THESIS

FREQUENCY RESPONSE ANALYSIS OF T-ACS EXPERIMENTAL DATA

by

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September 2000

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ABSTRACT (maximum 200 words)

Trial runs of a 1:24 scale model crane ship were conducted in the David Taylor Model Basin. The model’s response to regular waves under various ship configurations, crane configurations, sea states and ship headings relative to the incoming waves were recorded. The Response Amplitude Operator (RAO) Program analyzes the frequency responses to controlled, regular waves and generates full-scale RAOs as a prediction of the actual ship’s response. Accurate generation of these full-scale RAOs enables future prediction, using the principle of linear superposition, of ship motions in an irregular sea to be compared to actual, full-scale trial runs being conducted off the coast of California near Camp Pendleton in September 2000.
FREQUENCY RESPONSE ANALYSIS OF T-ACS EXPERIMENTAL DATA

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Trial runs of a 1:24 scale model crane ship were conducted in the David Taylor Model Basin. The model's response to regular waves under various ship configurations, crane configurations, sea states and ship headings relative to the incoming waves were recorded. The Response Amplitude Operator (RAO) Program analyzes the frequency responses to controlled, regular waves and generates full-scale RAOs as a prediction of the actual ships response. Accurate generation of these full-scale RAOs enables future prediction, using the principle of linear superposition, of ship motions in an irregular sea to be compared to actual, full-scale trial runs being conducted off the coast of California near Camp Pendleton in September 2000.
TABLE OF CONTENTS

I. INTRODUCTION ........................................................................................................... 1

II. PROBLEM FORMULATION ......................................................................................... 5

   A. THEORY ..................................................................................................................... 5
      1. Random Process ................................................................................................. 5
      2. Energy Spectra and Power Spectral Densities ................................................. 5
      3. Response Amplitude Operators ............................................................. 6

   B. COMPARISON TOOLS .......................................................................................... 7
      1. Spreadsheet Results ....................................................................................... 7
      2. MATLAB Methods .......................................................................................... 8
         a. Welch ........................................................................................................... 8
         b. Periodogram ............................................................................................... 10
         c. Multi-taper ............................................................................................... 11

III. PROGRAM DEVELOPMENT .................................................................................... 13

   A. GENERAL DESCRIPTION ..................................................................................... 13
      1. Initial Set-up ................................................................................................... 13
      2. Establish Proper String Configuration for the Data Run ......................... 15
      3. Determine Number of Data Channels to be Processed .......................... 15
      4. Establish File-path and Load the Raw, Time-based Data ...................... 16
      5. Compute both Model-Scale and Full-Scale Omega Ranges ............... 17
      6. Full-Scale Scalers, PSD Units and RAO Units Library ......................... 17
      7. Looping/Processing of Data Channels ...................................................... 18
      8. Base-lining the Raw, Time-based Data .................................................... 20
      9. FFT Computation .......................................................................................... 21
     10. Model-Scale PSD Computation .............................................................. 21
     11. Moving-window Averaging of Model-Scale PSDs ................................ 22
     12. Computation of Model-Scale RAOs .......................................................... 26
     13. Computation of Full-Scale RAOs .............................................................. 27
     14. Plot Model-Scale PSDs and Save Figure in jpg Format ....................... 27
     15. Plot Model-Scale RAOs and Save Figure in jpg Format ....................... 28
     16. Plot Full-Scale RAOs and Save Figures in jpg Format .......................... 29
     17. Save Omega Matrices as Last Column of Composite PSD and RAO Matrices ......................................................... 31
     18. Save Composite PSD and RAO Matrices .................................................. 31
B. VALIDATION

1. Load Applicable Matrices .................................................. 32
2. Base-line the Raw, Time-Based Data .................................. 33
3. Compute Wave Ht PSDs using MATLAB Methods .............. 33
4. Compute TACS Roll PSDs using MATLAB Methods .......... 34
5. Convert MATLAB Method Frequencies to Omegas .......... 34
6. Compute Areas under the PSD Curves for Comparison ... 35
7. Graphical Comparison of Model-Scale PSDs .................... 37
8. Compute Model-Scale RAOs ............................................. 41
9. Graphical Comparison of Model-Scale RAOs .................... 42
10. Scale to Full-Scale RAOs and Omegas ................................ 43
11. Graphical Comparison of Full-Scale RAOs ....................... 44

IV. CONCLUSIONS & RECOMMENDATIONS ........................................ 47

A. CONCLUSIONS ........................................................................ 47

B. RECOMMENDATIONS ................................................................ 48

APPENDIX A. TEST CONFIGURATIONS I ........................................ 49

APPENDIX B. TEST CONFIGURATIONS II ........................................ 61

APPENDIX C. TEST CONFIGURATIONS II ........................................ 63

APPENDIX D. MASTER CHANNEL LIST: CONFIGURATION I ........ 65

APPENDIX E. MASTER CHANNEL LIST: CONFIGURATION II .......... 67

APPENDIX F. MASTER CHANNEL LIST: CONFIGURATION III ....... 69

APPENDIX G. RAO PROGRAM ......................................................... 71

APPENDIX H. PTAVG COMPARISON PROGRAM .......................... 89

APPENDIX I. PSD AND RAO COMPARISONS PROGRAM .............. 91

LIST OF REFERENCES ................................................................. 97
I. INTRODUCTION

From July 15th to August 17th of 1997, trial runs using 1:24 scale models of a T-ACS Auxiliary Crane Ship, a DDG-963 Class Ship, a Commercial Container Ship and Lighter Barges were conducted in the seakeeping basin of the David Taylor Model Basin at Carderock Division Naval Surface Warfare Center (CDNSWC), Bethesda, Maryland. T-ACS Auxiliary Crane ships are ran by the Military Sealift Command Ready Reserve Force. These self-sustaining, rapidly-deployable ships support military sea transportation needs and are extremely useful in ports that have limited, damaged or undeveloped port facilities. The functions of T-ACS ships are to lift and transfer various loads from either themselves or adjacent vessels and piers.

A total of 251 different model-scale trial runs were performed, each running approximately 8 minutes, under a matrix of variable conditions:

<table>
<thead>
<tr>
<th>Variable Condition:</th>
<th>Description:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship Configurations</td>
<td>Config I</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Config II</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Config III  T-ACS in Center

Lighter Barges to Port

Ship Heading  45 degree increments from 0 to 360 degrees relative to incoming waves

Sea State  Model-scale sea states 3, 3 + swell, 4 and 4 + swell

Boom Slew Angle  Angles of 0, 45, 90, 270 and 315 degrees

Rider Block Location  Various positions from 0 to 45.3 degrees

Rider Block Inhaul Angle  Various angles from 0 to 16 degrees

Boom Luff Angle  Angles of 25, 29.6, 54.5 and 60 degrees

A composition of wave height, body motion, velocity and acceleration data for the vessels was recorded for each run from an array of sensors with their locations dependant upon the ship configurations listed above. Results from the 213 Configuration I trial runs, the most probable ship configuration, were provided for frequency response analysis of the raw data to estimate the Full-Scale Response Amplitude Operators (RAOs) of the T-ACS auxiliary crane ship. An RAO is basically a measure or ratio of a vessels response to a regular wave of unit amplitude and thus defined accordingly:

\[ RAO = \frac{\text{amplitude of response}}{\text{amplitude of the wave}} \]  

(Zubaly, 1996, pp. 322)
Tupper expresses the method of studying responses in a seaway in the following manner:

"... the apparently random surface of the sea can be represented by the summation of a large number of regular sinusoidal waves, each with its own length, height, direction and phase."

(Tupper, 1996, pp. 104)

"... the response of the ship in such a sea could be taken as the summation of its responses to all the individual wave components. Hence the basic building block for the general study of motions in a seaway is the response to a regular sinusoidal wave."

(Tupper, 1996, pp. 104)

These concepts strongly identify the need for multiple trial runs using a matrix of variable conditions. The study of responses such as severe rolling in a beam sea or excessive pitching and heaving in a head sea provides extremely valuable insight into a vessel's limitations. Operating or load-handling constraints can then be established based upon existing as well as predicted conditions to prevent material damage, downtime and/or, even worse, human injury.
II. PROBLEM FORMULATION

A. THEORY

1. Random Process

Determining RAOs begins with periodic sampling of random processes such as a changing waveheight or a vessels changing responses to the changing waveheight over an interval of time. In this case, each data channel was sampled at a rate of 32.2 Hz over an interval of approximately 8 minutes per data run. This sampling produces the raw data from which the entire RAO determination process is based upon. But, before the raw data can be used, it must be base-lined to remove any offset or bias errors inherent in the sampling system to prevent them from contaminating the process. This is done by determining the mean of the data points for a given channel and then subtracting this mean from each data point. When this step is completed for each data channel, the process is ready to continue.

2. Energy Spectra and Power Spectral Densities (PSDs)

The next phase in determining RAOs is to generate a representative energy spectrum curve for each data channel comprised of Power Spectral Densities (PSDs) vs. wave frequencies (omegas) in which the area under the curve represents the energy associated with the changing data. (Papoulias,2000,pp.109) The PSDs for this curve are
derived by expansion of the data points per channel into a Fourier series which approximates the shape of the energy spectrum at the various omegas. (Papoulias, 2000, pp. 121) The mean square of the base-lined, raw data record within a narrow band of omega centered at omega is represented as follows:

\[ r^2(\omega) = S(\omega) \Delta \omega \quad \text{where} \quad \bar{r} = \text{data\_mean\_over\_\omega\_band} \]

\[ S(\omega) = \text{energy\_spectra} \]

\[ \Delta \omega = \text{omega\_band} \]

(Papoulias, 2000, pp. 109)

Thus, as an integrity check along the way which is utilized later in the PSD and RAO comparison program, the mean square of the whole, base-lined, raw data record should equal the area under the entire spectral curve:

\[ r^2(\omega) = \int S(\omega) d\omega \]  

(Papoulias, 2000, pp. 109)

3. **Response Amplitude Operators (RAOs)**

Finally, the RAOs are determined by the ratio of the response PSDs over the reference waveheight PSDs as follows:
\[ |RAO_R|^2 = \frac{PSD_R}{PSD_w} \quad \text{where} \quad RAO_R = response_{RAO} \]

\[ PSD_R = response_{PSD} \]

\[ PSD_w = \text{waveheight}_{PSD} \]

(Papoulia, 2000, pp. 124)

B. COMPARISON TOOLS

1. Spreadsheet Results

Spreadsheet Results are selected PSDs, RAOs and Omegas for specific Configuration I trial runs that were initially processed by Mr. Dan Hayden of CDNSWC using a spreadsheet program. Only seven data channels were processed per run. These channels were the four pitch and roll channels (channels 3-6) as well as the three relative TACS/Lighter positions (channels 28-30). As for the specific data runs, only 19, 27, 57, 67, 390 and 392 were processed.

The Spreadsheet Results provided a reference to which the RAO Program results would be compared. If the RAO Program results were consistent with each of the seven processed channels, it was assumed that the remaining channels would be correct as well. In order to ensure that the referenced Spreadsheet Results were correct, three additional
MATLAB methods of computing PSDs were used to validate both the Spreadsheet Results and the RAO Program.

2. MATLAB Methods

In addition to the FFT method in the RAO Program, three additional methods of computing PSDs were utilized as comparison tools to ensure validity of both the Spreadsheet Results and the RAO Program: Welch, Periodogram and Multi-taper Methods. The PSDs are computed in units of power per radians while the frequencies in Hz are later converted to radians per second. Although there are many similarities, each method performs the task quite differently.

a. Welch: $[\text{PSDs,Freqs}] = \text{pwelch}(x,\text{nw\_window},\text{no\_overlap},\text{nfft},\text{fs})$

The selectable options when utilizing the Welch method are as described as follows:

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>Base-lined, Raw, Time-based Data Vector</td>
</tr>
<tr>
<td>nw_window</td>
<td>Hamming Window Length for Modified Periodograms</td>
</tr>
<tr>
<td></td>
<td>(Default of [] divides data vector into 8 equal-length windows with residual data points discarded)</td>
</tr>
<tr>
<td>no_overlap</td>
<td>Number of Overlapping, Windowed Data Points (Default of [] uses 50% overlap from window to window)</td>
</tr>
</tbody>
</table>
nfft Length of the Fourier Transform for each Window

fs Data Sampling Frequency (32.2 Hz)

(SPT,welch)

The Welch method produces PSDs by averaging periodograms of overlapping, Hamming-windowed sections of the data vector. Hamming windowing reduces possible sidelobes in the spectral estimate in order to reveal the presence of weaker components of the signal spectrum that may otherwise get hidden. (Marple, 1987, pp. 132) Specified-length, discrete Fourier transforms (DFTs) of the overlapping windows are computed as follows:

\[ X(k+1) = \sum_{n=0}^{N-1} x(n+1)W_n^{kn} \quad \text{where} \quad W_n = e^{-j(2\pi n/N)} \]

\[ N = length(x) \]

\[ X = DFT \]

(SPT,welch)

Indexing of (n+1) and (k+1) is used since MATLAB vectors run from 1 to N instead of 0 to N-1. (SPT,fft) A modified periodogram for each windowed segment is then computed:
\[
\text{Modified Periodogram} = S(e^{j\omega}) = \left( \frac{1}{n} \sum_{i=1}^{n} \omega_i x_i e^{j\omega} \right) \left( \frac{1}{n} \sum_{i=1}^{n} |\omega_i|^2 \right)^{-1}
\]

(SPT, periodogram)

The individual periodograms are averaged to produce just one representative periodogram. (SPT, periodogram) Finally, the PSDs are computed:

\[
\text{PSDs} = \left( \frac{1}{fs} \right) S_x(e^{j\omega})
\]

(SPT, periodogram)

b.  Periodogram: \([\text{PSDs, Freqs}] = \text{periodogram}(x, \text{window}, \text{nfft}, \text{fs})\)

The selectable options when utilizing the Periodogram method are as follows:

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>Base-lined, Raw, Time-based Data Vector</td>
</tr>
<tr>
<td>window</td>
<td>Window Coefficients for Modified Periodogram of the Input Matrix (Used for &quot;m&quot;x&quot;n&quot; matrixes. Default of [] implies single column data vector)</td>
</tr>
</tbody>
</table>
nfft  

Length of the Fourier Transform

fs  

Data Sampling Frequency (32.2 Hz)

(SPT,periodogram)

The Periodogram method produces PSDs in the same general manner as the Welch method previously discussed. A modified periodogram is generated which leads directly to computation of the PSDs. The differences between the two are that no windowing/segmenting of the data vector occurs and only one periodogram is generated. (SPT,periodogram) Thus, the Welch method is essentially a refinement of the Periodogram method.

c.  

Multi-taper:  \([PSDs,Freqs] = pmtm(x,nw,nfft,fs)\)

The selectable options when utilizing the third, Multi-taper, method are as follows:

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>Base-lined, Raw, Time-based Data Vector</td>
</tr>
<tr>
<td>nw</td>
<td>Determines Number of Discrete Prolate Spheroidal Sequences ((n = 2^{nw} - 1)) used as Data Tapers for of Estimation of PSDs (Default of [] is (nw = 4))</td>
</tr>
</tbody>
</table>
nfft \quad \text{Length of the Fourier Transform}

fs \quad \text{Data Sampling Frequency (32.2 Hz)}

(SPT,pmtm)

The Multi-taper method is by far the most complex of the three comparison methods for production of PSDs. This method combines linear and nonlinear modified periodograms to estimate the PSDs by computing each periodogram using a sequence of orthogonal tapers or windows in the frequency domain as specified from the discrete prolate spheroidal sequences. (SPT,pmtm)
III. PROGRAM DEVELOPMENT

A. GENERAL DESCRIPTION

The RAO program contains a sequence of events utilizing standard MATLAB functions. The validation methods to be discussed later are dependant upon the MATLAB Signals Processing Toolbox from which the commands are comprised of standard functions within the source code. Each significant event of the RAO program is addressed below:

1. Initial Set-up

Before processing a data run, both the raw data disc and the output storage disc must be placed in their respective designated drives. Designation of these drives must conform to the system being used for processing. In order to start the RAO program, the operator enters the desired run number to be processed as a MATLAB command in one of the following two formats:

<table>
<thead>
<tr>
<th>Command Format</th>
<th>Applicable DTMB Runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>rao(##)</td>
<td>19 - 99</td>
</tr>
<tr>
<td>rao(###)</td>
<td>101 – 587</td>
</tr>
</tbody>
</table>
Once this has been initiated, the program designates which drive the raw, time-based data is to be read from as well as which drive the generated jpg format figures and composite matrices for the specific run are to be saved to. A floating-point format with 5 digits is placed into effect and the following constants are established:

<table>
<thead>
<tr>
<th>Constant:</th>
<th>Definition:</th>
</tr>
</thead>
<tbody>
<tr>
<td>ptavg = 50</td>
<td>Number of Sequential PSDs used for Smoothing</td>
</tr>
<tr>
<td>window = 500</td>
<td>Number of PSDs within a Rational Freq Range</td>
</tr>
<tr>
<td>lambda = 24.175</td>
<td>Actual Model Scale (1:24.175)</td>
</tr>
<tr>
<td>freq = 32.2</td>
<td>Raw Data Sampling Frequency in Hz</td>
</tr>
</tbody>
</table>

Selection of the “ptavg” constant is the unavoidable compromise between display resolution and accuracy which will be addressed later. As for the “window” constant, it envelops the first 500 smoothed PSDs which encompass a reasonable range of omegas to be addressed under full-scale conditions. The remaining constant, “freq”, is the frequency at which the raw, time-based data was sampled.

```matlab
% Initial Set-up----------------------------------------
function rao(run)

sread = char('H:\');
swrite = char('D:\'

format short e
```

14
2. Establish Proper String Configuration for the Data Run

Based upon the run number entered by the operator, proper string configurations for the run as well as the folder to which results are to be saved are established. The program then differentiates between a two digit and a three digit run number so that the run string evolves as “R###” and the folder as “###”. Broad applicability of designators such as these are utilized throughout the RAO program.

```bash
% Establish Proper String Configuration for Data Run--
if run <= 99
    s1 = char('R0');
    s2 = char('0');
else
    s1 = char('R');
end

srun = num2str(run)
filename = strcat(s1,srun);

if run <= 99
    folder = strcat(s2,srun);
else
    folder = srun;
end
```

3. Determine Number of Data Channels to be Processed

The run number entered enables identification of the number of data channels to be processed due to the particular data channel configuration for the run as follows:
<table>
<thead>
<tr>
<th>DTMB runs:</th>
<th>Configuration:</th>
<th>Data Channels:</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 – 503</td>
<td>I</td>
<td>46</td>
</tr>
<tr>
<td>504 - 533</td>
<td>II</td>
<td>38</td>
</tr>
<tr>
<td>534 – 587</td>
<td>III</td>
<td>24</td>
</tr>
</tbody>
</table>

Each data channel is individually labeled per configuration as listed in Appendixes A, B, and C.

```matlab
% Determine Number of Data Channels to be Processed---
if run <= 503
    channels = 46;
elseif run <= 533
    channels = 38;
else
    channels = 24;
end
```

4. Establish File-path and Load the Raw, Time-based Data

Given the run number and drive designation from which the data is to be read, "filepath" is established as a string in order to execute the MATLAB command "load" to load the raw, time-based data matrix for processing. Once the matrix is loaded, its dimensions are identified utilizing the MATLAB command "size." The number of columns representing the individual data channels is designated as the variable "channels" and the number of rows representing the number of data points collected is designated as the variable "n", both of which will be used throughout the program.
% Establish Filepath and Load the Raw, Time-based Data
filepath = [sread, filename];
load(filepath)
size = size(data);
channels = size(2);
n = size(1);

5. Compute both Model-Scale and Full-Scale Omega Ranges

Before going any further, the Model-Scale omega range is computed based upon
the sampling frequency, total number of data points and the “window” length designated
earlier. Dividing the Model-Scale range by the square root of the model scale “lambda”
produces the Full-Scale omega range. This is supported by the basic assumption for
presentation of motion data that “Natural periods of motion vary as the square root of the
linear dimension.” (Tupper,1996, pp.106) In addition, Tupper identifies that “In watching
model experiments the motion always seems rather ‘rapid’ because of the way period
changes. Thus, a 1/25 model will pitch and heave in a period only a fifth of the full-
scale ship.

% Compute both Model-Scale and Full-Scale Omega Ranges
momega = 2*pi*freq/n*(0:window-1);
fomega = momega/sqrt(lambda);

6. Full-Scale Scalers, PSD Units and RAO Units Library

There are four individual sets of Full-Scale scalers, PSD units and RAO units in
the library associated with the type of data collected by the a particular channel. The
combinations are as follows:
### Data Type: Full-Scale Scaler: PSD Units: RAO Units:

<table>
<thead>
<tr>
<th></th>
<th>Full-Scale Scaler:</th>
<th>PSD Units:</th>
<th>RAO Units:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave Height</td>
<td>1</td>
<td>in</td>
<td>dimensionless</td>
</tr>
<tr>
<td>Distance</td>
<td>12/lambda</td>
<td>deg</td>
<td>deg/in</td>
</tr>
<tr>
<td>Velocity</td>
<td>12/lambda^(3/2)</td>
<td>deg/s</td>
<td>deg/in s</td>
</tr>
<tr>
<td>Acceleration</td>
<td>12/lambda^(2)</td>
<td>deg/s^(2)</td>
<td>deg/in s^(2)</td>
</tr>
</tbody>
</table>

% Full-Scale Scalers, PSD Units and RAO Units Library-
fs1 = 1;
pul = '(in)';
ru1 = '(dimensionless)';

fs2 = 12/lambda;
pu2 = '(deg)';
ru2 = '(deg/in)';
fs3 = 12/lambda^(3/2);
pu3 = '(deg/s)';
ru3 = '(deg/in s)';

fs4 = 12/lambda^2;
pu4 = '(deg/s^2)';
ru4 = '(deg/in s^2)';

7. **Looping/Processing of Data Channels**

It's now time to begin looping to process the "channels" sequentially. From the first data channel to the last, each is assigned a Full-Scale Scaler, "fscalar"; a PSD Units, "psdunits"; an RAO Units, "raounits"; and a Channel Title, "ctitle". These assignments will be utilized later for labeling the generated jpg figures.
% Looping/Processing of Data Channels-------------------
for ch = 1:channels

    if channels==46
        if ch==1
            fscaler = fs1;
            psdunits = pu1;
            raounits = ru1;
            chtitle = 'Wave Ht Bow';
        elseif ch==2
            fscaler = fs1;
            psdunits = pu1;
            raounits = ru1;
            chtitle = 'Sonix Sonic';
        ...
        ...
        elseif ch==46
            fscaler = fs4;
            psdunits = pu4;
            raounits = ru4;
            chtitle = 'Lghtr1-PBow TvAcc';
        else
            end
        elseif channels==38
            if ch==1
                fscaler = fs1;
                psdunits = pu1;
                raounits = ru1;
                chtitle = 'Wave Ht Bow';
            elseif ch==2
                fscaler = fs1;
                psdunits = pu1;
                raounits = ru1;
                chtitle = 'Sonix Sonic';
            ...
            ...
            elseif ch==38
                fscaler = fs4;
                psdunits = pu4;
                endif
raunits = 'ru4';
chtile = 'Lghtrl-PBowTvAcc';
else
end

elseif channels==24

if ch==1
    fscaler = 'fs1';
    psdunits = 'pu1';
    raunits = 'ru1';
    chtile = 'Wave Ht Bow';
elseif ch==2
    fscaler = 'fs1';
    psdunits = 'pu1';
    raunits = 'ru1';
    chtile = 'Sonix Sonic';
    ...
    ...
elseif ch==24
    fscaler = 'fs4';
    psdunits = 'pu4';
    raunits = 'ru4';
    chtile = 'BoomTip-Vert Acc';
else
end
end

8. Base-lining the Raw, Time-based Data

The actual processing of data begins here by base-lining or removing the mean from the raw, time-based data. Otherwise, "Failure to remove large sample means or other trends in the data may result in distorted or biased spectral estimates." (Marple, 1987, pp.132)
9. FFT Computation

The MATLAB command "fft" returns the Fourier transform of the base-lined, column data matrix. If the matrix length is a power of two, the "fft" command employs a high-speed fast Fourier transform algorithm. But, this is not always the case since the number of data points per channel varies from run to run. In this situation, an alternate mixed-radix algorithm finds the prime factors of the column matrix length then computes the discrete Fourier transforms of the shorter sequences. Either way, the Fourier transform of the base-lined data is produced.

10. Model-Scale PSD Computation

The Model-Scale PSD is computed by multiplying the elements of the Fourier Transform by their complex conjugate and dividing by the total number of elements.
11. **Moving-window Averaging of Model-Scale PSDs**

This is where the RAO program method differs significantly from the tools in MATLAB previously identified by offering a much finer control over the resolution vs. display accuracy issue. An envelope initially starts with half the “ptavg” window plus one PSD points, averages them together and assigns that average as the first, smoothed PSD point. The envelope then accepts the next sequential PSD point, averages the now larger window and assigns that average as the second, smoothed PSD point. The process continues until the envelope reaches it’s maximum size of “ptavg” plus one where the latest average is assigned as the smoothed PSD point for the middle of the envelope. From here on out, the envelope accepts the next sequential PSD point while dropping the first one, thus maintaining a fixed-length, moving window. Refer to the following example:
Example: Let “ptavg” = 4

[..................Freshly Produced PSD Data Points....................]  
[ #1  #2  #3  #4  #5  #6  #7  #8  #9  #10 ]

[ 1st avg PSD ] Window starts at half “ptavg” plus one (i.e. 2 + 1)

[ 2nd avg PSD ] Window increments in size by one

[ 3rd avg PSD ] Max capacity of ptavg + 1 (i.e. 4 + 1)

[ 4th avg PSD ] Window begins shift to the right

[ 5th avg PSD ] Window continues to shift

[ 6th avg PSD ] Window still shifting

[............... ] ...

At this point in the RAO program, the smoothed PSDs are designated as a column of data in a composite PSD matrix with the column designation correlating directly to the data channel being processed. Thus, the first channel processed becomes the first column of PSD data in the composite PSD matrix. As for the chosen window length of 50 plus one, tests of trial runs using incrementally larger point average envelopes yielded a
compromise of "ptavg" = 50 which offered the best display resolution while maintaining accuracy in comparison to the spreadsheet results provided (see figs. 1-3)

\[
\% \text{ Moving-window Averaging of Model-Scale PSDs for Smoothing}
\]
\[
\text{halfptavg} = \text{ptavg}/2;
\]
\[
\text{sum} = 0;
\]
\[
\text{for } k = 1: \text{ptavg}
\]
\[
\quad \text{sum} = \text{sum} + \text{PSD}(k,1);
\]
\[
\quad \text{if } k > \text{halfptavg}
\]
\[
\quad \quad \text{psd}(k-\text{halfptavg}, \text{ch}) = \text{sum}/k;
\]
\[
\quad \quad \text{else}
\]
\[
\quad \quad \text{end}
\]
\[
\quad \text{end}
\]
\[
\text{pts} = \text{window} + \text{halfptavg};
\]
\[
\text{ptavgplusone} = \text{ptavg} + 1;
\]
\[
\text{j} = 1;
\]
\[
\text{for } k = \text{ptavgplusone}: \text{pts}
\]
\[
\quad \text{sum} = \text{sum} + \text{PSD}(\text{ptavg}+j,1) - \text{PSD}(j,1);
\]
\[
\quad \text{psd}(k-\text{halfptavg}, \text{ch}) = \text{sum}/\text{ptavg};
\]
\[
\quad \text{j} = j + 1;
\]
\[
\text{end}
\]

\[
\text{meansqr} = \text{mean}(x.^2);
\]
\[
\text{psdarea} = \text{trap(momega,psd(:,ch))};
\]
\[
\text{psdscaler} = \text{meansqr}/\text{psdarea};
\]
\[
\text{psd(:,ch)} = \text{psd(:,ch)}*\text{psdscaler}
\]
Figure 1.

Figure 2.
12. Computation of Model-Scale RAOs

As previously addressed in the theory, RAOs are obtained by taking the individual square roots of the desired PSDs divided by the seaway or wave height PSDs. With the first data channel for each configuration allocated as the reference wave height, the first channel of RAOs processed will naturally be at unity, a constant dimensionless value of one.

```matlab
% Computation of Model-Scale RAOs-----------------------------
X = psd(:,ch)./psd(:,1);
mrao(:,ch) = sqrt(X);
```
13. **Computation of Full-Scale RAOs**

Computation of the Full-Scale RAOs is simply a process of multiplying the Model-Scale RAOs by the Full-Scale Scaler. This previously selected scaler is based upon the nature of the data sampled.

```matlab
% Computation of Full-Scale RAOs-
frao(:,ch) = mrao(:,ch)*f scaler;
```

14. **Plot Model-Scale PSDs and Save Figure in jpg Format**

A plot of the smoothed, Model-Scale PSDs vs. their associated Model-Scale omegas is generated (see fig. 4) then saved as a figure in jpg format in a folder dedicated to the particular run and titled accordingly with the run number, channel number and a "p" for Model-Scale PSDs label.

```matlab
% Plot Model-Scale PSDs and Save Figure in jpg Format-
clf
plot(momega(1,:),psd(:,ch))
grid
sch = num2str(ch);
title(['Model-Scale PSDs for DTMB Run 'srun,' /
      Channel ',sch,' : 'chtile])
xlabel('Omega (rad/s)')
ylabel(['PSD 'psdunits])
saveas(gcf,[swrite,folder,'\',filename,'C',sch,'p'],
   'jpg');
```
15. Plot Model-Scale RAOs and Save Figure in jpg Format

A plot of the Model-Scale RAOs vs. their associated Model-Scale omegas is generated (see fig. 5) then saved as a figure in jpg format in a folder dedicated to the particular DTMB run and titled accordingly with the run number, channel number and an "m" for Model-Scale RAOs label.

```matlab
clf
plot(momega(:,1),mrao(:,ch))
grid
title(['Model-Scale RAOs for DTMB Run ' 'srn, ' '/
    Channel ',sch,' : 'chttitle])
xlabel('Omega (rad/s)')
```
16. **Plot Full-Scale RAOs and Save Figure in jpg Format**

A plot of the Full-Scale RAOs vs. their associated Full-Scale omegas is generated (see fig. 6) then saved as a figure in jpg format in a folder dedicated to the particular run and titled accordingly with the run number, channel number and an "f" for Full-Scale RAOs label.
Processing of the first data channel is now complete. The RAO program then loops back to event 7 listed above, Looping/Processing of Data Channels, until all data channels for the specific run, as determined by the data configuration, have been processed to generate the Model-Scale PSDs, Model-Scale RAOs and Full-Scale RAOs.
17. Save Omega Matrices as Last Column of Composite PSD and RAO Matrices

For the purpose of convenient analysis, the single-column omega matrices are tacked on as the final columns of their respective PSD or RAO composite matrices. This basically eliminates the necessity of the jpg formatted figures by allowing direct comparison between any two columns of a composite matrix simply by using a plotting function. Thus, PSD vs. PSD, PSD vs. omega, RAO vs. RAO and RAO vs. omega plots can readily be produced

```matlab
% Save Omega Matrices as Last Column of Composite PSD
% and RAO Matrices
ch = ch + 1;
psd(:,ch) = momega(1,:);
mrao(:,ch) = momega(1,:);
frao(:,ch) = fomega(1,:);
```

18. Save Composite PSD and RAO Matrices

This final event in the sequence saves the composite PSD and RAO matrices along with the jpg formatted figures previously saved in the folder dedicated to the particular DTMB run. It's now time to process another DTMB run.

```matlab
% Save Composite PSD and RAO Matrices------------------------
save([swrite,folder,'\',filename,'psd.txt'],'psd',
     '-ascii','-tabs');
save([swrite,folder,'\',filename,'mrao.txt'],'mrao',
     '-ascii','-tabs');
save([swrite,folder,'\',filename,'frao.txt'],'frao',
     '-ascii','-tabs');
```
B. VALIDATION

Validation of the RAO Program was performed by utilizing a MATLAB comparison program, “psdandraocomparisons.m”, written to compare the various methods of resultant PSDs; Welch, Periodogram, Multi-taper, Spreadsheet and RAO Program. The comparison program is comprised of a sequence of events with each explained individually as applied to run 67:

1. Load Applicable Matrices

Once the comparison program has been initiated, the following matrices are loaded:

<table>
<thead>
<tr>
<th>Matrix</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>R067</td>
<td>Raw, Time-based Data (All 46 Channels)</td>
</tr>
<tr>
<td>Run67.txt</td>
<td>Spreadsheet Model-Scale Omegas, PSDs and RAOs</td>
</tr>
<tr>
<td>R067psd.txt</td>
<td>RAO Program Model-Scale PSDs and Omegas</td>
</tr>
<tr>
<td>R067mrao.txt</td>
<td>RAO Program Model-Scale RAOs and Omegas</td>
</tr>
<tr>
<td>R067frao.txt</td>
<td>RAO Program Full-Scale RAOs and Omegas</td>
</tr>
</tbody>
</table>
2. Base-line the Raw Time-Based Data

Prior to initiating the MATLAB methods of Welch, Periodogram and Multi-taper, the raw, time-based data for both Channel 1: Wave Ht and Channel 3: TACS Roll are base-lined for continuity just as it is done in the RAO Program.

```matlab
% Base-line the Raw Time-based Data from R067-------
x = data(:,1);  % Wave Ht Data
x = x - mean(x);

z = data(:,3);  % TACS Roll Data
z = z - mean(z);
```

3. Compute Wave Ht PSDs using MATLAB Methods

The Welch, Periodogram and Multi-taper methods are used to compute their Wave Ht PSDs and associated Frequencies. The Frequencies will be converted to Omegas later. For efficiency of computation, a maximum of 8096 FFTs is designated. This happens to be the largest power of two that is less that the total number of data points per channel which range from approximately 14,000 to 16,000. Otherwise, MATLAB uses a slower approach of seeking out the primes of the total number of data points and computing the FFTs according to these segments.
% Computation of Wave Ht PSDs and Associated Freqs----
[hwelch, fwelch] = powelch(x, [], [], .8096, 32.2);
[hperio, fperio] = periodogram(x, [], .8096, 32.2);
[hmulti, fmulti] = pmmtm(x, [], .8096, 32.2)
measqrx = mean(x.^2);
welchareaeh = trap(wwelch, hwelch);
perioareah = trap(wperio, hperio);
multiareah = trap(wmulti, hmulti);
hwelchscaled = hwelch*measqrx/welchareah;
hperioscaled = hperio*measqrx/perioareah;
hmultiiscaled = hmulti*measqrx/multiareah;

4. Compute TACS Roll PSDs using MATLAB Methods

The same process described above is now performed for the TACS Roll PSDs.

% Computation of TACS Roll PSDs and Associated Freqs----
[rwelch, fwelch] = pwelch(z, [], [], .8096, 32.2);
[rperio, fperio] = periodogram(z, [], .8096, 32.2);
[rmulti, fmulti] = pmmtm(z, [], .8096, 32.2);
measqrz = mean(z.^2);
welcharear = trap(wwelch, rwelch);
perioarear = trap(wperio, rperio);
multiarear = trap(wmulti, rmulti);
rwelchscaled = rwelch*measqrz/welcharear;
rperioscaled = rperio*measqrz/perioarear;
rmultiiscaled = rmulti*measqrz/multiarear;

5. Convert MATLAB Method Frequencies to Omegas

Conversion of frequency to omega is done simply by multiplying the frequency matrices by 2π.

34
6. Compute Areas under the PSD Curves

As an integrity check along the way, the mean squares of the base-lined data are compared to the areas under the PSD curves. At this point, both the Spreadsheet and RAO Program results are integrated into the comparison program to ensure continuity between the various methods with comparative results as follows:

\[ \text{Method:} \quad \text{Result:} \]

- Mean Square of Base-lined Wave Ht Data \quad 0.0124
- Welch Area (rad/s) \quad 0.0124
- Periodogram Area (rad/s) \quad 0.0124
- Multi-taper Area (rad/s) \quad 0.0124
- Spreadsheet Area (rad/s) \quad 0.0126
- RAO Program Area (rad/s) \quad 0.0124
From the results listed above for run 67, the Welch, Periodogram, Multi-taper and RAO Program methods agree to the nearest 1/1000\textsuperscript{th} when rounded to 5 decimal positions. In addition, each is within 1.6\% of the Spreadsheet results.

\textit{b. TACS Roll Comparison}

<table>
<thead>
<tr>
<th>Method:</th>
<th>Result:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Square of Base-lined TACS Roll Data</td>
<td>0.0061</td>
</tr>
<tr>
<td>Welch Area (deg/s)</td>
<td>0.0061</td>
</tr>
<tr>
<td>Periodogram Area (deg/s)</td>
<td>0.0061</td>
</tr>
<tr>
<td>Multi-taper Area (deg/s)</td>
<td>0.0061</td>
</tr>
<tr>
<td>Spreadsheet Area (deg/s)</td>
<td>0.0059</td>
</tr>
<tr>
<td>RAO Program Area (deg/s)</td>
<td>0.0061</td>
</tr>
</tbody>
</table>

From the results listed above for run 67, the Welch, Periodogram, Multi-taper and RAO Program methods agree to the nearest 1/1000\textsuperscript{th} when rounded to 5 decimal positions. In addition, each is within 3.3\% of the Spreadsheet results.
% Compute Areas under the Wave Ht PSD Curves--------
welchareah2 = trap(wwelch,hwelchscaled);
perioareah2 = trap(wperio,hiperoscaled);
multiareah2 = trap(wmulti,hmultiscaled);
spreadareah = trap(run67(:,2),run67(:,3));
raoprogareah = trap(R067psd(:,47),R067psd(:,1));

% Compare Areas under the Wave Ht PSD Curves against meansqrs
wavehtpsdareacomparison = [meansqrx welchareah2
                           perioareah2 multiareah2 spreadareah raoprogareah]

% Compute Areas under the TACS Roll PSD Curves--------
welcharear2 = trap(wwelch,rwelchscaled);
perioarear2 = trap(wperio,perioscaled);
multiarear2 = trap(wmulti,multiscaled);
spreadarear = trap(run67(:,2),run67(:,4));
raoprogarear = trap(R067psd(:,47),R067psd(:,3));

% Compare Areas under the TACS Roll PSD Curves against megsqrs
rollpsdareacomparison = [meansqrz welcharear2
                        perioarear2 multiarear2 spreadarear raoprogarear]

7. Graphical Comparison of Model-Scale PSDs

Plots of Model-Scale PSDs from all five methods for both the Wave Ht and TACS Roll are generated for visual comparison. From these comparison plots, it was determined that previously discussed “ptavg” selection of 50 was a very good compromise between display resolution and accuracy when compared to the other four methods of generating PSDs. (see figs. 7-10)
% Graphical Model-Scale Wave Ht PSDs Comparison-----
All 5 Methods

figure(1)
plot(wwelch,hwelchscaled) % Welch Method
hold on
plot(wperio,hperioscaled) % Perio Method
plot(wmulti,hmultiscalced) % Multi Method
plot(run67(:,2),run67(:,3)) % Spreadsheet
plot(R067psd(:,47),R067psd(:,1)); % Rao Program
title('R067CH01 Model-Scale Wave Ht PSDs Comparison')
xlabel('Omega (rad/s)')
ylabel('PSD (dimensionless)')
axis([0 6 0 .015])
grid

% Graphical Model-Scale Wave Ht PSDs Comparison--------
Spreadsheet vs. RAO Program only
figure(2)
plot(run67(:,2),run67(:,3)) % Spreadsheet
hold on
plot(R067psd(:,47),R067psd(:,1)) % Rao Program
title('R067CH01 Model-Scale Wave Ht PSDs Comparison')
xlabel('Omega (rad/s)')
ylabel('PSD (dimensionless)')
axis([0 6 0 .0065])
grid

% Graphical Model-Scale TACS Roll PSDs Comparison-----
All 5 Methods

figure(3)
plot(wwelch,rwelchscaled) % Welch Method
hold on
plot(wperio,rperioscaled) % Perio Method
plot(wmulti,rmultiscalced) % Multi Method
plot(run67(:,2),run67(:,4)) % Spreadsheet
plot(R067psd(:,47),R067psd(:,3)); % Rao Program
title('R067CH03 Model-Scale TACS Roll PSDs
Comparison')
xlabel('Omega (rad/s)')
ylabel('PSD (deg)')
axis([0 6 0 .02])
grid
% Graphical TACS Roll PSDs Comparison-----------------

Spreadsheet vs. RAO Program only

figure(4)
plot(run67(:,2),run67(:,4))          % Spreadsheet
hold on
plot(R067psd(:,47),R067psd(:,3))    % Rao Program

title('R067CH03 Model-Scale TACS Roll PSDs
Comparison')
xlabel('Omega (rad/s)')
ylabel('PSD (deg)')
axis([0 6 0 .009])
grid

Figure 7.
Figure 8.

Figure 9.

Note that the Spreadsheet and RAO Program PSDs are much smoother whilst the others are in their original, unsmoothed state.
8. Compute Model-Scale RAOs

Just as it is performed in the RAO Program, Model-Scale RAOs are computed for the Welch, Periodogram and Multi-taper methods by taking the square of the scaled TACS Roll PSDs divided by the scaled Wave Ht PSDs.

% Compute Model-Scale TACS Roll RAOs-----------------------
R1 = rwelchscaled./hwelchscaled;
welchmrao = sqrt(R1);
R2 = rperioscaled./hperioscaled;
periomrao = sqrt(R2);
R3 = rmultiscaled./hmultiscaled;
multimrao = sqrt(R3);
9. Graphical Comparison of Model-Scale RAOs

Plots of Model-Scale TACS Roll RAOs from all five methods are generated for visual comparison and they provide very satisfactory results. (see figs. 11-12)

Figure 11.
10. Scale to Full-Scale RAOs and Omegas

In order to compare Full-Scale RAOS and Omegas, the Model-Scale RAOs and Omegas are scaled accordingly just as they are done in the RAO Program.

```
% Scale to Full-Scale RAOs and Omegas---------------------
welchfrao     = welchmrao*12/24.175;
periofrao    = periomrao*12/24.175;
multifrao    = multimrao*12/24.175;

wwelchfull   = wwelch/sqrt(24.175);
wpériofull   = wperio/sqrt(24.175);
wmultifull   = wmulti/sqrt(24.175);
```
11. **Graphical Comparison of Full-Scale RAOs**

Finally, the Full-Scale RAOs and Omegas for the Welch, Periodogram, Multi-taper and RAO Program methods are plotted for visual comparison. (see figs. 13-14)

```matlab
% Graphical Full-Scale TACS Roll RAOs Comparison------
% 4 Methods Not including Spreadsheet
figure(7)
plot(wwelchfull,welchfrac) % Welch
hold on
plot(wperiofull,periofrac) % Periodogram
plot(wmultifull,multifrac) % Multi-taper
plot(R067frac(:,47),R067frac(:,3)) % RAO Program
title('R067CH03 Full-Scale TACS Roll RAOs Comparison')
xlabel('Omega (rad/s)')
ylabel('RAO (deg/in)')
axis([0 1.4 0 3])
grid

% Graphical Full-Scale TACS Roll RAOs Presentation------
% RAO Program only
figure(8)
plot(R067frac(:,47),R067frac(:,3)) % Rao Program
title('R067CH03 Full-Scale TACS Roll RAOs
Presentation')
xlabel('Omega (rad/s)')
ylabel('RAO (deg/in)')
axis([0 1.4 0 1.4])
grid
```
Note that the RAO Program RAOs are much smoother while the others are in their original, unsmoothed state.

Figure 13.

Figure 14.
IV. CONCLUSIONS & RECOMMENDATIONS

A. CONCLUSIONS

Due to the validation comparisons performed on run 67 above, the RAO Program performed quite admirably and accurately. The RAO Programs ability to accurately produce Model-Scale PSDs, Model-Scale RAOs and ultimately Full-Scale RAOs for each channel, along with their associated Omegas, attests to the programs performance. In addition, a short looping program, "raoloop.m", enabled up to seven data runs to be evaluated sequentially.

```
% Short Program Title: "raoloop.m"-------------------------
a = [19 21 23 25 27 29 31];      % DTMB Run Numbers
for z = 1:7
    rao(a(1,z));
end
```

The seven run looping limit was imposed due to local hardware configuration limitations. With each data run producing approximately 12.5 megabytes of stored figures and matrices, a 100 megabyte zip disc could safely store up to seven data runs. With a read/write CD drive, the looping capability would have been much greater.

Upon completion of processing the Configuration I runs, the composite matrices (Model-Scale PSDs, Model-Scale RAOs and Full-Scale RAOs) for each run were
assembled all on one compact disc as a convenient reference from which any two columns of results may be plotted against each other.

B. RECOMMENDATIONS

An opportunity for a logical continuation of this thesis will soon be available. Trial runs using the actual, Full-Scale ship, the USNS Grand Canyon State (ex-SS President Polk) (T-ACS 3), were conducted September 9th-16th off the coast of Southern California near Camp Pendleton. Data recorded from the Full-Scale trial runs could be processed in a manner similar to the RAO Program and used as a comparison tool to either disprove or further prove the validity of results from the RAO Program. If RAO results from both the at-sea Full-Scale trial runs and the RAO Program model-basin evaluations are in agreement, a multitude of combinations can then be evaluated to predict ship motions in an irregular sea by using the principle of linear superposition.
## APPENDIX A: TEST CONFIGURATION I

<table>
<thead>
<tr>
<th>CDNSWC Run #</th>
<th>Date</th>
<th>Run Storage Directory</th>
<th>Reference Zero Run</th>
<th>NRL Run #</th>
<th>Test Config #</th>
<th>Wave Heading</th>
<th>Sea State</th>
<th>Boom Slew Angle</th>
<th>Rider Block Location</th>
<th>Rider Block Inhaul Angle</th>
<th>Boom Luff Angle</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
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<td>TASCA2</td>
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<td>0 3</td>
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<td>54.5</td>
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<td>0</td>
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<td></td>
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<td>030,032</td>
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<td></td>
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24 file format

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240secs Static + Load Control Demo
240secs Static + Load Control Demo
240secs Static + Load Control Demo
200secs Static + Load Control Demo
## APPENDIX D: MASTER CHANNEL LIST: CONFIGURATION I

DTMB Runs 1-503 and NRL Runs 1-217

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DTMB Runs 534-587 and NRL Runs 227-251
function rao(run)

% Program Title: rao.m---------------------------------------------
% Referred to as RAO Program

% Must enter one of the following to initiate this program:
% rao(##) for DTMB run numbers <100
% rao(###) for DTMB run numbers >100

% Initial Set-up---------------------------------------------
sread = char('H:\');
fwrite = char('D:\');

format short e

ptavg    = 50;
window   = 500;
lambda   = 24.175;
freq     = 32.2;

% Establish Proper String Configuration for Data Run----
if run <= 99
    s1    = char('R0');
    s2    = char('0');
else
    s1    = char('R');
end

srun    = num2str(run);
filename = strcat(s1,srun);

if run <= 99
    folder = strcat(s2,srun);
else
    folder = srun;
end
% Determine Number of Data Channels to be Processed--------
if run <= 503
    channels = 46;
elseif run <= 533
    channels = 38;
else
    channels = 24;
end

% Establish Filepath and Load the Raw, Time-based Data-----
filepath = [sread,filename];
load(filepath)
szdata = size(data);
channels = szdata(2);
n = szdata(1);

% Compute both Model-Scale and Full-Scale Omega Ranges-----
momega = 2*pi*freq/n*(0:window-1);
fromega = momega/sqrt(lambda);

% Full-Scale Scalers, PSD Units and RAO Units Library------
fs1 = 1;
p1 = '(in)';
ru1 = '(dimensionless)';

fs2 = 12/lambda;
p2 = '(deg)';
ru2 = '(deg/in)';

fs3 = 12/lambda^(3/2);
p3 = '(deg/s)';
ru3 = '(deg/in s)';

fs4 = 12/lambda^2;
p4 = '(deg/s^2)';
ru4 = '(deg/in s^2)';

% Looping/Processing of Data Channels---------------------
for ch = 1:channels
    if channels==46
        if ch==1
            fscaler = fs1;
            psdunits = pu1;
            raounits = ru1;

72
```
chttitle = 'Wave Ht Bow';
elseif ch==2
    fscaler  = fs1;
    psdunits = pu1;
    raounits = ru1;
    chttitle = 'Sonix Sonic';
elseif ch==3
    fscaler  = fs2;
    psdunits = pu2;
    raounits = ru2;
    chttitle = 'TACS Roll';
elseif ch==4
    fscaler  = fs2;
    psdunits = pu2;
    raounits = ru2;
    chttitle = 'TACS Pitch';
elseif ch==5
    fscaler  = fs3;
    psdunits = pu3;
    raounits = ru3;
    chttitle = 'TACS Roll Rt';
elseif ch==6
    fscaler  = fs3;
    psdunits = pu3;
    raounits = ru3;
    chttitle = 'TACS Pitch Rt';
elseif ch==7
    fscaler  = fs3;
    psdunits = pu3;
    raounits = ru3;
    chttitle = 'TACS Yaw Rt';
elseif ch==8
    fscaler  = fs4;
    psdunits = pu4;
    raounits = ru4;
    chttitle = 'TACS CG ZAcc';
elseif ch==9
    fscaler  = fs4;
    psdunits = pu4;
    raounits = ru4;
    chttitle = 'TACS CG YAcc';
elseif ch==10
    fscaler  = fs4;
    psdunits = pu4;
    raounits = ru4;
    chttitle = 'TACS CG XAcc';
73
```
elseif ch==11
  fscaler = fs4;
  psdunits = pu4;
  raounits = ru4;
  chtitle = 'TACS CT ZAcc';
elseif ch==12
  fscaler = fs4;
  psdunits = pu4;
  raounits = ru4;
  chtitle = 'TACS CF YAcc';
elseif ch==13
  fscaler = fs2;
  psdunits = pu2;
  raounits = ru2;
  chtitle = 'Cntr Roll';
elseif ch==14
  fscaler = fs2;
  psdunits = pu2;
  raounits = ru2;
  chtitle = 'Cntr Pitch';
elseif ch==15
  fscaler = fs4;
  psdunits = pu4;
  raounits = ru4;
  chtitle = 'Cntr CG ZAcc';
elseif ch==16
  fscaler = fs4;
  psdunits = pu4;
  raounits = ru4;
  chtitle = 'Cntr CG YAcc';
elseif ch==17
  fscaler = fs4;
  psdunits = pu4;
  raounits = ru4;
  chtitle = 'Cntr CG XAcc';
elseif ch==18
  fscaler = fs1;
  psdunits = pu1;
  raounits = ru1;
  chtitle = 'TACS Cntr Rel X';
elseif ch==19
  fscaler = fs1;
  psdunits = pu1;
  raounits = ru1;
  chtitle = 'TACS Cntr Rel Y';
elseif ch==20
    fscalcr = fs1;
    psdunits = pu1;
    raounits = ru1;
    chtitle = 'TACS Cntr Rel Z';
elseif ch==21
    fscalcr = fs2;
    psdunits = pu2;
    raounits = ru2;
    chtitle = 'Lhtr Roll';
elseif ch==22
    fscalcr = fs2;
    psdunits = pu2;
    raounits = ru2;
    chtitle = 'Lhtr Pitch';
elseif ch==23
    fscalcr = fs3;
    psdunits = pu3;
    raounits = ru3;
    chtitle = 'Lhtr Roll Rt';
elseif ch==24
    fscalcr = fs3;
    psdunits = pu3;
    raounits = ru3;
    chtitle = 'Lhtr Pitch Rt';
elseif ch==25
    fscalcr = fs4;
    psdunits = pu4;
    raounits = ru4;
    chtitle = 'Lhtr CG ZAcc';
elseif ch==26
    fscalcr = fs4;
    psdunits = pu4;
    raounits = ru4;
    chtitle = 'Lhtr CG YAcc';
elseif ch==27
    fscalcr = fs4;
    psdunits = pu4;
    raounits = ru4;
    chtitle = 'Lhtr CG XAcc';
elseif ch==28
    fscalcr = fs1;
    psdunits = pu1;
    raounits = ru1;
    chtitle = 'TACS Lhtr Rel X';
elseif ch==29
  fscalar = fscal;
  psdunits = psd;
  raounits = ru;
  chtitle = 'TACS Lhtr Rel Y';
elseif ch==30
  fscalar = fscal;
  psdunits = psd;
  raounits = ru;
  chtitle = 'TACS Lhtr Rel Z';
elseif ch==31
  fscalar = fscal;
  psdunits = psd;
  raounits = ru;
  chtitle = 'Load Mo Orthogonal';
elseif ch==32
  fscalar = fscal;
  psdunits = psd;
  raounits = ru;
  chtitle = 'Load Mo Parallel';
elseif ch==33
  fscalar = fscal;
  psdunits = psd;
  raounits = ru;
  chtitle = 'Boom Tip-HorizAcc';
elseif ch==34
  fscalar = fscal;
  psdunits = psd;
  raounits = ru;
  chtitle = 'Boom Tip-VertAcc';
elseif ch==35
  fscalar = fscal;
  psdunits = psd;
  raounits = ru;
  chtitle = 'Lhtr4-Trn VAcc';
elseif ch==36
  fscalar = fscal;
  psdunits = psd;
  raounits = ru;
  chtitle = 'Lhtr4-Bow VAcc';
elseif ch==37
  fscalar = fscal;
  psdunits = psd;
  raounits = ru;
  chtitle = 'Lhtr3-Bow VAcc';
elseif ch==38
  fscaler = fs4;
  psdunits = pu4;
  raounits = ru4;
  chtitle = 'Lghtr2-Bow VAcc';
elseif ch==39
  fscaler = fs4;
  psdunits = pu4;
  raounits = ru4;
  chtitle = 'Lghtr1-Bow VAcc';
elseif ch==40
  fscaler = fs4;
  psdunits = pu4;
  raounits = ru4;
  chtitle = 'Lghtr2-SDShp VAcc';
elseif ch==41
  fscaler = fs4;
  psdunits = pu4;
  raounits = ru4;
  chtitle = 'Lghtr2-PMDShp VAcc';
elseif ch==42
  fscaler = fs4;
  psdunits = pu4;
  raounits = ru4;
  chtitle = 'Lghtr2-CLMDSp VAcc';
elseif ch==43
  fscaler = fs4;
  psdunits = pu4;
  raounits = ru4;
  chtitle = 'Lghtr1-CLMDSp VAcc';
elseif ch==44
  fscaler = fs4;
  psdunits = pu4;
  raounits = ru4;
  chtitle = 'Lghtr4-StrnLng Acc';
elseif ch==45
  fscaler = fs4;
  psdunits = pu4;
  raounits = ru4;
  chtitle = 'Lghtr4-PStrn TvAcc';
else
  fscaler = fs4;
  psdunits = pu4;
  raounits = ru4;
  chtitle = 'Lghtr1-PBow TvAcc';
end  % End of Configuration I sub-Loop
elseif channels==38

if ch==1
    fscalcer = fs1;
    psdunits = pu1;
    raounits = ru1;
    chtitle = 'Wave Ht Bow';
elseif ch==2
    fscalcer = fs1;
    psdunits = pu1;
    raounits = ru1;
    chtitle = 'Sonix Sonic';
elseif ch==3
    fscalcer = fs2;
    psdunits = pu2;
    raounits = ru2;
    chtitle = 'TACS Roll';
elseif ch==4
    fscalcer = fs2;
    psdunits = pu2;
    raounits = ru2;
    chtitle = 'TACS Pitch';
elseif ch==5
    fscalcer = fs3;
    psdunits = pu3;
    raounits = ru3;
    chtitle = 'TACS Roll Rt';
elseif ch==6
    fscalcer = fs3;
    psdunits = pu3;
    raounits = ru3;
    chtitle = 'TACS Pitch Rt';
elseif ch==7
    fscalcer = fs3;
    psdunits = pu3;
    raounits = ru3;
    chtitle = 'TACS Yaw Rt';
elseif ch==8
    fscalcer = fs4;
    psdunits = pu4;
    raounits = ru4;
    chtitle = 'TACS CG ZAcc';
elseif ch==9
    fscaler = fs4;
    psdunits = pu4;
    raunits = ru4;
    chtitle = 'TACS CG YAcc';
elseif ch==10
    fscaler = fs4;
    psdunits = pu4;
    raunits = ru4;
    chtitle = 'TACS CG XAcc';
elseif ch==11
    fscaler = fs4;
    psdunits = pu4;
    raunits = ru4;
    chtitle = 'TACS CT ZAcc';
elseif ch==12
    fsscaler = fs4;
    psdunits = pu4;
    raunits = ru4;
    chtitle = 'TACS CF YAcc';
elseif ch==13
    fscaler = fs2;
    psdunits = pu2;
    raunits = ru2;
    chtitle = 'Lhtr Roll';
elseif ch==14
    fscaler = fs2;
    psdunits = pu2;
    raunits = ru2;
    chtitle = 'Lhtr Pitch';
elseif ch==15
    fscaler = fs3;
    psdunits = pu3;
    raunits = ru3;
    chtitle = 'Lhtr Roll Rt';
elseif ch==16
    fscaler = fs3;
    psdunits = pu3;
    raunits = ru3;
    chtitle = 'Lhtr Pitch RT';
elseif ch==17
    fscaler = fs4;
    psdunits = pu4;
    raunits = ru4;
    chtitle = 'Lhtr CG ZAcc';
elseif ch==18
    fscalcr = fs4;
    psdunits = pu4;
    raounits = ru4;
    chtitle = 'Lhtr CG YAcc';
elseif ch==19
    fscalcr = fs4;
    psdunits = pu4;
    raounits = ru4;
    chtitle = 'Lhtr CG XAcc';
elseif ch==20
    fscalcr = fs1;
    psdunits = pu1;
    raounits = ru1;
    chtitle = 'TACS LhtRelX';
elseif ch==21
    fscalcr = fs1;
    psdunits = pu1;
    raounits = ru1;
    chtitle = 'TACS LhtRelY';
elseif ch==22
    fscalcr = fs1;
    psdunits = pu1;
    raounits = ru1;
    chtitle = 'TACS LhtRelZ';
elseif ch==23
    fscalcr = fs1;
    psdunits = pu1;
    raounits = ru1;
    chtitle = 'Load Mo Orthognl';
elseif ch==24
    fscalcr = fs1;
    psdunits = pu1;
    raounits = ru1;
    chtitle = 'Load Mo Parallel';
elseif ch==25
    fscalcr = fs4;
    psdunits = pu4;
    raounits = ru4;
    chtitle = 'BoomTip-HorizAcc';
elseif ch==26
    fscalcr = fs4;
    psdunits = pu4;
    raounits = ru4;
    chtitle = 'BoomTip-Vert Acc';


```c
elseif ch==27
fscalar = fs4;
psdunits = pu4;
raounits = ru4;
chttitle = 'Lghtr4-Strn VAcc';
elseif ch==28
fscalar = fs4;
psdunits = pu4;
raounits = ru4;
chttitle = 'Lghtr4-Bow VAcc';
elseif ch==29
fscalar = fs4;
psdunits = pu4;
raounits = ru4;
chttitle = 'Lghtr3-Bow VAcc';
elseif ch==30
fscalar = fs4;
psdunits = pu4;
raounits = ru4;
chttitle = 'Lghtr2-Bow VAcc';
elseif ch==31
fscalar = fs4;
psdunits = pu4;
raounits = ru4;
chttitle = 'Lghtr1-Bow VAcc';
elseif ch==32
fscalar = fs4;
psdunits = pu4;
raounits = ru4;
chttitle = 'Lghtr2-SCdShpVAc';
elseif ch==33
fscalar = fs4;
psdunits = pu4;
raounits = ru4;
chttitle = 'Lghtr2-PMdShpVAc';
elseif ch==34
fscalar = fs4;
psdunits = pu4;
raounits = ru4;
chttitle = 'Lghtr2-CLMdSpVAc';
elseif ch==35
fscalar = fs4;
psdunits = pu4;
raounits = ru4;
chttitle = 'Lghtr1-CLMdSpVAc';
```
elseif ch==36
    f scaler = fs4;
p sdunits = pu4;
raounits = ru4;
chtitle = 'Lghtr4-StrnLmgAc';
elseif ch==37
    f scaler = fs4;
p sdunits = pu4;
raounits = ru4;
chtitle = 'Lghtr4-PStrnTAcc';
else
    f scaler = fs4;
p sdunits = pu4;
raounits = ru4;
chtitle = 'Lghtr1-PBowTvAcc';
end % End of Configuration II sub-Loop

else

    if ch==1
        f scaler = fs1;
p sdunits = pu1;
raounits = ru1;
chtitle = 'Wave Ht Bow';
elseif ch==2
        f scaler = fs1;
p sdunits = pu1;
raounits = ru1;
chtitle = 'Sonix Sonic';
elseif ch==3
        f scaler = fs2;
p sdunits = pu2;
raounits = ru2;
chtitle = 'TACS Roll';
elseif ch==4
        f scaler = fs2;
p sdunits = pu2;
raounits = ru2;
chtitle = 'TACS Pitch';
elseif ch==5
        f scaler = fs3;
p sdunits = pu3;
raounits = ru3;
chtitle = 'TACS Roll Rt';
elseif ch==6
fscalar = fs3;
psdunits = pu3;
raunits = ru3;
chtite = 'TACS Pitch Rt';
elseif ch==7
fscalar = fs3;
psdunits = pu3;
raunits = ru3;
chtite = 'TACS Yaw Rt';
elseif ch==8
fscalar = fs4;
psdunits = pu4;
raunits = ru4;
chtite = 'TACS CG ZAcc';
elseif ch==9
fscalar = fs4;
psdunits = pu4;
raunits = ru4;
chtite = 'TACS CG YAcc';
elseif ch==10
fscalar = fs4;
psdunits = pu4;
raunits = ru4;
chtite = 'TACS CG XAcc';
elseif ch==11
fscalar = fs4;
psdunits = pu4;
raunits = ru4;
chtite = 'TACS CT ZAcc';
elseif ch==12
fscalar = fs4;
psdunits = pu4;
raunits = ru4;
chtite = 'TACS CF YAcc';
elseif ch==13
fscalar = fs2;
psdunits = pu2;
raunits = ru2;
chtite = 'DD 963 Roll';
elseif ch==14
fscalar = fs2;
psdunits = pu2;
raunits = ru2;
chtite = 'DD 963 Pitch';
elseif ch==15
    fscaler = fs4;
    psdunits = pu4;
    raounits = ru4;
    chtitle = 'DD 963 CG ZAcc';
elseif ch==16
    fscaler = fs4;
    psdunits = pu4;
    raounits = ru4;
    chtitle = 'DD 963 CG YAcc';
elseif ch==17
    fscaler = fs4;
    psdunits = pu4;
    raounits = ru4;
    chtitle = 'DD 963 CG XAcc';
elseif ch==18
    fscaler = fs1;
    psdunits = pu1;
    raounits = ru1;
    chtitle = 'TACS1 DD963 RelX';
elseif ch==19
    fscaler = fs1;
    psdunits = pu1;
    raounits = ru1;
    chtitle = 'TACS1 DD963 RelY';
elseif ch==20
    fscaler = fs1;
    psdunits = pu1;
    raounits = ru1;
    chtitle = 'TACS1 DD963 RelZ';
elseif ch==21
    fscaler = fs1;
    psdunits = pu1;
    raounits = ru1;
    chtitle = 'Load Mo Orthognl';
elseif ch==22
    fscaler = fs1;
    psdunits = pu1;
    raounits = ru1;
    chtitle = 'Load Mo Parallel';
elseif ch==23
    fscaler = fs4;
    psdunits = pu4;
    raounits = ru4;
    chtitle = 'BoomTip-HorizAcc';
else
  fscaler = fs4;
pdunits = pu4;
raunits = ru4;
chtile = 'BoomTip-Vert Acc';
end % End of Configuration III sub-Loop

end % End of the Overall Configuration Loop

% Base-lining the Raw, Time-based Data-----------------------------
x    = data(:,ch);
x    = x-mean(x);

% FFT Computation-------------------------------------------------
Y    = fft(x,n);

% Model-Scale PSD Computation--------------------------------------
PSD  = Y.*conj(Y)/n;

% Moving-window Averaging of Model-Scale PSDs for
smoothing----------------------------------------------------------
halfptavg = ptavg/2;
sum   = 0;
for k = 1:ptavg
  sum  = sum + PSD(k,1);
  if k > halfptavg
    psd(k-halfptavg,ch) = sum/k;
  else
    psd(k-halfptavg,ch) = sum/k;
  end
end
pts   = window + halfptavg;
ptavgplusone = ptavg + 1;
j    = 1;
for k = ptavgplusone:pts
  sum  = sum + PSD(ptavg+j,1) - PSD(j,1);
  psd(k-halfptavg,ch) = sum/ptavg;
  j    = j + 1;
end

meansqr = mean(x.^2);
psdarea = trap(moment,psd(:,ch));
psdscaler = meansqr/psdarea;
psd(:,ch) = psd(:,ch)*psdscaler;

85
% Computation of Model-Scale RAOs-----------------------------
X = psd(:,ch)./psd(:,1);
mrao(:,ch) = sqrt(X);

% Computation of Full-Scale RAOs-------------------------------
fraco(:,ch) = mrao(:,ch)*fscaler;

% Plot Model-Scale PSDs and Save Figure in jpg Format-------
cf
plot(momega(1,:),psd(:,ch))
grid
sch = num2str(ch);
title(['Model-Scale PSDs for DTMB Run 'srun, '/ Channel ','sch,' chtitle])
xlabel('Omega (rad/s)')
ylabel(['PSD ' psdunits])

saveas(gcf,[swrite,folder,'\',filename,'C',sch,'p'],jpg')
% D:\###\R###C##p.jpg

% Plot Model-Scale RAOs and Save Figure in jpg Format-------
cf
plot(momega(1,:),mrao(:,ch))
grid
title(['Model-Scale RAOs for DTMB Run 'srun, '/ Channel ','sch,' chtitle])
xlabel('Omega (rad/s)')
ylabel(['RAO ' raunits])

saveas(gcf,[swrite,folder,'\',filename,'C',sch,'m'],jpg')
% D:\###\R###C##m.jpg

% Plot Full-Scale RAOs and Save Figure in jpg Format--------
cf
plot(fomega(1,:),fraco(:,ch))
grid
title(['Full-Scale RAOs for DTMB Run 'srun, '/ Channel ','sch,' chtitle])
xlabel('Omega (rad/s)')
ylabel(['RAO ' raunits])

saveas(gcf,[swrite,folder,'\',filename,'C',sch,'f'],jpg')
% D:\###\R###C##f.jpg

end % End of all Channel Looping
% Save Omega Matrices as Last Column of Composite PSD and RAO Matrices

ch         = ch + 1;
psd(:,ch)   = momega(1,:);'
mrao(:,ch)  = momega(1,:);'
frao(:,ch)  = fomega(1,:);'

% Save Composite PSD and RAO Matrices

% D:\##\##\##\##psd.txt
% D:\##\##\##\##mrao.txt
% D:\##\##\##\##frao.txt
save([swrite,folder,‘\’,filename,‘psd.txt’],’psd’,’-ascii ‘,’-tabs’);
save([swrite,folder,‘\’,filename,‘mrao.txt’],’mrao’,’-ascii ‘,’-tabs’);
save([swrite,folder,‘\’,filename,‘frao.txt’],’frao’,’-ascii ‘,’-tabs’);

% End of RAO Program
APPENDIX H. PTAVG COMPARISON PROGRAM

% Program title: ptavgcomparison.m

clear
clc

% Load Spreadsheet Results for run 67
load run67.txt;

% Load RAO Program Results for ptavg = 26, 50, 76 and 100
load R067psd26.txt;
load R067psd50.txt;
load R067psd76.txt;
load R067psd100.txt;
load R067mrao26.txt;
load R067mrao50.txt;
load R067mrao76.txt;
load R067mrao100.txt;
load R067frao26.txt;
load R067frao50.txt;
load R067frao76.txt;
load R067frao100.txt;

% Plot Model-Scale PSD Comparison
figure(1)
plot(R067psd26(:,47),R067psd26(:,3),
     R067psd50(:,47),R067psd50(:,3),
     R067psd76(:,47),R067psd76(:,3),
     R067psd100(:,47),R067psd100(:,3),
     run67(:,2),run67(:,4))
title('R067CH3 Model-Scale TACS Roll PSDs "ptavg"
      Comparison')
xlabel('Omega (rad/s)')
ylabel('PSD (deg)')
grid
% Plot Model-Scale RAO Comparison-----------------------------
figure(2)
plot(R067mrao26(:,47),R067mrao26(:,3),...
     R067mrao50(:,47),R067mrao50(:,3),...
     R067mrao76(:,47),R067mrao76(:,3),...
     R067mrao100(:,47),R067mrao100(:,3),...
run67(:,2),run67(:,5))
title('R067CH3 Model-Scale TACS Roll RAOs "ptavg"
     Comparison')
xlabel('Omega (rad/s)')
ylabel('RAO (deg/in)')
grid

% Plot Full-Scale RAO Comparison-----------------------------
figure(3)
plot(R067frao26(:,47),R067frao26(:,3),...
     R067frao50(:,47),R067frao50(:,3),...
     R067frao76(:,47),R067frao76(:,3),...
     R067frao100(:,47),R067frao100(:,3))
title('R067CH3 Full-Scale TACS Roll RAOs "ptavg"
     Comparison')
xlabel('Omega (rad/s)')
ylabel('RAO (deg/in)')
grid

% End of ptavgcomparison program-----------------------------
APPENDIX I. PSD AND RAO COMPARISONS PROGRAM

% Program Title: psdandraocomparisons.m-------------------

% Computational and Graphical Comparison between the
various Methods----------------------------------------

clear
clc

format short

% Load Applicable Matrices-----------------------------
load R067; % Raw, Time-based Data
load run67.txt; % Spreadsheet PSD and RAO Results
load R067psd.txt; % RAO Program Model-Scale PSD Results
load R067mrao.txt; % RAO Program Model-Scale RAO Results
load R067frao.txt; % RAO Program Full-Scale RAO Results

% Base-line the Raw Time-based------------------------

x = data(:,1); % Wave Ht Data
x = x - mean(x);

z = data(:,3); % TACS Roll Data
z = z - mean(z);

% Computation of Wave Ht PSDs and Associated Frequencies---
[hwelch,fwelch] = pwelch(x,[],[],8096,32.2);
[hperio,fperio] = periodogram(x,[],8096,32.2);
[hmulti,fmulti] = pmtm(x,[],8096,32.2);
meansqrx = mean(x.^2); % Wave Ht Data
welchareah = trap(wwelch,hwelch); % Wave Ht
periaoareah = trap(wperio,hperio);
multiareah = trap(wmulti,hmulti);
hwelchscaled = hwelch*meansqrx/welchareah;
hperioscaled = hperio*meansqrx/periaoareah;
hmultiscaled = hmulti*meansqrx/multiareah;
% Computation of TACS Roll PSDs and Associated Frequencies-
[rwelch,fwelch] = pwelch(z,[],[],8096,32.2);
[rperio,fperio] = periodogram(z,[],8096,32.2);
[rmulti,fmulti] = pmtm(z,[],8096,32.2);
meansqrz = mean(z.^2); % TACS Roll Data
welchareas = trap(wwelch,rwelch); % TACS Roll
perioareas = trap(wperio,rperio);
multiareas = trap(wmulti,rmulti);
rwelschareas = rwelch*meansqrz/welchareas;
rperioschareas = rperio*meansqrz/perioareas;
rmultiareasch = rmulti*meansqrz/multiareas;

% Convert Frequency to Omega-----------------------------
wwwelch = 2*pi*fwelch;
wwperio = 2*pi*fperio;
wwmulti = 2*pi*fmulti;

% Compute Areas under the Wave Ht PSD Curves---------
welchareas = trap(wwwelch,wwelschareas);
perioareas = trap(wwperio,wwperioschareas);
multiareas = trap(wwmulti,wwmultiareasch);
spreadareas = trap(run67(:,2),run67(:,3));
raoprogareas = trap(R067psd(:,47),R067psd(:,1));

% Compare Areas under the Wave Ht PSD Curves against
meansqrs---------------------------------------------
wavehtpsdareas = [meansqrz welchareas ... perioareas multiareas spreadareas raoprogareas]

% Compute Areas under the TACS Roll PSD Curves---------
welchareas = trap(wwelch,wwelschareas);
perioareas = trap(wperio,wwperioschareas);
multiareas = trap(wmulti,wwmultiareasch);
spreadareas = trap(run67(:,2),run67(:,3));
raoprogareas = trap(R067psd(:,47),R067psd(:,1));

% Compare Areas under the TACS Roll PSD Curves against
meansqrs---------------------------------------------
rollpsdareas = [meansqrz welchareas ... perioareas multiareas spreadareas raoprogareas]

92
figure(1)
plot(wwelch,hwelchscaled) % Welch Method
hold on
plot(wperio,hperioscaled) % Periodogram Method
plot(wmulti,hmultiscal) % Multi-taper Method
plot(run67(:,2),run67(:,3)) % Spreadsheet Results
plot(R067psd(:,47),R067psd(:,1)); % Rao Program Results

title('R067CH01 Model-Scale Wave Ht PSDs Comparison')
xlabel('Omega (rad/s)')
ylabel('PSD (dimensionless)')
axis([0 6 0 .015])
grid

figure(2)
plot(run67(:,2),run67(:,3)) % Spreadsheet Results
hold on
plot(R067psd(:,47),R067psd(:,1)) % Rao Program Results

title('R067CH01 Model-Scale Wave Ht PSDs Comparison')
xlabel('Omega (rad/s)')
ylabel('PSD (dimensionless)')
axis([0 6 0 .0065])
grid

figure(3)
plot(wwelch,rwelchscaled) % Welch Method
hold on
plot(wperio,rperioscaled) % Periodogram Method
plot(wmulti,rmultiscal) % Multi-taper Method
plot(run67(:,2),run67(:,4)) % Spreadsheet Results
plot(R067psd(:,47),R067psd(:,3)); % Rao Program Results

title('R067CH03 Model-Scale TACS Roll PSDs Comparison')
xlabel('Omega (rad/s)')
ylabel('PSD (deg)')
axis([0 6 0 .02])
grid
% Graphical TACS Roll PSDs Comparison------------------------
% Spreadsheet vs. RAO Program only
figure(4)
plot(run67(:,2),run67(:,4)) % Spreadsheet Results
hold on
plot(R067psd(:,47),R067psd(:,3)) % Rao Program Results

title('R067CH03 Model-Scale TACS Roll PSDs Comparison')
xlabel('Omega (rad/s)')
ylabel('PSD (deg)')
axis([0 6 0 .009])
grid

% Compute Model-Scale Roll RAOs from MATLAB Methods-------
R1 = rwelchscaled./hwelchscaled;
welchmrao = sqrt(R1);
R2 = rperioscaled./hperioscaled;
periomrao = sqrt(R2);
R3 = rmultiscaled./hmultiscaled;
multimrao = sqrt(R3);

% Graphical Model-Scale TACS Roll RAOs Comparison of All 5
% Methods-----------------------------------------------
figure(5)
plot(wwelch,welchmrao) % Welch Method
hold on
plot(wperio,periomrao) % Periodogram Method
plot(wmulti,multimrao) % Multi-taper Method
plot(run67(:,2),run67(:,5)) % Spreadsheet Results
plot(R067mrao(:,47),R067mrao(:,3)); % Rao Program Results

title('R067CH03 Model-Scale TACS Roll RAOs Comparison')
xlabel('Omega (rad/s)')
ylabel('RAO (deg/in)')
axis([0 6 0 10])
grid

% Graphical Model-Scale TACS Roll RAOs Comparison---------
% (Spreadsheet vs. RAO Program only)
figure(6)
plot(run67(:,2),run67(:,5)) % Spreadsheet Results
hold on
plot(R067mrao(:,47),R067mrao(:,3)) % Rao Program Results
title('R067CH03 Model-Scale TACS Roll RA0s Comparison')
xlabel('Omega (rad/s)')
ylabel('RAO (deg/in)')
axis([0 6 0 2.2])
grid

% Scale to Full-Scale RA0s and Omegas-----------------------
welchfrao = welchmrao*12/24.175;
periofrao = periomrao*12/24.175;
multifrao = multimrao*12/24.175;

wwelchfull = wwelch/sqrt(24.175);
wperiofull = wperio/sqrt(24.175);
multifull = wmulti/sqrt(24.175);

% Graphical Full-Scale TACS Roll RA0s Comparison----------
% (4 Methods Not including Spreadsheet)
figure(7)
plot(wwelchfull,welchfrao) % Welch Method
hold on
plot(wperiofull,periofrao) % Periodogram Method
plot(multifull,multifrao)  % Multi-taper Method
plot(R067frao(:,47),R067frao(:,3)) % RA0 Program Results

title('R067CH03 Full-Scale TACS Roll RA0s Comparison')
xlabel('Omega (rad/s)')
ylabel('RAO (deg/in)')
axis([0 1.4 0 3])
grid

% Graphical Full-Scale TACS Roll RA0s Presentation---------
% RA0 Program only
figure(8)
plot(R067frao(:,47),R067frao(:,3)) % Rao Program Results

title('R067CH03 Full-Scale TACS Roll RA0s Presentation')
xlabel('Omega (rad/s)')
ylabel('RAO (deg/in)')
axis([0 1.4 0 1.4])
grid

% End of PSD and RA0 Comparison Program---------------------
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