Preliminary Mooring Plan for
The Empress 11 Barge

by
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APPROVED BY:

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The best method of mooring the Empress 11 and test vessel is by using a four-point mooring illustrated. Each point of the mooring will be a riser-type mooring with a buoy that can be used to moor the vessels because of their ease in handling. The mooring lines should: (1) stretch to act as shock (Con't)
absorbers; (2) have strength; (3) float or have floats attached; (4) resist abrasion; (5) resist chemicals and (6) resist ultraviolet light. The type and dimensions of the lines will be determined in the final design stage.

Several sites have been examined. The sheltered waters in the Chesapeake Bay are recommended for testing small to medium class ships. The Bay area has the advantages that waves are fetch- and depth limited and that land areas will tend to reduce local wind speed slightly. The major disadvantages of the Bay area are the limited water depth and maneuvering room which poses a hazards to large vessels. Test sites in coastal ocean waters have the advantages of greater water depth and maneuvering room for the test ship. However, waves at the ocean sites will be generally larger than in the Bay. Testing in the summer will minimize wave effects. An ocean mooring should be in at least 70 feet of water to reduce non-linear wave forces in the mooring.

Physical model tests are recommended to determine forces in the mooring and to examine motions of the moored barge.
EXECUTIVE SUMMARY

The best method of mooring the Empress II and test vessel is by using a four-point mooring illustrated in the attached figure. Each point of the mooring will be a riser-type mooring with a buoy that can be used to restrain the barge and/or test ship. Synthetic lines should be used to moor the vessels because of their ease in handling. The mooring lines should: (1) stretch to act as shock absorbers; (2) have strength; (3) float or have floats attached; (4) resist abrasion; (5) resist chemicals and (6) resist ultraviolet light. The type and dimensions of the lines will be determined in the final design stage.

Several sites have been examined. The sheltered waters in the Chesapeake Bay are recommended for testing small to medium class ships. The Bay area has the advantages that waves are fetch- and depth-limited and that land areas will tend to reduce local wind speeds slightly. The major disadvantages of the Bay area are the limited water depth and maneuvering room which poses a hazard to large vessels. Test sites in coastal ocean waters have the advantages of greater water depth and maneuvering room for the test ship. However, waves at the ocean sites will be generally larger than in the Bay. Testing in the summer will minimize wave effects. An ocean mooring should be in at least 70 feet of water to reduce non-linear wave forces in the mooring.

Physical model tests are recommended to determine forces in the mooring and to examine motions of the moored barge.

OPERATIONAL CONDITIONS

The following operational conditions are tentatively recommended:

a. Significant wave heights less than 5 feet (This height should be better defined as the highest waves when personnel can work and safely leave the barge. Further model studies and prototype experience will help define this limit).

b. Wind speeds less than 28 knots (below a "Moderate Gale")
EVACUATION

Personnel should seriously consider leaving the barge and have the barge towed into sheltered water from an operation-only mooring when the following are expected:
a. Significant wave heights of 5 feet or greater; or
b. Winds higher than 28 knots (a "Moderate Gale" or higher). These limitations can be relaxed if the freeboard can be increased by the crew and if an ocean storm-harden mooring is included.

SURVIVAL MOORING

The barge should be moved out of an operation-only mooring and put into the survival mooring if the wind speeds greater than 28 knots are expected.

DOWNTIME

Based on the above advice and available statistics, testing will not be possible for the following times:

Predicted Downtime When Testing Is Not Recommended Due To Adverse Wind and Wave Conditions (HOURS PER MONTH)

<table>
<thead>
<tr>
<th>Location</th>
<th>Due to Waves</th>
<th>Due to Wind</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chesapeake Bay (all year)</td>
<td>14</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>Dam Neck (May-July)</td>
<td>12</td>
<td>9</td>
<td>12 to 21</td>
</tr>
<tr>
<td>Caribbean (all year)</td>
<td>80</td>
<td>34</td>
<td>80 to 114</td>
</tr>
</tbody>
</table>

MOORING DESIGN

Each corner of the four-point mooring will consist of a mooring buoy, a riser chain and an anchor. The buoy should be large and 4-inch Grade 3 riser chain is recommended. A deadweight anchor will require a weight of several hundred tons made of scrap metal and concrete. The details of the final anchor design will depend on sediment characteristics at the site and the design loads determined from the model studies.
WORKING COST ESTIMATE

The approximate cost of the installed four-point mooring is $950K in FY83 dollars. Exact cost will depend on detailed design and location, as well as year of installation. The mooring line costs will have to be determined during final design.
Mooring Configuration for a Moored Test Ship

Note: Test ship leaves and the barge goes to a single-point mooring during storm conditions.
Preliminary Mooring Plan for the Empress II Barge

by

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Ocean Engineering & Construction Project Office

1. Introduction

The Empress II will be a test barge 120 feet long, 105 feet wide, 12 feet high with an operational freeboard of 3 feet. The barge holds a cone-shaped antenna 120 feet high with a maximum diameter of 220 feet. The barge will be used in sheltered water as well as in coastal ocean waters.

2. Problem

The problem is how to safely moor the barge during testing and for "survival" conditions. Factors that need to be considered are safety of the crew and equipment, operational requirements and cost.

3. Approach

This report presents preferred preliminary mooring designs and recommends methods of using these moorings. These designs were formulated after the following steps were taken:

a. reviewed previous work (Reference 1);
b. examined wind, wave and current statistics (References 2, 3 and 4);
c. determined operational requirements of the system;
d. formulated preliminary designs and made cost estimates;
e. performed computer analyses and limited physical model studies; and
f. selected the most promising designs.

4. Operational Requirements (per meeting of PM-23, NAVSEA & CHESDIV)

During operation the barge will have a freeboard of 3 feet and the amount of metal above this level should be minimized. During some tests the test ship will pass in the vicinity of the moored barge. During other tests the ship will be moored for as long as two weeks and moved into various positions. The barge should survive extreme storms in case it cannot be towed.
5. Conceptual Design

The design layout shown in Figure 1 (Reference 1) is ideal because it allows the barge (which has no internal propulsion) to position itself by letting out and pulling in on the various mooring lines. The test ship can also go into a bow-stern mooring between two of the four-point moorings (Figure 1).

Several of the possible designs for each point on the mooring are shown in Figure 2. The deadweight anchor type mooring with riser chain and buoy is recommended (Figure 2 D). Advantages of this last type of mooring are:

1) highly reliable
2) reasonable cost
3) design can easily be applied to a number of sites
4) simple design
5) easy to install (the deadweight anchor can be floated to the site)
6) low maintenance
7) no ground legs to tangle with ships anchors

The details of the anchor design will have to be worked out in final design to suit the selected site. Preliminary calculations show that it will have to be several hundred tons. However, costs can be kept reasonable if concrete and scrap metal are used to form a deadweight anchor.

Much of the design effort will have to be devoted to designing the lines used to moor the barge to the mooring, because this will be the weakest link in the system. These lines should resist the environmental forces, absorb dynamic loads, be easy to handle, resist wear and be non-ultraviolet sensitive. Working lines should float to allow easy usage.
6. **Wave Statistics**

Waves play an important role in the design of the moorings and in the operation of the barge for several reasons. First, at a 3-foot freeboard it will only take a relatively small wave to place the decks awash making operations hazardous and endangering the crew. During high waves the freeboard should be increased by deballasting and/or by moving the barge to sheltered waters. Second, waves can cause high mooring loads in a stiff mooring (Reference 5). Third, waves may damage the antenna through rapid accelerations and motions of the barge.

Model studies still need to be performed to determine under which wave conditions the crew can safely work and what is the maximum conditions under which evacuation can take place.

The Chesapeake Bay has the best wave climate of the sites proposed with significant wave heights 6 feet or higher less than 10 hours per month throughout the year (Figure 3). Dam Neck (off the mouth of the Chesapeake Bay) could also be used for testing during the months of May through July, when the chance of high waves is minimized (Figure 4). The best time to conduct tests in the Caribbean would be April through June or October through November (Figure 3).

The above statistics lead to the following conclusions: operate whenever possible in the Chesapeake Bay; operate off of the mouth of the Chesapeake Bay in the summer; and moor the barge in the Chesapeake Bay during major storms to reduce the possibility of problems caused by waves (see Figure 5 for wave height statistics in cumulative form and Table 1).

Mariners have long recognized that even small waves in shallow water are much more dangerous than larger waves in deep water. This is because as waves move into shallower water they shoal. These non-linear, shoaled waves produce a variety of problems, such as very high mooring loads (Reference 6). Mooring chain loads reach 1 million pounds (Reference 5) for the worst possible breaking wave conditions that can occur in 50 feet of water for the Empress II (wave period = 12 seconds,
see Figure 6). However, these monochromatic breaking two-dimensional wave conditions used in the laboratory tests are highly unlikely in nature. The natural wave trains have a three-dimensional nature and waves higher than the significant wave height occur only about 13% of the time.

The following method was used to select a maximum ocean design wave height for the various water depths of interest:

a. The maximum possible level of wave energy was determined at various ocean water depths using methods in Reference 7 with a deepwater design wave period of 12 seconds;
b. The wave energy was converted into a significant wave height and corrected for non-linear effects using techniques described in Reference 8; and
c. The maximum wave height was taken as 1.8 times the significant wave height (Reference 9).

The resulting ocean design wave heights for various water depths are given in Table 2, together with design wave forces in a riser-type chain mooring (see Figure 6). Note that the design force increases as the barge is moored in shallower ocean water, even though the design wave height decreases (Figure 6).
7. **Winds**

Winds are important because the force on the barge increases approximately as the square of the wind velocity and very high velocities are possible. Figure 7 shows wind speed statistics for extreme events in the Chesapeake Bay area. Some extreme winds and resulting forces are:

<table>
<thead>
<tr>
<th>Wind (knots)</th>
<th>Return Period (years)</th>
<th>Force on Barge (Kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>100</td>
<td>300*</td>
</tr>
<tr>
<td>105</td>
<td>40</td>
<td>225*</td>
</tr>
<tr>
<td>90</td>
<td>25</td>
<td>100</td>
</tr>
</tbody>
</table>

* includes wave forces in the Chesapeake Bay (33% of static force)

Winds are also important during operation because forces and moments are induced in the antenna, significant mooring line forces may occur and waves and wind will produce green water over the deck. The probabilities of various winds being exceeded, in terms of hours per month, is given in Table 3 and in cumulative form on Figure 8 and by month on Figure 8A.

8. **Currents**

Reference 1 shows that current forces are not very large, so an operational current of 1.5 knots and survival current of 2.0 knots are used in this study.

9. **Working Cost Estimate**

A four-point mooring placed in the Chesapeake Bay area will cost approximately $950K as outlined in Appendix A. Costs of the lines to moor the Empress II and test vessel to the four-point mooring will have to be worked out in final design. Physical model studies are recommended to provide information on mooring line forces due to waves.
10. **Summary and Recommendations**

The Empress II barge and test vessel can conveniently be moored as shown in Figure 1. In this configuration the barge is moored in a four-point mooring. The barge is then moved around for testing by letting in and out on the barge mooring lines. The vessel to be tested is in the meantime put into a two-point bow and stern mooring. The Empress II is moored with heavy lines to one of more of the buoys during poor weather.

The best place to conduct tests would be in sheltered water, such as the Chesapeake Bay. However, wind and wave conditions are quite mild off the Dam Neck area in the summer (especially May through July), so larger vessels requiring deep water or extra maneuvering room could be tested in the coastal Atlantic. Other sites, such as the Caribbean, could also be used.

Test sites exposed to ocean waves should be selected to have water depths of at least 70 feet. This will minimize forces due to waves because waves in deeper water are more linear. Water depths much greater than 100 feet should also be avoided to allow easy diver inspection of the moorings.

The two critical items requiring careful design are: (a.) the mooring lines between the Empress II and the buoys and (b.) the anchor. Large 1/28 scale model tests are recommended to aid in the final design of this mooring system.

Embedment anchors are a lower cost method of mooring the Empress II for temporary operation of less than a year.
References Cited


Table 1. Hours per Month Various Wave Heights are Exceeded

<table>
<thead>
<tr>
<th>Location</th>
<th>Significant Wave Height</th>
<th>3'</th>
<th>4'</th>
<th>5'</th>
<th>6'</th>
<th>10'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chesapeake Bay (all year)</td>
<td></td>
<td>90</td>
<td>40</td>
<td>14</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Dam Neck (May-Jul)</td>
<td></td>
<td>90</td>
<td>30</td>
<td>12</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>(all year)</td>
<td></td>
<td>260</td>
<td>140</td>
<td>80</td>
<td>44</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 2. Design Conditions for a Storm-Hardened Ocean Mooring

<table>
<thead>
<tr>
<th>Water Depth (ft)</th>
<th>$H_s$ (ft)</th>
<th>$H_{max}$ (ft)</th>
<th>Wave Force (kips)</th>
<th>Wind Force (kips)</th>
<th>Current Force (kips)</th>
<th>Total Force (kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>14.8</td>
<td>27</td>
<td>500</td>
<td>100</td>
<td>55</td>
<td>655</td>
</tr>
<tr>
<td>75</td>
<td>16.2</td>
<td>29</td>
<td>130</td>
<td>100</td>
<td>55</td>
<td>285</td>
</tr>
<tr>
<td>100</td>
<td>18.7</td>
<td>34</td>
<td>65</td>
<td>100</td>
<td>55</td>
<td>220</td>
</tr>
</tbody>
</table>

1 $H_{max}$ is used for design and here taken as 1.8 times $H_s$. Higher waves are possible, but unlikely.
2 A 90 knot wind is used for design; this has a 25 year return period.
3 A 2.0 knot current is used for design.
4 $\alpha=0.0081; \ R=1.0$
5 Tested with no hawser. A properly designed mooring hawser will reduce these wave forces.
Table 3. Hours per Month Various Wind Speeds are Exceeded

<table>
<thead>
<tr>
<th>Location</th>
<th>Wind Velocity in Knots</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>28</td>
</tr>
<tr>
<td>Chesapeake Bay</td>
<td></td>
</tr>
<tr>
<td>(all year)</td>
<td>42</td>
</tr>
<tr>
<td>Dam Neck</td>
<td></td>
</tr>
<tr>
<td>(May-Jul)</td>
<td>9</td>
</tr>
<tr>
<td>Puerto Rico</td>
<td></td>
</tr>
<tr>
<td>(all year)</td>
<td>30</td>
</tr>
</tbody>
</table>
Passing Test Ship

1000' < L < 1400'

Figure 1. The Mooring Plan
A) Single Embedment Anchors  
B) Dual Embedment Anchors  
C) Multiple Drag Anchors with Chain Riser  

Figure 2. Mooring Types
D) Deadweight Anchor & Riser Mooring

Figure 2. Mooring Types (cont.)
E) Pile Anchor & Riser Mooring

Figure 2. Mooring Types (cont)
Figure 3. Percent of time the significant wave height is greater than 6'.
Figure 4. Maximum Monthly Wave Heights Observed for the Dam Neck Area

Water depth = 59'
36° 11' N  75° 44.4' W

Month

1978  1981
1979  1982
1980  1983
Figure 5. Cumulative Wave Height Distribution

- Caribbean (all year)
- Atlantic (Jul-Sep)
- Dam Neck (May-Jul)
- Chesapeake Bay (all year)
Figure 6. Design Waves and Wave Forces for a Storm Hardened Mooring in the Ocean

**NOTE:** barge moored directly to the buoy

- Design wave force
- Design $H = 1.8 \times (H_s)_{max}$
- $d = 50'$
- $580^k$
- $75'$
- $100'$
- $250^k$
- $150^k$
- $65^k$

T = 12 sec

Barge 105' x 120' x 12'

**NOTE:** barge moored directly to the buoy
Figure 7. Extreme Wind Return Periods for the Chesapeake Bay Area
Figure B. Cumulative Wind Speed Statistics

- Caribbean
- Chesapeake Bay
- Dam Neck
Figure 8A. Wind statistics by month for Norfolk

- 22 Knots
- 28 Knots
- 34 Knots
- 48 Knots

Percent of Time which Wind Speed is exceeded (%) vs. Hours per month which Wind Speed is exceeded.

- Jan
- Feb
- Mar
- Apr
- May
- Jun
- Jul
- Aug
- Sep
- Oct
- Nov
- Dec

Months
Appendix A. Working Cost Estimate (Fy83 dollars)

Each Corner of the Mooring

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buoy</td>
<td>$50 K</td>
</tr>
<tr>
<td>Riser (4&quot; Grade 3 chain)</td>
<td>$47 K</td>
</tr>
<tr>
<td>Anchor</td>
<td></td>
</tr>
<tr>
<td>Concrete 110 yd$^3$ x $85/\text{yd}^3$ = $10 K</td>
<td></td>
</tr>
<tr>
<td>Forming</td>
<td>$8 K</td>
</tr>
<tr>
<td>Steel $950/\text{ton} \times 18 \text{ tons} = $17 K</td>
<td></td>
</tr>
<tr>
<td>Welding</td>
<td>$2 K</td>
</tr>
<tr>
<td>Misc</td>
<td>$13 K</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$50 K</td>
</tr>
</tbody>
</table>

Sub-Total                  $147 K

Total Cost of Mooring Buoy System

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Four-Point Mooring Materials $4 \times 147 K</td>
<td>$588 K</td>
</tr>
<tr>
<td>Installation &amp; Contingency</td>
<td>$342 K</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$930 K</td>
</tr>
</tbody>
</table>
Appendix B. Ship Forces on Moorings

If a ship is to be moored while testing, then wind and currents on the ship will transmit forces into the moorings. These are preliminary calculations to indicate the amount of force that must be witheld for a LHA-1 ship.
<table>
<thead>
<tr>
<th>Condition</th>
<th>Fully Loaded</th>
<th>1/3 Stores/Cargo</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam</td>
<td>106 feet</td>
<td>106 feet</td>
<td>106 feet</td>
</tr>
<tr>
<td>Length at waterline (LWL)</td>
<td>765 feet</td>
<td>765 feet</td>
<td>765 feet</td>
</tr>
<tr>
<td>Length Overall (LOA)</td>
<td>820 feet</td>
<td>820 feet</td>
<td>820 feet</td>
</tr>
<tr>
<td>Draft (T)</td>
<td>21.8 feet</td>
<td>21.8 feet</td>
<td>21.8 feet</td>
</tr>
<tr>
<td>Below water end area (A)</td>
<td>2100 sq.ft.</td>
<td>2100 sq.ft.</td>
<td>2100 sq.ft.</td>
</tr>
<tr>
<td>End-projected wind area (Ae)</td>
<td>11250 sq.ft.</td>
<td>11250 sq.ft.</td>
<td>11250 sq.ft.</td>
</tr>
<tr>
<td>Side-projected wind area (As)</td>
<td>74950 sq.ft.</td>
<td>74950 sq.ft.</td>
<td>74950 sq.ft.</td>
</tr>
<tr>
<td>Displacement (D)</td>
<td>30020 long tons</td>
<td>30020 long tons</td>
<td>30020 long tons</td>
</tr>
</tbody>
</table>

**B. Basic constants:**

\[
\text{BhW} = 0.48 \times \text{LOA}
\]

\[
**S = \left(1.7 \times \frac{\text{LWL}}{\text{T}}\right) = 27.700 \text{ sq.ft.}
\]

For a normal vessel S should be multiplied by a factor of 0.95.

\[
\begin{align*}
\frac{1}{2} \rho_c V_c^2 LWL & = C_{ym} 1/2 (1.9876) (2.53)^2 765 (21.8) = C_{ym} 1.04 \times 10^5 \\
M_c & = C_{ym} 1/2 (0.00237) (47.3)^2 74950 (765) C_{ym} 2.98 \times 10^4 \\
\frac{1}{2} \rho_w V_w^2 A_w & = C_{ym} 1/2 (0.00237) (47.3)^2 74950 = C_{ym} 1.99 \times 10^5 \\
M_u & = C_{ym} 1/2 (0.00237) (47.3)^2 74950 (765) C_{ym} 1.52 \times 10^8
\end{align*}
\]
C. Trial: LHA-1

WIND <\_Current

\[ \text{Wind/CURRENT ANGLE } \theta_c = 0 \degree \]
\[ \text{CURRENT ANGLE } \theta_c = 0 \degree \]
\[ \text{WIND ANGLE } \theta_w = 90 \degree \]

*\( \theta_c \) and \( \theta_w \) are measured clockwise from ship’s bow.

Note: Use sketch to indicate directions (+ or -) of Forces and Moments.

Coefficients for this \( \theta_c, \theta_w \) and \( \text{WIND}/\text{T} \):

\[
\begin{align*}
C_{xc} &= 0.35 \text{ (Figure 2)} \\
C_{yc} &= 0 \text{ (Figure 3)} \\
C_{xcb} &= C_{yc} \cos \theta_c \cos \theta_c = 0 \\
C_{xy} &= 0 \text{ (Figure 4)} \\
C_{xw} &= 0 \text{ (Figure 5)} \text{ Normal, or Hull-Dominated} \\
C_{yw} &= 1 \text{ (Figure 6)} \\
C_{xyw} &= -0.035 \text{ (Figure 7)}
\end{align*}
\]

Forces and Moments:

\[
\begin{align*}
F_{xc} &= \frac{1}{2} \frac{C_{xc} v^2}{L^2} + (C_{xcb} x) \\
F_{yc} &= \frac{1}{2} (1.9076) \left(2.53\right)^2 \left(0.35 \times 27700 \times \frac{10^6}{765}\right) = 8580 \text{ lb} \\
M_c &= C_{xy} x \\
F_{xy} &= C_{xy} \left(1.99 \times 10^5\right) = 199,000 \text{ lb} \\
M_w &= C_{xyw} x = 5.3 \times 10^6 \text{ ft-lb} \\
F_t &= F_{yc} + F_{yw} = 8580 \text{ lb} \\
M &= M_c + M_w = (F_t AB) = 83.7 \times 10^6 \text{ ft-lb}
\end{align*}
\]

a) If \( M \) equals zero, the equilibrating position has been found.

\[
F_H = F_x + F_t
\]

b) If \( M \) is a large positive or negative number, the vessel is not in equilibrating and a different ship position angle must be tried (i.e., \( \theta_c \) and/or \( \theta_w \) so that the ship is in a different position with regard to wind and current vectors).

FIGURE 8a (Continued)

Sample Calculation Procedure for Single-Bulled Vessels - Blank Form

26.6-17
LHA-1 1.5 Knot Current, 28 Knot Wind

\[
\text{WIND/CURRENT ANGLE } \theta_c = \frac{137}{0}^\circ
\]
\[
\text{*CURRENT ANGLE } \theta_e = \frac{137}{90}^\circ
\]
\[
\text{*WIND ANGLE } \theta_w = \frac{137}{60}^\circ
\]

*\( \theta_c \) and \( \theta_w \) are measured clockwise from ship's bow.

Note: Use sketch to indicate directions (+ or -) of Forces and Moments.

Coefficients for this \( \theta_c \), \( \theta_w \), and \( \text{W/D/T} \):

\begin{align*}
C_{x_{ca}} &= 0.0 \quad \text{(Figure 2)} \\
C_{yc} &= 1.3 \quad \text{(Figure 3)} \\
C_{xb} &= \left| C_{yc} \cos \theta_c \right| \cos \theta_e = 0.0 \quad \text{(Figure 4)} \\
C_{xy} &= 0.0 \quad \text{(Figure 6)} \\
C_{xy} &= 0.93 \quad \text{(Figure 5)} \\
C_{xy} &= 0.86 \quad \text{(Figure 6)} \\
C_{xy} &= 0.055 \quad \text{(Figure 7)}
\end{align*}

Forces and Moments:

\begin{align*}
F_x &= \frac{1}{2} \rho \alpha R^2 \left( C_{x_{ca}} S_{x_{ca}} \cos \theta_c + C_{xb} \cos \theta_e \right) \\
F_x &= \frac{1}{2} \rho \alpha R^2 \left( 1.3 \times 1.0 \times 10^5 \right) = 135,000 \text{ lb} \\
M_c &= C_{xy} \times 1.5 \times 10^5 \times 0 = 0 \text{ ft-lb} \\
F_{xy} &= C_{xy} \times 1.5 \times 10^5 \times 0.055 = 8,350,000 \text{ lb-ft} \\
F_x &= F_{xy} + F_{xy} = 0 + 8,350,000 - 305,000 (394) = -112,106 \text{ ft-lb}
\end{align*}

\( F_x = F_{xy} + F_{xy} \quad \text{and} \quad M = M_x + M_y - (F_{xy} R) \quad \text{for different ship positions.}

\text{Figure 8a (Continued)}


26.0-17
1.5 knot Current, 28 knot Wind

\[ \text{WD/T} = 2.6 \]

**WIND/CURRENT ANGLE**
\[ \theta_c = 0^\circ \]
\[ \theta_w = 60^\circ \]

*\( \theta_c \) and \( \theta_w \) are measured clockwise from ship's bow.

Note: Use sketch to indicate directions (+ or -) of Forces and Moments.

Coefficients for this \( \theta_c, \theta_w \) and \( \text{WD/T} \):

\[
\begin{align*}
C_{xca} &= 0.35 \quad \text{(Figure 2)} \\
C_{yc} &= 0 \quad \text{(Figure 3)} \\
C_{xcb} &= C_{yc} \cos \theta_c \cos \theta_c = 0 \\
C_{xyc} &= 0 \quad \text{(Figure 4)} \\
C_{xw} &= 0.24 \quad \text{(Figure 5)} \quad \text{Normal, or Hull-Dominated} \\
C_{yw} &= 0.86 \quad \text{(Figure 6)} \\
C_{xyw} &= 0.055 \quad \text{(Figure 7)}
\end{align*}
\]

Forces and Moments:

\[
\begin{align*}
F_x &= \frac{1}{2} \left( C_{xca} \left( \frac{B}{LWL} \right)^2 + (C_{xcb} A_b) \right) \\
&= 8,600 \quad \text{lbs} \\
F_{xc} &= \frac{1}{2} (1.985b) (2.53)^2 \left( (0.35 \times 27,700 \times 10^6) + (0) \right) = 8,600 \quad \text{lbs} \\
F_y &= C_{yc} \quad = 0 \quad \text{lbs} \\
M_y &= C_{xyc} \quad = 0 \quad \text{ft-lbs} \\
F_{xw} &= C_{xw} \quad = 6,850 \quad \text{lbs} \\
F_{yw} &= C_{yw} \quad = 171,000 \quad \text{lbs} \\
M_y &= C_{xyw} \quad = 8,350,000 \quad \text{ft-lbs} \\
F_g &= F_x + F_{xw} = 8,600 + 6,850 = 15,450 \quad \text{lbs} \\
F_t &= F_y + F_{yw} = 0 + 171,000 = 171,000 \quad \text{lbs} \\
M &= M_x + M_y = (t_e A_{p2}) = 0 + 8,350,000 - (171,000 \times 394) = -59,106 \quad \text{ft-lbs}
\end{align*}
\]

a) If \( M \) equals zero, the equilibrium position has been found.

\[
F_w = -\frac{F_x^2 + F_t^2}{F_x} \quad = \quad \text{lbs}
\]

b) If \( M \) is a large positive or negative number, the vessel is not in equilibrium and a different ship position angle must be tried (i.e., modify \( \theta_c \) and \( \theta_w \) so that the ship is in a different position with respect to wind and current vectors).

---

**FIGURE: R1 (Continued)**

Simple Calculation Procedure for Single-Hulled Vessels - Blank Form

26.6-17
**Given**

- Ship Designation: LHA-1
- Water Depth (W) = 65 feet
  - (W High Tide or W Low Tide)
- Current Speed \( V_c = (2 \text{ knots}) \times 1.689 = 3.3 \text{ ft/sec} \)
  - (Use average value of current profile between waterline and ship's keel)
- Wind Speed \( V_w = (40.3 \text{ mph}) \times 1.467 = 59 \text{ ft/sec} \)
  - (? 33 feet above water level)

* If current speed and wind speed are unknown, refer to Table 1.

In calculations below, use ft/sec quantities.

**Assumptions**

- Water density is constant and equals 1.9876 lb-sec^2/ft^4 @ 68°F.
- Air density is constant and equals 0.00237 lb-sec^2/ft^4 @ 68°F.

**Procedure**

A. From Table 2:

<table>
<thead>
<tr>
<th>Load condition:</th>
<th>Fully Loaded</th>
<th>1/3 Stores/Cargo</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft: T = ______ feet</td>
<td>2.13 feet</td>
<td>______ feet</td>
<td>______ feet</td>
</tr>
<tr>
<td>below water end area A_b = ______ sq.ft.</td>
<td>2100 sq.ft.</td>
<td>______ sq.ft.</td>
<td>______ sq.ft.</td>
</tr>
<tr>
<td>End-projected wind area A_e = ______ sq.ft.</td>
<td>11250 sq.ft.</td>
<td>______ sq.ft.</td>
<td>______ sq.ft.</td>
</tr>
<tr>
<td>Side-projected wind area A_s = ______ sq.ft.</td>
<td>74950 sq.ft.</td>
<td>______ sq.ft.</td>
<td>______ sq.ft.</td>
</tr>
<tr>
<td>Displacement = ______ long</td>
<td>30020 long</td>
<td>______ long</td>
<td>______ long</td>
</tr>
<tr>
<td>Total = ______ tons</td>
<td>______ tons</td>
<td>______ tons</td>
<td>______ tons</td>
</tr>
</tbody>
</table>

**Basic constants:**

- \( \text{ARM} = 0.48 \text{ LOA} \)
- \( **S = (1.7 \text{ T LWL}) + \left( \frac{350}{T} \right) \) = 394 feet
- \( **S = 27700 \text{ sq.ft.} \)

For a normal vessel S should be multiplied by a factor of 0.95.

\[
\begin{align*}
F_c &= C_{yc} 1/2 \rho V_c^2 LWL T = C_{yc} 1/2 (1.9876) (3.3)^2 765 (21.3) = 1.77 \times 10^5 \\
M_c &= C_{yc} 1/2 \rho V_c^2 LWL^2 T = C_{yc} 1/2 (1.9876) (3.3)^2 (765)^2 21.3 = 1.36 \times 10^8 \\
I_{xy} &= C_{xy} 1/2 \rho V_w^2 A_e = C_{xy} 1/2 (0.00237) (59)^2 11250 = 4.64 \times 10^4 \\
F_{yw} &= C_{yw} 1/2 \rho V_w^2 A_b = C_{yw} 1/2 (0.00237) (59)^2 74950 = 3.09 \times 10^5 \\
M_{yw} &= C_{xyw} 1/2 \rho V_w^2 A_b LWL = C_{xyw} 1/2 (0.00237) (59)^2 74950 (765) = 2.57 \times 10^8
\end{align*}
\]

**Figure 8a**

Sample Calculation Procedure for Single-Hulled Vessels - Blank Form

26.6-16
C. TRIAL # ____________

WIND/CURRENT ANGLE $\theta_c$ = ____________°
*CURRENT ANGLE $\theta_c$ = 0°
*WIND ANGLE $\theta_w$ = 90°

$\theta_c$ and $\theta_w$ are measured clockwise from ship's bow.

Note: Use sketch to indicate directions (+ or -) of Forces and Moments.

Coefficients for this $\theta_c$, $\theta_w$ and $\frac{W/D}{I}$:

$C_{x_{ca}} = 0.35$ (Figure 2)
$C_{yc} = 0.0$ (Figure 3)
$C_{x_{cb}} = C_{yc} \cos \theta_c \cos \theta_c = 0.$
$C_{y_{yc}} = 0.0$ (Figure 4)
$C_{xw} = 0.39$ (Figure 5) Normal, or $X_{Hull-Dominated}$
$C_{yw} = 0.5$ (Figure 6)
$C_{xvw} = 0.05$ (Figure 7)

Forces and Moments:

$F_{xc} = \frac{1}{2} \rho \frac{L}{S} \frac{V^2}{u}\{C_{x_{ca}} \cos \theta_c + (C_{x_{cb}} \cos \theta_c)\}$
$F_{xc} = \frac{1}{2} (1.9076) \ (3.3)^2 \left(0.35 \times 27700 \times \frac{106}{765} + (0.0)\right) = 14,600$ lbs

$F_{yc} = C_{yc} \frac{1.7770x}{5} = 0$ lbs

$M_c = C_{y_{yc}} \frac{1.34\times 10^{8}}{5} = 0$ ft-lbs

$F_{w} = C_{xw} \frac{4.64 \times 10^{4}}{5} = 18,100$ lbs

$F_{w} = C_{yw} \frac{3.09 \times 10^{5}}{5} = 155,000$ lbs

$M_y = C_{x_{vw}} \frac{1.91 \times 10^{7}}{5} = 33,000$ lbs

$F_{k} = F_{xc} + F_{cy} = 14,600 + 18,100 = 32,700$ lbs

$F_{k} = F_{yc} + F_{wy} = 0 + 155,000 = 155,000$ lbs

$M_x = M_y + M_{w} = 33,000 + 155,000 = -4,910^7$ ft-lbs

$\theta_k = \theta_c - \theta_w$ is measured clockwise from ship's bow.

a) If $M$ equals zero, the equilibrium position has been found.

$b) If M$ is a large positive or negative number, the vessel is not in equilibrium and a different ship position angle must be tried (i.e., modify $\theta_c$ and $\theta_w$ so that the ship is in a different position with respect to wind and current vectors).
**Coefficients for this $\theta_c$, $\theta_v$ and WD/T:**

\[
\begin{align*}
C_{x_c a} &= 0.35 \quad \text{(Figure 2)} \\
C_{y_c} &= 0. \quad \text{(Figure 3)} \\
C_{x_c b} &= \left| C_{y_c} \cos \theta_c \right| \cos \theta_c = 0. \quad \text{(Figure 4)} \\
C_{x_{y_c}} &= 0.0 \quad \text{(Figure 4)} \\
C_{x_w} &= 0.0 \quad \text{(Figure 5)} \quad \text{Normal, or Hull-Dominated} \\
C_{y_w} &= 1.0 \quad \text{(Figure 6)} \\
C_{x_{y_w}} &= -0.035 \quad \text{(Figure 7)}
\end{align*}
\]

**Forces and Moments:**

\[
\begin{align*}
F_x &= 1/2 C_{x_c} V^2 \left( C_{x_c a} S \frac{\theta_c}{2} + C_{x_c b} A \right) \\
F_x &= 1/2 (1.9875) (3.3)^2 \left( 0.35 \times 27700 \times \frac{106}{763} \right) = 14,600 \quad \text{lbs} \\
F_y &= C_{y_c} \quad \text{lbs} \\
M_c &= C_{x_{y_c}} \quad \text{lbs-ft} \\
F_{x_w} &= C_{x_w} \frac{4.64 \times 10^4}{2} = 0 \quad \text{lbs} \\
F_{y_w} &= C_{y_w} \frac{3.01 \times 10^5}{2} = 309,000 \quad \text{lbs} \\
M_w &= C_{x_{y_w}} \frac{2.37 \times 10^8}{2} + 0.035 \times 2.37 \times 10^6 = 8.3 \times 10^6 \quad \text{ft-lbs} \\
F_f &= F_x + F_{x_w} = 14,600 \quad \text{lbs} \\
F_f &= F_{y_c} + F_{y_w} = 0 \quad \text{lbs} \\
M_e &= M - (F_{t, \text{ARM}}) = 0 + 8.3 \times 10^6 - (3 \times 10^5 \times 394) = 114,106 \quad \text{lbs} \\
\end{align*}
\]

**a)** If $M$ equals zero, the equilibrium position has been found.

\[
F_{\text{eq}} = F_x^2 + F_f^2 = 14,600 \quad \text{lbs}
\]

**b)** If $M$ is a large positive or negative number, the vessel is not in equilibrium and a different ship position angle must be tried (i.e., modify $\theta_c$ and $\theta_v$ so that the ship is in a different position with respect to wind and current vectors).

---

**FIGURE 8a (Continued)**

Sample Calculation Procedure for Single-Hulled Vessels - Blank Form

26.6-17