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A STUDY OF THE PLACEMENT OF MASTHEAD LIGHTS ON VESSELS LESS THAN 50 METERS

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16. Abstract

A study was conducted to determine whether or not navigation safety is affected when the masthead light is placed aft of amidships and aft of the sidelights light on power driven vessels less than 50 meters in length that have a single masthead light.

Computer simulation was used to display oncoming vessels to observers. Vessels were represented only by their navigation lights, which were not always placed in compliance with current regulations. Observers were not informed of the actual vessel navigation light placements, which is akin to the situation on the open water.

Two different situations were simulated. In one situation, observers had to judge aspect after a brief look at an oncoming vessel, similar to the situation when an oncoming vessel is first noticed. In the other situation, observers were given a long period of time to watch an oncoming vessel. These observers were asked to judge the vessel's course. In both situations there was no statistically significant difference between the responses given when vessels complied with current regulations and responses given when the masthead was free to vary forward and aft of the sidelights. Keywords: Navigation, [illegible] simulation, Naval vessels, merchant vessels, Surface navigation, [illegible]

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METRIC CONVERSION FACTORS

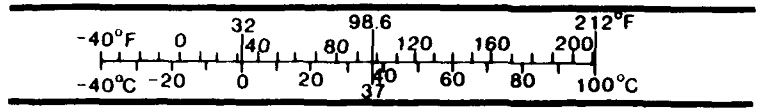
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13 10 286

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 EXECUTIVE SUMMARY

This report issues the findings from a study conducted at the United States Coast Guard Research and Development Center (USCG R&DC) on the relationship between the placement of the navigation lights on vessels less than 50 meters and the quality of course/aspect information provided by such lights. Several groups requested that the Coast Guard evaluate the effects on maritime safety of relaxing the rules governing the placement of forward masthead lights. This study focused on whether or not navigation safety was affected when the masthead light is placed aft of amidships and aft of the sidelights light on power driven vessels less than 50 meters in length that have a single masthead light.

Computer simulation was used to display oncoming vessels to observers. Vessels were represented only by their navigation lights, which were not always placed in compliance with current regulations. Observers were not informed of the actual vessel navigation light placements, which is akin to the situation on the open water.

Two different situations were simulated. In one situation, observers had to judge aspect after a brief look at an oncoming vessel, similar to the situation when an oncoming vessel is first noticed. In the other situation, observers were given a long period of time to watch an oncoming vessel. These observers were asked to make judgments of the course of the oncoming vessel. We sought to determine whether or not relaxing the requirements to place a masthead light forward, and to place the sidelights aft of the masthead light results in poorer judgments of course and aspect of oncoming vessels.

In both situations, the first glance and the longer view, there were no statistically significant differences between the responses given when vessels complied with current regulations and responses given when the masthead was placed aft of the sidelights. When an observer only has information derived from looking at the navigation lights, the task of making course or aspect judgments is difficult. Allowing the masthead light to be placed aft of the sidelights does not make the task any more difficult.

In addition to studying the effectiveness of vessel navigation lights, thought was given to ways to improve the usefulness of information they provide. Because current regulations allow a large degree of freedom in navigation light placement, it is impossible to directly relate lighting configurations and vessel course or aspect. To make navigation lights better tools for determining course or aspect of oncoming vessels, the requirements for placement must be more specific than the present regulations mandate. Two sample configurations are provided to illustrate this point.

2.0 INTRODUCTION

Current regulations governing the placement of lights on power-driven vessels between 20 and 50 meters in length require a minimum of one masthead light forward and sidelights placed at or near the sides of the vessel and aft of the forward masthead light. Forward has generally been interpreted to be forward of the vessel amidshipline. Several groups have requested that the Coast Guard evaluate the effects on maritime safety of relaxing the rules governing the placement of forward masthead lights. The Office of Navigation Safety and Waterway Services at U.S. Coast Guard Headquarters requested that the Research and Development Center investigate whether or not the placement of the masthead light aft of amidships and/or aft of the sidelights influences navigation safety.

Safe navigation requires that a mariner have adequate information about the activity of an oncoming vessel in order to make sound maneuvering decisions. We reduced the problem of navigation safety to the study of how accurately observers can judge the aspect or course of an oncoming vessel.

Our intent was to study the information provided solely by navigation lights. The simulation was equivalent to that of an oncoming vessel on a dark, cloudy night. Thus, the navigation lights were the only parts of the oncoming vessel that were visible. The hull of the oncoming vessel was not visible. Therefore, only information about the relative positions of the navigation lights was available to observers.

3.0 OBJECTIVE

The primary objective of our study was to evaluate the effects of placement of vessel navigation lights on navigation safety using simulation to represent oncoming vessels. Specifically, we wanted to determine if there is an effect on navigation safety of moving the forward masthead light aft of the sidelights.

4.0 METHODS

4.1 Procedure

The method chosen for observers to provide responses consisted of an arrow displayed on the monitor immediately following a simulated scene. Observers used button controls to rotate this arrow to match the aspect or course of the simulated, oncoming vessel.

We tested the observer's ability to properly align the arrow after showing them a full daylight view (approximately 5-sec long) of a 9-in long toy boat which was placed directly forward of and below the monitor, about 48-in from the observer. Observers were able to align the arrow to within +/-2 degrees of the aspect of the vessel. Based on this result, we were satisfied that observers could convert a three dimensional view of a vessel into a two dimensional angular representation with minimal error.

Observers were required to judge the aspect or course of a moving vessel simulated on a high resolution color monitor. The vessel speed and position of its masthead light were varied between presentations. After viewing the moving vessel for a brief period of time, an arrow was displayed on the monitor. Observers were asked to rotate the arrow to point in the direction that matched the aspect or course of the simulated vessel. The computer recorded the observer's judgment and then presented the next simulation.

Two separate experiments were conducted. In the first experiment, we evaluated the information displayed during an initial brief look at an oncoming vessel's navigation lights. This was designated the "First Glance" experiment. In the second experiment, we investigated the information provided by an oncoming vessel's navigation lights over a time period of 1.5 minutes. Since real time was compressed into an observation period of 10 seconds, this was designated the "Time Compression" experiment.

Each experiment was divided into two parts with similar experimental design in each part. In part A, subjects were instructed that the masthead light was always in compliance with regulations, i.e. always forward of the sidelights. The masthead light was placed either 1, 15 or 30-ft forward of the sidelights. In part B subjects were told that the masthead light could be forward or aft of the sidelights. In this experiment the masthead light was 15 or 30-ft forward, or 15 or 30-ft aft of the sidelights.

Vessel courses were 005, 012, 020, 050, 075, and 090 degrees relative to the observer. Vessels were placed in motion at speeds of 10 and 15 knots along each course. The basic vessel was 60-ft wide[1]. Sidelights were placed 50-ft aft of the bow, at the sides of the vessel, 10-ft above the waterline. Observers were seated 27-in from the monitor to provide a 30 degree field-of-view. All scenes started with the vessels 5000-ft away from observers.

In the First Glance experiment, observers saw a 3-sec view of a moving vessel. In the Time Compression experiment we displayed

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[1] The width of the vessel was intentionally exaggerated because of limitations in display resolution.

1.5 minutes of vessel movement in 10-sec of observation time.[2] This was done using three, 3-sec views, with each view separated by 0.5-sec "blank" period where the vessel disappeared from the display. During each 3-sec view, the vessel was shown moving along the specified course at a constant speed. During the 0.5 second blank period, a new position for the vessel was computed, as if the vessel had been moving continuously for 40.5 sec. After the 0.5 second was complete, the vessel reappeared at the new position and resumed moving along the specified course at constant speed.

Prior to viewing the experimental situations, observers were given practice at the task with feedback. Feedback was provided during a training session by displaying the actual course of a vessel after the observer had indicated the perceived course. The training session was viewed immediately prior to the experimental script.

4.2 *Computer Hardware and Software*

Simulation was performed on a Hewlett-Packard Series 900 Model 320 computer with graphics accelerator and eight color graphics planes. The monitor was 19-in diagonal with resolution of 1024 x 768 pixels.

The simulation program was written in the C language and utilized routines from the Starbase Graphics software library. Several data and parameter files were developed to maximize flexibility of simulation. One file, commonly called the "ship file", contained vessel definition information, which included light color, placement (x, y, z) and sector over which the light is visible. A second file (script file) contained information controlling the actions of vessels in the scenes to be generated, including course, speed, aspect, starting position and observer's height of eye. A third file (parameter file) contained scene display parameters, including field-of-view and sky and sea colors. A results file was generated during the experiment which pooled the information from the script file and the responses of the observer.

4.3 *Observers*

All observers were employees of the Coast Guard Research and Development Center in Groton, CT. Some were Coast Guard officers and the others were civilian employees and avid boaters. All

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[2] The selection of time period for time compression was constrained by the field of view of the display. Vessels on courses greater than 070 at speeds greater than 10 kts went off the edge of the display after 1.5-min of motion. Thus, 1.5-min period was selected for all presentations in this experiment.

observers were familiar with Rules of the Road. Twelve observers participated in the Time Compression experiment, and four observers participated in the First Glance experiment.

5.0 RESULTS

5.1 First Glance

Figure 1 shows differences (delta) between the perceived aspect angle (as determined by the adjustment of the arrow) and the true aspect angle of the vessel. Positive deltas indicate that the perceived aspect angle was overestimated, while negative values indicate that the perceived aspect angle was underestimated. Vertical bars represent +/- 1 standard deviation. If performance was perfect all data would lie on the dashed line at a delta of 0.0. The data are the average of judgments for vessels with the masthead light 30, 15 and 1-ft forward of the sidelights.

The differences between perceived and true aspect angle varied with angle. When true aspect angle was 5 degrees, observers correctly judged the angle. At 12 degrees observers tended to overestimate aspect angle by an average of 9 degrees. At large aspect angles observers tended to underestimate the aspect angle.

Figure 2 shows the results when the masthead light was varied both forward and aft of the sidelights. Note that the results are not different from the previous figure where the masthead light was constrained to be forward of the sidelights. A repeated measures analysis of variance showed no significant difference in overall performance between having the masthead light forward or the masthead light forward and aft at the 95% significance level. At some angles observers tended to overestimate aspect angle, while at others they underestimated aspect angle. Variability in judgments was not significantly different between this and the previous condition.

5.2 Time Compression

When observers are provided with multiple views of the navigation lights over a 1.5 minute time period their performance is different than in the single glimpse experiment but not necessarily better. When the masthead light is always forward of the sidelights (Figure 3) or both forward and aft (Figure 4) observers still tend to overestimate some angles and underestimate others. Again, a repeated measures analysis of variance shows no significant difference in overall performance between having the masthead light forward and the masthead light forward or aft.

When the masthead light was always forward of the sidelights, an analysis of variance did reveal a significant effect of masthead position ($F(2,342) = 10.98$, $p < .0001$). Figures 5 (Mast Forward) and 6 (Mast Forward and Aft) show deltas for the different masthead positions in the Time Compression experiment. When the masthead was 30-ft forward, observers tended to overestimate the

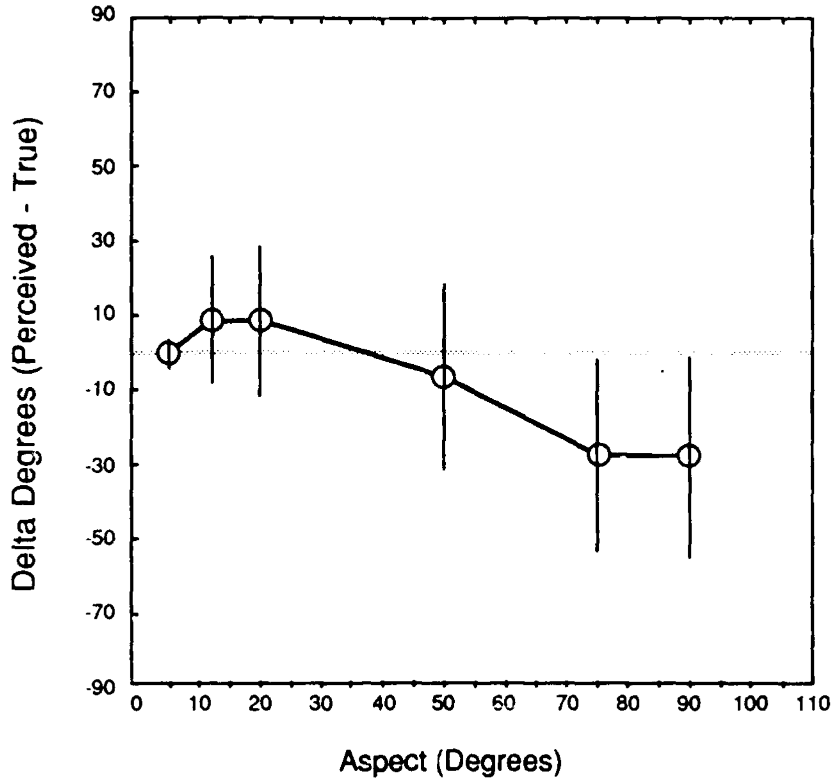

Figure 1. First Glance, Mast Forward

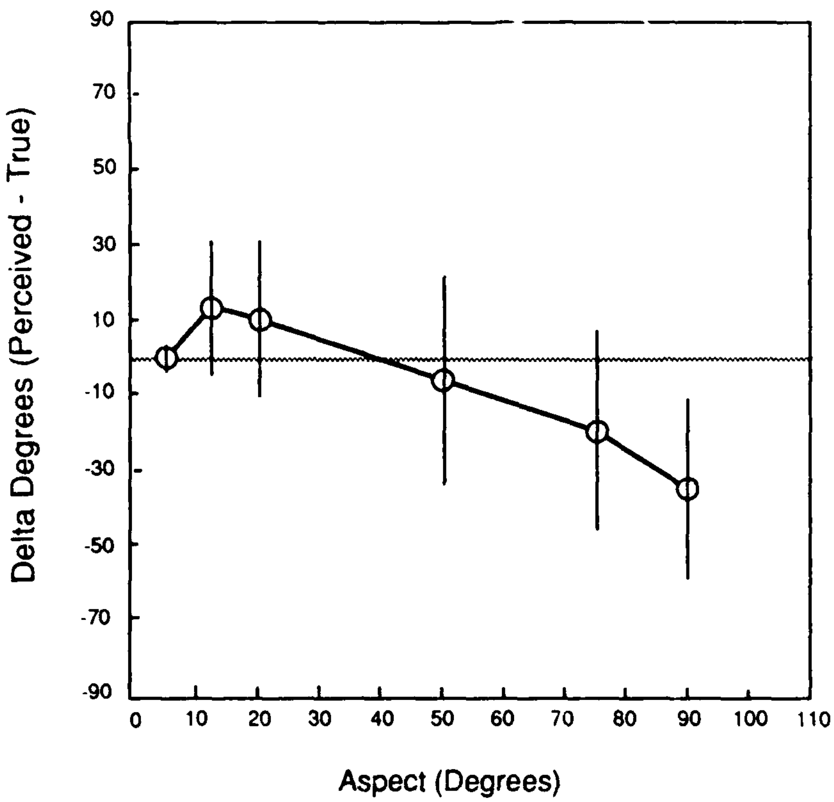

Figure 2. First Glance, Mast Forward & Aft

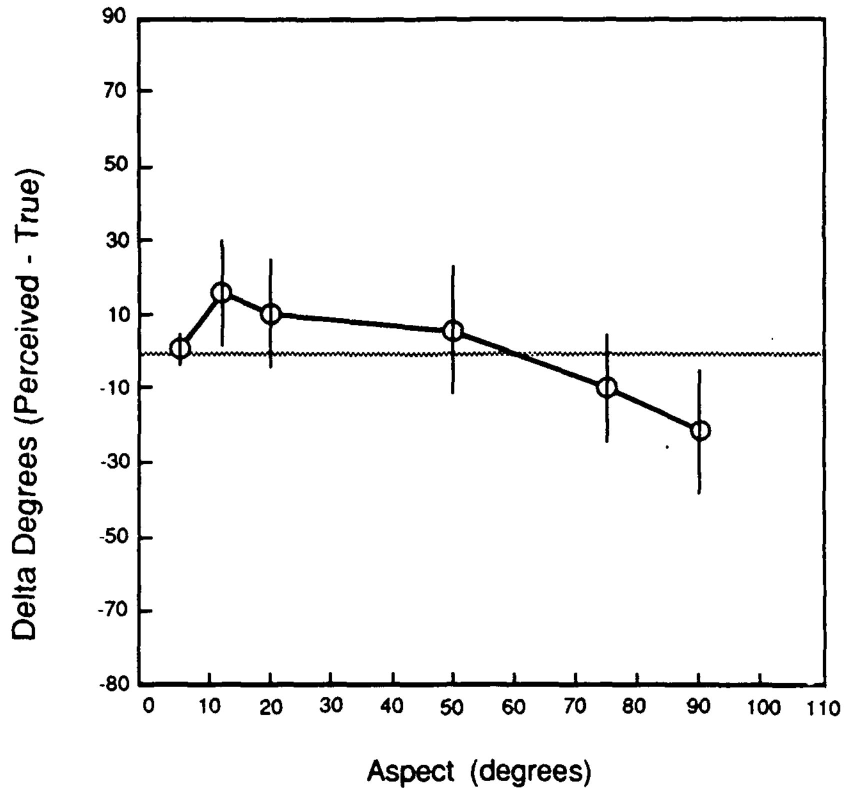

Figure 3. Time Compression, Mast Forward

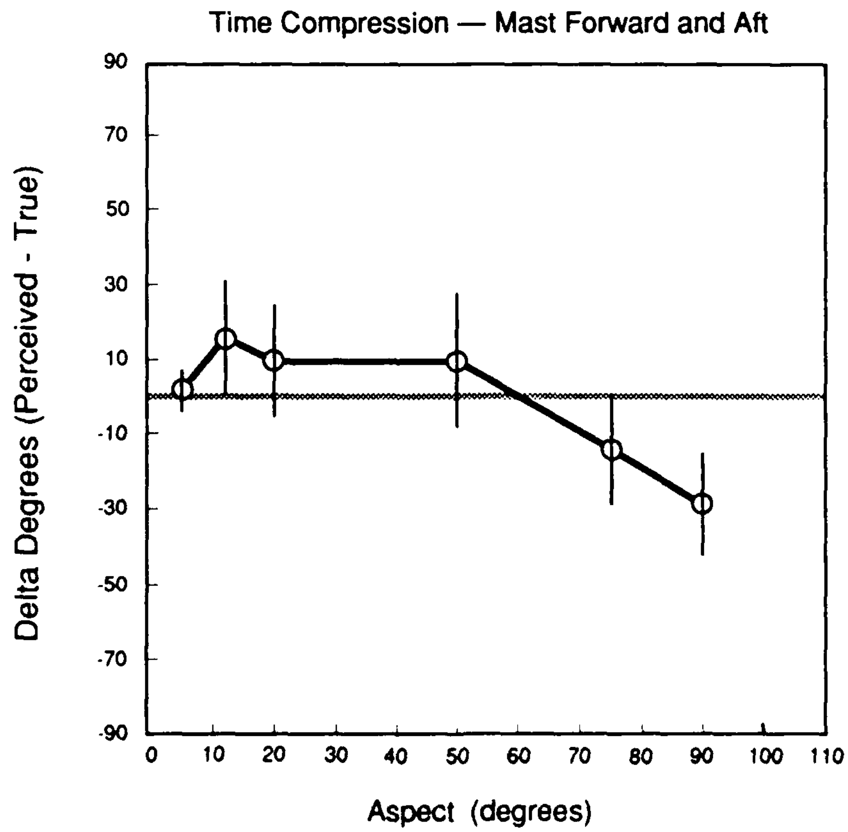

Figure 4. Time Compression, Mast Forward & Aft

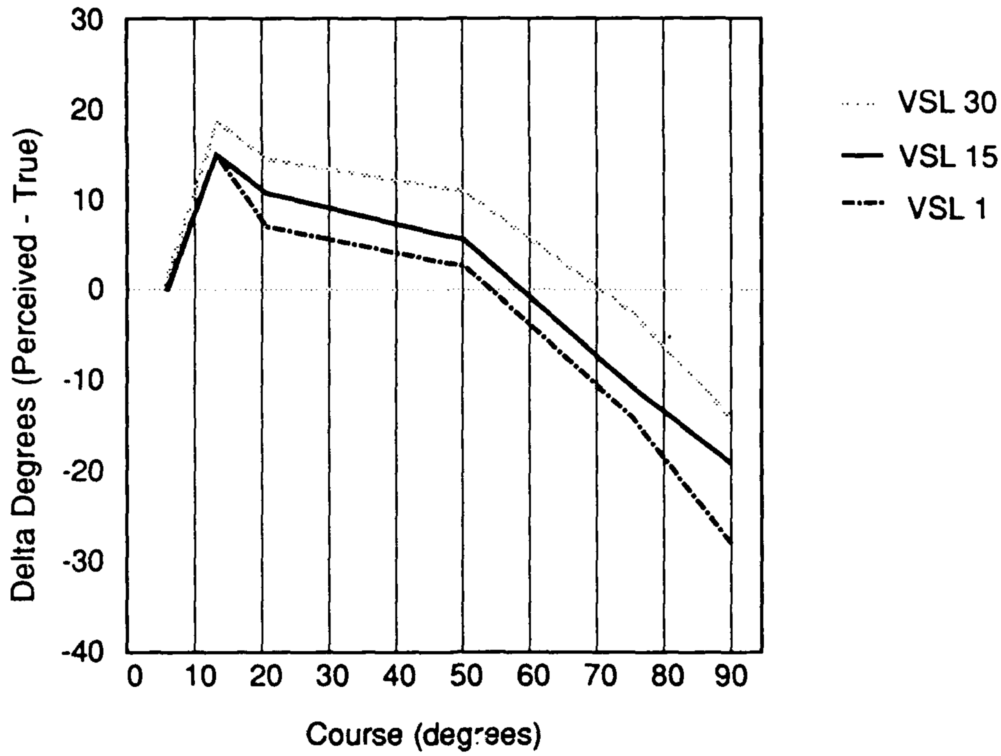

Figure 5. Time Compression, Mast Forward, by Ship

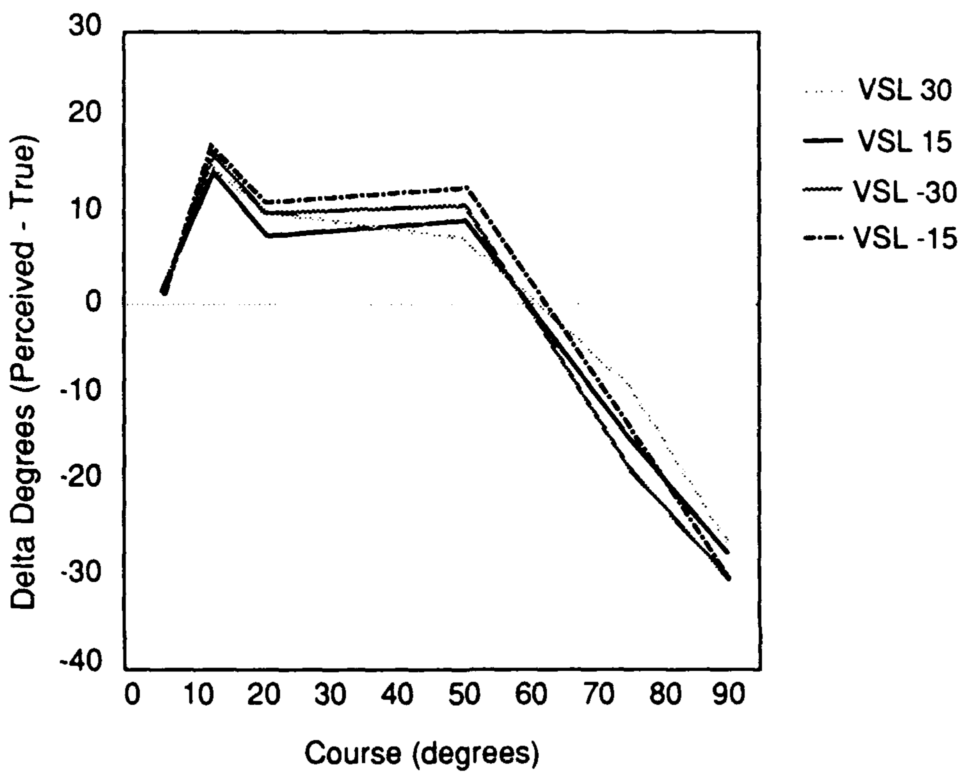

Figure 6. Time Compression, Mast Forward & Aft, by Ship

angle at small aspect angles by a greater amount than when the masthead light was only 1-ft forward. There was no significant difference in performance between having the masthead position 30-ft forward or 30-ft aft. Similarly, there was no difference in performance between having the masthead light 15-ft forward or 15-ft aft.

6.0 IMPLICATIONS

The results indicate that it is difficult to judge aspect or course from the appearance of the navigation lights. Since there is little difference between situations where the masthead light is forward or where it varies between forward and aft, it is not surprising that subjects do not perform the task with great accuracy. Given the performance in this laboratory simulation, there is no evidence to support the notion that there is a detriment to navigation safety of having the masthead light aft of the sidelights.

Observers who participated in our experiments, all skilled mariners, remarked at the difficulty of the tasks. Many noted that the cues they were given were inadequate for judging aspect or course. Observers noted that they often have the outline of the hull to use for their judgments, or that they use radar to obtain the course, or that there is a background against which a vessel is viewed that provides additional information. Navigation lights are required and regulated in order to ensure that mariners can see and recognize other vessels and judge aspect and course. The results of these experiments show that the current configuration of navigation lights is inadequate for providing precise information about vessel course.

7.0 NAVIGATION LIGHT POSITION CONSIDERATIONS

Prior to data collection, we anticipated that observers would have a difficult time judging the aspect and course of oncoming vessels since the position of the masthead light was free to vary along the entire forward half of the vessel. Without knowing precisely where the masthead light was located, the angular separation between masthead and sidelights provides ambiguous information about size, aspect and course of a vessel. Figures 7 and 8 illustrate this point.

In Figure 7, we diagram a hypothetical vessel with different navigation light arrangements. For discussion purposes, the distance from the centerline to the sidelights, w, remains constant. The longitudinal distance from the position of the sidelights to the masthead light, l, is varied to create the different lighting configurations. Defining the position ratio, $R = l/w$, provides a single value to describe a particular vessel's configuration. This figure shows position ratios of 3, 2, 1, 0, -1, and -2.

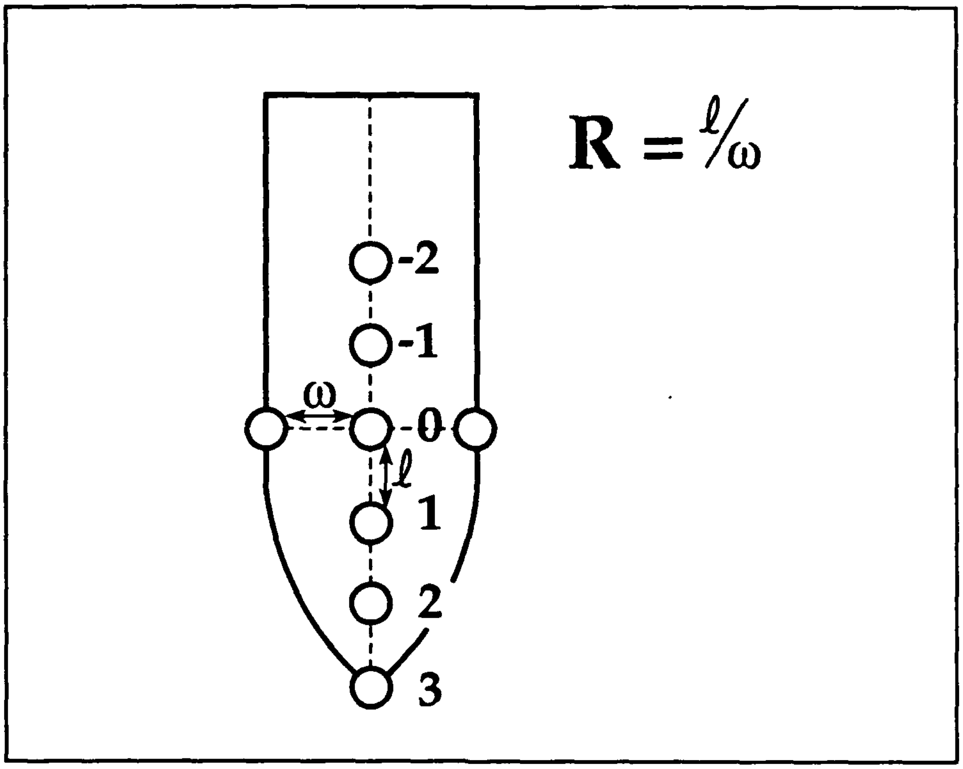

Figure 7. Top View of Vessel

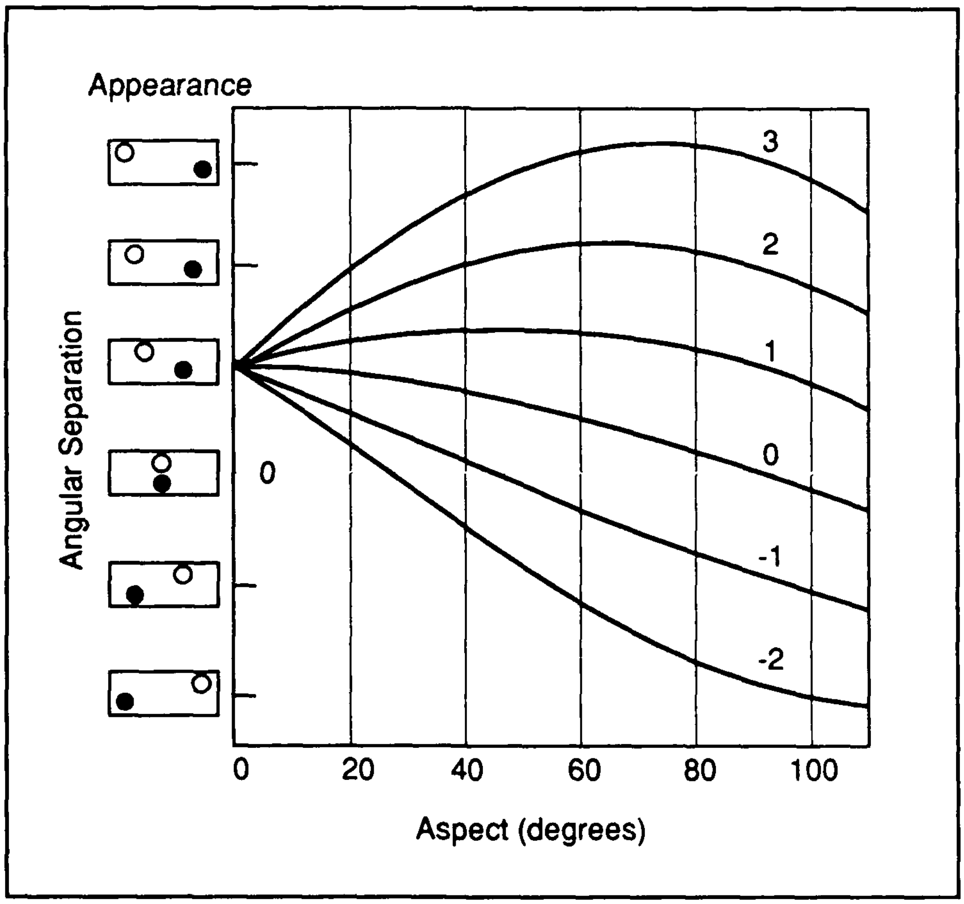

Figure 8. Mast/Side Light Separation

Figure 8 shows the angular separation between the sidelight and the masthead light at various aspects. Each curve represents the horizontal separation for a particular position ratio, labeled as the parameter of each curve. Note that we have only represented a small set of the infinite number of possible curves. Also, the ordinate values are not provided since we are representing relative separations. The ordinate must be scaled appropriately for any particular combination of distance to the oncoming vessel and **w**. When scaled, however, the relationship between curves and the intersection of each curve with the line representing a zero separation do not change.

This figure indicates that a particular horizontal separation between sidelight and masthead light does not provide sufficient information to determine the size, aspect or course of the vessel since an infinite number of configurations, sizes and distances could yield identical separations. A particular angular separation could correspond to two very different aspects.

7.1 Improved Lighting Configurations

While the current lighting regulations require configurations that provide little information about the size, aspect or course of oncoming vessel, we believe improvement is possible. The principal change necessary to make the navigation lights better tools for determining size, aspect, and course of oncoming vessels is to be more specific in the requirements governing placement. Two conceptual lighting configurations supporting this point are provided as Figures 9 and 10.

Figure 9 shows a vessel where the masthead light is aft of the sidelights. By fixing the ratio $R=l/w$, where l and w are as shown on the figure, a particular angle exists where the two lights are in vertical alignment. If vessel aspect is greater than this angle, the masthead light appears aft of the sidelights, or conversely, if the aspect is less than this angle the masthead light appears forward of the sidelights. The angle at which the lights are in vertical alignment varies inversely with R; alignment occurs at smaller angles as R increases. This configuration of lights has the advantage that, if the masthead light is seen to be forward of the sidelight, a mariner knows for certain that the aspect or course is less than some angle which is determined by R. The relationship between R and the angle where the lights are aligned does not depend on the distance to an oncoming vessel.

Figure 10 shows a vessel with all navigation lights on the centerline. If the distance, l, between the sidelights and masthead light is fixed then all vessels at a particular distance and aspect will show identical patterns of lights. Moreover, as aspect increases the separation of the sidelight and masthead increases monotonically between an aspect of 0 and 90 degrees.

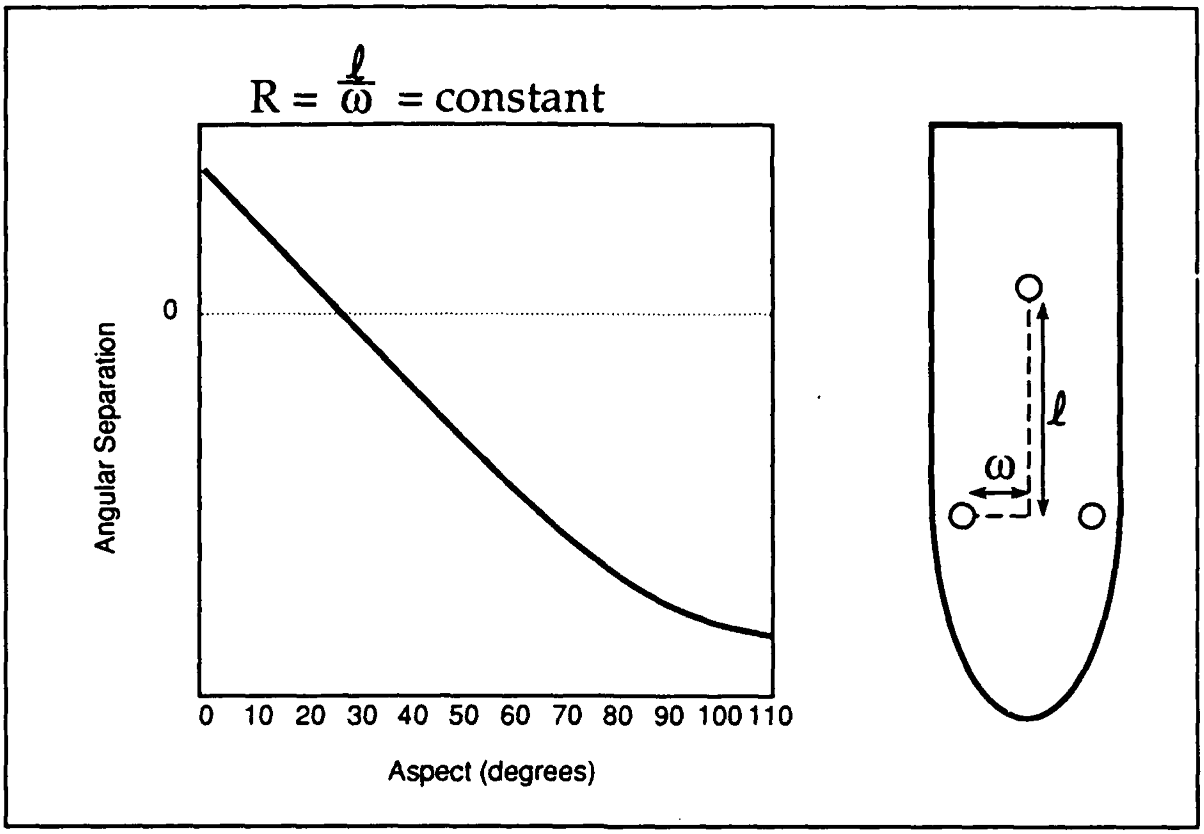

Figure 9. Configuration 1

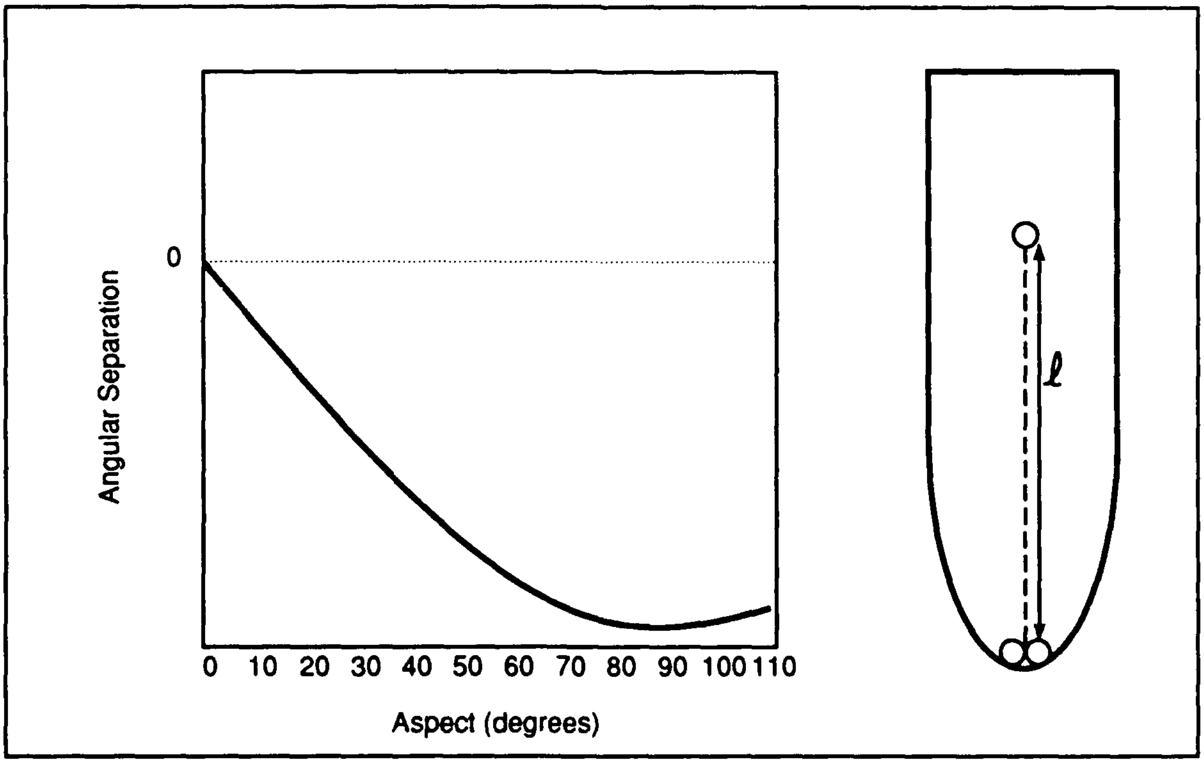

Figure 10. Configuration 2

This configuration has the advantage that masthead and sidelight act as a range, a scheme that has been shown to yield very sensitive judgments. However, for a mariner to fully exploit the course or aspect information in the manner just described, he must have some idea of the distance to the oncoming vessel.

7.2 *Absolute vs Relative Positioning*

In this study we addressed the issue of placing the masthead light forward of the sidelights but we did not specifically investigate the requirement that the masthead light be placed forward of amidships. Based on the results of our efforts to date, we have some reservations about the usefulness of this requirement.

If, as in the circumstances simulated in these experiments, the hull of the vessel is not visible, the only information available to the mariner is obtained from the navigation lights. Since the forward light is presently allowed to vary in location along 50% of the vessel, little information is provided about the forward part of the vessel that is not already provided by the color of the sidelight currently in view.

If additional hull or deck light information about the vessel is present, we believe that the size, aspect, and course information provided by visual cues other than the navigation lights will provide more useful information than navigation lights alone.

8.0 CONCLUSIONS

Judgments regarding size, aspect or course of an oncoming vessel are very difficult if the sidelights are the only source of information about the activity of the vessel. Permitting the forward masthead light to be positioned aft of amidships and aft of the sidelights does not affect mariners' abilities to judge aspect or course. Constraining the relationship between masthead and sidelights has the potential to enhance greatly the accuracy of observer judgments.