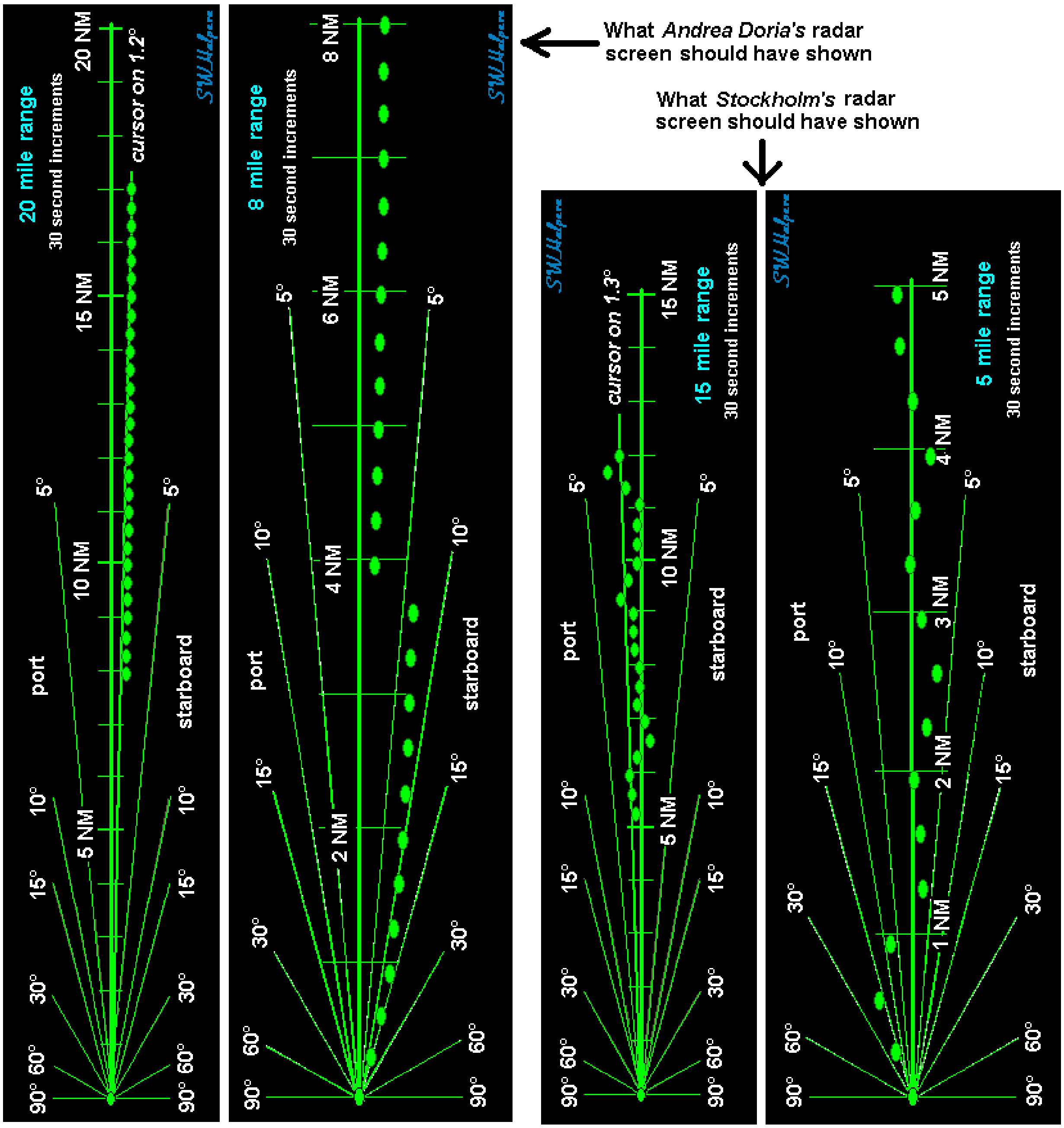


CLAIMS VS. REALITY

From the same analysis that led us to recreate the true events leading up to the collision at 11:11 p.m. local time, we can produce what the relative radar pictures should have looked like on the

[19] Although a precise location of impact does not show up as clear on *Andrea Doria's* course recorder as it does on *Stockholm's*, the dynamics of the collision show that the impact would cause an added rotation to *Andrea Doria's* rate of turn to port. Very rapid turning to port appears on the course recorder detail between recorder values of about 270° to 250°, corresponding to gyro compass headings of 259° to 239° true. A slight jog in the quadrant pen also shows up during the start of the transition from the 270-360 recorder quadrant into the 180-270 quadrant. *Andrea Doria's* officers estimated that their ship had turned about 10 to 15 degrees before *Stockholm* struck. We are taking it at 10 degrees, thus making a heading of 254° true at the time of impact.

radarscopes of both ships assuming they both had perfectly working, aligned, and calibrated equipment with zero display error. These partial segment diagrams (showing just a few degrees to either side of the heading flasher line) for a head-up plan position indicator display are shown below in 30 second increments.



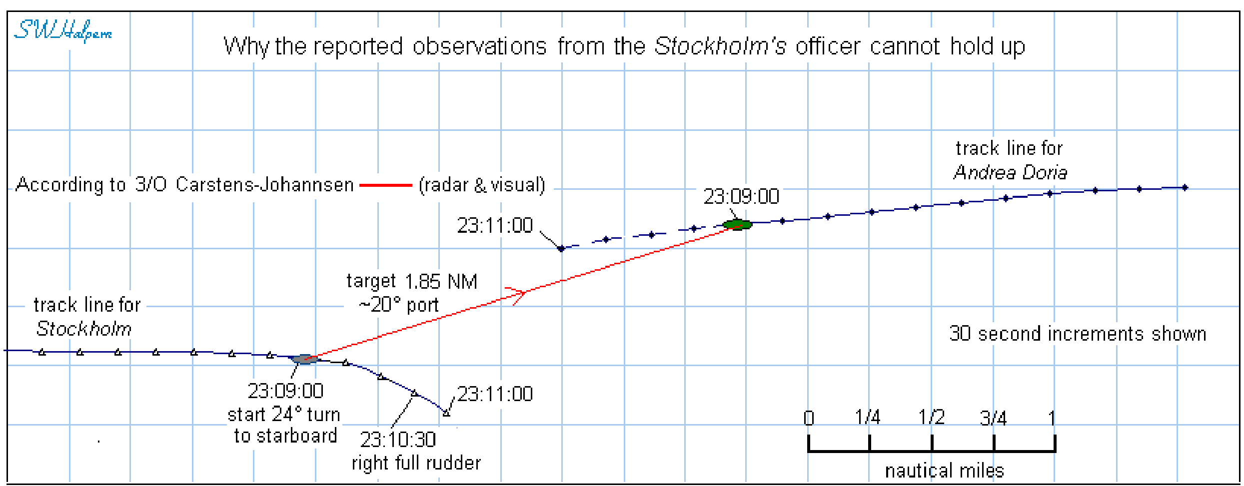
On *Andrea Doria* the first image of *Stockholm* on radar should have been a little over 1 degree to starboard of the heading flasher (as marked by the cursor line) at a distance of 17 miles. From there the bearing would open up very, very slowly until a distance of just under 4 miles when the order for a 4-degree course change to port took place. This can be seen on the 8 mile range scale.

From then on, the bearing would have increased to over 15 degrees when the lights of *Stockholm* would become visible just under 1 mile.

On *Stockholm* the first image of *Andrea Doria* on radar should have been a little over 1 degree to port of the heading flasher on the 15 mile scale at a distance of 12 miles. From then on we would see the bearing keeping mostly to port until the distance came under about 4 nautical miles. Then, as seen on the 5 mile scale, the bearing to the target would seem to keep mostly near or to starboard of the heading flasher until that late course change of more than 20 degrees to starboard was ordered. This then put the target well over to port. Wide variations in the relative bearing to the target should have been quite noticeable if the radar was monitored continuously. Those variations would have reflected the inattentiveness of the helmsman in keeping to a steady course line as verified by the course recorder print.

Despite our ability to recreate what should have been seen on radar from what the course recorders tell us, the stories presented in sworn evidence by those responsible on the bridge of each ship gives us a very different set of conflicting pictures. So we must ask, is it possible that there is something that we may be overlooking? Can it be that one party was in fact reporting the reality of the situation while the other was not? The one thing we know for certain is that both parties cannot be right.

Through the use of the spreadsheet we can study the claims of both parties to see if it is remotely possible that one may be close to being right. So let's first take the case of *Stockholm*. *Stockholm's* third officer, Carstens-Johannsen, said that he saw lights of the approaching vessel when it was between 1.8 and 1.9 miles away as checked by his radar and bearing about 20 degrees to port. He then claimed that he ordered a turn of some 20 degrees to starboard to open the passing distance to more than a mile. This situation can be setup in the spreadsheet and the results plotted as shown below.

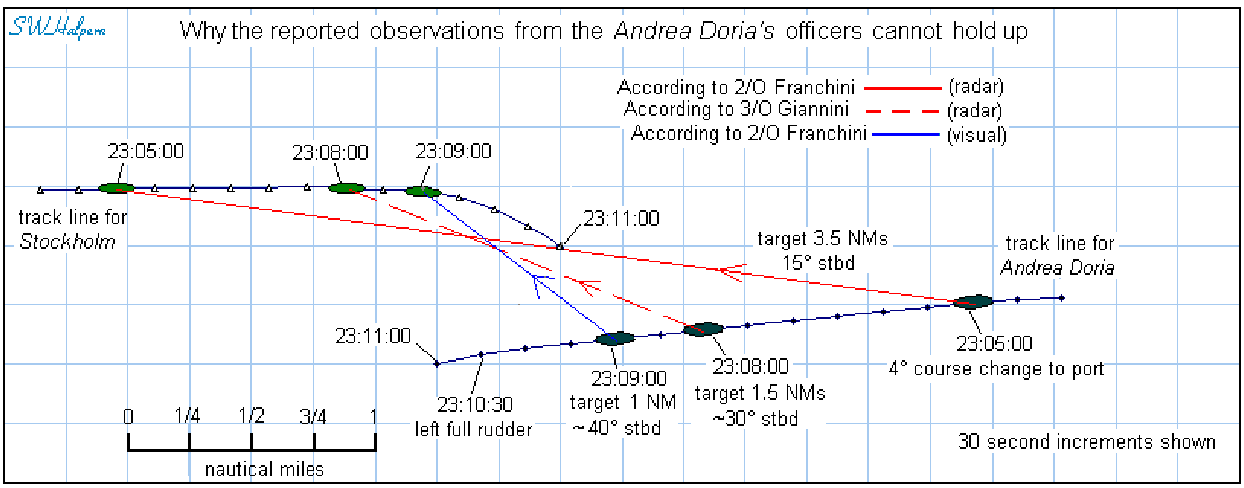


The starboard turn ordered by Carstens began at 11:09:00 p.m. and was completed at 11:10:00 according to *Stockholm's* course recorder data. The actual turn was 24 degrees. A half minute later, at 11:10:30, a hard right turn begins, and at 11:11:00 the two ship's collide. The path of *Stockholm* based on data from her course recorder is shown above. So too is the path of *Andrea*

Doria based on her course recorder data but adjusted so that at 11:09:00 she is 1.85 nautical miles bearing 20° off *Stockholm's* port bow as Carstens had claimed. It is quite clear from the above picture that there is no way that a collision would have resulted if the situation as described by *Stockholm's* third officer was correct.

We now can do a similar analysis for *Andrea Doria*. *Andrea Doria's* senior second officer, Curzio Franchini, claimed that *Stockholm* was 3.5 nautical miles away and bearing about 15° to starboard on his radar when Capt. Calamai ordered a 4° course change to port to open the passing distance between the two ships. Third Officer Eugenio Giannini, claimed that the target was bearing about 30° to 35° to starboard when it was about 1 ½ miles away. And Franchini claimed that when the lights of the vessel were first seen about a mile away it was bearing about 40° to starboard.

Again using the power of the spreadsheet, the situation can be setup and the results plotted as shown below.



The path of *Andrea Doria* based on data from her course recorder is shown above. So too is the path of *Stockholm* based on her course recorder data but adjusted so that at 11:05 p.m. she was located 3.5 nautical miles bearing 15° off *Andrea Doria's* starboard bow as claimed by the *Doria's* officers. As was for the case of *Stockholm*, it is quite clear from the above picture that there was no way that a collision would have resulted if the situations as described by *Andrea Doria's* officers were correct.

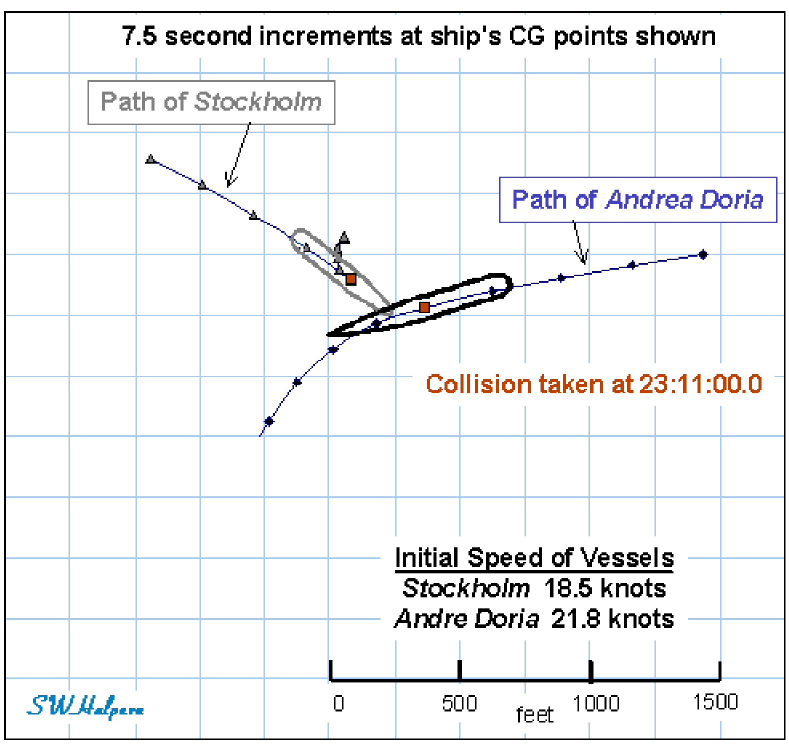
The bottom line is that the stories given by both sides do not hold up to careful forensic analysis based on data taken from the course recorders of each ship. Essentially, the two ships were heading nearly head on to each other, and both failed to take appropriate and decisive action early enough to avoid a collision.

THE DYNAMICS OF THE COLLISION

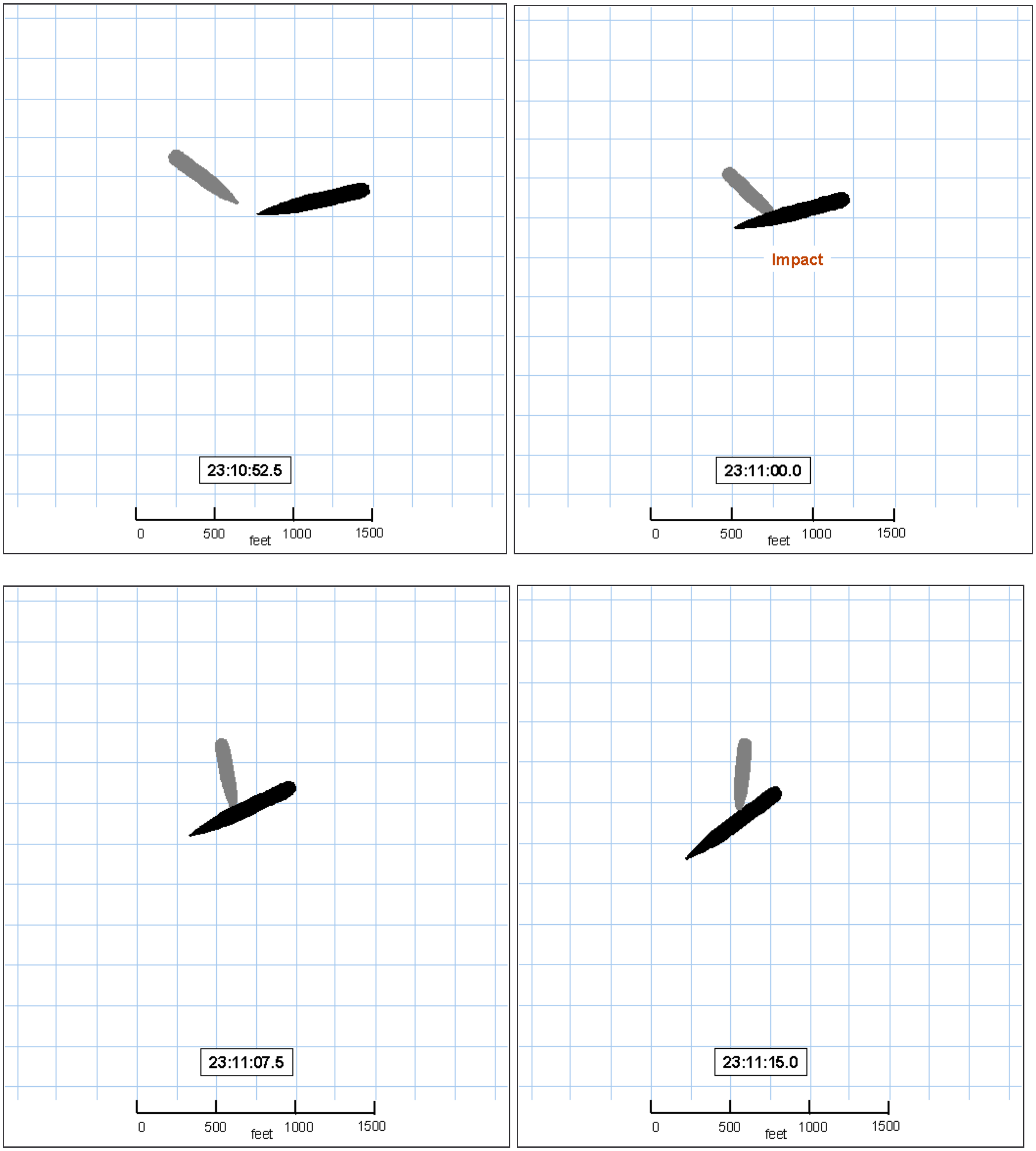
In addition to recreating the true approach picture leading up to the collision, we can also analyze the dynamics of the collision itself and the resulting short term movements of both ships immediately following the collision. This is described in some detail in Appendix C, and the reader is referred to that section for many of the specifics.

Based on the analysis of the dynamics, we find that the total combined kinetic energy before the collision was about 713,000 ft-tons. As a result of the collision, there was a loss of 55% of this total energy which was released in the crushing of the ship structures. The impact of the two ships resulted in a decrease in speed for *Andrea Doria* from 21.8 knots to 15.6 knots in a matter of a few seconds. For *Stockholm*, the result of the impact was not only to kill her forward speed of 18.5 knots, but to impart a speed of 5.1 knots in the astern direction moments after impact. The reason for this was a transfer of some of *Andrea Doria's* energy to *Stockholm*, as the Italian liner was the much more massive of the two vessels and was also traveling at the higher speed to begin with.

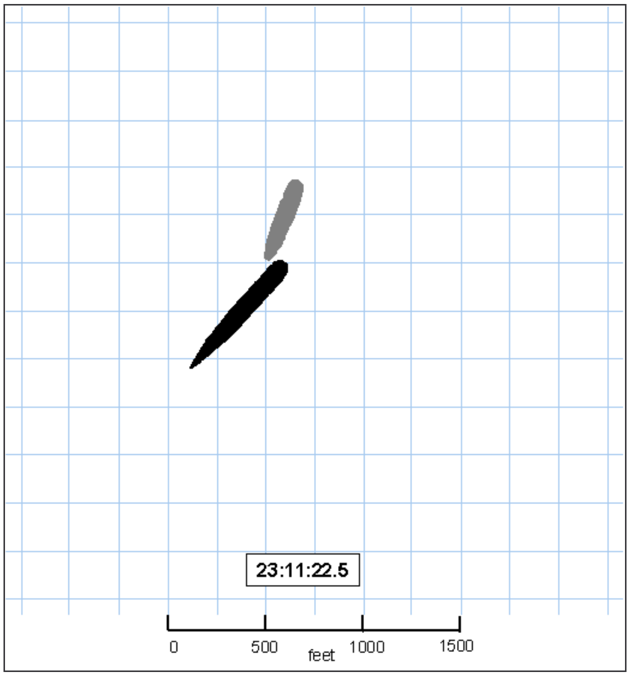
In addition to changes in velocities immediately following the impact, the *Andrea Doria* was imparted with an additional turning rate of 1.4° per second to port as a result of the location of the strike point and the direction of the impact impulse. *Stockholm* too was imparted with an added rotational velocity but it was 4.7° per second to starboard as a result of the impact impulse. Taking these results, and using data from the course recorders for before and after the collision, we can trace the movements of both ships through the collision process itself. This is shown in the diagram below in 7.5 second increments from interpolated data from the spreadsheet analysis.

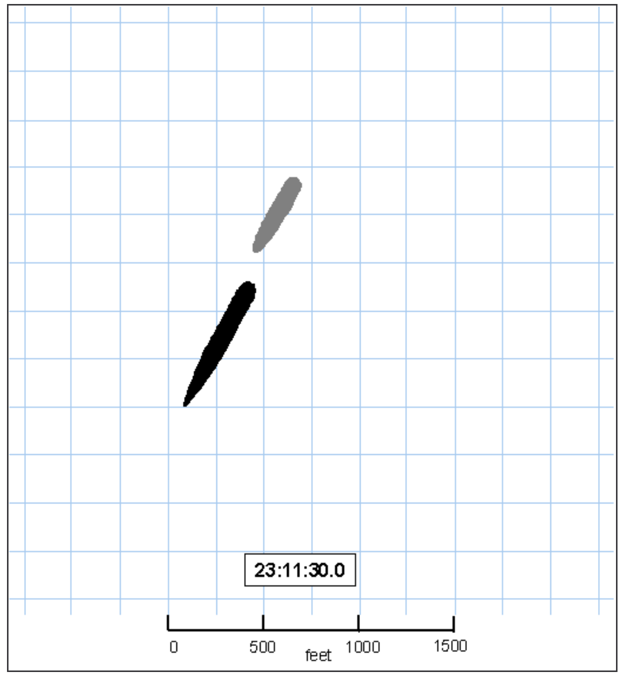


Not only can we show the movements of the center of gravity points of both ships before and after the collision, we can also animate the collision itself with the use of the heading data taken from the course recorders.[20] A sequence of these animated frames are presented below showing the collision itself from 7.5 seconds before impact to 30 seconds after impact.



[20] The only assumptions included here was the amount of deceleration of both vessels following the initial change in velocity vectors resulting from the impact itself.





Notice how quickly *Stockholm* was turned around by the more massive *Andrea Doria*, and how *Stockholm's* remaining bow would have scraped along the *Doria's* starboard side producing the shower of sparks described by witnesses as the *Doria* sped by at reduced speed.

THE ANGLE OF ENTRY

There have been several studies conducted over the years as to how these two ships ended up in collision. Reference has already been made to the work of John Carrothers in 1971. In that work, Carrothers shows *Stockholm* on a heading of 132° and *Andrea Doria* on a heading of 262° at the moment of collision, giving an angle of entry between the two ships of 50 degrees. Carrothers assumed that *Andrea Doria* turned only 3° before the impact came, and referred to a jog in the quadrant pen of the *Doria's* course recorder seen on the right side of the 270-360 quadrant line. A similar analysis was done by Captain Gustaf Ahrne in 1972 and presented in an article written for The Swedish Club, one of *Stockholm's* insurers.[21] Ahrne shows *Stockholm* on a heading of 130° and *Andrea Doria* on a heading of 220° at the moment of collision, giving an angle of entry of 90 degrees. Ahrne based that entry angle on damage seen in photographs of *Stockholm's* bow, thus deriving a 220° heading for the *Doria* at the moment of collision.

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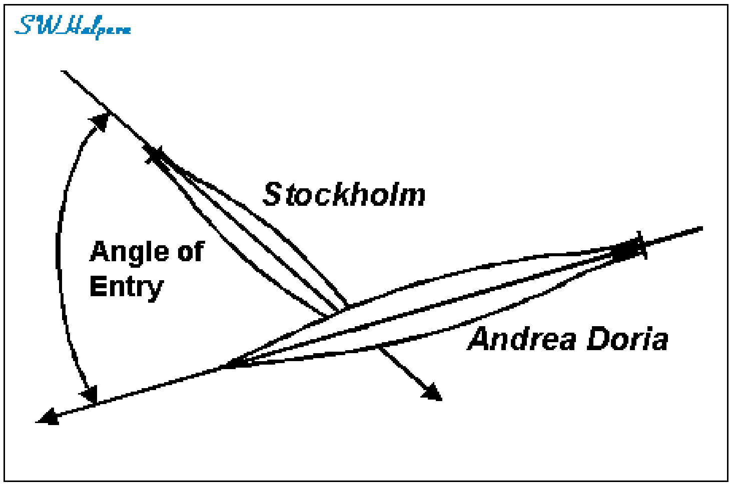
[21] Capt. Gustaf Ahrne, "A Radar Assisted Collision," reproduced in Appendix B of Algot Mattsson's book, *Out of the Fog*.



I believe a heading close to 220° for *Andrea Doria* does not seem to fit what her course recorder tells us because it shows a noted *decrease* in the turn rate that began near that heading angle.[22] This is just the opposite from what the collision dynamics tells us. The collision dynamics show that *Andrea Doria* would have been turned more rapidly to port immediately following the impact in addition to being slowed down. In the analysis presented here, I have the *Stockholm* on a heading of 129.5° and *Andrea Doria* on a heading of 254° at the moment of collision, giving an angle of entry of about 56° degrees. My observations that tend to support this are:

1. the jog from the pen on *Stockholm's* course recording near a recorder heading of 132,[23]
2. the jog from the quadrant pen of *Andrea Doria's* course recorder just as it started transitioning from the 270-360 quadrant into the 180-270 quadrant,[24]
3. the smudge that can be seen on *Andrea Doria's* course recoding near a recorder heading of 265,[25] and
4. the observation by *Andrea Doria's* officers that their ship had turned about 10-15 degrees to port just before the collision took place.

One of the claims made by the Swedish Line was to the effect that *Andrea Doria* started her final turn three minutes before the collision, and that the collision took place at the point where *Andrea Doria* stopped turning to port and started to turn to starboard as indicated on the course recorder graph. Their argument was that *Stockholm* broke the *Doria's* left turn and pivoted the

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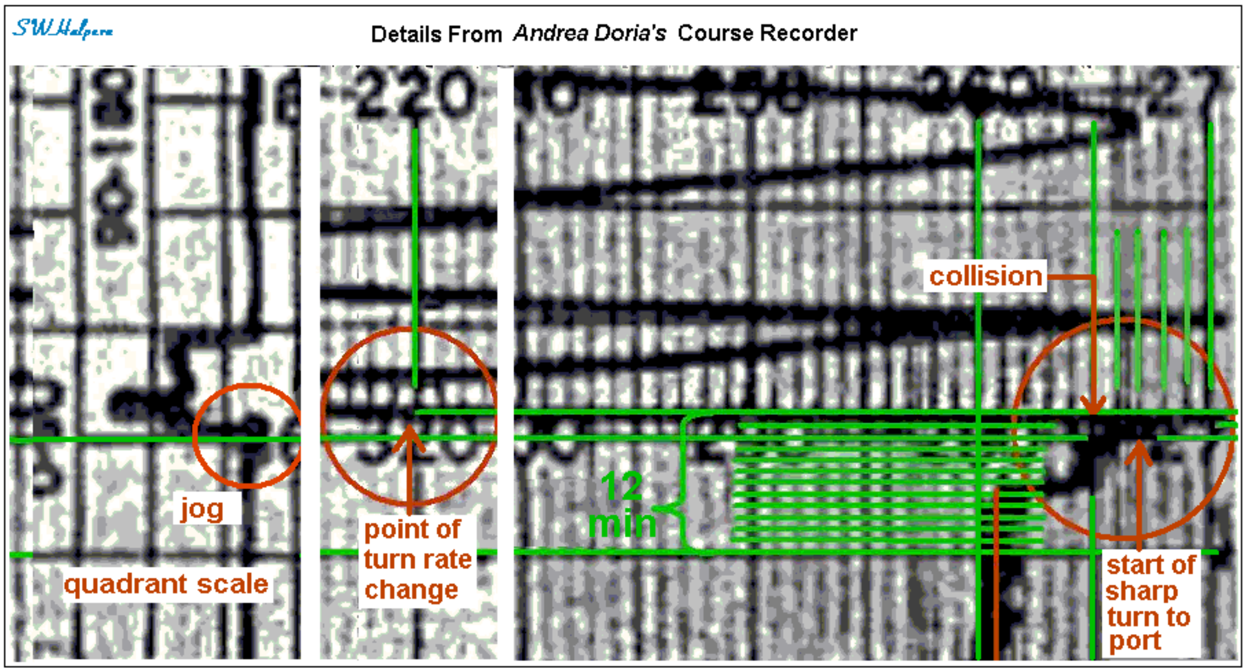
[22] The noted decrease in turn rate seen on the course recorder (about 210° true) was probably caused by tons water entering through the large gash left in the *Doria's* hull soon after the two ships separated from each other. At the same time, the *Doria* started to develop a list of 18° to starboard as tons of water came pouring in. *Andrea Doria* continued turning to port until it reached a heading of about 150° true. It then started to turn in the opposite direction as it was now moving somewhat out of control.

[23] The course pen on *Stockholm's* recorder was reading 2 ½ degrees ahead of the gyro compass.

[24] The momentary jog of the quadrant pen to the right (as viewed by the mark it left on the graph) is not at all inconsistent with the impact occurring after the ship turned at least 5 degrees to port from her previous course line.

[25] The course pen on the *Doria's* recorder was reading 11 degrees ahead of the gyro compass.

ship to the right when it became imbedded in *Andrea Doria's* side. This claim is false and does not hold up under careful analysis which shows that an impact just aft of the bridge wing would have caused *Andrea Doria* to swing further to port, not pivoting her to the right. Also, if the Swedish Line's contentions were true, the *Andrea Doria* would have had to turn about 110° prior to impact, and the entry angle between the two ships would have been about 145° bringing the *Stockholm* crashing in from aft instead of from ahead of the faster moving Italian liner. This claim is inconsistent with 75 feet of *Stockholm's* bow being crushed in after penetrating about 30 feet into *Andrea Doria's* side. It is also inconsistent with the *Doria* being spotted at 1.85 miles and 20° to port of *Stockholm* at the start of the final 3 minute sequence as was proven in the work of John Carrothers.[26]



A FEW "WHAT IF" SCENARIOS

It is always interesting to see what would have happened if certain events during the approach of the two vessels had or had not taken place. Once again we can use the power of the spreadsheet to investigate these. What is presented below is series of these "what if" scenarios based on the analysis that was developed. The results shown are from 11:04 to 11:11 p.m.

The first diagram shows the collision sequence in 30 second increments as it actually happened. *Stockholm* is coming from the west, and *Andrea Doria* from the east. (The scale shown in all these diagrams is ¼ nautical mile per division.)

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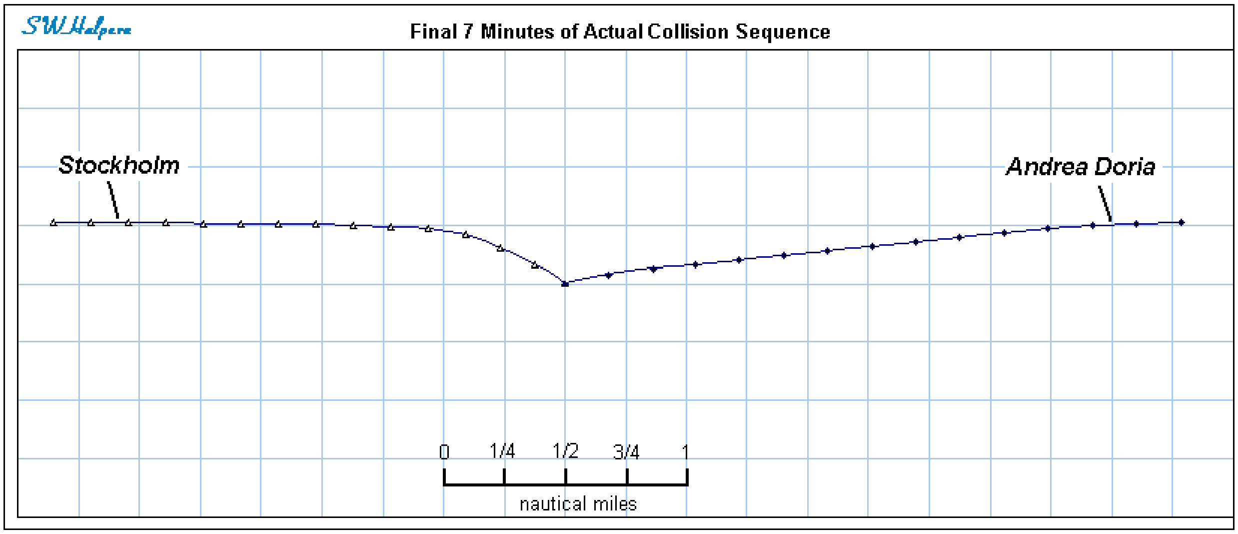
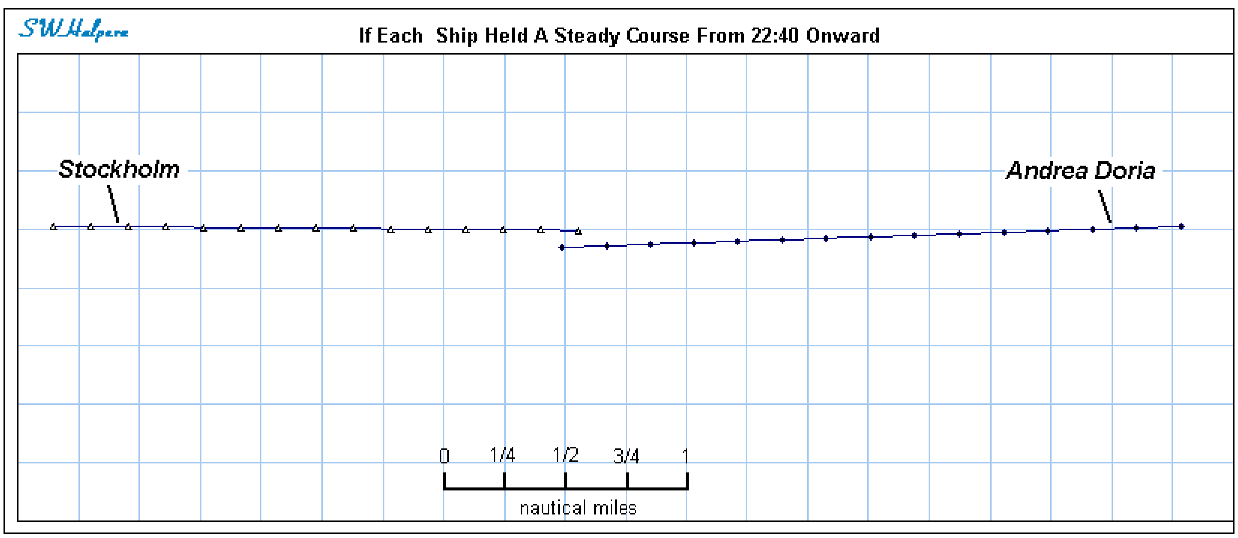
[26] Carrothers, Fig. 3.

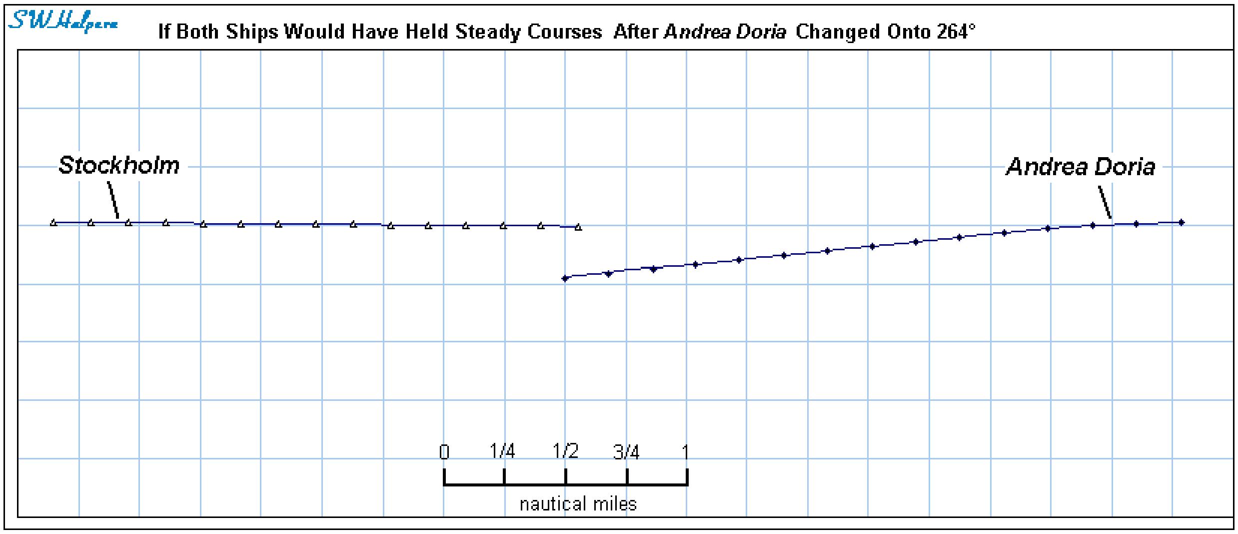


The next diagram shows what would have happened if each ship were held to a steady course from 10:40 p.m. onward. In this case *Stockholm* would have been on a mean heading between 090.5° and 091.0°, and *Andrea Doria* would have been held to a mean heading of 268°. What we see is that the two ships would have barely passed each other starboard-to-starboard at a very uncomfortable distance of less than 1/10 of a mile apart, less than the length of the *Andrea Doria*.[27]

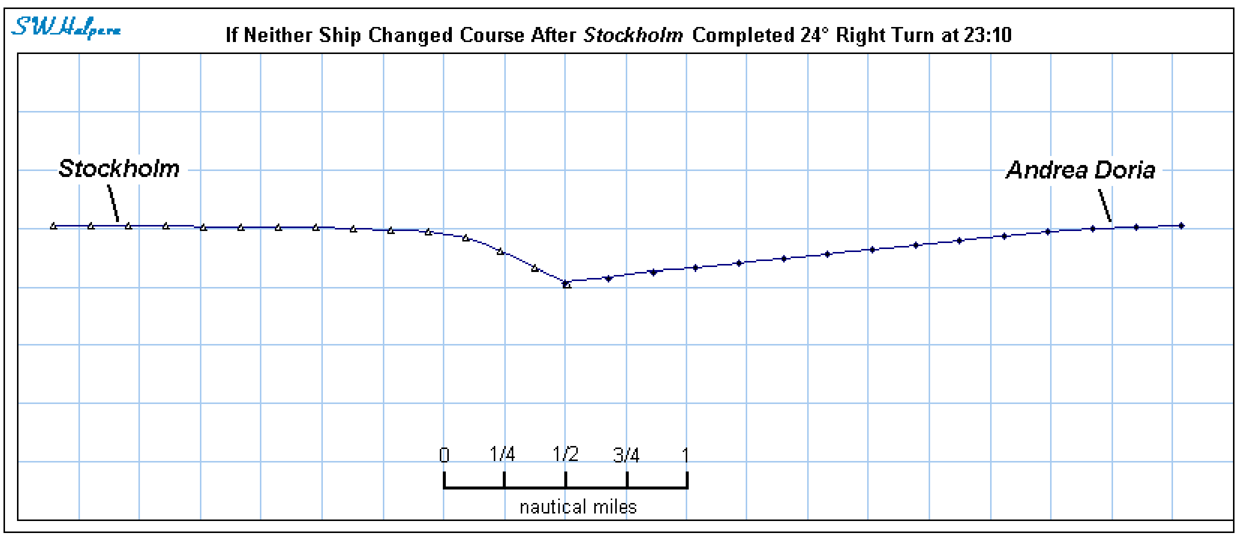


The next diagram shows what would have happened if each ship were held to a steady course after *Andrea Doria* changed course by 4° to port starting at 11:05 p.m. This time we see the two ships passing each other starboard-to-starboard at a distance slightly less than ¼ mile apart. Still too close for comfort.

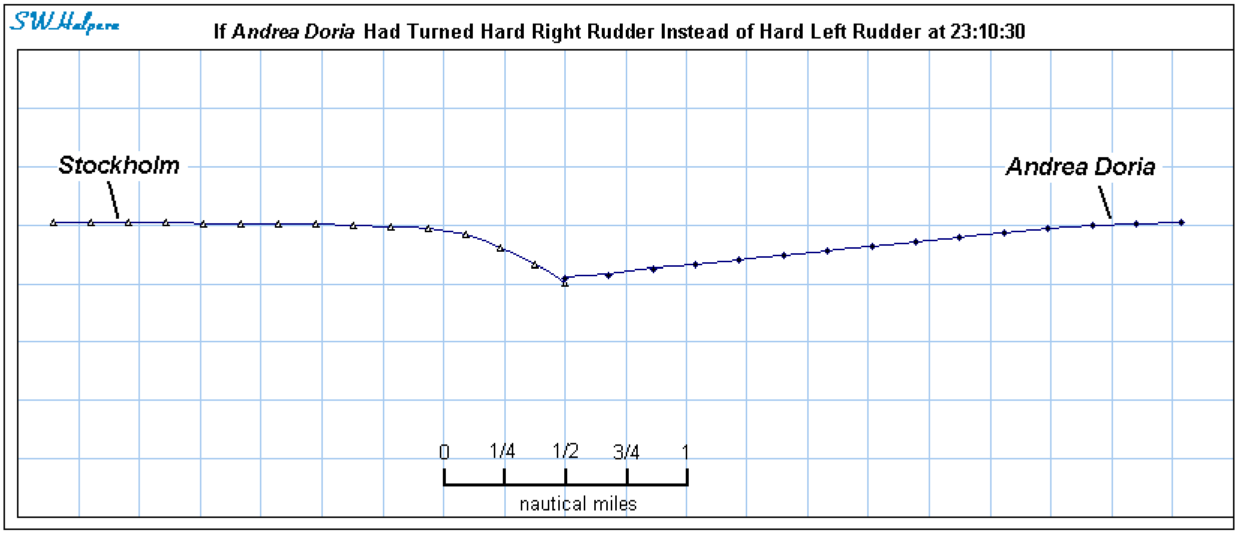
[27] *Andrea Doria* was 697 feet long, or 0.115 nautical miles in length. *Stockholm* was 525 feet long, or 0.086 nautical miles in length.



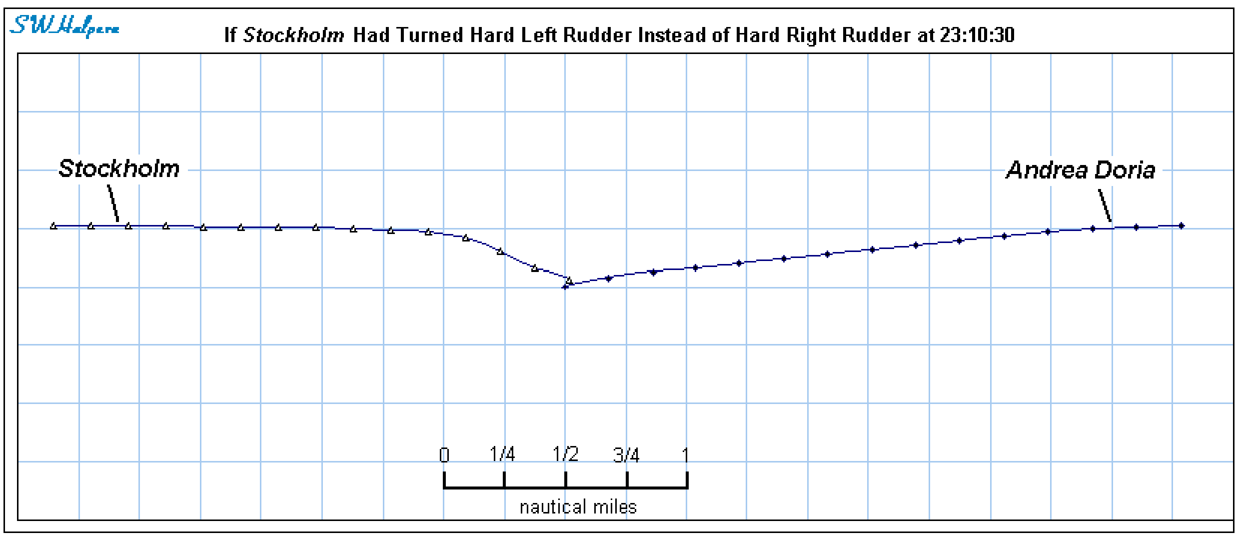
The next scenario shows what would have happened if neither ship changed course after *Stockholm* completed her 24° course change to starboard at 11:10 p.m. In this case, a collision would result.



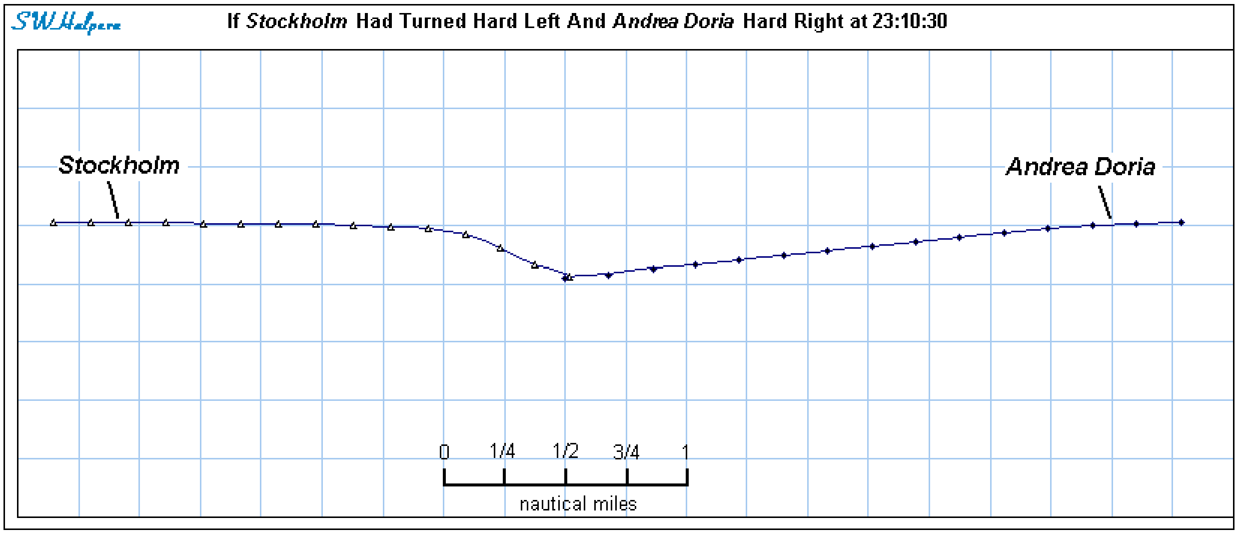
It has been suggested that Capt. Calamai should have ordered a hard turn to starboard rather than a hard turn to port when it became clear to him after seeing *Stockholm's* lights that the oncoming ship was turning toward them. The result of taking this action is shown in the next diagram. Again a collision would have resulted but with *Andrea Doria* striking into *Stockholm* rather the other way around.



Similarly, if Carstens-Johannsen would have ordered hard-aport instead of hard-astarboard when it was clear that *Andrea Doria* was crossing his bow, the result would still have ended in a collision, but this time with *Stockholm* striking further aft nearer *Andrea Doria's* stern.

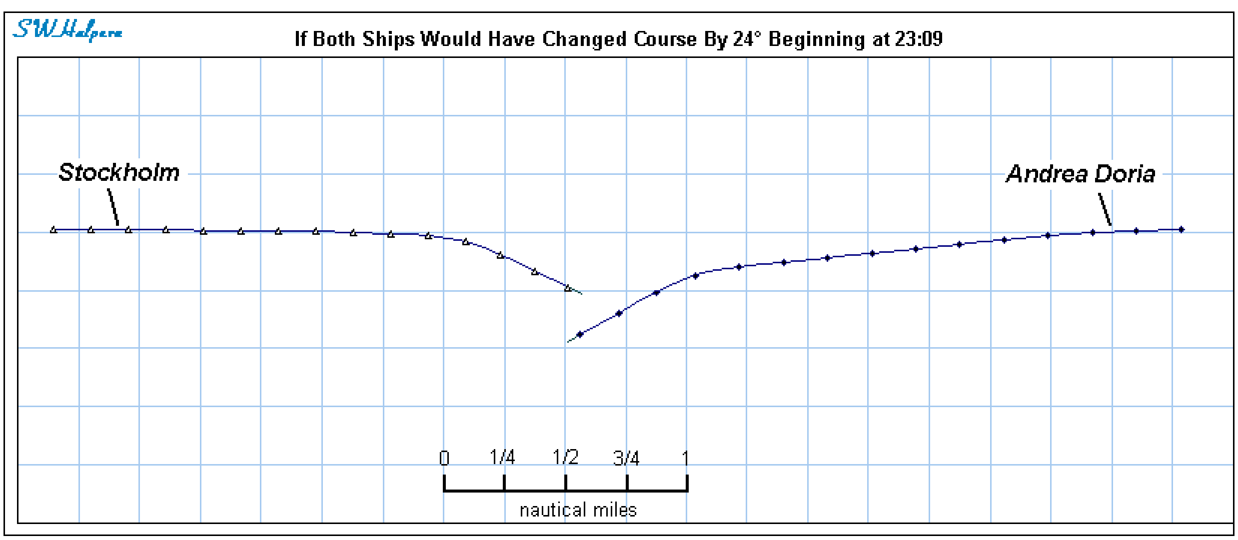


Finally, if *Stockholm* would have turned left and *Andrea Doria* turned right (the opposite of what they both did) when it became clear that the two ships were on a collision course, the result would still have ended in disaster with the possibility that neither ship would have remained afloat because of the sharp strike angle between them.



These last four scenarios show that once *Stockholm's* 24-degree turn to starboard was completed, a collision was unavoidable. During the pretrial hearings it was brought up that Carstens-Johannsen failed to signal his hard-astarboard turn when he tried to take evasive action after seeing *Andrea Doria* about to cross his bow, while Capt. Calamai did signal his hard-aport turn when he took evasive action after seeing *Stockholm* turning toward him.[28] The results above clearly show that it just didn't matter if whistle signals were given or not. Essentially, it was all too late. There was nothing that either side could really do once these ships came out of the fog.

There were two other scenarios that were considered. The first was what if *Andrea Doria* had started a 24° turn to port at the same time *Stockholm* had started her 24° turn to starboard. The result would have been that the two ships would have passed each other with about a ¼ mile separation between them with *Andrea Doria* crossing ahead of *Stockholm's* bow as seen below.



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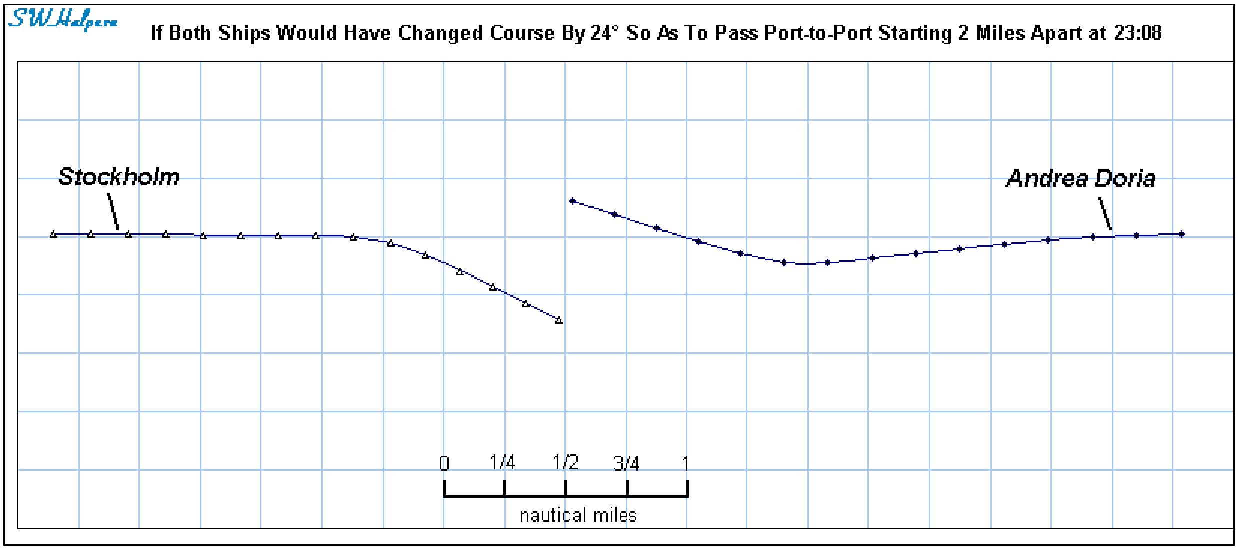
[28] The signals to be given was to sound the whistle with one short blast to indicate a turn to starboard, or two short blasts to indicate a turn to port.

The last scenario considered was what if both ships had turned 24° to the *right* as late as 11:08 p.m. when they were only 2 miles apart so as to pass each other port-to-port as required by law for two ships in visual contact and approaching each other nearly head on with a possibility of collision. The result, as shown below, would have been a safe port-to-port passing at distance of about ½ nautical mile.



WHY DID IT HAPPEN?

There were many actions and inactions that one can point to as contributing directly or indirectly to this collision.

1. The first started with the choice of using an eastbound route which put *Stockholm* into the direct path of oncoming westbound shipping heading to New York. Capt. Nordenson's argument that meeting ships head on would be safer than meeting them in a crossing situation was fallacious. Going eastbound on the recommended westbound lane would expose his ship to oncoming traffic for over a distance of about 200 miles. Crossing those westbound lanes going northward after departing the recommended eastbound lane to the south would expose his vessel to crossing traffic from ships coming from Irish, English and Mediterranean waters over a distance of only 10 to 15 miles. The exposure interval to crossing traffic would be only 5%-8% of the exposure interval to head-on traffic. The real reason for taking the more northern route was that it shortened slightly the overall distance his ship had to travel home, and more importantly and unstated, it kept him from having to give way to any westbound ships that would be crossing his bow from the starboard side as he was heading northward in accordance with the rules of the road that were in effect.[29] Essentially, it was all about cutting distance and saving a little time.

[29] The rule states that when two power-driven vessels are crossing so as to involve risk of collision, the vessel which has the other on her starboard side shall keep out of the way and shall, if the circumstances of the case admit, avoid crossing ahead of the other vessel.

2. Another contributing factor was the inexperience of the young third officer who was left to work the bridge by himself on *Stockholm.* Despite being assisted by three seaman, Carstens-Johannsen was expected to do it all. He was require to personally maintain a lookout, monitor the radar set, take periodic RDF bearings, plot his ship's course, keep a close eye on an inattentive helmsman, note the time and order course changes as needed, and so on. Despite taking several RDF bearings on the Nantucket Shoals lightship at different times, the young third officer was unaware that the lightship was broadcasting special weather reports indicating that it was in dense fog while he was on the bridge.[30] When *Andrea Doria* was seen closing rapidly on his radar screen at under 6 miles, Carstens never once suspected that the reason he could not see the lights of the approaching ship was that it was enveloped by fog ahead; fog that was known to form in those waters for that time of the year by those who traveled them often enough to know. The thought of calling Capt. Nordeson when he began to worry why he couldn't see the lights of the oncoming ship apparently never crossed his mind. He assumed he would see it soon enough to maneuver his ship to pass it safely on his port side.

3. Another contributing factor appears to be the dependence on *Stockholm's* helmsman to provide accurate heading reports while Carstens-Johannsen was trying to plot the radar picture. This helmsman was known to be inattentive, and was not keeping a very steady course. This may also have distracted Carstens from keeping his concentration on the approaching vessel once it appeared on the radar. As a result of having to depend on an inattentive helmsman, errors in reporting his own ship's true heading may have contributed to errors on the radar plot that suggested that the approaching vessel would pass them port-to-port at a distance of about ½ mile.

4. The next contributing factor was the inexcusable failure of those on the bridge of *Andrea Doria* to plot the radar picture as it was developing. Additionally, it is also possible that accurate radar bearings were not taken by using the cursor on the radar screen as the two ships were drawing nearer to each other, thereby contributing to wider bearing angles being interpreted and reported than what was actually the case. Neither Capt. Calamai nor Senior Second Officer Farnchini, who manned the radar scope for most of the time, had any special training in the use of radar.[31] The plotting board was kept in the chart room and was not used when needed the most. As Capt. Calamai was forced to admit during the pretrial hearings, "If I would have had that information [that the passing distance had closed from 0.8 mile to 0.2 miles], I would have stopped the engines immediately, giving then full speed astern and coming possibly to the right, giving the signal of a turn to the right." Second Officer Franchini was also forced to admit under oath that if he were in command of the *Doria* and had seen by plotting the radar picture that the passing distance between the ships was actually closing rather than opening, then he too would have taken a different course of action. As we have seen, there was plenty of time for them to play it

[30] Goldstein, Ch. 6. Forecast weather reports available to Carstens earlier that day had indicated fog to the east of the lightship.

[31] Moscow, Ch. 14.

safe and go for a port-to-port passing by turning to starboard early on. It was admitted that there was plenty of open water for them to do that.

5. In addition to not plotting the radar picture, there appears to have been a breakdown in what today is called bridge team management on the *Andrea Doria*, as well as a situation awareness failure. As mentioned before, once Second Officer Franchini heard a report that the faint glow of lights could be seen in the nighttime fog from out on the bridge wing, he decided to leave the radar and go out on the bridge wing to join Capt. Calamai and Third Officer Giannini to see for himself. As Franchini was about to do that, he was further distracted by a phone call from the lookout stationed out on the bow who called to report seeing lights off to starboard. The possibility of seeing that the bearing to *Stockholm* was not opening up was thereby missed. Similarly on *Stockholm*, Third Officer Carstens-Johannsen was distracted by a phone call from the lookout in the crow's nest. In this case, Carstens was kept from maintaining visual contact on the lights of the *Doria* that were fast becoming visible off his port bow. As on the *Doria*, there was nobody at the radar once the glow of lights were seen.

6. Another contributing factor to the collision was Capt. Calamai ordering his ship's course be changed by a mere 4 degrees at 11:05 p.m. to open a starboard-to-starboard passing distance between ships. A heading change of 4 degrees will not be easily noticed on the radar screen of an approaching vessel. It would take several minutes to realize that the direction of relative motion has changed. The fatal error made by Capt. Calamai was to *assume* that the other ship had also decided to pass starboard-to-starboard. He did not allow for any sudden or unexpected course changes by the unseen approaching vessel, or imagine that the approaching vessel would try to pass port-to-port as required by the rules of the road for two ships approaching each other nearly head on.

7. The next contributing factor was Carstens-Johannsen waiting as late as 11:09 p.m. to order a course change of more than 20 degrees to starboard to ensure a safe port-to-port passing. At the time he ordered that change, the two ships were only 1.3 miles apart, not the 1.85 miles as he was to claim later at the pretrial hearings. As we have seen from the relative radar picture that we constructed from the data analysis, the relative bearing of the approaching *Andrea Doria* was mostly head on to him or slightly to starboard from 4 miles and under. Carstens made the right decision to pass the oncoming vessel port-to-port, but he waited far too long to take decisive action. As we have seen, by the time that starboard turn was completed, the fate of both ships had been sealed.

As Captain Richard Cahill, fellow of Britain's Royal Institute of Navigation and former professor at the US Merchant Marine Academy had put it, "Both vessels were to blame."[32]

Another item raised at the pretrial hearings was the practice of speeding in conditions of reduced visibility such as fog. The rule in effect at the time called for ships to proceed at a moderate speed under such conditions. It was understood that moderate speed meant that a ship must be able to stop within one-half the distance of the prevailing visibility. The rationale was quite

[32] Goldstein, Ch. 33.

simple. If the visibility was 2 miles, and each ship could come to a stop within 1 mile, then a collision could be avoided. However, in practice, few ships with a schedule to keep actually followed this. The *Andrea Doria* made a token reduction in speed from 23.3 knots to 21.8 knots. The *Stockholm* did not reduce speed at all since it was claimed that she was not in any fog up to the time of the accident, and that the diesel motor ship *Stockholm*, unlike a steam turbine driven ship such as *Andrea Doria*, could come to a dead stop from full ahead within a distance of only 1 mile if need be. This of course assumed that the engine room personnel were kept on standby. However, it was admitted by *Stockholm's* chief officer, Herbert Kallback, that it was *not* the practice on *Stockholm* to reduce speed fog.[33]

In reality, the issue of speed was brought up for the purpose of attempting to lay blame. But both ships were not exactly running blind. They both were equipped with radar which showed where the other ship was relative to their own with each sweep of the rotating flasher hand. The failure was the dependence that those on the bridge of each ship placed on what they saw on the radar or interpreted from it, and a failure to appreciate some of its limitations and allow enough time or distance for sudden actions to be taken by the target vessel.[34]

A COLLISION CHRONOLOGY

Based on the analysis presented here, we can construct a chronology of the key events leading up to the collision. This is presented below.

TIME	EVENT
8:00:00 PM	Change of watch. On *Andrea Doria,* Senior Second Officer Curzio Franchini takes over as OOW from First Officer Luigi Oneto, and Junior Third Officer Eugenio Giannini relieves Junior Second Officer Guido Badano. Capt. Piero Calamai was in command of the vessel and on the bridge. *Andrea Doria* heading 267° at 21.8 knots in relatively dense fog. On *Stockholm*, seaman Sten Johansson came on as standby, seaman Ingemar Bjorkman took the helm, and seaman Peder Larsen went up into the crow's nest as lookout. *Stockholm* heading 090° at 18.5 knots with 5 to 6 miles visibility.
8:30:00 PM	Twenty-six year old Third Officer Carstens-Johannsen takes over as OOW on *Stockholm* from Senior Second Officer Lars Enestrom.
9:00:00 PM	Approximate time *Stockholm's* Capt. Gunnar Nordenson comes up to the bridge to check things over.
9:20:00 PM	On *Andrea Doria* Giannini picks up the Nantucket Shoals lightship on radar, dead ahead at a distance of about 17 miles. On *Stockholm*, Johansson takes over at the helm, Bjorkman takes the lookout, and Larsen becomes the standby.

[33] Moscow, Ch. 13.

[34] For example, you can determine the range and bearing to a target, but you would not know the target's mean heading without plotting two or more positions taken some time apart. If a target made a sudden unexpected turn, there was no way to know that until some time later when you could see how it affected the course she was on. By then it might be too late to react.

9:40:00 PM	Capt. Calamai orders *Andrea Doria's* course changed from 267° to 261° to pass 1 to 2 miles south of the Nantucket lightship which is seen about 14 miles ahead on the radar. On *Stockholm* Capt. Nordenson orders a course change from 090° to 087° so his ship would pass within 1 to 2 miles south of the Nantucket lightship.
10:00:00 PM	Approximate time Capt. Nordenson leaves *Stockholm's* bridge to go below to his cabin.
10:04:00 PM	Carstens-Johannsen decides to fix *Stockholm's* position by taking RDF bearings off Block Island and the Nantucket lightship.
10:10:00 PM	Carstens-Johannsen orders a course change from 087° to 089° to compensate for the current that was setting *Stockholm* more northward than the course line laid out by Capt. Nordenson.
10:20:00 PM	2/O Franchini at *Andrea Doria's* radar reports they are 1 mile abeam the Nantucket lightship, and Capt. Calamai orders a course change from 261° to 268° to put *Andrea Doria* on a heading for the Ambrose Channel lightship.
10:30:00 PM	Approximate time Carstens-Johannsen takes RFD bearings on Block Island, the Nantucket lightship, and the Pollock Rip lightship to fix *Stockholm's* position.
10:40:00 PM	On *Stockholm,* Peder Larsen takes over at the helm, Johansson takes the lookout, and Bjorkman becomes the standby. Carstens-Johannsen orders a course change from 089° to 091°.
10:45:30 PM	*Stockholm* is picked up on *Andrea Doria's* radar at a distance of about 17 nautical miles bearing slightly to the right of the heading flasher.
10:53:00 PM	*Andrea Doria* is picked up on *Stockholm's* radar at a distance of about 12 nautical miles bearing slightly to the left of the heading flasher.
10:56:00 PM	Carstens-Johannsen plots *Andrea Doria* at 10 miles bearing 2° to port. In reality, *Andrea Doria* was close to dead ahead.
11:02:00 PM	Carstens-Johannsen plots *Andrea Doria* at 6 miles bearing 4° to port. In reality, *Andrea Doria* was only 2° to port.
11:05:00 PM	*Andrea Doria* and *Stockholm* are just 4 mile apart and both would be slightly to starboard of each other at this time.
11:05:30 PM	Capt. Calamai orders a course change of "4° to the left, nothing to the right" for *Andrea Doria*. The two ships are 3.6 miles apart when *Andrea Doria* comes on a heading of 264°.
11:09:00 PM	Carstens-Johannsen orders a turn to starboard on *Stockholm*. Distance between ships now at 1.3 nautical miles.
11:10:00 PM	*Stockholm* comes onto a heading of 117°. Johansson goes to the phone to call Carstens on the bridge as he sees lights about 20 degrees to port. Lights of the *Stockholm* are starting to appear to those out on the starboard bridge wing of *Andrea Doria* and to the lookout out on the bow. 2/O Franchini leaves the radar to go out to the bridge wing to see for himself, and is further distracted by a call from the lookout out on the bow. The ships are now just 0.6 miles apart.

11:10:30 PM Carstens gets off the phone and goes out onto *Stockholm's* port bridge wing where he sees the *Andrea Doria* showing a green sidelight about to cross his bow from left to right. He orders full right rudder and goes to the engine telegraphs to signal full astern. Out on the starboard bridge wing of *Andrea Doria*, Capt. Calamai sees the *Stockholm* showing a red sidelight and her forward masthead light swinging out to the left of the higher aft masthead light indicating the oncoming ship was turning into them. Calamai orders hard left rudder and calls for a whistle signal be given to indicate a turn to port.

11:11:00 PM Impact! The bow of *Stockholm* strikes into *Andrea Doria* just aft of the starboard bridge wing. *Stockholm* completed only 13 degrees of her hard turn to starboard, while A*ndrea Doria* completed only about 10 degrees of a hard turn to port. The impact of the collision rotates *Andrea Doria* even further to her left, and slows her forward movement down from 21.8 knots to 15.6 knots. *Stockholm* is thrown backward by about 5 knots initially, and rotated very sharply to starboard in the process.

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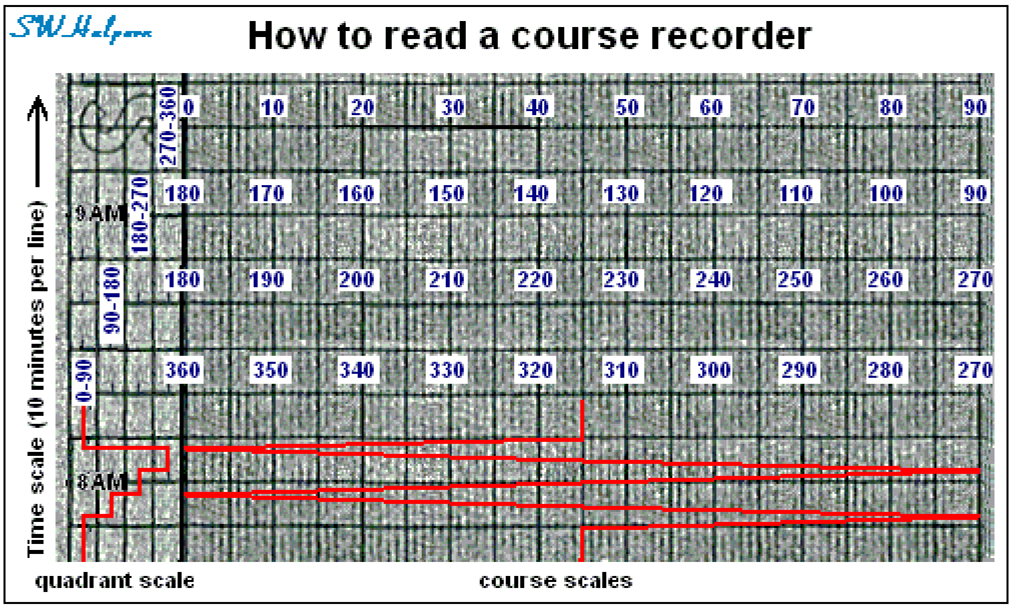
ACKNOWLEDGEMENT

I would like to thank Captain Charles Weeks, Professor of Marine Transportation and Nautical Science at the Maine Maritime Academy, and Capt. Les Eadie, Assistant Professor of Marine Transportation Operations at the Maine Maritime Academy, for reviewing this work and for the many helpful suggestions they offered.

APPENDIX A – COURSE RECORDERS

Course recorders were carried on both the *Andrea Doria* and *Stockholm* in July of 1956. These devices were linked to the ship's gyro compass and recorded the ship's heading as a function of time on a rolling strip of paper. The recording was made by two ink pens, one showing the heading of the ship covering a range of 90 degrees for a particular quadrant that the ship was heading in, and the other showing what quadrant to read from.

An example of a course recorder graph is shown below.

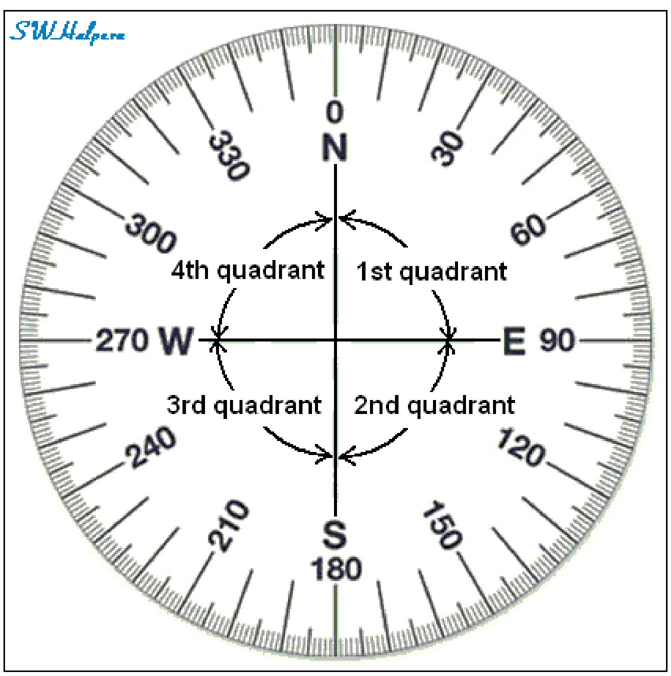


On the left most side of the paper strip is the quadrant scale. There are four quadrants marked off by heavy vertical lines, beginning from left to right: 0°-90°, 90°-180°, 180°-270°, and 270°-360°, as shown. The left-side pen will record which of these four quadrants the ship's head is pointing in. The right side of the paper strip has the course scale which records the actual course the ship is on when sailing in a given quadrant. The major divisions marked off by heavy vertical lines are in 5° increments. The smaller divisions marked off by thin vertical lines are in 1° increments. When the ship is sailing in the first quadrant, courses beginning from 0° on the far left to 90° on the far right will be recorded. When in the second quadrant, 90° starts on the far right going to 180° on the far left. The third quadrant has 180° on the far left going to 270° on the far right. And for the fourth quadrant, 270° is on the far right and goes to 360° on the far left.

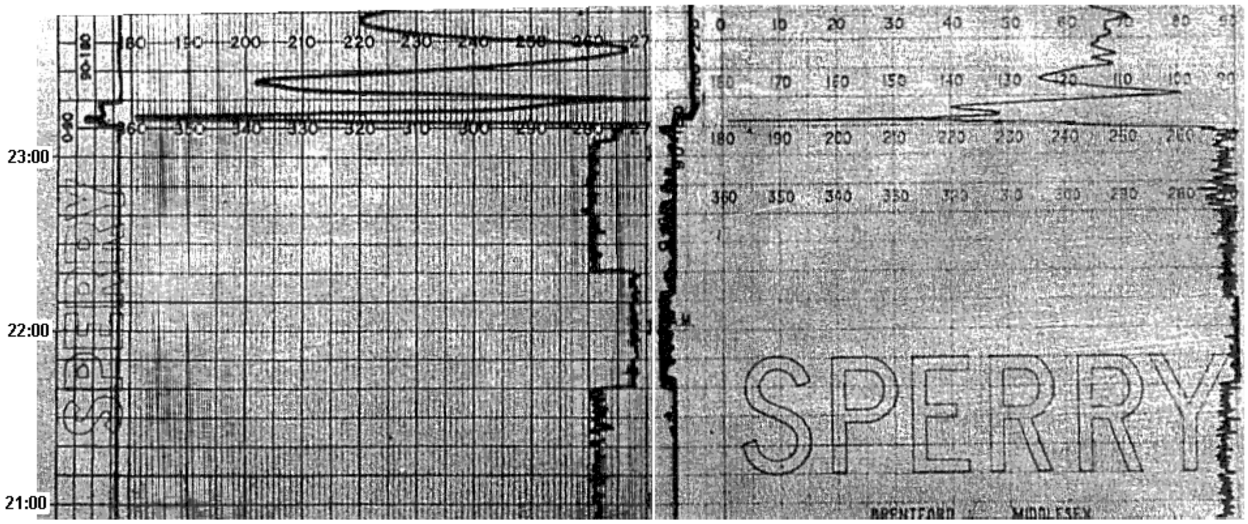
Time is shown by the heavy horizontal lines on the graph. These are in 10 minute increments. On-the-hour times are also marked. In the example strip of paper shown above, you can make out 8 AM and 9 AM marked on the left most side of the paper where the quadrant scale is. Increasing time moves up the paper as the motorized feed causes the paper to move downward under the recording pens.

An example of a recording of ship slowly changing direction to starboard is shown (in red) in the sample strip above. A the very bottom of the strip we see a ship on a steady heading of 045°. We know this because the quadrant pen is recording in the left most quadrant column, the one labeled 0-90, and the course pen is recording on the major line between the one marked 40 and the one marked 50 for course readings in the first quadrant. At 10 minutes before 8 AM (07:50:00) the ship starts to change its course very slowly to starboard. We know this because the course pen is seen moving across to the right indicating the course angle is increasing for a heading in the first quadrant. By 07:52:30 a heading of 090 is reached and the quadrant pen shifts into the second quadrant, 90-180, while the course pen is seen to reverse its direction of movement, now going from right to left. Because the ship's heading is now in the second quadrant, movement of the course pen from right to left means the course angle is still increasing. In other words, the ship is continuing to turn to starboard. By 07:55:00 it passes 135°, and by 07:57:30 it reaches 180°. At that point we see the quadrant pen move into the third quadrant, 180-270, and the course pen starts moving from left to right again, reaching the 225° line at 08:00:00 and continuing on to 270° which is reached at 08:02:30. Now the quadrant pen moves into the fourth quadrant as the course pen starts to move from right to left again. At 08:05:00 the course pen passes the line for 315°, and at 08:07:30 it reaches 360° when the quadrant pen moves back into the first quadrant. Now the course pen is seen moving from left to right again and reaches 045° at 08:10:00 where it stops moving across. At this point the ship has completed a full 360-degree turn, returning to its original course heading of 045° after taking a very long 20 minutes to complete a full turn.

For visual reference, quadrants and headings on a compass rose are shown below:



Copies of segments from the actual course recorder strips taken from *Andrea Doria* and *Stockholm* are shown below. These were aligned so that their time axes are in sync. Local Eastern Daylight Time (EDT) is also noted using 24 hour notation. Prior to the time of collision on the recorder charts, 23:11 (11:11 p.m. EDT), we can see the various headings and course changes made by both ships leading up to the final minute before the collision. After the collision we can see the very large swings in the headings of both ships as a result of both of them moving out of control.

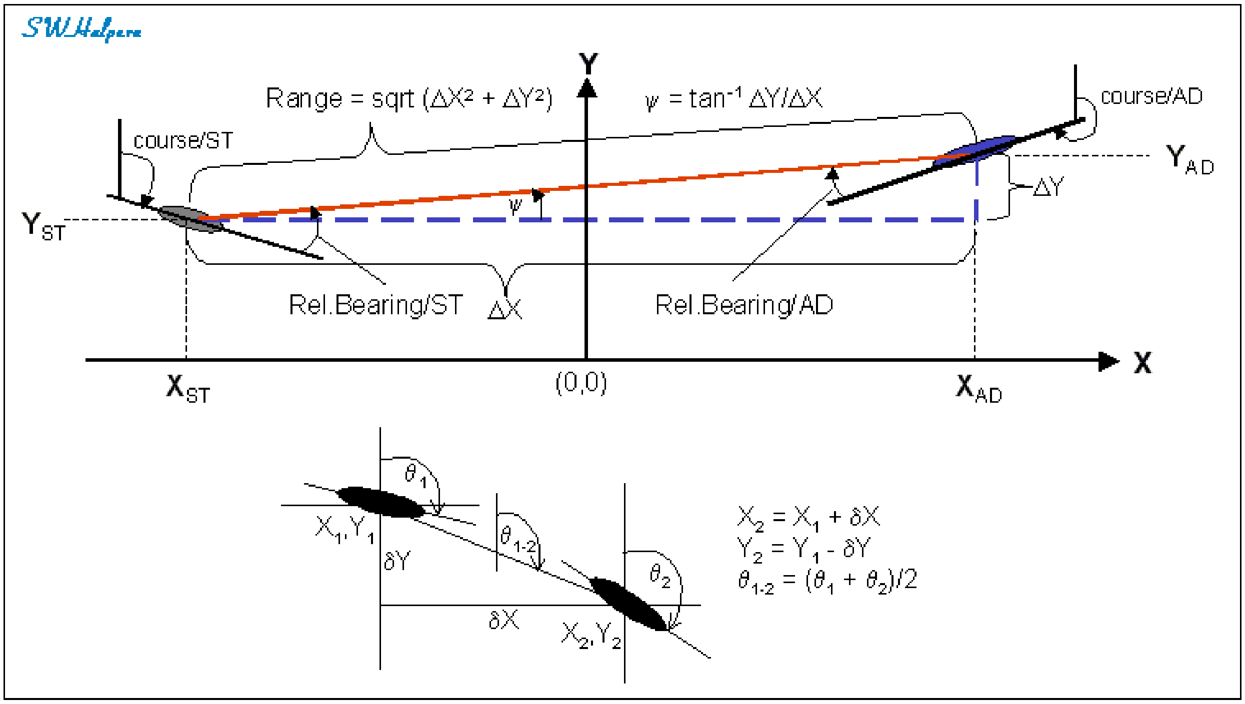


Andrea Doria **Course Recorder Prints** *Stockholm*

It must be noted that the actual times printed on the strip from *Stockholm* were in Greenwich Mean Time (GMT), or 4 hours ahead of Eastern Daylight Time. Thus the collision shows up at 03:11 GMT on the *Stockholm* strip. The time of collision on the strip from *Andrea Doria* reads close to 12:11 because when the recorder pen ran dry in Naples, the recorder time was no longer put in sync with GMT. These differences are easily compensated for when interpreting the actual data from the recorders. The other difference that must be compensated for is that between the heading given by the course recorder and the heading given by the ship's gyro compass. An offset between the two can exist depending how carefully the pen on the recorder was adjusted. For example, *Andrea Doria's* recorder was deliberately set about 10 degrees ahead of the gyro compass the day before the accident so as to keep it from recording near the edge of the paper as the ship was then heading close to due west. When interpreting readings from each recorder, a correction of *minus* 2 ½ degrees needs to be applied for *Stockholm,* and *minus* 11 degrees for *Andrea Doria* to get their correct gyro compass headings as a function of time.

APPENDIX B – SPREAD SHEET ANALYSIS
Working the Problem Backwards

Knowing the speeds and exact headings of each vessel we can reconstruct the movements of each vessel as a function of time. We can also determine the distance between vessels and the relative bearings of each as seen from the other for any given time. The set up for this is shown below.



The **X-Y** scale is in nautical miles. The coordinate system is chosen so that the collision point is taken at the origin, **X**=0,**Y**=0. In the above, **ST** = *Stockholm*, and **AD** = *Andrea Doria.* As can be seen in the diagram, **X** scale values for *Stockholm* ($\mathbf{X}_{ST}$) will be negative prior to the collision, while **X** scale values for *Andrea Doria* ($\mathbf{X}_{AD}$) will be positive prior to the collision.

The speed of *Stockholm* is taken at 18.5 knots, or 0.308 nautical miles per minute. The speed of *Andrea Doria* is taken at 21.8 knots, or 0.364 nautical miles per minute. The relative bearings are in degrees plus or minus, where a positive value means a bearing angle to starboard while a negative value means a bearing angle to port. "Rel.Bearing/ST" means the relative bearing of *Andrea Doria* as seen from *Stockholm*; while "Rel.Bearing/AD" means the relative bearing of *Stockholm* as seen from *Andrea Doria*. Course angles for both ships were taken from their respective course recorder data after correction for adjustment error was made as explained in Appendix A. For *Stockholm* this adjustment was –2.5°; while for *Andrea Doria* this adjustment was –11.0°. Using 24-hour notation, the time of collision was taken at 23:11:00 EDT based on the jump in the course heading pen seen on the recorder plot for *Stockholm.* This was precisely at 11 minutes past the hour line. Close examination and correlating course recorder data from both ships show that the 10 minute lines of *Andrea Doria*'s recorder were running about ½ minute ahead of those on *Stockholm*. Thus the collision event marked on *Stockholm's* graph at 03:11:00 GMT would have corresponded to 12:11:30 on *Andria Doria's* graph. (*Andrea Doria*'s recorder time was not keeping GMT but was showing 9 hours ahead of GMT after a pen was replaced when the ship was in Naples.) All these adjustments were accounted for when entering data into a spread sheet.

Starting at the origin at 23:11:00 and working backwards in 30 second increments, the X-Y coordinates of each ship were calculated based on its previous coordinates, its known speed, and the mean course heading between the two 30 second increments. A sample from the actual spreadsheet results for the last seven minutes leading up to the collision is shown below.

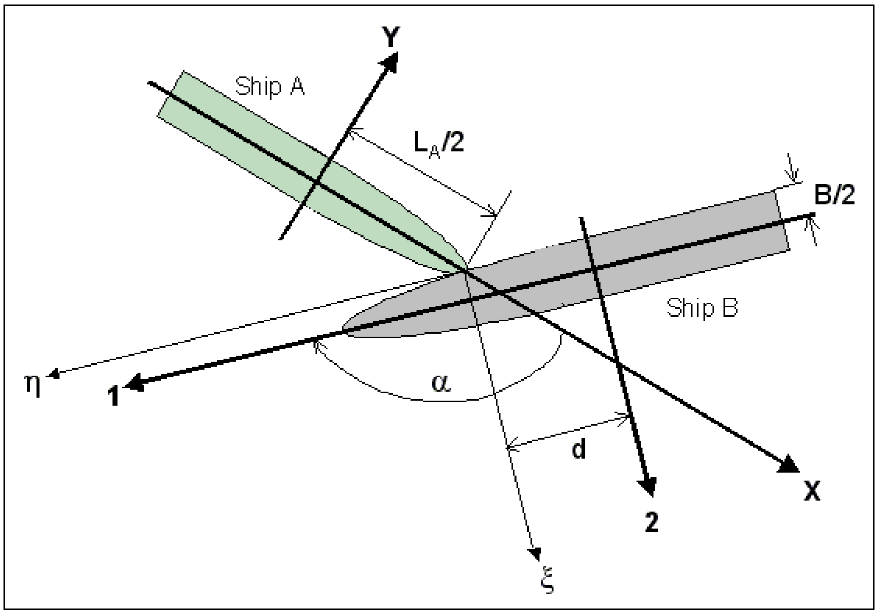
Sample of Spread Sheet Values from 11:04 P.M. to 11:11 P.M. in 30 Second Increments

time	course/ST	course/AD	Xst	Yst	Xad	Yad	ΔX	ΔY	Range	Ψ	Rel.B/ST	Rel.B/AD
23:04:00	90.5	268.0	-2.10	0.23	2.53	0.26	4.64	0.03	4.64	0.3	-0.8	1.7
23:04:30	89.5	268.0	-1.95	0.23	2.35	0.25	4.30	0.02	4.30	0.3	0.2	1.7
23:05:00	88.0	268.0	-1.79	0.24	2.17	0.25	3.96	0.01	3.96	0.1	1.9	1.9
23:05:30	89.5	264.0	-1.64	0.24	1.99	0.23	3.63	-0.01	3.63	-0.1	0.6	6.1
23:06:00	90.5	264.0	-1.49	0.24	1.81	0.22	3.29	-0.03	3.29	-0.5	0.0	6.5
23:06:30	89.5	264.0	-1.33	0.24	1.63	0.20	2.96	-0.04	2.96	-0.9	1.4	6.9
23:07:00	88.0	264.0	-1.18	0.24	1.44	0.18	2.62	-0.07	2.62	-1.5	3.5	7.5
23:07:30	90.0	264.0	-1.02	0.25	1.26	0.16	2.29	-0.09	2.29	-2.2	2.2	8.2
23:08:00	92.5	264.0	-0.87	0.24	1.08	0.14	1.95	-0.10	1.96	-3.1	0.6	9.1
23:08:30	92.5	264.0	-0.72	0.24	0.90	0.12	1.62	-0.12	1.62	-4.1	1.6	10.1
23:09:00	92.5	264.0	-0.56	0.23	0.72	0.10	1.28	-0.13	1.29	-5.8	3.3	11.8
23:09:30	105.0	264.0	-0.41	0.21	0.54	0.08	0.95	-0.12	0.96	-7.5	-7.5	13.5
23:10:00	116.5	263.0	-0.27	0.15	0.36	0.06	0.63	-0.09	0.63	-8.3	-18.2	15.3
23:10:30	116.5	262.0	-0.13	0.08	0.18	0.04	0.31	-0.05	0.31	-8.5	-18.0	16.5
23:11:00	129.5	254.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	#DIV/0!	#DIV/0!	#DIV/0!

APPENDIX C – EXTERNAL DYNAMICS OF THE COLLISION

The motor ship *Stockholm* (the striking ship), was listed at 12,165 Gross Registered Tons (GRT), 525 feet long, with a 69 foot beam and a 25 foot draft. The steam ship *Andrea Doria* (the struck ship), was listed at 29,100 GRT, 697 feet long, with a 90 foot beam and a 30 foot draft.

The setup used in deriving the external dynamics of the collision is shown below.



The notations and equations used for all the calculations come from the 1999 thesis of Shengming Zhang, "The Mechanics of Ship Collisions."[35] The relevant parameters are:

Ship A = *Stockholm*, the striking ship.

Ship B = *Andrea Doria*, the struck ship.

Direction of axis X = 130° true, the heading of *Stockholm* taken at the moment of collision.

Direction of axis 1 = 254° true**,** the heading of *Andrea Doria* taken at the moment of collision.

L_A = 525 ft, the length of the striking ship *Stockholm*.

L_B = 697 ft, the length of the struck ship *Andrea Doria***.**

[35] Shengming Zhang, "The Mechanics of Ship Collisions," Department of Naval Architecture and Offshore Engineering, Technical University of Denmark, 1999.

$B = 90$ ft, the beam (width) of the *Andrea Doria*.

$d = L_B /6 = 116$ ft, the approximate distance of the collision point ahead of the struck ship's center of gravity. (The center of gravity point was taken at amidships).

$\alpha = 124°$, the angular difference between the course headings of both ships at the time of the collision.

$M_B/M_A = 2.4$, the ratio of displacement of ship B to ship A (taken to be the same as the ratio of their Gross Registered Tonnage).

$W_B = 26{,}400$ long tons, the displacement (weight) of ship B.

$M_B = 1.8 \times 10^6$ slugs, the mass of ship B.

The results of the analysis based on Zhang's equations are listed below:

Kinetic energy of ships before impact

Stockholm = 164,000 ft-tons

Andrea Doria = 549,000 ft-tons

Total combined energy of both ships = 713,000 ft-tons

Impact impulses

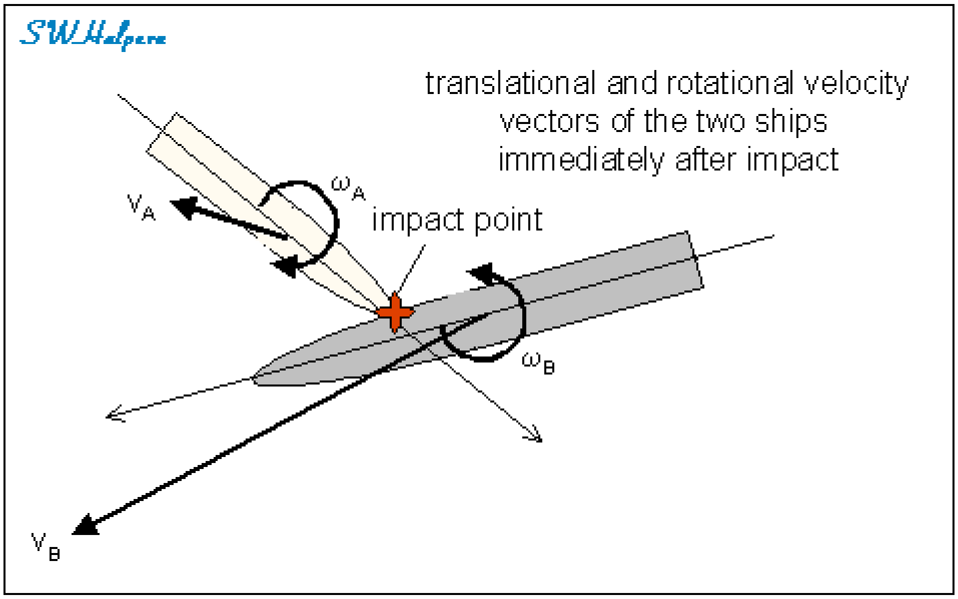
In longitudinal direction of *Andrea Doria* $I\eta = -9{,}650$ ton-seconds
In lateral direction of *Andrea Doria* $I\xi = +10{,}000$ ton-seconds

Energy released during crushing of ship structures

In longitudinal direction of *Andrea Doria* $E\eta = 264{,}000$ ft-tons
In lateral direction of *Andrea Doria* $E\xi = 129{,}000$ ft-tons

Total combined energy *loss* during collision = 393,000 ft-tons
or 55% of total combined kinetic energy before the collision.

Besides the energies involved, we can also analyze the movements of both ships immediately before and after the collision. A change in translational velocities and imparted rotational velocities took place. Translational and rotational velocity vectors immediately after the collision are shown in the diagram below. (A negative value implies an astern velocity; a positive value implies an ahead velocity.)



Velocities of both ships before impact

Stockholm (V_A) = +31.2 ft/sec *immediately before* impact (+18.5 knots)
Andrea Doria (V_B) = +36.9 ft/sec *immediately before* impact (+21.8 knots)

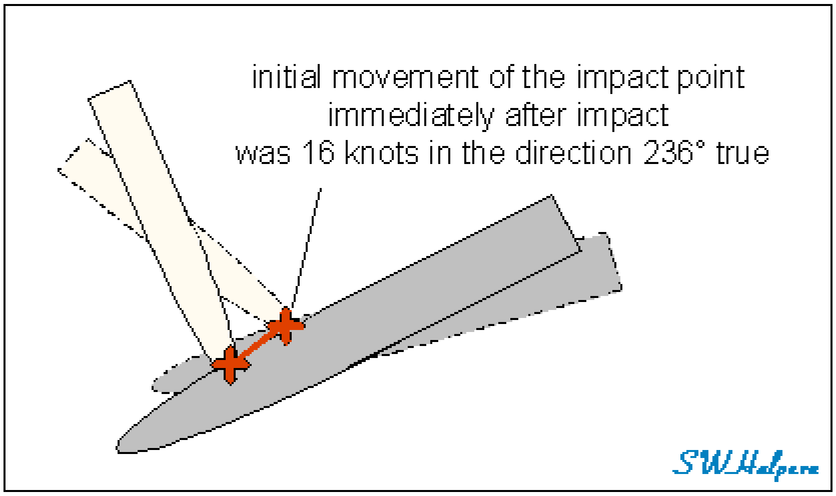
Velocities of both ships immediately after impact

Stockholm (v_A) = -8.6 ft/sec *immediately after* impact (-5.1 knots)
Andrea Doria (v_B) = +26.4 ft/sec *immediately after* impact (+15.6 knots)

Additional imparted rotations *immediately after* impact

Stockholm (ω_A) = 4.7°/sec to starboard
Andrea Doria (ω_B) = 1.4°/sec to port

As a result of the initial movement of both ships immediately after impact, the impact point itself, the point where two ships were locked in contact with each other, was moving at about 16 knots in the direction of 236° true as shown in the following diagram.



This movement of the impact point as shown was a combination of the rotational and translational movements of both ships and lasted only for the very brief time that both ships were locked together.