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THESIS

A CHARACTERIZATION OF SWAY FORCES INDUCED BY CLOSE PROXIMITY SHIP TOWING

by

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March 2002

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The scope of this thesis is to characterize the connection forces in the horizontal plane of surface ships in close proximity towing in waves. Strip theory calculations are used in order to predict the hydrodynamic coefficients and wave exciting forces and moments in sway and yaw. The resistance-speed characteristics of the leading ship are used to provide the matching condition between the two ships. The two-parameter Bretschneider spectrum is used to model the sea environment. Results are presented in terms of speed polar and sea state polar plots. An extensive set of parametric studies is presented in regular waves as well as in a wide variety of sea states.

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A CHARACTERIZATION OF SWAY FORCES INDUCED BY CLOSE PROXIMITY SHIP TOWING

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ABSTRACT

The scope of this thesis is to characterize the connection forces in the horizontal plane of surface ships in close proximity towing in waves. Strip theory calculations are used in order to predict the hydrodynamic coefficients and wave exciting forces and moments in sway and yaw. The resistance-speed characteristics of the leading ship are used to provide the matching condition between the two ships. The two-parameter Bretschneider Spectrum is used to model the sea environment. Results are presented in terms of speed and sea state polar plots. An extensive set of parametric studies is presented in regular waves as well as in a wide variety of sea states.

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TABLE OF CONTENTS

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LIST OF FIGURES

I. INTRODUCTION

A. PROBLEM STATEMENT

This study is a continuation of the work done previously by LT Christopher Nash for evaluating the feasibility of high-speed close proximity towing. His work evaluated the interaction forces due to random seas for the vertical plane forces, heave and pitch. The goal of this study is to utilize the same foundation provided by LT Nash and to apply it to the horizontal plane forces, sway and yaws. Such interaction forces have caused great concerns for personnel, equipment, and safe sea keeping, not only for conventional towing, but also for towing operations conducted by the U. S. Navy. "Snap back" is the general term used by the U. S. Navy to describe, in essence, a line breaking and whipping back. Normally, such phenomena occur during mooring and underway replenishments operations. However, high magnitude forces caused by random waves can result in peak amplitudes that can either snap the towline and/or damage or uproot attached equipment or solid foundation. Conventional towing hampers sea keeping at sea, but more profoundly in constrained waterways where maneuverability is a necessity. The purpose of this study is to verify if the magnitude of the horizontal plane force is significant or negligible during high-speed, close proximity towing. Horizontal plane forces may affect vertical motions and vice versa. This will help determine whether or not a coupled approach is required for both horizontal and vertical plane forces when evaluating the notional tow connection. The continued development for a notional tow connection for high-speed, close proximity towing will help resolve the issues of a viable alternative to the cumbersome conventional towing methods currently used today.

B. RESEARCH APPROACH

The data files for the platforms, KAIMALINO and SLICE, and MATLAB code used by LT Nash will be utilized in this study. The MATLAB code will be modified to evaluate the behavior of the connection force due to the horizontal plane force. The connection force will first be evaluated in regular waves to establish its relationship to irregular wave motion in order to use theoretical or experimental spectral analysis of waves (Zubaly).

1. Background

LT Nash developed the MATLAB code used to evaluate the individual ship motions (KAIMALINO AND SLICE), i.e., to calculate vessel interactions, and to predict regular and random wave responses of the notional tow. SLICE modeling data was established by D. B. Lesh, which was incorporated in the combination model of both SLICE and KAIMALINO. The modeling data for KAIMALINO was developed and verified by LT Nash. Utilizing a commercial FORTRAN based, SHIPMO, code, LT Nash achieved a suitable model for evaluating the integrated towing unit. In essence, strip theory calculations of the integrated towing unit motions can now be achieved as an individual ship. Using Linear Superposition, standard sea keeping analysis allows the motions of a body to be looked at separately; in this case, only sway and yaw. Linear Superposition will be applied to the six degrees of freedom equations in order to decouple the motions.

II. MODELING

A. OVERVIEW

Motion of a rigid body in 3-D space can be described in 6 degrees of freedom. Three translational (surge, sway, heave), and three rotational (roll, pitch, yaw) displacements are required (Nash). The diagram below illustrates these motions.

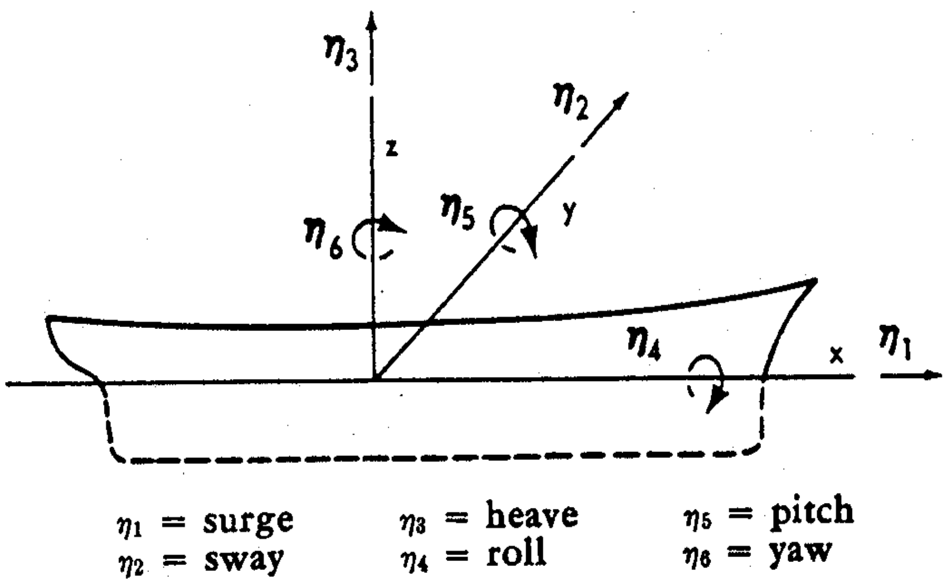

Figure 1. Ship’s motion in six degrees of freedom.

A ship’s motion can be shown using a standard coordinate system where plane progressive waves of amplitude A and direction theta are incident upon a body, which moves in response to these waves. In general, these motions can be described in six degrees of freedom system.

B. SHIP MOTION IN REGULAR WAVES

1. Background

The model of the integrated tow unit, KAIMALINO AND SLICE, motion in waves will be used in this study to formulate the equation of motion with horizontal plane forces only. The following symbols are used to describe a ship's motion in a body reference frame (Nash).

Displacement	Velocity	Acceleration
$\eta_1 - surge$	$\dot{\eta}_1 - surge, vel$	$\ddot{\eta}_1 - surge, accel$
$\eta_2 - sway$	$\dot{\eta}_2 - sway, vel$	$\ddot{\eta}_2 - sway, accel$
$\eta_3 - heave$	$\dot{\eta}_3 - heave, vel$	$\ddot{\eta}_3 - heave, accel$
$\eta_4 - roll$	$\dot{\eta}_4 - roll, vel$	$\ddot{\eta}_4 - roll, accel$
$\eta_5 - pitch$	$\dot{\eta}_5 - pitch, vel$	$\ddot{\eta}_5 - pitch, accel$
$\eta_6 - yaw$	$\dot{\eta}_6 - yaw, vel$	$\ddot{\eta}_6 - yaw, accel$

2. Overview

The KAIMALINO/SLICE model was developed with the understanding that a ship's response can be complicated due to the interactions between a ship's dynamics and several distinct hydrodynamic forces (Lewis). The assumption of linearity for the ship's response will be used in order to analyze a model's response. Consequently, for an arbitrarily shaped vessel, six non-linear equations of motion, with six unknowns, must be set up and solved simultaneously (Lewis). Previous studies have shown that response can be reduced into a Newtonian spring-mass-damper form that is frequency dependent (Nash). Further, in the case of slender hulls and moderate sea states the six non-linear equations reduce to two sets of three uncoupled equations (Lewis).

Vertical plane motions (surge, heave, pitch) are decoupled from the transverse motions (sway, roll, yaw).

Given the simple model below, a ship's interaction with a given seaway can be describe similarly to a spring-mass damper system (Nash):

$$[M]\ddot{\vec{\eta}}+[B]\dot{\vec{\eta}}+[C]\vec{\eta}=[F_{ex}]$$

[M] = Mass of vessel and moments of inertia. (6x6)

[B] = Hydrostatic damping, due to energy dissipated in wave making. (6x6)

[C] = Restoring force and moment constants due to buoyancy. (6x6)

$[F_{ex}]$ = Excitation forces and moments from seaway.

A more complete equation of motion is given by the following (Nash):

$$[M]\ddot{\vec{\eta}}+[B]\dot{\vec{\eta}}+[C]\vec{\eta}=[F_{ex}]$$

[M] = [m+A] (6x6)

[B] = Hydrostatic damping, due to energy dissipated in wave making.

[C] = Restoring force and moment constants due to buoyancy.

$[F_{ex}] = [f_k + f_{diff}]$ (6x1)

where the elements of the matrices are solved analytically with strip theory.

Finally, the sway and yaw equation of motion were written in the frequency domain. This allows more accurate prediction of motions in waves for any given forward speed and wave angle. Since linear theory requires that vessel response be directly proportional to wave amplitude at the perceived frequency of incident waves, for regular waves, the vessel motions will be sinusoidal (Nash).

B. SWAY/YAW EQUATIONS OF MOTION

$$A_{22}\eta_2 + A_{26}\eta_6 = F_2 + f$$
$$A_{62}\eta_2 + A_{66}\eta_6 = F_6 + fx,$$
$$A_{22} = -\omega_e^2(M_{22} + A_{22}) + i\omega_e B_{22} + C_{22}$$
$$A_{26} = -\omega_e^2(M_{26} + A_{26}) + i\omega_e B_{26} + C_{26}$$
$$A_{62} = -\omega_e^2(M_{62} + A_{62}) + i\omega_e B_{62} + C_{62}$$
$$A_{66} = -\omega_e^2(M_{66} + A_{66}) + i\omega_e B_{66} + C_{66}$$

The equations of motion for sway and yaw are similar to the heave and pitch equation of motions derived by LT Nash. Therefore, we have the following equations

for each of the two ships:

where,

ω_e = Frequency of encounter

η_2, η_6 = Complex sway and yaw amplitudes of motion

A_{ij} = Added mass term

F_2, F_6 = Waves exciting forces

f = Horizontal connection force

B_{ij} = Hydrostatic damping, due to energy dissipated in wave making

C_{ij} = Restoring force and moment constants due to buoyancy

M = inertia and cross coupling terms

C. SIMPLIFICATION OF EQUATION OF MOTIONS

The motions due to regular waves of a given wavelength and direction were determined for the integrated tow vessel with forward speed (V) by LT Nash. The derived equations decoupled Transverse and longitudinal motions. Instead of solving a 6x6 system, it can now be reduced as two distinct 3x3 systems, namely heave and pitch & sway and yaw. Heave and pitch will be neglected. Also, Surge motion may also be neglected because in long, slender ships, surge effects are small relative to heave and pitch (Zubaly). To simplify the equations of motion, all motions except η_2 and η_6 are set to zero. The expanded equations of motion in two degrees of freedom become:

$$\begin{array}{l} \text{sway} - \\ \text{yaw} - \end{array} \begin{bmatrix} \bar{A}_{22} & \bar{A}_{26} \\ \bar{A}_{62} & \bar{A}_{66} \end{bmatrix} \begin{bmatrix} \eta_2 \\ \eta_6 \end{bmatrix} = \begin{bmatrix} F_2 + f \\ F_6 + fx \end{bmatrix}$$

D. COUPLING

The complex sway and yaw amplitudes of motion, η_2 & $\eta 6$, are derived similarly to the mathematical procedure derived by LT Nash. The net equation is given below:

$$\eta_2 = \mu_2 - f\nu_2$$
$$\eta_6 = \mu_6 - f\nu_6$$

where,

μ = motion due to the excitation force

ν = motion due to the connection force

By using Cramer's Rule and the assumption of a unit connection force, f, η_2 and η_6 can be solved in terms of f. Using the solution given by LT Nash for the connection points, the horizontal motions at the connections points are given by,

$$\xi = \eta_2 + \eta_6 x$$

where,

ξ = the integrated tow motion (SLICE AND KAIMALINO).

By assuming a theoretical relationship between the connection force and difference in absolute motion, a generic spring-damper interface is inserted and the matching condition simplifies the amplitude equation, and thus allowing the connection force to be solved as given below:

$$f = T\frac{\xi_S - \xi_K}{l}$$

Therefore, the connection force can now be evaluated.

E. REGULAR WAVE RESULTS

The Matlab code developed by LT Nash was utilized and updated to evaluate the horizontal plane force as a total connection force in a non-dimensionalized term, F_H. The regular wave results were generated via parametric runs in terms of ship speed, heading, and connection length of the tow. Conveniently, figure (2) and (3) are provided below to show the general relationship between the three parameters listed above.

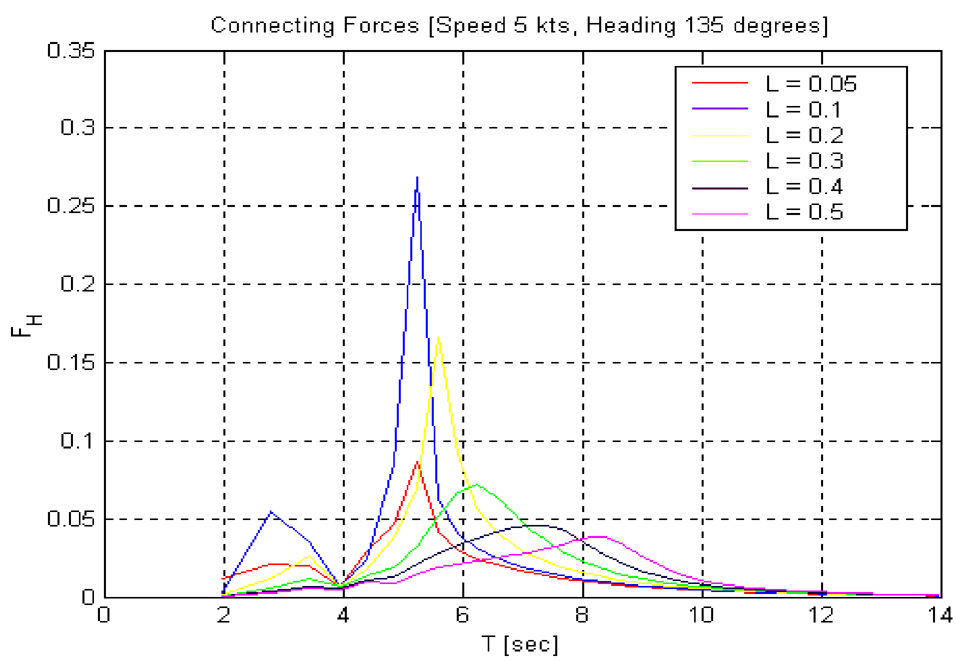

Figure 2. Connection Forces [Speed 10 kts, Heading 135 degrees]

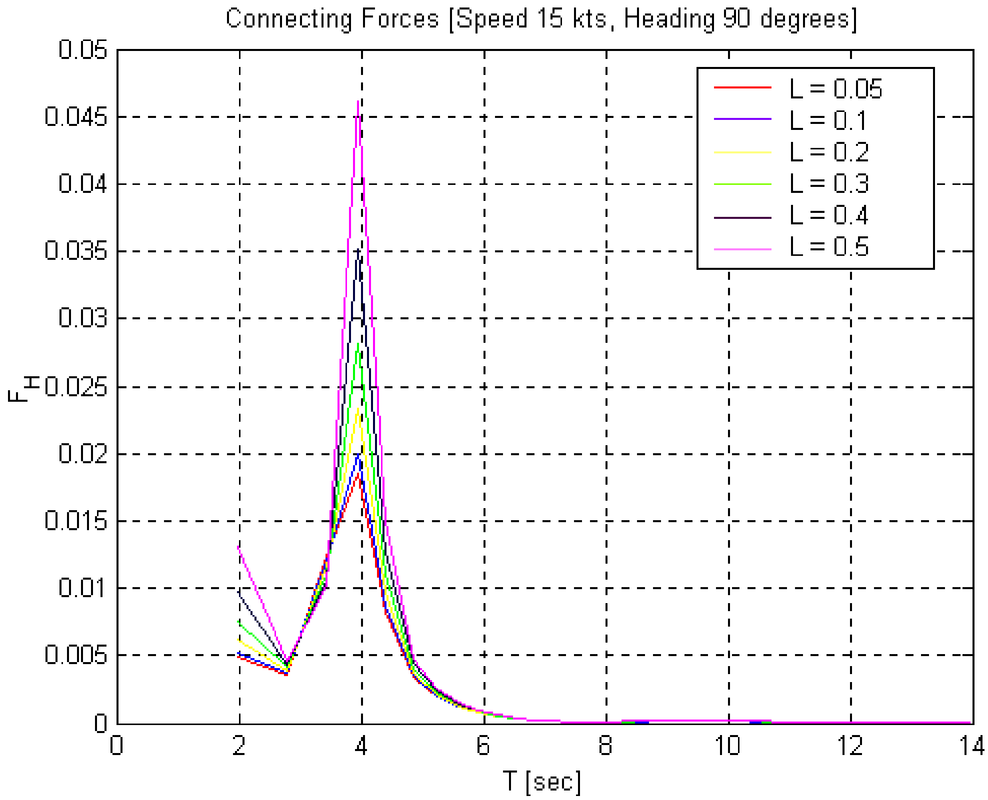

Figure 3. Connection Forces [Speed 10 kts, Heading 90 degrees]

From Figure (2) and (3), one can see that the forces can be highly resonant. The magnitude and the location of the resonant peak is very sensitive to the connection tow length and wave heading (directionality). The location of the peak is less sensitive to speed. Furthermore, there is no conclusive patterns to show that the one parameter changes consistently with the other. The directionality does play a factor, which in combination with changes in speed, show multiple resonant peaks especially at the beam and quartering seas. Regular waves are simple sinusoidal waves. With directionality, there are multiple peaks. In view of this, the response in random waves must be evaluated.

F. SHIP MOTION IN RANDOM WAVES

Based on the results from the regular waves, resonant peak magnitude and location is a strong function of frequency. Therefore we must keep the predominant wave frequency as part of the random wave results. We must use at least a two-parameter spectrum. LT Okan and LT Nash used the Pierson-Moskowitz Spectrum.

This spectrum represents sully-developed seas and is a special case of the Bretschneider formulation. The Pierson-Moskowitz spectrum underestimates the peak frequency for the higher spectra and conversely the smaller waves (Lewis). Figure (4) shows typical spectra based on the wind speed. By using the Bretschneider spectrum, the significant wave height and modal frequency are used to represent a wide range of single peaked wave spectra. This spectrum will allow more accurate results.

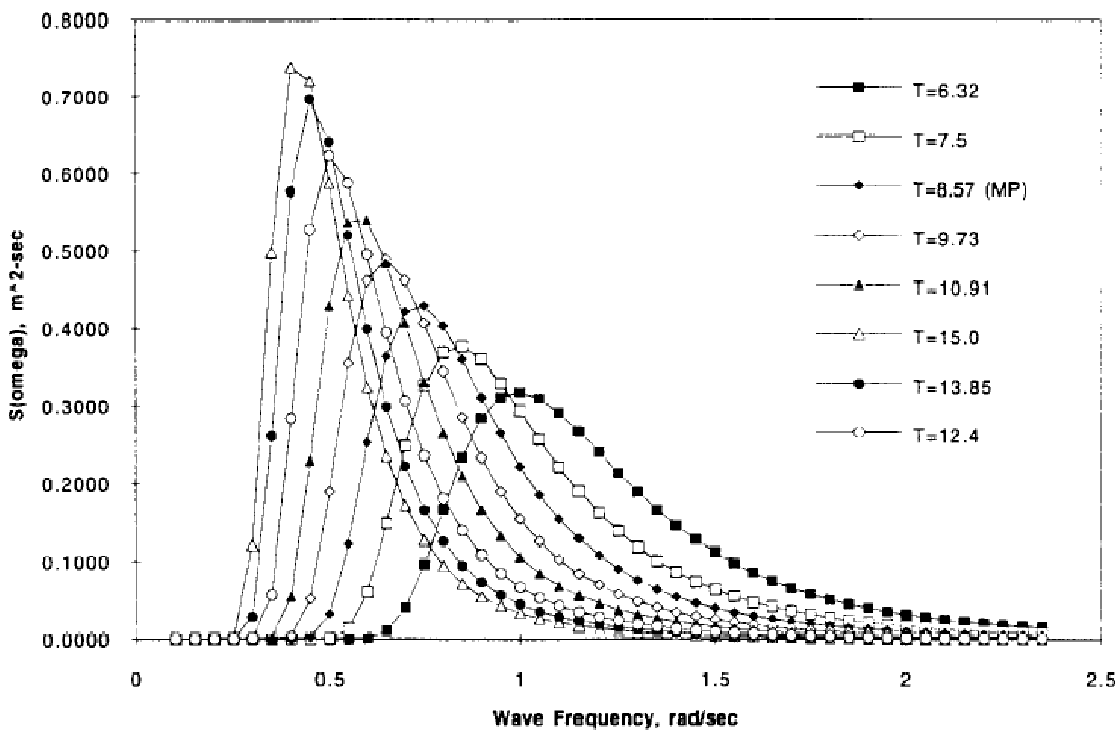

Figure 4. A range of Bretschneider spectra from a mid Sea State 4

The Bretschneider Spectrum, in general, will provide a visual picture of the total energy contained in the seaway and how it is distributed over the frequency range. Figure (5) is the Sea State Table for the General North Atlantic. The Significant Wave Height (SWH) is defined as the average of the highest 1/3 of the amplitudes of the response (Lewis). The Matlab code utilized by LT Nash will be modified to include the Significant Wave height (both minimum and maximum wave height) and the average modal period.

Sea State	Significant Wave Height (m)	(ft)	Modal Period Range (sec)	Most Probable Modal Period (sec)	Sustained Wind Speed (kts)
0-1	0-0.1	0-0.33	-	-	0-6
2	0.1-0.5	0.33-1.64	3.3-12.8	7.5	7-10
3	0.5-1.25	1.64-4.10	5.0-14.8	7.5	11-16
4	1.25-2.5	4.10-8.20	6.1-15.2	8.8	17-21
5	2.5-4.0	8.20-13.12	8.3-15.5	9.7	22-27
6	4.0-6.0	13.12-19.69	9.8-16.2	12.4	28-47
7	6.0-9.0	19.69-29.53	11.8-18.5	15.0	48-55
8	9.0-14.0	29.53-45.93	14.2-18.6	16.4	56-63
>8	>14.0	>45.93	15.7-23.7	20.0	>63

Figure 5. Sea State Table for the General North Atlantic

G. RANDOM WAVE RESULTS

The results of the Random Waves are presented in polar grids. This will give us a 360-° aspect with the ship in the center. The angular coordinates is the heading, where 0 corresponds to following (astern) seas and 180 to head (bow) seas. The radial coordinate is either the SWH or speed. The Modal period and the connection tow lengths are constant. The contours show constant connection force. Figure (6) and (7) are provided for general relationship between Sea State , speed, and directionality. Further graphs are provided in Appendix B for various speed and tow connection lengths. From Figure (7), the connection forces are most severe in the head quartering seas and 30° aft of beam. The radii rings are constant SWH, increasing outward with increasing sea state. Figure (8) shows that, once again, head quartering seas have higher connection forces, but decreasing as speed increases. The radii rings are constant speeds, increasing outward from 0 – 20 knots. All results are presented in terms of connection force Root Mean Square (RMS) values. The significant single amplitude of the response can be obtained by multiplying the RMS value by 2, while an 8-hour maximum value can be obtained by multiplying the RMS value by 4.

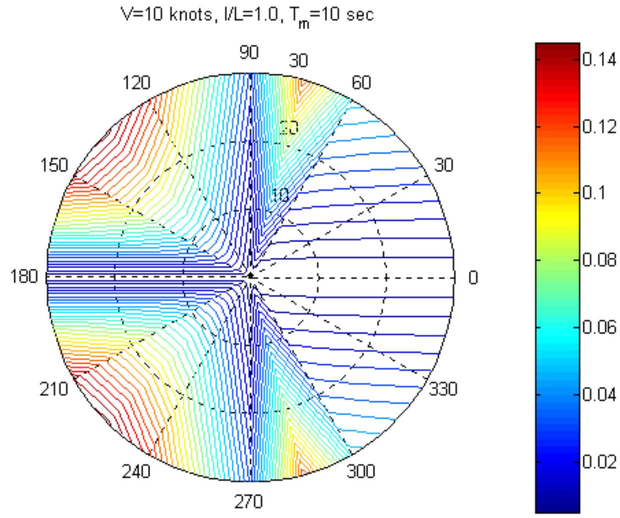

Figure 6. Sea State Polar Plot

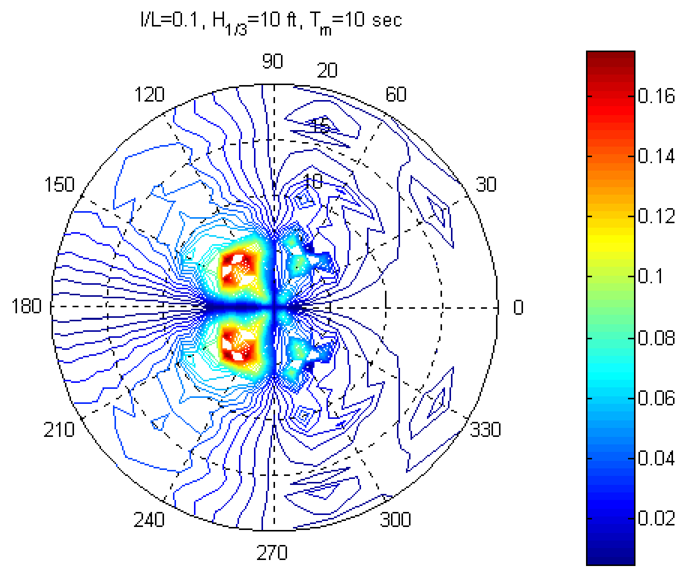

Figure 7. Speed Polar Plot

III. CONCLUSIONS AND RECCOMMENDATIONS

A. CONCLUSIONS

The Rand Wave Results showed that significant and highly resonant forces may develop in the horizontal plane due to close proximity coupling. Head quartering and aft of beam seas generate the highest forces. The connection force does not have a clear-cut trend, instead, it varies greatly with speed, directionality (heading), and the tow connection length. In general, the higher the ship's speed, the smaller the connection forces.

B. RECOMENDATIONS

Based on LT Nash's and my results, the study of the coupling of both horizontal and vertical plane force should be done. Random wave results should be extended to allow for short crested seas. This is expected to smooth out the sharp differences in the connection force magnitudes that are observed at beam seas.

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LIST OF REFERENCES

Lewis, E. V., "Principles of Naval Architecture, Volume III, Chapter III, 1989.

Nash, C. A., "Vertical Plane Response of Surface Ships in Close Proximity Towing," Naval Postgraduate School, Monterey, CA, June 2001.

Zubaly, Robert B., "Applied Naval Architecture," First edition, 1996.

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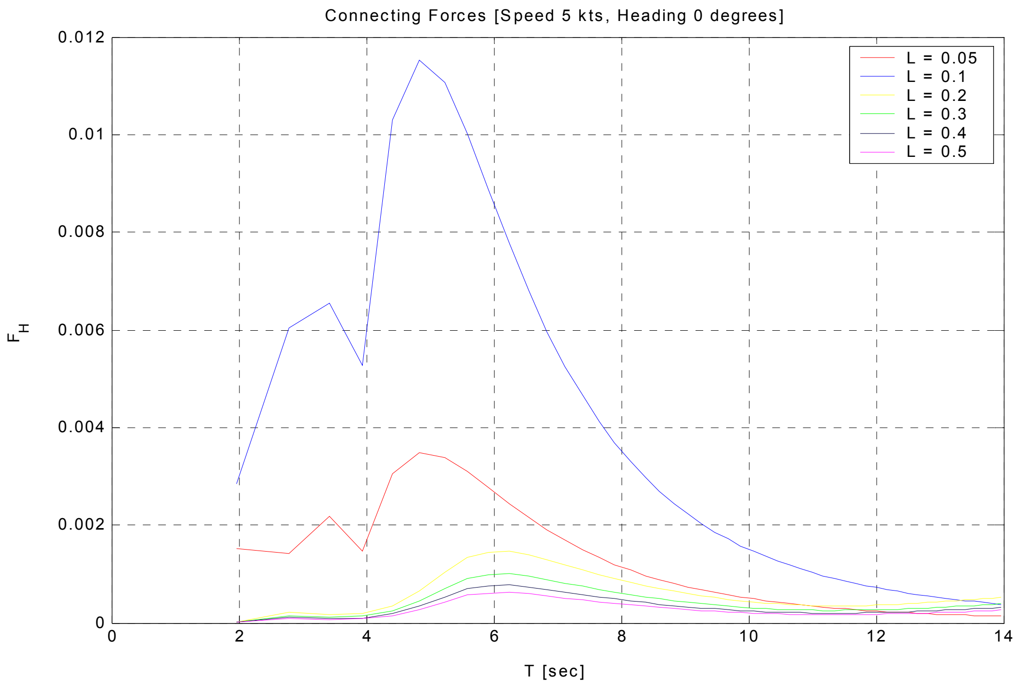
APPENDIX A



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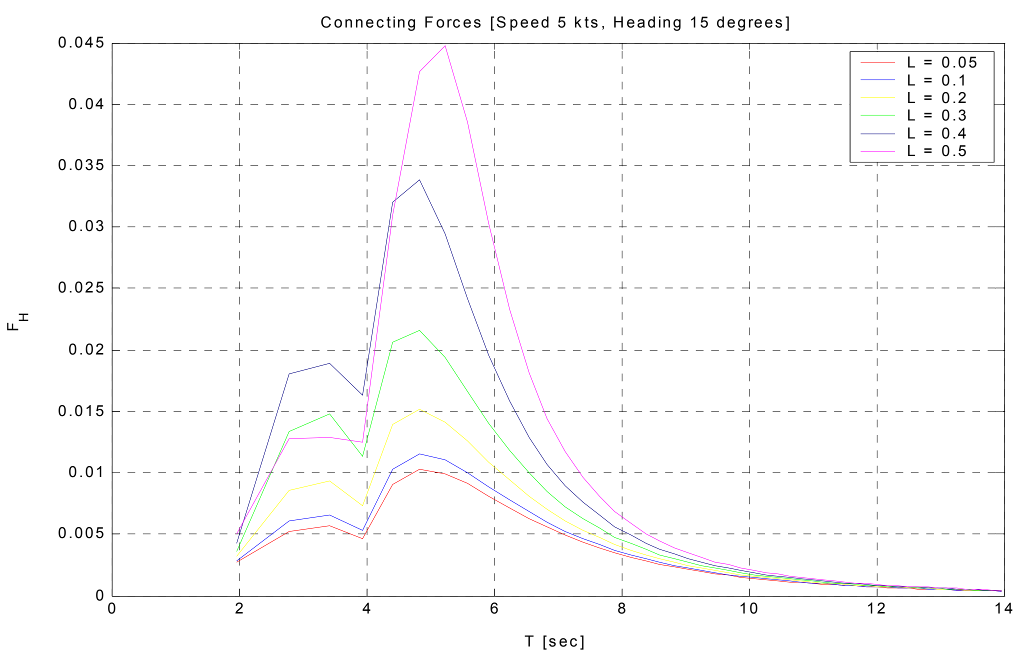

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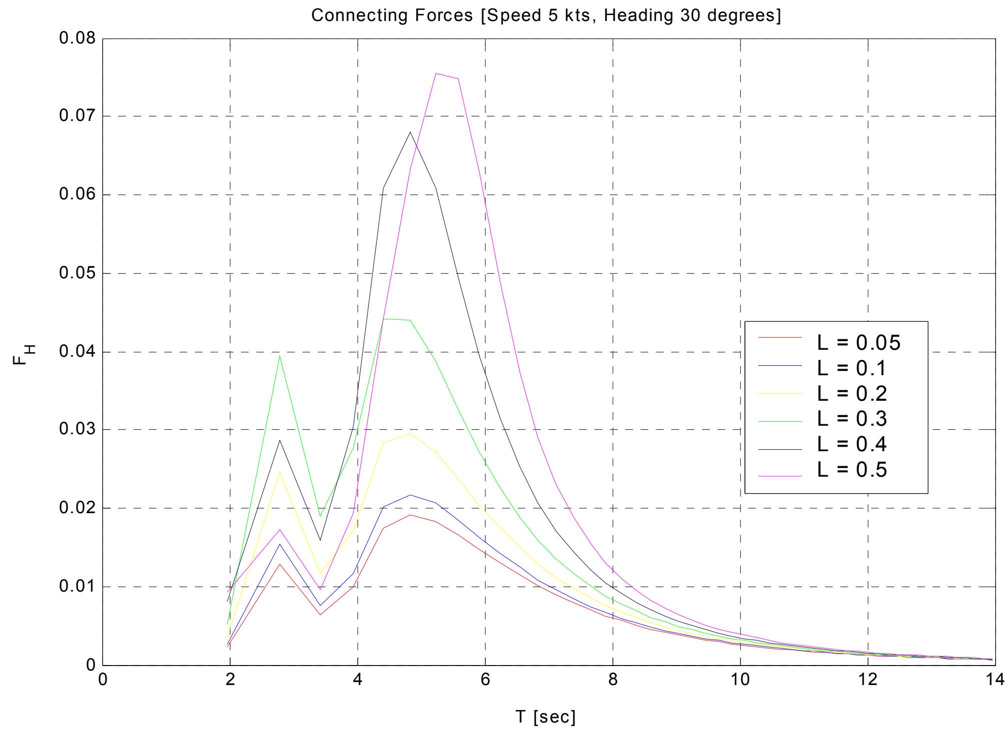

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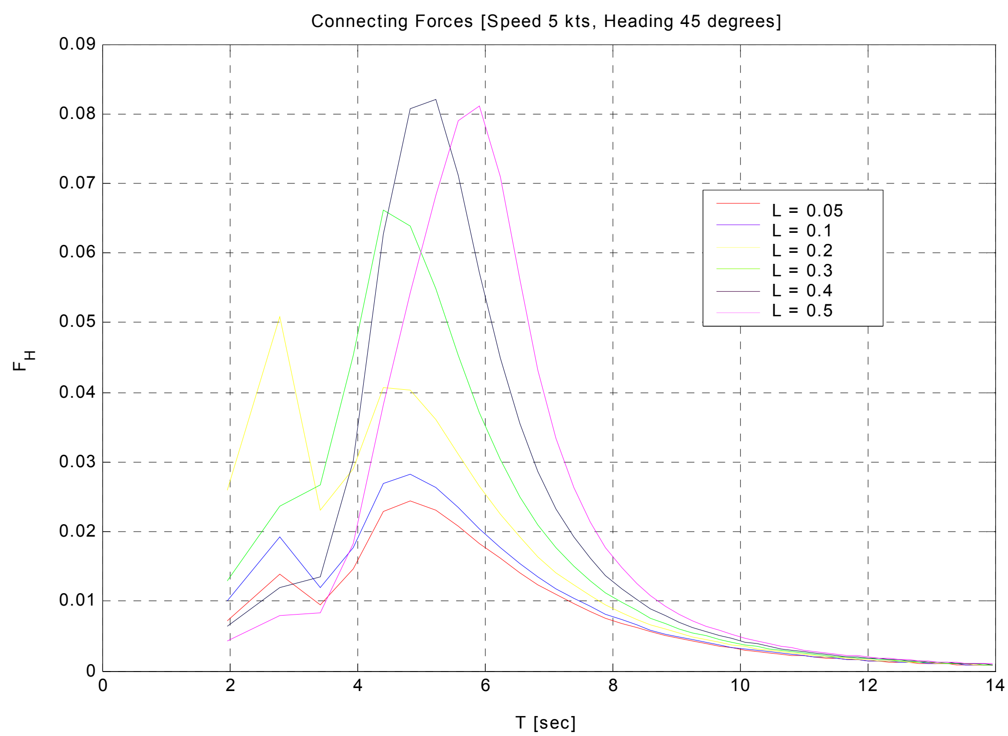

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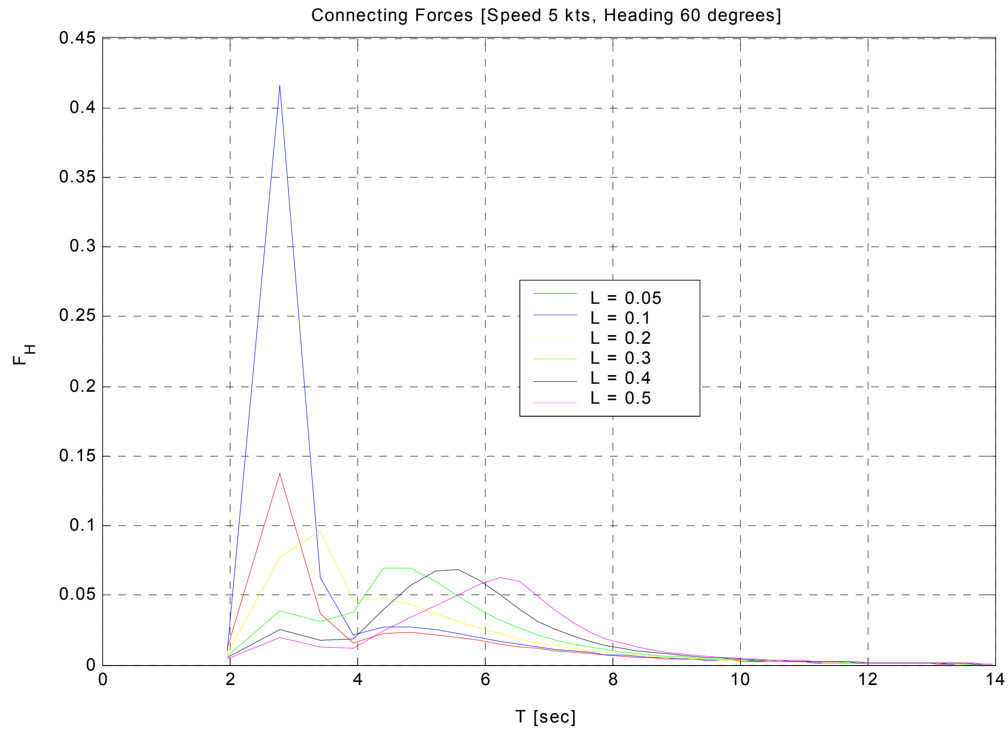

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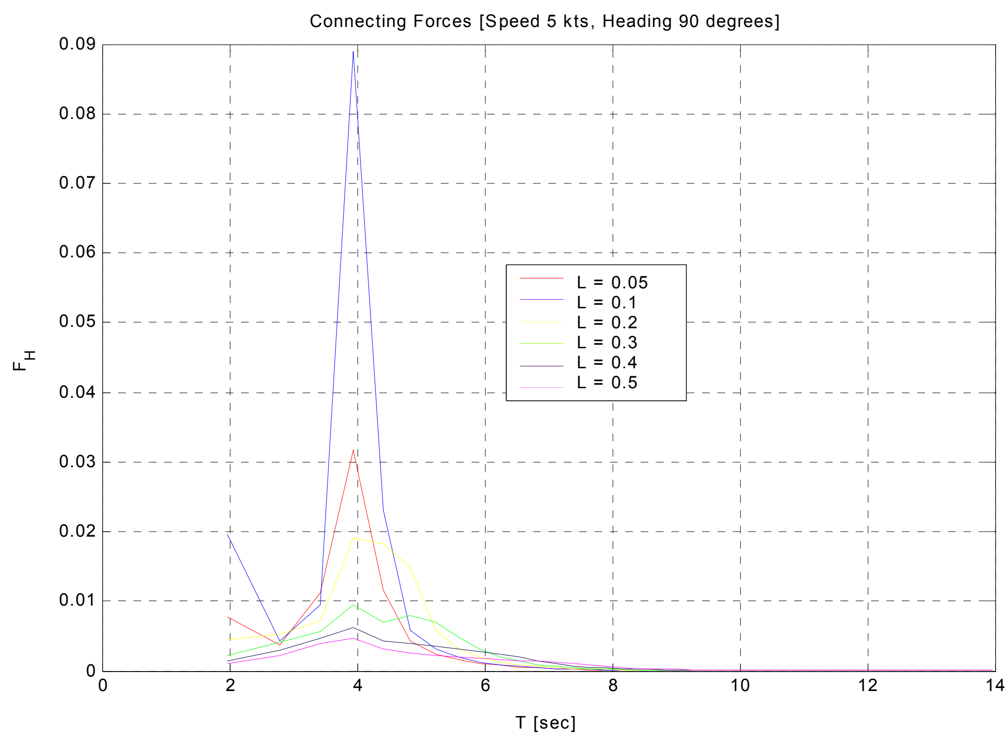

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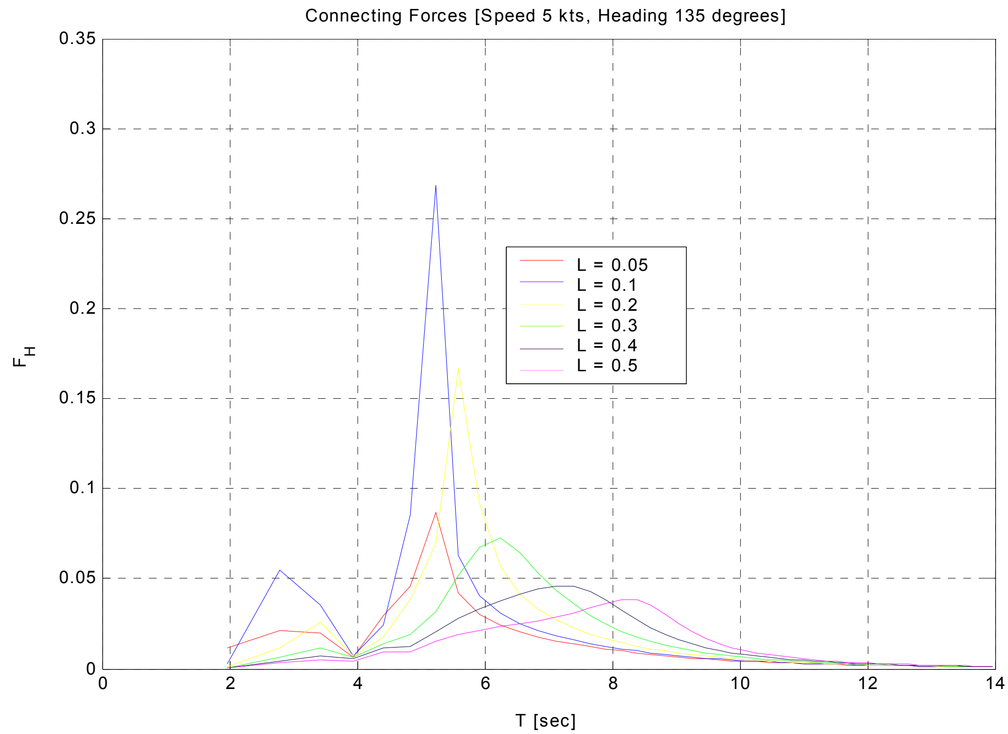

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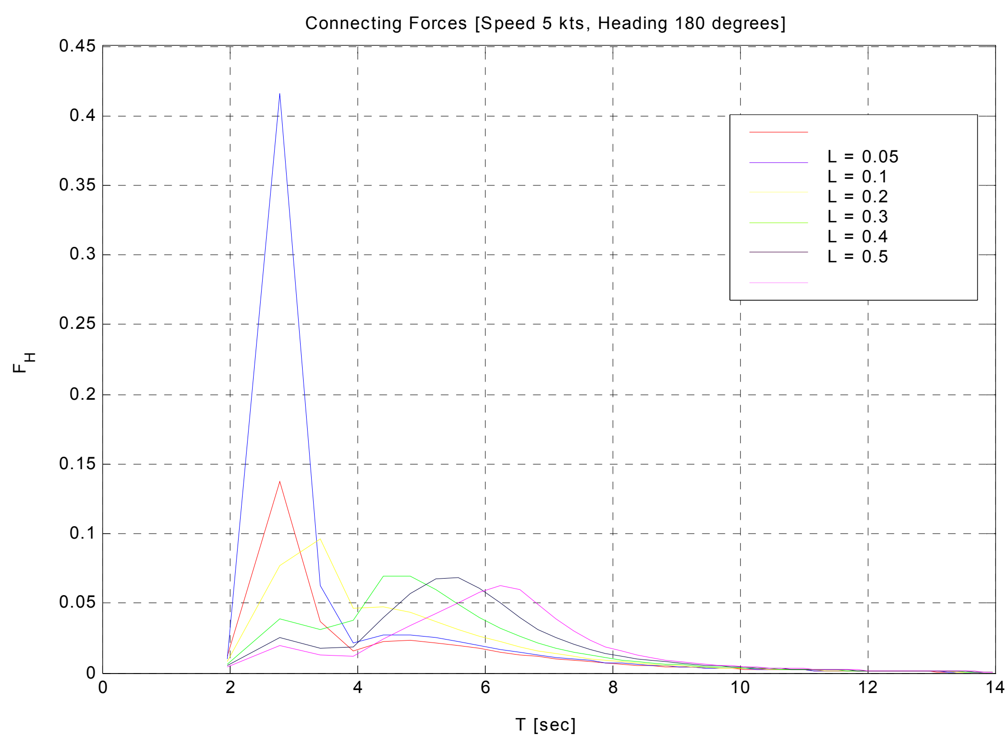

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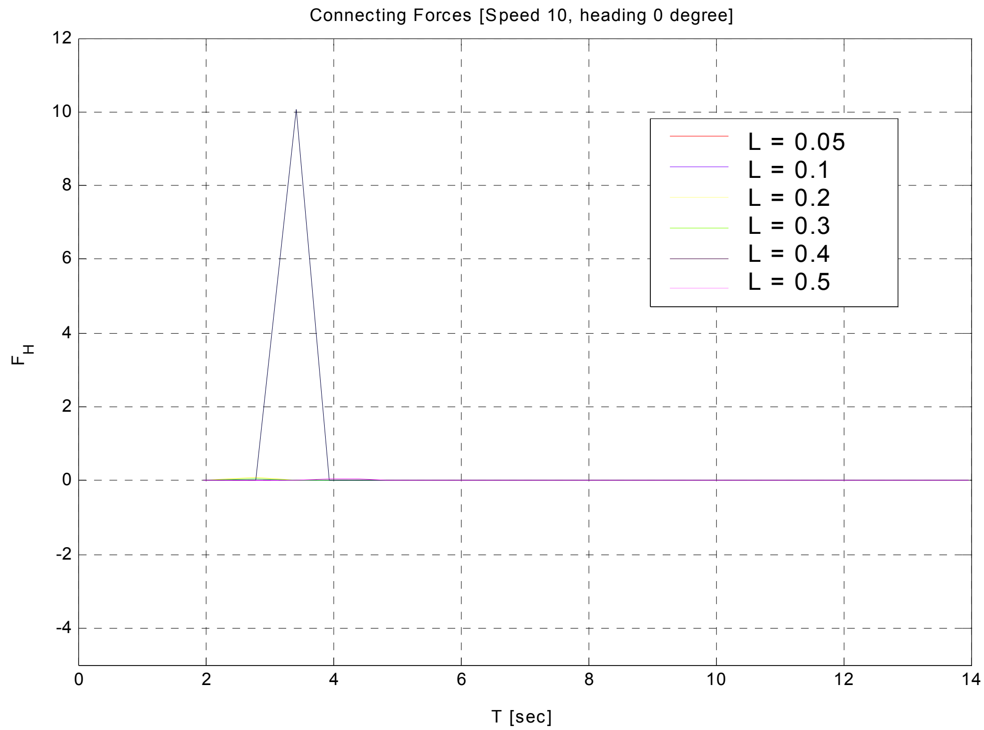

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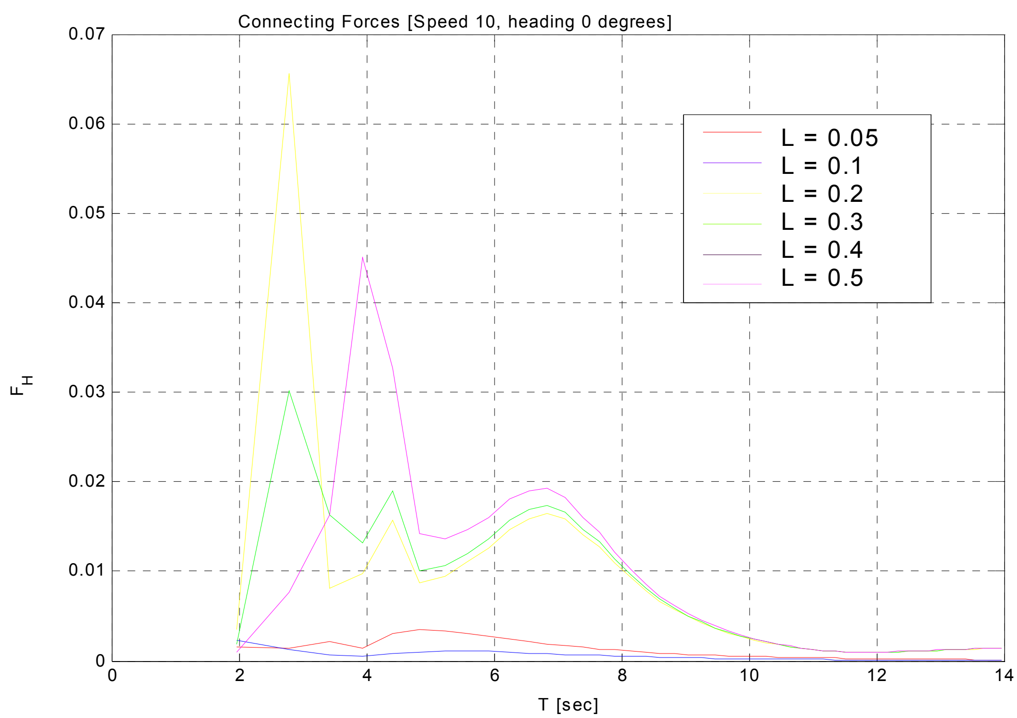

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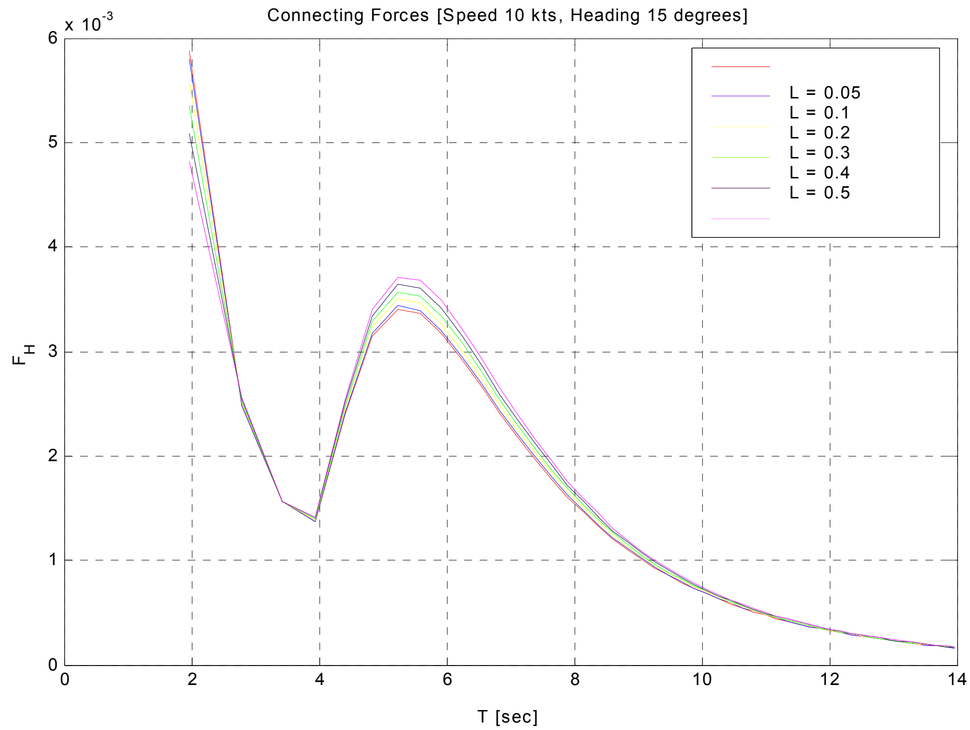

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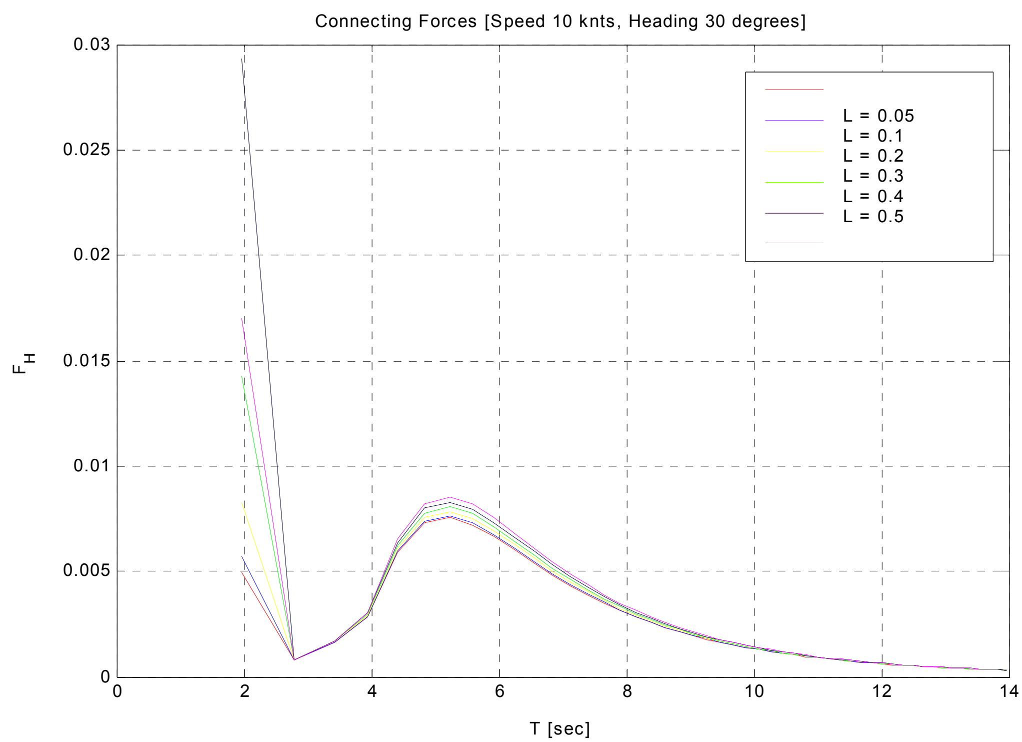

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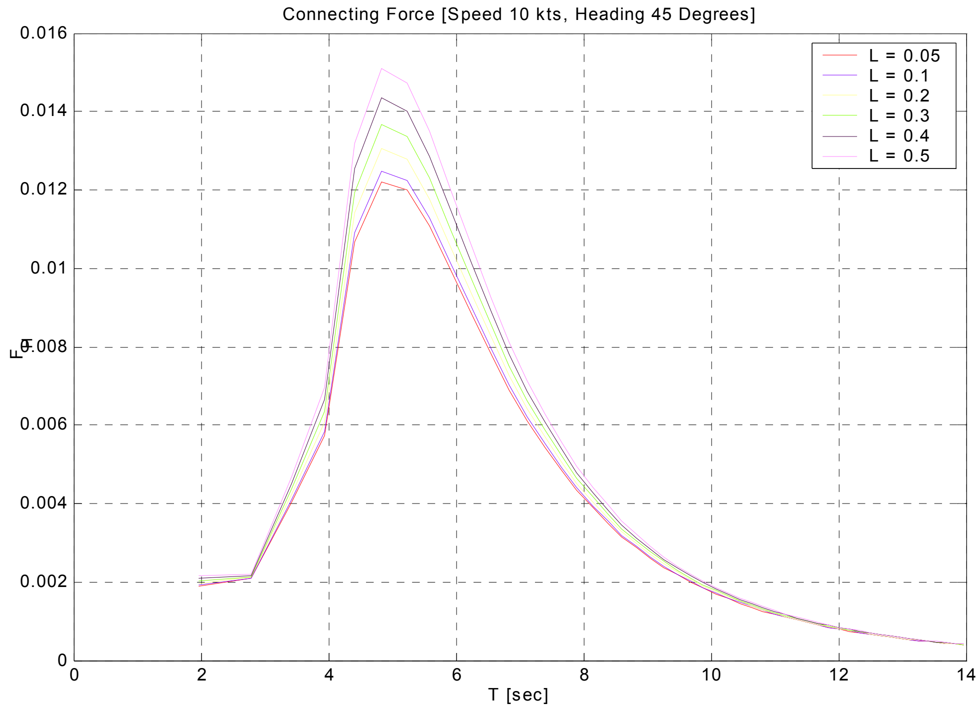

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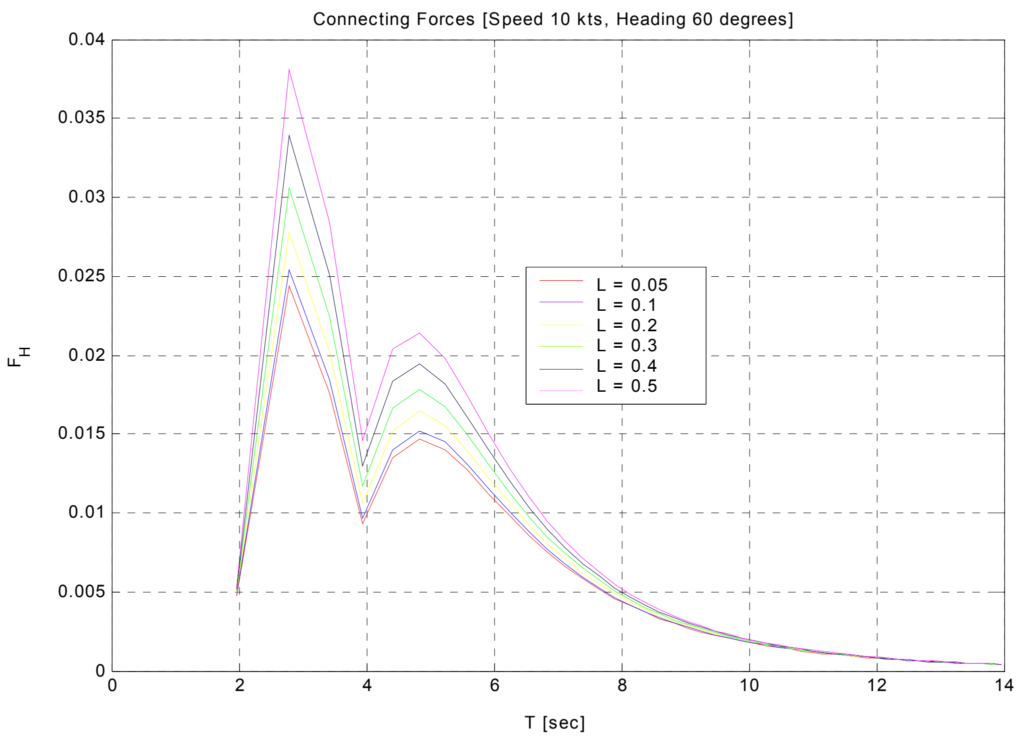

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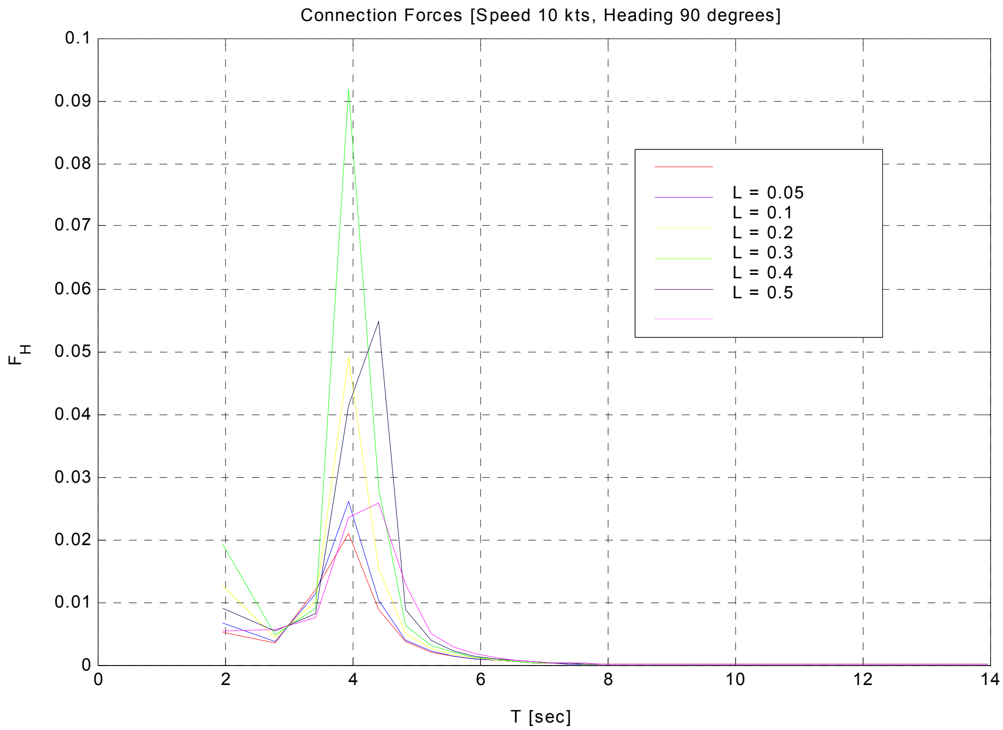

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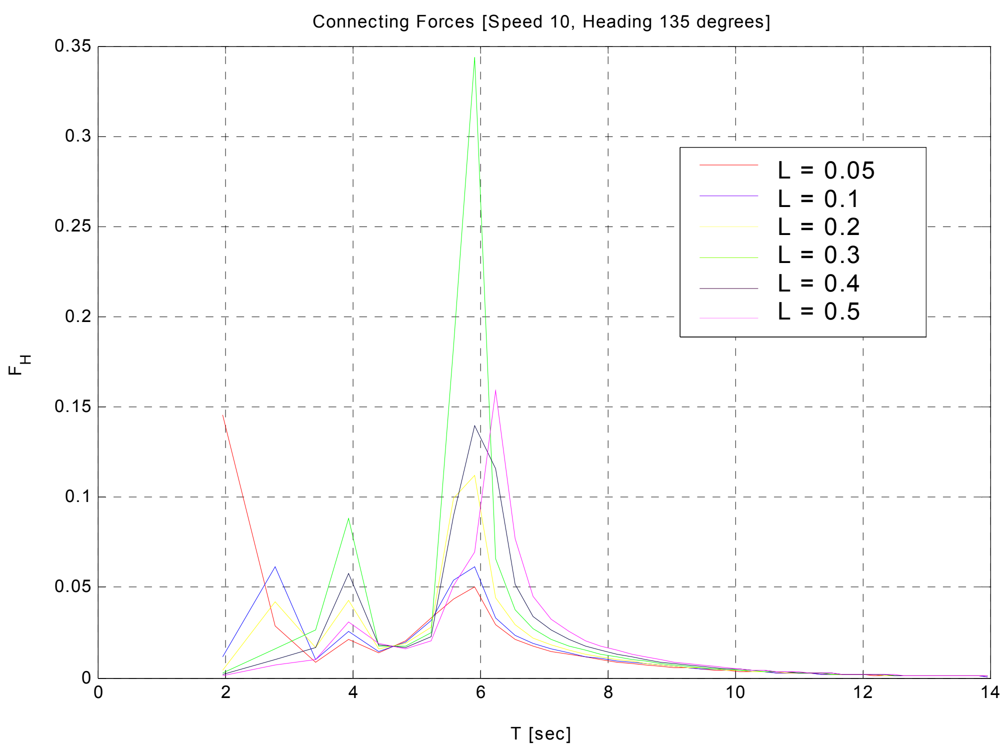

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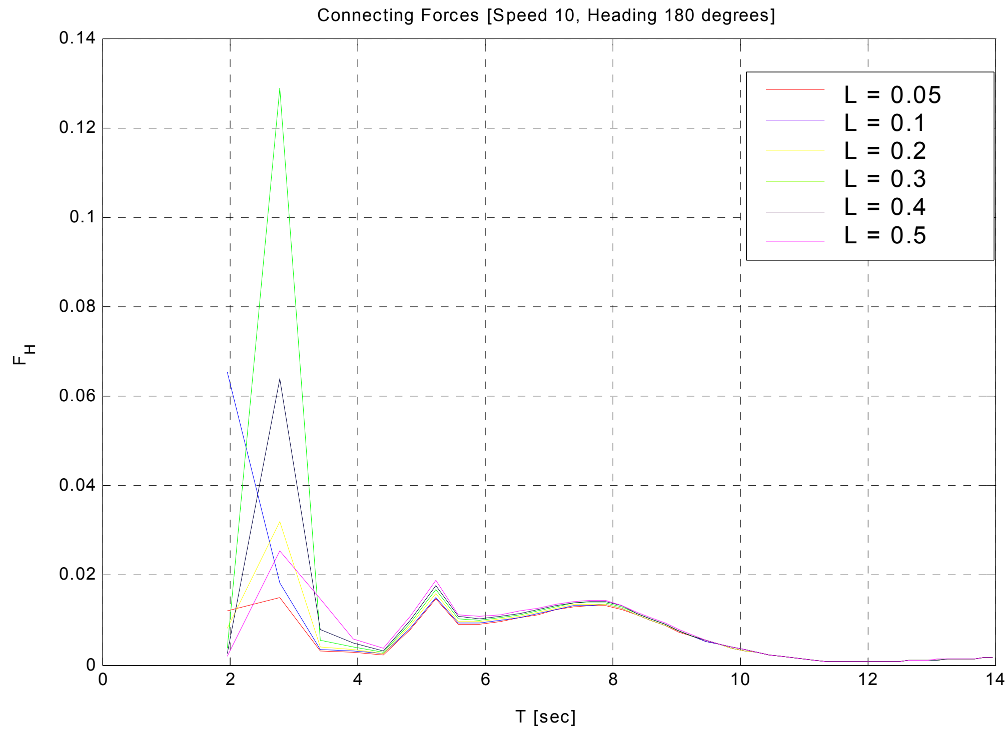

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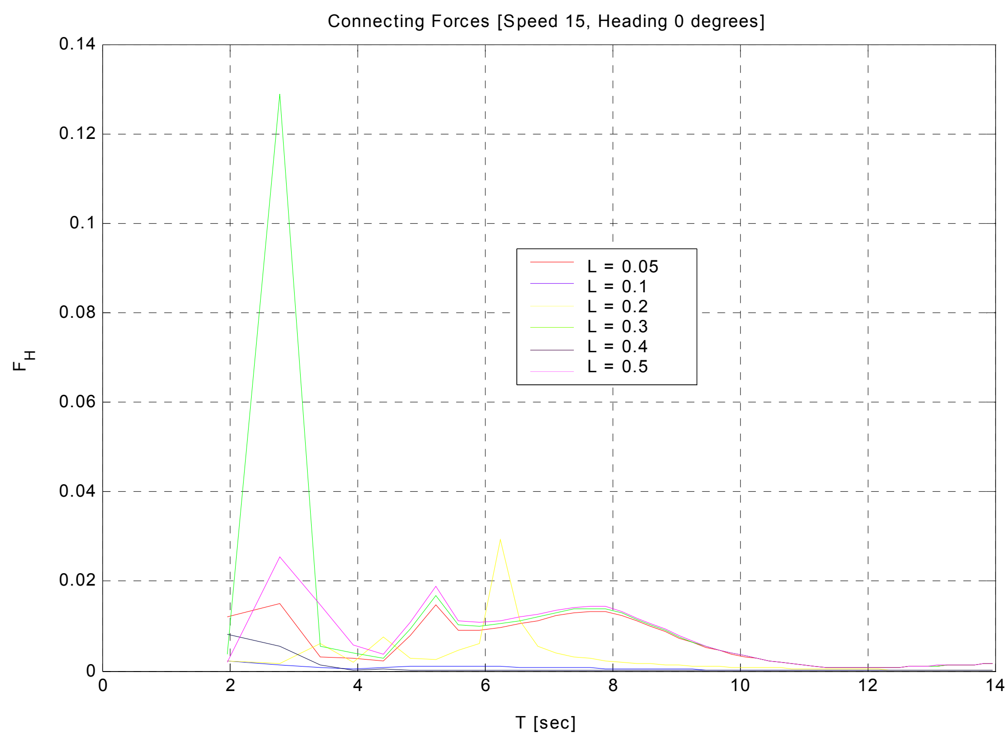

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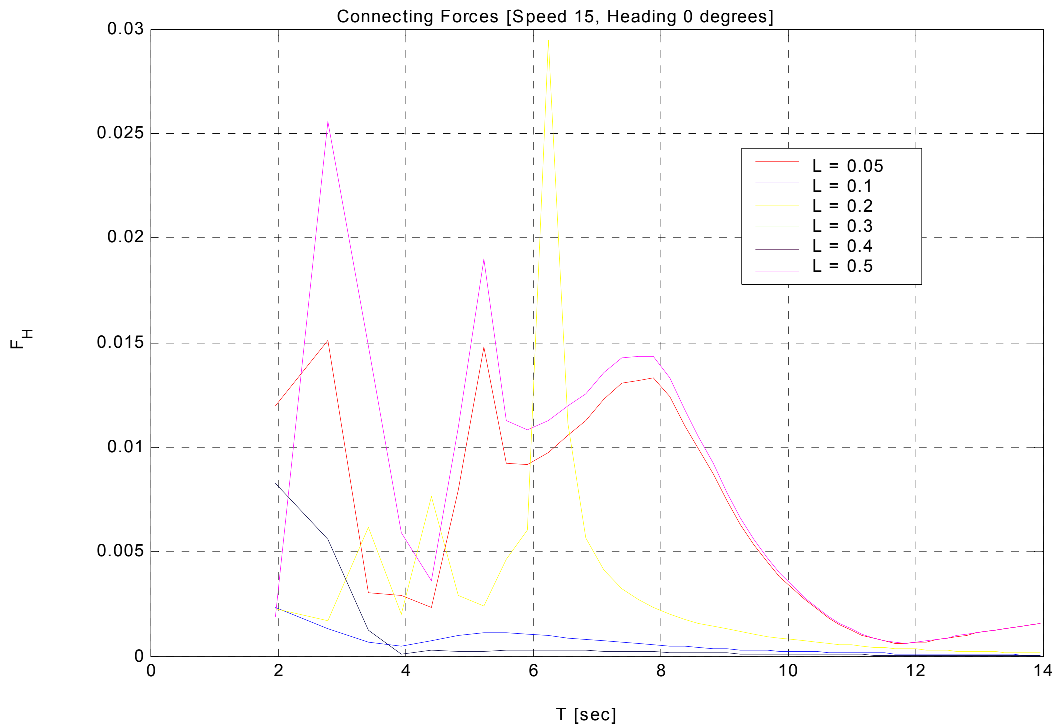

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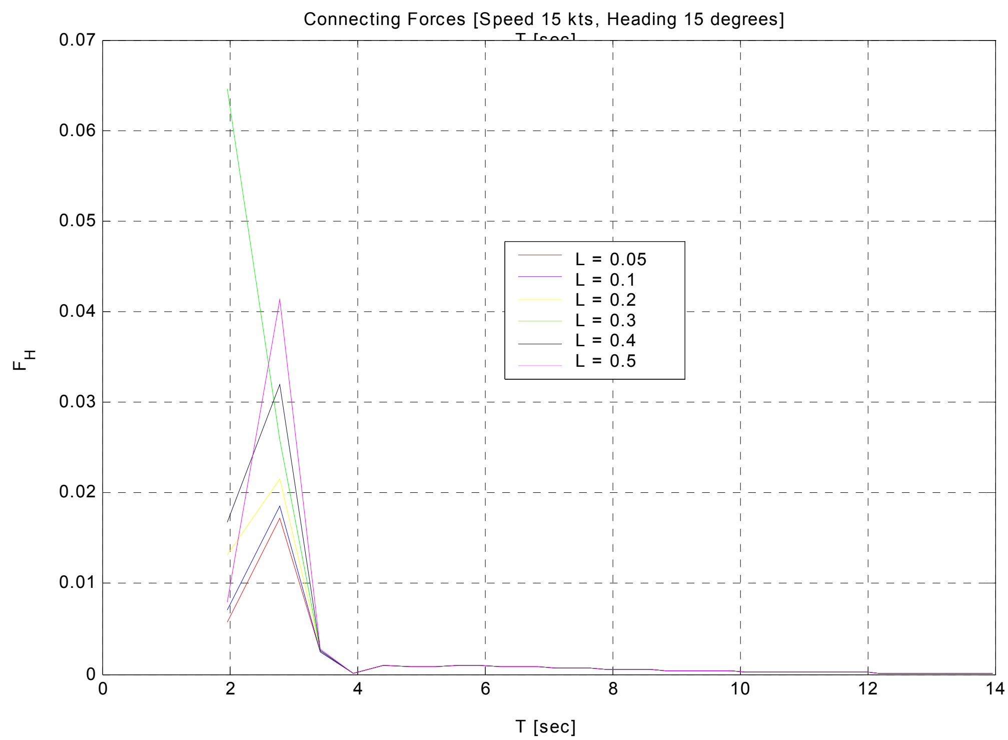


Figure A-18-15-15

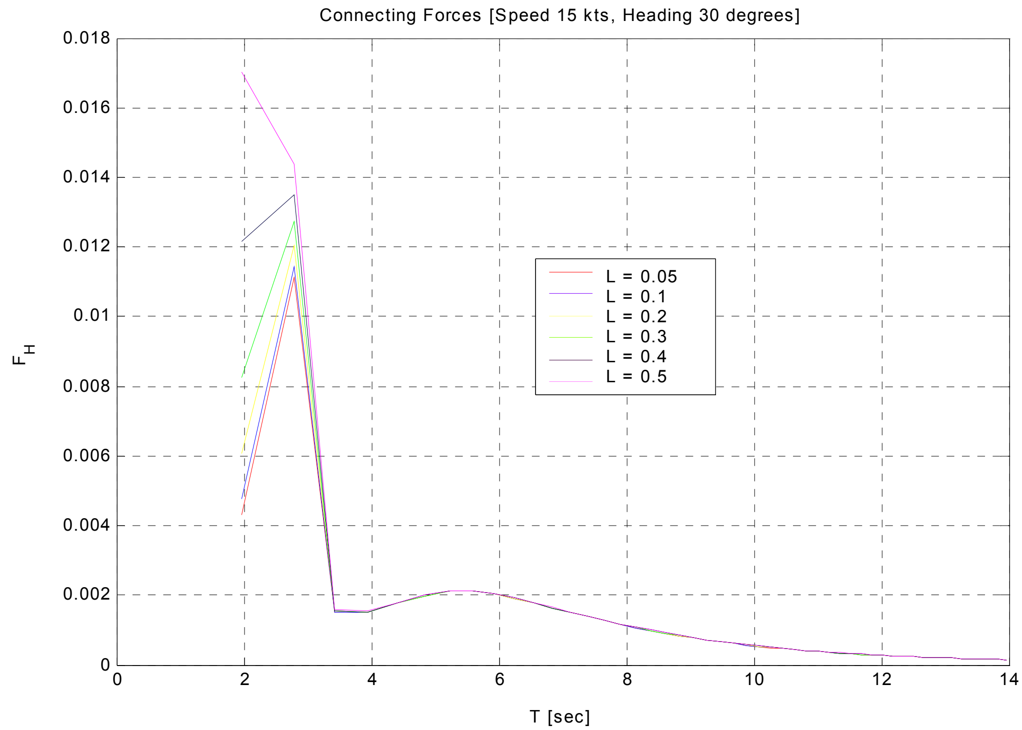


Figure A-19-15-30

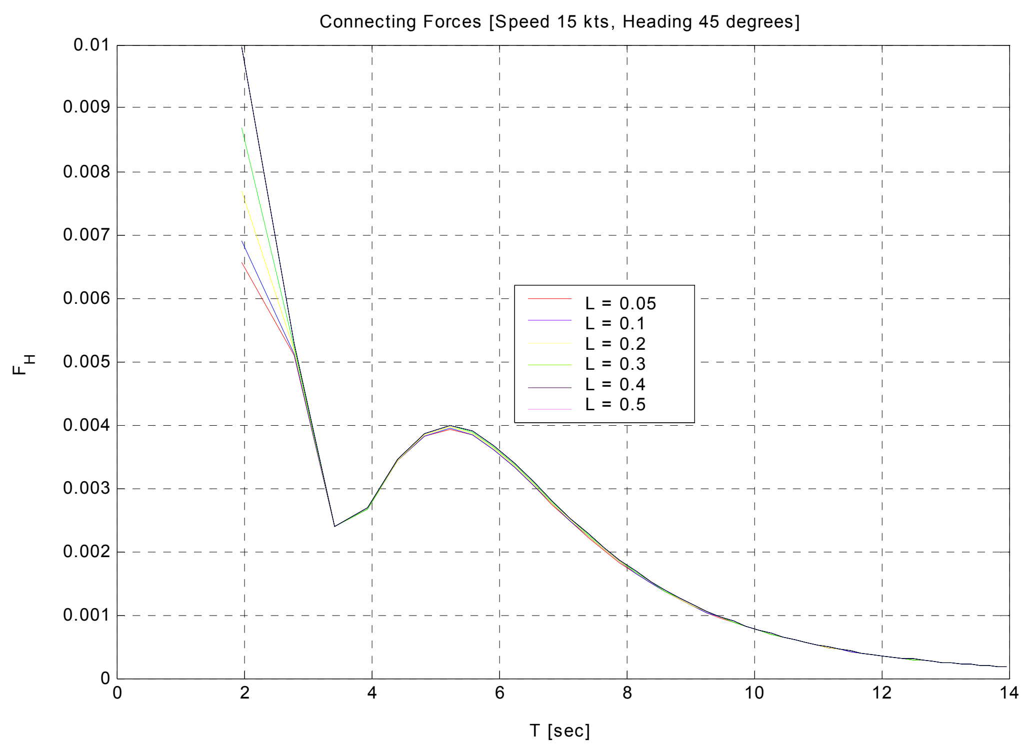


Figure A-20-15-45

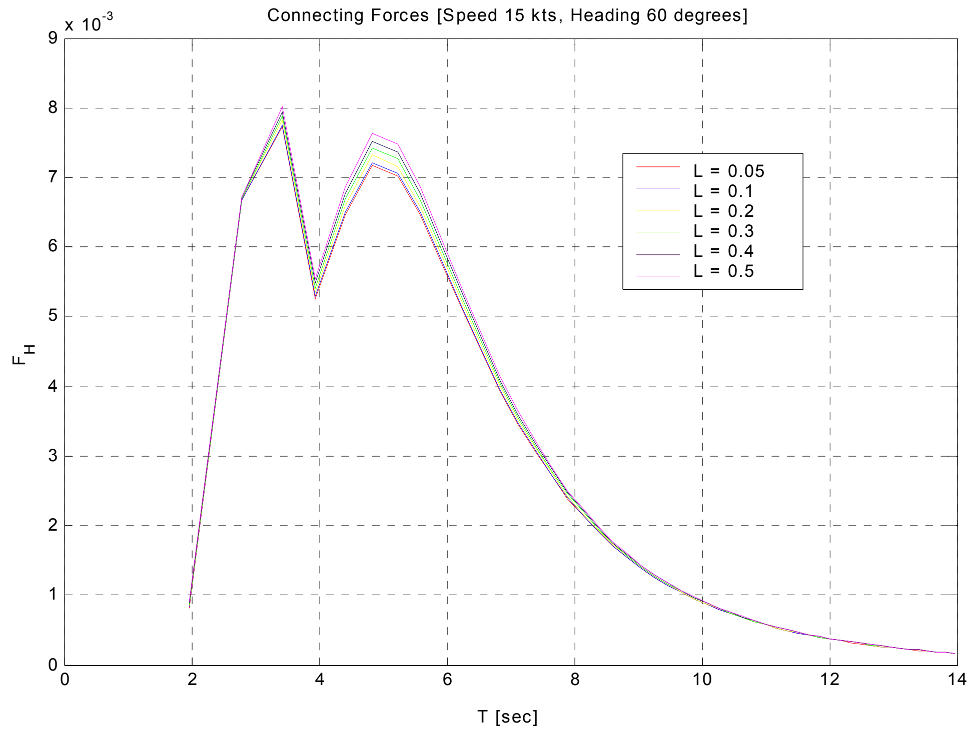


Figure A-21-15-60

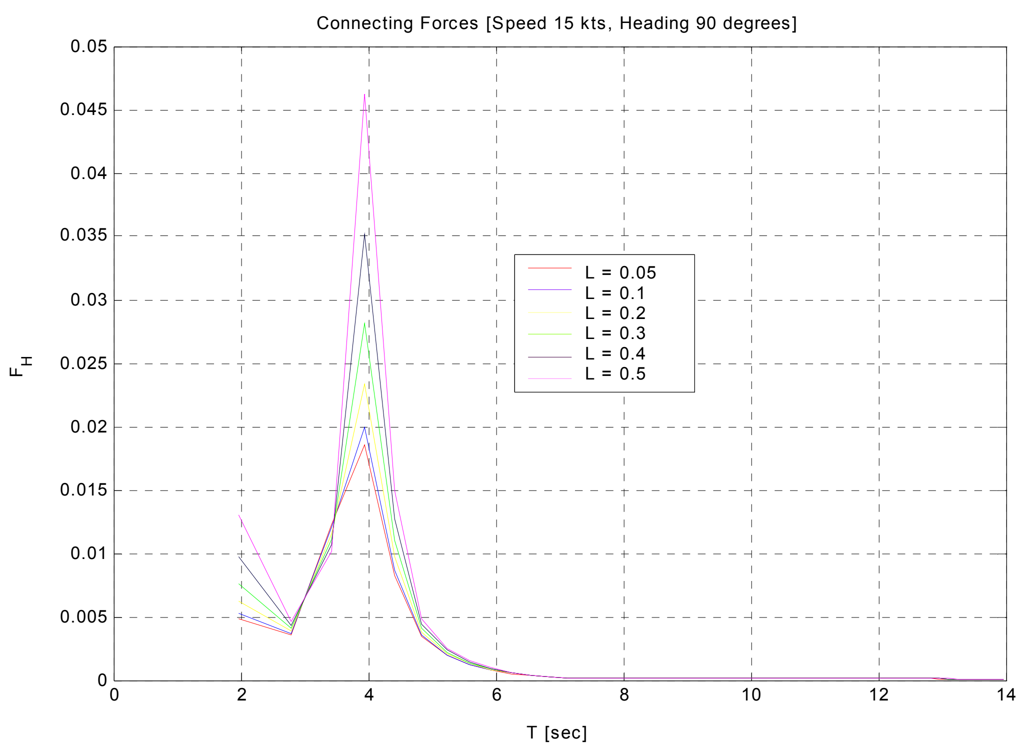


Figure A-22-15-90

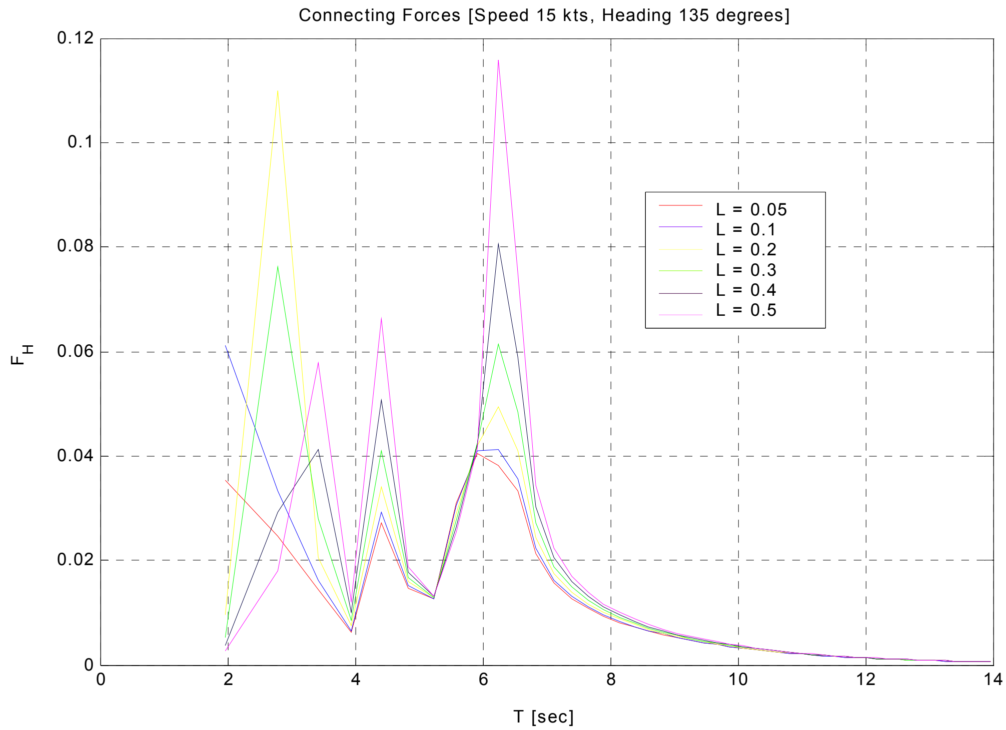


Figure A-23-15-135

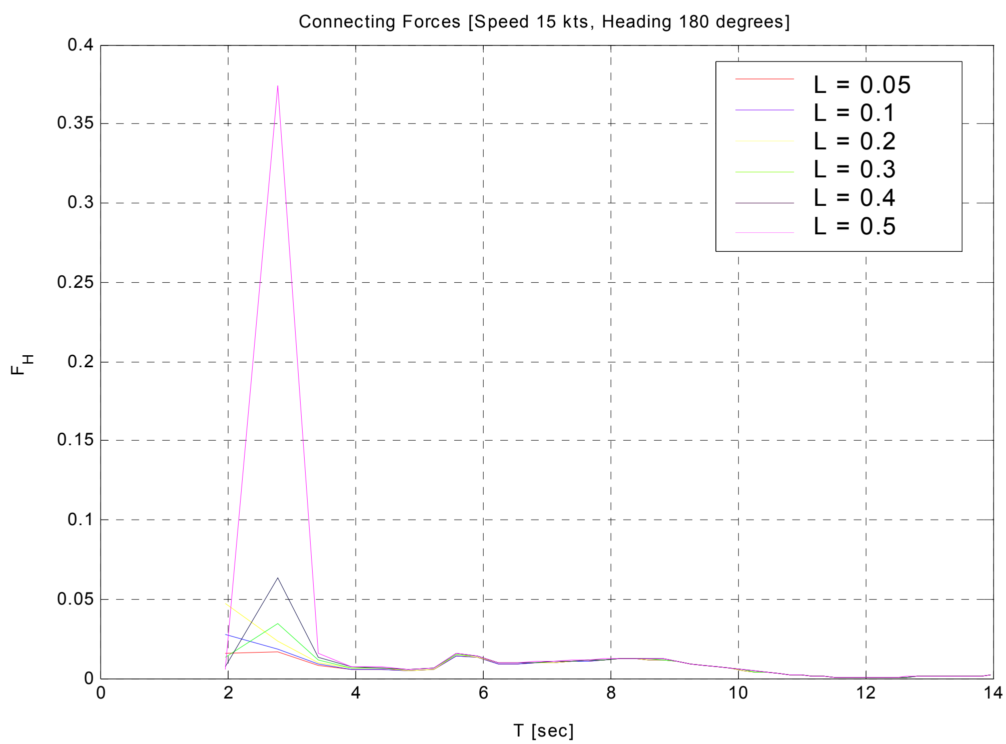


Figure A-24-15-180a

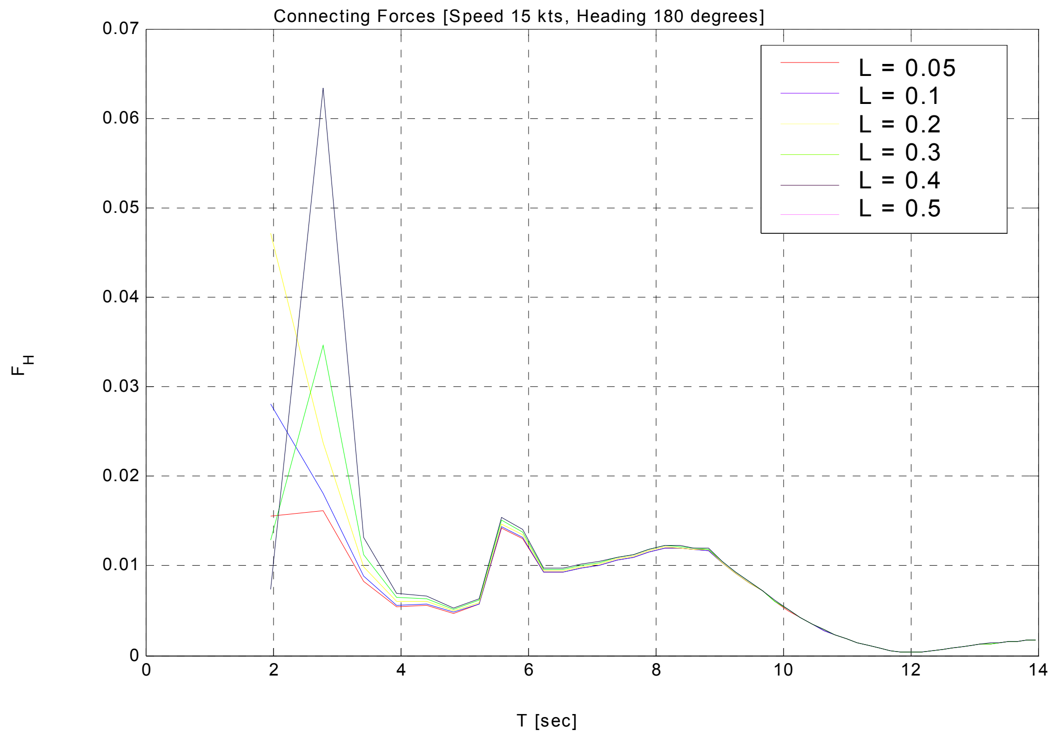


Figure A-25-15-180b

T [sec]

APPENDIX B

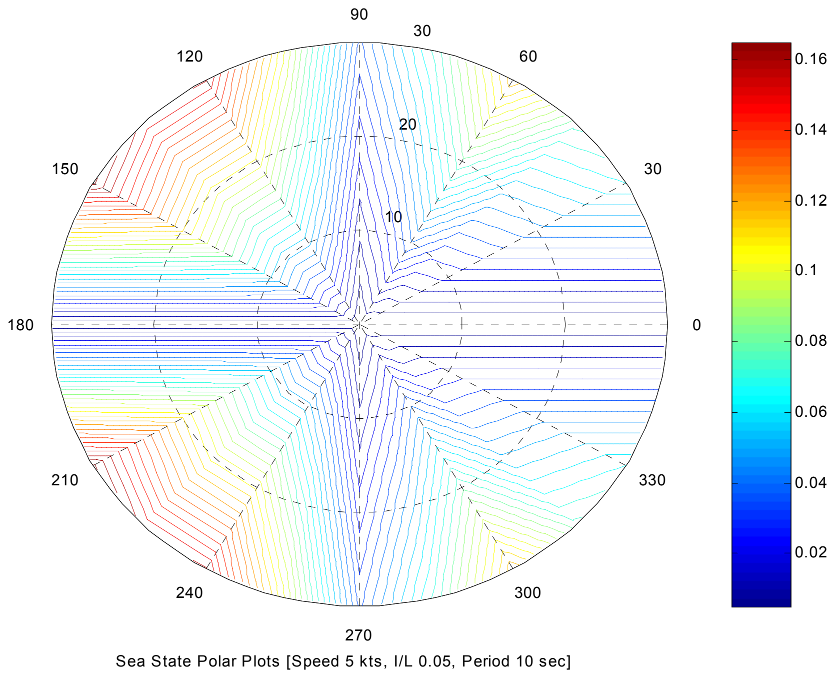


Figure B-1

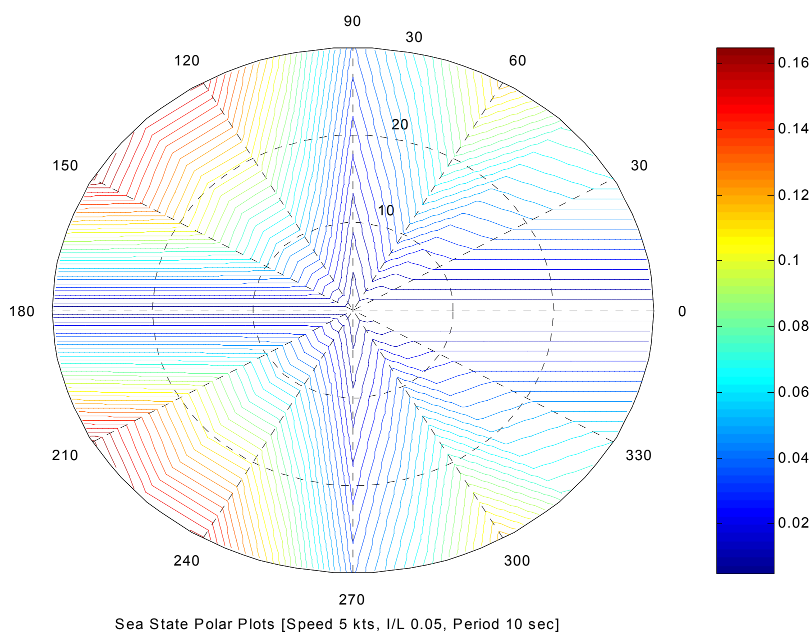
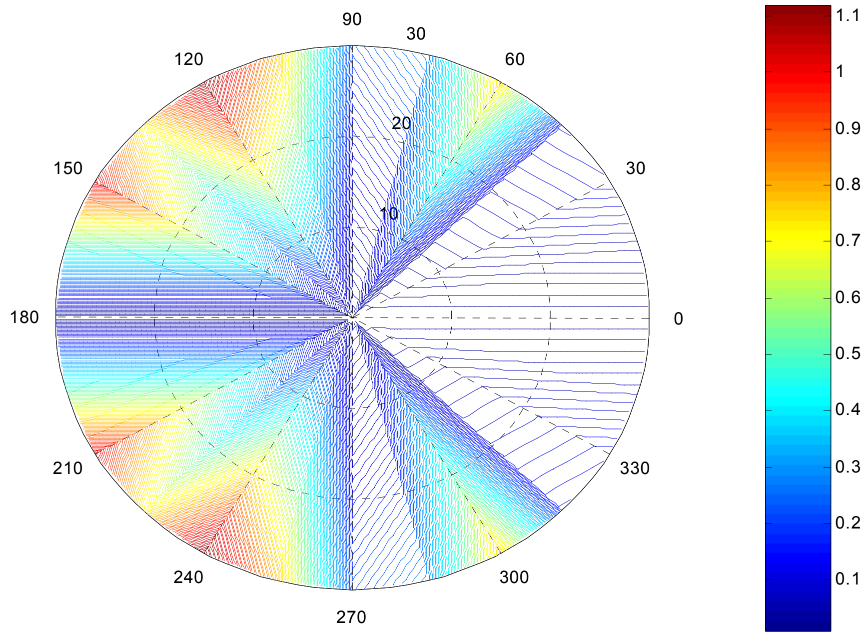
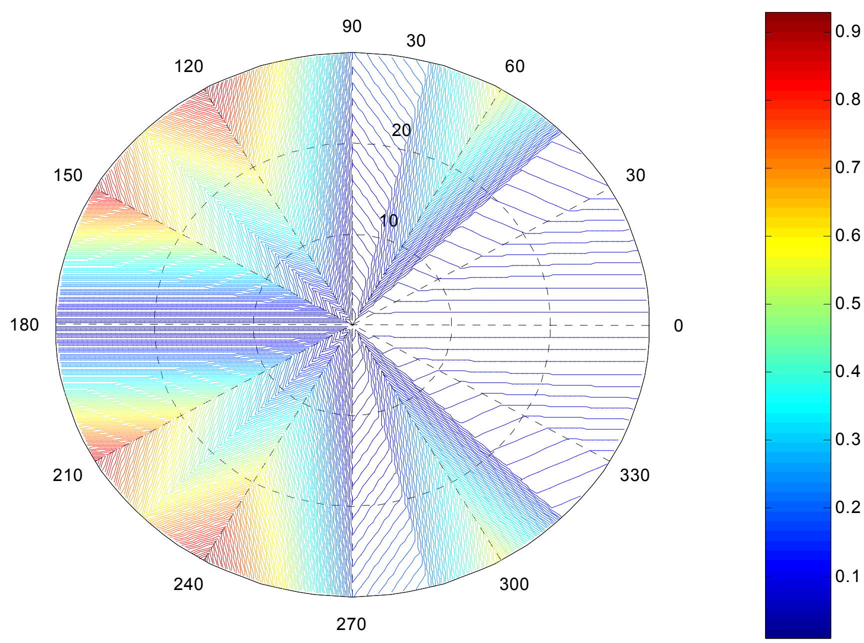


Figure B-2



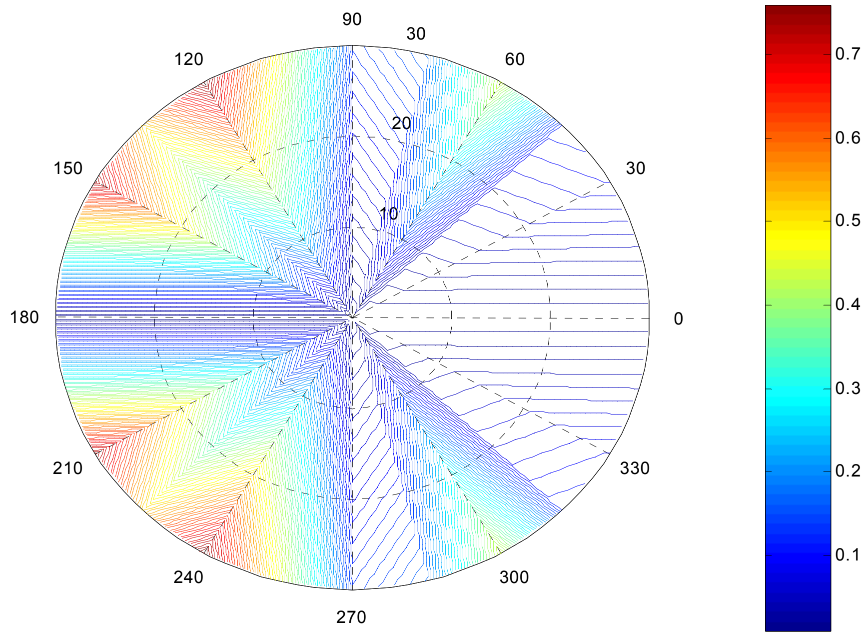
Sea State Polar Plots [Speed 5 kts, I/L= 0.1, Period 6 secs]

Figure B-3



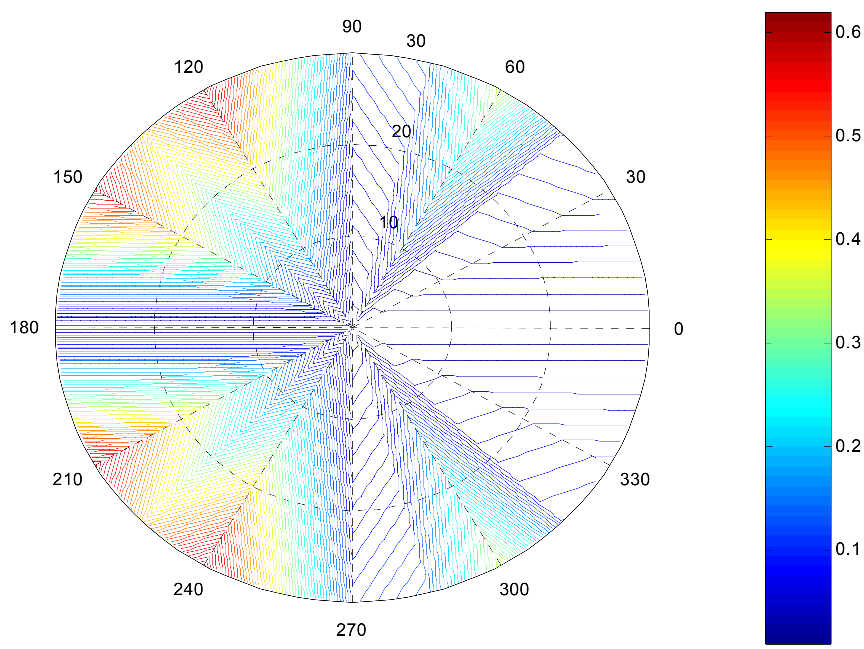
Sea State Polar Plots [Speed 5 kts, I/L=0.1, Period 7 secs]

Figure B-4



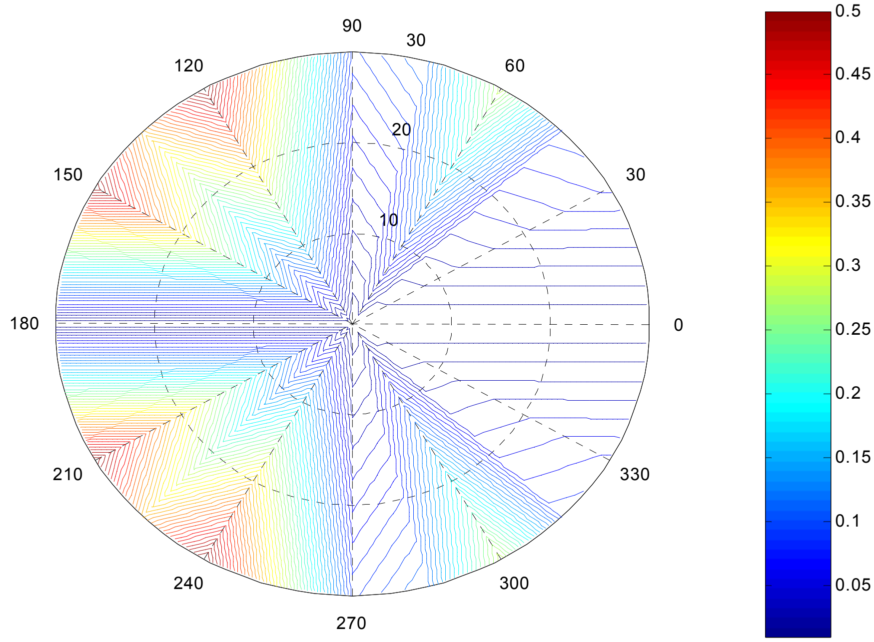
Sea State Polar Plots [Speed 5 kts, l/L=0.1, Period 8 secs]

Figure B-5



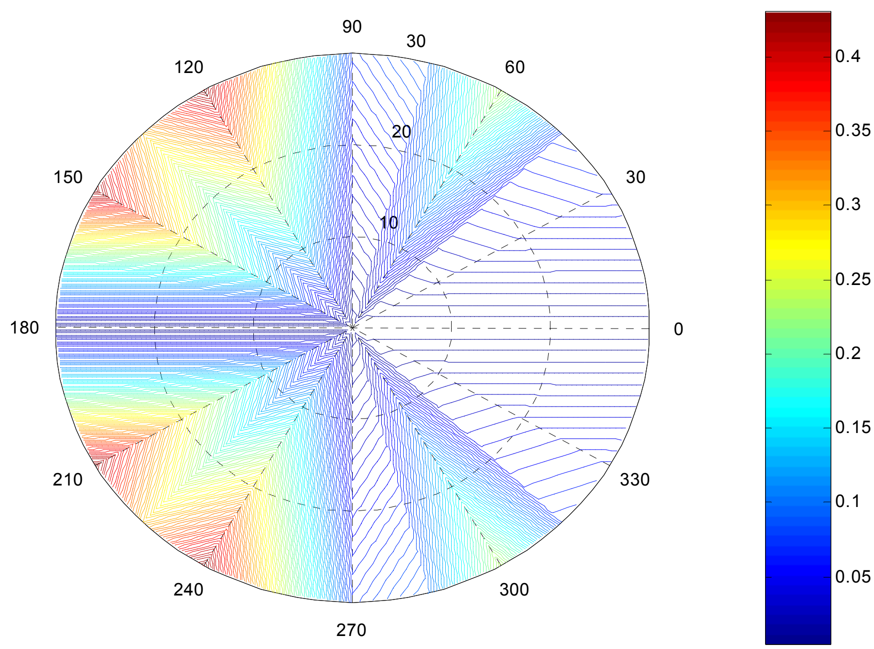
Sea State Polar Plots [Speed 5 kts, l/L=0.1, Period 9 secs]

Figure B-6



Sea State Polar Plots [Speed 5 kts, I/L=0.1, Period 10 secs]

Figure B-8



Sea State Polar Plots [Speed 5 kts, I/L=0.1, Period 11 secs]

Figure B-9

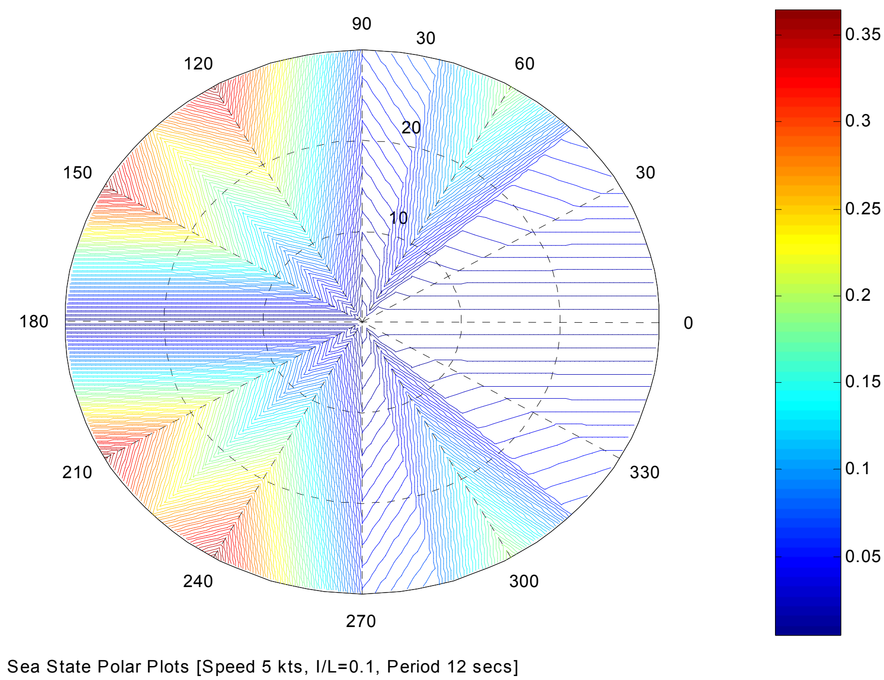


Figure B-10

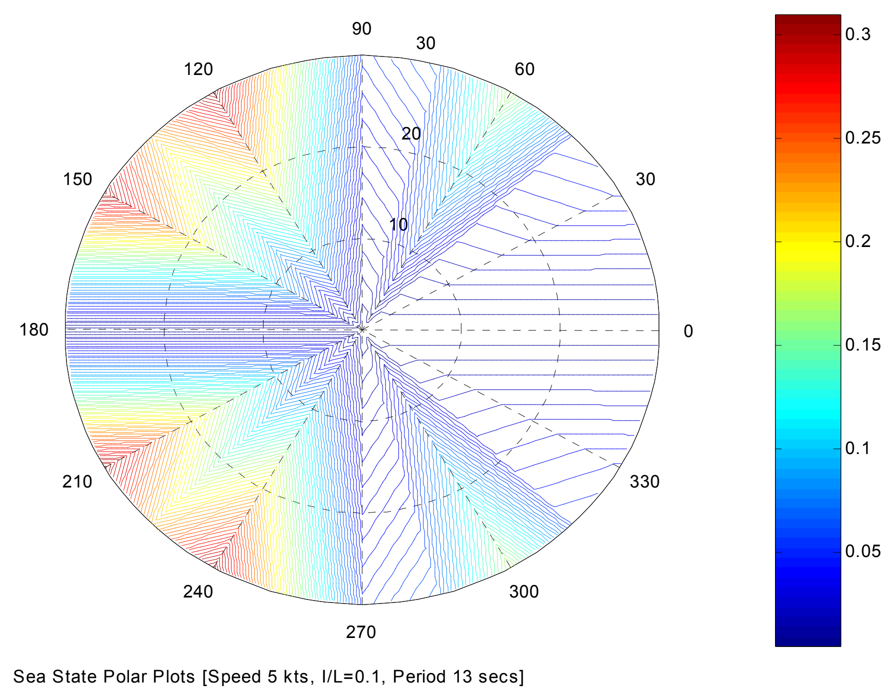
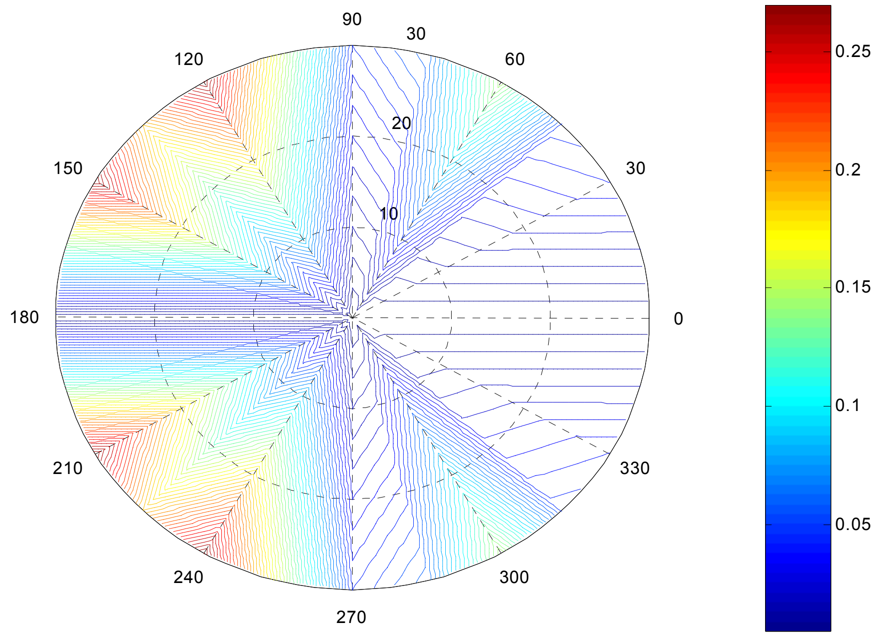
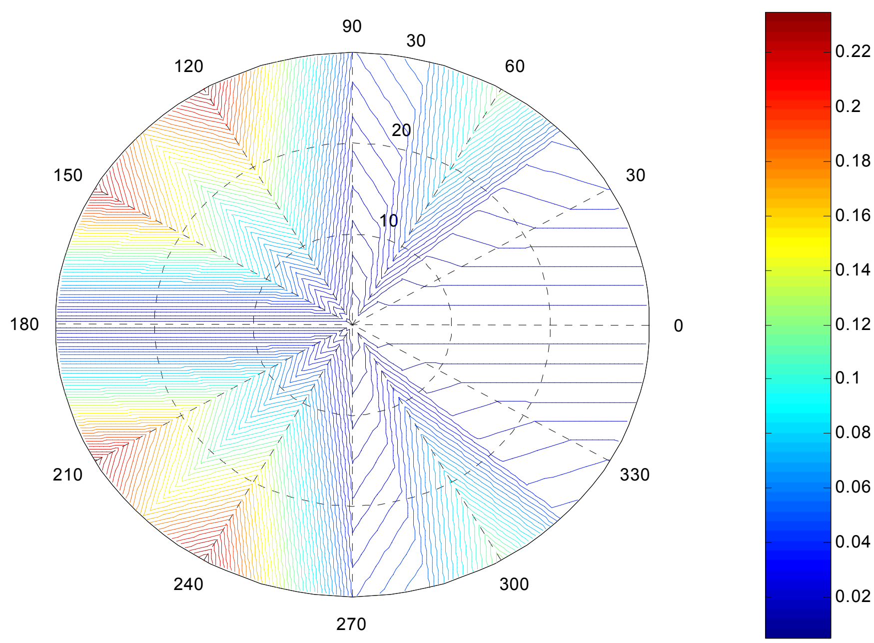


Figure B-11



Sea State Polar Plots [Speed 5 kts, I/L=0.1, Period 14 secs]

Figure B-12



Sea State Polar Plots [Speed 5 kts, I/L=0.1, Period 15 secs]

Figure B-13

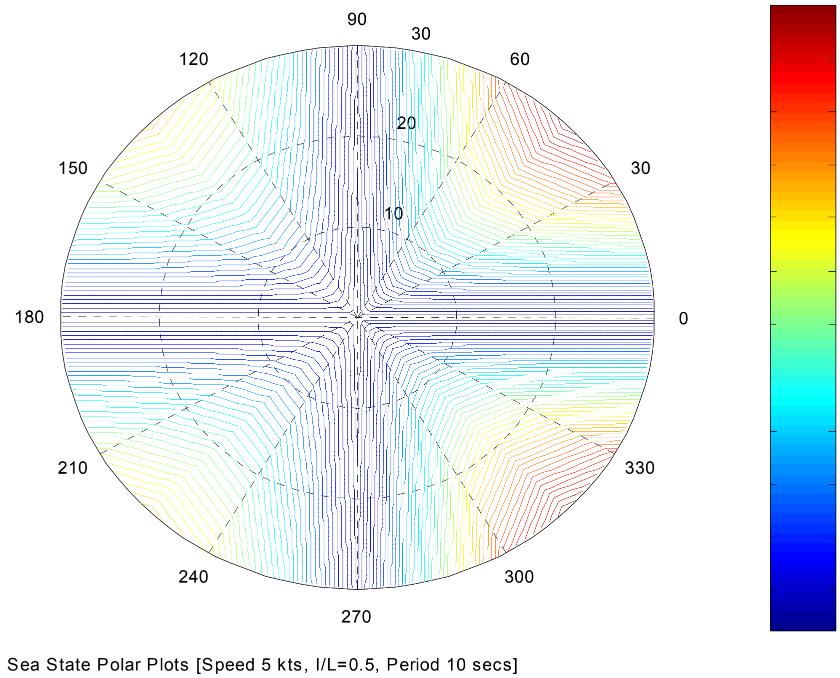


Figure B-14

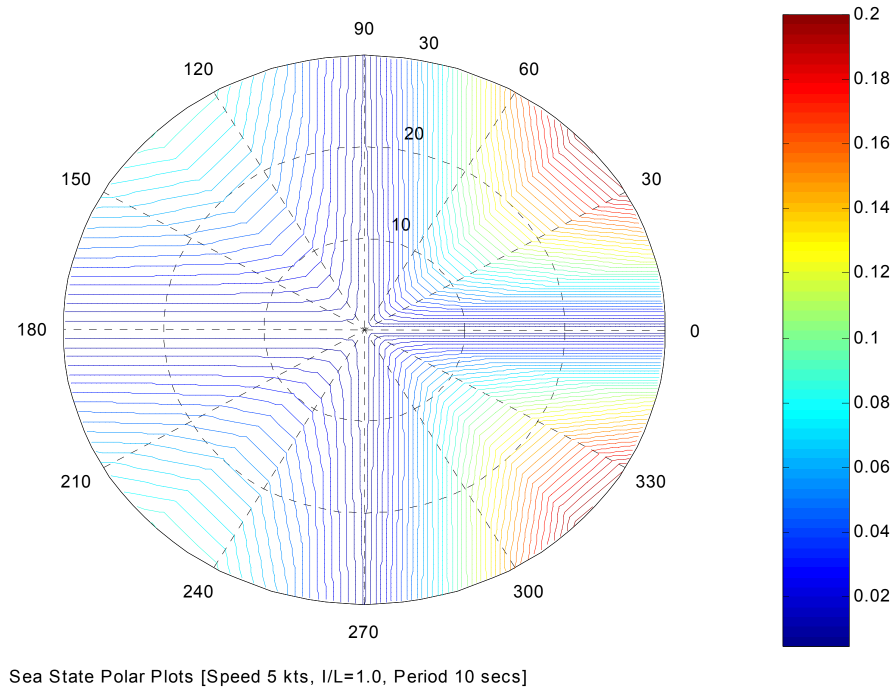
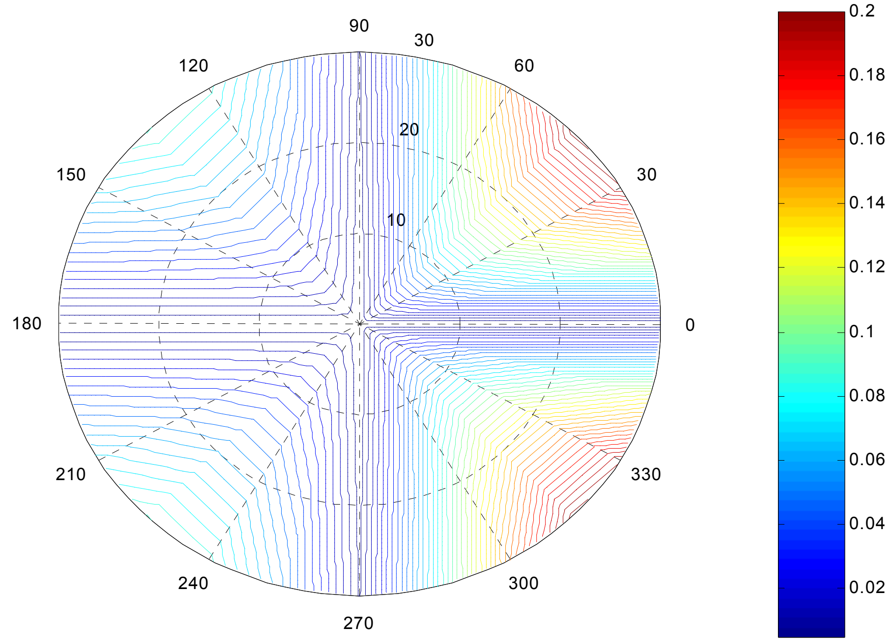
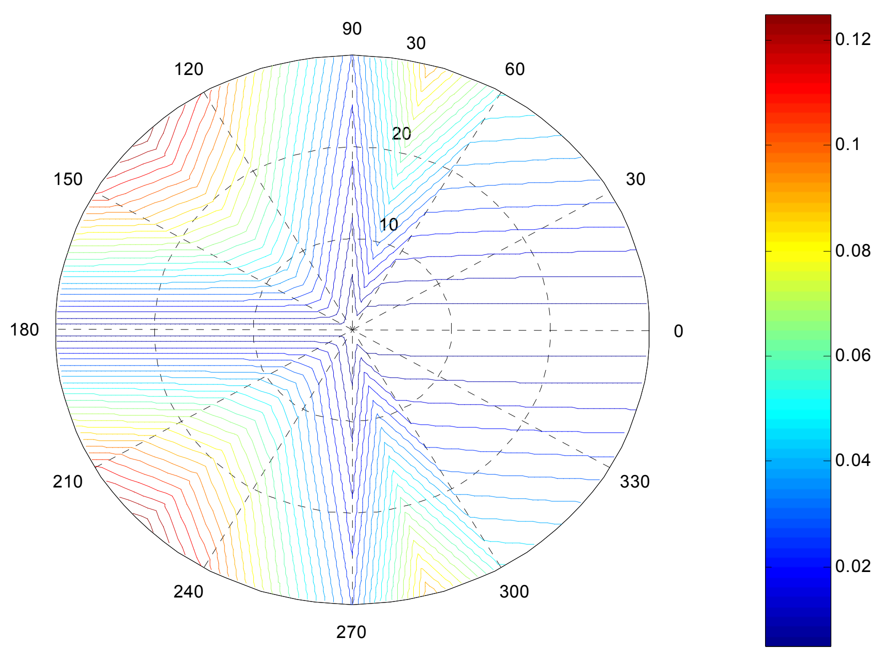


Figure B-15



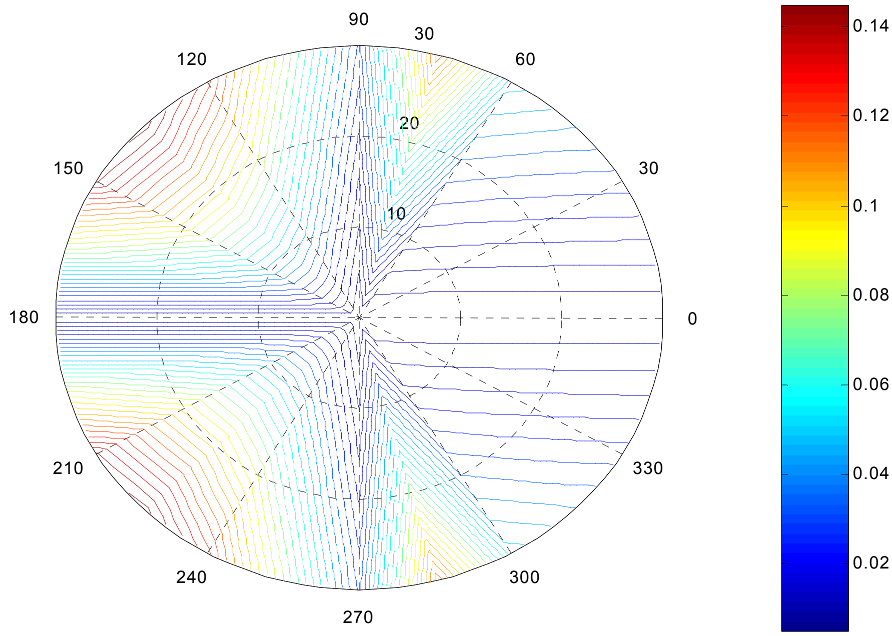
Sea State Polar Plots [Speed 5 kts, I/L=1.0, Period 10 secs]

Figure B-16



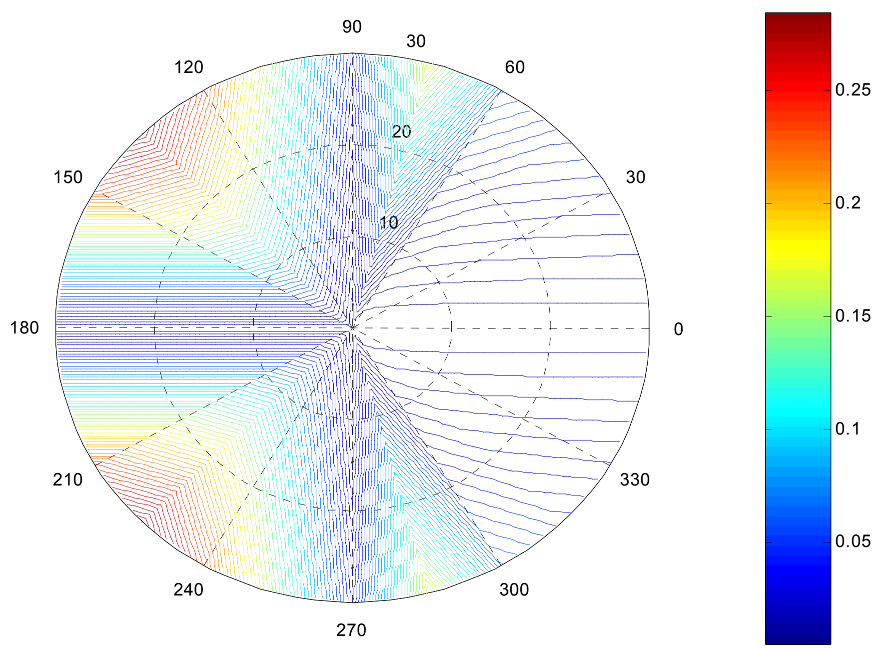
Sea State Polar Plots [Speed 10 kts, I/L=0.05, Period 10 secs]

Figure B-17



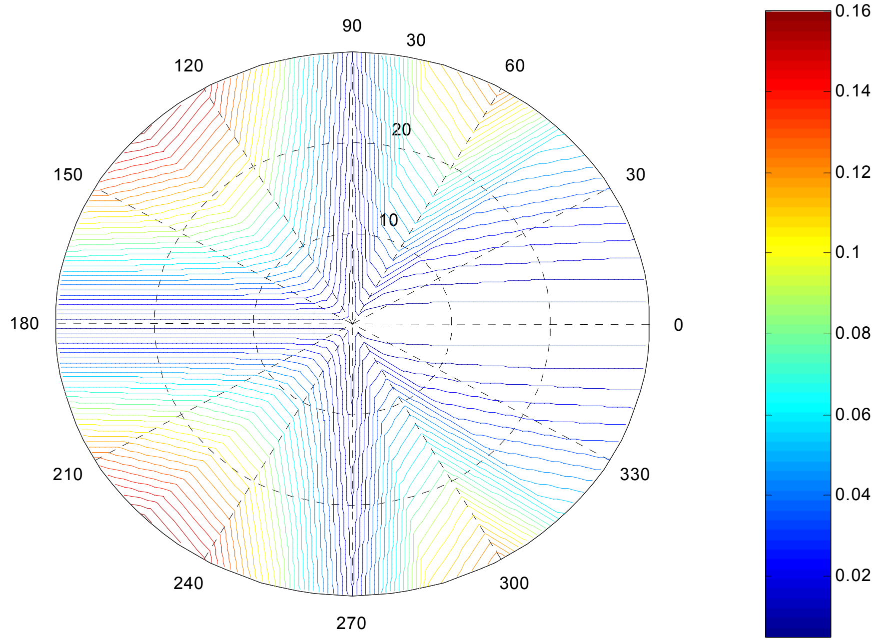
Sea State Polar Plots [Speed 10 kts, l/L=0.1, Period 10 secs]

Figure B-18



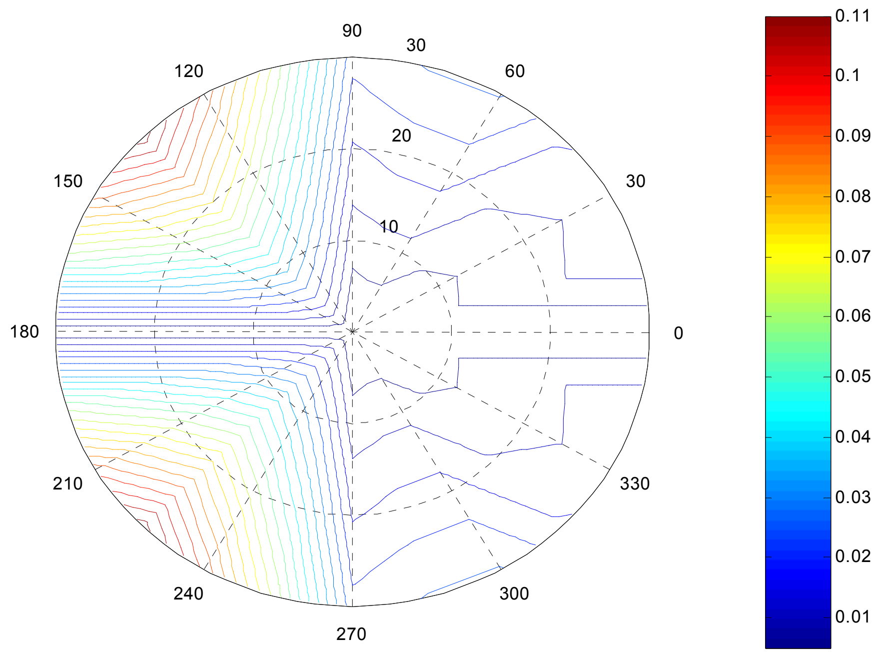
Sea State Polar Plots [Speed 10 kts, l/L=0.5, Period 10 secs]

Figure B-19



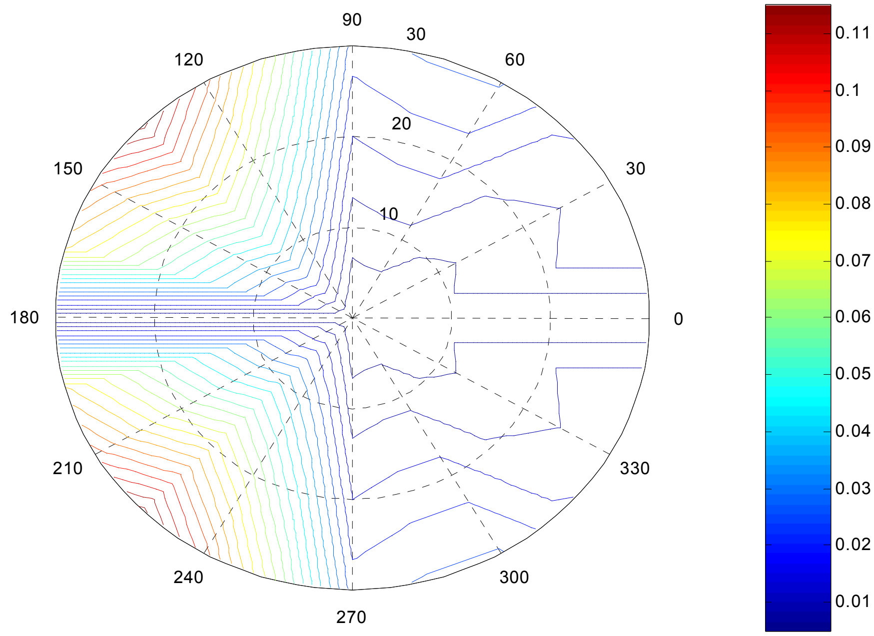
Sea State Polar Plots [Speed 10 kts, I/L=1.0, Period 10 secs]

Figure B-20



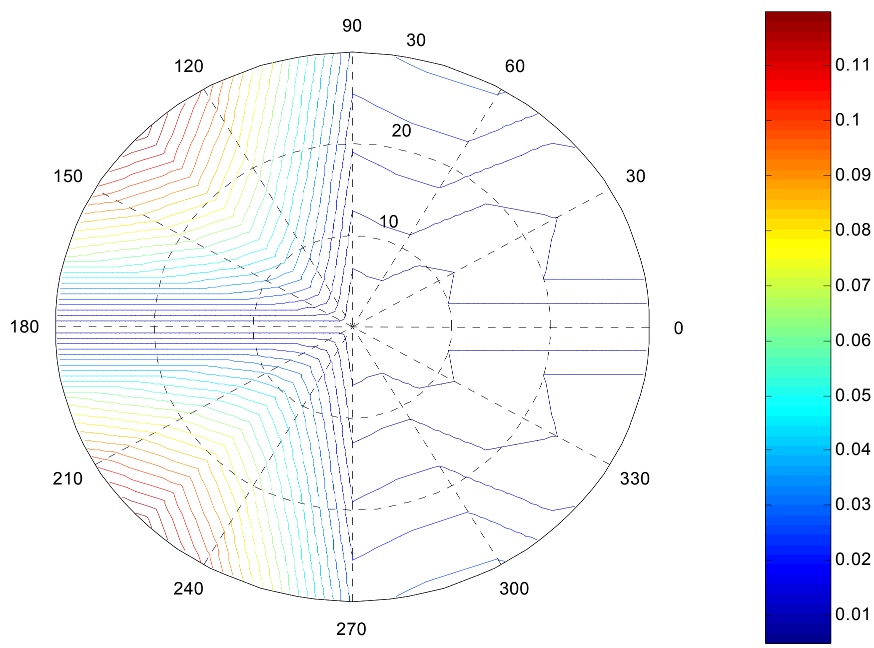
Sea State Polar Plots [Speed 15 kts, I/L=0.01, Period 10 secs]

Figure B-21



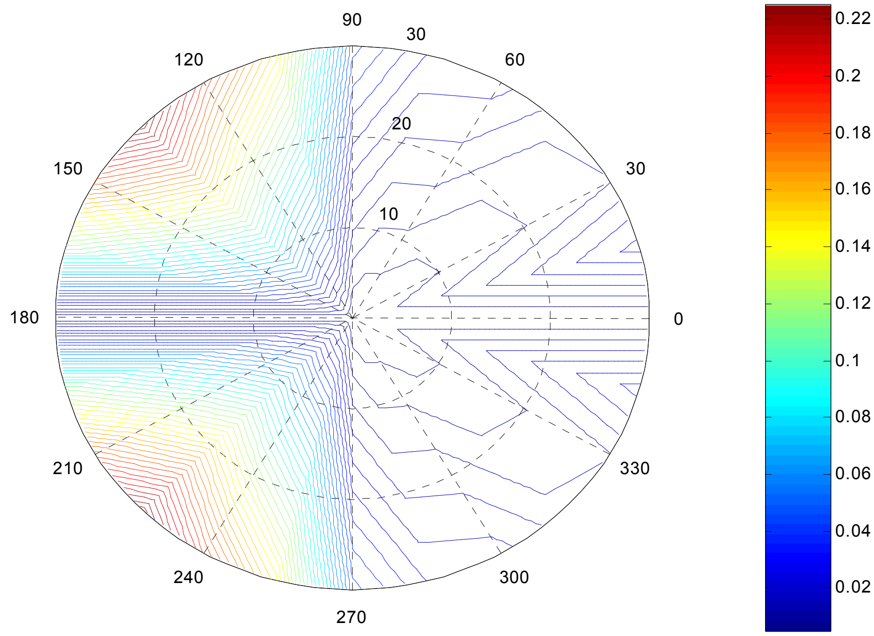
Sea State Polar Plots [Speed 15 kts, l/L=0.05, Period 10 secs]

Figure B-22



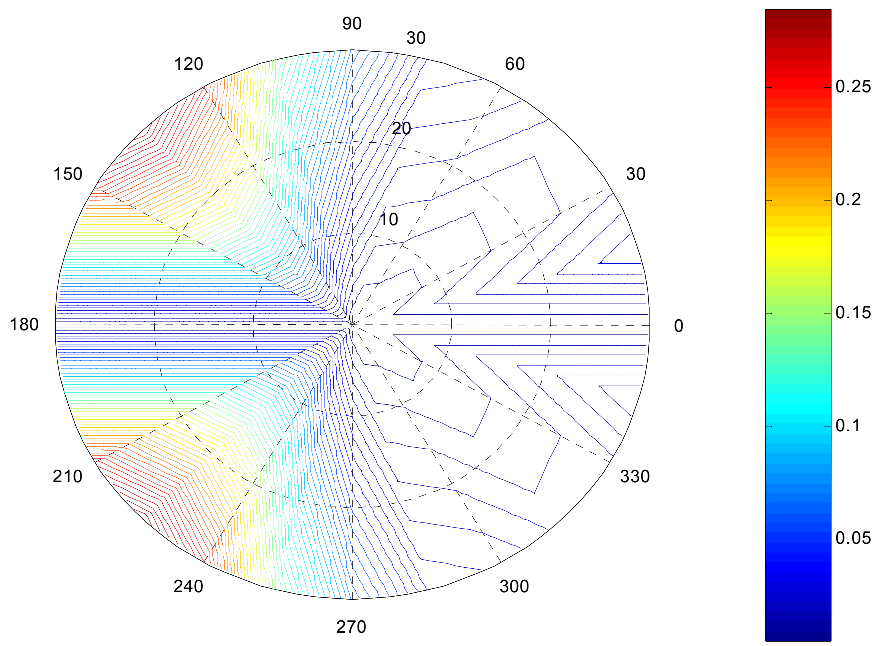
Sea State Polar Plots [Speed 15 kts, l/L=0.1, Period 10 secs]

Figure B-23



Sea State Polar Plots [Speed 15 kts, I/L=0.5, Period 10 secs]

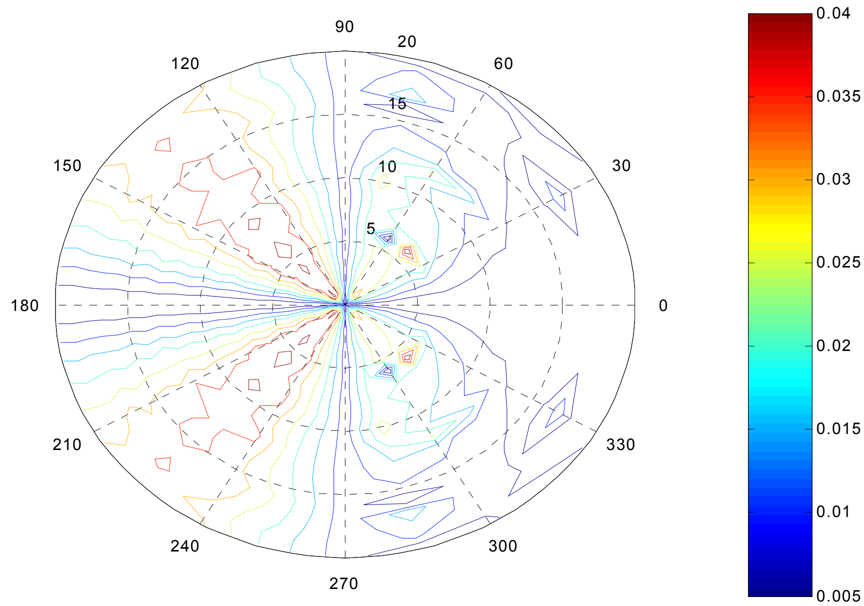
Figure B-24



Sea State Polar Plots [Speed 15 kts, I/L=1.0, Period 10 secs]

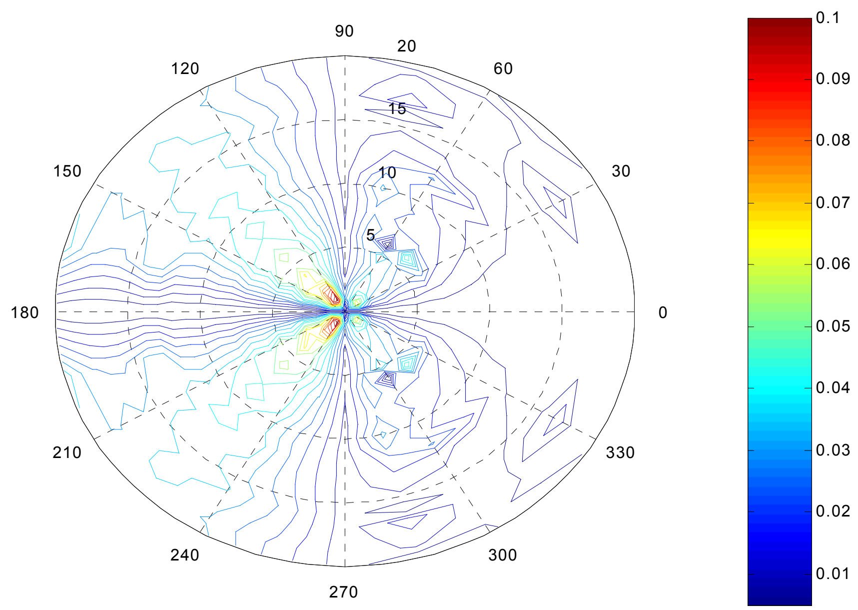
Figure B-25

APPENDIX C



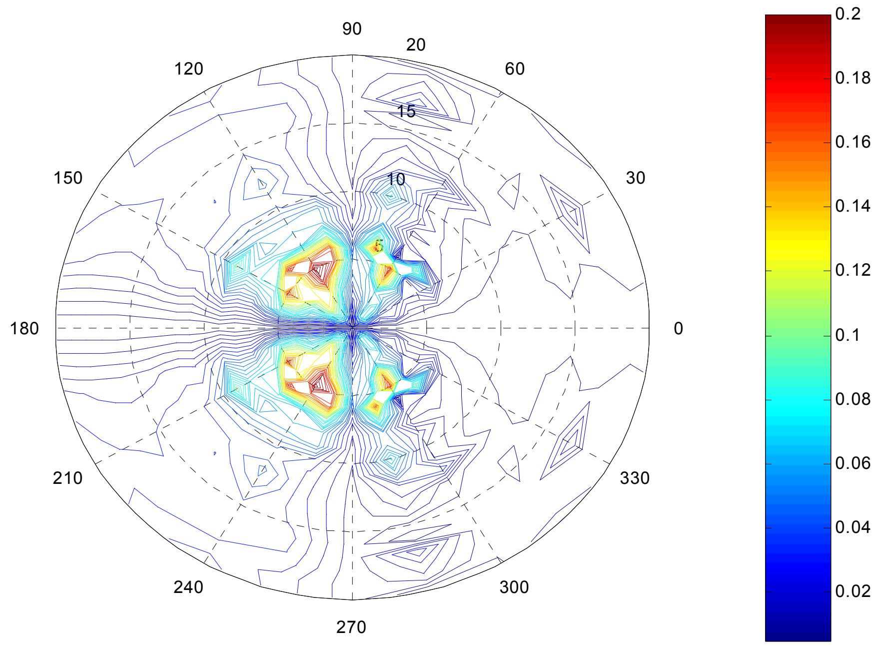
Speed Polar Plots [I/L=0.01, Significant Wave Ht. 10 ft, Period 10 secs]

Figure C-1



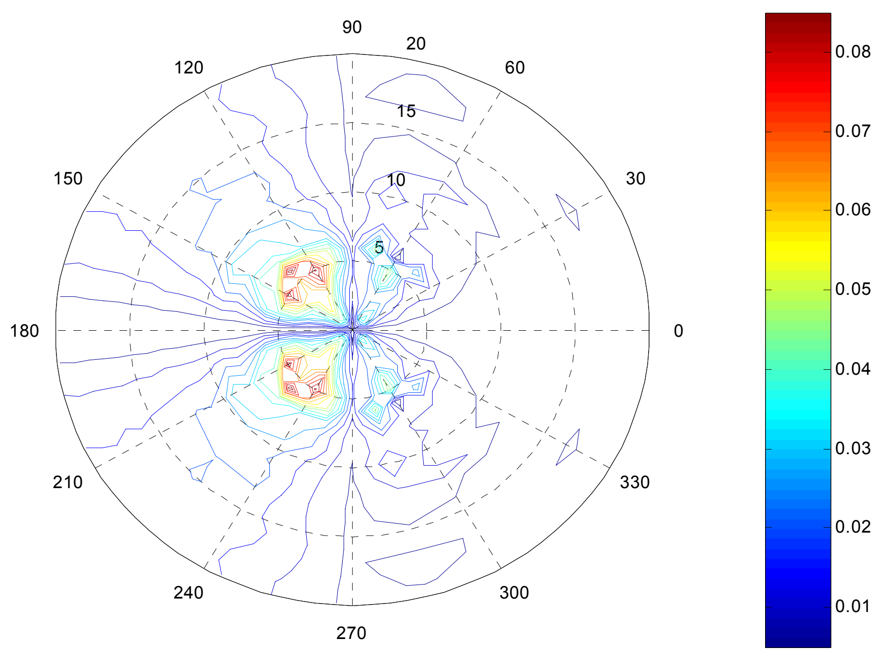
Speed Polar Plots [I/L=0.05, Significant Wave Ht. 10 ft, Period 10 secs]

Figure C-2



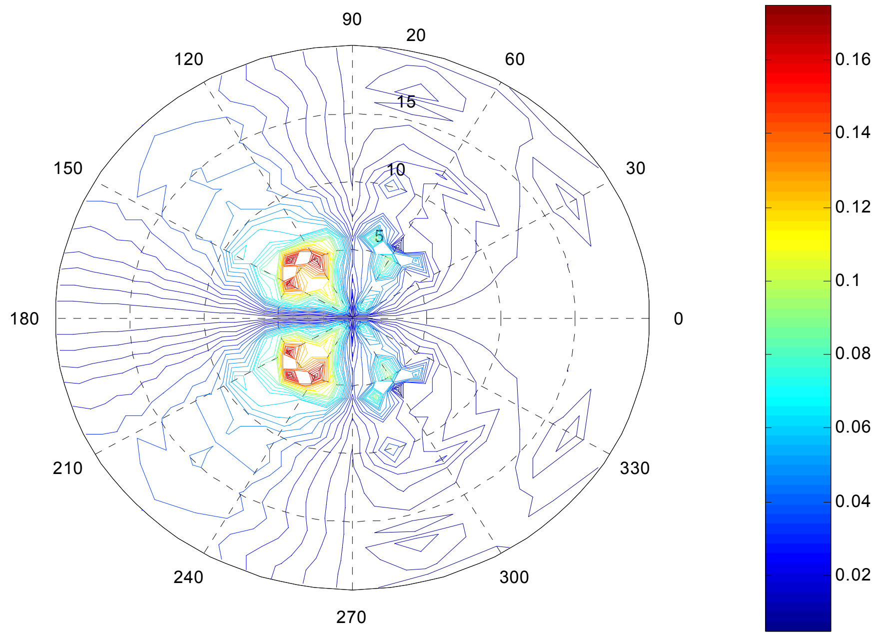
Speed Polar Plots [I/L= 0.1, Significant Wave Ht. 5 ft, Period 5 secs]

Figure C-3



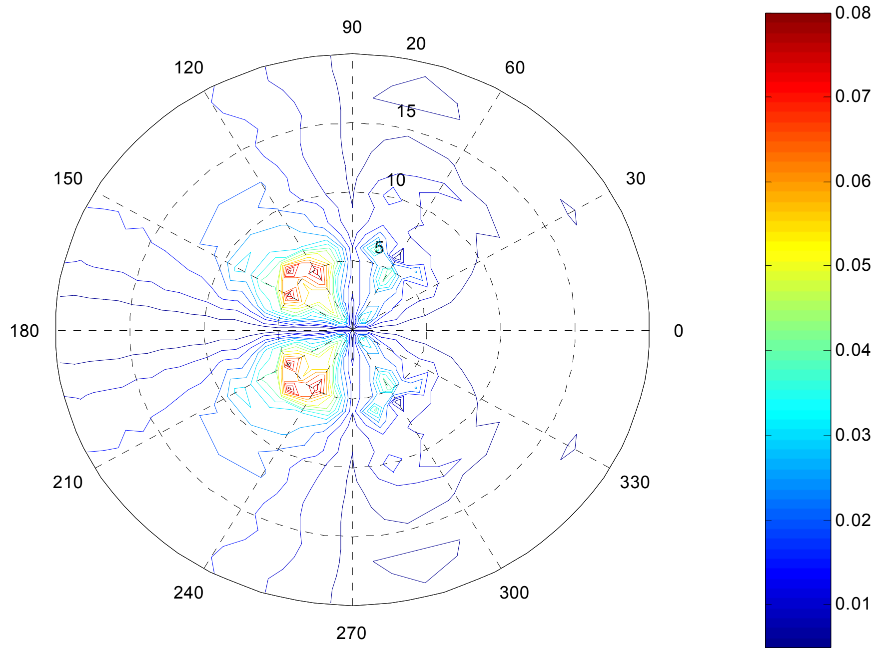
Speed Polar Plots [I/L=0.1, Significant Wave Ht. 5 ft, Period 10 secs]

Figure C-4



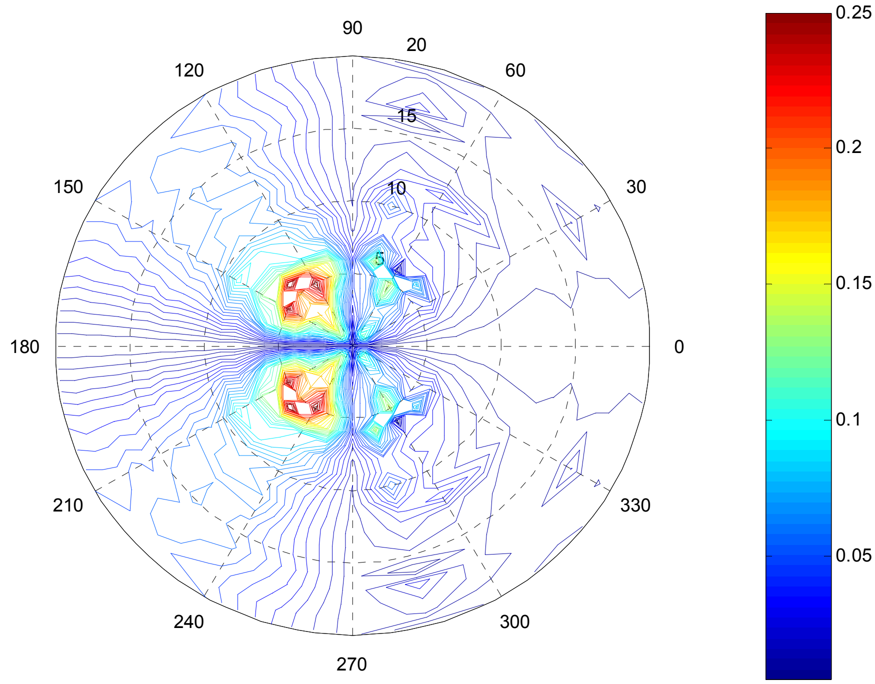
Speed Polar Plots [I/L=0.1, Significant Wave Ht. 10 ft, Period 10 secs]

Figure C-5



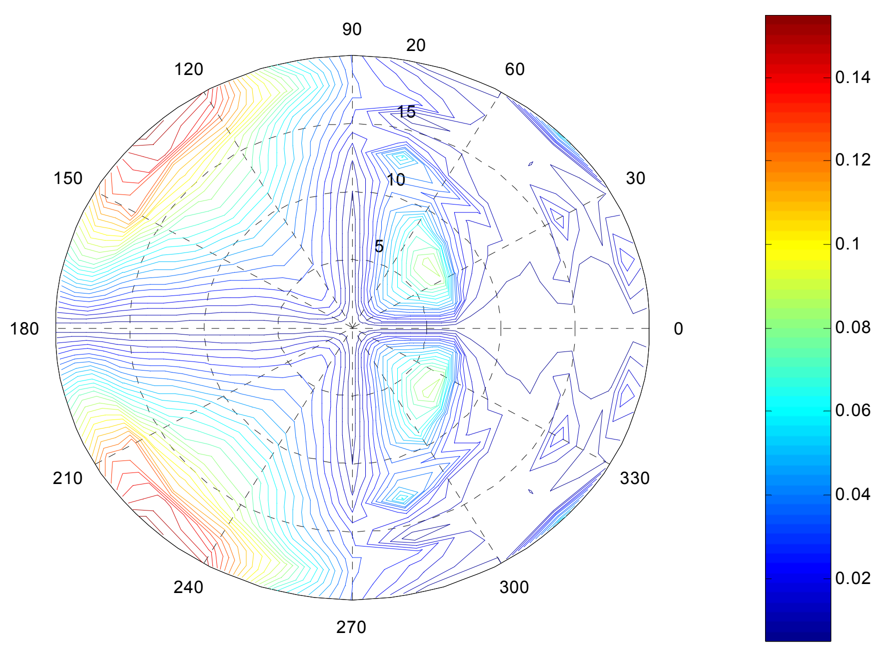
Speed Polar Plots [I/L=0.1, Significant Wave Ht 10 ft, Period 15 secs]

Figure C-6



Speed Polar Plots [l/L=0.1, Significant Wave Ht 15 ft, Period 10 secs]

Figure C-7



Speed Polar Plots [l/L=1.0, Significant Wave Ht 10 ft, Period 10 secs]

Figure C-8

APPENDIX D

```
% Vertical Plane
% Dimensional version (U.S. units)
%
% Get run info
%
V   =input('Speed (knots) = ');
beta=input('Heading (deg) = ');
l   =input('Length (l/L)  = ');
HS  =input('Significant Wave Height (ft) = ');
T_m_min =input('Minimum Modal Period (sec) = ');
T_m_max =input('Maximum Modal Period (sec) = ');
omega_m_min=2*pi/T_m_min;
omega_m_max=2*pi/T_m_max;
%
% Get tension from curve fitting data.
% Applicable for speeds between 1 and 20 ft/sec.
%
T=-1.762*V^4+63.675*V^3-580.8*V^2+2485.9*V-34.047;
%
V_string   =num2str(V);
beta_string=num2str(beta);
%
```

```
% The matdata output files default to the vertical only format when the
% heading angle is 0 or 180 degrees.
% Set up file reading format.
%
trigg = 30;
f2loc = 26; f6loc=30;
if beta==0
   trigg = 27;
   f2loc = 25; f6loc=27;
elseif beta==180
   trigg = 27;
   f2loc = 25; f6loc=27;
end
%
% Load FRONT SHIP data file msvhV_beta.txt
%
load_filename=strcat('msvh',V_string,'_',beta_string,'.txt');
filename_s=load(load_filename);
%
% Load REAR SHIP data file
%
load_filename=strcat('mkvh',V_string,'_',beta_string,'.txt');
filename_k=load(load_filename);
%
```

```
% GENERAL DATA
%
V=V*1.6878;                              % Convert to ft/sec
lambda_min=20;                  % Min wave length (ft)
lambda_max=1000;   % Max wave length (ft)
delta_lambda=20;    % Wave length increment (ft)
rho=1.9905;                              % Water density
zeta=1;                                  % Regular wave height
L=105;                                   % Reference length for
nondimensionalization
g=32.2;                                              %
Gravitational constant
x_s=-46;                          % FRONT SHIP attachment point
x_k=+40;                        % REAR SHIP attachment point

beta      = beta*pi/180;
lambda     = lambda_min:delta_lambda:lambda_max;
% Vector of wavelengths
wavenumber = 2.0*pi./lambda;


 %    Wave number omega      = sqrt(wavenumber*g);

%  Wave frequency
```

```
omegae     = omega-wavenumber*V*cos(beta);
                                                % Frequency of encounter
period     = 2.0*pi./omega;
periode    = 2.0*pi./omegae;
omega      = omega';
omegae     = omegae';
filesize   = size(lambda);
lambda_size= trigg*filesize(2);
%
% HORIZONTAL PLANE RESPONSE CALCULATIONS
%
% SLICE
%
% Set mass matrix elements
%
M22s=filename_s(2:trigg:lambda_size,2);
M26s=filename_s(2:trigg:lambda_size,6);
M62s=filename_s(6:trigg:lambda_size,2);
M66s=filename_s(6:trigg:lambda_size,6);
%
% Added mass terms
%
A22s=filename_s(8:trigg:lambda_size,2);
A26s=filename_s(8:trigg:lambda_size,6);
```

```
A62s=filename_s(12:trigg:lambda_size,2);
A66s=filename_s(12:trigg:lambda_size,6);
%
% Damping terms
%
B22s=filename_s(14:trigg:lambda_size,2);
B26s=filename_s(14:trigg:lambda_size,6);
B62s=filename_s(18:trigg:lambda_size,2);
B66s=filename_s(18:trigg:lambda_size,6);
%
% Hydrostatic terms
%
C22s=filename_s(20:trigg:lambda_size,2);
C26s=filename_s(20:trigg:lambda_size,6);
C62s=filename_s(24:trigg:lambda_size,2);
C66s=filename_s(24:trigg:lambda_size,6);

if beta==0
  F2s_t=zeros(50,1); F6s_t=zeros(50,1);
elseif beta==180
   F2s_t=zeros(50,1); F6s_t=zeros(50,1);
else
%
% Total exciting forces
```

```
%
F2s_t_amp=filename_s(f2loc:trigg:lambda_size,5);
F6s_t_amp=filename_s(f6loc:trigg:lambda_size,5);
F2s_t_pha=filename_s(f2loc:trigg:lambda_size,6);
F6s_t_pha=filename_s(f6loc:trigg:lambda_size,6);
F2s_t=F2s_t_amp.*exp(i*F2s_t_pha.*pi/180.0);
F6s_t=F6s_t_amp.*exp(i*F6s_t_pha.*pi/180.0);
%
% Froude/Krylov exciting forces
%
F2s_f_amp=filename_s(f2loc:trigg:lambda_size,1);
F6s_f_amp=filename_s(f6loc:trigg:lambda_size,1);
F2s_f_pha=filename_s(f2loc:trigg:lambda_size,2);
F6s_f_pha=filename_s(f6loc:trigg:lambda_size,2);
F2s_f=F2s_f_amp.*exp(i*F2s_f_pha.*pi/180.0);
F6s_f=F6s_f_amp.*exp(i*F6s_f_pha.*pi/180.0);
%
% Diffraction exciting forces
%
F2s_d_amp=filename_s(f2loc:trigg:lambda_size,3);
F6s_d_amp=filename_s(f6loc:trigg:lambda_size,3);
F2s_d_pha=filename_s(f2loc:trigg:lambda_size,4);
F6s_d_pha=filename_s(f6loc:trigg:lambda_size,4);
F2s_d=F2s_d_amp.*exp(i*F2s_d_pha.*pi/180.0);
```

```
F6s_d=F6s_d_amp.*exp(i*F6s_d_pha.*pi/180.0);
%
end
% KAIMALINO
%
% Set mass matrix elements
%
M22k=filename_k(2:trigg:lambda_size,2);
M26k=filename_k(2:trigg:lambda_size,6);
M62k=filename_k(6:trigg:lambda_size,2);
M66k=filename_k(6:trigg:lambda_size,6);
%
% Added mass terms
%
A22k=filename_k(8:trigg:lambda_size,2);
A26k=filename_k(8:trigg:lambda_size,6);
A62k=filename_k(12:trigg:lambda_size,2);
A66k=filename_k(12:trigg:lambda_size,6);
%
% Damping terms
%
B22k=filename_k(14:trigg:lambda_size,2);
B26k=filename_k(14:trigg:lambda_size,6);
B62k=filename_k(18:trigg:lambda_size,2);
```

```
B66k=filename_k(18:trigg:lambda_size,6);
%
% Hydrostatic terms
%
C22k=filename_k(20:trigg:lambda_size,2);
C26k=filename_k(20:trigg:lambda_size,6);
C62k=filename_k(24:trigg:lambda_size,2);
C66k=filename_k(24:trigg:lambda_size,6);


if beta==0
  F2k_t=zeros(50,1); F6k_t=zeros(50,1);
elseif beta==180
   F2k_t=zeros(50,1); F6k_t=zeros(50,1);
else
%
% Total exciting forces
%
F2k_t_amp=filename_k(f2loc:trigg:lambda_size,5);
F6k_t_amp=filename_k(f6loc:trigg:lambda_size,5);
F2k_t_pha=filename_k(f2loc:trigg:lambda_size,6);
F6k_t_pha=filename_k(f6loc:trigg:lambda_size,6);
F2k_t=F2k_t_amp.*exp(i*F2k_t_pha.*pi/180.0);
F6k_t=F6k_t_amp.*exp(i*F6k_t_pha.*pi/180.0);
%
```

```
% Froude/Krylov exciting forces
%
F2k_f_amp=filename_k(f2loc:trigg:lambda_size,1);
F6k_f_amp=filename_k(f6loc:trigg:lambda_size,1);
F2k_f_pha=filename_k(f2loc:trigg:lambda_size,2);
F6k_f_pha=filename_k(f6loc:trigg:lambda_size,2);
F2k_f=F2k_f_amp.*exp(i*F2k_f_pha.*pi/180.0);
F6k_f=F6k_f_amp.*exp(i*F6k_f_pha.*pi/180.0);
%
% Diffraction exciting forces
%
F2k_d_amp=filename_k(f2loc:trigg:lambda_size,3);
F6k_d_amp=filename_k(f6loc:trigg:lambda_size,3);
F2k_d_pha=filename_k(f2loc:trigg:lambda_size,4);
F6k_d_pha=filename_k(f6loc:trigg:lambda_size,4);
F2k_d=F2k_d_amp.*exp(i*F2k_d_pha.*pi/180.0);
F6k_d=F6k_d_amp.*exp(i*F6k_d_pha.*pi/180.0);
end
%
% MATCHING CONDITION
%
A22bar_s=-(omegae.^2).*(M22s+A22s)+i*omegae.*B22s+C22s;
A26bar_s=-(omegae.^2).*(M26s+A26s)+i*omegae.*B26s+C26s;
A62bar_s=-(omegae.^2).*(M62s+A62s)+i*omegae.*B62s+C62s;
```

```
A66bar_s=-(omegae.^2).*(M66s+A66s)+i*omegae.*B66s+C66s;
A22bar_k=-(omegae.^2).*(M22k+A22k)+i*omegae.*B22k+C22k;
A26bar_k=-(omegae.^2).*(M26k+A26k)+i*omegae.*B26k+C26k;
A62bar_k=-(omegae.^2).*(M62k+A62k)+i*omegae.*B62k+C62k;
A66bar_k=-(omegae.^2).*(M66k+A66k)+i*omegae.*B66k+C66k;
%
mu2_s=(A66bar_s.*F2s_t-A26bar_s.*F6s_t)./(A22bar_s.*A66bar_s-
A26bar_s.*A62bar_s);
nu2_s=(A66bar_s-A26bar_s*x_s)./(A22bar_s.*A66bar_s-
A26bar_s.*A62bar_s);
mu6_s=(A22bar_s.*F6s_t-A62bar_s.*F2s_t)./(A22bar_s.*A66bar_s-
A62bar_s.*A26bar_s);
nu6_s=(A22bar_s*x_s-A62bar_s)./(A22bar_s.*A66bar_s-
A62bar_s.*A26bar_s);
mu2_k=(A66bar_k.*F2k_t-A26bar_k.*F6k_t)./(A22bar_k.*A66bar_k-
A26bar_k.*A62bar_k);
nu2_k=(A66bar_k-A26bar_k*x_k)./(A22bar_k.*A66bar_k-
A26bar_k.*A62bar_k);
mu6_k=(A22bar_k.*F6k_t-A62bar_k.*F2k_t)./(A22bar_k.*A66bar_k-
A62bar_k.*A26bar_k);
nu6_k=(A22bar_k*x_k-A62bar_k)./(A22bar_k.*A66bar_k-
A62bar_k.*A26bar_k);
%
a=mu2_s+mu6_s*x_s-mu2_k-mu6_k*x_k;
b=nu2_s+nu6_s*x_s+nu2_k+nu6_k*x_k;
f=a./(l/T+b);
```

```
%
f_s=-f;                          % Connection force on SLICE
f_k=f;                  % Connection force on KAIMALINO
eta2_s=mu2_s+nu2_s.*f_s;          % SLICE sway
eta6_s=mu6_s+nu6_s.*f_s;          % SLICE yaw
eta2_k=mu2_k+nu2_k.*f_k;          % KAIMALINO sway
eta6_k=mu6_k+nu6_k.*f_k;          % KAIMALINO yaw
xi_s=eta2_s+eta6_s*x_s;                      % SLICE motion at
connection
xi_k=eta2_k+eta6_k*x_k;                      % KAIMALINO motion
at connection
xi0_s=mu2_s+mu6_s*x_s;                      % SLICE motion at
connection for zero f
xi0_k=mu6_k+mu6_k*x_k;           % KAIMALINO motion at connection
for zero f
for i_loop=1:100,
   omega_m=  omega_m_min + (i_loop-1)*( omega_m_max - omega_m_min) /
(100-1);
   omega_m_vector(i_loop)=omega_m;
   T_m_vector(i_loop)=(2*pi)/omega_m;
%
% Random wave calculations
% Bretschneider spectrum
%
A=(1.25/4)*(omega_m^4)*(HS^2);
```

```
B=1.25*omega_m^4;
S     =(A./omega.^5).*exp(-B./omega.^4);
Se    =S./(1-(2.0/g)*omega*V*cos(beta));                  % Convert S(w) to S(we)
%
% Define response spectra
%
Sf     =((abs(f)).^2).*Se;
Sxi_s  =((abs(xi_s)).^2).*Se;
Sxi_k  =((abs(xi_k)).^2).*Se;
Sxi0_s =((abs(xi0_s)).^2).*Se;
Sxi0_k =((abs(xi0_k)).^2).*Se;
SF2s_t =((abs(F2s_t)).^2).*Se;
SF2k_t =((abs(F2k_t)).^2).*Se;
%
% Initializations
%
Sf_i=0;
Sxi_s_i=0;
Sxi_k_i=0;
Sxi0_s_i=0;
Sxi0_k_i=0;
SF2s_t_i=0;
SF2k_t_i=0;
%
```

```
% Integral S(w)*|RAO|^2
%
for I=2:1:filesize(2),
  Sf_i    = Sf_i     + 0.5*(Sf(I)     + Sf(I-1))     * (omegae(I-1)-omegae(I));
  Sxi_s_i = Sxi_s_i  + 0.5*(Sxi_s(I)  + Sxi_s(I-1))  * (omegae(I-1)-omegae(I));
  Sxi_k_i = Sxi_k_i  + 0.5*(Sxi_k(I)  + Sxi_k(I-1))  * (omegae(I-1)-omegae(I));
  Sxi0_s_i= Sxi0_s_i + 0.5*(Sxi0_s(I) + Sxi0_s(I-1)) * (omegae(I-1)-
omegae(I));
  Sxi0_k_i= Sxi0_k_i + 0.5*(Sxi0_k(I) + Sxi0_k(I-1)) * (omegae(I-1)-
omegae(I));
  SF2s_t_i= SF2s_t_i + 0.5*(SF2s_t(I) + SF2s_t(I-1)) * (omegae(I-1)-
omegae(I));
  SF2k_t_i= SF2k_t_i + 0.5*(SF2k_t(I) + SF2k_t(I-1)) * (omegae(I-1)-
omegae(I));
end
%
% RMS values
%
RMS_f     = sqrt(Sf_i);
RMS_xi_s  = sqrt(Sxi_s_i);
RMS_xi_k  = sqrt(Sxi_k_i);
RMS_xi0_s = sqrt(Sxi0_s_i);
RMS_xi0_k = sqrt(Sxi0_k_i);
RMS_F2s_t = sqrt(SF2s_t_i);
RMS_F2k_t = sqrt(SF2k_t_i);
```

```
%
RMS_f_vector(i_loop)=RMS_f/(rho*g*L^2);
end
plot(T_m_vector,RMS_f_vector),grid,xlabel('Modal Period'),ylabel('RMS force')
```

APPENDIX E

```
% Horizontal Plane
% Dimensional version (U.S. units)
%
% Get run info
%
clear
%
V   =input('Speed (knots) = ');
beta=input('Heading (deg) = ');
l   =input('Length (l/L)  = ');
%
% Get tension from curvefitting data.
% Applicable for speeds between 1 and 20 ft/sec.
%
T=-1.762*V^4+63.675*V^3-580.8*V^2+2485.9*V-34.047;
%
V_string   =num2str(V);
beta_string=num2str(beta);
%
% The matdata output files default to the horizontal only format when the
% heading angle is 0 or 180 degrees.
% Set up file reading format.
```

```
%
trigg = 30;
f2loc = 26; f6loc = 30;
if beta==0
   trigg = 27;
   f2loc = 25; f6loc = 27;
elseif beta==180
   trigg = 27;
   f2loc = 25; f6loc = 27;
end
%
% Load SLICE data file msvhV_beta.txt
%
load_filename=strcat('msvh',V_string,'_',beta_string,'.txt');
filename_s=load(load_filename);
%
% Load KAIMALINO data file
%
load_filename=strcat('mkvh',V_string,'_',beta_string,'.txt');
filename_k=load(load_filename);
%
% GENERAL DATA
%
V=V*1.6878;                                        % Convert to ft/sec
```

```
lambda_min=20;                  % Min wave length (ft)
lambda_max=1000;   % Max wave length (ft)
delta_lambda=20;    % Wave length increment (ft)
rho=1.9905;                                  % Water density
zeta=1;                                      % Regular wave height
L=105;                                       % Reference length for
nondimensionalization
g=32.2;                                                %
Gravitational constant
x_s=-46;                         % SLICE attachment point
x_k=+40;                        % KAIMALINO attachment point
HS=10;                                                 %
Significant wave height (ft)
beta      = beta*pi/180;
lambda     = lambda_min:delta_lambda:lambda_max;
% Vector of wavelengths
wavenumber = 2.0*pi./lambda;

% Wave number
omega      = sqrt(wavenumber*g);
                                             % Wave frequency
omegae     = omega-wavenumber*V*cos(beta);
                                % Frequency of encounter
period     = 2.0*pi./omega;
periode    = 2.0*pi./omegae;
omega      = omega';
```

```
omegae     = omegae';
filesize   = size(lambda);
lambda_size= trigg*filesize(2);
%
% HORIZONTAL PLANE RESPONSE CALCULATIONS
%
% SLICE
%
% Set mass matrix elements
%
M22s=filename_s(2:trigg:lambda_size,2);
M26s=filename_s(2:trigg:lambda_size,6);
M62s=filename_s(6:trigg:lambda_size,2);
M66s=filename_s(6:trigg:lambda_size,6);
%
% Added mass terms
%
A22s=filename_s(8:trigg:lambda_size,2);
A26s=filename_s(8:trigg:lambda_size,6);
A62s=filename_s(12:trigg:lambda_size,2);
A66s=filename_s(12:trigg:lambda_size,6);
%
% Damping terms
%
```

```
B22s=filename_s(14:trigg:lambda_size,2);
B26s=filename_s(14:trigg:lambda_size,6);
B62s=filename_s(18:trigg:lambda_size,2);
B66s=filename_s(18:trigg:lambda_size,6);
%
% Hydrostatic terms
%
C22s=filename_s(20:trigg:lambda_size,2);
C26s=filename_s(20:trigg:lambda_size,6);
C62s=filename_s(24:trigg:lambda_size,2);
C66s=filename_s(24:trigg:lambda_size,6);


if beta==0
  F2s_t=zeros(50,1); F6s_t=zeros(50,1);
elseif beta==180
   F2s_t=zeros(50,1); F6s_t=zeros(50,1);
else
   %
% Total exciting forces
%
F2s_t_amp=filename_s(f2loc:trigg:lambda_size,5);
F6s_t_amp=filename_s(f6loc:trigg:lambda_size,5);
F2s_t_pha=filename_s(f2loc:trigg:lambda_size,6);
F6s_t_pha=filename_s(f6loc:trigg:lambda_size,6);
```

```
F2s_t=F2s_t_amp.*exp(i*F2s_t_pha.*pi/180.0);
F6s_t=F6s_t_amp.*exp(i*F6s_t_pha.*pi/180.0);
%
% Froude/Krylov exciting forces
%
F2s_f_amp=filename_s(f2loc:trigg:lambda_size,1);
F6s_f_amp=filename_s(f6loc:trigg:lambda_size,1);
F2s_f_pha=filename_s(f2loc:trigg:lambda_size,2);
F6s_f_pha=filename_s(f6loc:trigg:lambda_size,2);
F2s_f=F2s_f_amp.*exp(i*F2s_f_pha.*pi/180.0);
F6s_f=F6s_f_amp.*exp(i*F6s_f_pha.*pi/180.0);
%
% Diffraction exciting forces
%
F2s_d_amp=filename_s(f2loc:trigg:lambda_size,3);
F6s_d_amp=filename_s(f6loc:trigg:lambda_size,3);
F2s_d_pha=filename_s(f2loc:trigg:lambda_size,4);
F6s_d_pha=filename_s(f6loc:trigg:lambda_size,4);
F2s_d=F2s_d_amp.*exp(i*F2s_d_pha.*pi/180.0);
F6s_d=F6s_d_amp.*exp(i*F6s_d_pha.*pi/180.0);
%
end


% KAIMALINO
```

```
%
% Set mass matrix elements
%
M22k=filename_k(2:trigg:lambda_size,2);
M26k=filename_k(2:trigg:lambda_size,6);
M62k=filename_k(6:trigg:lambda_size,2);
M66k=filename_k(6:trigg:lambda_size,6);
%
% Added mass terms
%
A22k=filename_k(8:trigg:lambda_size,2);
A26k=filename_k(8:trigg:lambda_size,6);
A62k=filename_k(12:trigg:lambda_size,2);
A66k=filename_k(12:trigg:lambda_size,6);
%
% Damping terms
%
B22k=filename_k(14:trigg:lambda_size,2);
B26k=filename_k(14:trigg:lambda_size,6);
B62k=filename_k(18:trigg:lambda_size,2);
B66k=filename_k(18:trigg:lambda_size,6);
%
% Hydrostatic terms
%
```

```
C22k=filename_k(20:trigg:lambda_size,2);
C26k=filename_k(20:trigg:lambda_size,6);
C62k=filename_k(24:trigg:lambda_size,2);
C66k=filename_k(24:trigg:lambda_size,6);

if beta==0
  F2k_t=zeros(50,1); F6k_t=zeros(50,1);
elseif beta==180
   F2k_t=zeros(50,1); F6k_t=zeros(50,1);
else
%
% Total exciting forces
%
F2k_t_amp=filename_k(f2loc:trigg:lambda_size,5);
F6k_t_amp=filename_k(f6loc:trigg:lambda_size,5);
F2k_t_pha=filename_k(f2loc:trigg:lambda_size,6);
F6k_t_pha=filename_k(f6loc:trigg:lambda_size,6);
F2k_t=F2k_t_amp.*exp(i*F2k_t_pha.*pi/180.0);
F6k_t=F6k_t_amp.*exp(i*F6k_t_pha.*pi/180.0);
%
% Froude/Krylov exciting forces
%
F2k_f_amp=filename_k(f2loc:trigg:lambda_size,1);
F6k_f_amp=filename_k(f6loc:trigg:lambda_size,1);
```

```
F2k_f_pha=filename_k(f2loc:trigg:lambda_size,2);
F6k_f_pha=filename_k(f6loc:trigg:lambda_size,2);
F2k_f=F2k_f_amp.*exp(i*F2k_f_pha.*pi/180.0);
F6k_f=F6k_f_amp.*exp(i*F6k_f_pha.*pi/180.0);
%
% Diffraction exciting forces
%
F2k_d_amp=filename_k(f2loc:trigg:lambda_size,3);
F6k_d_amp=filename_k(f6loc:trigg:lambda_size,3);
F2k_d_pha=filename_k(f2loc:trigg:lambda_size,4);
F6k_d_pha=filename_k(f6loc:trigg:lambda_size,4);
F2k_d=F2k_d_amp.*exp(i*F2k_d_pha.*pi/180.0);
F6k_d=F6k_d_amp.*exp(i*F6k_d_pha.*pi/180.0);
end
%
% MATCHING CONDITION
%
A22bar_s=-(omegae.^2).*(M22s+A22s)+i*omegae.*B22s+C22s;
A26bar_s=-(omegae.^2).*(M26s+A26s)+i*omegae.*B26s+C26s;
A62bar_s=-(omegae.^2).*(M62s+A62s)+i*omegae.*B62s+C62s;
A66bar_s=-(omegae.^2).*(M66s+A66s)+i*omegae.*B66s+C66s;
A22bar_k=-(omegae.^2).*(M22k+A22k)+i*omegae.*B22k+C22k;
A26bar_k=-(omegae.^2).*(M26k+A26k)+i*omegae.*B26k+C26k;
A62bar_k=-(omegae.^2).*(M62k+A62k)+i*omegae.*B62k+C62k;
```

```
A66bar_k=-(omegae.^2).*(M66k+A66k)+i*omegae.*B66k+C66k;
%
mu2_s=(A66bar_s.*F2s_t-A26bar_s.*F6s_t)./(A22bar_s.*A66bar_s-
A26bar_s.*A62bar_s);
nu2_s=(A66bar_s-A26bar_s*x_s)./(A22bar_s.*A66bar_s-
A26bar_s.*A62bar_s);
mu6_s=(A22bar_s.*F6s_t-A62bar_s.*F2s_t)./(A22bar_s.*A66bar_s-
A62bar_s.*A26bar_s);
nu6_s=(A22bar_s*x_s-A62bar_s)./(A22bar_s.*A66bar_s-
A62bar_s.*A26bar_s);
mu2_k=(A66bar_k.*F2k_t-A26bar_k.*F6k_t)./(A22bar_k.*A66bar_k-
A26bar_k.*A62bar_k);
nu2_k=(A66bar_k-A26bar_k*x_k)./(A22bar_k.*A66bar_k-
A26bar_k.*A62bar_k);
mu6_k=(A22bar_k.*F6k_t-A62bar_k.*F2k_t)./(A22bar_k.*A66bar_k-
A62bar_k.*A26bar_k);
nu6_k=(A22bar_k*x_k-A62bar_k)./(A22bar_k.*A66bar_k-
A62bar_k.*A26bar_k);
%
a=mu2_s+mu6_s*x_s-mu2_k-mu6_k*x_k;
b=nu2_s+nu6_s*x_s+nu2_k+nu6_k*x_k;
f=a./(l/T+b);
%
f_s=-f;
    % Connection force on SLICE
f_k=f;                                  %
Connection force on KAIMALINO
```

```
eta2_s=mu2_s+nu2_s.*f_s;            % SLICE sway
eta6_s=mu6_s+nu6_s.*f_s;            % SLICE yaw
eta2_k=mu2_k+nu2_k.*f_k;            % KAIMALINO sway
eta6_k=mu6_k+nu6_k.*f_k;            % KAIMALINO yaw
xi_s=eta2_s+eta6_s*x_s;                         % SLICE motion at
connection
xi_k=eta2_k+eta6_k*x_k;                         % KAIMALINO motion
at connection
xi0_s=mu2_s+mu6_s*x_s;                          % SLICE motion at
connection for zero f
xi0_k=mu6_k+mu6_k*x_k;              % KAIMALINO motion at connection
for zero f



%
% Random wave calculations
% Pierson-Moscowitz spectrum
%
POWER =-.032*(g/HS)^2;
S    =(0.0081*g^2).*exp(POWER./(omega.^4))./(omega.^5);
Se   =S./(1-(2.0/g)*omega*V*cos(beta));             % Convert S(w) to S(we)
%
% Define response spectra
%
Sf    =((abs(f)).^2).*Se;
```

```
Sxi_s  =((abs(xi_s)).^2).*Se;

Sxi_k  =((abs(xi_k)).^2).*Se;

Sxi0_s =((abs(xi0_s)).^2).*Se;

Sxi0_k =((abs(xi0_k)).^2).*Se;

SF2s_t =((abs(F2s_t)).^2).*Se;

SF2k_t =((abs(F2k_t)).^2).*Se;

%

% Initializations

%

Sf_i=0;

Sxi_s_i=0;

Sxi_k_i=0;

Sxi0_s_i=0;

Sxi0_k_i=0;

SF2s_t_i=0;

SF2k_t_i=0;

%

% Integral S(w)*|RAO|^2

%

for I=2:1:filesize(2),

  Sf_i    = Sf_i     + 0.5*(Sf(I)     + Sf(I-1))     * (omegae(I-1)-omegae(I));

  Sxi_s_i = Sxi_s_i  + 0.5*(Sxi_s(I)  + Sxi_s(I-1))  * (omegae(I-1)-omegae(I));

  Sxi_k_i = Sxi_k_i  + 0.5*(Sxi_k(I)  + Sxi_k(I-1))  * (omegae(I-1)-omegae(I));
```

```
    Sxi0_s_i= Sxi0_s_i + 0.5*(Sxi0_s(I) + Sxi0_s(I-1)) * (omegae(I-1)-
omegae(I));
    Sxi0_k_i= Sxi0_k_i + 0.5*(Sxi0_k(I) + Sxi0_k(I-1)) * (omegae(I-1)-
omegae(I));
    SF2s_t_i= SF2s_t_i + 0.5*(SF2s_t(I) + SF2s_t(I-1)) * (omegae(I-1)-
omegae(I));
    SF2k_t_i= SF2k_t_i + 0.5*(SF2k_t(I) + SF2k_t(I-1)) * (omegae(I-1)-
omegae(I));
end
%
% RMS values
%
RMS_f     = sqrt(Sf_i);
RMS_xi_s  = sqrt(Sxi_s_i);
RMS_xi_k  = sqrt(Sxi_k_i);
RMS_xi0_s = sqrt(Sxi0_s_i);
RMS_xi0_k = sqrt(Sxi0_k_i);
RMS_F2s_t = sqrt(SF2s_t_i);
RMS_F2k_t = sqrt(SF2k_t_i);
%
figure (1)
plot(period,abs(xi0_s),'r',period,abs(xi_s),'b'),grid,legend('w/o connection','with
connection')
title('Leading Ship Motion'),xlabel('T [sec]'),ylabel('\xi_H [ft/ft]')
figure (2)
```

```
plot(period,abs(xi0_k),'r',period,abs(xi_k),'b'),grid,legend('w/o connection','with
connection')

title('Trailing Ship Motion'),xlabel('T [sec]'),ylabel('\xi_H [ft/ft]')

figure (3)

plot(period,abs(f),'r',period,F2s_t_amp,'b',period,F2k_t_amp,'g'),grid,legend('con
nection force','wave, leading ship','wave, trailing ship')

title('Exciting Forces'),xlabel('T [sec]'),ylabel('F [lbs/ft]')
```

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