Real Time Navigation Simulation Study (STAR Center)

Technical Memorandum

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EXECUTIVE SUMMARY

This report presents the results of a full-mission real-time simulation study of large cruise ship transits of Tongass Narrows. The program was developed to assist in the selection of one of three options for siting a bridge crossing to Gravina Island from Ketchikan, Alaska. The study was conducted at RTM STAR Center in Dania Beach, Florida. This report has been prepared by The Glosten Associates who participated in designing the simulation program, participated in conducting the tests and did the statistical analysis of the resulting data. There is a companion report prepared by RTM STAR Center.

The simulator provides for a 360° pilothouse view of the Ketchikan waterway, including simulated views of the three bridge options. It is in color and is adequately realistic for experienced pilots to recognize landmarks and existing aids to navigation. The simulator has a full scale mock-up of a cruise ship bridge (pilothouse) from which the simulated ship is controlled by full-scale equipment matching that which can be found on board a real vessel. A helmsman is provided to whom the pilot can give steering orders. There is a chart table, simulated radar display and ECDIS (electronic chart display and information system). The full-mission real-time simulation is often used for crew and pilot training and is thus designed to be as realistic as possible. The hydrodynamic computer models used in the simulator realistically replicate wind and currents forces as well as bank suction, bank cushion, shallow water and passing ship effects.

The real-time simulation of cruise ship transits of Tongass Narrows was carried out during the weeks of 1 May through 22 May 2002. A total of 144 simulations were accomplished. The program was attended by 10 experienced pilots from Ketchikan. They took turns guiding the simulated ships in transits of the channels of Tongass Narrows.

The matrix of simulation scenarios undertaken included combinations of 2 ship types (1 large azipod and 1 slightly smaller conventionally propelled ship), 4 wind conditions from several directions with differing gust factors, and 3 different visibility cases (day, night and fog). Simulations were run in each of the three channels of Tongass Narrows, identified in this report and East Channel, West Channel and North Channel. North Channel is not an official name. It is defined herein as the portion of Tongass Narrows north of a line between East Clump light and buoy "WR6" and running between Charcoal Point and the airport up to Peninsula Point. Simulations were run in both the northbound and southbound directions. Most simulations were terminated when the ship passed under the bridge of interest; however some of the East and West Channel cases either started or ended at the cruise ship terminal.

The primary conclusion of the real-time simulation project is that there is a significant difference in the perception of risk of using West Channel and the statistics of risk based on pilot performance in West Channel. The pilots were exceedingly skillful in their ability to safely simulate the transit of very large cruise ships in severe and extreme wind conditions up West Channel and under the F3 bridge option. The measures of the difficulty of the task, the number of navigation adjustments as the bridge is approached, also demonstrate that the F1 and F3 bridge options are in navigation nominally similar. However, in spite of their success, the pilots found the transit of West Channel to be more stressful, difficult and unsafe than transits of East Channel..

The discrepancy between the success of the pilots in the simulated transits of West Channel and the level of stress, task difficulty and unsafe conditions reported in the post-exercise evaluations needs an explanation. It appears from the verbal comments gathered by the authors and the written comments in the final evaluations that their concern is primarily one of the options available if something went wrong. It was clearly demonstrated that large cruise ships could be safely piloted up West Channel by experienced and skilled pilots in all of the conditions simulated. It is also clear that they felt that if something went wrong mechanically or if a misjudgment was made or if the wind took an unexpected shift or if some other vessel was unable or unwilling to give way, the options for saving the situation were significantly less in West Channel compared to East Channel. The primary difference between West Channel and East Channel is not in the error-free transit, but in the cases were something goes wrong. The options for emergency maneuvers, i.e., crash stop, dropping anchor, emergency avoidance maneuvers, emergency U-turns, or the use of escort tugs, were not attempted nor evaluated in either the real-time or fast-time simulation program.

Transiting North Channel under bridge option C3/C4 was demonstrated to be a straight forward navigational problem. It generated very little comment and proved to be the lowest risk option in both the real-time and fast-time analyses.

The other significant conclusion is that the measures of relative risk developed by fast-time simulation are upheld. The comparative risk of potential groundings and allisions contained in Table 4.13 of [2], are still valid.

Section 7 contains brief discussions of several "mitigation" options. The "mitigations" are proposed as actions to be considered that may improve the safety of navigation and/or reduce the cost of getting to the cruise ship terminal from the different bridge options. The proposal can be called a "mitigations" if it reduces the impact of a particular bridge choice. The "mitigation" options include;

1. The establishment of a Vessel Traffic System (VTS).
2. Adding aids to navigation
3. Adding the use of harbor or escort tugs.
4. Removal of Starkweather Shoal and/or the sunken concrete barge
5. Relocation of the West Channel underwater cables.
6. Should there be Speed Limit Extensions
7. Reconfiguring the anchorage

1—Introduction

A full mission (360° bridge view) simulation of cruise ship transits of Tongass Narrows was conducted at STAR Center in Dania, Florida, during the weeks of 1 May through 22 May 2002. A complete description of the procedures and models is contained the RTM STAR Center report [1]. That report contains their recommendations regarding navigation at each of the three proposed bridge sites. This report contains a presentation of the pilots' evaluations of each of the runs and the results of an analysis of the ship maneuvers and position as they approached and transited under the bridge sites.

This study looked at navigation under a proposed high bridge at three sites: over East Channel with bridge option F1, over West Channel with bridge option F3, and over 'North Channel' (near the airport) with bridge option C3/C4. Options C3 and C4 present the same navigational opening for ships transiting North Channel. The navigation opening (not the bridge span as indicated in [1]) was set for each bridge at 550'. This is the distance between the east and west bridge pier fenders. The positions of the bridge piers and fenders and the calculation of the navigational opening are given in Appendix B.

The simulations were conducted with four ships. They were: the *Carnival Destiny*, *Carnival Spirit*, *Voyager of the Seas* and *Golden Princess*. These ships are described in detail in the STAR Center report [1]. The *Voyager of the Seas* is the largest of the ships considered. It is an azipod ship. The *Carnival Spirit* was used for one day only. It is also an azipod ship. The *Carnival Destiny* and *Golden Princess* are conventionally steered ships (rudders behind twin open propellers). They are slightly smaller than the *Voyager of the Seas.*

The environmental conditions tested are also described in STAR Center report [1]. The variables included wind speed and direction, currents, visibility (both day and night, and in fog) and run direction (northbound and southbound). Four wind speed conditions were simulated: calm, 15 knots, 20 knots and 30 knots. The 30 knot wind speed was proposed by the Ketchikan pilots as an extreme case, but one that they are faced with in piloting cruise ships into and out of Ketchikan in the summer months. It should be noted that winds of this velocity are rarely measured at Ketchikan airport; see [2]. The wind was modeled as fluctuating in both magnitude and direction. The magnitude fluctuation was ±50% with direction fluctuating ±15°. The wind speed model was frequently criticized as not being realistic, and indeed it did not include all of the local variations that may be experienced due to local typography and thermal variations. However, although the wind was not perfect, the extreme value clearly demonstrated the limiting difficulty of using any of the bridge options.

The tidal current model was also frequently criticized as not accurately representing the real world condition. Again the model did not include all of the local variations that may be experienced due to local bathymetry and other effects. However, it is not expected that the lack of reality of the currents as modeled will affect the degree of difficulty of navigating either the East or North Channel bridge options. Based on the comments of the pilots, the West Channel navigation is expected to be more difficult than demonstrated herein, because of localized current effects.

Ten experienced pilots from Alaska participated in this study. They included pilots from the Southeast Alaska Pilots Association and Alaskan Coastwise Pilot Association. The individuals were selected by their respective pilot associations to represent a cross section of experience and familiarity with the Ketchikan waterway. An additional pilot was provided by STAR Center. This pilot was not experienced in Ketchikan waters, but was experienced in handling large cruise ships in the Caribbean and elsewhere. His runs and comments are evaluated separately from those of the Ketchikan pilots to see if there were prejudices about the bridge/channel options that were affecting the tests.

The matrix of tests run is given in Appendix A. A run number, purpose, ship name, wind speed and direction, current condition, visibility and pilot number are given for each test. The run numbers can be used to identify the conditions in the plots of the results.

There were several runs in East Channel where the navigational opening distance between the pier fenders for the F1 bridge were inadvertently set to 750'. The runs are listed in the STAR Center report [1] as 2, 3, 4, 5 and 6. These runs have been removed from all of the following analyses. Run 3b was an attempt to determine the maximum wind speed that a particular pilot could handle a ship in East Channel. It was added at the last minute and was not intended to be part of the test matrix. The data for the run was not archived (only the plot is provided in the RTM STAR Center Report [1]). This run has been removed from the analysis.

2—Analysis of Navigation Data

The objective of this analysis is to evaluate the probability of aberrancy (aka probability of allision) with the three option bridge piers and compare the results with the Monte Carlo fast time simulation reported in [2].

In addition to the probability of aberrancy, the data were evaluated to see if there were other measures of the degree of difficulty in navigating the three different channels with the three bridge options simulated. This analysis looked at the number of adjustments the pilots made to the rudder (or thruster direction for azipods), the use of bow thrusters and adjustments to RPM as they approached the bridge. These adjustments are accepted as one measure of the degree of apprehension as a difficult maneuver is being approached.

Average speed in each of the channels for each direction is calculated. An additional measure of difficulty is the standard deviation of the rudder angle (or thruster direction for azipods). This measure looks at how much the rudder was varied during the approach to the bridge, not the absolute value of the rudder angle.

The final navigation analysis is of the time it took for the simulated voyages to reach the F1 and F3 bridges when proceeding southbound from a standstill at the dock, and the times it took for northbound vessels to go from either the F1 or F3 bridges up to the dock. These numbers can be used to study the additional time required to maneuver into and out-of West Channel.

2.1 Probability of Aberrancy

2.1.1 Calculation of the Probability of Aberrancy

The probability of aberrancy (called probability of allision in the Monte Carlo report [2]) was calculated using the same methodology as it was in that report. The procedure is as follows:

1. For each simulated transit under each bridge determine the closest point on the ship to the east bridge pier.
2. For the same transit, determine the furthest point on the ship to the east bridge pier.

   (These points are calculated using the latitude / longitude positions and headings of the simulated transit contained in the run data file. Four points on the ship are chosen as the extreme outboard points (2 forward and 2 aft). The track of these four points is calculated for every time step in the data file (every 5 seconds) and checked as to when the path between the points intersects the line between the bridge piers. The distance from the intersection of the path of the extreme outboard points to the bridge pier is easily calculated. The difference between the two points, closest and furthest distances, is the swept path of the ship under the bridge. It is a measure of the horizontal clearance required by that particular transit.)

3. Each set of distances (2 for each bridge site) are binned in 10 foot increments to define the probability distribution of the closest point of approach and the cumulative distribution function for the same. The cumulative distributions are then fit with a Weibel Type-II probability function so that distances from the east bridge pier can be interpolated/extrapolated at specified probability levels. The six Weibel functions are shown in Figures 2.1 through 2.6. Note that the graphs always show the closest point of approach to the nearest bridge pier. The furthest distance to the east pier is the closest point to the west pier subtracted from 550'.

   (The graphs of the Weibel functions also show confidence bands at 68% and 98%for the interpolated and/or extrapolated values. Although these uncertainties are not carried through to the determination of the probability of aberrancy, the width of the confidence bands demonstrates the uncertainty of extrapolating to extreme (infrequent) value events from the limited data sets gathered in the real-time simulation program.)

4. The interpolated/extrapolated distribution functions are then plotted referenced to a common point (the east pier of the individual bridges), and the swept distances at discrete probability levels are calculated. The calculation of the probability of horizontal clearance does not use the same transit case for both the nearest and furthest points. This means that we are not determining how much space an individual ship needs, but rather the amount of space needed to accommodate all transits at a particular probability level. This process is shown in Figures 2.7, 2.8 and 2.9.

5. The probability of horizontal clearance measured as the distance between the nearest and furthest point of approach to the reference point (east bridge pier) is again fit with a Weibel Type-II probability function so that the probability of aberrancy for various horizontal clearances can be determined. The probability of aberrancy (probability of allision) is $1-P(H<X)$ where H is the horizontal clearance and X is the value of interest. These fits are shown in Figures 2.10, 2.11 and 2.12. Although the confidence bands are quite narrow for these fits, it is only because we are now working with previous fitted data and the scatter from the raw data sets has been lost.

6. The probability of aberrancy computed from the fast-time Monte Carlo simulations is replotted and is also shown in Figures 2.13, 2.14 and 2.15. These are the same as Figures 4.14 for North Channel, 4.23 for West Channel and 4.28 for East Channel from the Monte Carlo Simulation Technical Memorandum [2]. The calculation probability of aberrancy has been added to the bottom of each figure.

2.1.2 Figures for Section 2.1

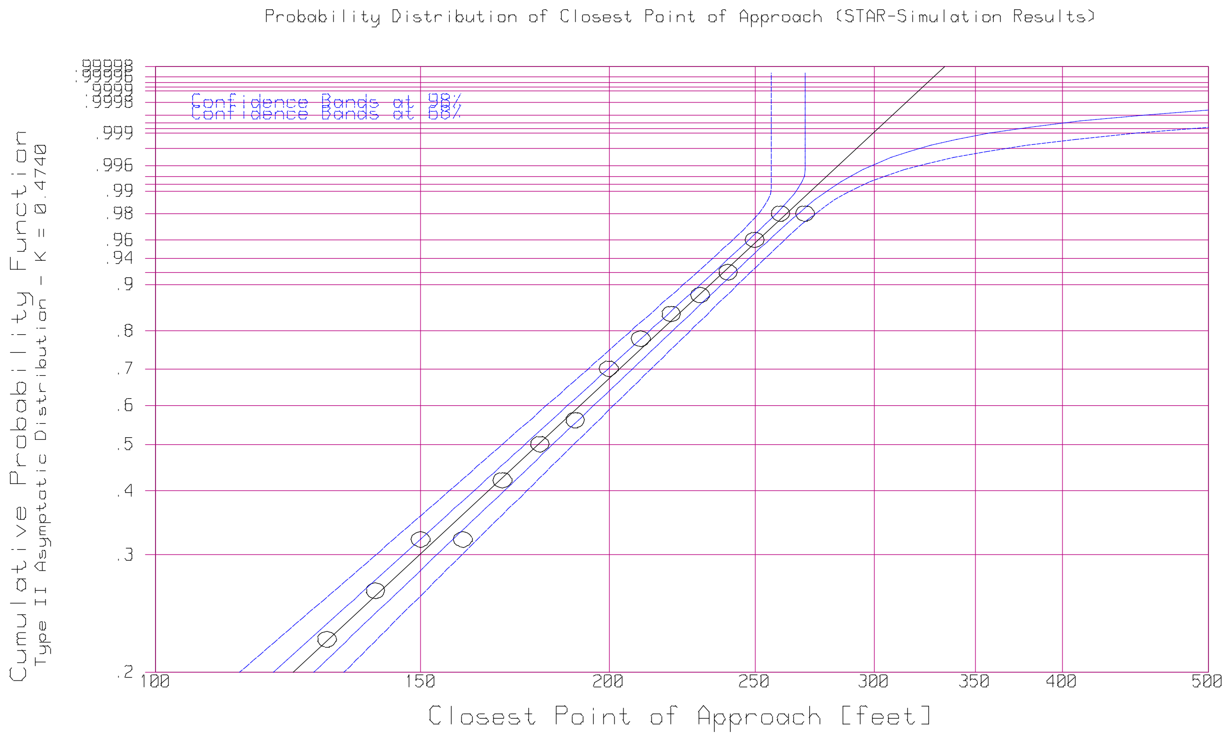


FIGURE 2.1
CUMULATIVE PROBABILITY DISTRIBUTION FIT FOR CLOSEST POINT OF APPROACH EAST CHANNEL – EAST PIER OF BRIDGE OPTION F1

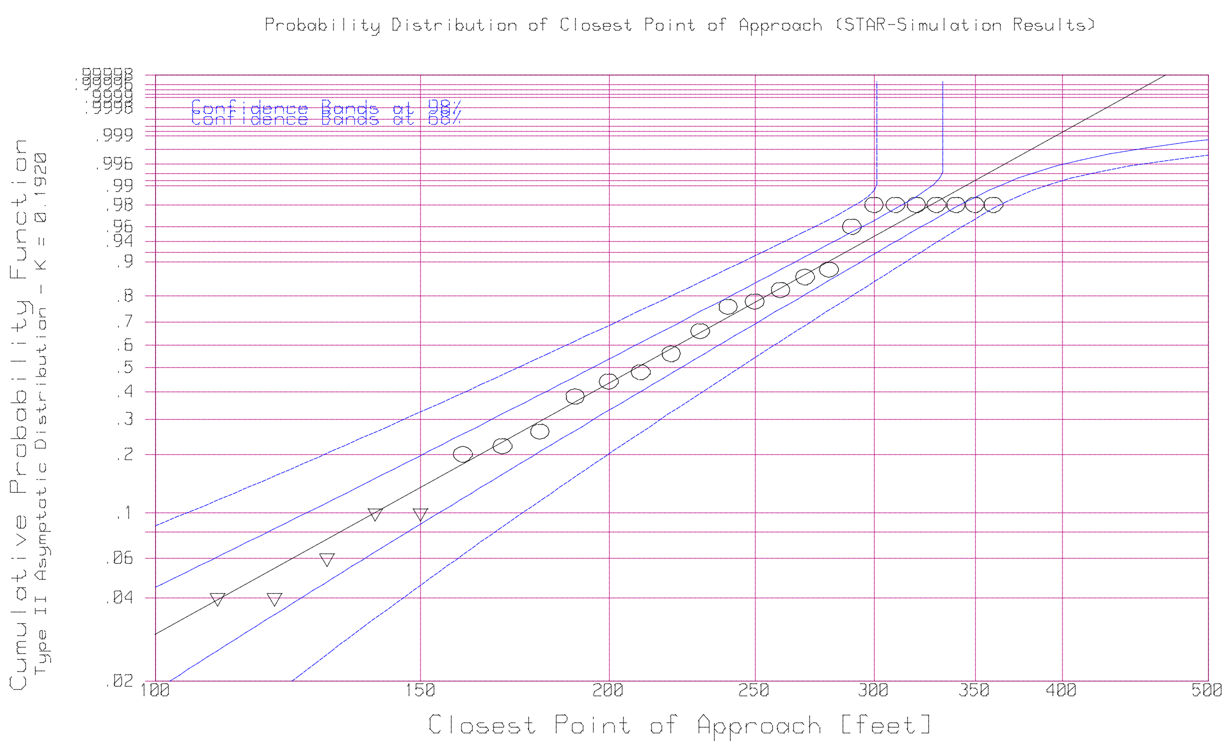


FIGURE 2.2
CUMULATIVE PROBABILITY DISTRIBUTION FIT FOR CLOSEST POINT OF APPROACH EAST CHANNEL – WEST PIER OF BRIDGE OPTION F1

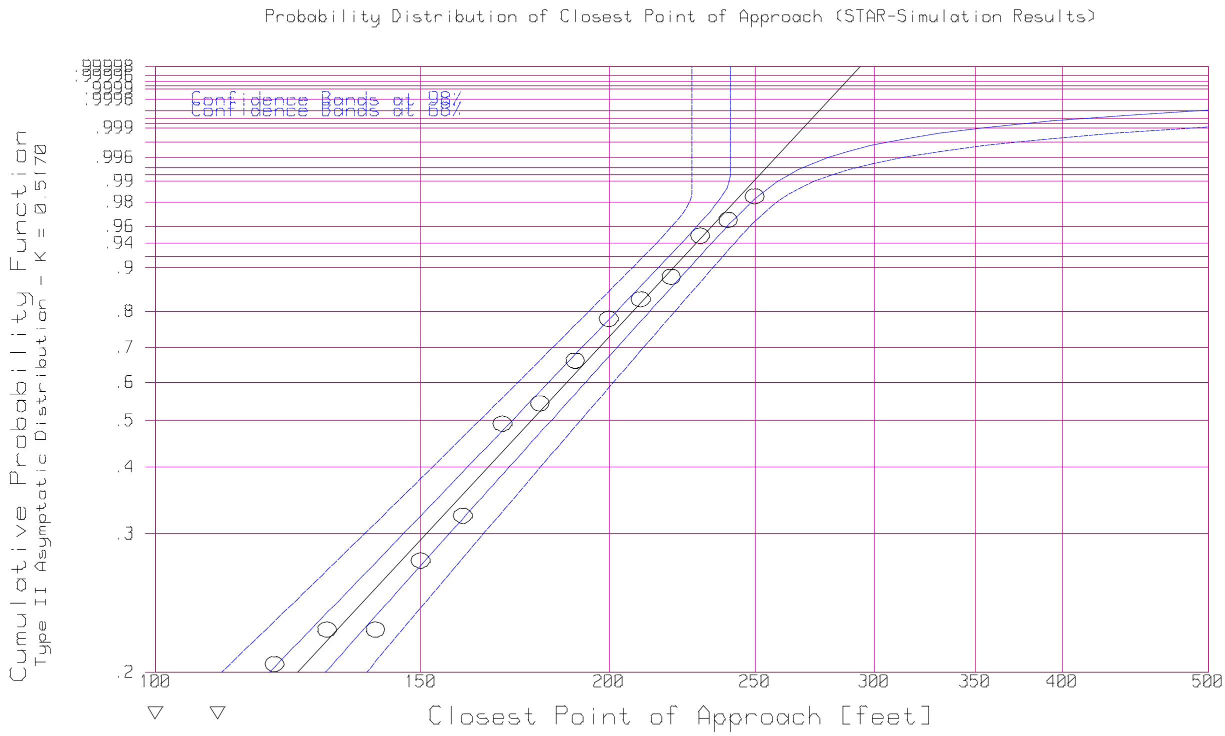


FIGURE 2.3
CUMULATIVE PROBABILITY DISTRIBUTION FIT FOR CLOSEST POINT OF APPROACH WEST CHANNEL – EAST PIER OF BRIDGE OPTION F3

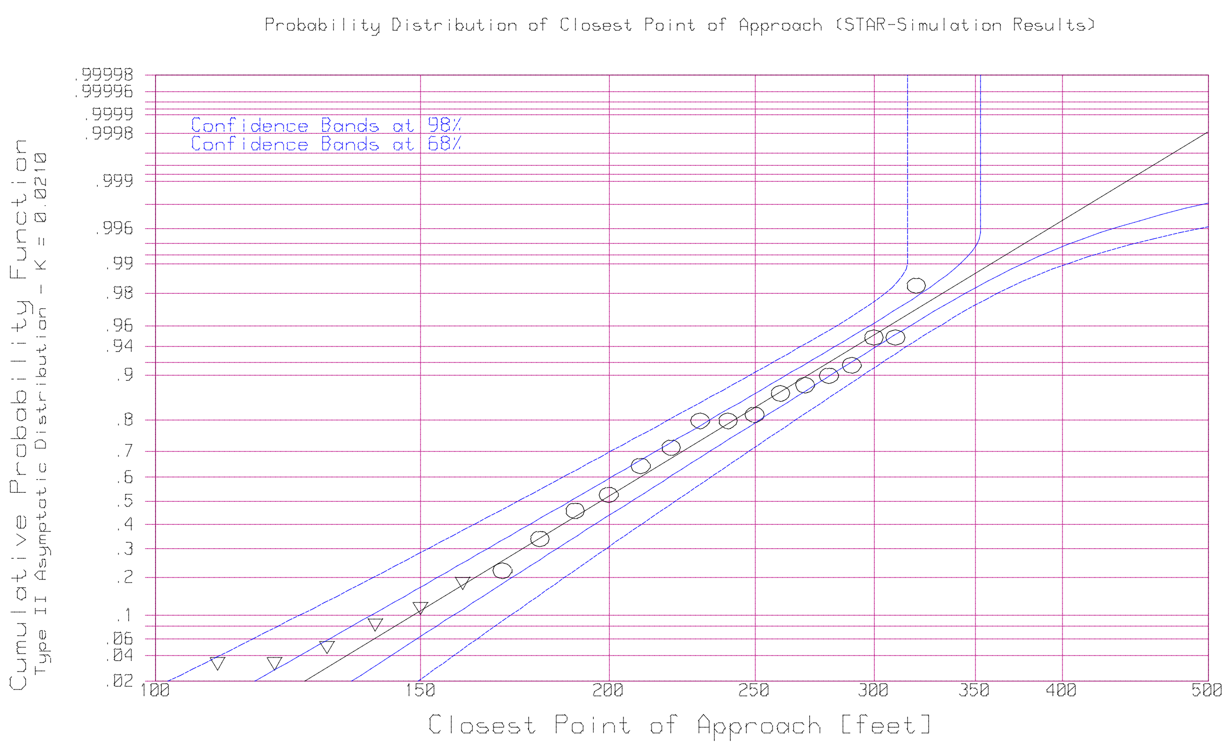


FIGURE 2.4
CUMULATIVE PROBABILITY DISTRIBUTION FIT FOR CLOSEST POINT OF APPROACH WEST CHANNEL – WEST PIER OF BRIDGE OPTION F3

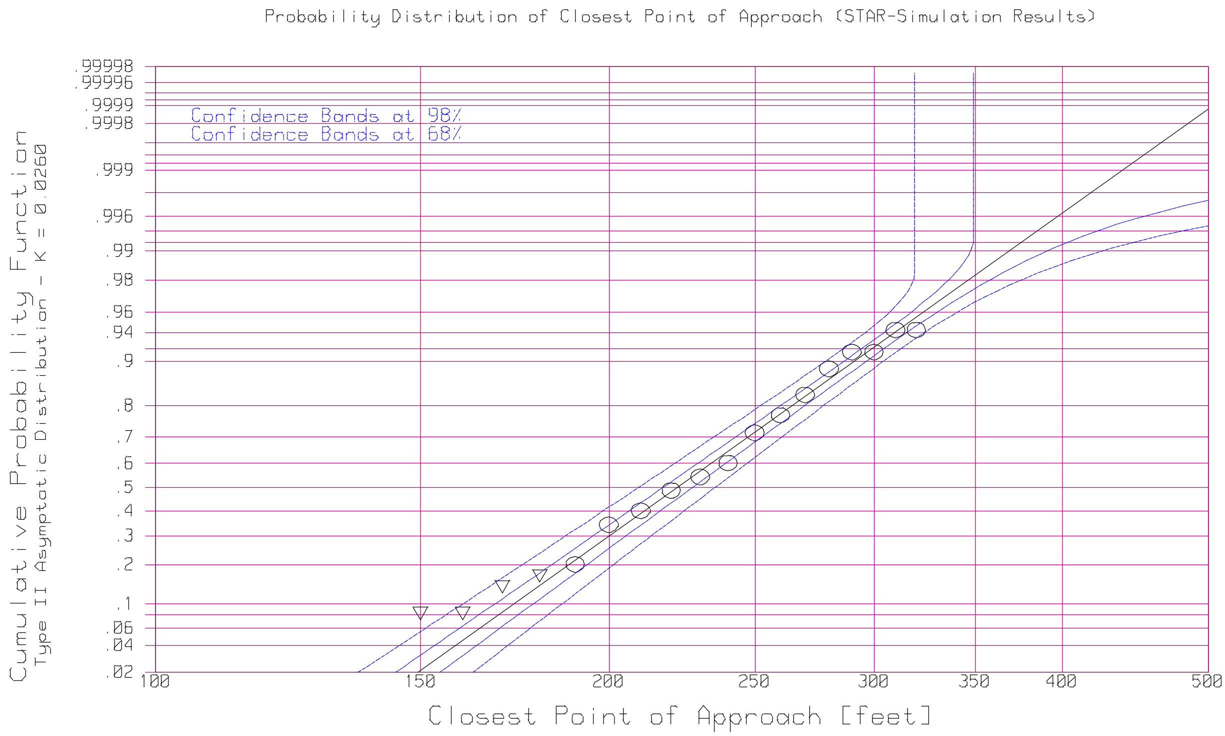


FIGURE 2.5
CUMULATIVE PROBABILITY DISTRIBUTION FIT FOR CLOSEST POINT OF APPROACH NORTH CHANNEL – EAST PIER OF BRIDGE OPTION C3/C4

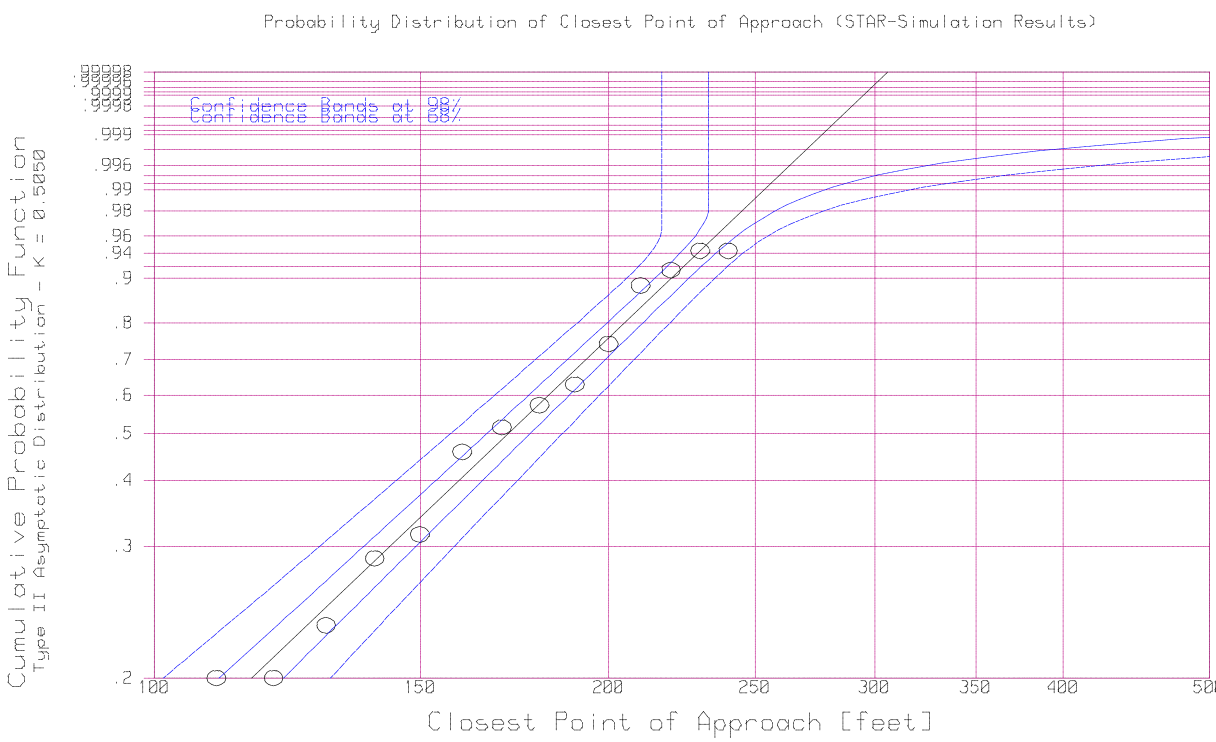


FIGURE 2.6
CUMULATIVE PROBABILITY DISTRIBUTION FIT FOR CLOSEST POINT OF APPROACH NORTH CHANNEL – WEST PIER OF BRIDGE OPTION C3/C4

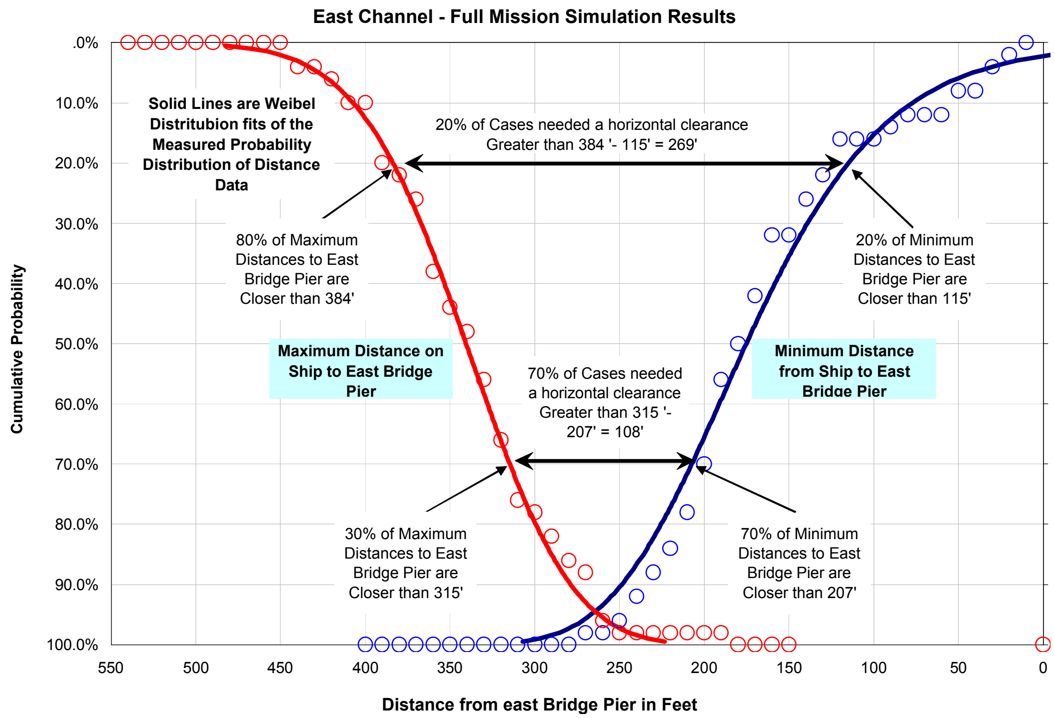


FIGURE 2.7
CUMULATIVE PROBABILITY DISTRIBUTION (RAW DATA AND FIT) FOR DISTANCES TO EAST PIER EAST CHANNEL – BRIDGE OPTION F1

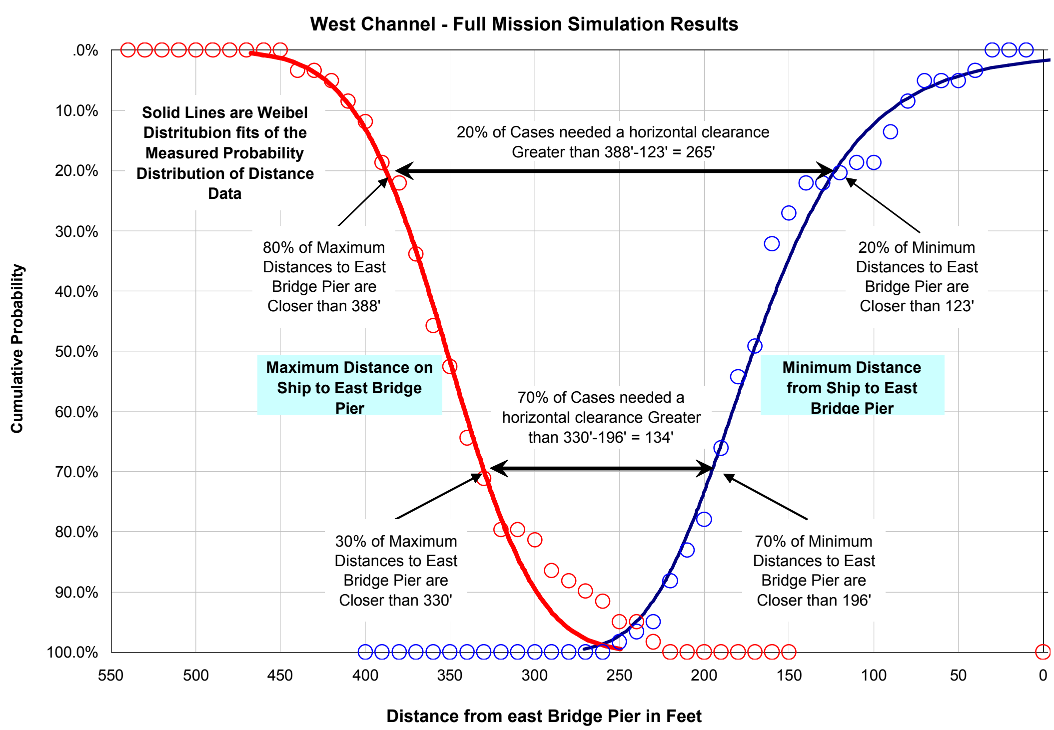


FIGURE 2.8
CUMULATIVE PROBABILITY DISTRIBUTION (RAW DATA AND FIT) FOR DISTANCES TO EAST PIER WEST CHANNEL – BRIDGE OPTION F3

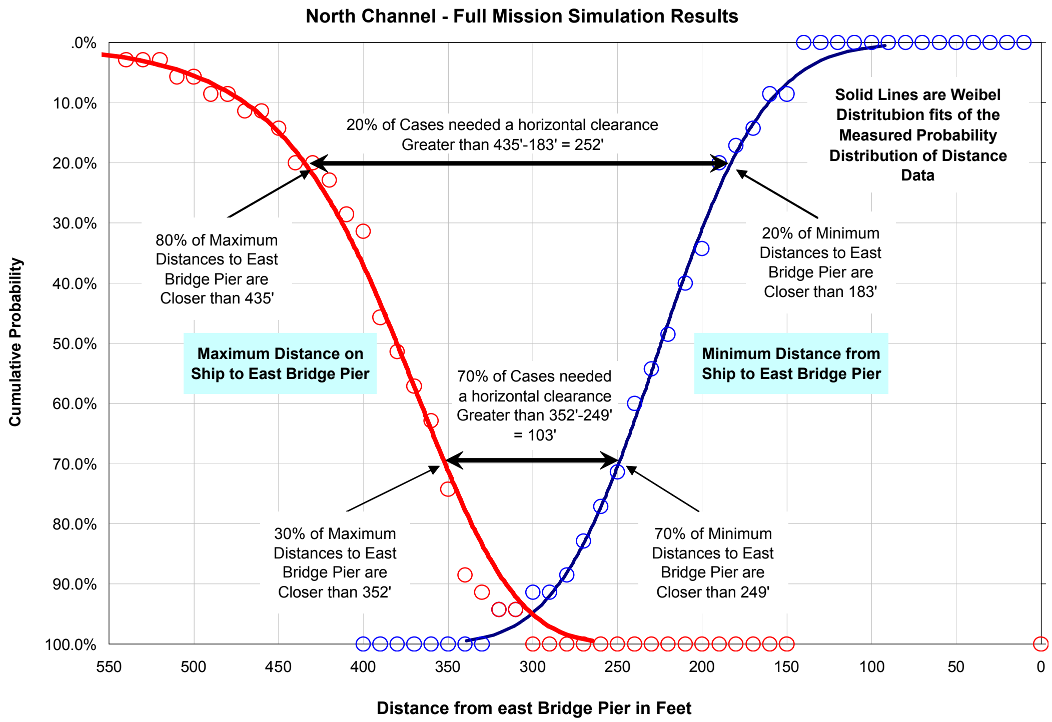


FIGURE 2.9
CUMULATIVE PROBABILITY DISTRIBUTION (RAW DATA AND FIT) FOR DISTANCES TO EAST PIER NORTH CHANNEL – BRIDGE OPTION C3/C4

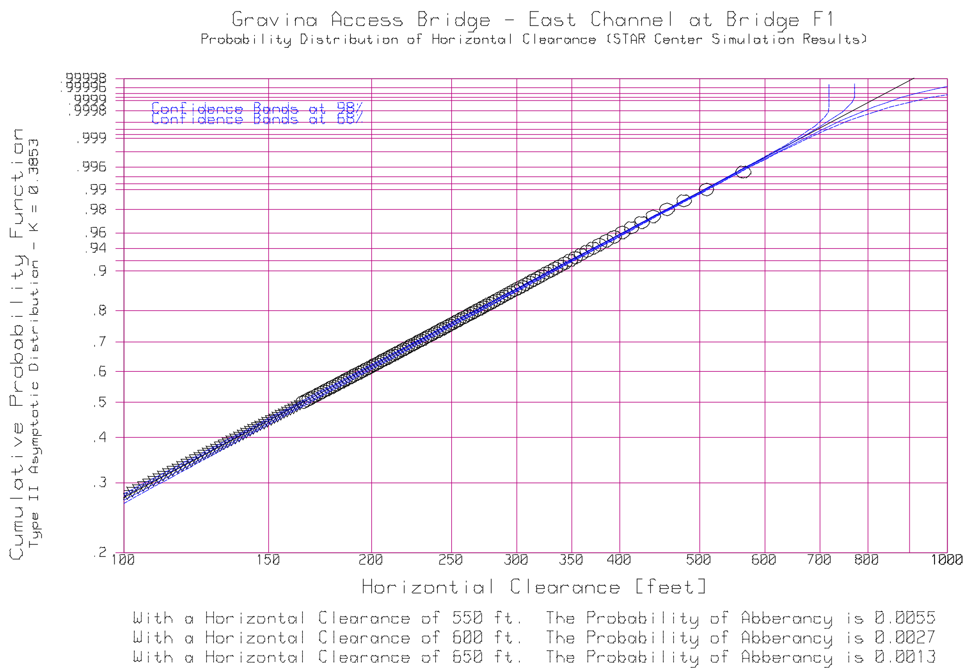


FIGURE 2.10
EXTRAPOLATION OF TYPE II EXTREMAL PROBABILITY FOR HORIZONTAL CLEARANCE FOR COMBINED NORTH- AND SOUTHBOUND TRANSITS OF EAST CHANNEL REAL-TIME (STAR CENTER) SIMULATION RESULTS - BRIDGE OPTION F1

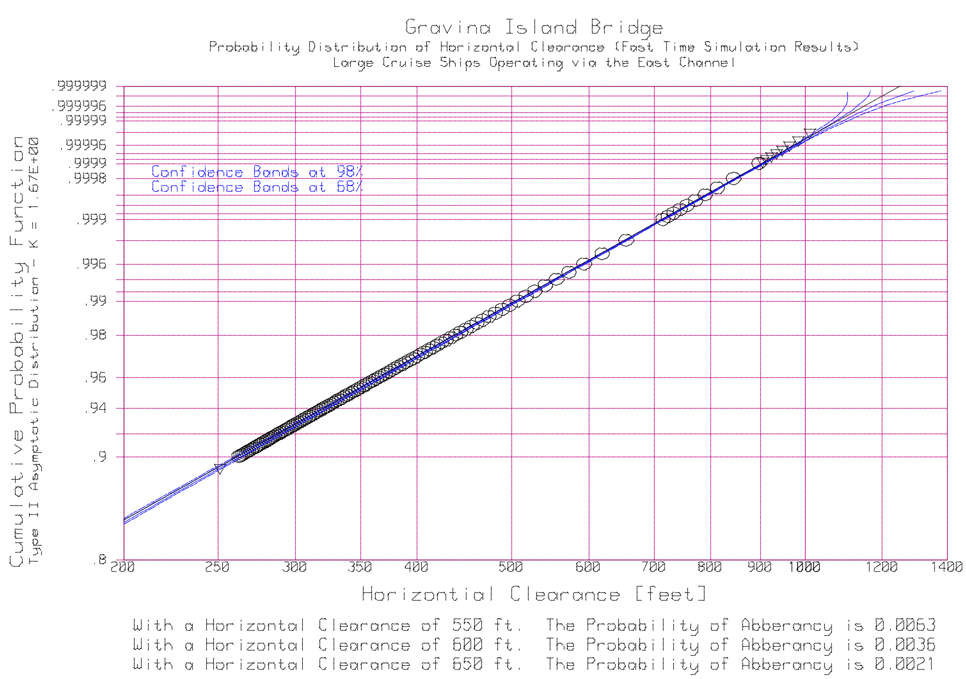


FIGURE 2.11
EXTRAPOLATION OF TYPE II EXTREMAL PROBABILITY FOR HORIZONTAL CLEARANCE FOR COMBINED NORTH- AND SOUTHBOUND TRANSITS OF EAST CHANNEL FAST-TIME (MONTE CARLO WITH AUTOPILOT) SIMULATION RESULTS - BRIDGE OPTION F1

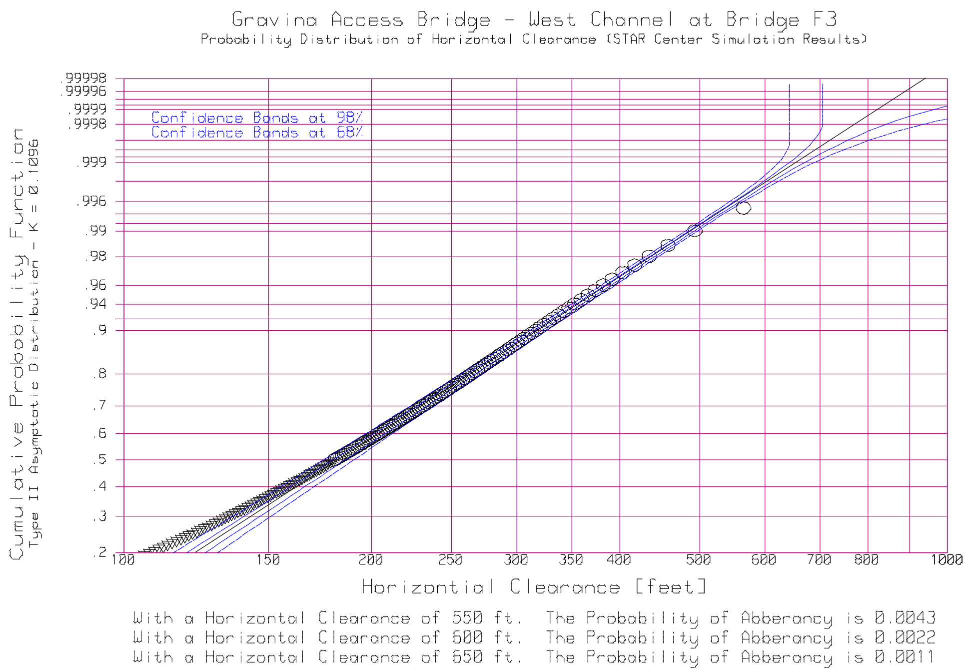


FIGURE 2.12
EXTRAPOLATION OF TYPE II EXTREMAL PROBABILITY FOR HORIZONTAL CLEARANCE FOR COMBINED NORTH- AND SOUTHBOUND TRANSITS OF WEST CHANNEL REAL-TIME (STAR CENTER) SIMULATION RESULTS - BRIDGE OPTION F3

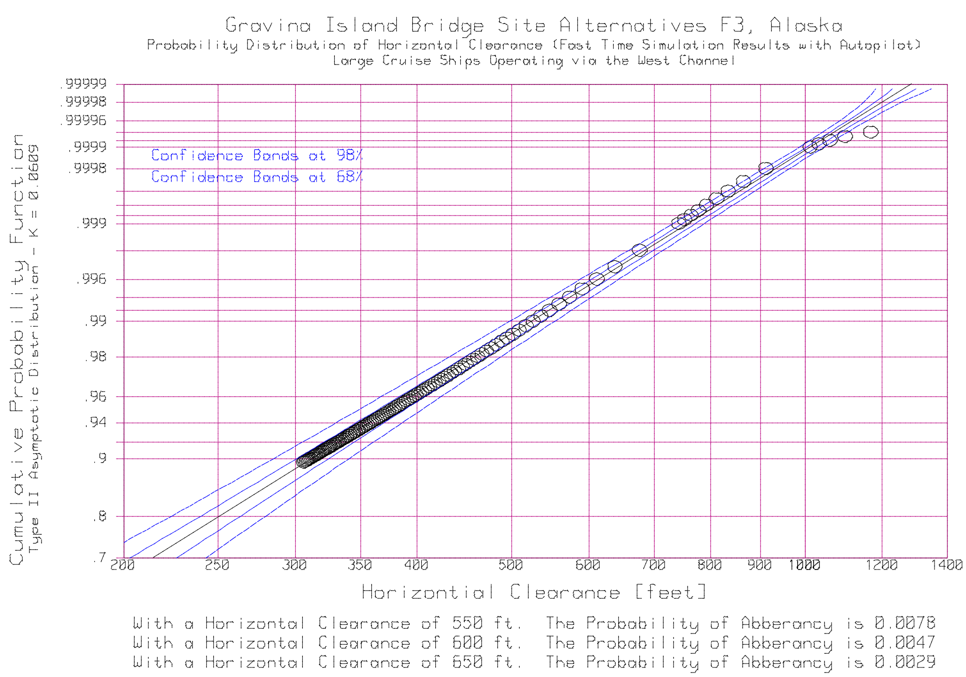


FIGURE 2.13
EXTRAPOLATION OF TYPE II EXTREMAL PROBABILITY FOR HORIZONTAL CLEARANCE FOR COMBINED NORTH- AND SOUTHBOUND TRANSITS OF WEST CHANNEL FAST-TIME (MONTE CARLO WITH AUTOPILOT) SIMULATION RESULTS - BRIDGE OPTION F3

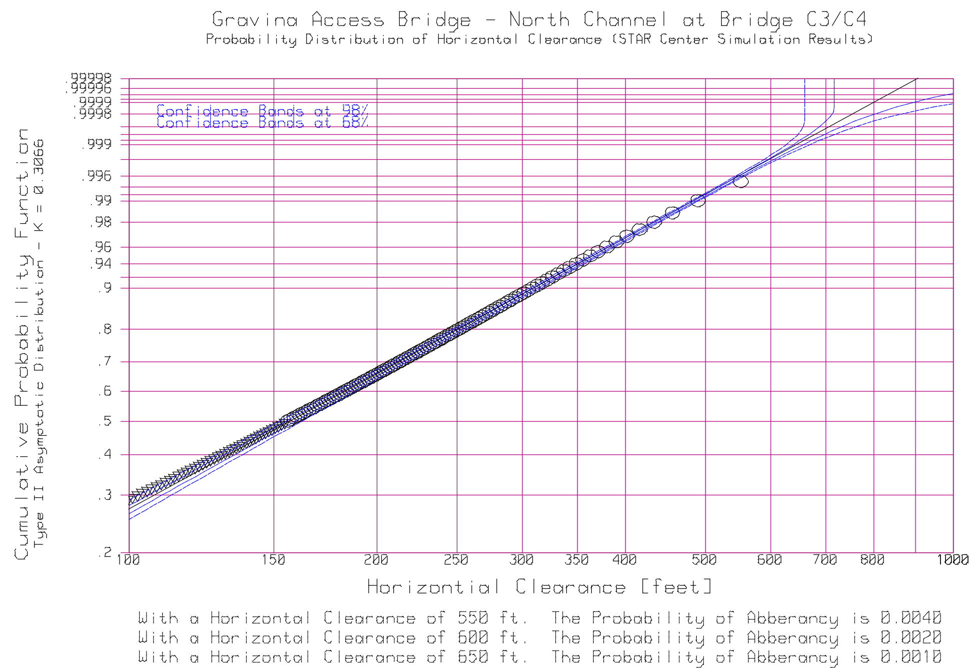


FIGURE 2.14
EXTRAPOLATION OF TYPE II EXTREMAL PROBABILITY FOR HORIZONTAL CLEARANCE FOR COMBINED NORTH- AND SOUTHBOUND TRANSITS OF NORTH CHANNEL REAL-TIME (STAR CENTER) SIMULATION RESULTS - BRIDGE OPTION C3/C4

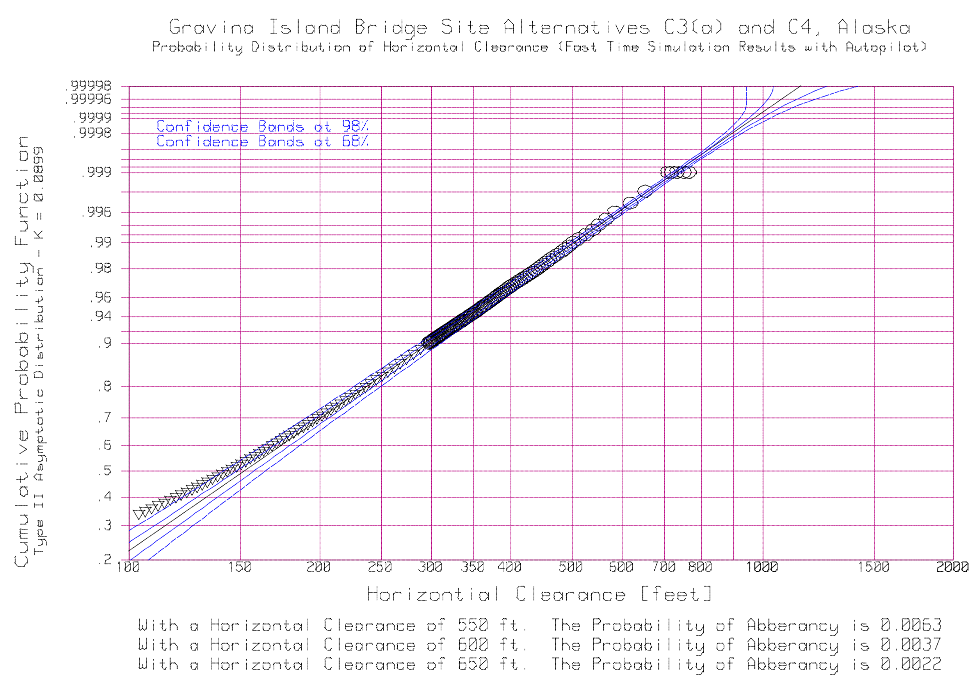


FIGURE 2.15
EXTRAPOLATION OF TYPE II EXTREMAL PROBABILITY FOR HORIZONTAL CLEARANCE FOR COMBINED NORTH- AND SOUTHBOUND TRANSITS OF NORTH CHANNEL FAST-TIME (MONTE CARLO WITH AUTOPILOT) SIMULATION RESULTS - BRIDGE OPTION C3/C4

2.1.3 Results

The newly determined probabilities of aberrancy (probability of allision) are shown in Tables 2.1 through 2.4. Table 2.4 shows the probabilities of aberrancy for the 550' horizontal clearance for all three bridges.

The probabilities shown in these table are the probabilities for each transit that a cruise ship (from the population of simulated) will hit one or the other side of the navigational opening. The fast time simulations were done for a population of cruise ships representative of those currently calling in Ketchikan, with some modifications to model expected growth in very large ship traffic. The fast-time simulations were also calculated for a distribution of wind speeds based on statistics from the site.

The real-time (STAR Center) simulations were done for only four ships, all of which were over 100,000 GRT. Thus it can be assumed that the probabilities determined from the STAR Center tests are conservative because of the large ship sizes chosen (assuming smaller ships are easier to control). The estimates are also conservative in that the real-time tests did not have a distribution of wind speeds based on statistics from the site. The set of cases simulated over-represented severe and extreme wind conditions.

TABLE 2.1
EXTRAPOLATION OF TYPE II EXTREMAL PROBABILITY OF ABERRANCY FOR COMBINED NORTH- AND SOUTHBOUND TRANSITS OF EAST CHANNEL FAST-TIME AND REAL-TIME SIMULATION RESULTS - BRIDGE OPTION F1

Horizontal Clearance (feet)	GLOSTEN Monte Carlo Fast-time simulation estimate of Aberrancy	STAR Center Real-time simulation estimate of Aberrancy	Ratio of Real-time Estimate to Fast-time Estimate
477	1.3519%	1.5307%	1.13
500	1.0662%	1.1146%	1.05
525	0.8203%	0.7852%	0.96
550	0.6286%	0.5503%	0.88
575	0.4798%	0.3838%	0.80
600	0.3649%	0.2664%	0.73
625	0.2765%	0.1840%	0.67
650	0.2088%	0.1266%	0.61
675	0.1571%	0.0867%	0.55
700	0.1179%	0.0592%	0.50
725	0.0882%	0.0402%	0.46
750	0.0657%	0.0272%	0.41
775	0.0489%	0.0184%	0.38
800	0.0362%	0.0123%	0.34

TABLE 2.2
EXTRAPOLATION OF TYPE II EXTREMAL PROBABILITY OF ABERRANCY
FOR COMBINED NORTH- AND SOUTHBOUND TRANSITS OF WEST CHANNEL
FAST-TIME AND REAL-TIME SIMULATION RESULTS - BRIDGE OPTION F3

Horizontal Clearance (feet)	GLOSTEN Monte Carlo Fast-time simulation estimate of Aberrancy	STAR Center Real-time simulation estimate of Aberrancy	Ratio of Real-time Estimate to Fast-time Estimate
476'	1.6742%	1.1849%	0.71
500	1.3014%	0.8526%	0.66
525	1.0040%	0.6050%	0.60
550	0.7768%	0.4292%	0.55
575	0.6027%	0.3044%	0.51
590†	0.5183%	0.2478%	0.48

† The channel width (from 5 fathom to 5 fathom contour, bathymetry from [2]) at the location of the F3 bridge is approximately 590' measured perpendicular to the trackline (course) of ships at this point. Thus the probability of aberrancy to 590' is the probability of grounding at this point.

The probability of aberrancy for widths greater than 590' have no meaning, for the ship would be aground on either the west or east side of the channel.

TABLE 2.3
EXTRAPOLATION OF TYPE II EXTREMAL PROBABILITY OF ABERRANCY
FOR COMBINED NORTH- AND SOUTHBOUND TRANSITS OF NORTH CHANNEL
FAST-TIME AND REAL-TIME SIMULATION RESULTS - BRIDGE OPTION C3/C4

Horizontal Clearance (feet)	GLOSTEN Monte Carlo Fast-time simulation estimate of Aberrancy	STAR Center Real-time simulation estimate of Aberrancy	Ratio of Real-time Estimate to Fast-time Estimate
500	1.0674%	0.8171%	0.77
525	0.8183%	0.5761%	0.70
550	0.6289%	0.4049%	0.64
575	0.4846%	0.2837%	0.59
600	0.3743%	0.1983%	0.53
625	0.2898%	0.1382%	0.48
650	0.2248%	0.0961%	0.43
675	0.1748%	0.0666%	0.38
700	0.1362%	0.0461%	0.34
725	0.1063%	0.0318%	0.30
750	0.0832%	0.0219%	0.26
775	0.0652%	0.0151%	0.23
800	0.0511%	0.0103%	0.20

TABLE 2.4
EXTRAPOLATION OF TYPE II EXTREMAL PROBABILITY OF ABERRANCY
FOR COMBINED NORTH- AND SOUTHBOUND TRANSITS OF ALL CHANNELS
FAST-TIME AND REAL-TIME SIMULATION RESULTS FOR 550' HORIZONTAL CLEARANCE

Horizontal Clearance (feet)	GLOSTEN Monte Carlo Fast-time simulation estimate of Aberrancy	STAR Center Real-time simulation estimate of Aberrancy	Ratio of Real-time Estimate to Fast-time Estimate
East Channel Option F1 550'	0.63%	0.55%	0.88
West Channel Option F3 550'	0.78%	0.43%	0.55
North Channel Option C3/C4 550'	0.63%	0.40%	0.64

2.1.4 Discussion

There are two comments worth noting with respect to the probability of aberrancy.

The first is the demonstration that the fast-time Monte Carlo simulations are conservative estimates with respect to the piloted real-time simulations. This was expected. The autopilot of the fast-time simulator is not as good in decision making with respect to course keeping and way point arrivals as are experienced human pilots. It is interesting to note that the improvement with respect to the autopilot simulations was greatest for the West Channel cases. The hypothesis here is that the human pilots demonstrated a heightened level of effort and caution when using West Channel compared to the wider East Channel. The autopilot was programmed to treat each of the channels the same. The increased probability of allision with the F3 bridge calculated in the fast-time Monte Carlo simulations was due to the narrowness of the channel and resulting bank suction effects. The autopilot is not programmed to be prepared for bank suction, but the human pilots are.

The second observation is that the probability of allision for a 550' bridge opening is less in the West Channel with the F3 option than it is in either North Channel or East Channel. In addition, the North Channel bridge option is less likely to be struck than the East Channel bridge. Thus based on the data from the real-time simulations a 550' horizontal opening bridge in the West Channel is less likely to be struck than either of the other two options.

This conclusion is most probably the result of the shape of the approach channel and does not indicate the level of safety of using the channel. The pilots were very skillful in navigating the cruise ships in the simulations through each of the channels. The narrowness of West Channel and also of North Channel forced the pilots into a narrower horizontal clearance when using these two bridges. In East Channel there is more room both to the north and to the south of the bridge (F1). The data indicate that it is not necessary to cross under the F1 bridge in as narrow a width as is necessary in the other two locations. The evidence suggests that the risk of using West Channel is not due to the probability of hitting the bridge.

An estimate of the probability of running aground can also be developed from the data. However, this estimate will be only for the probability of running aground at the site of the bridges. It is possible to develop probabilities of running aground at other sites along the length of the channel; however, the data required to make this determination have not been retained from the simulations. However, looking at the probability of going aground at the bridge location can be used to develop a reasonable approximation of the risks of grounding in the three waterways.

The minimum natural channel widths for each of the three channels as presented in the Monte Carlo simulation report [2] are shown in Table 2.5 along with the estimates of the probability of exceedence (probability of potential grounding) from both the fast-time and real-time simulations. The distances are measured perpendicular to the nominal trackline (course) of the ships using the channel and measured from the 5 fathom contour on the east side to the 5 fathom contour on the west side. The minimum widths are measured as the projection of the natural opening perpendicular to the ship track. The probabilities shown are measured at the bridge site and assumed to be comparable to the probabilities of width required at other narrow sites in the waterway. Again it must be noted that these values are based on the population set of cruise ships used in simulations and for the distribution of wind conditions simulated. The fast-time simulated probabilities of grounding are assumed to be conservative with respect to real world probabilities because the ships were driven by an autopilot. The real-time simulated probabilities of grounding are assumed to be conservative with respect to real world probabilities because the experimental set used only large cruise ships and was overpopulated by severe and extreme wind conditions. However, in spite of these limitations, the relative risk of grounding in the three channels is instructive.

TABLE 2.5
EXTRAPOLATION OF TYPE II EXTREMAL PROBABILITY OF GROUNDING
FOR COMBINED NORTH- AND SOUTHBOUND TRANSITS OF ALL CHANNELS
FAST-TIME AND REAL-TIME SIMULATION RESULTS

Minimum Horizontal Clearance (feet)	Estimate of the Probability of Grounding, including cases were avoidance maneuvers would prevent grounding		Ratio to North Channel Risk	
	GLOSTEN Monte Carlo Fast-time simulation	STAR Center Real-time simulation	from Fast-time cases	from Real-time cases
East Channel at Idaho/Calif. Rocks 477'	1.3519%	1.5307%	**8.66**	**27.4**
West Channel north of G"5" 476'	1.6742%	1.1849%	**10.72**	**21.2**
North Channel at Charcoal Pt. 687'	0.1561%	0.0559%	**1**	**1**

The results of the real-time simulation study at STAR Center as presented in Table 2.5 found that the risk for a potential grounding in East Channel is somewhat higher than was determined by the fast-time simulation program and that the risk for a potential grounding in West Channel is somewhat lower than was determined by the fast-time study.

2.1.5 Modifications to 50-Year Potential Grounding Statistics

The information in Table 2.6 was prepared for and presented in the Glosten fast-time Monte Carlo simulation study [2]. The comparable results from the real-time simulation are given in Table 2.7.

TABLE 2.6
FAST-TIME SIMULATION RESULTS
EXTRAPOLATION OF TYPE II EXTREMAL PROBABILITY 50-YEAR[1] ORDER STATISTICS FOR POTENTIAL GROUNDINGS[5] OF LARGE CRUISE SHIPS OPERATING IN EAST AND WEST CHANNELS

Channel	*Most Probable Number of Potential Groundings*	*Probability of Exceeding Most Probable Number of Potential Groundings*	*Median Number of Potential Groundings*	*Expected Number of Potential Groundings*	*Average Number of Potential Groundings per Year*
East[2]	181	0.865	523	1,353	27
West[3]	224	0.866	649	1,583	32
North[4]	20	0.873	60	243	5

[1]Order statistics for 26,639 large cruise ship transits corresponding to 50 years, according to the middle series projections of Reference 3.

[2]Natural channel width of East Channel is approximately 477 feet between the 5 fathom (30 foot) depth contours.

[3]Natural channel width of West Channel is approximately 476 feet between the 5 fathom (30 foot) depth contours.

[4]Natural channel width of North Channel is approximately 687 feet between the 5 fathom (30 foot) depth contours.

[5]Potential groundings are events that would result in an actual grounding if extreme avoidance measures are not implemented in a timely manner.

TABLE 2.7
REAL-TIME SIMULATION RESULTS
EXTRAPOLATION OF TYPE II EXTREMAL PROBABILITY 50-YEAR[1] ORDER STATISTICS FOR POTENTIAL GROUNDINGS[5] OF LARGE CRUISE SHIPS OPERATING IN EAST AND WEST CHANNELS

Channel	*Most Probable Number of Potential Groundings*	*Probability of Exceeding Most Probable Number of Potential Groundings*	*Median Number of Potential Groundings*	*Expected Number of Potential Groundings*	*Average Number of Potential Groundings per Year*
East[2]	205	0.865	593	1,483	30
West[3]	158	0.866	459	1,227	25
North[4]	7	0.881	22	102	2

[1]Order statistics for 26,639 large cruise ship transits corresponding to 50 years, according to the middle series projections of Reference 3.

[2]Natural channel width of East Channel is approximately 477 feet between the 5 fathom (30 foot) depth contours.

[3]Natural channel width of West Channel is approximately 476 feet between the 5 fathom (30 foot) depth contours.

[4]Natural channel width of North Channel is approximately 687 feet between the 5 fathom (30 foot) depth contours.

[5]Potential groundings are events that would result in an actual grounding if extreme avoidance measures are not implemented in a timely manner.

The potential number of groundings given in Tables 2.6 and 2.7 are the result of a statistical extrapolation of the swept widths calculated in the fast-time and measured in the real-time simulation studies. However, it is important to understand that each potential grounding does not imply that a grounding occurs. A potential grounding is comparable to an aviation near-miss. Most aviation near-misses do not become mid-air collisions and most potential groundings doe not become actual groundings. Most can be prevented by avoidance maneuvers.

The extrapolation gives a measure of the relative risk of using the two waterways, but is not a measure of absolute risk. An estimate of actual risk can be postulated by comparing the potential groundings with actual groundings. In the 10 year period from 1991 to 2000 there were 3,304 large cruise ship calls in Ketchikan. There were no groundings in East or North Channels. Thus the real world sample of the upper bound of the conditional probability of a grounding given a potential grounding is less than 1 grounding in 10 years or 1 in the number of potential groundings in 3,304 transits. The expected number of potential groundings determined by fast-time simulation for 10 years in North Channel is 50; the expected number in East Channel is 270. Thus the sample conditional probability for a grounding given a potential grounding is less than 1/(50+270) i.e. less than 0.31%. In other words for every 1,000 potential groundings avoidance maneuvers by the pilots would prevent 997 of them from becoming actual groundings. Thus for 50 years of transits of East Channel between California and Idaho Rocks with 1,353 predicted potential groundings only 4 are predicted to be actual groundings. The upper-bound risk of grounding per transit over a fifty year period assuming that the risk is the same in the next fifty years as it has been in the previous 10 years is 4/26,639, approximately 0.00016. Assuming this accident avoidance rate is the same for both East and West Channels, the risk of grounding per transit for West Channel is estimated to be (0.0031 x 1,583) / 26,639 = 0.00019. These calculations have been done using the results of both fast-time and real-time results and are presented in Table 2.8.

TABLE 2.8
ESTIMATE OF THE UPPER-BOUND LIMIT OF THE RISK OF GROUNDING OF LARGE CRUISE SHIPS OPERATING IN EAST AND WEST CHANNELS

Channel	*Predicted Number of Potential Groundings in 10 Years*	*Upper-bound Conditional Probability of Grounding given a Potential Grounding*	*Expected Number of Potential Groundings in 50 years*	*Expected Number of "Actual" Groundings in 50 years*	*Risk of Grounding per Transit*
Fast-Time Simulation Results					
East/North	270 + 50	1/(270+50)=0.003125	1,353	4	0.000159
West/North		*same as East Channel*	1,583	5	0.000186
Real-Time Simulation Results					
East/North	300 + 20	1/(300+20)=0.003125	1,483	5	0.000174
West/North		*same as East Channel*	1,227	4	0.000144

Order statistics for 26,639 large cruise ship transits corresponding to 50 years, according to the middle series projections of Reference 6.

Natural channel width of West Channel is approximately 476 feet between the 5 fathom (30 foot) depth contours.

Natural channel width of East Channel is approximately 477 feet between the 5 fathom (30 foot) depth contours.

Potential groundings are events that would result in an actual grounding if extreme avoidance measures are not implemented in a timely manner.

These estimates from the two simulation studies indicate a comparable risk of grounding in East Channel at Idaho/California Rocks and in West Channel north of buoy G"5". However it can be reasonably argued that the grounding potential at Idaho/California Rocks is less then it is in West Channel. The hazard in East Channel is a point hazard, can be maneuvered through in a slight zigzag (thus widening the effective opening slightly) and has a fair amount of maneuvering room both north and south of the rocks. The minimum clearance in West Channel lasts for a significant distance (approximately 2,500 feet, equal to about 2-½ to 3 ship lengths), and thus does not allow for any maneuvers that might ease the passage, and does not have much additional room south of or north of the constriction.

There were 2 groundings of interest in the real-time simulation cases. Both were in West Channel. One occurred during a northbound transit when the ship hit the shoal just north of the F3 site on the east side of the channel (Pennock Island side). The other also occurred on a northbound transit just north of the F3 site, however on the west side of the channel (Gravina Island side). One transit was handled by the STAR Center pilot on the conventionally propelled ship, the other was on the large azipod ship and was handled by an individual who is not yet qualified as a Ketchikan pilot. It should be noted again that the STAR Center pilot was not familiar with navigating in Tongass Narrows. His only familiarity with the waters was from his discussions with the Ketchikan pilots, looking at the charts and running one previous simulated transit through West Channel which was a nighttime southbound case. Given the circumstances of these two cases, the authors feel that these groundings are not representative of the grounding rate to be expected from experienced Ketchikan pilots. However they do support the generalization that West Channel is more difficult and risky than East Channel, but are not adequate to develop a quantitative measure of the level of risk.

There were three near miss groundings in East Channel. Runs 12a, 12b and 301 were all within 75 feet of the 5 fathom shoal at Idaho Rock. All were northbound transits. Southbound runs were not continued down as far as Idaho/California Rocks.

There was also a grounding at Gravina Point during the turn into West Channel from Nichols Passage. However this difficult turn can be avoided by entering West Channel from Revillagigedo Channel.

Unfortunately, we do not have adequate data from either simulation set or from real world statistics that would allow for a more accurate quantification of the effect of the differences in the two channels.

The upper-bound limit on the grounding risk per transit predicted by both the fast-time and real-time simulations studies can be used in a risk factored cost analysis of the two bridge options. The predicted risks are very low and essentially identical given the differences in the uncertainties associated with the tow studies. The real-time study with a small sample size has a lower statistical significance and higher uncertainty. Again is it to be understood that the real-time simulation program looked only at very large cruise ships with human pilots and the fast-time simulation program looked at a representative mixed of cruise ship sizes guided by an autopilot.

2.2 Degree of Difficulty

2.2.1 Statistical Measures of the Degree of Difficulty

The simulation data files contain continuous records of the rudder angle (or thruster angle for azipods), propeller RPM, bow and/or stern thruster power and speed through the water. It is generally accepted that the number of changes that the pilot makes to rudder angle, RPM and the thrusters is one measure of the apprehension that the pilot is experiencing when approaching a critical navigational point. In addition, the number of adjustments (changes) is dependent on the wind, current and bank conditions as well as the on the type and size of ship. Thus it is expected that the number of adjustments is a measure of the degree of difficulty of the task. This is not an exact measure and is only proposed as an additional way of looking at the data.

The method chosen and described here does not include the degree of difficulty of maneuvering into or out of the channel. It is only proposed as a measure of the degree of difficulty of passing through the bridge opening. There is clearly a difference between maneuvering into and out of West Channel, either northbound or southbound, and entering and/or exiting from East Channel or North Channel. The maneuver into or out of Nichols Passage during the entrance into or exit from West Channel is discussed in a separate section and is not considered as part of the measure of the relative degree of difficulty in transiting under the F1 or F3 bridge options. The difficulties associated with entering or exiting the north end of West Channel are quantified only in terms of the time it takes to transit to or from the F1 or F3 bridges to the dock. The stress and task difficulty of the in-port maneuver or the Nichols Passage maneuver can be gleaned from the post-exercise pilot comments (presented in Section 3).

To calculate the number of adjustment made during the approach to the bridges, the following steps were taken:

1. A region was defined for each channel in each direction as the final approach to the bridge. The region is where the ship is on a direct alignment to the bridge opening. It was chosen to exclude the navigation required to enter the channel. The idea is to choose a region were the navigational challenge is directly comparable. The selected regions are:
    a. East Channel southbound: between Thomas Basin entrance light and F1
    b. East Channel northbound: between Idaho Rock marker and F1
    c. West Channel southbound: between Pennock Reef buoy "PR" and F3
    d. West Channel northbound: between buoy R"2" and F3
    e. North Channel southbound: between Peninsula Point buoy N"2" and C3/C4
    f. North Channel northbound: north of buoy WR"6" and C3/C4

The location of the GPS antenna on the simulated ship is used as the reference location to determine whether the ship is in or out of the region of interest. The selected regions are shown in Figs 2.16 and 2.17.

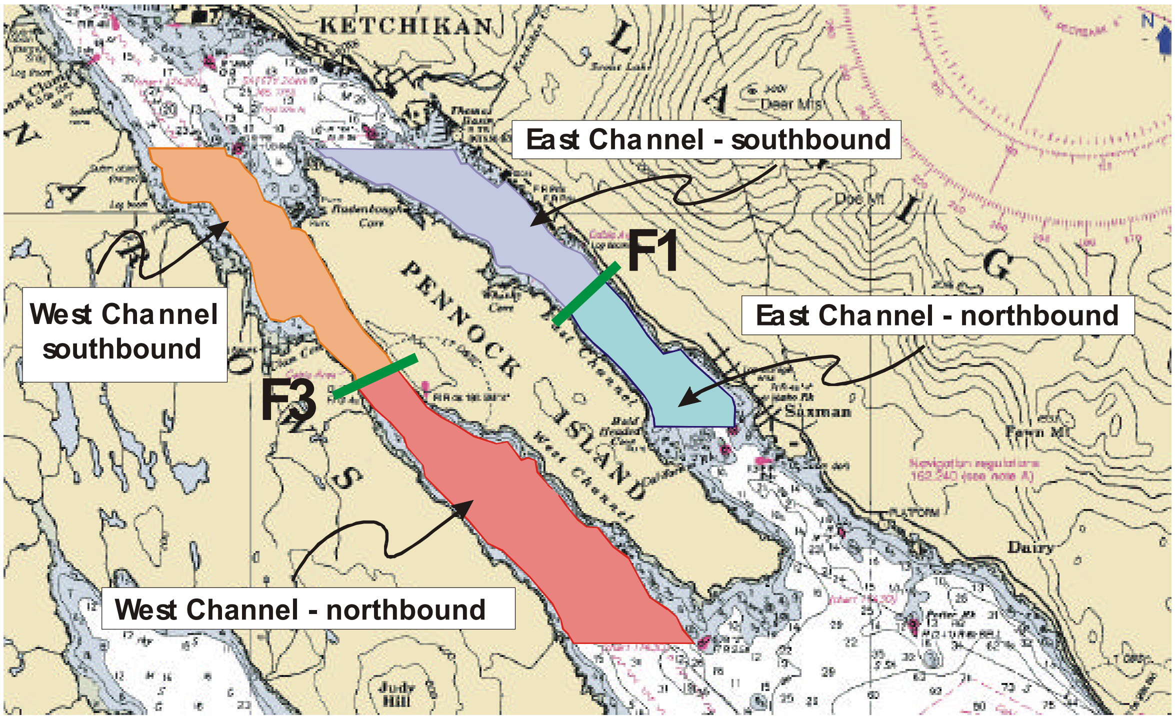


FIGURE 2.16
REGIONS CONSIDERED AS FINAL APPROACH TO BRIDGES F1 AND F3
ADJUSTMENTS IN THESE REGIONS ARE COUNTED AS A MEASURE OF DEGREE OF DIFFICULTY

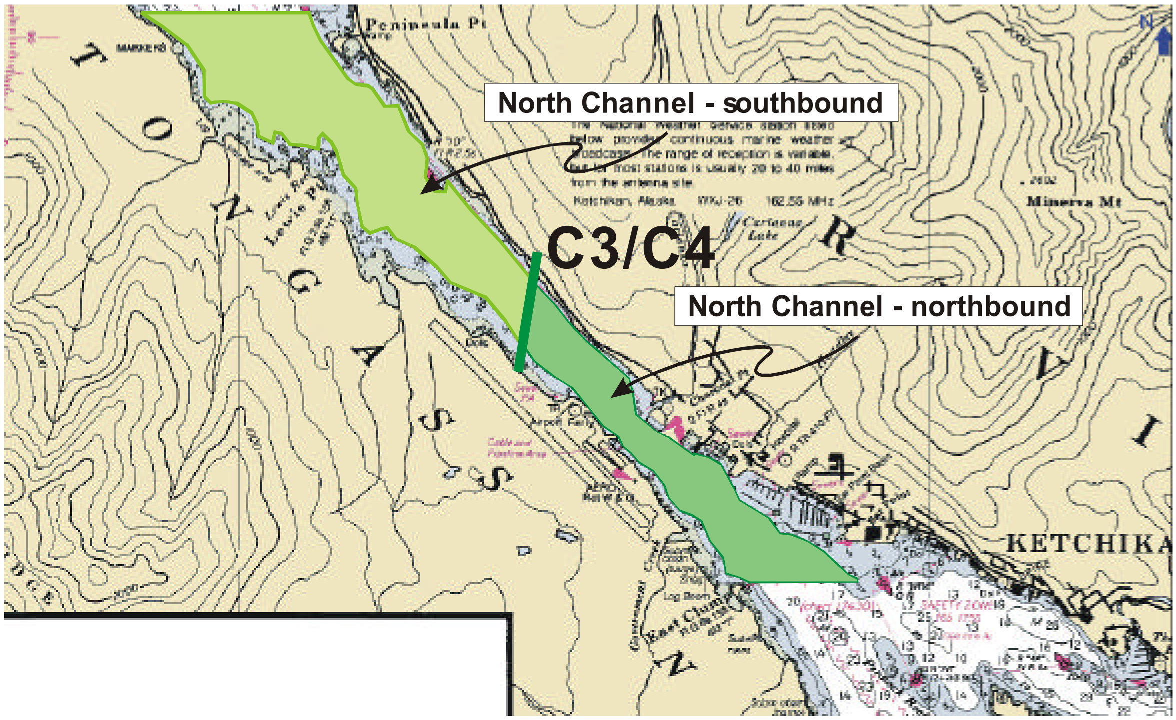


FIGURE 2.17
REGIONS CONSIDERED AS FINAL APPROACH TO BRIDGE C3/C4
ADJUSTMENTS IN THESE REGIONS ARE COUNTED AS A MEASURE OF DEGREE OF DIFFICULTY

2. The length of each region is determined from the position data so that the number of adjustments can be normalized. The number of adjustments is divided by the length of the region to give the number of adjustments per nautical mile. Thus the different approaches with slightly different lengths can be compared on a common basis. This comparison of adjustments per nautical mile is only valid for approaches of approximately length.
3. The number of adjustment was determined by counting the number of times the rudder angle, propeller RPM and thruster power were changed (in 5 second intervals) while the ship was in the region of interest.
4. On the advice of the STAR Center staff, the number of adjustments in RPM and bow/stern thrusters was cut in half from the actual count. They reported that in their experience pilots do approximately twice as many adjustments in RPM and thrusters on a simulated ship as they do with a real ship. This is apparently due to the fact that in the simulated ship the pilot had direct control of RPM and thrust and will therefore adjust it more frequently than on a real ship. On a real ship a command must be given to a quartermaster (or ship's officer) to make the adjustment.
5. The standard deviation of the amount of rudder angle (thruster angle for azipods) is also calculated. This is a measure of the amount of movement of the rudder, not the actual angle of the rudder. This measure also captures the level of maneuvering (thus degree of difficulty) required to navigate through the channel and under the bridge.
6. The average speed through the water is calculated for each channel in each direction. This can also be related to the degree of difficult of using the waterway, as higher speeds are sometimes required to maintain heading and course in difficult wind, current or bank suction conditions. It should be noted that there is a 7 knot speed limit in each of the regions evaluated except south of F3 in West Channel.

Thus the higher average speed recorded for northbound transits of West Channel might in part be attributed to the lack of this restriction and not just to the requirement for maintaining control.

2.2.2 Figures for Section 2.2

The following figures show bar graphs with the adjustments per nautical mile, average speed and rudder angle standard deviation for each of the individual runs. The average and plus and minus one standard deviation for each channel are also shown. The direction of transit is shown as a variation in the color a group of the bars.

The individual run numbers for the bars in the figures are sequenced as follows. The text on the x-axis of the graphs is too small to read.

TABLE 2.9
RUN NUMBERS FOR X-AXIS LABEL IN FIGURES 2.18 – 2.20 AND FIGURES 3.1 – 3.6

East Channel Northbound	East Channel Southbound	North Channel Northbound	North Channel Southbound	West Channel Northbound	West Channel Southbound
(1) Run 12a	(1) Run 17a	(1) Run 52	(1) Run 36	(1) Run 53a	(1) Run 250
(2) Run 12b	(2) Run 8	(2) Run 56	(2) Run 34	(2) Run 53	(2) Run 251
(3) Run 13	(3) Run 17	(3) Run 47a	(3) Run 32	(3) Run 51	(3) Run 336
(4) Run 12	(4) Run 7	(4) Run 54a	(4) Run 36a	(4) Run 244	(4) Run 337
(5) Run 3a	(5) Run 16	(5) Run 54	(5) Run 222	(5) Run 246	(5) Run 338
(6) Run 11	(6) Run 15	(6) Run 219	(6) Run 223	(6) Run 248	(6) Run 339
(7) Run 201	(7) Run 206	(7) Run 220	(7) Run 225	(7) Run 249	(7) Run 340
(8) Run 202	(8) Run 207	(8) Run 227	(8) Run 226	(8) Run 341	(8) Run 25
(9) Run 203	(9) Run 208	(9) Run 228	(9) Run 321	(9) Run 342	(9) Run 27
(10) Run 204	(10) Run 209	(10) Run 229	(10) Run 323	(10) Run 343	(10) Run 28
(11) Run 205	(11) Run 210	(11) Run 318	(11) Run 22	(11) Run 344	(11) Run 23
(12) Run 211	(12) Run 777	(12) Run 319	(12) Run 20	(12) Run 46	(12) Run 21a
(13) Run 212	(13) Run 888	(13) Run 320	(13) Run 221	(13) Run 44a	(13) Run 21
(14) Run 213	(14) Run 999	(14) Run 43	(14) Run 224	(14) Run 44	(14) Run 230
(15) Run 311	(15) Run 314	(15) Run 218	(15) Run 324	(15) Run 42	(15) Run 231
(16) Run 312	(16) Run 315	(16) Run 327	(16) Run 325	(16) Run 40	(16) Run 232
(17) Run 313	(17) Run 316	(17) Run 328	(17) Run 326	(17) Run 241	(17) Run 233
(18) Run 301	(18) Run 317	(18) Run 329		(18) Run 242	(18) Run 234
(19) Run 302	(19) Run 6a			(19) Run 245	(19) Run 236
(20) Run 303	(20) Run 214			(20) Run 247	(20) Run 237
(21) Run 304	(21) Run 215			(21) Run 666	(21) Run 238
(22) Run 305	(22) Run 216			(22) Run 388	(22) Run 239
	(23) Run 217			(23) Run 345	(23) Run 240
	(24) Run 306			(24) Run 346	(24) Run 555
	(25) Run 307			(25) Run 347	(25) Run 330
	(26) Run 308			(26) Run 348	(26) Run 331
	(27) Run 309			(27) Run 349	(27) Run 332
	(28) Run 310				(28) Run 333
					(29) Run 334
					(30) Run 335
					(31) Run 350

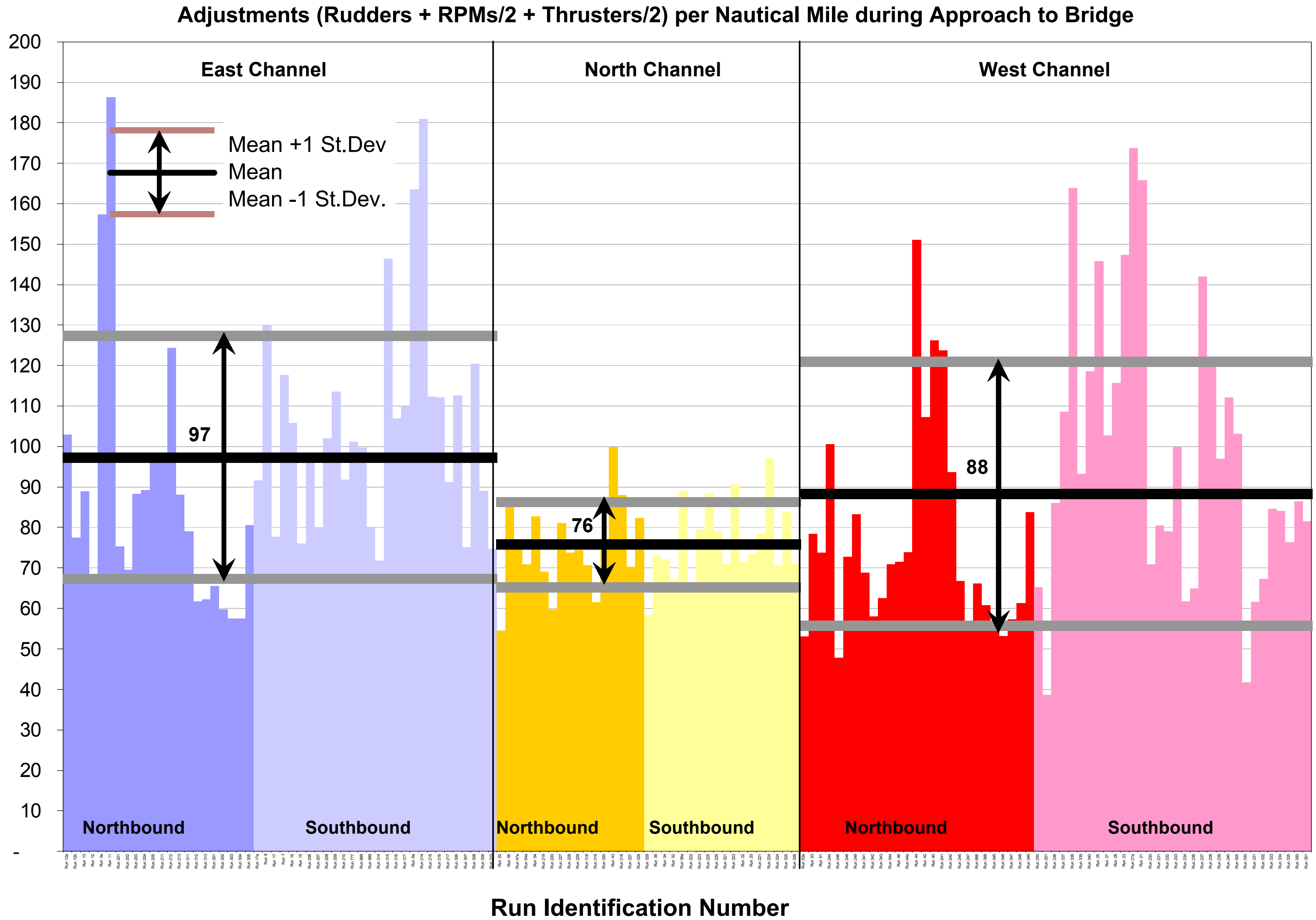


FIGURE 2.18
ADJUSTMENTS PER NAUTICAL MILE DURING FINAL APPROACH TO BRIDGE

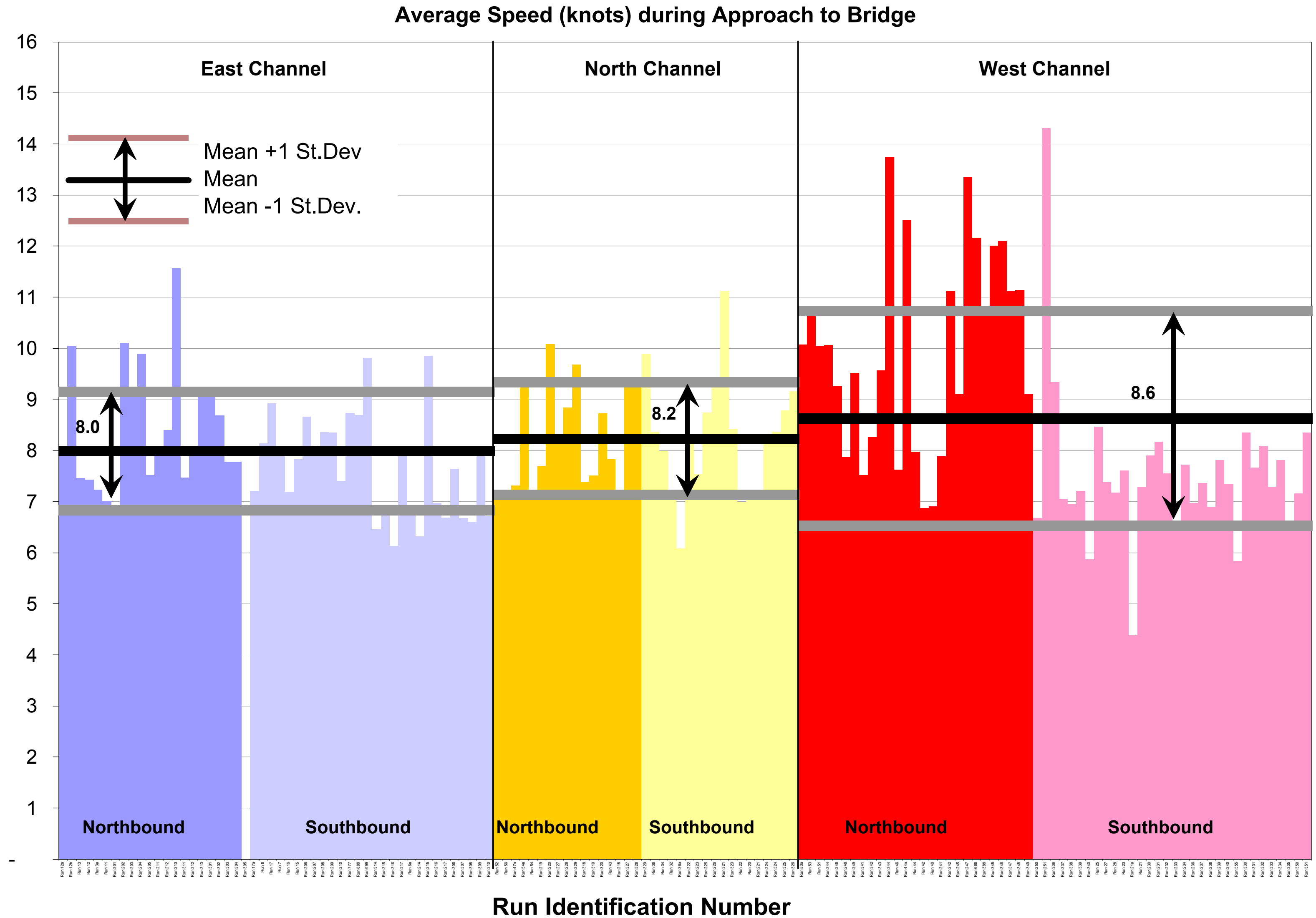


FIGURE 2.19
AVERAGE SPEED DURING FINAL APPROACH TO BRIDGE

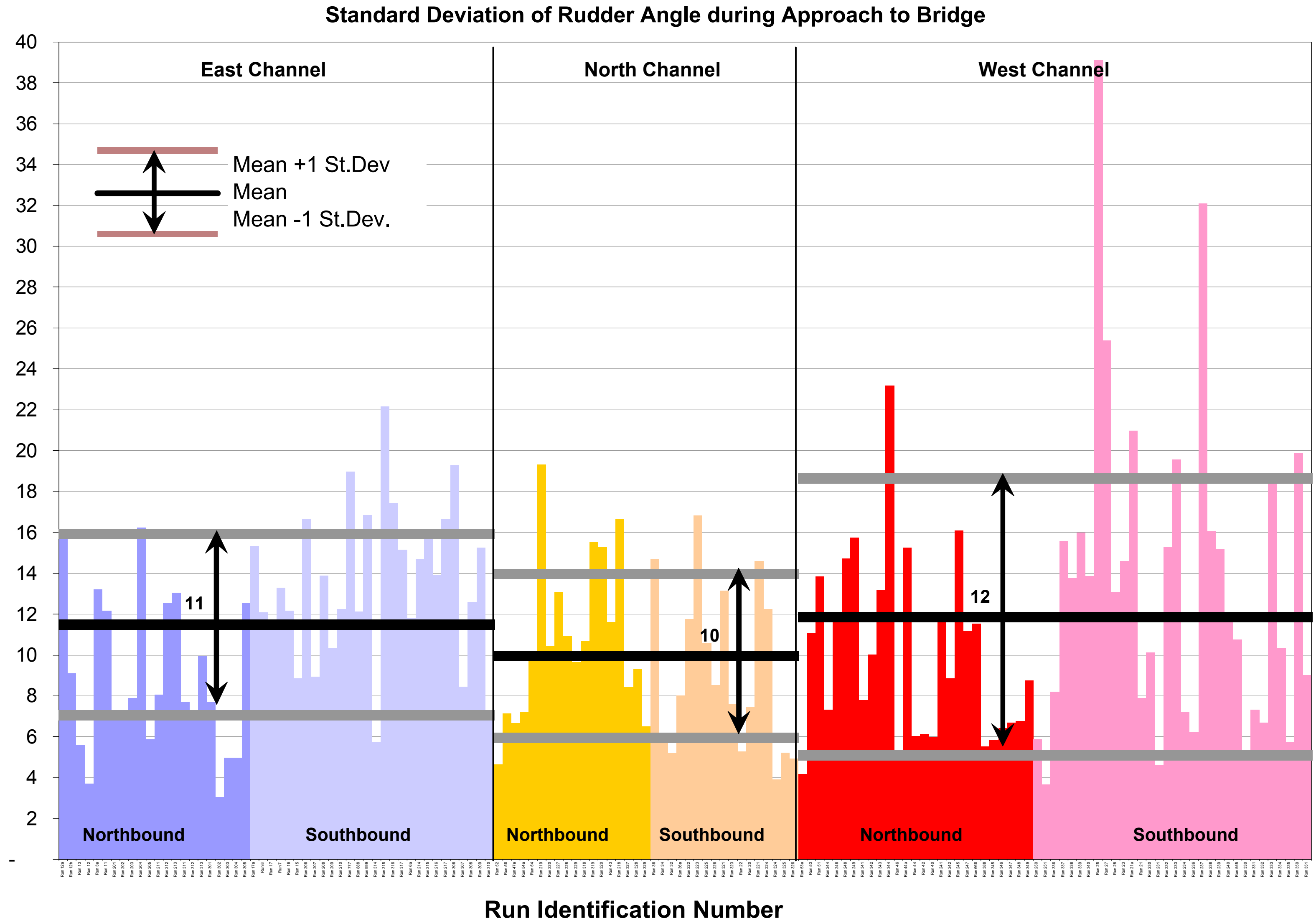


FIGURE 2.20
RUDDER ADJUSTMENTS DURING FINAL APPROACH TO BRIDGE

2.2.3 Results

Table 2.6 contains results of the above described measures of degree of difficulty for navigation in each channel in each direction based on the real-time simulated transits.

TABLE 2.6
SUMMARY OF RESULTS FOR MEASURES OF DEGREE OF DIFFICULTY

		Average of All Runs in each Channel		
		East Channel	**North Channel**	**West Channel**
Adjustments per nautical mile	both directions	**97**	**76**	**88**
	northbound	88	74	77
	southbound	105	78	98
Standard Deviation of Rudder Angle (deg.)		**11.5**	**10.0**	**11.9**
	northbound	8.9	10.7	10.0
	southbound	13.5	9.2	13.4
Speed (knots)	both directions	**8.0**	**8.2**	**8.6**
	northbound	8.4	8.3	9.9
	southbound	7.4	8.2	7.5

2.2.4 Discussion

These measurements do not indicate that the West Channel bridge option (F3) is significantly more difficult to navigate than either the East Channel bridge option (F1) or the North Channel option (C3/C4). In navigating the three channels the pilots required a comparable number of adjustments and rudder deflections as they approached the bridges. The slightly higher number for the southbound East Channel maneuvers may indicate that the ships were not quite up to speed in the early part of the analysis region and thus more rudder movements were required to counter wind and current effects. It is also possible that the extra width in East Channel allowed for more adjustments; i.e., the pilots had more lateral room and freedom to make adjustments to improve their alignment with the bridge opening.

There may be other psychological and physical factors at work that caused the pilots to hold commands longer in the C3/C4 and F3 approaches than in the F1 approach; however, these reasons are not evident in the data or in the post-exercise pilot evaluations. The high levels of stress and task difficulty noted for West Channel in the post-exercise pilot evaluation (see Section 3) are not evident in the way the ship was piloted.

2.3 Measurements of Time Delays for Ships using West Channel

2.3.1 Run Time from Dock to Bridge and Bridge to Dock

Each simulation run data file contains the times for vessel position in 5 second intervals. With this information it is possible to determine the time it took for the simulated ship to go from the dock to the bridge or from the bridge to the dock (see Tables 2.7 and 2.8). The simulations departing from the dock started with zero forward speed, but with the ship several feet off. The times do not include casting-off and any delays due to other traffic in the area. The time of arrival at the dock was chosen by the pilot as indicating that the ship had arrived. The speed was near stop at this point. Again the times do not include making up lines and any delays due to other traffic in the area. Only a subset of the total number of cases was simulated starting from the dock or was run all the way to arrival at the dock.

On average, West Channel required 22 more minutes when southbound and 24 more minutes when northbound compared with East Channel. Differences in run time due to maneuvers at the south end of either channel have not been computed. This set of tests was not designed to evaluate maneuvers south of Pennock or Gravina Islands

TABLE 2.7
RUN TIMES FOR WEST CHANNEL

For Northbound ships: time is from the point where GPS antenna passes under bridge F3 until the simulation stops just off the dock.

For Southbound ships: time is from start at dock until GPS antenna of ship passes under bridge F3.

Run Description – West Channel	Dock to Bridge F3	Bridge F3 to Dock
	minutes	minutes
Run51 (W): Ship: Destiny, Wind: SE 15 ± 8 kts, Sailing Direction: N		29.33
Run248 (W): Ship: Destiny, Wind: SE 15 ± 8 kts, Sailing Direction: N		54.17
Run249 (W): Ship: Destiny, Wind: WNW 15 ± 8 kts, Sailing Direction: N		29.92
Run40 (W): Ship: Voyager, Wind: 0, Sailing Direction: N		41.17
Run348 (W): Ship: Voyager, Wind: ESE 15 ± 8 kts, Sailing Direction: N		50.25
Run349 (W): Ship: Voyager, Wind: WNW 15 ± 8 kts, Sailing Direction: N		35.42
Run250 (W): Ship: Destiny, Wind: ESE 15 ± 8 kts, Sailing Direction: S	38.92	
Run251 (W): Ship: Destiny, Wind: ESE 15 ± 8 kts, Sailing Direction: S	29.50	
Run340 (W): Ship: Destiny, Wind: WNW 15 ± 8 kts, Sailing Direction: S	37.42	
Run21a (W): Ship: Voyager, Wind: WNW 15 ± 8 kts, Sailing Direction: S	43.92	
Run234 (W): Ship: Voyager, Wind: WNW 15 ± 8 kts, Sailing Direction: S	31.17	
Run240 (W): Ship: Voyager, Wind: WNW 15 ± 8 kts, Sailing Direction: S	24.92	
Run334 (W): Ship: Voyager, Wind: WNW 15 ± 8 kts, Sailing Direction: S	29.67	
Run335 (W): Ship: Voyager, Wind: WNW 15 ± 8 kts, Sailing Direction: S	35.58	
Run350 (W): Ship: Voyager, Wind: ESE 15 ± 8 kts, Sailing Direction: S	33.25	
AVERAGES (minutes)	**34.3**	**40.0**

TABLE 2.8
RUN TIMES FOR EAST CHANNEL

For Northbound ships: time is from the point where GPS antenna passes under bridge F1 until the simulation stops just off the dock.
For Southbound ships: time is from start at dock until GPS antenna of ship passes under bridge F1

Run Description – East Channel	Dock to Bridge F1	Bridge F1 to Dock
	minutes	minutes
Run201 (E): Ship: Destiny, Wind: SE 30 ± 15 kts, Sailing Direction: N		11.33
Run211 (E): Ship: Destiny, Wind: SE 15 ± 8 kts, Sailing Direction: N		15.92
Run212 (E): Ship: Destiny, Wind: SE 20 ± 10 kts, Sailing Direction: N		16.67
Run213 (E): Ship: Destiny, Wind: 0, Sailing Direction: N		15.50
Run312 (E): Ship: Destiny, Wind: SE 20 ± 10 kts, Sailing Direction: N		19.17
Run313 (E): Ship: Destiny, Wind: ESE 30 ± 15 kts, Sailing Direction: N		17.42
Run17a (E): Ship: Destiny, Wind: NW 30 ± 15 kts, Sailing Direction: S	11.00	
Run8 (E): Ship: Destiny, Wind: WNW 30 ± 15 kts, Sailing Direction: S	11.58	
Run17 (E): Ship: Destiny, Wind: NW 20 ± 10 kts, Sailing Direction: S	9.83	
Run7 (E): Ship: Destiny, Wind: WNW 20 ± 10 kts, Sailing Direction: S	11.33	
Run16 (E): Ship: Destiny, Wind: NW 15 ± 8 kts, Sailing Direction: S	13.25	
Run15 (E): Ship: Destiny, Wind: 0, Sailing Direction: S	11.33	
Run206 (E): Ship: Destiny, Wind: NW 30 ± 15 kts, Sailing Direction: S	12.50	
Run207 (E): Ship: Destiny, Wind: WNW 30 ± 15 kts, Sailing Direction: S	11.17	
Run208 (E): Ship: Destiny, Wind: NW 20 ± 10 kts, Sailing Direction: S	10.17	
Run777 (E): Ship: Destiny, Wind: NW 40 ± 10 kts, Sailing Direction: S	10.75	
Run888 (E): Ship: Destiny, Wind: NW 35 ± 10 kts, Sailing Direction: S	12.33	
Run314 (E): Ship: Destiny, Wind: WNW 15 ± 8 kts, Sailing Direction: S	13.25	
Run315 (E): Ship: Destiny, Wind: WNW 20 ± 10 kts, Sailing Direction: S	11.92	
Run317 (E): Ship: Destiny, Wind: WNW 15 ± 8 kts, Sailing Direction: S	11.00	
Run6a (E): Ship: Voyager, Wind: WNW 15 ± 8 kts, Sailing Direction: S	14.75	
Run214 (E): Ship: Voyager, Wind: WNW 15 ± 8 kts, Sailing Direction: S	15.50	
Run215 (E): Ship: Voyager, Wind: WNW 20 ± 10 kts, Sailing Direction: S	12.08	
Run216 (E): Ship: Voyager, Wind: NW 30 ± 15 kts, Sailing Direction: S	13.67	
Run306 (E): Ship: Voyager, Wind: 0, Sailing Direction: S	10.67	
Run307 (E): Ship: Voyager, Wind: WNW 15 ± 8 kts, Sailing Direction: S	12.75	
Run308 (E): Ship: Voyager, Wind: WNW 20 ± 10 kts, Sailing Direction: S	11.75	
Run309 (E): Ship: Voyager, Wind: NW 30 ± 15 kts, Sailing Direction: S	10.25	
Run310 (E): Ship: Voyager, Wind: WNW 15 ± 8 kts, Sailing Direction: S	11.42	
AVERAGES (minutes)	**11.9**	**16.0**

3—Analysis of Post-Exercise Pilot Evaluations

3.1 Description

After each exercise the pilot for that exercise was asked to fill out (without consultation from his associates) a questionnaire about the exercise. The questionnaire and all the original answers are contained in reference [1]. Several of the questions were in regard to the controllability of the simulated ship model. The answers to these questions are not evaluated herein. Of particular interest were the answers to the following questions:

	Extremely Satisfactory				Not at all Satisfactory
Vessel Trackline					
- Vessel position with regard to centerline	5	4	3	2	1
- CPA to channel boundaries and/or buoys	5	4	3	2	1
- Transiting Bridge span	5	4	3	2	1
	Absolutely Safe				Not at all safe
Overall Safety	5	4	3	2	1
Task Difficulty	5	4	3	2	1
Stress Level	5	4	3	2	1

The answers have been sorted by channel and sailing direction. The answers to the last three questions were also sorted to separate out the comments of the Ketchikan pilots from those of an experienced pilot provided by STAR Center. The participation and comments from a pilot who was not familiar with pilotage in Ketchikan was requested by the project sponsor. It is of interest to determine if there were prejudices about navigation in each of the channels that might affect the objectivity of the tests.

3.2 Results

Statistics of the post-exercise pilot evaluations are presented in Table 3.1. Averages are also presented in reference [1] using a slightly different nomenclature and different sort. The calculations are in essential agreement.

The evaluations for each individual run are shown in graphical form in Figures 3.1 to 3.6. Each channel is shown in a different color. The average values from the Ketchikan pilots in each channel are shown as horizontal lines. The average evaluation of the STAR Center pilot is shown as a dotted horizontal line. The individual evaluations of the STAR Center pilot are shown in a darker color in the plots for overall safety, task difficult and stress level. The STAR Center pilot's evaluations for the vessel trackline issues were not separated out from the Ketchikan pilots' evaluations.

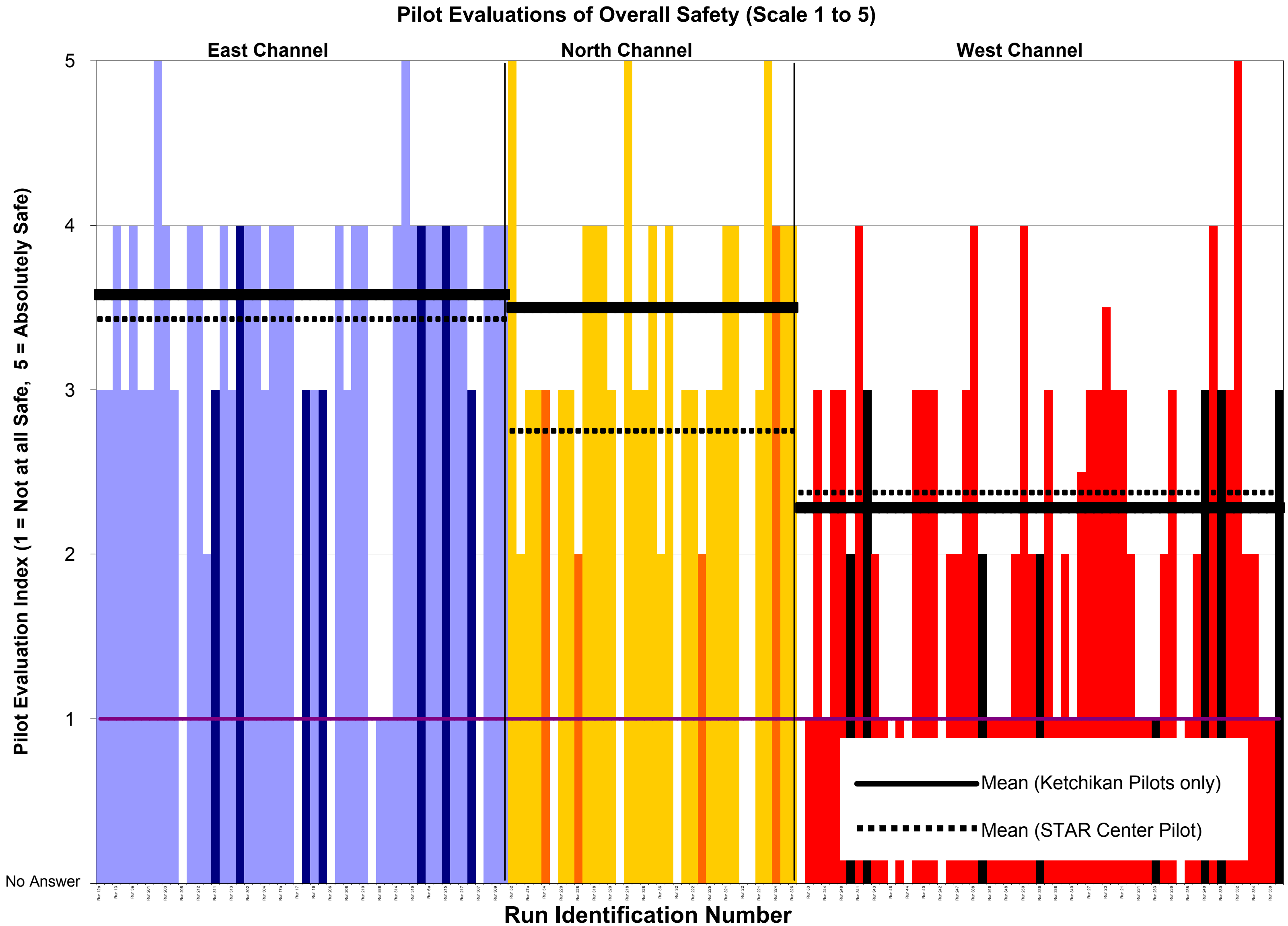
The sequence of runs is the same as given in Table 2.9. Again the labels on the horizontal axis are too small to read.

Figures 3.7 and 3.8 are an attempt to determine if the evaluations of the pilots for overall difficulty and stress level correlate with the degree of difficulty as measured by the number of adjustments per nautical mile described in Section 2.2.1. A correlation line is shown on the plots; however, the very large scatter in the adjustments data indicates that correlation is tenuous.

TABLE 3.1
RESULTS OF POST-EXERCISE PILOT EVALUATIONS

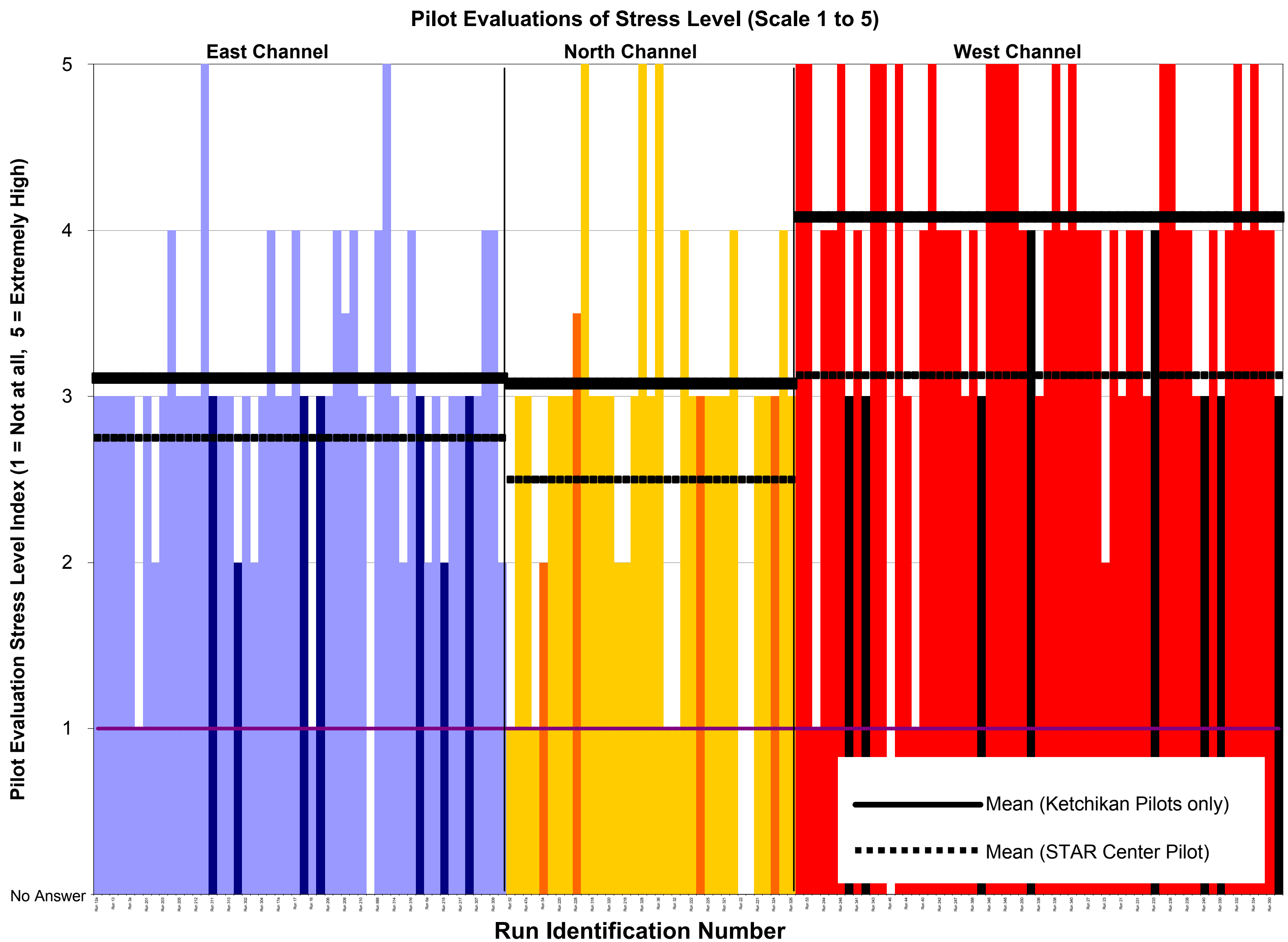
	Average of All Runs in each Channel		
	East Channel	**North Channel**	**West Channel**
All Pilot Evaluation (Scale 1 to 5)			
Vessel position with regard to centerline (1 = Not at all Satisfactory, 5 = Extremely Satisfactory)	4.1	3.9	3.3
CPA to channel boundaries and/or buoys (1 = Not at all Satisfactory, 5 = Extremely Satisfactory)	4.1	4.0	2.8
Transiting bridge span (1 = Not at all Satisfactory, 5 = Extremely Satisfactory)	4.0	3.8	2.7
Ketchikan Pilot Evaluation (Scale 1 to 5)			
Overall Safety (1 = Not at all Safe, 5 = Absolutely Safe)	3.6	3.5	2.3
Task Difficulty Index (1 = Not at all Difficult, 5 = Extremely Difficult)	3.3	3.2	4.3
Stress Level Index (1 = Not at all, 5 = Extremely High)	3.1	3.1	4.1
STAR Center Pilot Evaluation (Scale 1 to 5)			
Overall Safety (1 = Not at all Safe, 5 = Absolutely Safe)	3.4	2.8	2.4
Task Difficulty Index (1 = Not at all Difficult, 5 = Extremely Difficult)	2.6	3.0	3.5
Stress Level Index (1 = Not at all, 5 = Extremely High)	2.8	2.5	3.1

3.3 Figures



Darker color in each group shows evaluation of STAR Center Pilot

FIGURE 3.1
PILOT EVALUATION OF OVERALL SAFETY



Darker color in each group shows evaluation of STAR Center Pilot

FIGURE 3.2
PILOT EVALUATION OF STRESS LEVEL

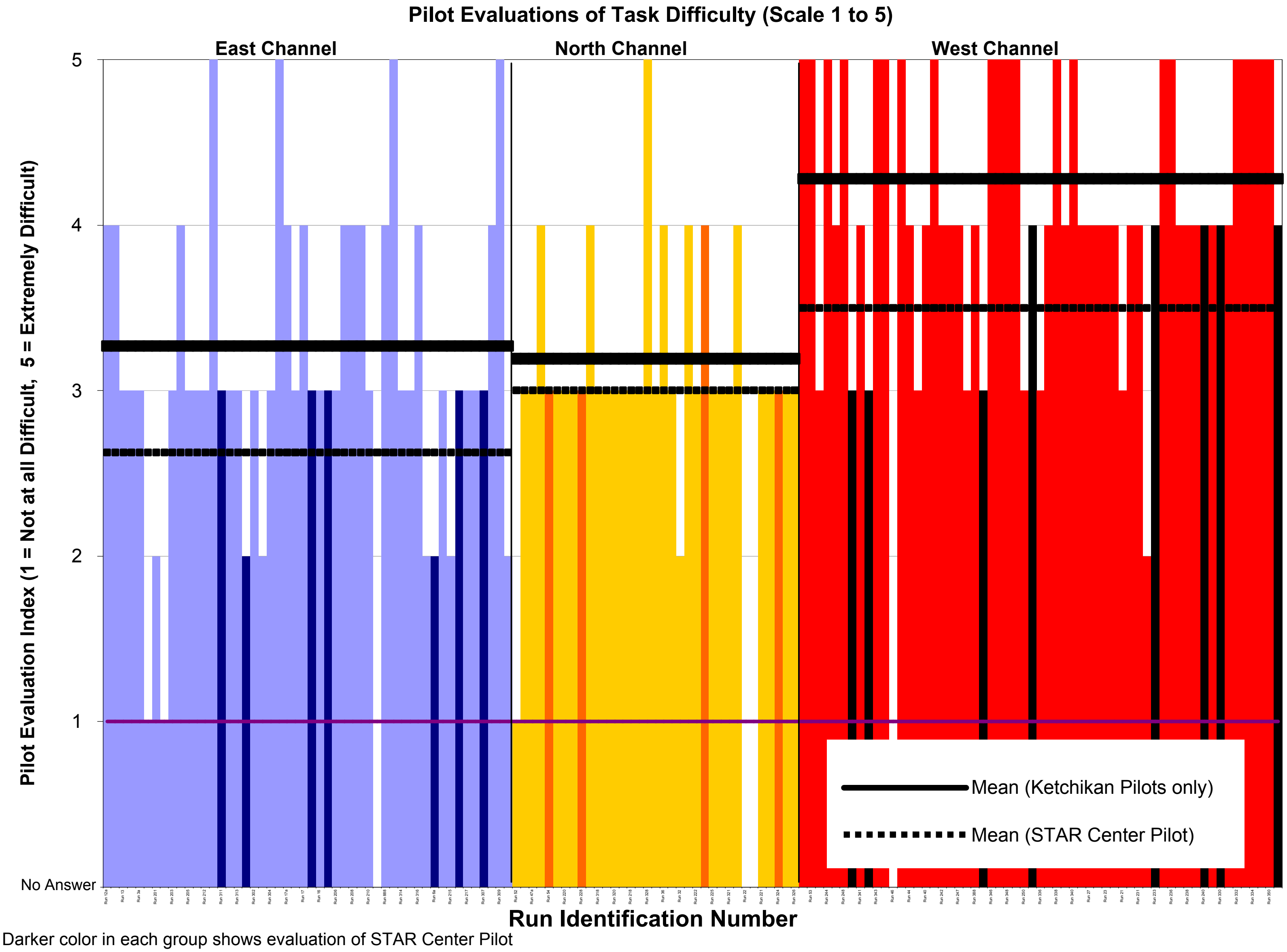


FIGURE 3.3
PILOT EVALUATION OF TASK DIFFICULTY

Pilot Evaluations of Vessel Position with Respect to Centerline of Channel (Scale 1 to 5)

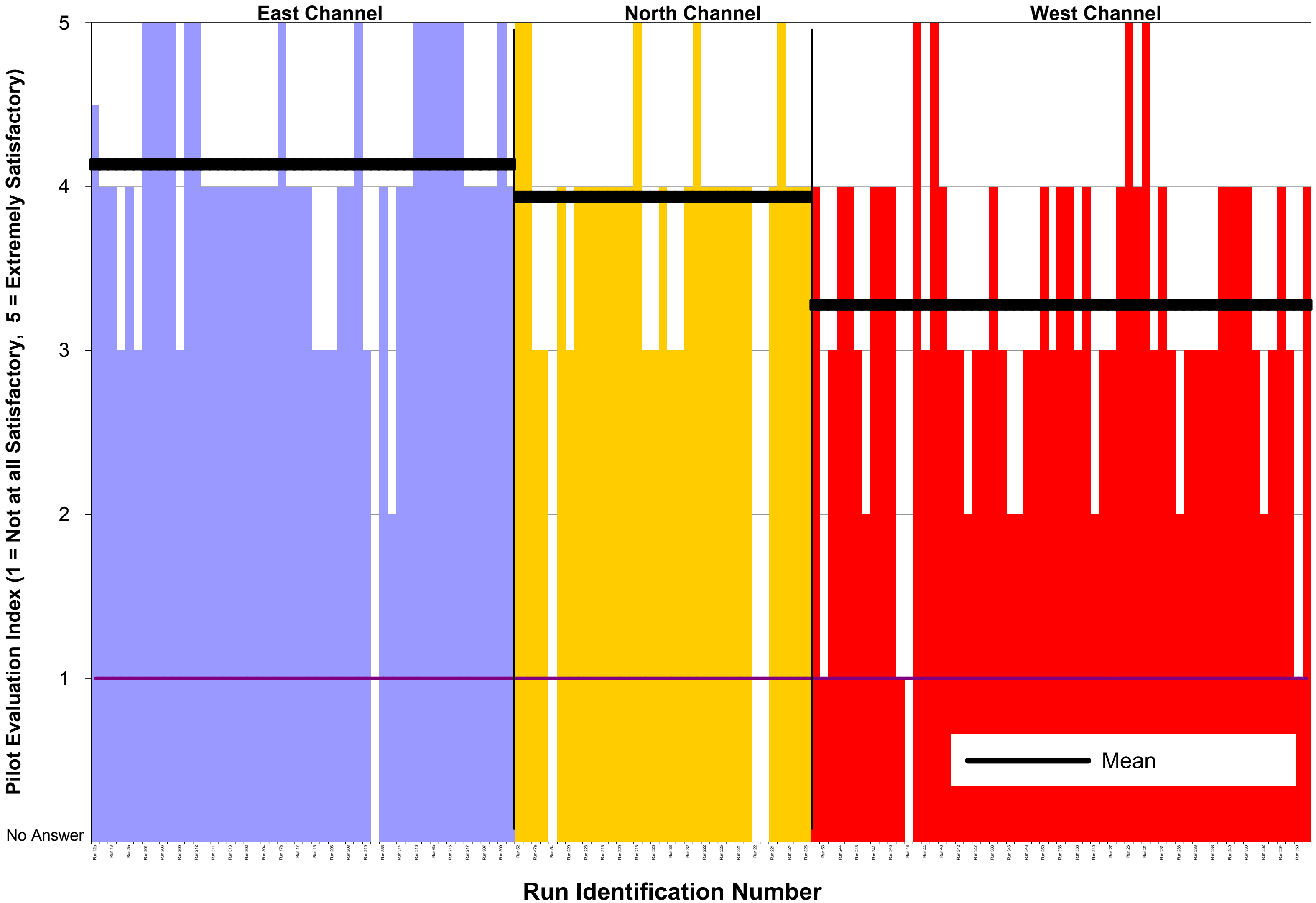


FIGURE 3.4
PILOT EVALUATION OF VESSEL POSITIONY

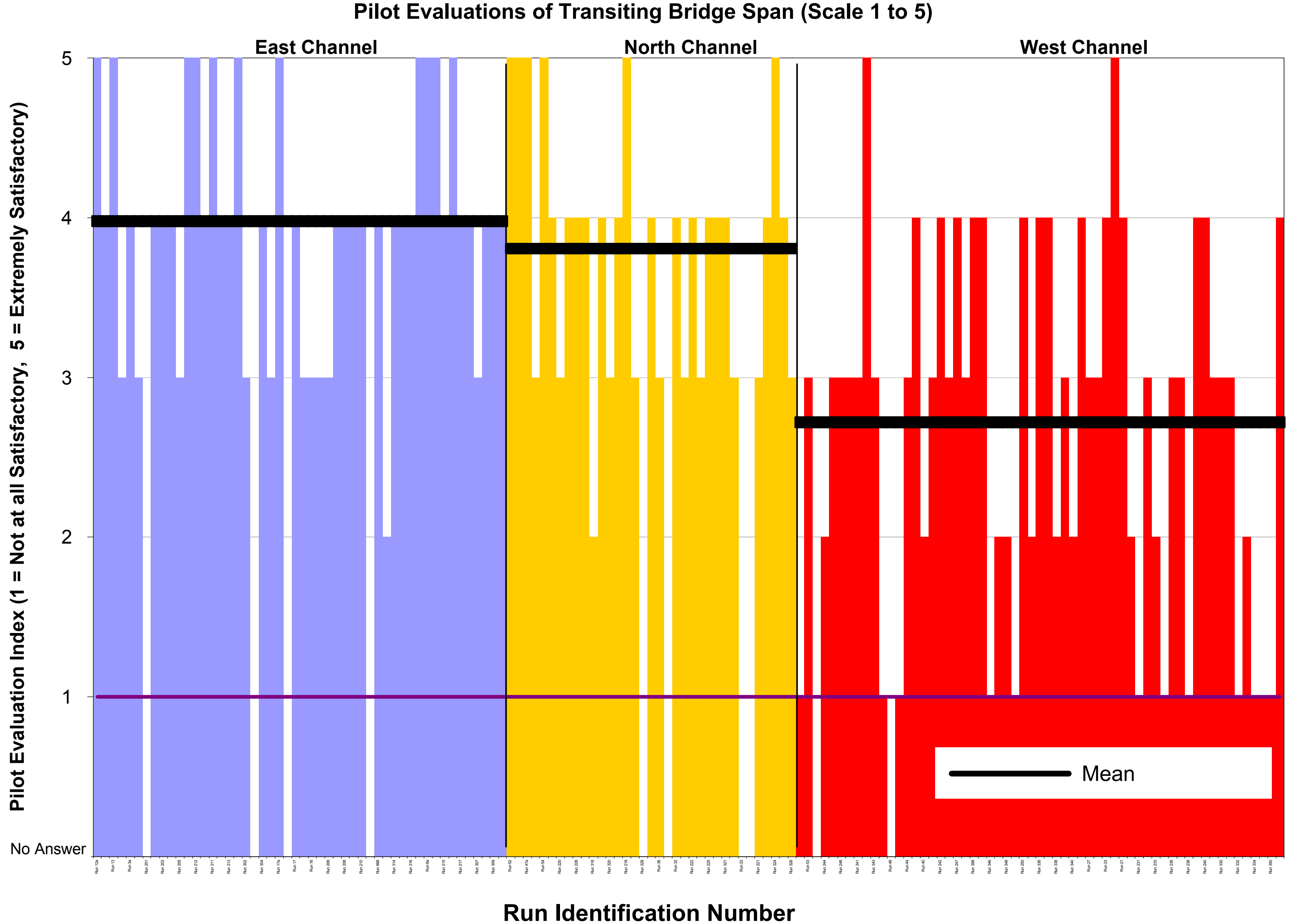


FIGURE 3.5
PILOT EVALUATION OF TRANSITING BRIDGE SPAN

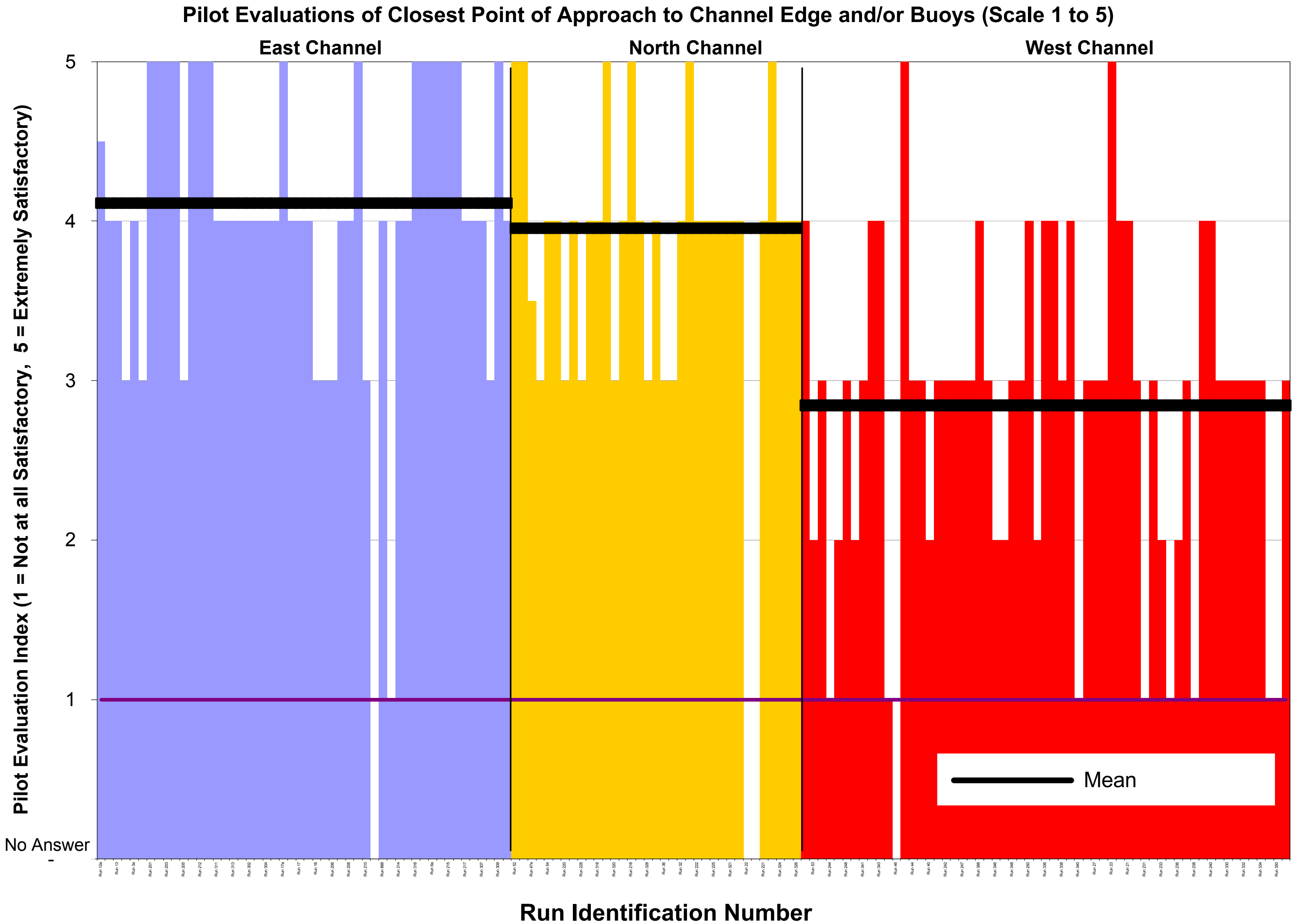


FIGURE 3.6
PILOT EVALUATION OF CLOSEST POINT OF APPROACH TO CHANNEL EDGE OR BUOYS

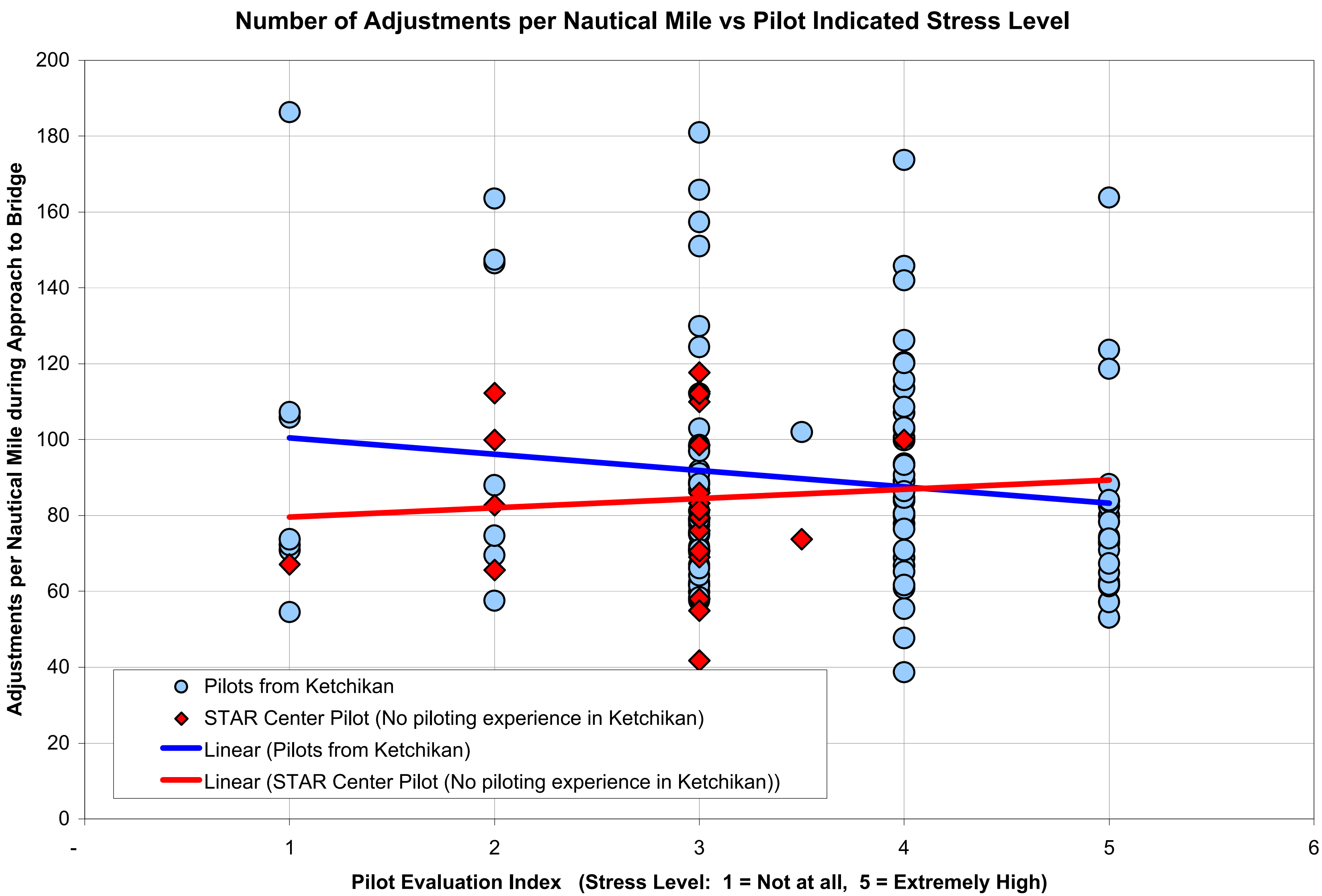


FIGURE 3.7
CORRELATION OF ADJUSTMENTS PER NAUTICAL MILE TO PILOT INDICATED STRESS LEVEL

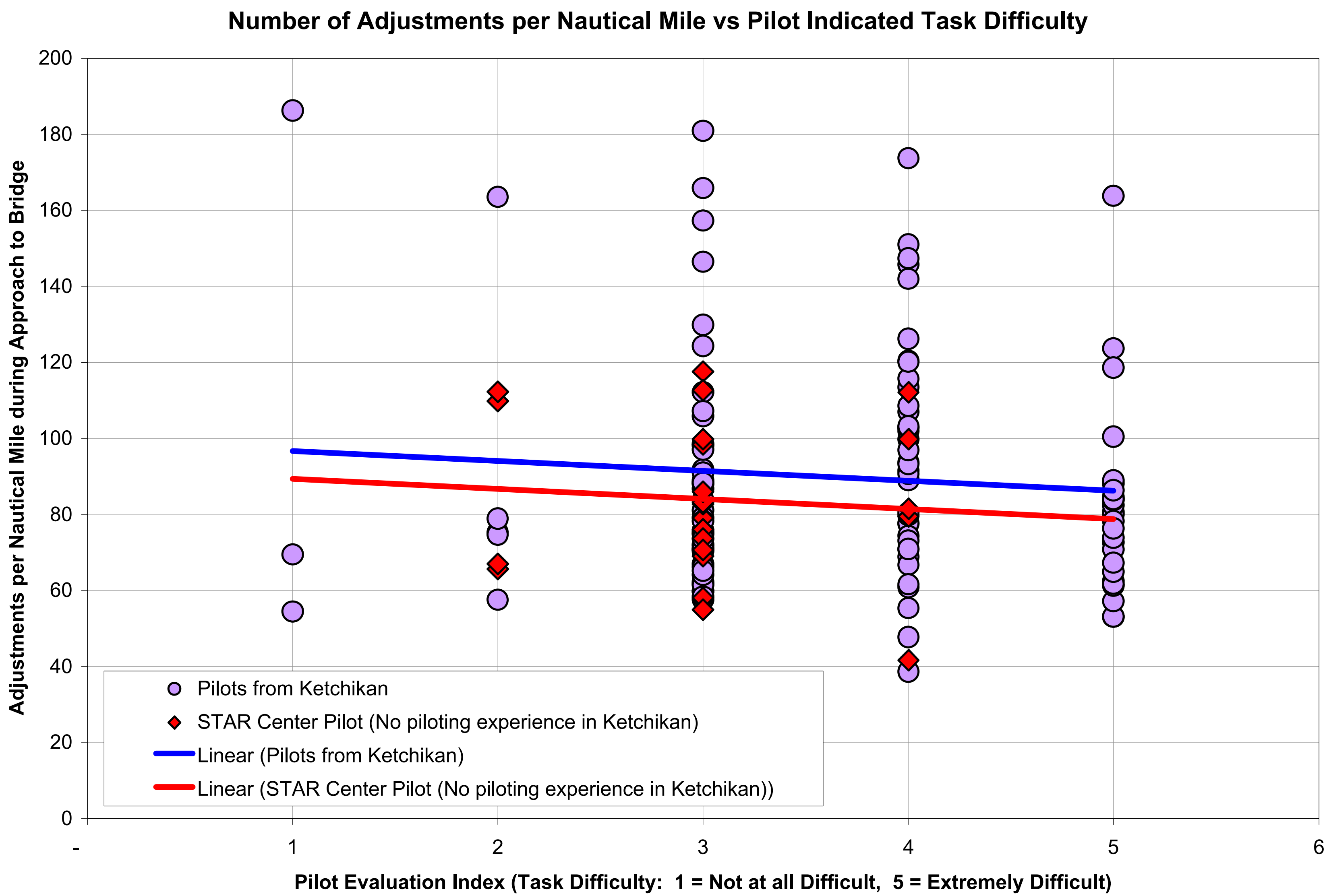


FIGURE 3.8
CORRELATION OF ADJUSTMENTS PER NAUTICAL MILE TO PILOT INDICATED TASK DIFFICULTY

3.4 Comments on Post-Exercise Pilot Evaluations

The post-exercise pilot evaluations contain a perspective on navigation in East, West and North Channels that is not captured in the analysis of the ship data. It is apparent in the opinion of the pilots that navigation in West Channel is more stressful, more difficult and is less safe overall. Their evaluations of vessel position with respect to centerline, channel boundaries and when transiting the bridge also show a dissatisfaction with their simulated transits of West Channel. There is almost no difference in their post-exercise evaluations of a bridge in North Channel or a bridge in East Channel.

It is noteworthy that the comments of the STAR Center pilot do show some small prejudice on the part of the Ketchikan pilots with respect to stress, difficulty and safety when comparing East and West Channels. The responses of the STAR Center pilot indicate that he felt the task of navigating West Channel was slightly less difficult and slightly less stressful than the other pilots. However, he rated the overall safety of both East and West Channels as being about the same as the Ketchikan pilots. Because the data sets are so small, we have not done tests to see if this difference of opinion is statistically significant. It is also possible that the Ketchikan pilots are commenting on real-world experience with respect to stress and difficulty in using West Channel and the STAR Center pilot is reacting only to the simulated world experience. It is intuitive that the simulated experience is neither as stressful nor as difficult as the real world experience. Supporting this observation is the fact that the STAR Center pilot on average found transiting all three channels to be less stressful and less difficult than did the Ketchikan pilots. Nonetheless, he thought that the C3/C4 bridge option and navigating North Channel was less safe than did the Ketchikan pilots.

It is also of interest to find that there is no evidence of an increasing number of adjustments in rudder angle and thrust settings when compared with post-exercise evaluation of increased stress or increased task difficulty. Only the responses of the STAR Center pilot indicate that he made more adjustments in those scenarios he ranked as more stressful. On average the responses and behaviors of both sets of pilots showed a very sight decrease in the number of adjustments per nautical mile with an increase in their opinion as to the difficulty of the task. Note again that the scatter in the data is very high and correspondingly the confidence in the correlation is very low.

4—Glosten Observations

4.1 WEEK 1

There were numerous comments from the pilots regarding the modeling of bank suction and bank cushion effects in West Channel. They seemed to believe that the lack of reality in this area would invalidate any West Channel conclusions that might be drawn about the F3 option. The STAR Center staff stated that bank suction effects were implemented. However, they are of the opinion that since the bathymetric model is based only on NOAA charted bathymetry it may not be exact. Since bathymetry from recent field surveys was not available, they felt they were in not position to comment one way or the other on the reality of the effects. Glosten has every reason to believe that the hydrodynamic modelers that developed the computer codes for the STAR simulator fully understand and have implemented bank suction and bank cushion effects to the current state of the art of the industry. It would be surprising if the bank suction forces (moments) would change significantly if the bathymetry in the region of the West Channel bridge were more closely matched to the actual configuration of the channel. The authors are of the opinion that the bank suction and bank cushion effects were adequately represented in the STAR simulation model. Differences will certainly exist between the nominally average scenarios that were modeled and worst cases from the real-world. However, we believe that this discrepancy does not affect the validity of conclusions to be drawn from the simulation exercise.

There were many comments from the pilots that the wind speed data from the Ketchikan airport was not representative of the conditions they have experienced in piloting cruise ships in Tongass Narrows. They were convinced that there are frequently wind speeds greater than we had proposed as the maximum based on the statistics from the airport. To accommodate their experience we added to the matrix of scenarios a much higher wind speed than the airport data indicates. A number of cases in wind speeds of 30 knots with gusts to 45 knots were added. This was accepted by the pilots, however with some argument that it should be higher. The pilots have lots of experience with and anecdotal information about the wind in Tongass Narrows. However their contention that winds are frequent higher elsewhere in the Narrows than at the airport is not supported by available data and is not obviously true given the location of the airport anemometer and the topography of the waterways. Wind speed records from other locations in the Narrows would be required to develop a statistical check of their contention.

The model of tidal currents also caused considerable discussion. We settled on using a charted (mapped) 1 knot ebb and a 1 knot flood as defined by the pilots. We also settled on a 3 knot flood at 0 deg (due north) in Nickols Passage which significantly effects the turn into West Channel from that direction. The current model continued to change during the three weeks of simulations. The reality and perceptions of the pilots were never exactly matched. Our intention was to model the nominally average situation, the pilots wished to model the worst case situation so as to demonstrate how difficult it can be. Although the extreme difficulties resulting from current (either experienced or expected) was probably not accurately captured, it is the opinion of the authors that the conclusions regarding the relative risk of using West Channel and East Channel are still valid.

There was also much discussion of the realism of the heel angle calculation, the heel angle display, and what the limiting angle should be. On a real cruise ship the pilots stated that they would make no turns that would case the ship to roll more than 3 degrees. The pilots thought that the roll angle calculation for the *Voyager of the Seas* was incorrect, although there is no obvious source of error in this regard. The concern about heel angle is of importance during some of the maneuvers necessary to get into West Channel from Nichols Passage, but is of no concern during the bridge alignment maneuvers once in the channels. The only other place were heel angle is of concern is the maneuver across the harbor when arriving or departing via West Channel. However in the harbor maneuvers the speeds can in general be held low enough to prevent heel angles over 3 degrees.

There was general agreement among the pilots that cruise ships would have to choose arrival and departure through Nichols Passage if West Channel were to be used. The statement was that the time lost using West Channel (due to maneuvering requirements in the harbor) would have to be made up by heading in or out through Nichols Passage in order to save time on the trip to or from Seymour Narrows. This primarily applies to southbound trips where arrival time at Seymour Narrows is critical.

The pilots were insistent that running simulations from Nichols Passage was critical to understanding the use of West Channel. Their continued participation in and support for the project seemed to hinge on acceptance of this addition to the proposed simulations. The additional time to do the Nichols Passage runs was accepted by Glosten and The STAR Center staff to keep the simulation program moving smoothly ahead.

We ran arrival (northbound West Channel) simulations starting in Nichols Passage. The cases demonstrated the difficulty of making the port turn into West Channel, especially if roll angles were to be limited to realistic requirements. The difficulty was apparent in all wind conditions, especially with the strong current (3 to 3.5 knots setting northerly) and the 30 knots of wind from the SE. The best and easiest maneuver seemed to be to bring the ship to almost a stop at the southern end of west channel, rotate it 90° to port using the bow thrusters and then proceeding north into the channel. However, the pilots indicated that this would be frowned upon in real life.

We did not continue the southbound simulations in West Channel out to the turn to Nichols Passage, however the issues seem to be the same as for the inbound (northbound) cases.

A chart showing the difference in sailing distance to Seymour Narrows in shown in Figure 4.1. The idea that using Nichols Passage to save time in transit to or from Seymour Narrows is not clearly supported. There may be other reasons to use Nichols Passage in combination with West Channel, however the reasons will need to be clearly demonstrated by others. The data analysis contained in this report does not address risk factors associated with the turn between West Channel and Nichols Passage. However, it should be noted that pilot comments regarding West Channel use (especially in the northbound cases) may be influenced by their difficulties with the turn from Nichols Passage.

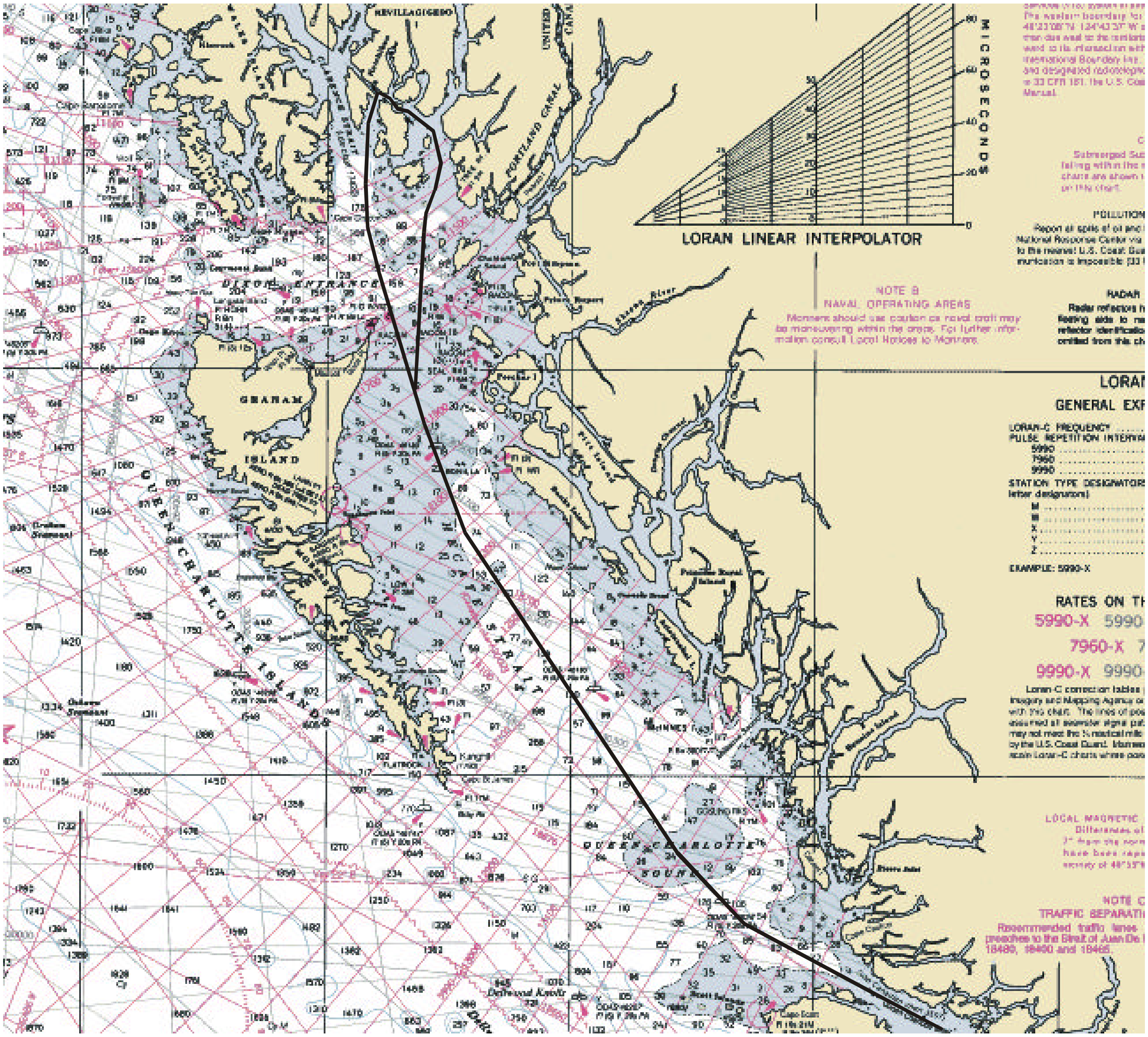


FIGURE 4.1
APPROXIMATE ROUTE BETWEEN THE SOUTH END OF PENNOCK ISLAND AND SEYMOUR NARROWS

It is the opinion of the authors that the use of Nichols Passage in combination with West Channel is not mandated. A comparison of the risks of the F1 and F3 bridge options can reasonably be made assuming that northbound and southbound traffic to either channel will be via Revillagigedo Channel.

4.2 WEEK 2

Additional runs were made in week 2 to study the difficult of getting cruise ships off the dock in extreme wind conditions. The additional runs were at 40 knots NW gusting to 50 and two with 35 knots gusting to 45. The dock maneuver part of these simulations is not directly relevant to the Gravina bridge options, however it did provide the pilots a chance to evaluate using the simulator in severe wind conditions. Each case demonstrated the difficulty of getting the ships off the dock and in reality serious damage would have resulted. In real-world cases the ships may have elected to stay on the dock or call for tug assistance. It was also pointed out that the ships would be limited in their ability to use bow and or stern thrusters or rotate the azipods athwarthship because the docks sit on pilings and small vessels are moored on the opposite side.

Again there was considerable discussion about the modeling of currents and winds. Several modifications were made to these variables to better match the experience of the pilots in the various channels.

The pilots in Week 2 were unanimously against using West Channel. Their concerns are best understood by reading the post-exercise evaluations contained in the STAR Center report [1].

4.3 WEEK 3 (Observations from Captain Trafford Taylor)

The following are edited observations from a recorded teleconference with Captain Trafford Taylor, the Glosten representative for the third week of testing.

We'll start with East Channel. They did not appear to be too apprehensive about East Channel northbound or southbound. They felt it was a bit of a trap in any conditions. The line-up, although Idaho Rock is pretty tight there, they can line up pretty well if the prevailing winds don't get them set off, you know, in a crab-like manner. So either northbound or southbound East Channel it is not a problem. West Channel, especially on the approach when they're coming in from Pennock Island and they have to make that hard turn from Nichols Passage. That caused them some difficulty, especially with a strong flood and a bit of a tide, they need a little practice to get over that.

Northbound on West Channel, when there's any kind of a breeze blowing they had a devil of a time not so much getting through the bridge but getting hung up on the shoals on the port-hand side when they're northbound just past bridge. That was real tight in there. You can't just go mid-channel. You have to go a little bit starboard as you're northbound. And without exception all of them said and the instructor said they didn't consider that a safe passage.

They also had great difficulty southbound on West Channel. Again, getting lined up you really have to hug Pennock Island on your port-hand side. They were really terrified of the shoals. So keeping to port as you're lining up was a real problem while trying to stay away from Pennock Reef.

North Channel – no problems whatsoever, I don't think we had a problem at all. There were no complaints about the loss of width of the channel by putting in the ramp.

And what were your comments about the realism of it all? (This is <u>your</u> comments now on the realism of it all.) I think it was very well simulated. I think the simulation was very well done and it was conducted appropriately.

The pilots did their best. They all did their best and a couple of times, you know, they were making the turn into West Channel northbound and they got themselves in dire straits. They approached a little too fast. There were significant differences between the azipod and the conventional ship – the azipod being much more forgiving, much more maneuverable and much more appropriate, I think, if you are going to use West Channel.

Trafford, can you make any characterization about whether there's a wind limit for West Channel or whether when you say – is it safe passage up to some wind limit and not for higher winds?

Well, it's a measure of risk. I think that the risk goes up exponentially after you get above, you know, 20 knots. It's a pretty dramatic rise in risk, but I'm not a statistician.

Did you go through West Channel in calm conditions, no wind?

Yes.

And you still felt the risks were high?

They were high, but they could be ameliorated. I mean, I understand the economics of the venture, but that if you get rid of that shoal when you're going northbound just under the bridge on the west side – that would certainly help them a lot.

Did you find that the pilots had to maintain a higher speed through West Channel than East Channel?

Yes, in some cases they did. And it was noticeable that the pilots who had more experience went faster. They sometimes went 11 knots. On average they went faster through West Channel. I always do.

What were your thoughts about the need to come through Nichols Passage when trying to get to Seymour Narrows on time.

I don't know I didn't quite understand that one either. Because when I look at the distances, it doesn't make a whole lot of difference.

Did you do any runs from Nichols Passage into the East Channel?

Yes. **(Authors' note: this reply is in error, only Run 314 looked at East Channel and Nichols Passage and it was a southbound run. There were no tests of the northbound turn from Nichols Passage into East Channel. There was one southbound and one northbound run into West Channel from Revillagigedo Channel. These are runs 555 and 666 during Week 2.)**

What about mitigations like removing the shoal right off the cruise ship dock.

Yes, yes that would help. It would help in terms of timing and it would also help in terms of risk.

For the F3 bridge option should the low bridge over East Channel be high enough to accommodate all barge traffic?

It would make a big difference. The extent that one can open up East Channel at least to quite a bit of traffic, now what you're creating – right now you have a natural traffic separation scheme that verges kind of on parallel tracks north of Pennock Island. What you'd be creating now would be almost a crossing traffic scheme for the merge.

Yes, northbound in West Channel they have to reverse and come back to the docks – of course they would cross, or angle across or converge with the northbound traffic in Tongass Narrows or in East Channel and going on through. That creates a very different traffic pattern in the harbor than it is now. Is that an issue?

No, I don't think so. Not in terms of risk.

5—Summary and Conclusions

The STAR Center real-time simulation program was proposed as a verification and refinement procedure for a selected bridge site alternative. Real-time simulation is most useful in identifying navigation problem areas, refining aids to navigation, developing pilot confidence in the selected alternative and for training pilots in techniques for navigating the selected channel. Also, since the cases in the real-time matrix tended toward severe and extreme weather conditions, these simulations demonstrate the possibility and difficulty of worst case conditions. The fact that the three bridge options can be navigated with similar ease in benign conditions does not tell the decision makers the whole story. Similar risks in the three channels in benign conditions does not mean similar risks in worst case conditions. The real-time simulations illuminated this for these channels.

The real-time program is also of value in determining the navigation time differences between the options.

Using real-time simulation to prepare statistical evaluations of alternatives is limited in its usefulness. Statistical significance improves with experimental repeats. Unfortunately real-time simulation takes time. The 15 day program at STAR Center completed 144 transits averaging 9.4 cases per day. The cases were set up to include; 3 bridge sites, 2 transit directions, 2 ship types, 4 wind conditions, day, night and fog conditions and harbor modifications. Nominally the program could complete only 1 case for each combination of the above variables. Multiple repeats were possible only by doing a limited number of night and fog conditions. In the final analysis the real-time simulations taken alone provide only synoptic and anecdotal information about the alternatives.

However, the statistical information that was developed from the real-time simulations has been enormously useful as a confirmation of the larger and statistically more significant body of work prepared using Monte Carlo methods and the PC-based fast-time simulator. The limited statistics from the real-time simulations for the probability of aberrancy, relative risk, probability of potential grounding and risk of grounding are astonishing similar to the more statistically significant numbers from the fast-time program. Thus the real-time simulations can be seen as a verification of the models and conclusions of the fast-time program. However again it must be emphasized that there were significant differences in the two programs. The fast-time program depended on a computerized three-term autopilot to handle the ships, however included a matrix of actual ships representative of the distribution of ships calling at Ketchikan and included a distribution of wind conditions representing the statistics of the site. Approximately 50,000 transits with large cruise ships were simulated. The real-time simulation program although guided by experienced human pilots, was limited to 2 ships and 4 wind conditions, two of which were a statistical rarity for summer months in Ketchikan. The program was skewed toward worst case scenarios. Yet despite the differences the results of both approaches are of the same order of magnitude.

The primary conclusion of the real-time simulation project is that there is a significant difference in the perception of risk of using West Channel and the statistics of risk based on pilot performance in West Channel. The pilots were exceedingly skillful in their ability to safely simulate the transit of very large cruise ships in severe and extreme wind conditions up West Channel and under the F3 bridge option. The confines of West Channel forced them to use a smaller amount of the navigational opening under the F3 bridge option than they did under the F1 bridge option. The measures of the difficulty of the task, the number of navigation adjustments as the bridge is approached, also demonstrate that the F1 and F3 bridge options are in navigation are nominally similar. However, in spite of their success, the pilots found the transit of West Channel to be more stressful, difficult and unsafe than transits of East Channel.

The other significant conclusion is that the measures of relative risk developed by fast-time simulation are upheld. The comparative risk of potential groundings and allisions contained in Table 4.13 of [2], are still valid. The normalized risk factors from that table are supported by the real-time simulation program. They are as follows:

Location	Normalized Risk Relative to the Natural Channel at Charcoal Point
Charcoal Point	1.0
North Channel with C3/C4 550' bridge	4.0
East Channel at Idaho/California Rocks	8.7
West Channel north of G"5"	10.7

The risk of using West Channel at its narrowest point is estimated to be 24% greater than the risk of transiting East Channel at its narrowest point.

6—Mitigations

1. Would a VTS (vessel traffic system) be a "mitigation" for F3 option?

A VTS would be a clear and unequivocal mitigation for the F3 bridge option, (large ships using West Channel). The system can be set up so as to direct traffic in East and West Channel to reduce congestion and reduce risk for passing, overtaking, or crossing vessels. Good communications and up-to-date information are essential for safe navigation in congested waters. A VTS system would enforce good communications and insure up-to-date information. The system would require that vessels able to use East Channel with the low bridge do so.

The two criticisms of VTS are that it gives authority and control to individuals who are not on the ship and that it adds additional humans to the loop and humans make errors. This happens with air-traffic control systems, but not frequently.

2. Are more aids to navigation required and where?

Properly configured aids to navigation are essential to safe navigation in congested and challenging waterways. Centerline lights on the underside of the bridge are assumed. These lights can be placed on poles extending from the roadway level of the bridge to add to their usefulness as range lights. Lights on the bridge pier protection are also assumed. It may be possible to configure a range using the bridge centerline and a light on East Clump, Charcoal Point or at the south end of the airport. These options should be studied and implemented if a suitable configuration can be achieved. The drawback of light based ranges is their usefulness is lost in fog.

Radar reflectors can also be used to create a range and can still be effective in fog. However it is not clear that suitable locations can be found for a radar range in West Channel. Radar transponders (devices that broadcast a radar signal) can also be configured to supply information to vessels about their position. Radars and radar transponders should be studied and implemented if it is found that they added to the safety of navigation.

3. Would the use of tugs be a "mitigation" for the F3 option?

The discussion of tugs as a "mitigation" should be divided into two categories. One is harbor assist tugs, the other is escort tugs. They are very different vessels with very different functions and very different costs.

Harbor assist tugs push ships in to piers and push or pull them off. They may also be used to rotate slowly moving vessels. They are needed and used at the pier when wind conditions are such that the vessel is unable or is at risk when propelling itself off the pier. They are used now when needed and can be assumed to be used in the future when needed. This function is not a mitigation for any bridge option. There is some possibility that harbor tugs could be used to assist and control cruise ships as they are making the "S"-turn into or out of the cruise ship terminal bound for or arriving from West Channel. If it can be demonstrated that this type of assist can save time or reduce risk during the "S"-turn maneuver then additional harbor-type tugs could be considered a mitigation for F3. Although the "S"-turn to or from West Channel takes a significant amount of concentration and skill from the pilots, the STAR Center real-time simulation studies demonstrated that the ships simulated have adequate maneuvering control to execute the turn in wind conditions up to at least the limiting condition for docking and undocking. Harbor tugs were not needed and would represent only a small mitigation with respect to this turn. In some conditions the pilot could choose to do a "U"-turn on arrival and a "U"-turn on departure eliminating an "S"-turn altogether. Harbor tugs would be of very little added value in assisting with this turn.

The other possibility for harbor tugs is that they could be used to reduce the time required to make the "U" or "S" turns when arriving or departing via West Channel. If they are capable of saving an amount of time whose cost equivalent (i.e. economic "utility") is equal or greater than the cost of employing them, then harbor tugs could be considered a mitigation for the F3 bridge alternative.

The time differential computed from the real-time simulation of cruise ships arriving and/or departing from the terminal to or from the F1 or F3 bridges is approximately 25 minutes. The distance and average speed between the terminal and F1 and F3 are as follows:

	F1 to terminal (6 runs)	Terminal to F1 (23 runs)	F3 to terminal (6 runs)	Terminal to F3 (6 runs)
Ave. Distance	0.83 n.m.	1.01 n.m.	1.68 n.m.	1.40 n.m.
Ave. Time	16 min.	12 min.	40 min.	34 min.
Ave. Speed	3.2 kts	5.1 kts	2.5 kts	2.5 kts

- Clearly the pilots chose to approach and depart the terminal when coming from or going to West Channel with a lower average speed than they did in the straight line maneuver into or from East Channel. However it is not at all clear that hiring a harbor tug would significantly speed up the West Channel maneuver. It is only the time spent in the initial or final 'U'-turn at the dock that might be reduced by employing a harbor tug. The turn around Pennock Reef into or out of West Channel is necessarily of fairly large radius and would not benefit from harbor tug assist. The departure from the terminal for West Channel took on average 8.5 minutes when docked starboard-side-to (facing north) and 12 minutes when docked port-side-to (facing south). It took 18 minutes to complete the arrival 'S'-turn (run 348) inbound from West Channel. It is expected that in the real world these times could be significantly longer, especially if the harbor is busy. However even if these times could be halved by a harbor assist tug, the saving would be a small percentage of the overall time it took to get to or from the F3 bridge. Thus is can be reasonable concluded that harbor assist tugs would not be a "mitigation" for the F3 option.

- Escort tugs are purpose designed and built vessels which can be effectively used to intervene in the event of a mechanical (steering or propulsion) failure on board a transiting ship. The mission of an escort tug is to stop and/or steer a disabled transiting ship within the navigational space of the waterway thus preventing an allision or grounding that might otherwise have occurred. The critical distinction between an escort tug and a conventional tug is its ability to apply controlling forces to the disabled vessel at significant speeds through the water. Properly designed and deployed escort tugs can begin applying effective controlling forces at transits speed up to 12 knots. It is essential in emergency situations with a moving ship that the escort tug begins applying controlling forces quickly. Tugs escorting tankers are expected to be able to begin applying controlling forces within 30 seconds of the recognition of the mechanical failure. The other significant different between escort and harbor tugs is in the magnitude and manner in which forces are applied. Escort tugs can generate very large control forces (100 – 300 tons). The forces are applied to the disabled ship by towline attached to the transiting ship's stern bitt or bitts. Nearly all of the tankers trading in areas where escort tugs are required have had to modify or add stern bitts to take loads of these magnitudes. There is very little chance that cruise ships are fitted with stern bitts of this strength. Modifying or adding stern bitts to withstand escort tug forces to each cruise ship calling in Ketchikan would not be economically justified. In addition the escort tug would be employed in Ketchikan only for the cruise ship season and employment in another escort type situation would have to be found for the remainder of the year. This is unlikely, except perhaps as the emergency stand-by tug stationed during the winter at Neah Bay at the entrance to the Straits of Juan de Fuca in Washington state.

In summary it is our opinion that a purpose-designed and built escort tug would not be economically viable in Ketchikan and would consequently not be a "mitigation" for the F3 option.

4. Would the removal of Starkweather Shoal, the concrete barge and a portion of the West Channel reef or other obstacles be a "mitigation" for the F3 option?

By unanimous agreement the pilots, STAR Center and The Glosten Associates believe that the removal of Starkweather Shoal would be a "mitigation" for all maneuvers to and from the cruise ship terminal. The removal would be particularly helpful in reducing the grounding risk if an 'S'-turn is attempted on arrival from or departure to West Channel for a starboard-side-to docking.

Removal of the sunken concrete barge should also be considered a "mitigation" for the F3 bridge option. Its removal enables ships using West Channel to have access to increased maneuvering room north of Pennock Reef. This will be particularly helpful when there are ships at anchor.

Removal of the portion of the West Channel reef near the F3 bridge location would be a "mitigation" for that option. This conclusion is also stated in the RTM STAR Center "Ketchikan Bridge Project, Summary Report." A hydraulic study could be undertaken to determine if the reef could be reconfigured (rather than removed) to minimize the current set toward Pennock Island.

5. Would relocation of the West Channel underwater cables to a non-midchannel location be a "mitigation" for the F3 option?

The relocation of the West Channel underwater cables to a non-midchannel location has been proposed so that in emergency situations cruise ships could anchor in the channel without damaging them.

Emergency anchoring to stop a disabled moving ship is an extreme measure especially at the transit speeds that are expected south of the F3 bridge. The average speed determined from the STAR Center real-time simulations is approximately 10 knots. Dropping an anchor or pair of anchors at this speed to stop a disabled vessel would be a rare occurrence. Moving the underwater cables to accommodate this emergency would need careful study. The opinions of the pilots, statistics of emergency anchoring and a risk based cost analysis should be undertaken. It is the opinion of The Glosten Associates that moving the underwater cables in West Channel to prevent their damage in case of emergency anchoring would not be found to be reasonable "mitigation" for the F3 bridge option.

The other scenario for anchoring in West Channel would be the anchoring of an able ship in order to wait out unexpected conditions that would prevent the ship from continuing safely. This might include minor shipboard disablements, unexpected blocking traffic or a casualty elsewhere in the channel, or a sudden and unexpected change in the weather. Anchoring in this scenario would occur after the ship is brought to a complete stop in a satisfactory location. West Channel south of the F3 bridge may in some locations be wide enough to accommodate voluntary anchoring without moving the underwater cables. Most of West Channel south of F3 is nearly as wide as the anchorage between Pennock Reef and Ketchikan. In addition, cruise ships with significant dead slow maneuverability (especially those with lots of bow thruster power and/or azipods) should be able to stop, rotate and leave West Channel if necessary (depending on wind and current conditions). This would not be possible during the narrow approach to F3, either north or south of the bridge, however neither would it be possible to stop, rotate and leave East Channel from some locations. The possibilities for controlled anchoring in West Channel for unexpected conditions either with or without moving the underwater cables needs further study by pilots, port authorities, utility officials and others. However it is the expectation of The Glosten Associates that moving the cables would be a very small "mitigation" for the F3 bridge option.

6. Should there be speed limit extensions?

Speed limits reduce the maneuverability of cruise ships when transiting narrow channels, especially in wind and current. Extensions of the current speed limits would make the situation more difficult.

7. Would maneuvering around anchored (lightered) ships be possible with the F3 option?

Maneuvering around anchored ships was demonstrated in a couple of cases in the STAR Center real-time simulations. Clearly the ability to safely execute this maneuver depends on the capability of the arriving ship, the weather conditions, the size and number of ships at anchor and if the sunken concrete barge is removed. However the opinion of STAR Center that "the use of West Channel as the only navigation route from the south would likely preclude the use of the anchorage north of Pennock Island by any large vessels," needs to be seriously considered. The F3 bridge option would require an extensive reconsideration of port practices and possible reconfiguration of all anchorages.

7—References

1. RTM STAR Center, "Ketchikan Bridge Project, Summary Report", July 2002.

2. The Glosten Associates, Inc., "Monte Carlo Navigation Simulation, Technical Memorandum, Draft", prepared for the State of Alaska, Department of Transportation and Public Facilities, DOT&PF Project 67698, January 2002.

3. The Glosten Associates, Inc., "Cruise Ship Traffic Projections," Gravina Access Project Technical Memorandum, September 2001.

APPENDIX A
Simulation Matrix

Run ID	Purpose	Sailing Direction	Ship	Bridge	Wind (knots)	Current (knots)	Fog	Time
12a	East Channel - Extreme Wind test	N	*Destiny*	F1	SE 30 ± 15	0.2		Day
12b	East Channel - Extreme Wind test	N	*Destiny*	F1	SE 30 ± 15	1.5@315°		Day
13	East Channel - Fog test	N	*Destiny*	F1	0	0.2	.25	Day
12	East Channel - Max. Wind test	N	*Destiny*	F1	SE 20 ± 10	0.2		Day
3a	East Channel - Max. Wind test	N	*Destiny*	F1	ESE 20 ± 10	1 kt flood		Day
11	East Channel - Moderate Wind test	N	*Destiny*	F1	SE 15 ± 8	0.2		Day
201	East Channel - Extreme Wind test	N	*Destiny*	F1	SE 30 ± 15	0.2		Day
202	East Channel - Extreme Wind test	N	*Destiny*	F1	SE 30 ± 15	1.5@315°		Day
203	East Channel - Fog test	N	*Destiny*	F1	0	0.2	.25	Day
204	East Channel - Max. Wind test	N	*Destiny*	F1	SE 20 ± 10	0.2		Day
205	East Channel - Max. Wind test	N	*Destiny*	F1	ESE 20 ± 10	1 kt flood		Day
211	East Channel - Moderate Wind test	N	*Destiny*	F1	SE 15 ± 8	0.2		Day
212	East Channel Arrival - Max. Wind	N	*Destiny*	F1	SE 20 ± 10	1 kt flood	-	Day
213	East Channel Baseline Existing Arrival (no bridge)	N	*Destiny*	F1	0	0.2		Day
311	East Channel Arrival - Moderate Wind	N	*Destiny*	F1	SE 15 ± 8	1 kt flood	-	Day
312	East Channel Arrival - Max. Wind	N	*Destiny*	F1	SE 20 ± 10	1 kt flood	-	Day
313	East Channel Arrival - Extreme Wind	N	*Destiny*	F1	ESE 30 ± 15	1 kt flood	-	Day
301	East Channel Baseline Arrival	N	*Voyager*	F1	0	1 kt flood	-	Day

Run ID	Purpose	Sailing Direction	Ship	Bridge	Wind (knots)	Current (knots)	Fog	Time
302	East Channel - Moderate Wind	N	*Voyager*	F1	ESE 15 ± 8	1 kt flood	-	Day
303	East Channel - Max. Wind	N	*Voyager*	F1	ESE 20 ± 10	1 kt flood	-	Day
304	East Channel - Extreme Wind	N	*Voyager*	F1	SE 30 ± 15	1 kt flood	-	Day
305	East Channel - Fog	N	*Voyager*	F1	ESE 15 ± 8	1 kt flood	.1	Day
17a	East Channel - Extreme Wind test	S	*Destiny*	F1	NW 30 ± 15	1.5@135°		Day
8	East Channel - Extreme Wind test	S	*Destiny*	F1	WNW 30 ± 15	1 kt ebb		Day
17	East Channel - Max. Wind test	S	*Destiny*	F1	NW 20 ± 10	1@135°		Day
7	East Channel - Max. Wind test	S	*Destiny*	F1	WNW 20 ± 10	1 kt ebb		Day
16	East Channel - Moderate Wind test	S	*Destiny*	F1	NW 15 ± 8	0.2		Day
15	East Channel - Night test	S	*Destiny*	F1	0	0.2		Night
206	East Channel - Extreme Wind test	S	*Destiny*	F1	NW 30 ± 15	1.5@135°		Day
207	East Channel - Extreme Wind test	S	*Destiny*	F1	WNW 30 ± 15	1 kt ebb		Day
208	East Channel - Max. Wind test	S	*Destiny*	F1	NW 20 ± 10	1@135°		Day
209	East Channel - Max. Wind test	S	*Destiny*	F1	WNW 20 ± 10	1 kt ebb		Day
210	East Channel - Moderate Wind test	S	*Destiny*	F1	NW 15 ± 8	0.2		Day
777	East Channel Departure - Extreme Wind	S	*Destiny*	F1	NW 40 ± 10	1.5 ebb		Night
888	East Channel Departure - Extreme Wind	S	*Destiny*	F1	NW 35 ± 10	1.5 ebb		Night
999	East Channel - Night test	S	*Destiny*	F1	NW 35 ± 10	1.5 ebb		Night
314	East Channel Departure - Moderate Wind	S	*Destiny*	F1	WNW 15 ± 8	1 kt ebb	-	Day
315	East Channel Departure - Max. Wind	S	*Destiny*	F1	WNW 20 ± 10	1 kt ebb	-	Day

Run ID	Purpose	Sailing Direction	Ship	Bridge	Wind (knots)	Current (knots)	Fog	Time
316	East Channel Departure - Extreme Wind	S	*Destiny*	F1	NW 30 ± 15	1 kt ebb	-	Day
317	East Channel Departure - Night - Moderate Wind	S	*Destiny*	F1	WNW 15 ± 8	1 kt ebb	-	Night
6a	East Channel - Night Departure	S	*Voyager*	F1	WNW 15 ± 8	1 kt ebb		Night
214	East Channel Departure - Moderate Wind	S	*Voyager*	F1	WNW 15 ± 8	1 kt ebb		Night
215	East Channel Departure - Max. Wind	S	*Voyager*	F1	WNW 20 ± 10	1 kt ebb		Day
216	East Channel Departure - Extreme Wind	S	*Voyager*	F1	NW 30 ± 15	1 kt ebb		Day
217	East Channel Departure - Night - Moderate Wind	S	*Voyager*	F1	WNW 15 ± 8	1 kt ebb		Day
306	East Channel Baseline Departure	S	*Voyager*	F1	0	1 kt ebb	-	Day
307	East Channel - Moderate Wind	S	*Voyager*	F1	WNW 15 ± 8	1 kt ebb	-	Day
308	East Channel - Max. Wind	S	*Voyager*	F1	WNW 20 ± 10	1 kt ebb	-	Day
309	East Channel - Extreme Wind	S	*Voyager*	F1	NW 30 ± 15	1 kt ebb	-	Day
310	East Channel - Night	S	*Voyager*	F1	WNW 15 ± 8	1 kt ebb	-	Night
52	North Channel - Departure - Moderate Wind	N	*Destiny*	F4	SE 15 ± 8	0.2		Day
56	North Channel - Departure Fog - Moderate Wind	N	*Destiny*	F4	SE 15 ± 8	0.2	.1	Day
47a	North Channel - Departure Night - Moderate Wind	N	*Destiny*	F4	SE 15 ± 8	0.2		Night
54a	North Channel - Extreme Wind test	N	*Destiny*	F4	SE 30 ± 15	1.5		Day
54	North Channel - Max. Wind test	N	*Destiny*	F4	SE 20 ± 10	1		Day
219	North Channel - Departure - Moderate Wind	N	*Destiny*	F4	SE 15 ± 8	0.2		Day
220	North Channel - Departure Fog - Moderate Wind	N	*Destiny*	F4	SE 15 ± 8	0.2	.1	Day
227	North Channel - Departure Night - Moderate Wind	N	*Destiny*	F4	SE 15 ± 8	0.2		Night

Run ID	Purpose	Sailing Direction	Ship	Bridge	Wind (knots)	Current (knots)	Fog	Time
228	North Channel - Extreme Wind test	N	*Destiny*	F4	SE 30 ± 15	1.5		Day
229	North Channel - Max. Wind test	N	*Destiny*	F4	SE 20 ± 10	1		Day
318	North Channel Departure - Moderate Wind	N	*Destiny*	F4	ESE 15 ± 8	1 kt flood	-	Day
319	North Channel Departure - Max. Wind	N	*Destiny*	F4	ESE 20 ± 10	1 kt flood	-	Day
320	North Channel Departure - Extreme Wind	N	*Destiny*	F4	SE 30 ± 15	1 kt flood	-	Day
43	North Channel - Departure - Moderate Wind	N	*Voyager*	F4	SE 15 ± 8	0.2		Day
218	North Channel - Departure - Moderate Wind	N	*Voyager*	F4	SE 15 ± 8	0.2		Day
327	North Channel Departure - Moderate Wind	N	*Voyager*	F4	ESE 15 ± 8	1 kt flood	-	Day
328	North Channel Departure - Max. Wind	N	*Voyager*	F4	ESE 20 ± 10	1 kt flood	-	Day
329	North Channel Departure - Extreme Wind	N	*Voyager*	F4	SE 30 ± 15	1 kt flood	-	Day
36	North Channel - Extreme Wind test	S	*Destiny*	F4	NW 30 ± 15	1.5@135°		Day
34	North Channel - Max. Wind test	S	*Destiny*	F4	NW 20 ± 10	1@135°		Day
32	North Channel - Moderate Wind test	S	*Destiny*	F4	NW 15 ± 8	0.2		Day
36a	North Channel - Wind & Fog	S	*Destiny*	F4	NW 15 ± 8	0.2	0	Day
222	North Channel - Extreme Wind test	S	*Destiny*	F4	NW 30 ± 15	1.5@135°		Day
223	North Channel - Max. Wind test	S	*Destiny*	F4	NW 20 ± 10	1@135°		Day
225	North Channel - Moderate Wind test	S	*Destiny*	F4	NW 15 ± 8	0.2		Day
226	North Channel - Wind & Fog	S	*Destiny*	F4	NW 15 ± 8	0.2	0	Day
321	North Channel Arrival - Moderate Wind	S	*Destiny*	F4	ESE 15 ± 8	1 kt ebb	-	Day
323	North Channel Arrival - Extreme Wind	S	*Destiny*	F4	SE 30 ± 15	1 kt ebb	-	Day

Run ID	Purpose	Sailing Direction	Ship	Bridge	Wind (knots)	Current (knots)	Fog	Time
22	North Channel - Max. Wind test	S	*Spirit*	F4	NW 20 ± 10	0.2		Day
20	North Channel - Moderate Wind test	S	*Spirit*	F4	NW 15 ± 8	0.2		Day
221	North Channel - Max. Wind test	S	*Spirit*	F4	NW 20 ± 10	0.2		Day
224	North Channel - Moderate Wind test	S	*Spirit*	F4	NW 15 ± 8	0.2		Day
324	North Channel Arrival - Moderate Wind	S	*Voyager*	F4	WNW 15 ± 8	1 kt ebb	-	Day
325	North Channel Arrival - Max. Wind	S	*Voyager*	F4	WNW 20 ± 10	1 kt ebb	-	Day
326	North Channel Arrival - Extreme Wind	S	*Voyager*	F4	NW 30 ± 15	1 kt ebb	-	Day
53a	West Channel - Extreme Wind test	N	*Destiny*	F3	SE 30 ± 15	3 N / 1 NW		Day
53	West Channel - Max. Wind test	N	*Destiny*	F3	SE 20 ± 10	3 N / 1 NW		Day
51	West Channel - Moderate Wind test	N	*Destiny*	F3	SE 15 ± 8	3 N / 1 NW		Day
244	West Channel - Extreme Wind test	N	*Destiny*	F3	SE 30 ± 15	3 N / 1 NW		Day
246	West Channel - Max. Wind test	N	*Destiny*	F3	SE 20 ± 10	3 N / 1 NW		Day
248	West Channel - Moderate Wind test	N	*Destiny*	F3	SE 15 ± 8	3 N / 1 NW		Day
249	West Channel Arrival - Harbor Modifications	N	*Destiny*	F3	WNW 15 ± 8	1 kt ebb	-	Day
341	West Channel Arrival - No Wind	N	*Destiny*	F3	0	3 kt North / 1 kt flood	-	Day
342	West Channel Arrival - Moderate Wind	N	*Destiny*	F3	ESE 15 ± 8	3 kt North / 1 kt flood	-	Day
343	West Channel Arrival - Max. Wind	N	*Destiny*	F3	ESE 20 ± 10	3 kt North / 1 kt flood	-	Day
344	West Channel Arrival - Extreme Wind	N	*Destiny*	F3	SE 30 ± 15	3 kt North / 1 kt flood	-	Day
46	West Channel - Arrival Fog - Moderate Wind	N	*Voyager*	F3	SE 15 ± 8	0.2	.1	Day
44a	West Channel - Extreme Wind test	N	*Voyager*	F3	SE 30 ± 15	3.5		Day

Run ID	Purpose	Sailing Direction	Ship	Bridge	Wind (knots)	Current (knots)	Fog	Time
44	West Channel - Max. Wind test	N	*Voyager*	F3	SE 20 ± 10	1		Day
42	West Channel - Moderate Wind test	N	*Voyager*	F3	SE 15 ± 8	0.2		Day
40	West Channel - Baseline Arrival	N	*Voyager*	F3	0	0.2		Day
241	West Channel - Arrival Fog - Moderate Wind	N	*Voyager*	F3	SE 15 ± 8	0.2	.1	Day
242	West Channel - Extreme Wind test	N	*Voyager*	F3	SE 30 ± 15	3.5		Day
245	West Channel - Max. Wind test	N	*Voyager*	F3	SE 20 ± 10	1		Day
247	West Channel - Moderate Wind test	N	*Voyager*	F3	SE 15 ± 8	0.2		Day
666	West Channel Baseline Arrival	N	*Voyager*	F3	0	0.2		Day
388	West Channel - Extreme Wind	N	*Voyager*	F3	NW 30	1 kt ebb		
345	West Channel Arrival - Moderate Wind	N	*Voyager*	F3	ESE 15 ± 8	3 kt North / 1 kt flood	-	Day
346	West Channel Arrival - Max. Wind	N	*Voyager*	F3	ESE 20 ± 10	3 kt North / 1 kt flood	-	Day
347	West Channel Arrival - Extreme Wind	N	*Voyager*	F3	SE 30 ± 15	3 kt North / 1 kt flood	-	Day
348	West Channel Arrival - Fog	N	*Voyager*	F3	ESE 15 ± 8	3 kt North / 1 kt flood	.1	Day
349	West Channel Arrival - Harbor Modifications	N	*Voyager*	F3	WNW 15 ± 8	1 kt ebb	-	Day
250	West Channel Arrival - Harbor Modifications	S	*Destiny*	F3	ESE 15 ± 8	1 kt ebb	-	Day
251	West Channel Departure - Harbor Modifications	S	*Destiny*	F3	ESE 15 ± 8	1 kt ebb	-	Night
336	West Channel Departure - No Wind	S	*Destiny*	F3	0	1 kt ebb	-	Day
337	West Channel Departure - Moderate Wind	S	*Destiny*	F3	WNW 15 ± 8	1 kt ebb	-	Day
338	West Channel Departure - Max. Wind	S	*Destiny*	F3	WNW 20 ± 10	1 kt ebb	-	Day
339	West Channel Departure - Extreme Wind	S	*Destiny*	F3	NW 30 ± 15	1 kt ebb	-	Day

Run ID	Purpose	Sailing Direction	Ship	Bridge	Wind (knots)	Current (knots)	Fog	Time
340	West Channel Departure - Night	S	*Destiny*	F3	WNW 15 ± 8	1 kt ebb	-	Night
25	West Channel - Extreme Wind test	S	*Voyager*	F3	WNW 30 ± 15	1 kt ebb		Day
27	West Channel - Departure Fog - Moderate Wind	S	*Voyager*	F3	WNW 15 ± 8	1 kt ebb	.1	Day
28	West Channel - Departure Night - Moderate Wind	S	*Voyager*	F3	WNW 15 ± 8	1 kt ebb		Night
23	West Channel - Max. Wind test	S	*Voyager*	F3	WNW 20 ± 10	1 kt ebb		Day
21a	West Channel - Moderate Wind - Crowded Harbor	S	*Voyager*	F3	WNW 15 ± 8	1 kt ebb		Day
21	West Channel - Moderate Wind test	S	*Voyager*	F3	NW 15 ± 8	0.2		Day
230	West Channel - Extreme Wind test	S	*Voyager*	F3	WNW 30 ± 15	1 kt ebb		Day
231	West Channel - Departure Fog - Moderate Wind	S	*Voyager*	F3	WNW 15 ± 8	1 kt ebb	.1	Day
232	West Channel - Departure Night - Moderate Wind	S	*Voyager*	F3	WNW 15 ± 8	1 kt ebb		Night
233	West Channel - Max. Wind test	S	*Voyager*	F3	WNW 20 ± 10	1 kt ebb		Day
234	West Channel - Moderate Wind - Crowded Harbor	S	*Voyager*	F3	WNW 15 ± 8	1 kt ebb		Day
236	West Channel Departure - No Wind	S	*Voyager*	F3	0	1 kt ebb	-	Day
237	West Channel Departure - Moderate Wind	S	*Voyager*	F3	WNW 15 ± 8	1 kt ebb	-	Day
238	West Channel Departure - Max. Wind	S	*Voyager*	F3	WNW 20 ± 10	1 kt ebb	-	Day
239	West Channel Departure - Extreme Wind	S	*Voyager*	F3	NW 30 ± 15	1 kt ebb	-	Day
240	West Channel Departure - Night	S	*Voyager*	F3	WNW 15 ± 8	1 kt ebb	-	Night
555	West Channel - Moderate Wind test	S	*Voyager*	F3	NW 15 ± 8	0.2		Day
330	West Channel Departure - No Wind	S	*Voyager*	F3	0	1 kt ebb	-	Day
331	West Channel Departure - Moderate Wind	S	*Voyager*	F3	WNW 15 ± 8	1 kt ebb	-	Day

Run ID	Purpose	Sailing Direction	Ship	Bridge	Wind (knots)	Current (knots)	Fog	Time
332	West Channel Departure - Max. Wind	S	*Voyager*	F3	WNW 20 ± 10	1 kt ebb	-	Day
333	West Channel Departure - Extreme Wind	S	*Voyager*	F3	NW 30 ± 15	1 kt ebb	-	Day
334	West Channel Departure - Night	S	*Voyager*	F3	WNW 15 ± 8	1 kt ebb	-	Night
335	West Channel Departure - Fog	S	*Voyager*	F3	WNW 15 ± 8	1 kt ebb	.1	Day
350	West Channel Arrival - Harbor Modifications	S	*Voyager*	F3	ESE 15 ± 8	1 kt ebb	-	Day
351	West Channel Departure - Harbor Modifications	S	*Voyager*	F3	ESE 15 ± 8	1 kt ebb	-	Night

APPENDIX B
Positions of Bridge Piers and Calculation of Navigational Opening

North Channel

Center of East Stanchion

C3 A	Latitude	55° 21.764' N
C4	Longitude	131° 42.746' W

Center of West Stanchion

C3 A	Latitude	55° 21.663' N
C4	Longitude	131° 42.835' W

Distance = 687.71 feet or 209.67 meters

Mid-point of East Fender

C3 A	Latitude	55° 21.755' N
C4	Longitude	131° 42.754' W

Mid-point of West Fender

C3 A	Latitude	55° 21.674' N
C4	Longitude	131° 42.826' W

Distance = 551.24 feet or 168.06 meters

East Channel

Center of East Stanchion

F1	Latitude	55° 19.621' N
	Longitude	131° - 37.196' W

Center of West Stanchion

F1	Latitude	55° 19.567' N
	Longitude	131° 37.360' W

Distance = 654.82 feet or 199.64 meters

Mid-point of East Fender

F1	Latitude	55° 19.617' N
	Longitude	131° 37.210' W

Mid-point of West Fender

F1	Latitude	55° 19.571' N
	Longitude	131° 37.347' W

Distance = 549.79 feet or 167.62 meters

West Channel

Center of East Stanchion

F3	Latitude	55° 19.224' N
	Longitude	131° 38.762' W

Center of West Stanchion

F3	Latitude	55° 19.193' N
	Longitude	131° 38.956' W

Distance = 654.82 feet or 199.64 meters

Mid-point of East Fender

F3	Latitude	55° 19.220' N
	Longitude	131°38.783' W

Mid-point of West Fender

F3	Latitude	55° 19.193' N
	Longitude	131° 38.934' W

Distance = 549.56 feet or 167.55 meters