

Lights to Port - Lights to Starboard

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

by
Samuel Halpern

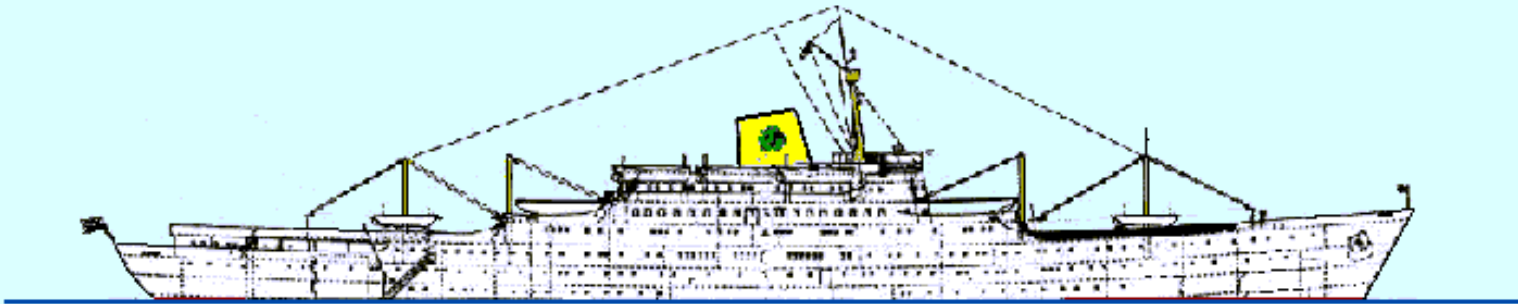
November 2008

STOCKHOLM and ANDREA DORIA

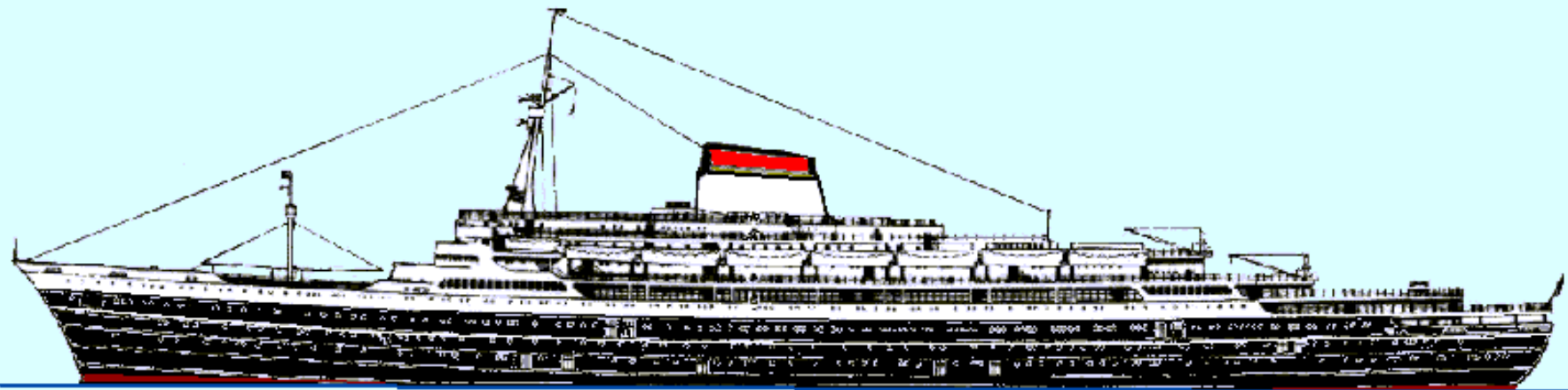
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The Two Ships



Stockholm — 12165 GRT, Length 525 ft, Beam 69 ft, Draft 25 ft



Andrea Doria — 29100 GRT, Length 697 ft, Beam 90 ft, Draft 30 ft

Stockholm

Before



After



Andrea Doria

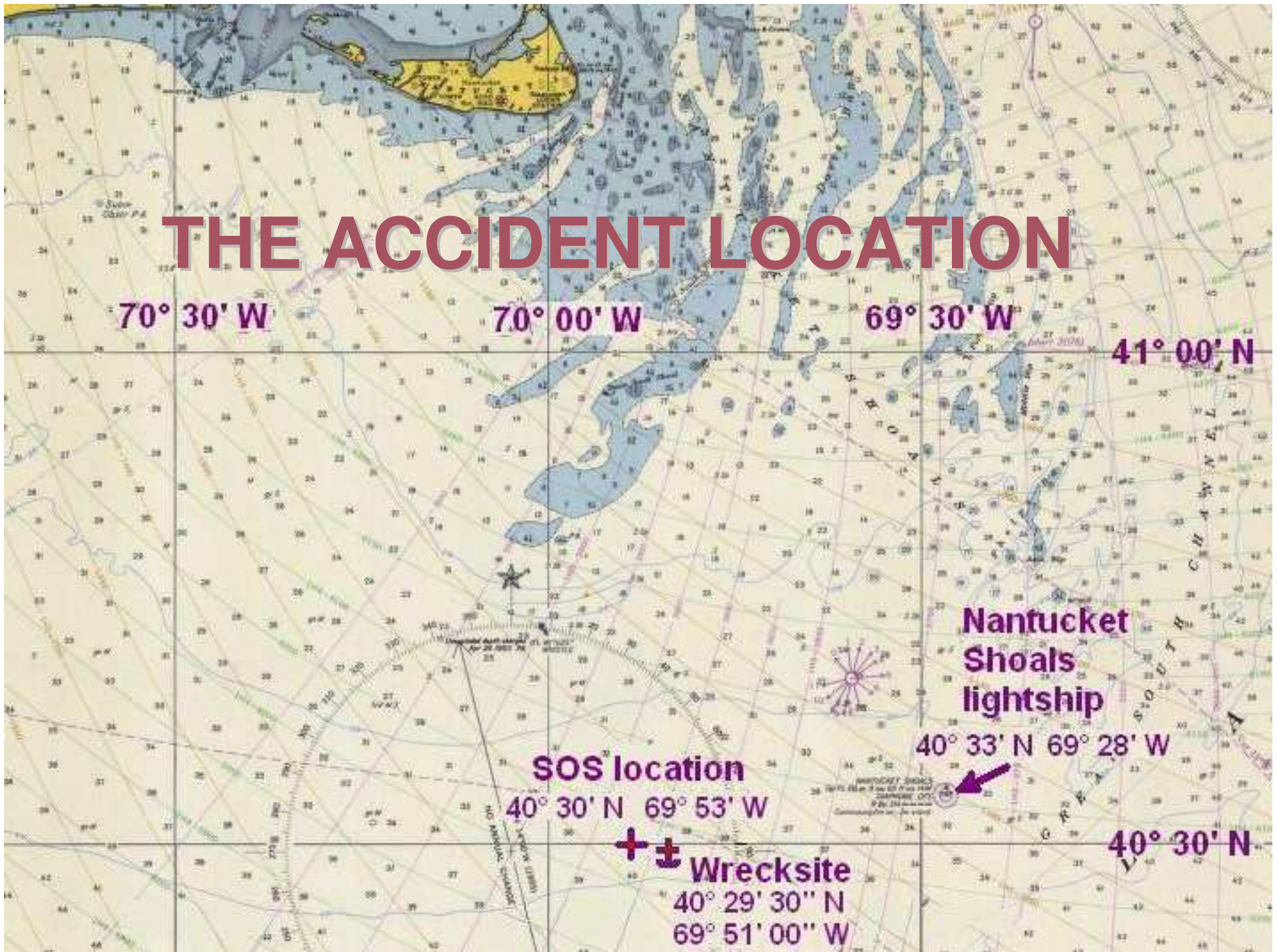
Before



After



THE ACCIDENT LOCATION



70° 30' W

70° 00' W

69° 30' W

41° 00' N

Nantucket
Shoals
lightship

40° 33' N 69° 28' W

SOS location

40° 30' N 69° 53' W



Wrecksite

40° 29' 30" N

69° 51' 00" W

40° 30' N

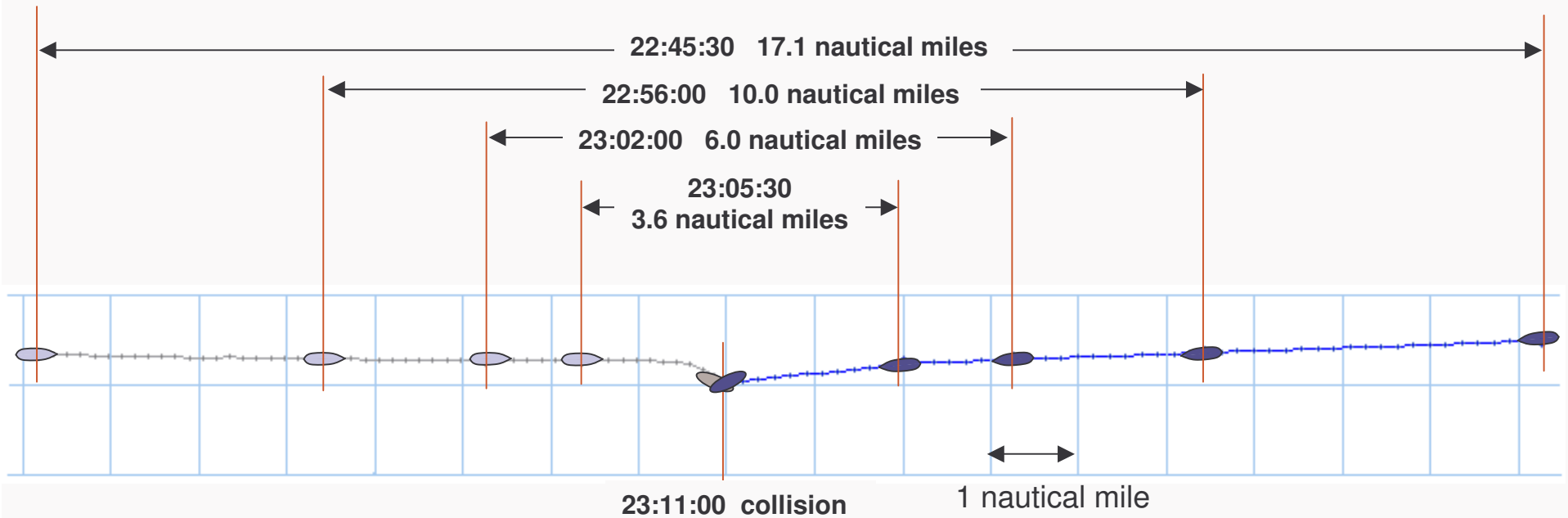
Some Key Events Before the Collision

20:00:00	<i>Andrea Doria</i> heading 267° at 21.8 knots in relatively dense fog. <i>Stockholm</i> heading 090° at 18.5 knots with 5 to 6 miles visibility.
21:40:00	Capt. Calamai orders <i>Andrea Doria's</i> course changed from 267° to 261° to pass 1 to 2 miles south of the Nantucket Shoals lightship. Capt. Nordenson orders <i>Stockholm's</i> course changed from 090° to 087° to pass within 1 to 2 miles south of the Nantucket lightship.
22:10:00	<i>Stockholm's</i> 3/O Carstens-Johannsen orders a course change from 087° to 089° to compensate for current drift that was setting <i>Stockholm</i> more northward than course line laid out by Capt. Nordenson.
22:20:00	<i>Andrea Doria's</i> 2/O Franchini reports Nantucket lightship 1 mile on starboard beam on radar. Capt. Calamai orders a course change from 261° to 268° to put <i>Andrea Doria</i> on a heading for the Ambrose Channel lightship.

Some Key Events Before the Collision

22:40:00	Carstens-Johannsen orders a course change from 089° to 091° for <i>Stockholm</i> to further compensate for a northerly current drift.
22:45:30	<i>Stockholm</i> is picked up on <i>Andrea Doria</i> 's radar at a distance of about 17 nautical miles bearing slightly to the right of the heading flasher.
22:53:00	<i>Andrea Doria</i> is picked up on <i>Stockholm</i> 's radar at a distance of about 12 nautical miles bearing slightly to the left of the heading flasher.
22:56:00	Carstens-Johannsen plots <i>Andrea Doria</i> at 10 miles bearing 2° to port. In reality, <i>Andrea Doria</i> was close to dead ahead.
23:02:00	Carstens-Johannsen plots <i>Andrea Doria</i> at 6 miles bearing 4° to port. In reality, <i>Andrea Doria</i> was only 2° to port.
23:05:00	Capt. Calamai orders a course change of "4° to the left, nothing to the right" for <i>Andrea Doria</i> . The two ships are 3.6 miles apart when <i>Andrea Doria</i> comes on to a heading of 264° 30 seconds later.

Approach From 17 Mile Separation Derived From Course Recorder Data and Ship Speeds

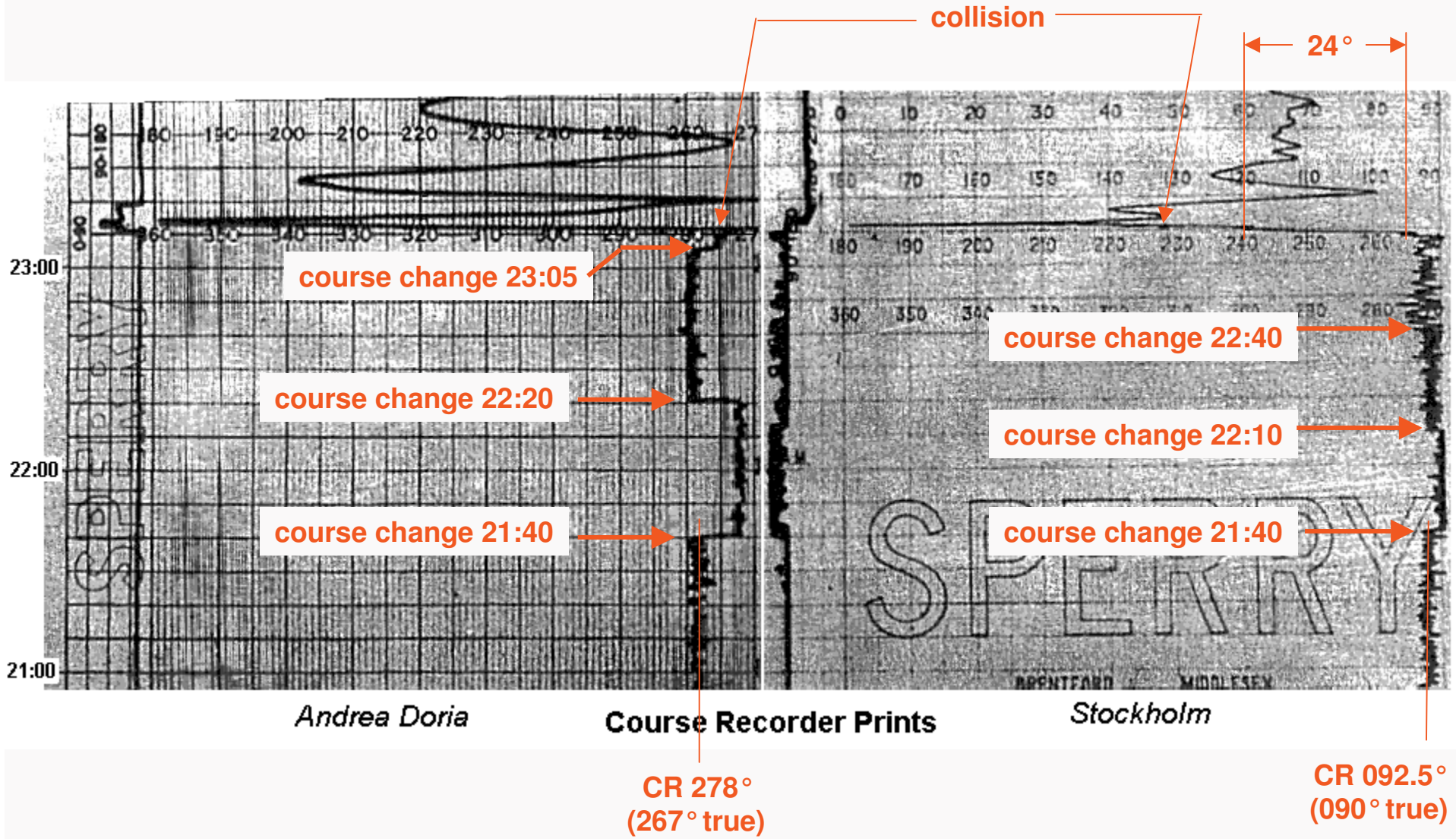


Time	Range (NMs)	Mean Heading of Stockholm	Mean Heading of Andrea Doria	Rel. Bearing of Andrea Doria from Stockholm	Rel. Bearing of Stockholm from Andrea Doria
22:45:30	17.1	090°	268°	1° port	1° stbd
22:56:00	10.0	090°	268°	dead ahead	1° stbd
23:02:00	6.0	092°	268°	2° port	2° stbd
23:05:00	4.0	088°	268°	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

Some Key Events Before the Collision

23:09:00	Carstens-Johannsen orders a 2-point starboard turn on <i>Stockholm</i> . Distance between ships now at 1.3 nautical miles.
23:10:00	<p><i>Stockholm</i> completes 24° turn. Lookout Johansson calls bridge to tell Carstens that he sees lights about 20 degrees to port.</p> <p>Lights of the <i>Stockholm</i> starting to appear to Capt. Calamai and 3/O Giannini out on <i>Andrea Doria's</i> starboard bridge wing and to the lookout out on the bow. <i>Andrea Doria's</i> 2/O Franchini leaves the radar when hearing reports of lights being seen. The ships are now just 0.6 miles apart.</p>
23:10:30	Carstens hangs up the phone and goes out onto <i>Stockholm's</i> port bridge wing and sees <i>Andrea Doria</i> 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. Capt. Calamai sees <i>Stockholm</i> showing a red sidelight and her forward masthead light swinging out to the left of the higher aft masthead light. Calamai orders hard left rudder and calls for a whistle signal be given to indicate a turn to port.
23:11:00	Impact! The bow of <i>Stockholm</i> strikes into <i>Andrea Doria</i> just aft of the starboard bridge wing.

Course Recorder Outputs



Interpretation of Data From Course Recorders

Course recorder data for *Stockholm* (adjustment to gyro heading = -2.5°)

time from course recorder	heading (deg)	
	recorder	gyrocomp value
20:00-21:40	mean heading 092.5	090
21:40-22:10	mean heading 089.5	087
22:10-22:40	mean heading 091.5	089
22:40:30-22:50:00	mean heading 093	090.5
22:50:30-23:07:30	mean heading 092.5	090
23:08:00-23:09:00	mean heading 095	092.5
23:09:00-23:10:00	start right turn 095 to 107.5	092.5 to 105
23:10:00-23:10:30	mean heading 119	116.5
23:10:30-23:11:00	hard right turn 119 to 132	116.5 to 129.5
23:11:00	impact at 132	129.5
23:11:00-23:11:30	30 sec time jump at 138	135.5
23:11:30-23:12:00	very sharp right 138 to 212	135.5 to 209.5
23:12-23:13:30	turning right 212 to 228	209.5 to 225.5
23:13:30	228 starts turning left	225.5

Helmsman changed on *Stockholm* at 20:00, 21:20, and 22:40

Course recorder data for *Andrea Doria* (adjustment to gyro heading = -11°)

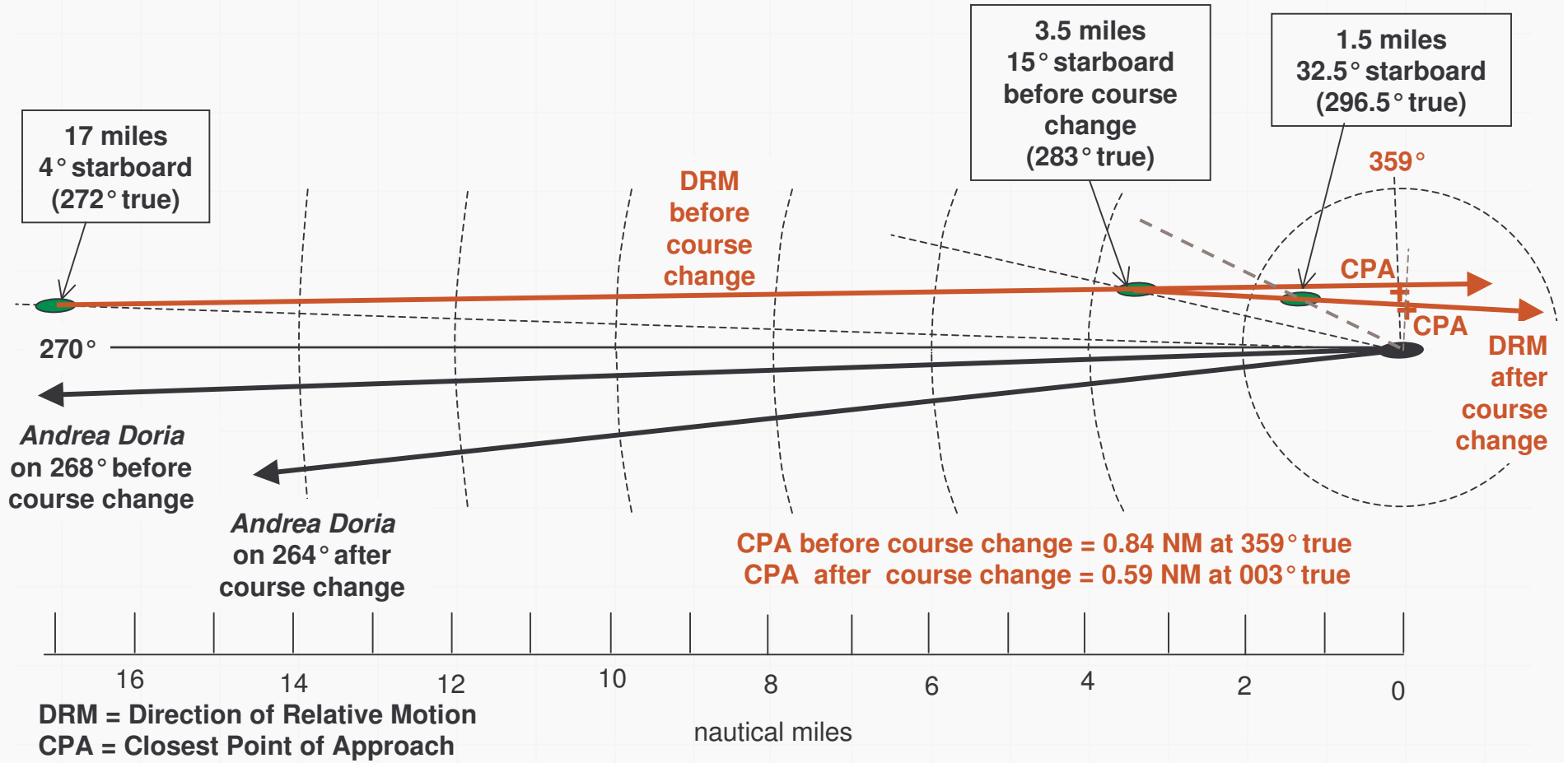
time from course recorder	heading (deg)	
	recorder	gyrocomp value
21:00-21:40	mean heading 278	267
21:40-22:21	mean heading 272	261
22:21:00-23:05:30	mean heading 279	268
23:05:30-23:06:00	start left turn 279 to 275	268-264
23:06:00-23:10:00	mean heading 275	264
23:10:00-23:11:00	drift left 275 to 273	264 to 262
23:11:00	start left turn from 273	262
23:11:30*	impact at 265	254
23:11:30-23:12:00	cont. left 265 to 220**	254 to 209
23:12-23:13:30	cont. left 220 to 160	209 to 149
23:13:30	160 starts turning right	149

* Course recorder time for AD appears to be ~30 sec ahead of that on *Stockholm*. adjustment taken in spreadsheet data.

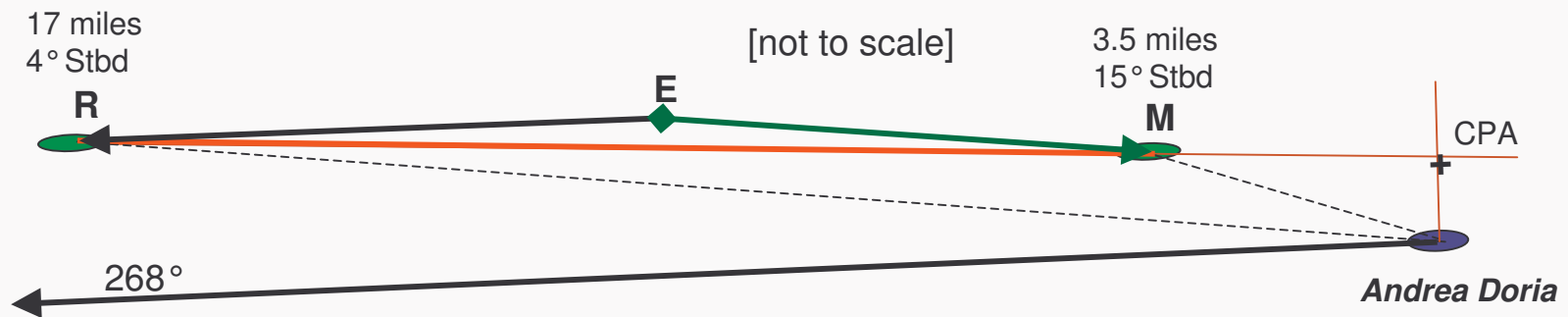
** Change in heading rate noted at 220° on recorder graph.

Conflicting Accounts - Radar Plot for Andrea Doria

Based on Information Provided by Second and Third Officers



Stockholm's Heading Derived From *Andrea Doria's* Reported Radar Readings And Known Speed Of Vessels



The Vector Triangle

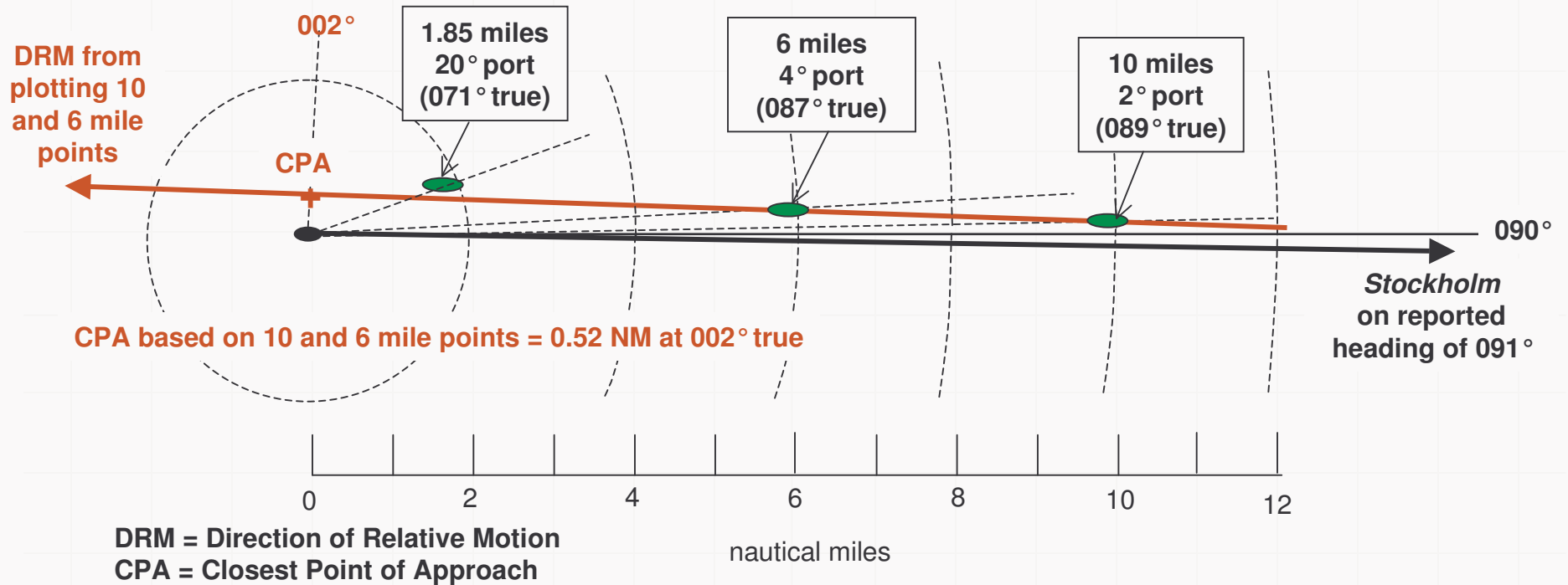
E-R = course vector for "our" ship [*Andrea Doria*]
 E-M = course vector for "them" [*Stockholm*]
 R-M = relative motion vector
 CPA = closest point of approach

Radar Plot Analysis

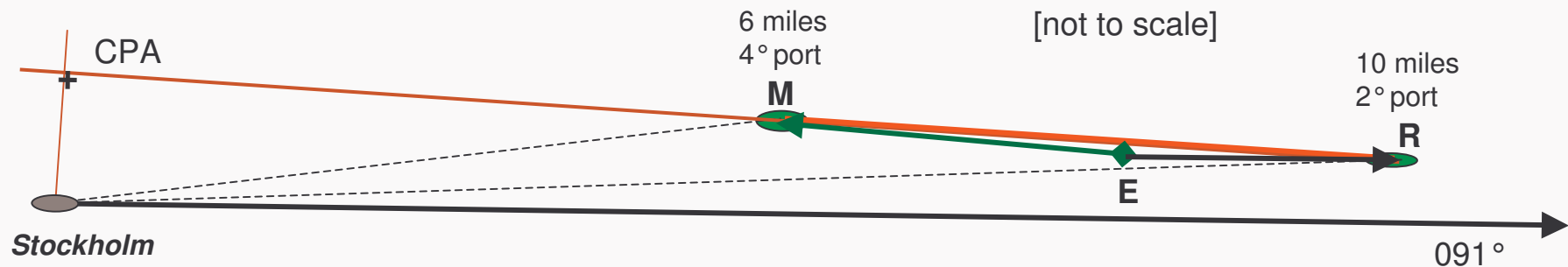
Time interval = 20.25 minutes
Andrea Doria's reported heading = 268°
 ER = 7.36 miles
 EM = 6.14 miles
 RM = 13.5 miles
 Direction of relative motion = 089°
 EM heading (*Stockholm*) = 090.6°
 CPA = 0.84 miles
 Bearing to CPA = 359°

Actual mean headings of *Stockholm* ranged from 089° to 092° over relevant time interval showing wide yaw variations on her course recorder.

Conflicting Accounts - Radar Plot for *Stockholm* Based on Information Provided by Third Officer



Andrea Doria's Heading Derived From Stockholm's Reported Radar Readings And Known Speed Of Vessels



The Vector Triangle

E-R = course vector for "our" ship [*Stockholm*]
 E-M = course vector for "them" [*Andrea Doria*]
 R-M = relative motion vector
 CPA = closest point of approach

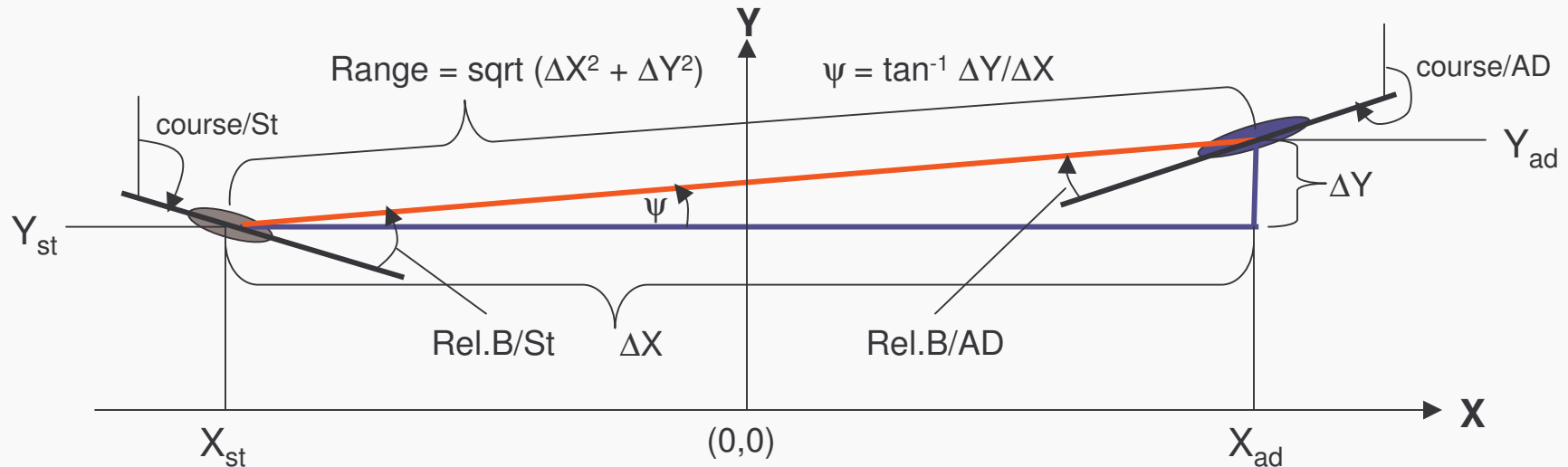
Radar Plot Analysis

Time interval = 6 minutes
Stockholm's reported heading = 091°
 ER = 1.82 miles
 EM = 2.18 miles
 RM = 4.00 miles
 Direction of relative motion = 272°
 EM heading (*Andrea Doria*) = 272.8°
 CPA = 0.52 miles
 Bearing to CPA = 002°

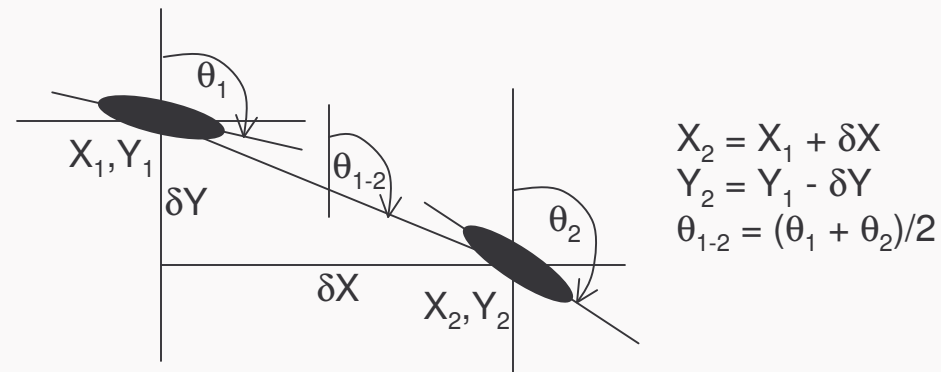
Actual mean heading of *Andrea Doria* was 268° over relevant time interval with low yaw variations seen on her course recorder.

Spreadsheet 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 range between vessels and the relative bearings of each as seen from the other for any given time.



Spreadsheet Analysis

Working the Problem Backwards From 23:00:00

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!
time	course/ST	course/AD	Xst	Yst	Xad	Yad	ΔX	ΔY	Range	Ψ	Rel.B/ST	Rel.B/AD

X-Y coordinates in nautical miles (NMs)

St = *Stockholm*

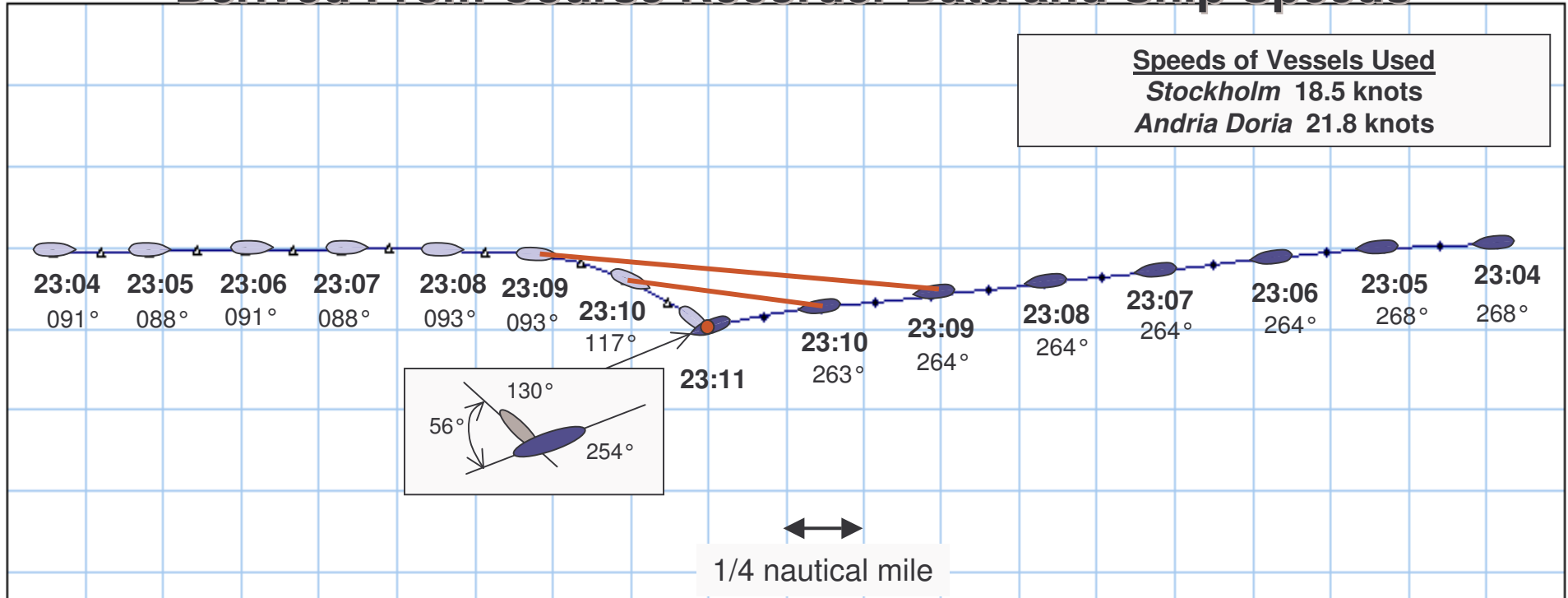
AD = *Andrea Doria*

Speed of *Stockholm* = 0.308 NMs/min (18.5 knots)

Speed of *Andrea Doria* = 0.364 NMs/min (21.8 knots)

Rel.B = relative bearing (+ starboard; - port)

Plot of Collision Sequence From 23:04:00 to 23:11:00 Derived From Course Recorder Data and Ship Speeds

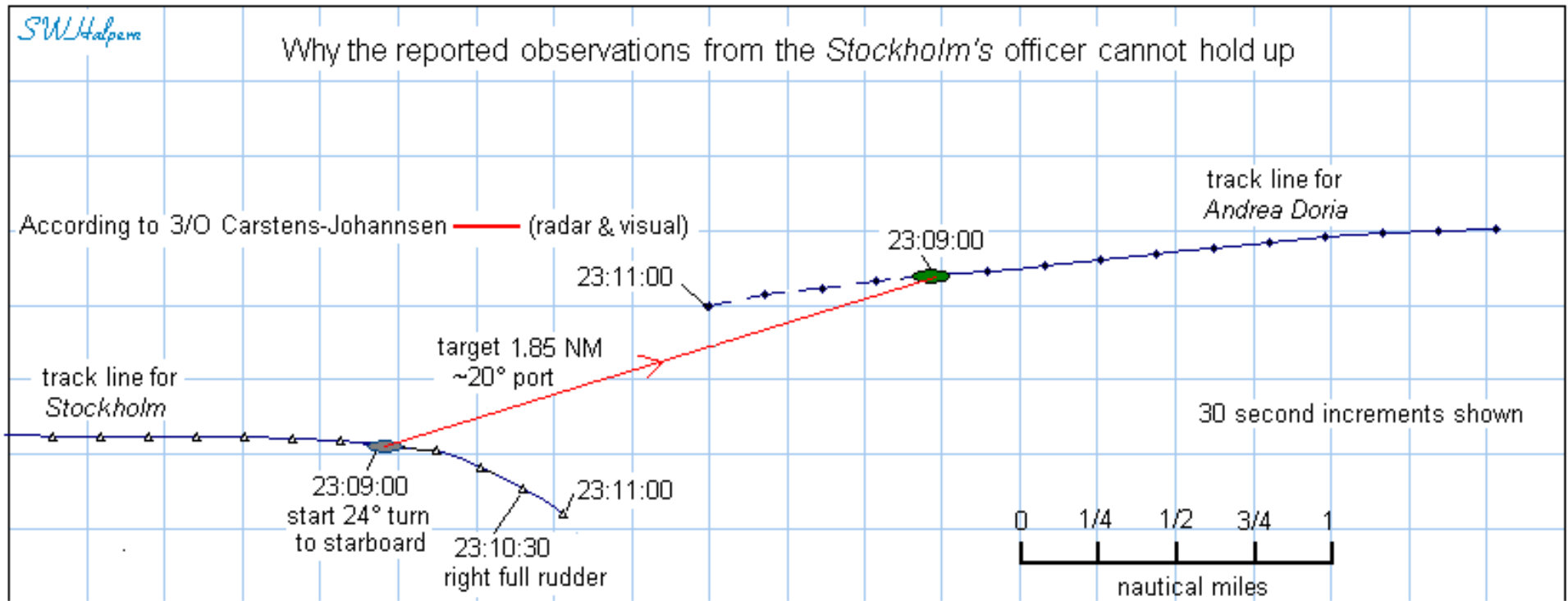


The Final Two Minutes of the Approach (all headings and bearings rounded to the nearest degree)

Time	Visual Observations and Actions Taken	Range (NMs)	Heading of <i>Stockholm</i>	Heading of <i>Andrea Doria</i>	Rel. Bearing of <i>Andrea Doria</i> from <i>Stockholm</i>	Rel. Bearing of <i>Stockholm</i> from <i>Andrea Doria</i>
23:09:00	Ships not yet visible	1.3	093°	264°	3° stbd	12° stbd
23:09:30	<i>Stockholm</i> 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

Conflicting Accounts - *Stockholm's* Story

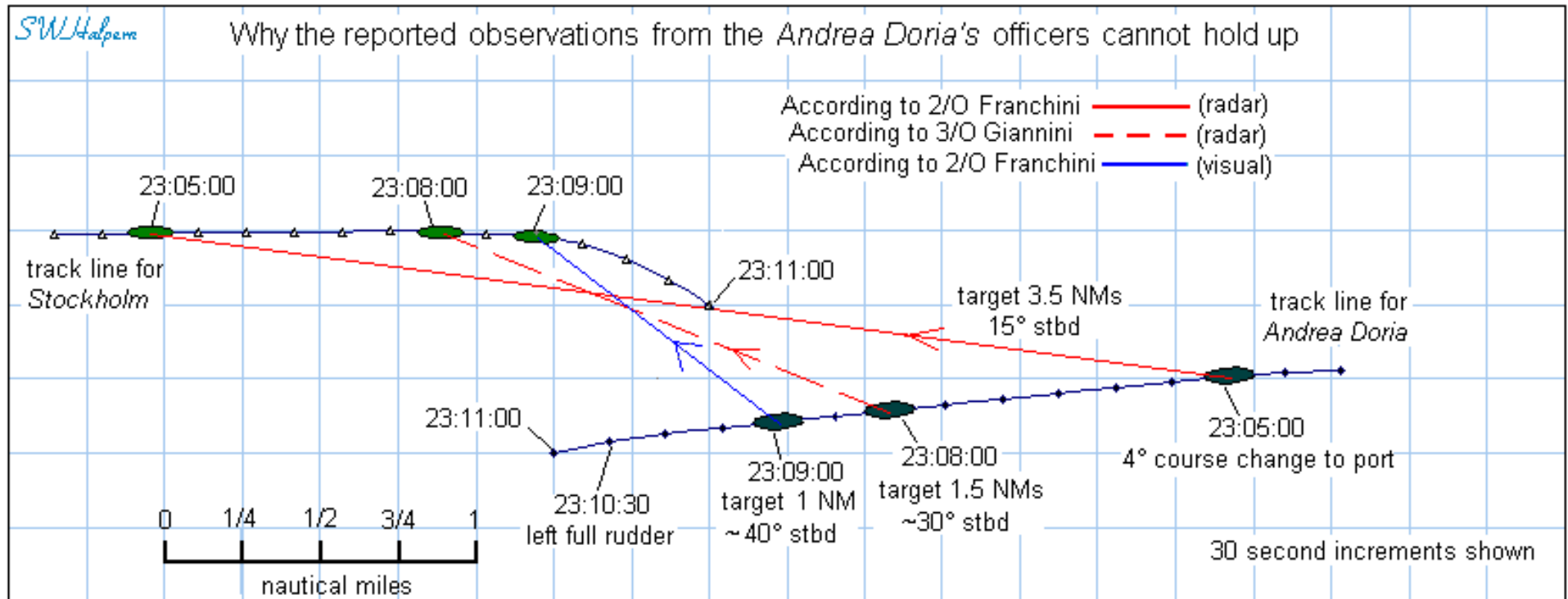
Andria Doria Allegedly Sighted At 1.8 to 1.9 NMs About 20° Off Port Bow



Actual Spreadsheet Data Values				
Time	Range (NMs)	Mean Heading <i>Stockholm</i>	Mean Heading <i>Andrea Doria</i>	Rel. Bearing of <i>Andrea Doria</i> from <i>Stockholm</i>
22:09:00	1.85	092.5°	264°	20° port

Conflicting Accounts - *Andrea Doria's* Story

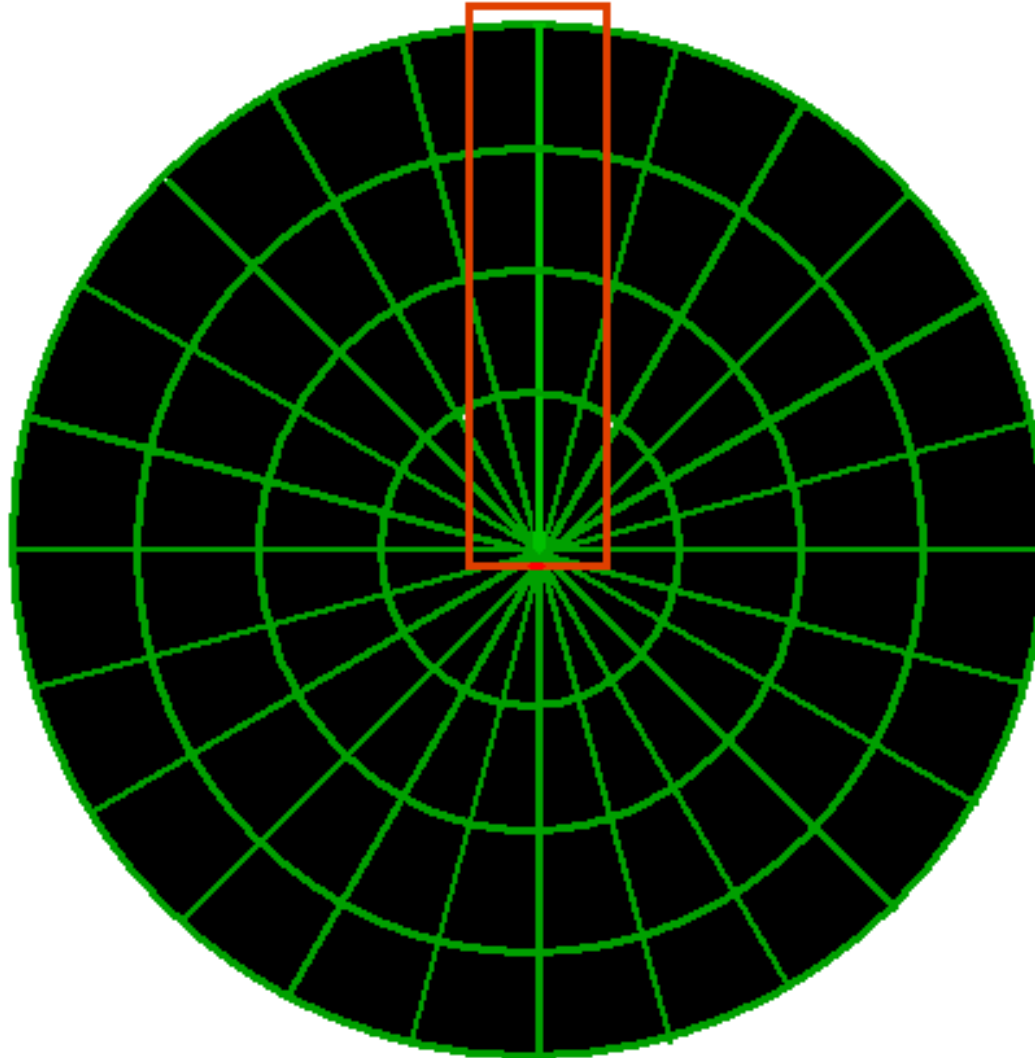
Stockholm Allegedly Sighted At 1 NM About 40° Off Starboard Bow

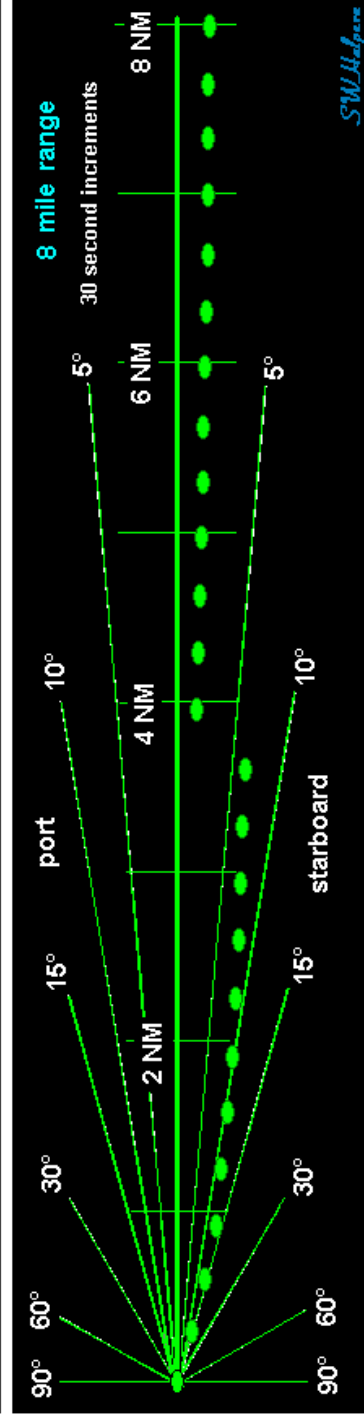
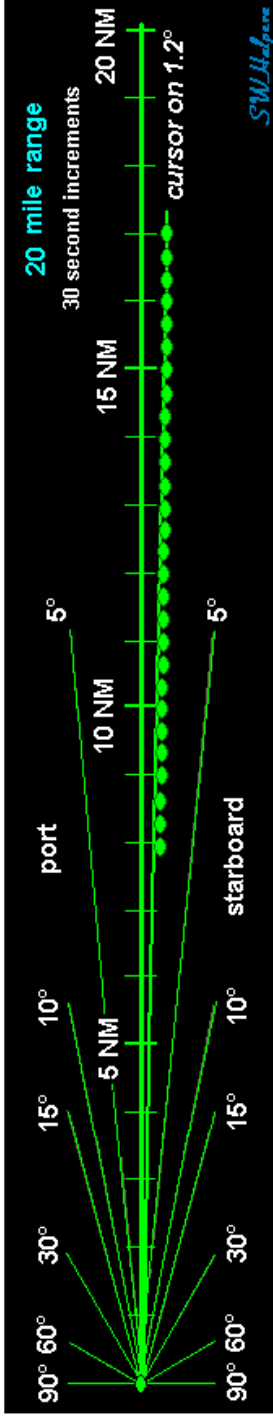


Actual Spreadsheet Data Values				
Time	Range (NMs)	Mean Heading <i>Andrea Doria</i>	Mean Heading <i>Stockholm</i>	Rel. Bearing of <i>Stockholm</i> from <i>Andrea Doria</i>
22:05:00	3.5	264°	088°	14° starboard
23:08:00	1.6	264°	092.5°	29° starboard
23:09:00	1.0	264°	092.5°	45° starboard

What Should the Radar Screens Have Shown Using a Heads-Up Display?

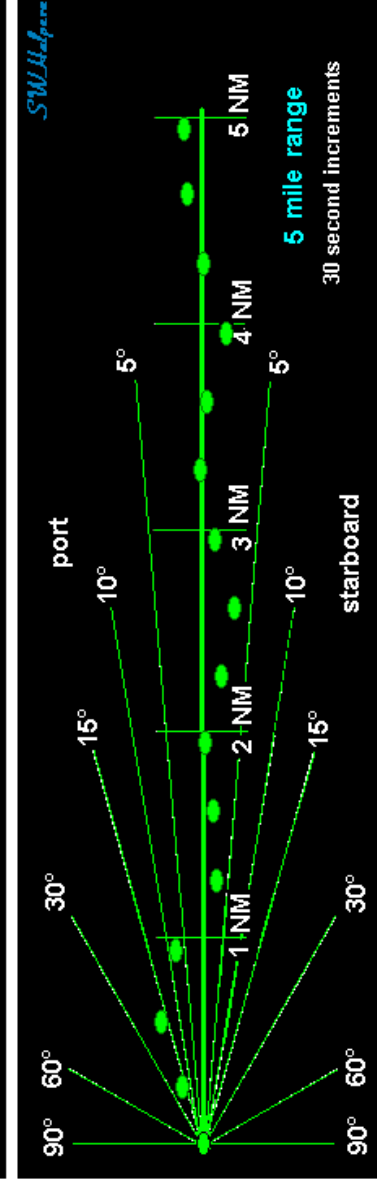
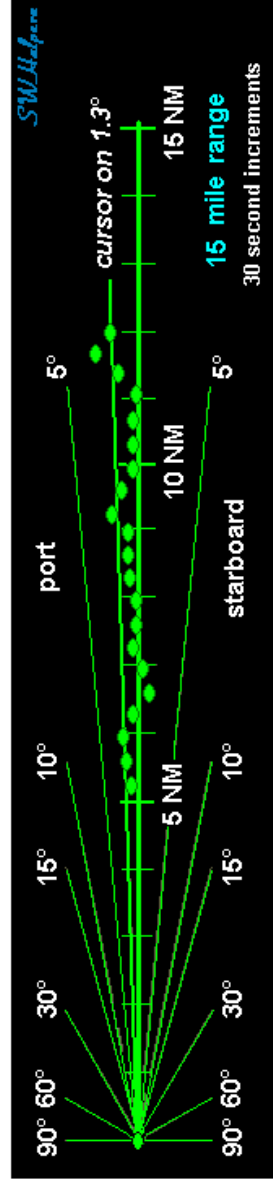
Sector of Interest on the Radar Screen



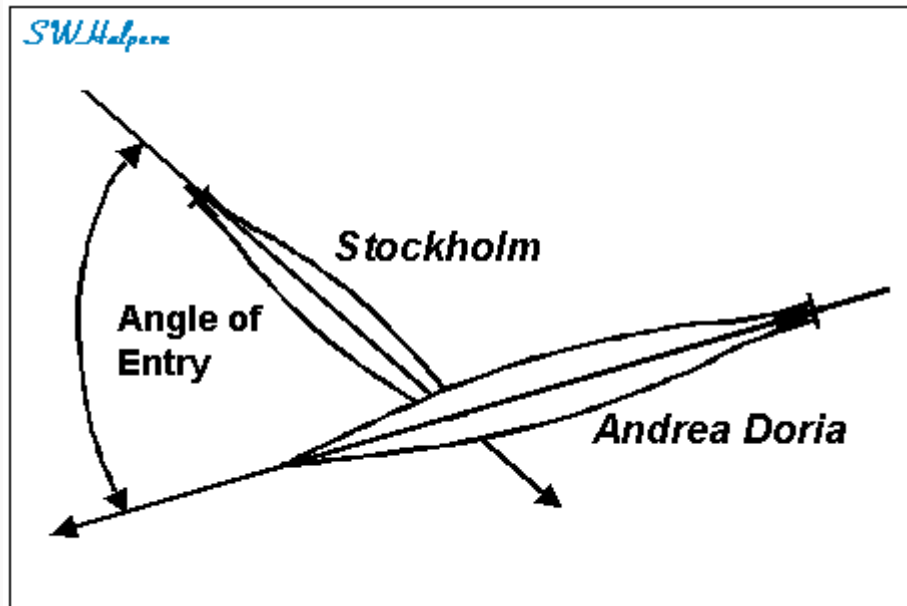


← What *Andrea Doria's* radar screen should have shown

What *Stockholm's* radar screen should have shown

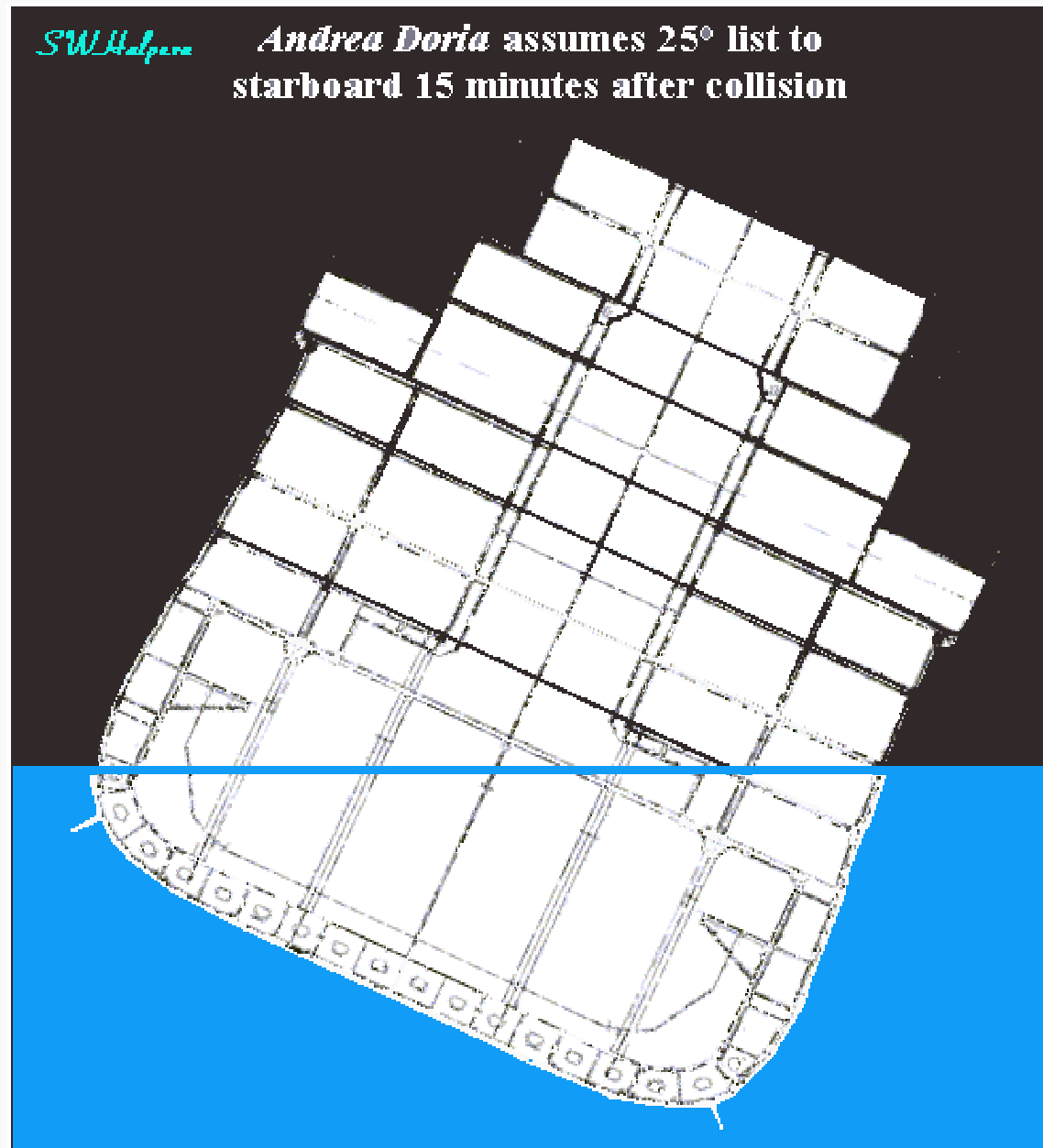


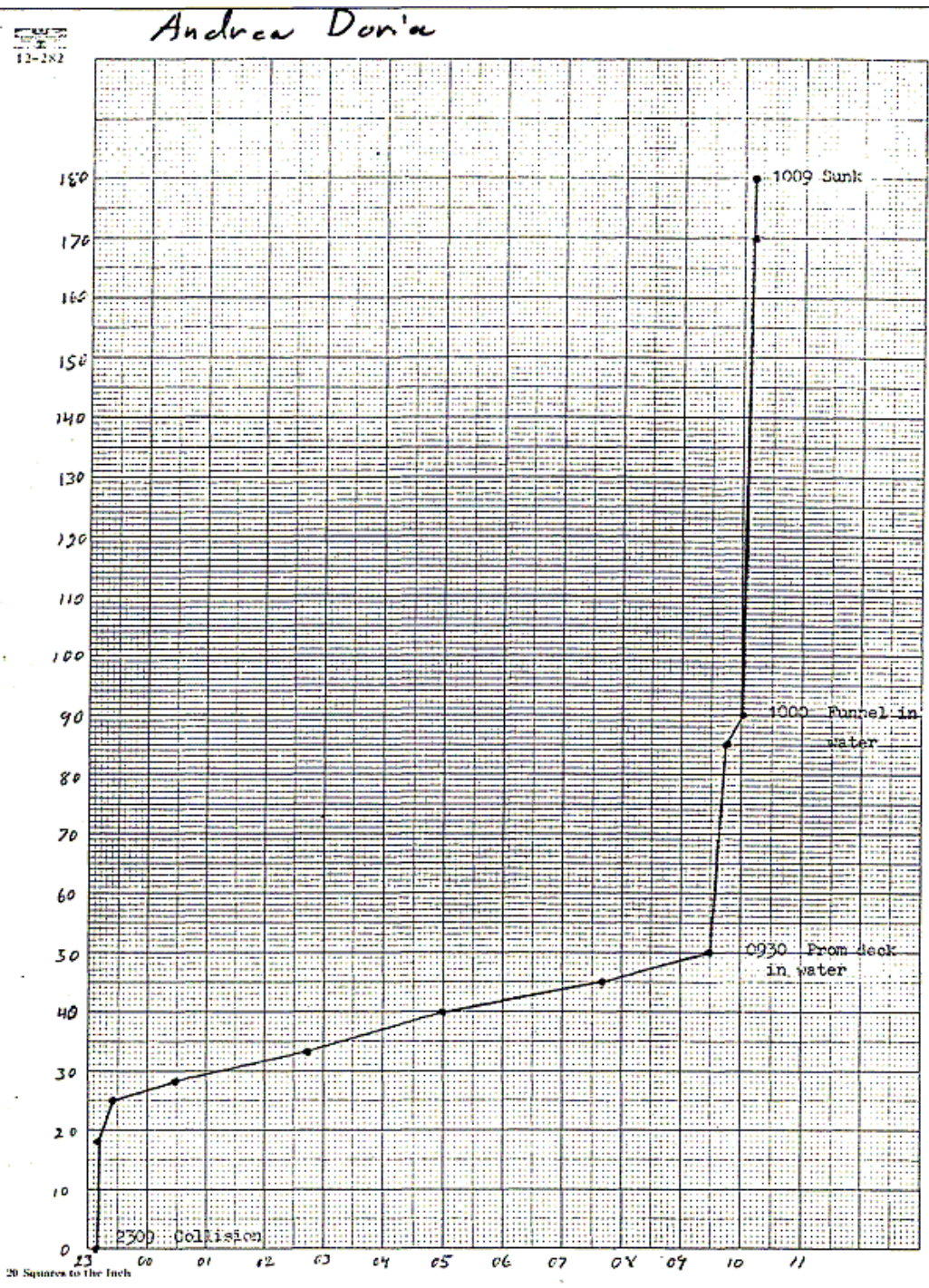
Collision



Angle of entry was about 56° following last minute unsuccessful evasive actions that were taken by both ships.

***Andrea Doria* Cannot Launch Port-Side Lifeboats Due To Severe And Immediate List To Starboard**





LIST VS. TIME

- 18° list to starboard in the first 3 minutes
- 25° list to starboard after 15 minutes
- List doubles to 50° in the next 10 hours.

Plot by Capt. Charles Weeks,
Maine Maritime Academy

External Dynamics of the Collision

Ship A = *Stockholm*

Ship B = *Andrea Doria*

Direction of axis X = 130° true

Direction of axis 1 = 254° true

$L_A = 525$ ft

$L_B = 697$ ft

$B = 90$ ft

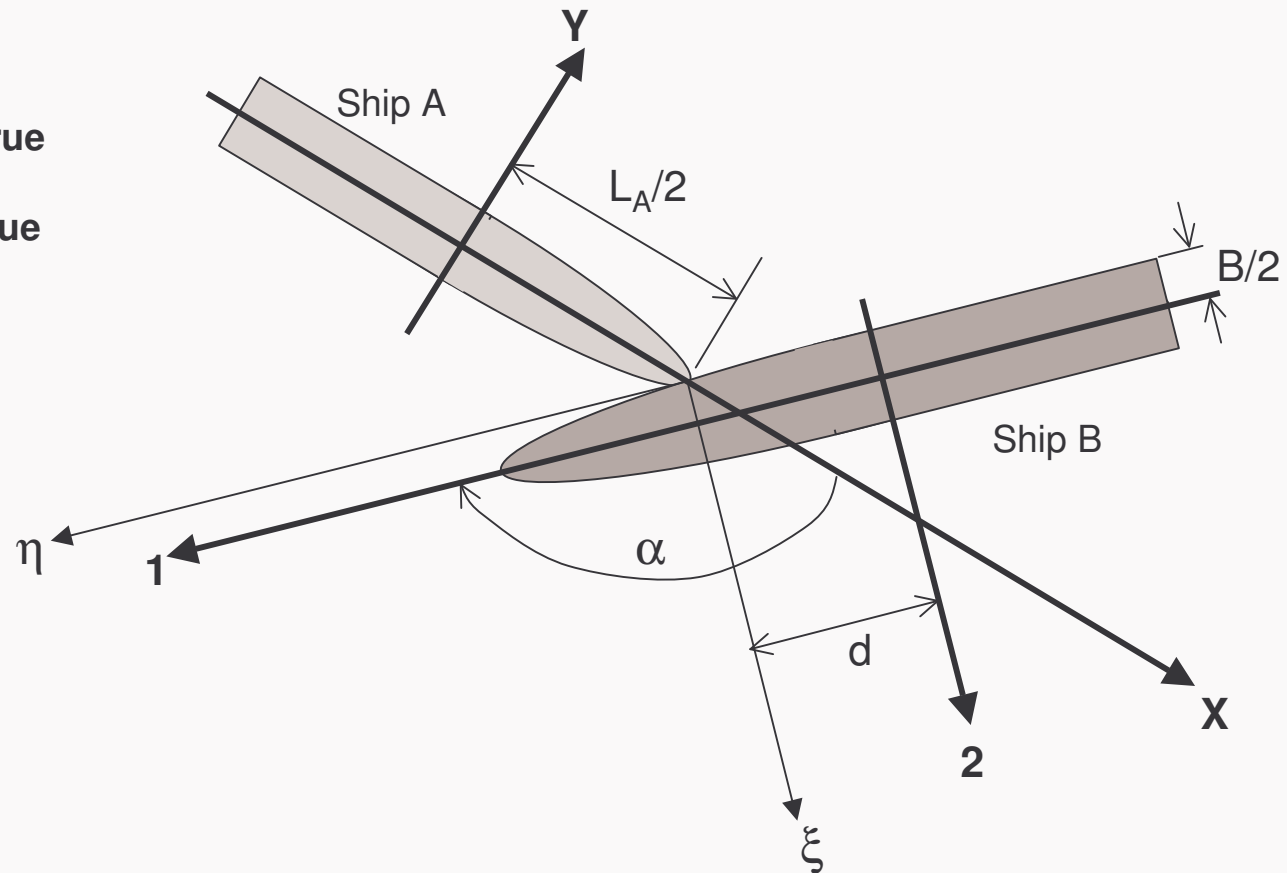
$d = L_B / 6 = 116$ ft

$\alpha = 124^\circ$

$M_B / M_A = 2.4$

$W_B = 26400$ tons

$M_B = 1.8 \times 10^6$ Slugs



Primary Reference: Shengming Zhang, "The Mechanics of Ship Collisions," Dept. of Naval Architecture and Offshore Engineering, Tech. University of Denmark, 1999.

Results of External Dynamic Analysis - 1

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 collision

Results of External Dynamic Analysis - 2

Velocities of ships before and immediately after impact

Stockholm (V_A) = +31.2 ft/sec immediately before impact = +18.5 knots

Stockholm (v_A) = -8.6 ft/sec immediately after impact = -5.1 knots

Andrea Doria (V_B) = +36.9 ft/sec immediately before impact = +21.8 knots

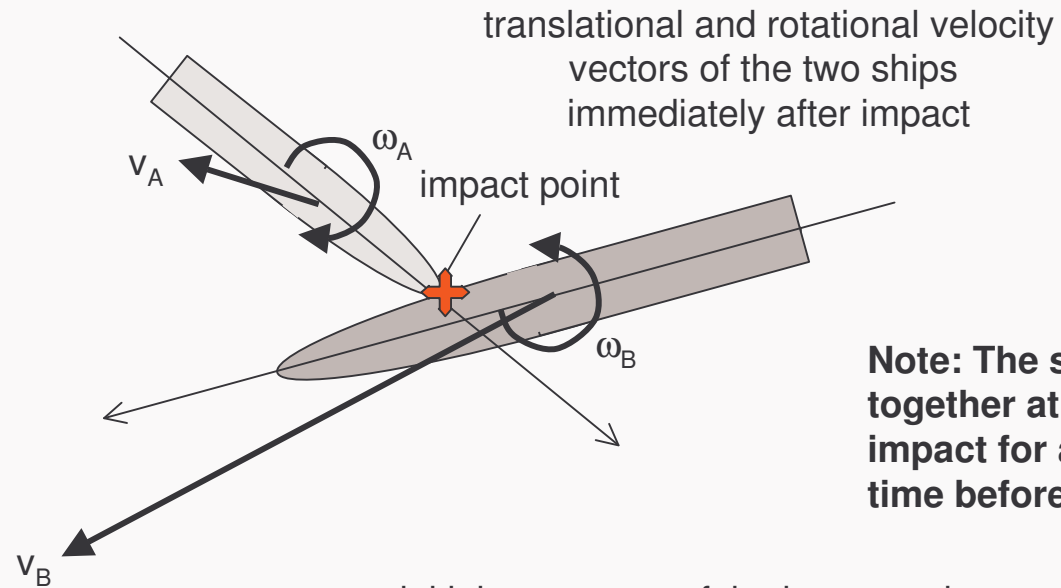
Andrea Doria (v_B) = +26.4 ft/sec immediately after impact = +15.6 knots

Additional imparted rotations immediately after impact

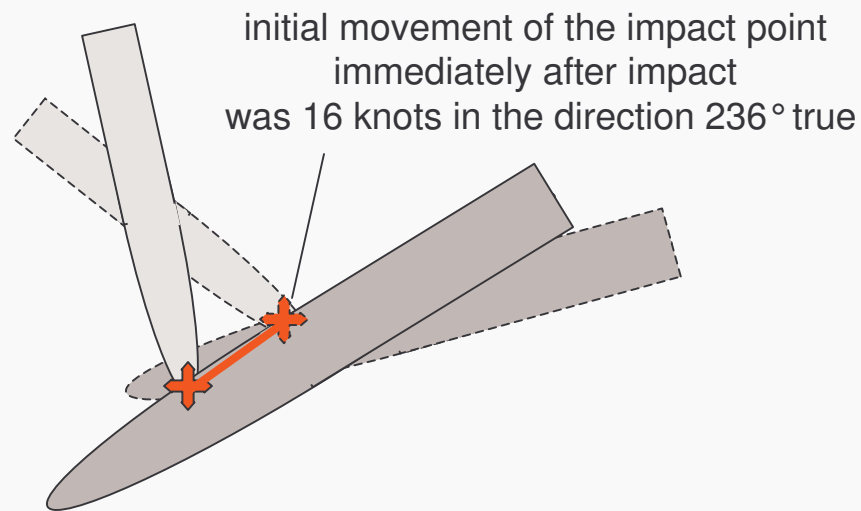
Stockholm (ω_A) = 4.7°/sec to starboard

Andrea Doria (ω_B) = 1.4°/sec to port

Initial Movement at the Point of Impact *Immediately After Impact*

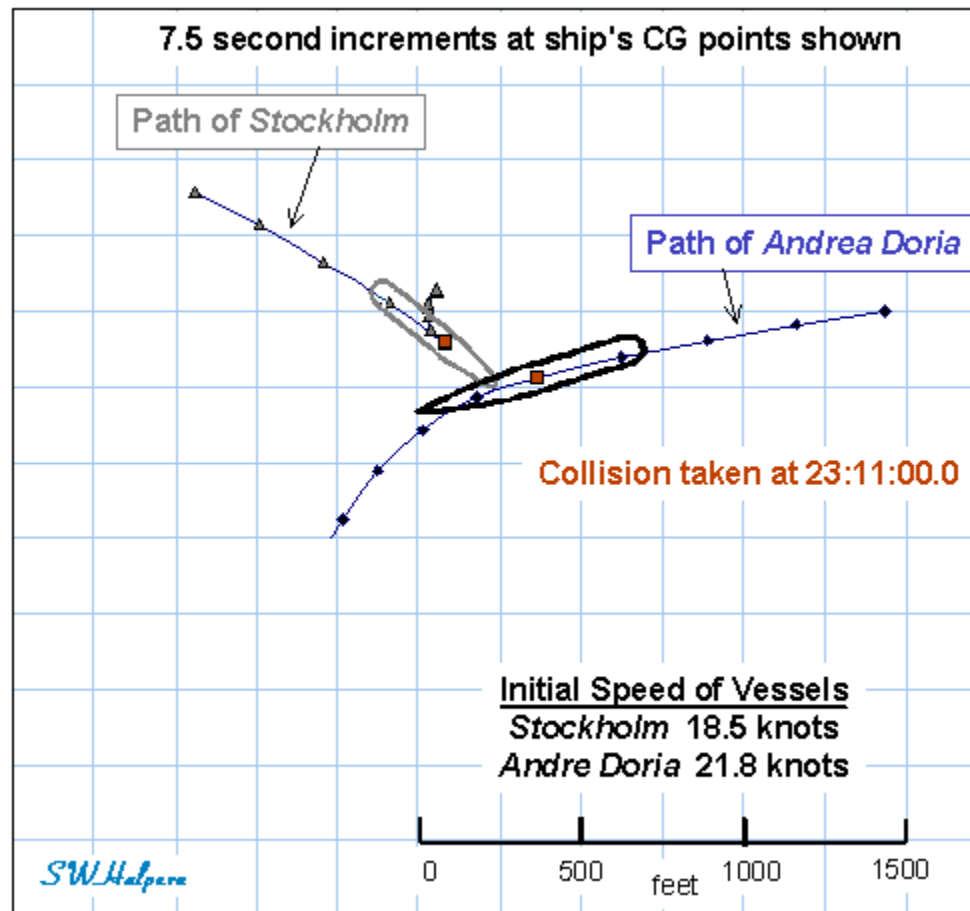


Note: The ships were stuck together at the point of impact for a very short time before separating.

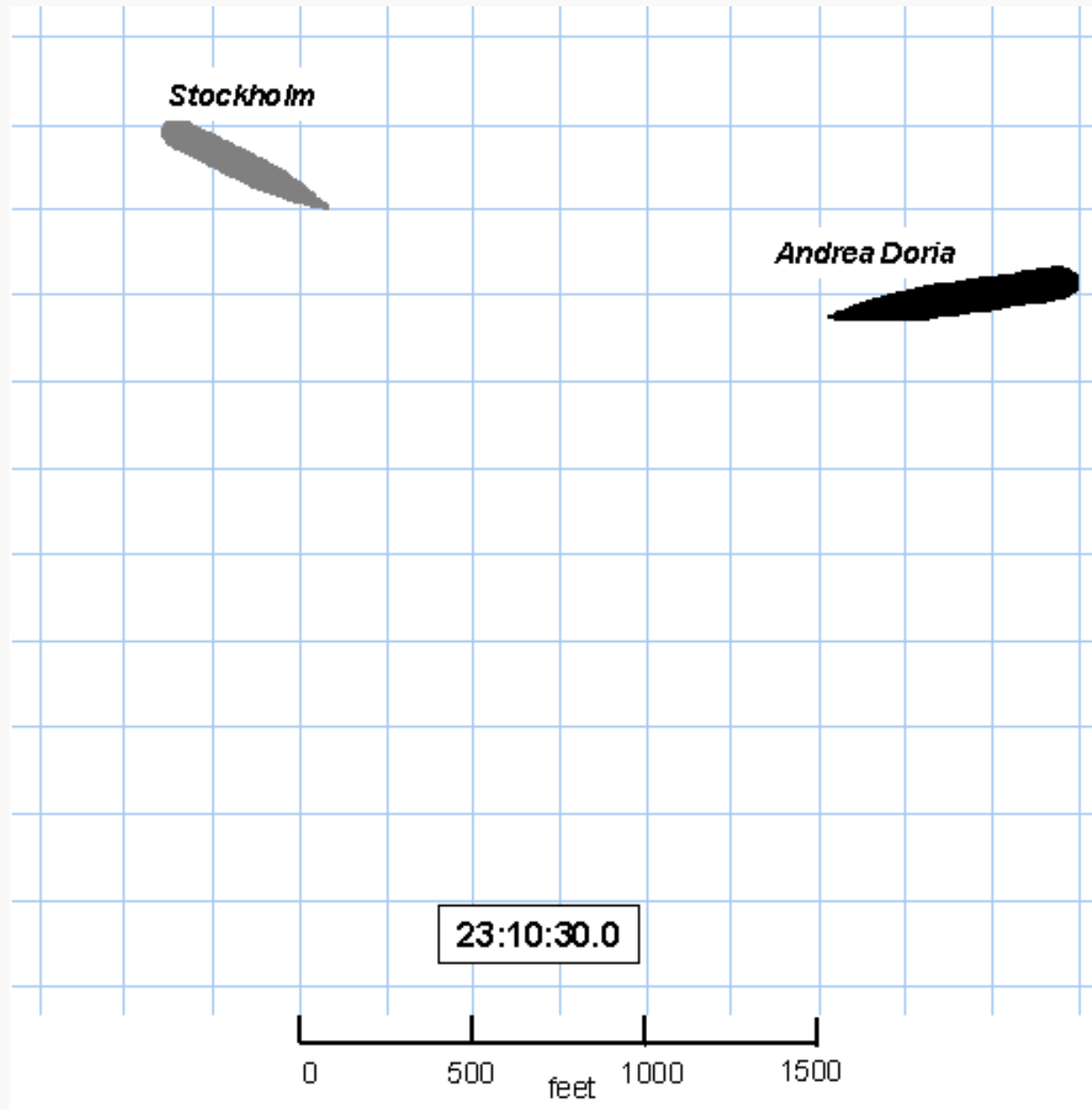


Detailed Movements Before and After Collision

(From 23:10:30.0 To 23:11:30.0)



Detailed Collision Sequence Animation

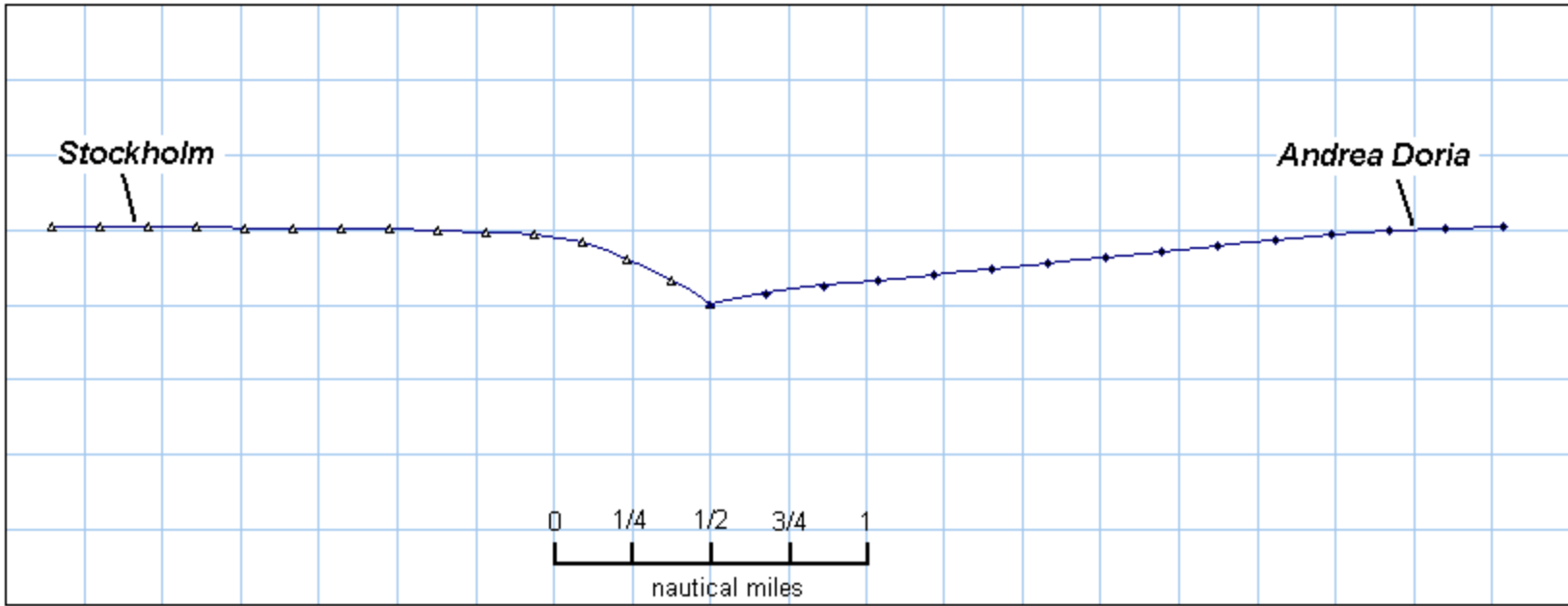


A FEW "WHAT IF?" SCENARIOS

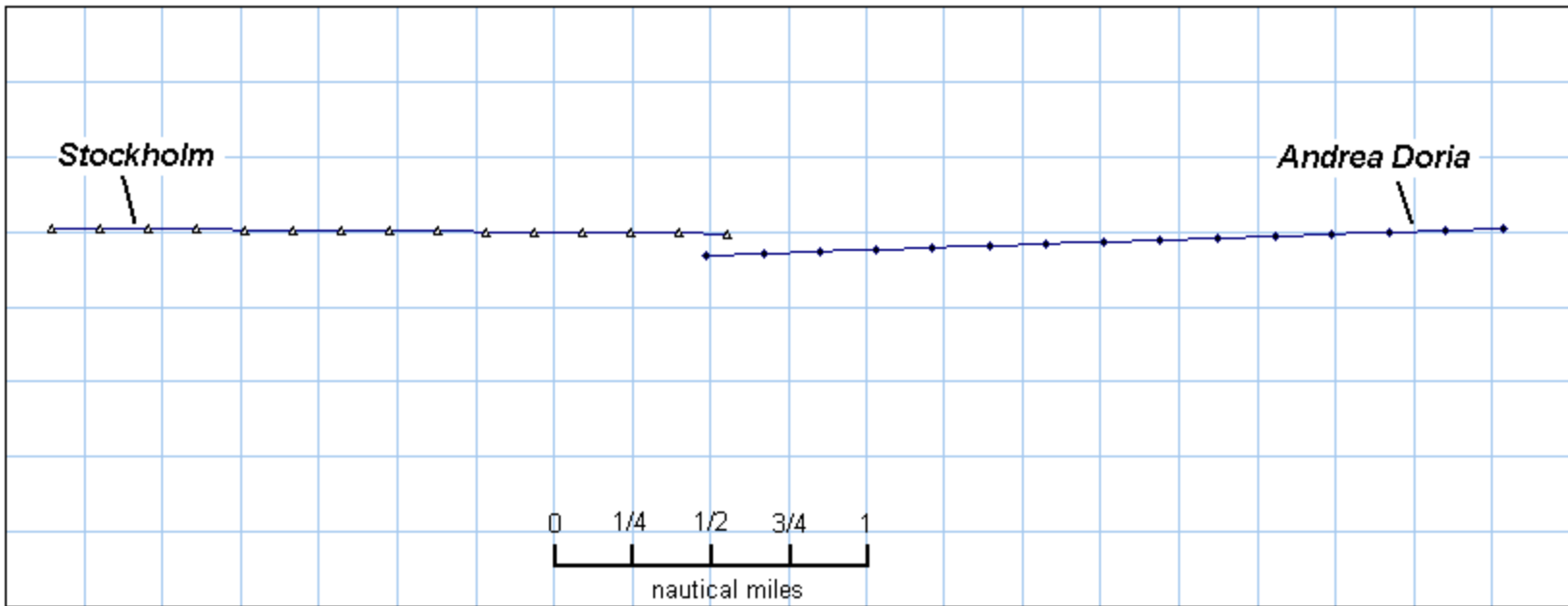
In the sequence of slides that follow, ship positions are shown in 30 second increments from 23:04 to 23:11 derived from course recorder data. *Stockholm* is coming from the left; *Andrea Doria* is coming from the right.

SWHalpern

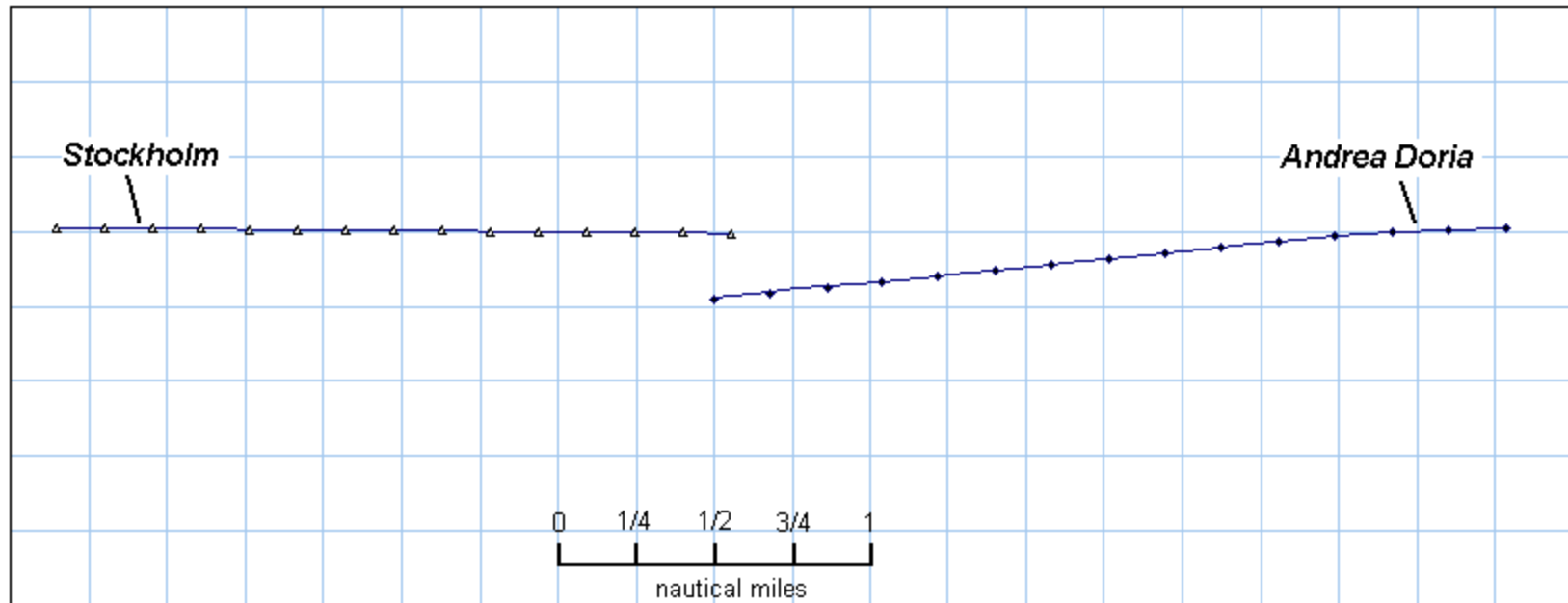
Final 7 Minutes of Actual Collision Sequence

*SWHalpern*

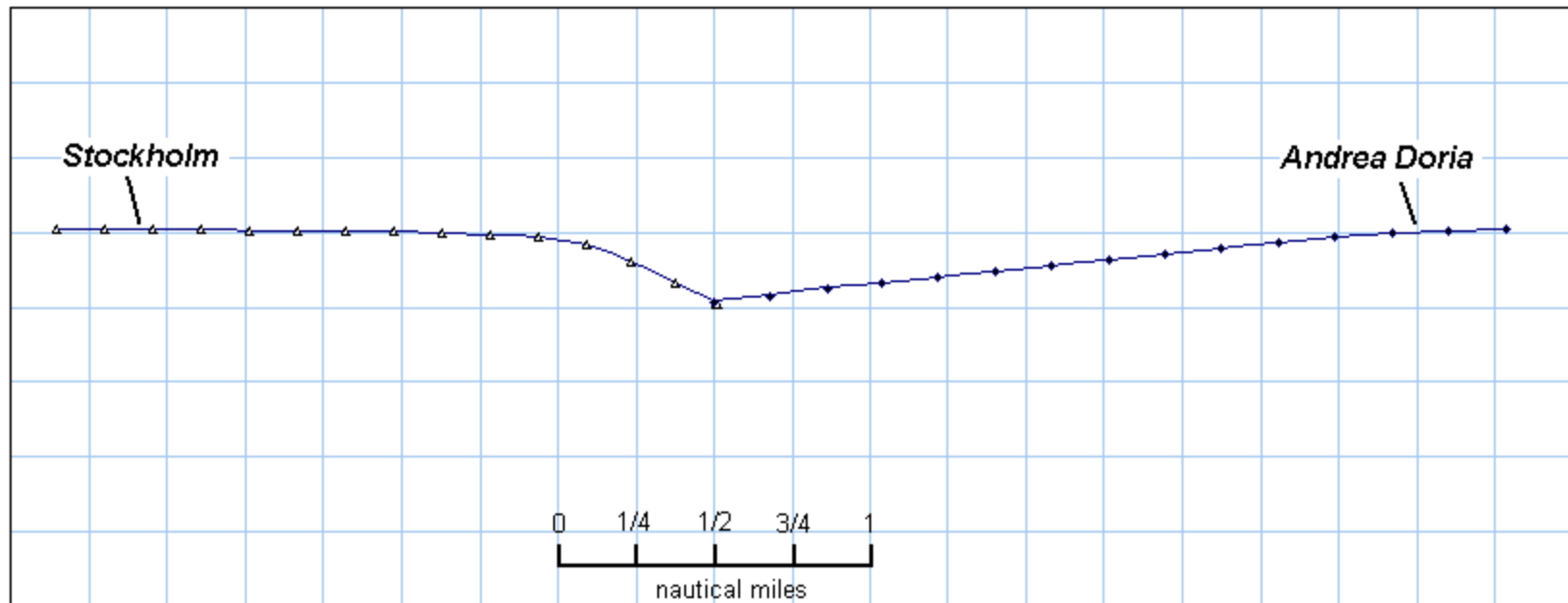
If Each Ship Held A Steady Course From 22:40 Onward



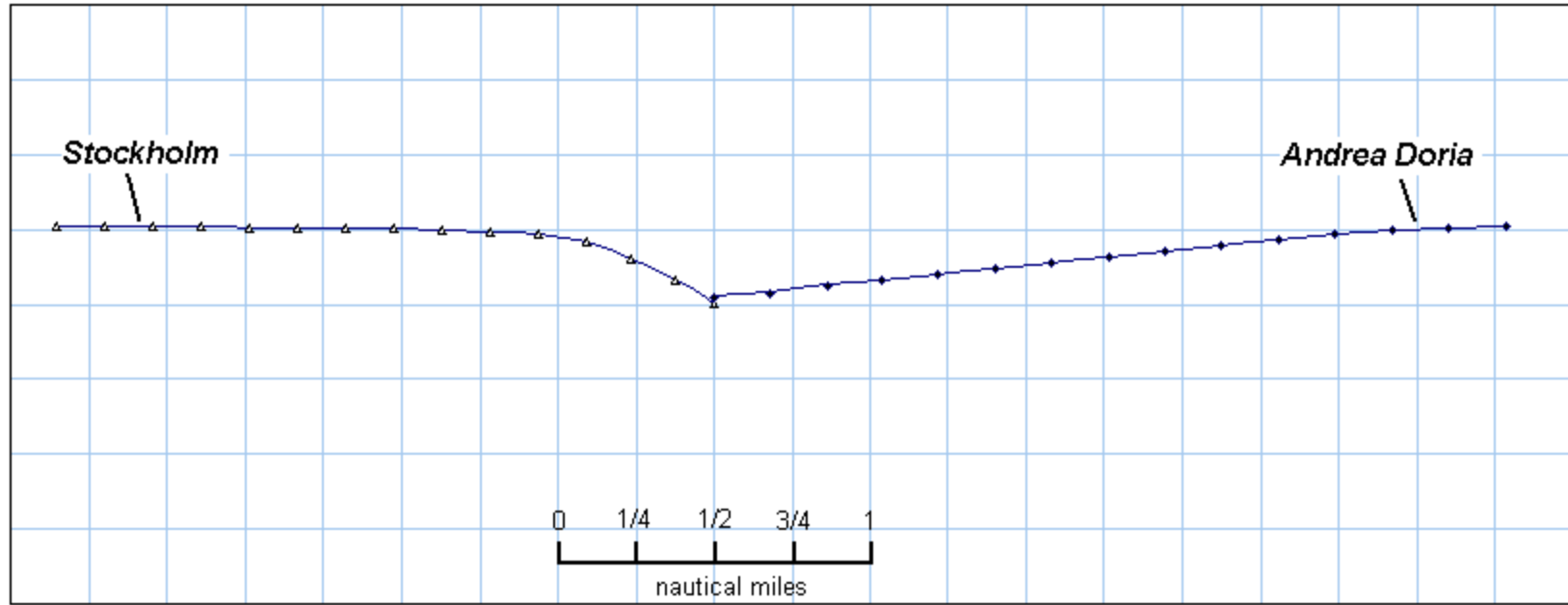
SW Halpern

If Both Ships Would Have Held Steady Courses After *Andrea Doria* Changed Onto 264°

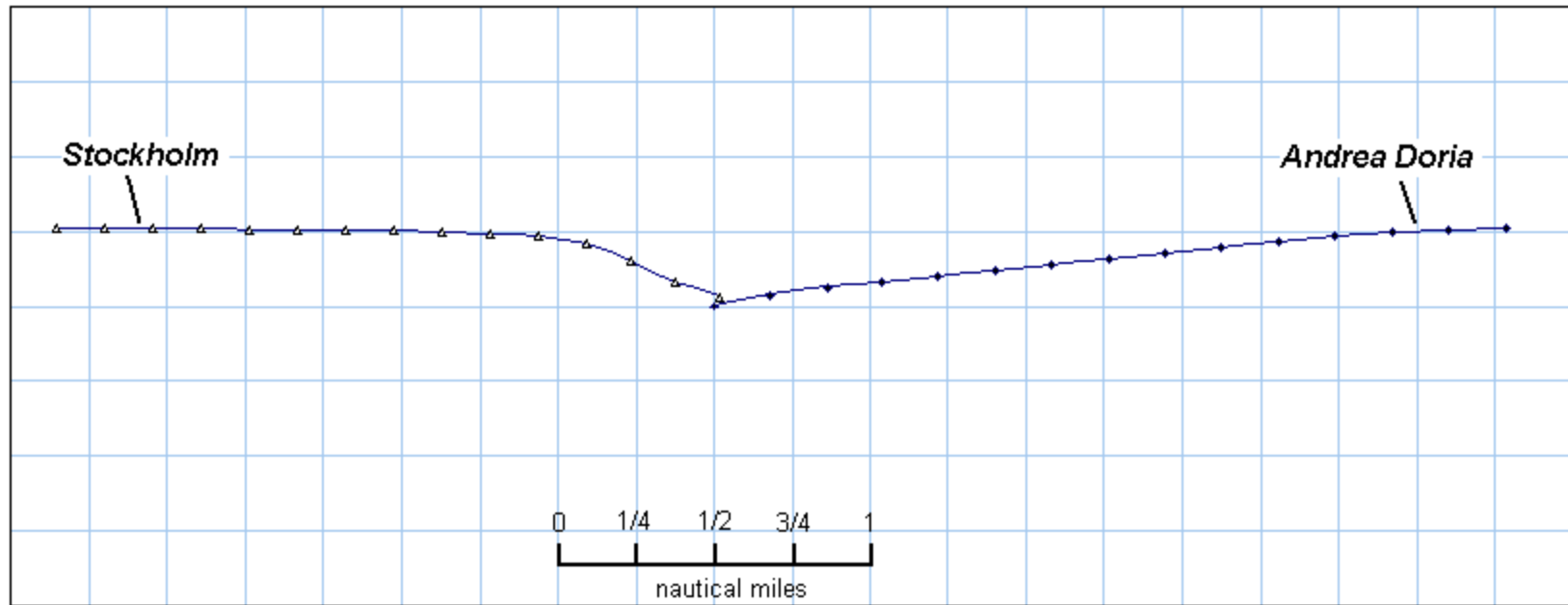
SW Halpern

If Neither Ship Changed Course After *Stockholm* Completed 24° Right Turn at 23:10

SW Halpern

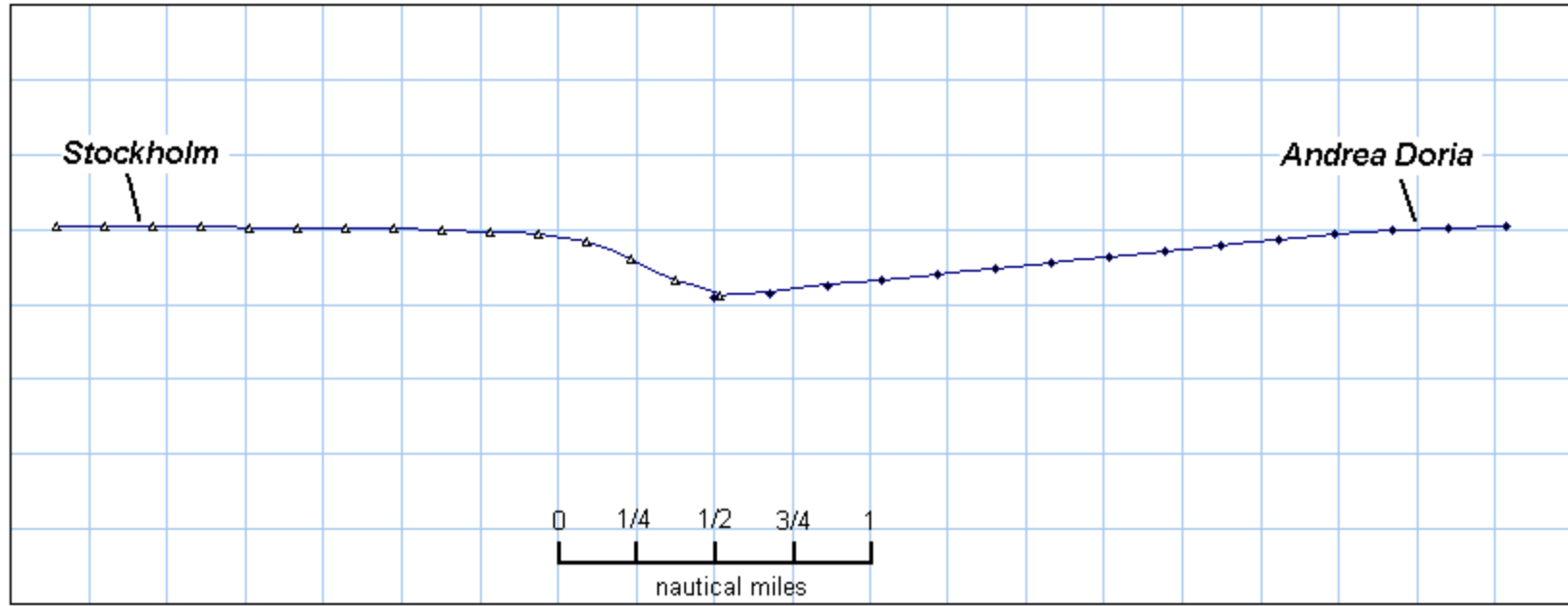
If *Andrea Doria* Had Turned Hard Right Rudder Instead of Hard Left Rudder at 23:10:30

SW Halpern

If *Stockholm* Had Turned Hard Left Rudder Instead of Hard Right Rudder at 23:10:30

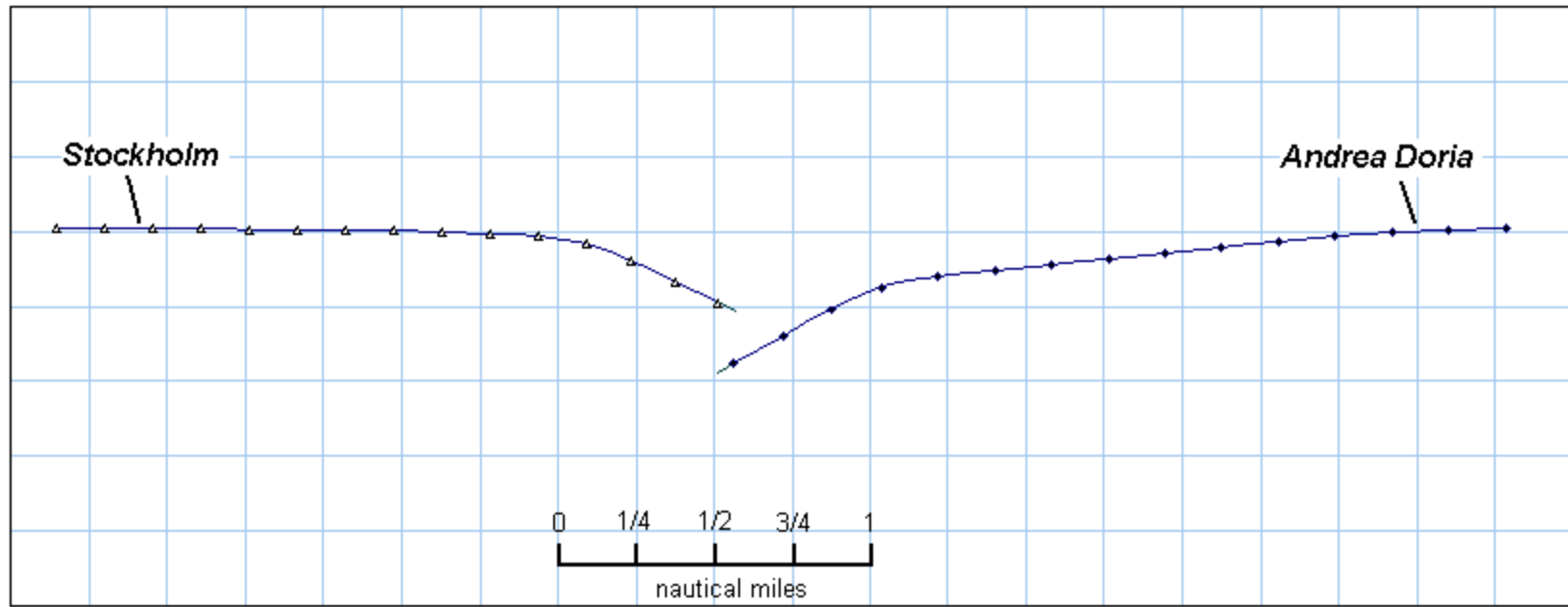
SW Halpern

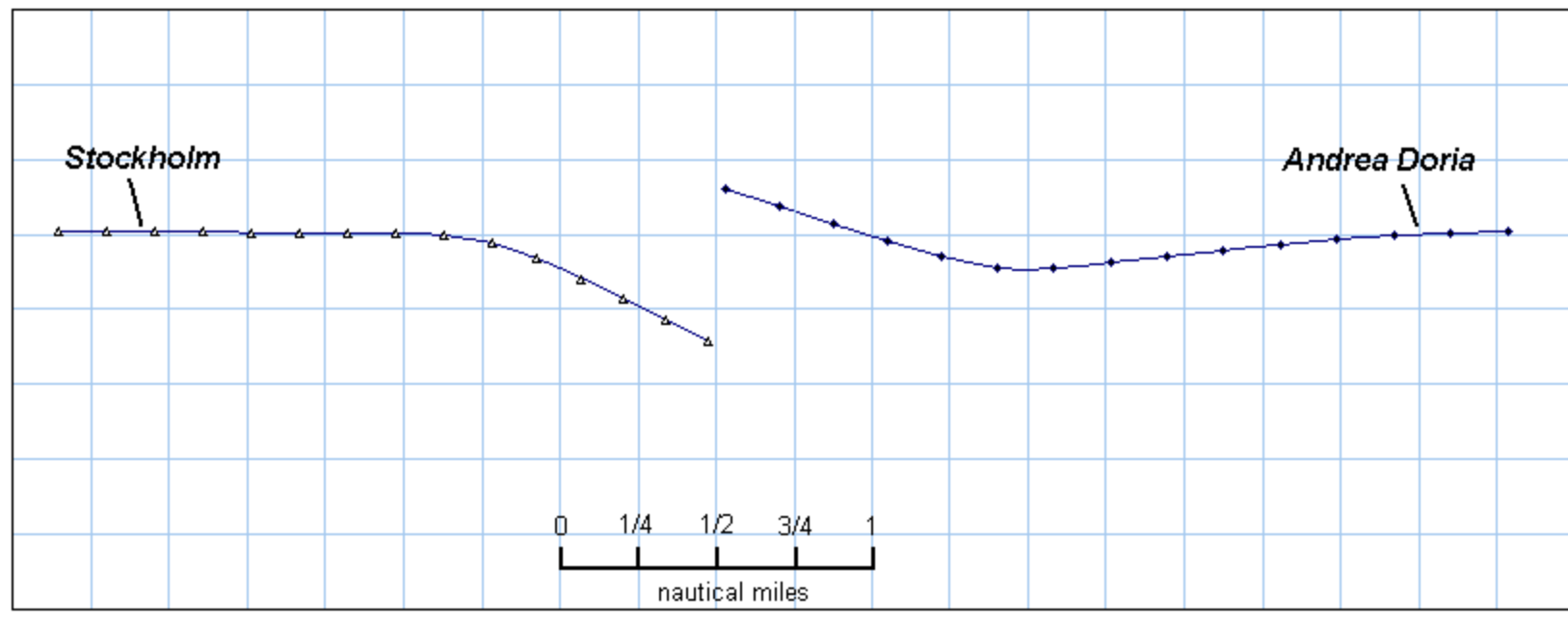
If Stockholm Had Turned Hard Left And Andrea Doria Hard Right at 23:10:30



SW Halpern

If Both Ships Would Have Changed Course By 24° Beginning at 23:09



*SW Halpern*If Both Ships Would Have Changed Course By 24° So As To Pass Port-to-Port Starting 2 Miles Apart at 23:08

CONCLUSIONS

WHY DID IT HAPPEN?

1. The choice of using an eastbound route putting *Stockholm* directly into the path of westbound shipping heading to New York just to save a little time and distance.
2. The failure of the *Stockholm's* Third Officer to call his captain or suspect fog when he could not see the lights of the fast approaching ship as it came under 6 miles almost dead ahead on his radar.
3. Dependence on an inattentive helmsman to keep a steady course and provide accurate heading reports while the third officer was trying to plot the radar picture on *Stockholm*. This may also have distracted the Third Officer from concentrating on the approaching vessel once it appeared on the radar.
4. The failure of those on the bridge of *Andrea Doria* to plot the radar picture as the situation developed, and the lack of special training by those manning the radar.
5. A possible breakdown in bridge team management on the *Andrea Doria* as the Second Officer left the radar upon hearing that lights were becoming visible. Also loss of situation awareness by the OOW of *Stockholm* caused by a phone call distraction during critical moments.

CONCLUSIONS

WHY DID IT HAPPEN?

6. Failure of *Andrea Doria's* Capt. Calamai to clearly signal his intentions to pass starboard-to-starboard by initiating a *significant* course change to port early enough for it to be seen on *Stockholm's* radar. Turning a mere 4° to port at a distance of just under 4 miles would not be noticed. Capt. Calamai also failed to imagine that the unseen 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 under visual conditions.
7. Failure of the *Stockholm's* Third Officer to signal his intentions for a port-to-port passing by initiating his 2-point turn to starboard early enough for it to be seen on the *Andrea Doria's* radar.

Those responsible on the bridge of each ship placed a great deal of dependence on what was seen on their respective radars, and how they interpreted the data. They both failed to appreciate the limitations of using radar by not allowing enough time or distance for sudden actions to be taken by the approaching target vessel. When decisive actions were finally taken, it was too little and too late.