April 11, 2019

# *USS John S McCain* and *Alnic MC* Collision Reconstruction Study

## I. ACCIDENT

| | |
|---|---|
| NTSB Number: | DCA17PM024 |
| Location: | Singapore Strait |
| Date: | August 21, 2017 |
| Time: | 0524 Singapore Standard Time |
| Vessel 1: | *USS John S McCain* (Arleigh Burke-class destroyer) |
| Vessel 2: | *Alnic MC (*tank vessel*)* |

## II. VEHICLE PERFORMANCE SPECIALIST

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## 1.0 INTRODUCTION

The NTSB Office of Research and Engineering was requested to reconstruct the vessel collision event based on parametric data recorded from each ship, the respective geometry for each ship, and estimated GPS antenna location data. The available *Alnic MC* sea trials data were subsequently used to evaluate a hypothetical collision avoidance scenario. Coordinated Universal Time (UTC) is used to present the time of day data in this study. Add eight (8) hours to the UTC time values shown to recover Singapore local time.

## 2.0 METHOD

Based on the *Alnic MC* sea trials data and the *John S McCain*'s recorded maneuvering up to the point of impact, the NTSB conducted a study to determine the latest time that the *Alnic MC* Master could have unilaterally acted to avoid a collision. The study assumed that the *John S McCain* continued along its track defined by the recorded variable turn and deceleration rates while the *Alnic MC* accomplished a deceleration of 1.0 knot per minute for a to-be-determined period during the 90-second window prior to the collision. The 1.0 knot per minute deceleration rate was within the tanker's performance capability demonstrated during sea trials. The study did not consider an *Alnic MC* turn to port or a turn to starboard. Moreover, possible ship-to-ship communication scenarios including VHF radio and ship's horn warnings of impending collision were not evaluated.

Recorded parameters used in the collision reconstruction included time, latitude, longitude, speed, and heading data. Calculated parameters included vessel heading rate in degrees per minute, deceleration rate in knots per minute, time in seconds for the *Alnic MC* bow to reach the projected centerline of the *John S McCain*, time in seconds for the *John S McCain* stern to clear the projected centerline of the *Alnic MC* bow, and distance north and east of a reference origin (the runway 20C threshold at Singapore Changi Airport).

## 2.1 Factual Evidence

The pertinent factual evidence provided by the Office of Marine Safety investigation team for the collision reconstruction included:

1. The destroyer *John S McCain* was positioning to overtake the *Alnic MC* on her starboard side.
2. The *John S McCain* was positioned to starboard and aft or just abreast the *Alnic MC* until about 2 minutes prior to the collision. It took additional time for the collision intercept opportunity to develop and be recognized by either or both crew(s).
3. The *John S McCain* was a fast and highly maneuverable ship compared to typical merchant type vessels with displacement hulls.
4. The control station transfer of rudder control on the *John S McCain* began at 21:20:40 and resulted in a small rate of turn to port.
5. The throttles on the *John S McCain* became mismatched at 21:22:20 and resulted in a measureable increase in the rate of turn to port.
6. The *John S McCain* turned to port (toward the *Alnic MC*) about 98 seconds prior to the collision, using the inadvertent throttle mismatch as the “start of turn” reference.
7. The *John S McCain*’s rate of turn to port was variable (not a constant turn rate).
8. The *John S McCain* decreased speed during the turn to port—from about 18.6 knots when the turn began to about 10.8 knots shortly before the collision.
9. The *Alnic MC* Master had no knowledge of the *John S McCain* throttle mismatch or loss of steering control prior to the collision.
10. Neither ship’s crew communicated via VHF radio or ship’s horn to warn the opposing vessel crew of an imminent collision.
11. The *Alnic MC* Master’s ability to slow his ship was limited. The partially laden vessel was propelled by a slow-speed diesel engine driving a single propeller. The ship had a low thrust-to-weight ratio and could not respond quickly to engine orders. For example, based on sea trials maneuvering data posted on the tanker’s bridge, the stopping distance of the vessel in ballast from a full speed of 14.9 knots with crash astern ordered was about 2,500 meters—more than 1.3 nautical miles.
12. The recorded rudder surface position was 15 degrees to starboard on the *John S McCain* at least 15 seconds before impact.
13. The *Alnic MC* Master acted to slow the tanker’s engine RPM about 14.5 seconds before impact.
14. Impact occurred at time 21:23:58.
15. The *Alnic MC* dimensions were length overall 183 m, beam 32.2 m, bridge front to bow 148 m, and bridge front to stern 35 m. The GPS antenna location is 161 m aft of bow, 5 m starboard of centerline.
16. The *John S McCain* dimensions were length 154 m and beam 20 m. The GPS antenna location is protected information.

## 2.2 Graphical Data

The latitude and longitude position data for each vessel were converted to distances north and east of the reference origin, plotted, and annotated with recorded time, speed, heading, and calculated heading rate of change data. A subset of the vessel three-view drawing data was digitized to construct a scale model for each vessel hull. The vessel hull models were subsequently added to the graphical plots by accounting for the GPS antenna locations as well as the necessary translation and rotation matrix terms for each vessel at each time step.

## 2.3 Projected Vessel Position Vectors

The two-dimensional, planform view, graphical data described in Section 2.2 were used as the foundation for building projected position vectors for each vessel. At each time step, the respective vessel instantaneous speed and course data were assumed to be held constant and used to estimate the projected vessel position vector during the next two minutes. Five-second time intervals were selected to resolve the projected vector magnitude and direction for each vessel.

The reference origin for the *John S McCain* projected position vector was the vessel stern. The reference origin for the *Alnic MC* projected position vector was the vessel bow. Given the two projected vessel position vectors uniformly divided into five-second time intervals, the projected vector intercept position can be readily calculated, plotted, and visually validated at each time step.

The difference between the estimated time of arrival of the *Alnic MC* bow at the intercept point and the estimated time of arrival of the *John S McCain* stern at the same point is defined as the Centerline (C/L) Clearance Margin for this study. When the *John S McCain* stern arrives at a given projected vector intercept point before the *Alnic MC* bow arrives, a collision event is unlikely. Conversely, when the *Alnic MC* bow arrives at a given point before the *John S McCain* stern arrives, a collision event becomes increasingly probable in the absence of mitigating actions by either or both vessel crews. Note that this position vector intercept estimation technique does not account for the beam dimension of either vessel, the effect of future alternate control input orders (for example, emergency engine and/or rudder commands), or the effect of environmental factors (e.g., currents, waves, winds, hydrodynamic interaction between vessels in close proximity).

## 2.4 Hypothetical Collision Avoidance Scenarios

A subset of the available crash stop and crash astern sea trials data for the *Alnic MC* is presented in Attachment 1. Note that the *Alnic MC* (IMO No. 9396725) was originally named the *M/T Mexico*, which is the vessel referenced in the Results of Sea Trial documentation provided by the *Alnic MC* owner. The demonstrated *Alnic MC* deceleration capability during its crash astern test was about 1.25 knots per minute, derived from data showing the vessel slowing from 14.9 knots to 7.2 knots over a period of about 360 seconds. This empirically-based deceleration rate includes the residual effects of the slow-speed diesel engine fuel injection shutdown schedule, the dissipation of engine, shaft, and propeller rotational energy to reach the unpropelled engine/shaft/propeller windmilling speed profile, and the effects of nonconservative winds and seas (38.8 knot winds on the bow, 4.0 m swells) relative to calm winds and seas. Of note, the first 100 seconds of the *Alnic MC's* recorded crash astern response indicated negligible (nearly 0 degree) yaw angle values.

The demonstrated *Alnic MC* deceleration capability during the crash stop test was about 1.1 knots per minute, derived from data documenting the vessel slowing from 14.5 knots to 11.2 knots over a period of about 180 seconds. This empirically-based deceleration rate includes the residual effects of the slow-speed diesel engine fuel injection shutdown schedule, the dissipation of engine, shaft, and propeller rotational energy to reach the unpropelled engine/shaft/propeller windmilling speed profile, and the effects of winds and seas near the idealized calm winds and seas scenario (light winds on the stern, 1.0 m swells). The first 100 seconds of the *Alnic MC's* recorded crash stop response indicated yaw angles ranging from 0 to at most 5 degrees.

The deceleration capability documented by the *Alnic MC* sea trials data for speeds ranging from 10 to 6 knots was examined more closely for this study because the *Alnic MC* was maintaining course at about 9.5 knots prior to the collision and the available time window to recognize an impending collision was only about two minutes, given the *John S McCain's* position approaching abreast of the *Alnic MC* about two minutes before the collision. However, the *Alnic MC* sea trials deceleration data in this narrowed speed range (10 to 6 knots) were less conservative (i.e., yielded higher deceleration rates than the more rational value of 1.0 knot/minute determined in this study) due in part to the larger yaw angles developed during sea trials as the *Alnic MC* continued to slow from 15 knots for time values greater than 100 seconds. To address a wide range of interpretations of the *Alnic MC's* demonstrated deceleration capability during sea trials and to account for unquantified external variables such as currents, winds, waves, and hydrodynamic interaction between the vessels, the effects of both hypothetically higher and lower *Alnic MC* deceleration rates are addressed in the sensitivity study described in Section 3.2.

The *Alnic MC* sea trials data indicate that crash astern provided no additional stopping performance benefit over crash stop during the first several minutes. That is, either a crash stop or a crash astern order would yield similar deceleration rates, about 1.1 knots per minute, for the first several minutes. Note that the performance goal was not to try to bring the *Alnic MC* to a stop but rather to calculate how much the tanker would have to slow in a to-be-determined time window to allow the *John S McCain* stern to pass clear (assuming the destroyer continued to decelerate at its recorded pre-collision rate and continued on its recorded pre-collision path).

The two-dimensional, planform view, graphical data described in Section 2.2 were used together with the aforementioned *Alnic MC* sea trials data to calculate the incremental speed and course data for four hypothetical *Alnic MC* and *John S McCain* collision avoidance scenarios. *Alnic MC* deceleration rates of 0.75, 1.0, 1.25, and 1.5 knots per minute were evaluated beginning X, X-10, X-20, and X-30 seconds prior to the collision, respectively, where the value of X was initially estimated using constant acceleration equations and later refined using the graphical solution method outlined in Section 2.3. These *Alnic MC* deceleration scenarios assume that the *Alnic MC* Master ordered the engine to crash stop or crash astern and maintained vessel course for the applicable X- to X-30 second time window.

## 3.0 RESULTS

The study results are presented in this section.

### 3.1 Collision Reconstruction

The collision reconstruction results are presented in a series of two animated .gif files described below, organized by level of detail and playback rate.[1] The .gif file content progressively increases in complexity as a function of the content level presented, as follows:

Level 1: A top view shows each vessel hull positioned and oriented along its respective recorded ground track path as a function of time. See Figure 1 for an exemplar image.

Level 2: The addition of projected vector positions for each vessel (stern of the *John S McCain*; bow of the *Alnic MC*) to content Level 1, projected forward in time over a period of two minutes at five-second increments, based on the instantaneous vessel speed and orientation data at each time step. See Figure 2 for an exemplar image.

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[1] The resulting animated .gif files can be opened on an iPhone, iPad, in QuickTime, and in Internet Explorer (and other internet browsers). Open the attachment, wait for it to load, and use a mouse or finger(s) to pan and/or zoom to the area of interest.

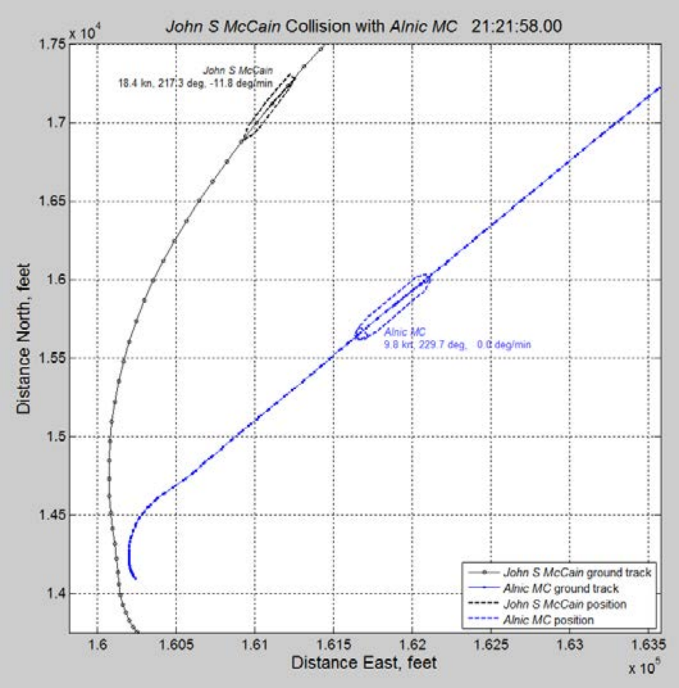


Figure 1: Two minutes prior to collision. *John S McCain* is approaching abreast position off starboard side of *Alnic MC*.

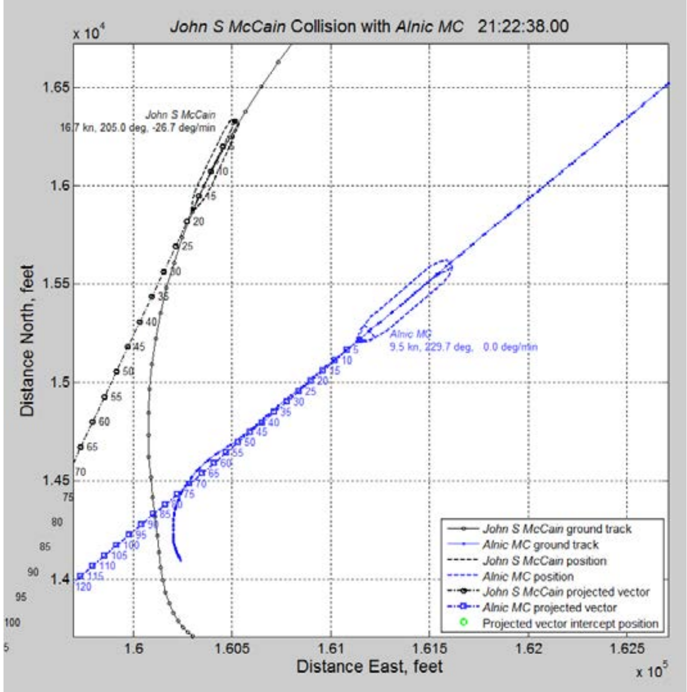


Figure 2: Eighty seconds prior to collision. Projected vector intercept position indicates destroyer stern will pass clear of tanker bow before tanker arrives.

### 3.2 Collision Avoidance Sensitivity Study

A collision avoidance sensitivity study was used to quantify the window of opportunity for the *Alnic MC* Master to take unilateral action to reduce the tank vessel speed in an attempt to avoid colliding with the *John S McCain*. The results are summarized in Table 1 below, which indicates hypothetical *Alnic MC* deceleration scenarios that would allow the *John S McCain* stern to clear the *Alnic MC* bow via an *Alnic MC* engine crash stop or crash astern order.

Table 1: Hypothetical *Alnic MC* deceleration scenarios (assumes unilateral action to avoid collision)

| **Scenario Number** | ***Alnic MC* Deceleration Rate, knots per minute** | **Required Deceleration Period to Avoid Collision, seconds** | **Comment** |
|---|---|---|---|
| 1 | 0.75 | 90 | More conservative relative to demonstrated sea trials capability |
| 2 | 1.0 | 80 | Reasonably conservative relative to demonstrated sea trials capability |
| 3 | 1.25 | 70 | Upper bound of demonstrated sea trials deceleration capability |
| 4 | 1.5 | 60 | Deceleration rate exceeds demonstrated sea trials capability |

A deceleration rate of 1.0 knot per minute incorporates reasonable margin regarding the tank vessel speed reduction capability within the two-minute window prior to the collision and provides margin to account for the effects of variable currents, waves, winds, and hydrodynamic interaction between vessels in close proximity.

The study discussion and conclusions are largely based on the *Alnic MC* 1.0 knot per minute deceleration baseline case. However, the 1.0 ± 0.25 knots per minute deceleration rates in Scenarios 1–3 all yield similar results, that the *Alnic MC* crew had limited time to recognize an impending collision, decide what unilateral action(s) to take, and accomplish constructive action(s) to avoid the collision.

### 3.3 Collision Avoidance Scenarios

The hypothetical collision avoidance scenario results are presented in a series of two animated .gif files described below, organized by level of detail and playback rate.[1] As before, the.gif file content progressively increases in complexity as a function of the content level presented, as follows:

Level 3: The addition of alternate vessel position and orientation data for the *John S McCain* and the *Alnic MC* to content Level 1, assuming that the *Alnic MC* decelerated at the assumed rate. See Figure 3 for an exemplar image corresponding to a 1.0 knot per minute deceleration rate initiated 80 seconds prior to the collision.

Level 4: The addition of alternate vessel position and orientation data for the *John S McCain* and the *Alnic MC* to content Level 2, assuming that the *Alnic MC* decelerated at the assumed rate. See Figure 4 for an exemplar image corresponding to a 1.0 knot per minute deceleration rate initiated 80 seconds prior to the collision.

Vessel position, orientation, time, and speed data were updated for each vessel every 0.5 seconds. Playback rates at real time (1x), two times faster than real time (2x), four times faster than real time (4x), and eight times faster than real time (8x) are available. Please refer to Attachment 2 for ten representative figures with explanatory notes.

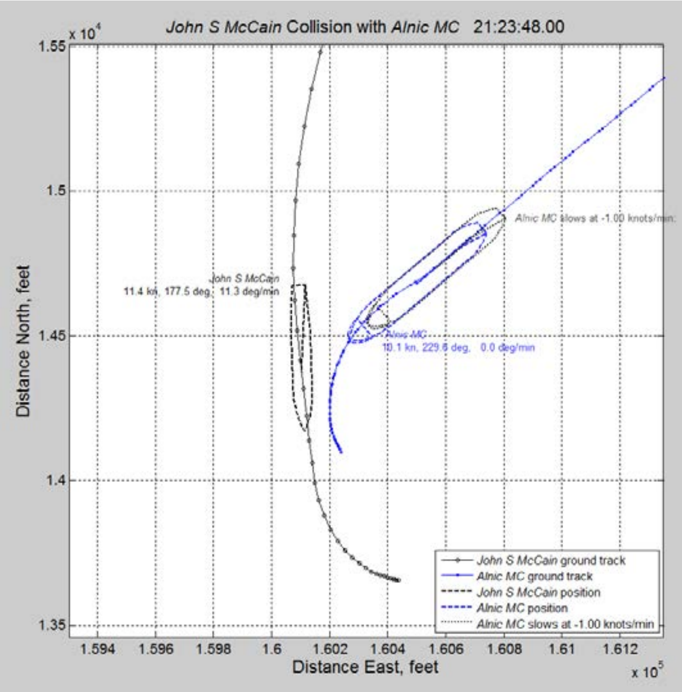


Figure 3: Ten seconds prior to collision. Gray colored *Alnic MC* hull position shown for 1 knot/minute deceleration.

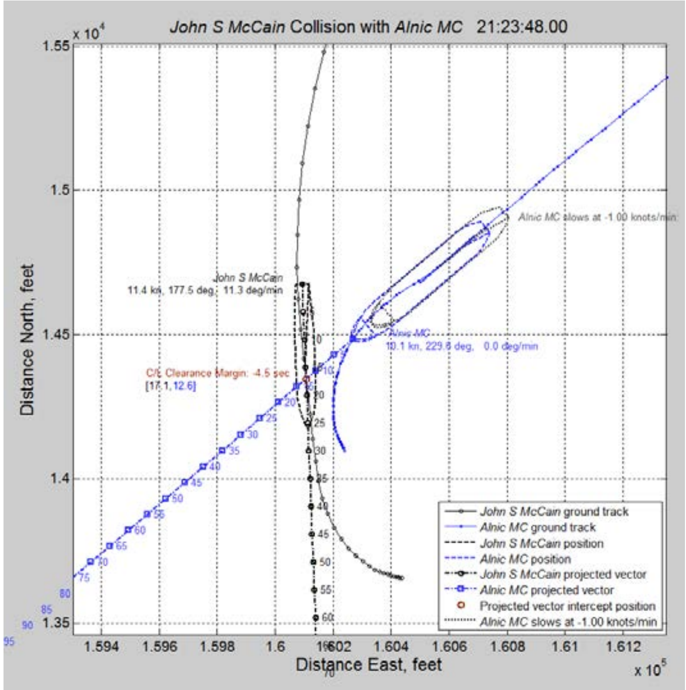


Figure 4: Ten seconds prior to collision. C/L Clearance Margin is negative, indicating *John S McCain* collision with tanker is probable.

The performance data indicate that the *Alnic MC* Master would need to order his engine to crash stop or crash astern no later than the 70- to 90-second window prior to the collision in order to slow his vessel enough to allow the *John S McCain* stern to just clear his bow. Given uncertainties regarding the currents, waves, winds, and hydrodynamic effects acting on the two vessels, a more realistic *Alnic MC* unilateral collision avoidance opportunity via vessel speed reduction alone is engine to crash stop or crash astern at least 80- to 90-seconds before the collision.

## 3.4 Discussion

The reconstructed vessel path and speed data indicate that neither vessel crew acted to avoid the collision or mitigate the consequences thereof until very shortly before the collision (via a starboard rudder surface position of 15 degrees on the *John S McCain* at least 15 seconds before impact and engine RPM reduction on the *Alnic MC* about 14.5 seconds before impact).

This study introduces a Centerline (C/L) Clearance Margin metric to help quantify the risk of impending collision between the *John S McCain* and the *Alnic MC*. The metric is calculated by subtracting the time required for the *John S McCain* stern to reach the projected vector intercept position from the time required for the *Alnic MC* bow to reach the same intercept position. The more positive the C/L Clearance Margin value, the lower the risk of collision. The more negative the C/L Clearance Margin, the higher the risk of collision (excluding hypothetical scenarios where the *Alnic MC* stern passes in front of the *John S McCain* bow). As the C/L Clearance Margin value approaches zero, the risk of collision increases but a collision may still be avoidable, for example, if the more maneuverable vessel takes constructive action and has adequate performance capability via throttle and/or steering to avoid the collision.

The projected position vector intercept data in Attachment 2 indicate positive C/L Clearance Margin values, meaning that the *John S McCain* stern will pass clear of the *Alnic MC* bow, until about 30 seconds prior to the collision, when the C/L Clearance Margin values become negative. These data show that the crew of the *John S McCain* had a collision avoidance opportunity window until at least 30 seconds prior to the collision based on the destroyer's recorded path and speed information. Given the Section 3.2 sensitivity study results that the *Alnic MC's* crew would have had to take unilateral action 70 to 90 seconds prior to the collision, the *John S McCain's* crew had a collision avoidance opportunity window 40 to 60 seconds longer (i.e., 70 – 30 = 40 seconds; 90 – 30 = 60 seconds) than the collision avoidance opportunity window available to the *Alnic MC* crew (assuming the *Alnic MC* accomplished the respective deceleration rates shown in Table 1 and maintained its course).

Regarding collision avoidance scenario modeling, the following questions were considered:

> *What effect would a 1-knot change in Alnic MC's speed produce in intervals of 1, 2, and 3 minutes? Where would the Alnic MC end up if this happened? Would the vessels have collided (assuming nothing changes on the John S McCain)?*
>
> **Response:** These questions are addressed in the current study.
>
> *What effect does a 1-, 2-, or 3-knot change in the John S McCain's speed produce in intervals of 1, 2 and 3 minutes? Where would the John S McCain end up if the Alnic MC did exactly what the data shows (assume no change)? Would there be a collision?*
>
> **Response:** These hypothetical *John S McCain* questions could be modeled but the answers add limited information at the expense of assumptions that are not applicable to the United States Navy crew. The factual data indicate that the destroyer had adequate performance capability to

avoid or escape the impending collision until at least 30 seconds prior to impact, based on the calculated C/L Clearance Margin data. However, collision avoidance required timely *John S McCain* crew awareness followed by complementary crew decisions and actions.

## 4.0 CONCLUSIONS

The NTSB reconstructed a subset of the accident voyage for each ship using recorded parametric data from each vessel. The addition of projected position vector data for each vessel enabled an intuitive and quantified assessment of the transition time from a probable near miss event to a probable collision event. Note that the results presented in this study assume that the *John S McCain* simply proceeded on its recorded pre-collision path at its recorded turn and deceleration rates.

The collision avoidance study results indicate that the *Alnic MC* Master would have needed to order the engine to crash stop or crash astern 70 to 90 seconds before the accident to pass astern of the *John S McCain* without making contact. At that time, the destroyer was 0.21 miles off the tanker's beam on a heading of 205 degrees and at a speed of 16.7 knots. The tanker was on a heading of 230 degrees at a constant speed of about 10 knots.

The projected position vector intercept data indicate positive C/L Clearance Margin values until about 30 seconds prior to the collision, when the values became negative. These calculated data indicate that the crew of the *John S McCain* had a collision avoidance opportunity window in time that was at least 40 to 60 seconds longer than the collision avoidance window available to the *Alnic MC* crew. Although the destroyer performance capability was not quantified in this study, the recorded destroyer data, the ship's mission design, and the ship's class operations show that the destroyer performance capability far exceeded the tank vessel performance capability.

The *Alnic MC* Master theoretically had an opportunity to perceive the *John S McCain's* increased turn rate (in response to the destroyer's inadvertent asymmetric engine throttle command), decide whether or not to act, and take action. The data shows that the *Alnic MC* master had about 98 seconds available (from the time the *John S McCain's* throttles were inadvertently mismatched) to slow the tanker and he needed 70 to 90 seconds, discounting independent constructive actions by the *John S McCain's* crew or their actions in response to a hypothetical *Alnic MC* VHF radio call and/or ship's horn warning. The *Alnic MC* Master therefore had an 8- to 28-second window to recognize the developing collision hazard, identify options, decide how to respond, and take action. It is noteworthy that throughout this timeframe, with the benefit of investigative hindsight, the projected vector intercept position data indicated that the *John S McCain* stern would clear the *Alnic MC* bow.

The reconstructed vessel path and speed data show that neither vessel crew acted to avoid the collision or mitigate the consequences thereof until very shortly before the collision (as evidenced by the recorded 15 degrees starboard rudder surface position on the *John S McCain* at least 15 seconds before impact and the engine RPM reduction on the *Alnic MC* about 14.5 seconds before impact).

## 5.0 ATTACHMENTS

A summary of the animated .gif files that support this study is provided in Table 2. A subset of the *Alnic MC* sea trials data for the crash astern and crash stop maneuvers are included in Attachment 1. Attachment 2 contains images extracted from a subset of the animated .gif files with explanatory notes.

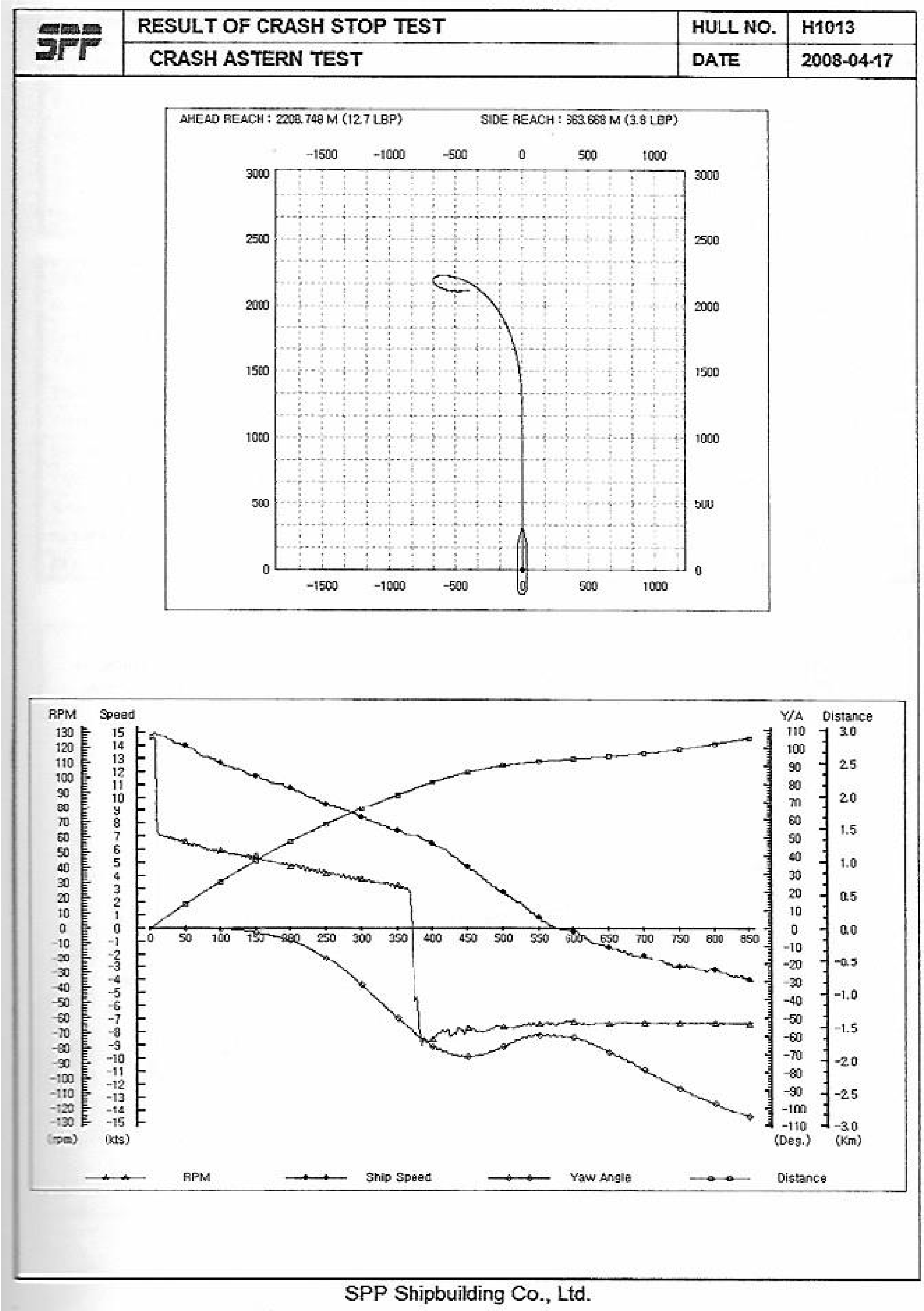
Table 2: Animated .gif files

| File | Content Level | Name | Decel. knot/min | Playback Rate |
|---|---|---|---|---|
| 1 | 1 | John_S_McCain_Alnic_MC_collision_resconstruction_real_time.gif | N/A | 1x |
| 2 | 1 | John_S_McCain_Alnic_MC_collision_resconstruction_2X_real_time.gif | N/A | 2x |
| 3 | 1 | John_S_McCain_Alnic_MC_collision_resconstruction_4X_real_time.gif | N/A | 4x |
| 4 | 1 | John_S_McCain_Alnic_MC_collision_resconstruction_8X_real_time.gif | N/A | 8x |
| 5 | 2 | John_S_McCain_Alnic_MC_collision_resconstruction_projected_vectors_5_sec_incr_to_2_min_real_time.gif | N/A | 1x |
| 6 | 2 | John_S_McCain_Alnic_MC_collision_resconstruction_projected_vectors_5_sec_incr_to_2_min_2X_real_time.gif | N/A | 2x |
| 7 | 2 | John_S_McCain_Alnic_MC_collision_resconstruction_projected_vectors_5_sec_incr_to_2_min_4X_real_time.gif | N/A | 4x |
| 8 | 2 | John_S_McCain_Alnic_MC_collision_resconstruction_projected_vectors_5_sec_incr_to_2_min_8X_real_time.gif | N/A | 8x |
| 9 | 3 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_0.75_knot_per_min_real_time.gif | 0.75 | 1x |
| 10 | 3 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_0.75_knot_per_min_2X_real_time.gif | 0.75 | 2x |
| 11 | 3 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_0.75_knot_per_min_4X_real_time.gif | 0.75 | 4x |
| 12 | 3 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_0.75_knot_per_min_8X_real_time.gif | 0.75 | 8x |
| 13 | 3 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.00_knot_per_min_real_time.gif | 1.00 | 1x |
| 14 | 3 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.00_knot_per_min_2X_real_time.gif | 1.00 | 2x |
| 15 | 3 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.00_knot_per_min_4X_real_time.gif | 1.00 | 4x |
| 16 | 3 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.00_knot_per_min_8X_real_time.gif | 1.00 | 8x |
| 17 | 3 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.25_knot_per_min_real_time.gif | 1.25 | 1x |
| 18 | 3 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.25_knot_per_min_2X_real_time.gif | 1.25 | 2x |
| 19 | 3 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.25_knot_per_min_4X_real_time.gif | 1.25 | 4x |
| 20 | 3 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.25_knot_per_min_8X_real_time.gif | 1.25 | 8x |
| 21 | 4 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_0.75_knot_per_min_projected_vectors_5_sec_incr_to_2_min_real_time.gif | 0.75 | 1x |
| 22 | 4 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_0.75_knot_per_min_projected_vectors_5_sec_incr_to_2_min_2X_real_time.gif | 0.75 | 2x |
| 23 | 4 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_0.75_knot_per_min_projected_vectors_5_sec_incr_to_2_min_4X_real_time.gif | 0.75 | 4x |
| 24 | 4 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_0.75_knot_per_min_projected_vectors_5_sec_incr_to_2_min_8X_real_time.gif | 0.75 | 8x |
| 25 | 4 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.00_knot_per_min_projected_vectors_5_sec_incr_to_2_min_real_time.gif | 1.00 | 1x |
| 26 | 4 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.00_knot_per_min_projected_vectors_5_sec_incr_to_2_min_2X_real_time.gif | 1.00 | 2x |
| 27 | 4 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.00_knot_per_min_projected_vectors_5_sec_incr_to_2_min_4X_real_time.gif | 1.00 | 4x |
| 28 | 4 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.00_knot_per_min_projected_vectors_5_sec_incr_to_2_min_8X_real_time.gif | 1.00 | 8x |
| 29 | 4 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.25_knot_per_min_projected_vectors_5_sec_incr_to_2_min_real_time.gif | 1.25 | 1x |
| 30 | 4 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.25_knot_per_min_projected_vectors_5_sec_incr_to_2_min_2X_real_time.gif | 1.25 | 2x |
| 31 | 4 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.25_knot_per_min_projected_vectors_5_sec_incr_to_2_min_4X_real_time.gif | 1.25 | 4x |
| 32 | 4 | John_S_McCain_Alnic_MC_collision_resconstruction_Alnic_MC_decel_1.25_knot_per_min_projected_vectors_5_sec_incr_to_2_min_8X_real_time.gif | 1.25 | 8x |

# Attachment 1

Subset of *Alnic MC* class sea trials data

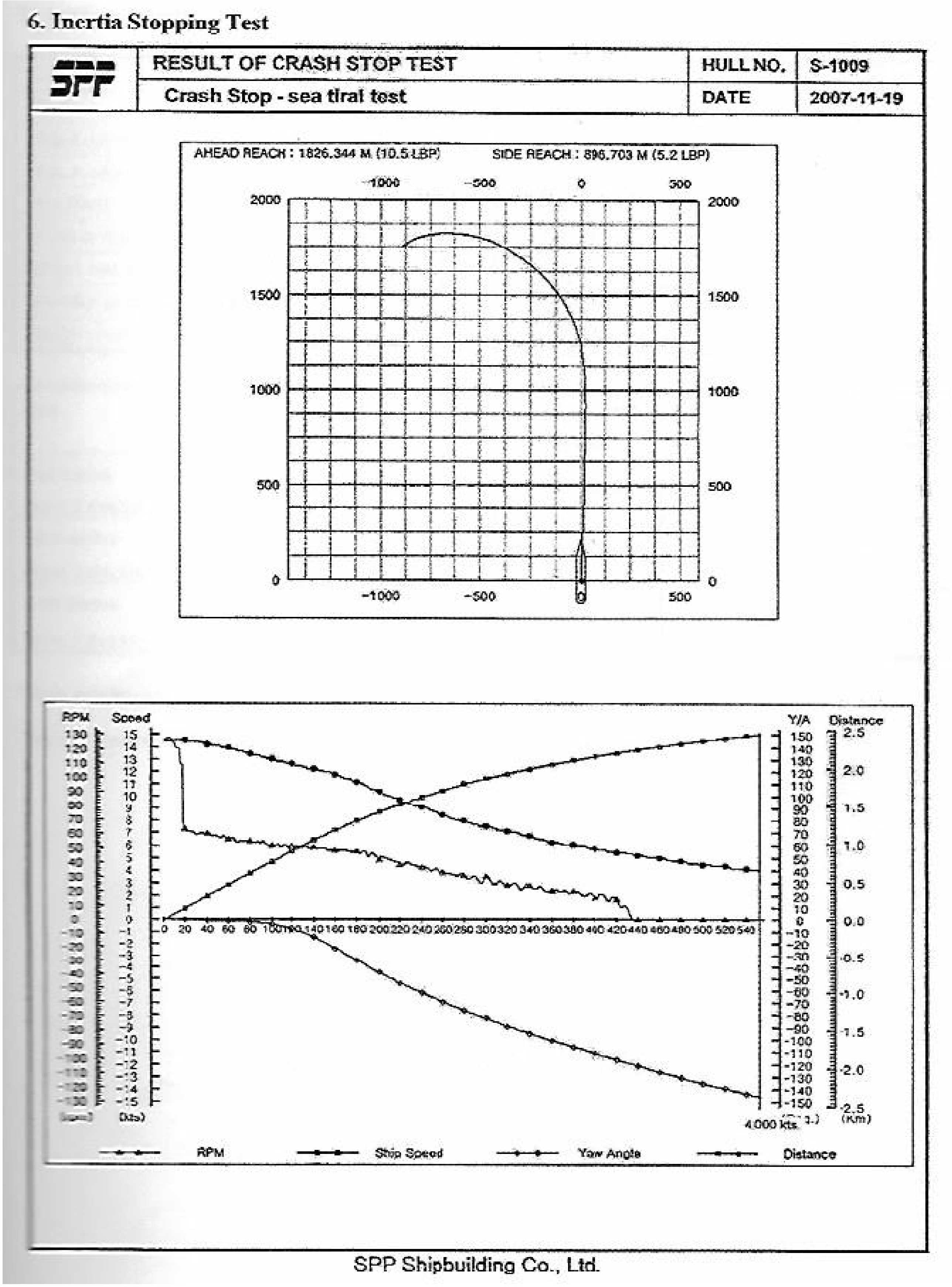
Excerpted from:
Dwg. No. DB405001DB, rev. F, April 21, 2008
Result of Sea-Trial, M/T Mexico, Hull No. H-1013
50,000 DWT Oil/Chemical Tanker
DSEC Co., LTD., SPP Shipbuilding Co., LTD



| SPP | RESULT OF CRASH STOP TEST | HULL NO. | H1013 |
|---|---|---|---|
| | CRASH ASTERN TEST | DATE | 2008-04-17 |

SPP Shipbuilding Co., Ltd.

Subset of *Alnic MC* class sea trials stopping performance data for the crash astern test maneuver.



## 6. Inertia Stopping Test

| | | | |
|---|---|---|---|
| SPP | RESULT OF CRASH STOP TEST | HULL NO. | S-1009 |
| | Crash Stop - sea tiral test | DATE | 2007-11-19 |

SPP Shipbuilding Co., Ltd.

Subset of *Alnic MC* class sea trials stopping performance data for the crash stop test maneuver.

# Attachment 2

Images extracted from a subset of the animated .gif files with explanatory notes

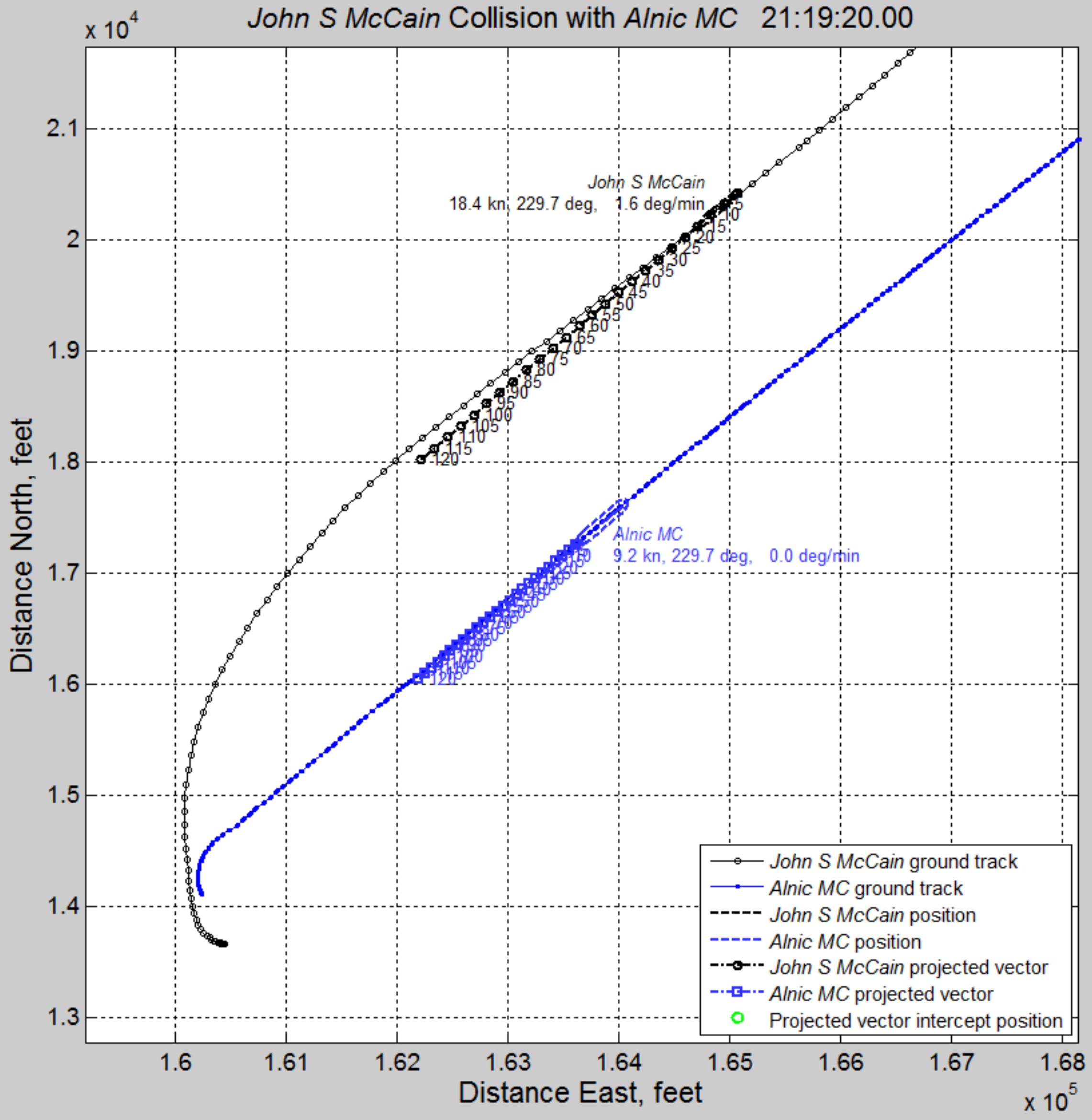


Figure A.1: Planform view of vessel ground track paths (including speed, heading, and heading rate of change), hull perimeters, and projected vector positions over the next two minutes in five-second increments. Origin for the distance measurements is the Singapore Changi Airport runway 20C threshold. Time of collision is 21:23:58.

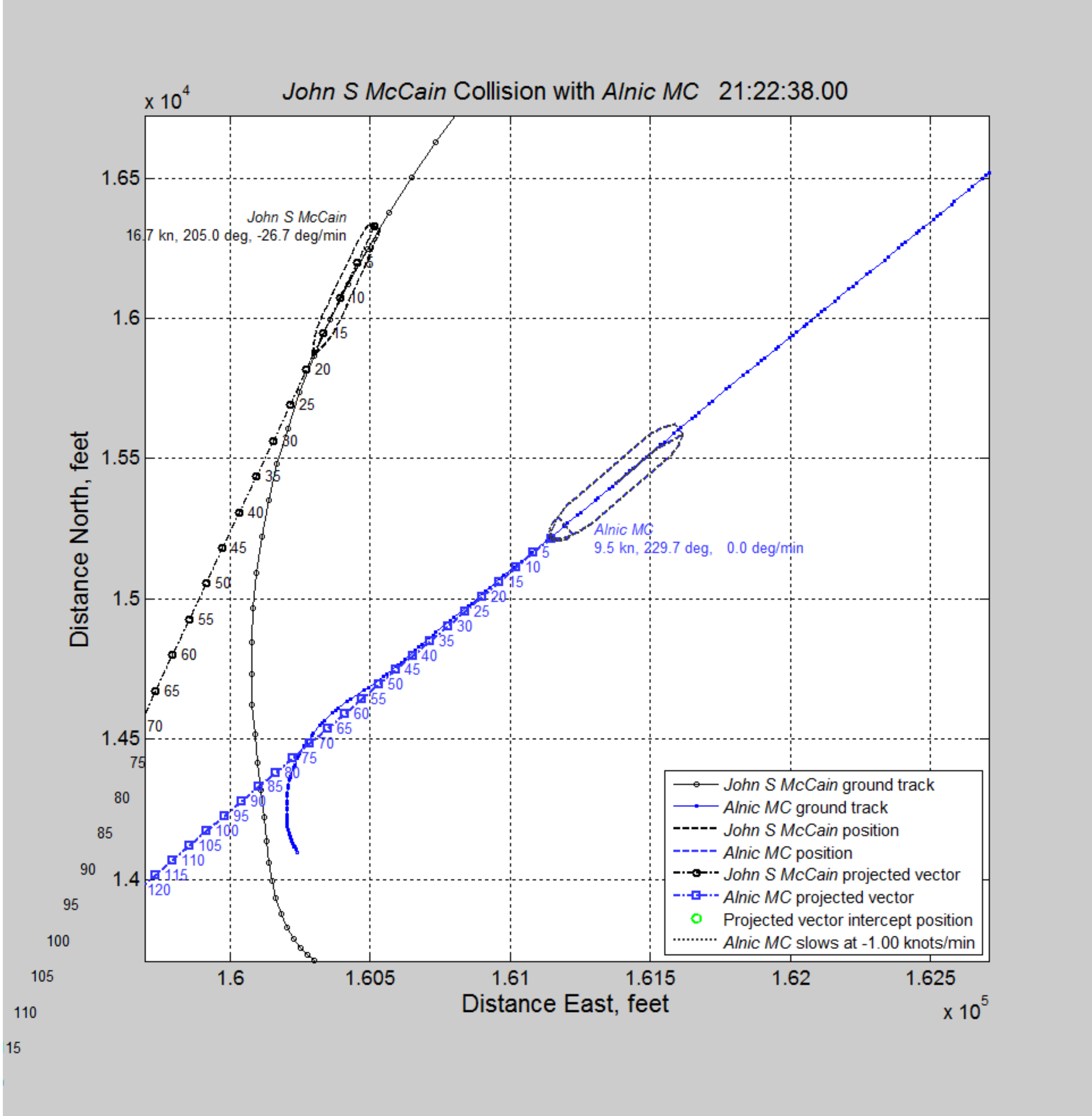


Figure A.2: Eighty seconds prior to the collision event, introduction of hypothetical *Alnic MC* crash stop or crash astern order to slow the vessel by 1.0 knot per minute in an effort to allow the *John S McCain* stern to clear the *Alnic MC* bow. Hull position of the *Alnic MC* following the hypothetical crash stop or crash astern order is illustrated by the gray dotted line. Figure includes planform view of vessel ground track paths (including speed, heading, and heading rate of change), hull perimeters, and projected vector positions over the next two minutes in five-second increments. Origin for the distance measurements is the Singapore Changi Airport runway 20C threshold. Time of collision is 21:23:58.

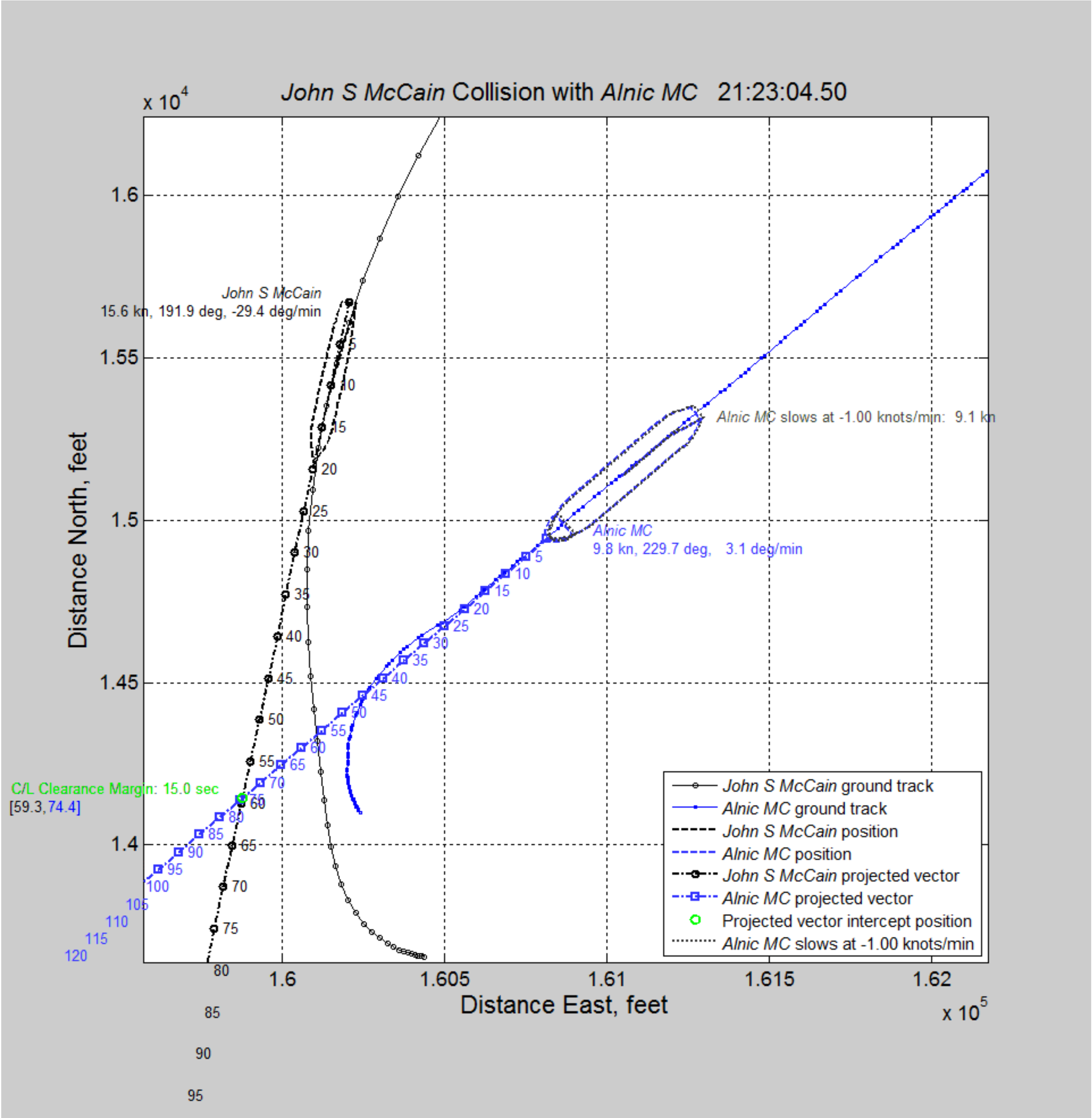


Figure A.3: Example of positive Centerline (C/L) Clearance Margin, defined as the difference in estimated time of arrival (that is, the estimated *Alnic MC* bow C/L arrival time minus the estimated *John S McCain* stern C/L arrival time) at the intersection point of the respective vessel projected position vectors. Green text and intercept position values indicate that the two vessels will not likely collide if current speed and course are maintained for each vessel. Hull position of the *Alnic MC* following the hypothetical crash stop or crash astern order (given at 21:22:38, 26.5 seconds earlier) to slow the vessel by 1.0 knot per minute is illustrated by the gray dotted line. Figure includes planform view of vessel ground track paths (including speed, heading, and heading rate of change), hull perimeters, and projected vector positions over the next two minutes in five-second increments. Origin for the distance measurements is the Changi runway 20C threshold. Time of collision is 21:23:58.

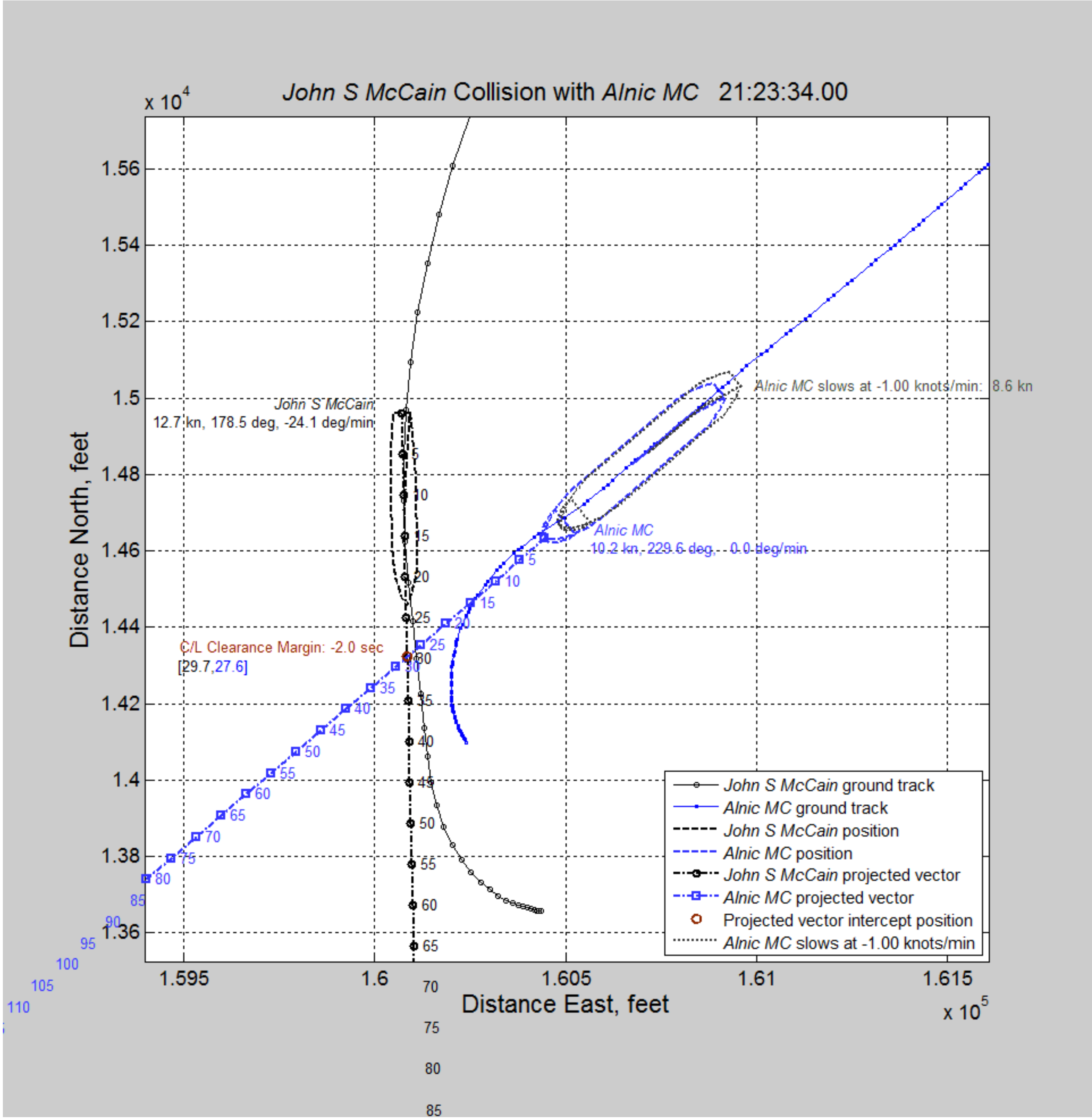


Figure A.4: Example of negative Centerline (C/L) Clearance Margin, defined as the difference in estimated time of arrival (that is, the estimated *Alnic MC* bow C/L arrival time minus the estimated *John S McCain* stern C/L arrival time) at the intersection point of the respective vessel projected position vectors. Red text and intercept position values indicate that the two vessels will likely collide if current speed and course are maintained for each vessel. Hull position of the *Alnic MC* following the hypothetical crash stop or crash astern order (given at 21:22:38, 56 seconds earlier) to slow the vessel by 1.0 knot per minute is illustrated by the gray dotted line. Figure includes planform view of vessel ground track paths (including speed, heading, and heading rate of change), hull perimeters, and projected vector positions over the next two minutes in five-second increments. Origin for the distance measurements is the Changi runway 20C threshold. Time of collision is 21:23:58.

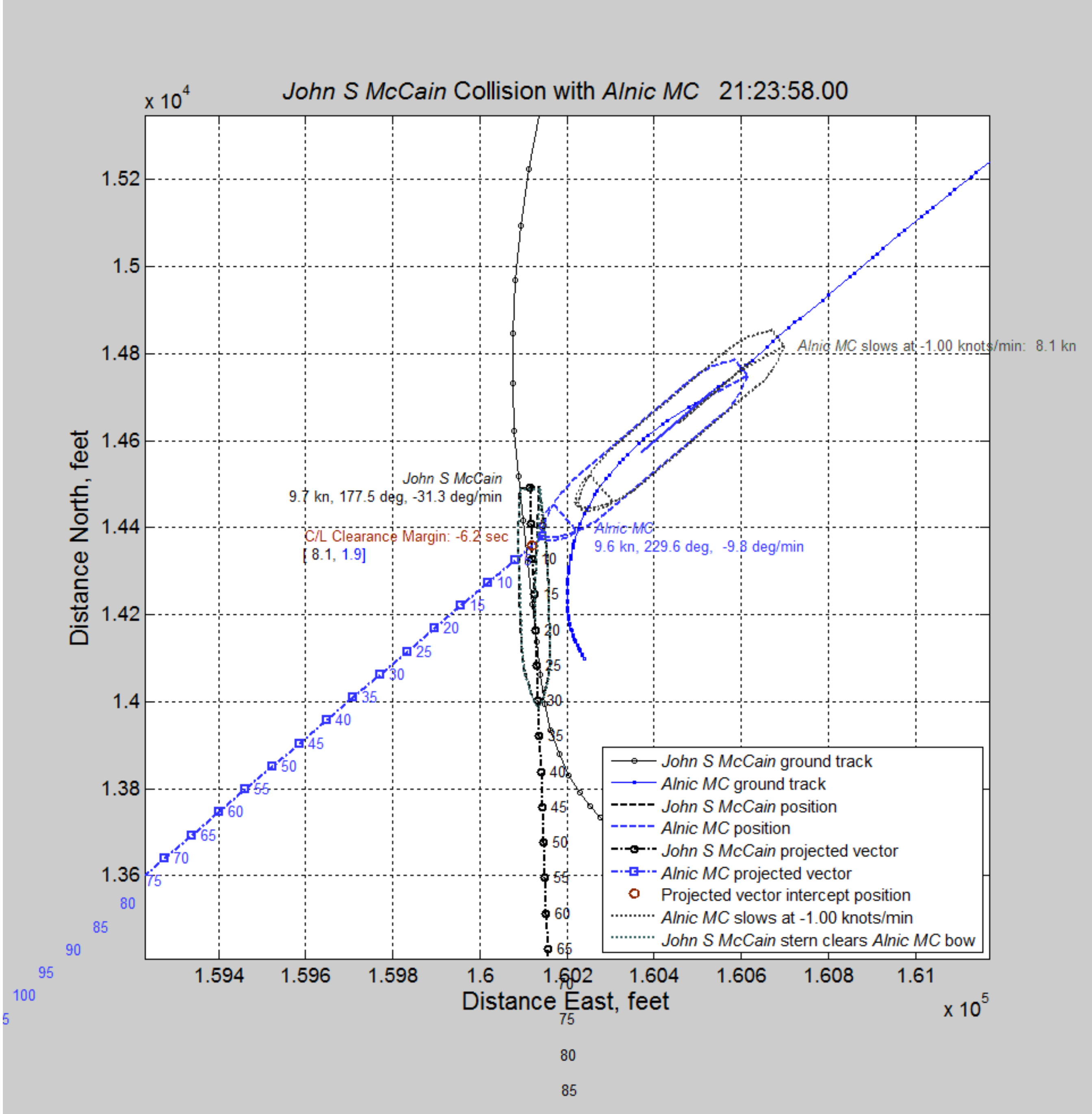


Figure A.5: Time of collision (21:23:58). Hull positions of the *Alnic MC* and the *John S McCain* following the hypothetical crash stop or crash astern order (given at 21:22:38, 80 seconds earlier) to slow the *Alnic MC* by 1.0 knot per minute are illustrated by the respective gray dotted lines. Figure includes planform view of the respective collision vessel ground track paths (including speed, heading, and heading rate of change), collision event hull perimeters (*Alnic MC* colored blue, *John S McCain* colored black/gray), and projected vector positions over the next two minutes in five-second increments. Origin for the distance measurements is the Singapore Changi Airport runway 20C threshold.

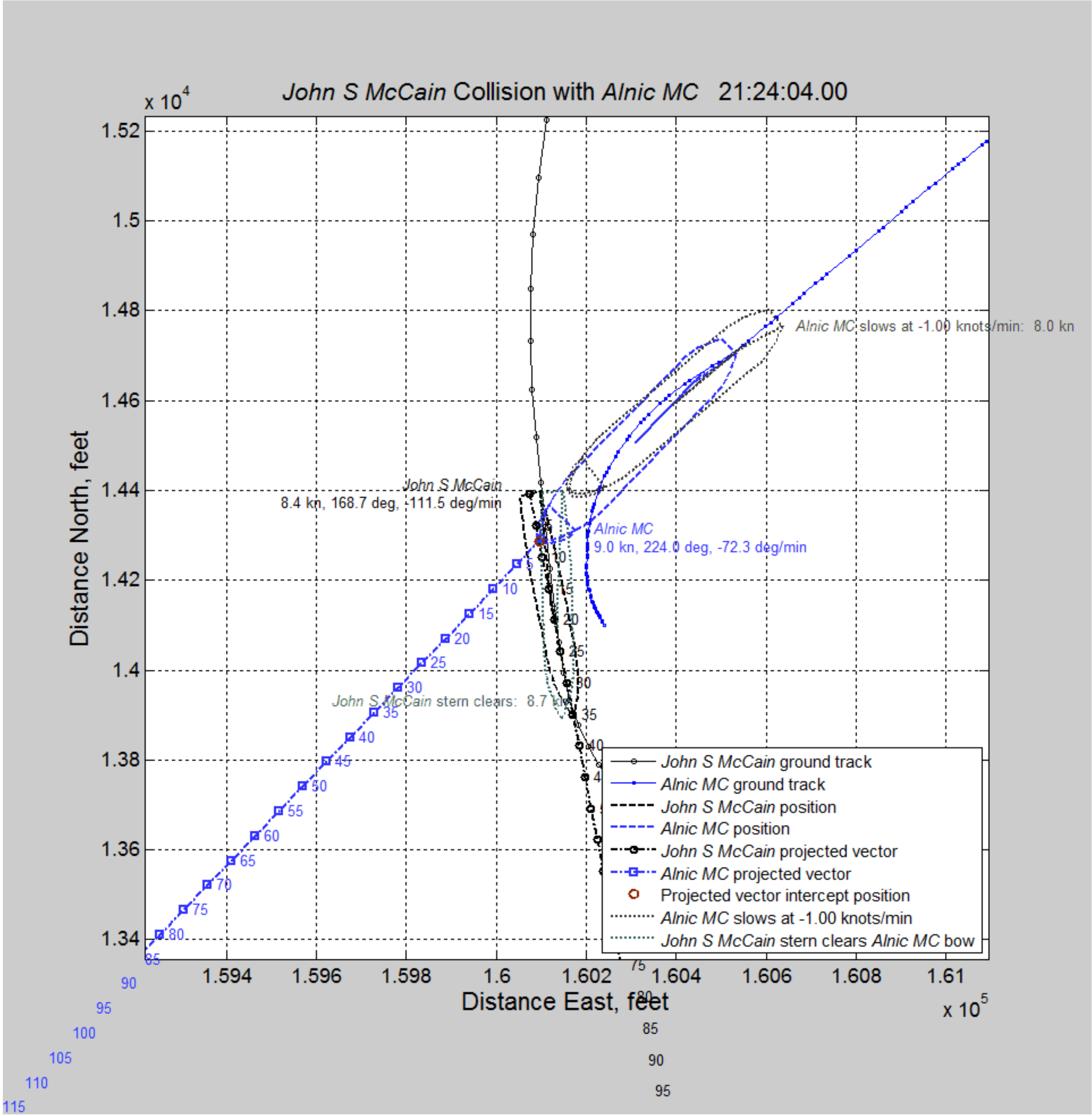


Figure A.6: Time of collision plus 6 seconds. Hull positions of the *Alnic MC* and the *John S McCain* following the hypothetical crash stop or crash astern order (given at 21:22:38, 86 seconds earlier) to slow the *Alnic MC* by 1.0 knot per minute are illustrated by the respective gray dotted lines. Figure includes planform view of the respective collision vessel ground track paths (including speed, heading, and heading rate of change), post-collision event hull perimeters (*Alnic MC* colored blue, *John S McCain* colored black), and projected vector positions over the next two minutes in five-second increments. Origin for the distance measurements is the Singapore Changi Airport runway 20C threshold.

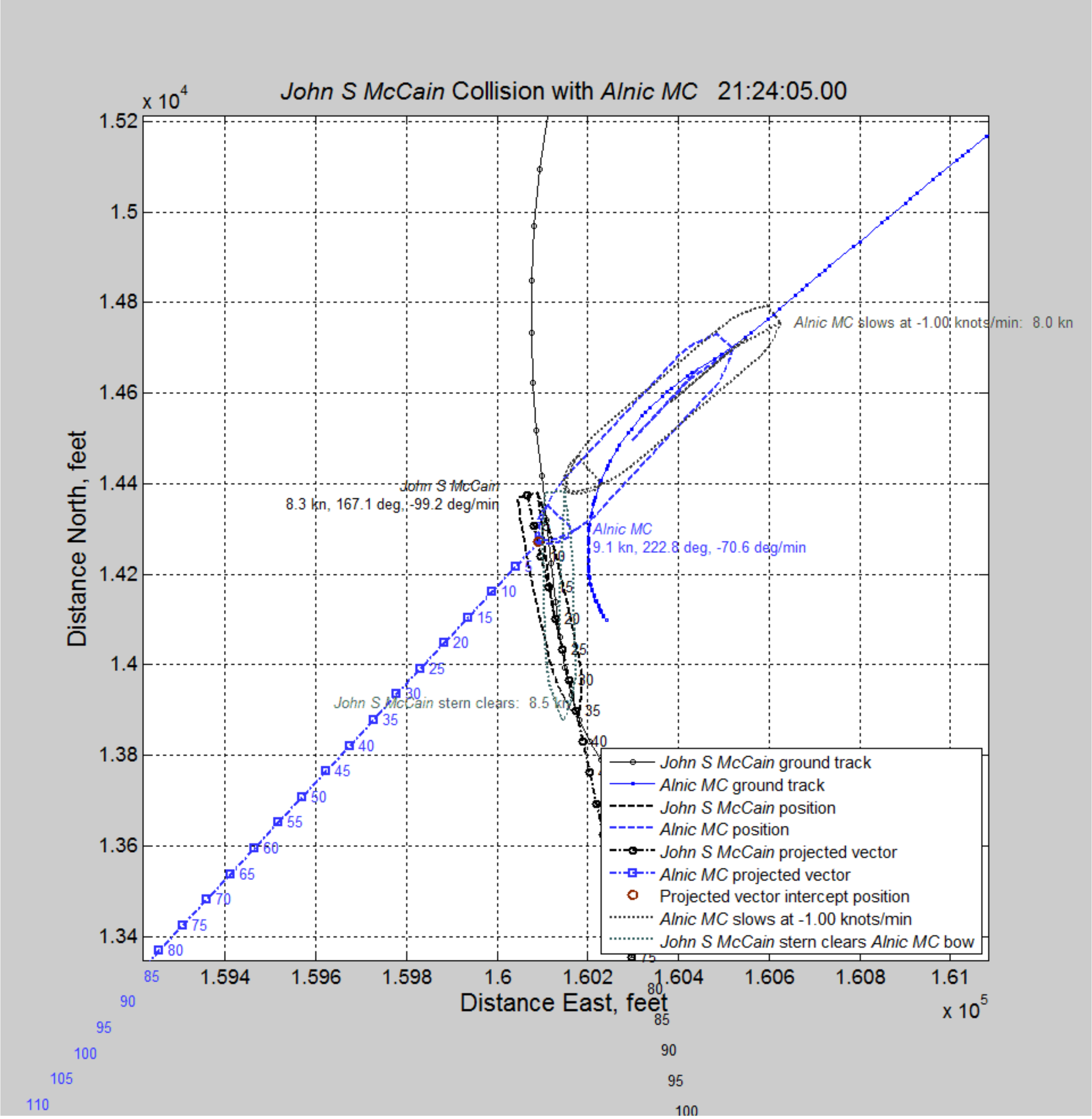


Figure A.7: Time of collision plus 7 seconds. Hull positions of the *Alnic MC* and the *John S McCain* following the hypothetical crash stop or crash astern order (given at 21:22:38, 87 seconds earlier) to slow the *Alnic MC* by 1.0 knot per minute are illustrated by the respective gray dotted lines. Figure includes planform view of the respective collision vessel ground track paths (including speed, heading, and heading rate of change), post-collision event hull perimeters (*Alnic MC* colored blue, *John S McCain* colored black), and projected vector positions over the next two minutes in five-second increments. Origin for the distance measurements is the Singapore Changi Airport runway 20C threshold.

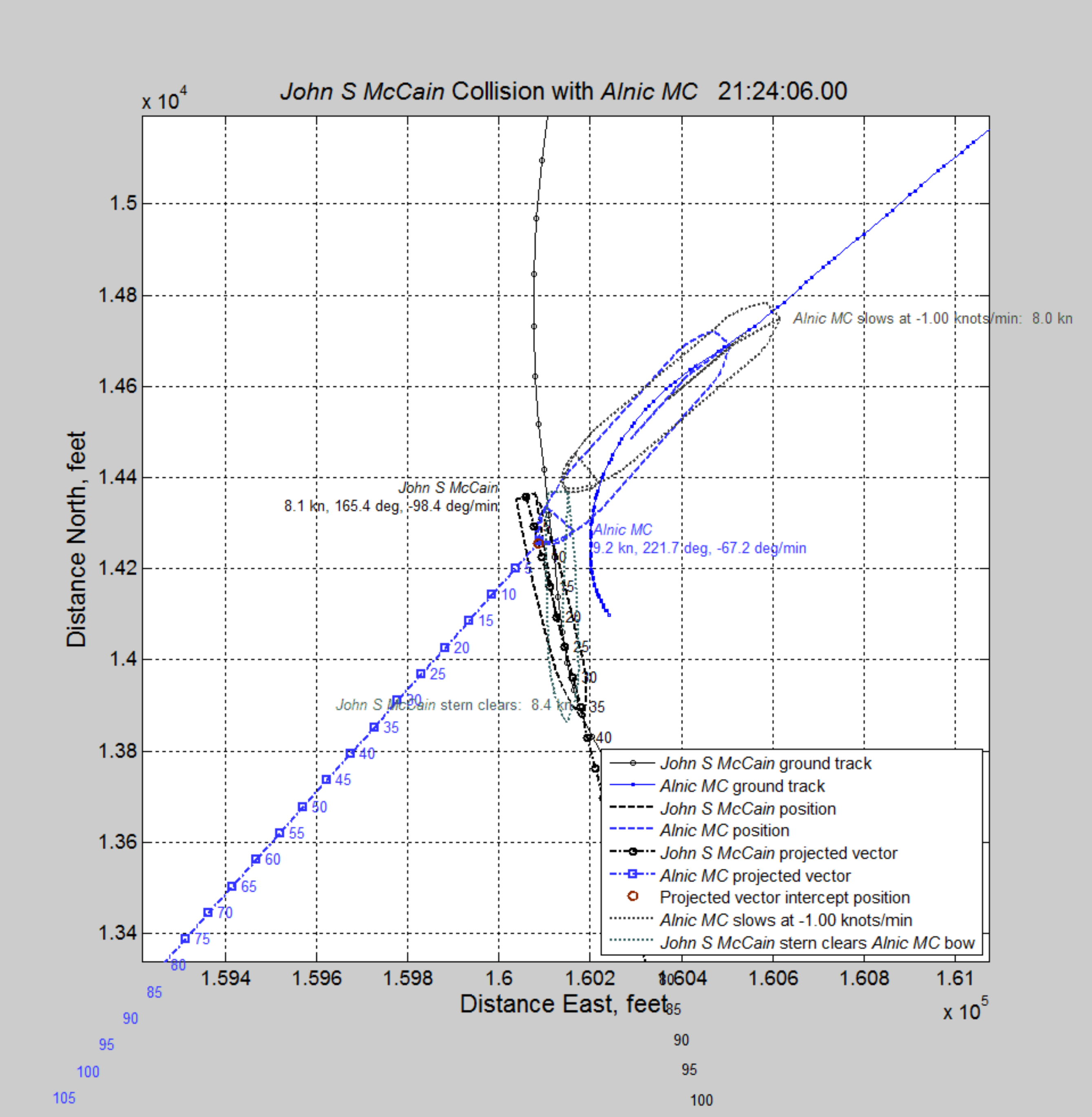


Figure A.8: Time of collision plus 8 seconds. Hull positions of the *Alnic MC* and the *John S McCain* following the hypothetical crash stop or crash astern order (given at 21:22:38, 88 seconds earlier) to slow the *Alnic MC* by 1.0 knot per minute are illustrated by the respective gray dotted lines. Figure includes planform view of the respective collision vessel ground track paths (including speed, heading, and heading rate of change), post-collision event hull perimeters (*Alnic MC* colored blue, *John S McCain* colored black), and projected vector positions over the next two minutes in five-second increments. Origin for the distance measurements is the Singapore Changi Airport runway 20C threshold.

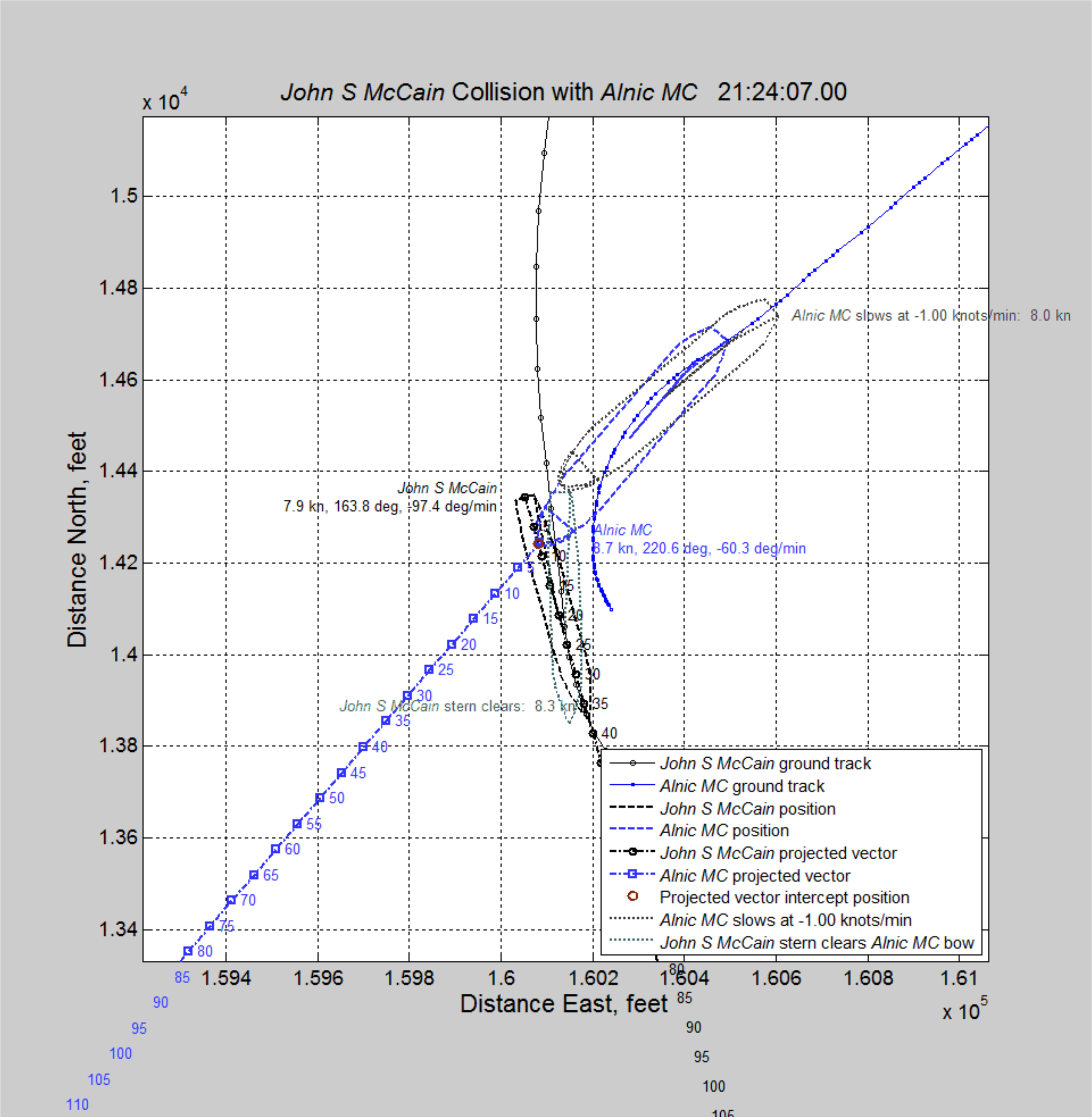


Figure A.9: Time of collision plus 9 seconds. Hull positions of the *Alnic MC* and the *John S McCain* following the hypothetical crash stop or crash astern order (given at 21:22:38, 89 seconds earlier) to slow the *Alnic MC* by 1.0 knot per minute are illustrated by the respective gray dotted lines. Figure includes planform view of the respective collision vessel ground track paths (including speed, heading, and heading rate of change), post-collision event hull perimeters (*Alnic MC* colored blue, *John S McCain* colored black), and projected vector positions over the next two minutes in five-second increments. Origin for the distance measurements is the Singapore Changi Airport runway 20C threshold.

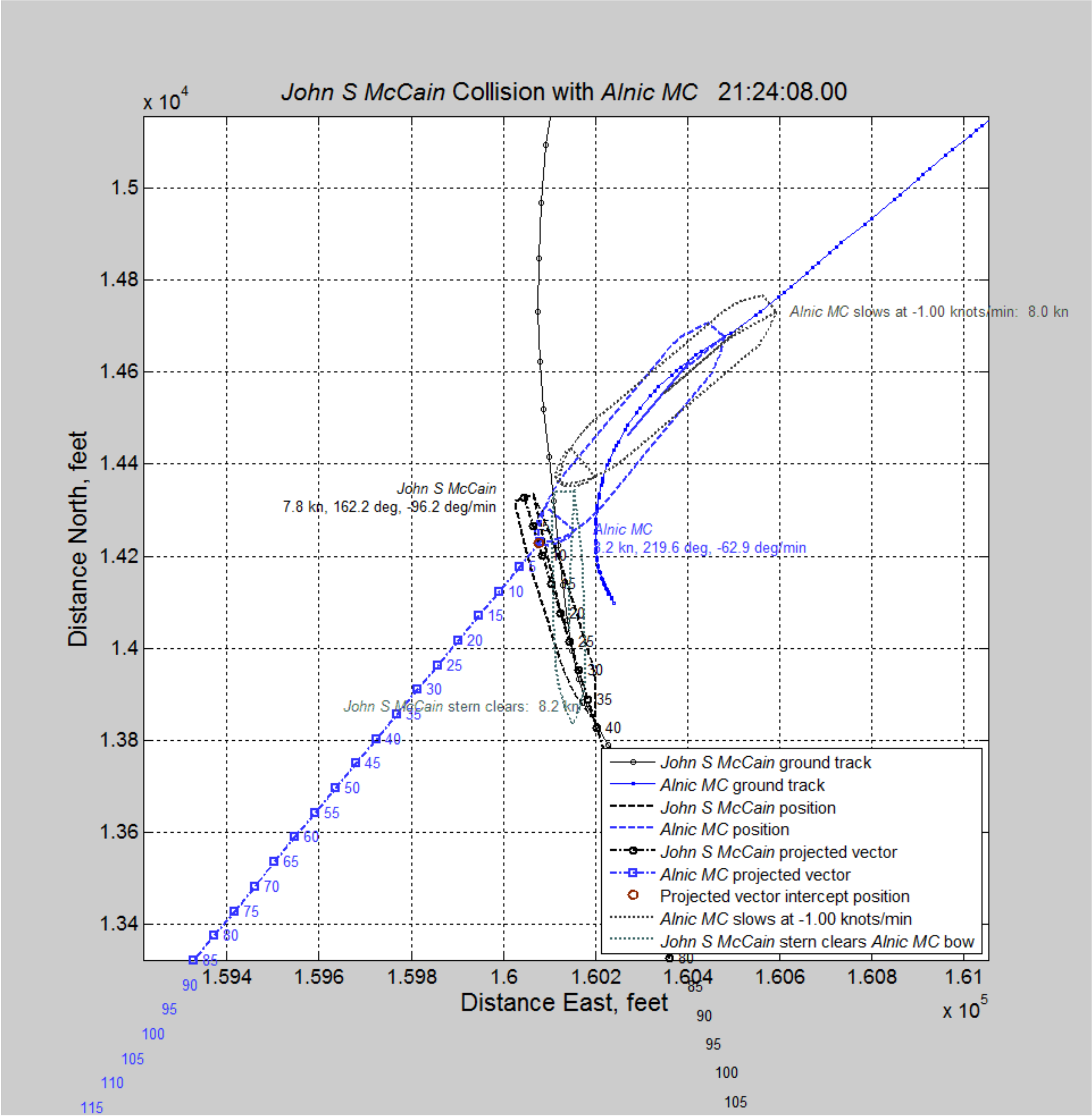


Figure A.10: Time of collision plus 10 seconds. Hull positions of the *Alnic MC* and the *John S McCain* following the hypothetical crash stop or crash astern order (given at 21:22:38, 90 seconds earlier) to slow the *Alnic MC* by 1.0 knot per minute are illustrated by the respective gray dotted lines. Figure includes planform view of the respective collision vessel ground track paths (including speed, heading, and heading rate of change), post-collision event hull perimeters (*Alnic MC* colored blue, *John S McCain* colored black), and projected vector positions over the next two minutes in five-second increments. Origin for the distance measurements is the Singapore Changi Airport runway 20C threshold.