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CALCULATION OF MOMENT OF INERTIA AND SHEAR AREA OF A SHIP CROSS-SECTION

BY MICHAEL L. MARSHALL

RESEARCH AND TECHNOLOGY DEPARTMENT

28 JANUARY 1977

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 14 NSWC/WOL/TR-77-26	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 Calculation of Moment of Inertia and Shear Area of a Ship Cross-Section		5. TYPE OF REPORT & PERIOD COVERED 9 Interim rept.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Michael L. Marshall		8. CONTRACT OR GRANT NUMBER(s) 16
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Surface Weapons Center White Oak Laboratory White Oak, Silver Spring, Maryland 20910		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62633N; SF33 351; 17 SF33 351 32B; WR-17BA52D;
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 11 28 Jan[redacted]977
		13. NUMBER OF PAGES 23
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) 12 26 p.		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Inertia
Shear Area
Whipping
Ship Structures
Explosions
Damage Calculations
Ship Strength

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

When calculating the whipping motions of a surface ship caused by an underwater explosion, it is necessary to have a structural model of the ship in finite element form. Among the input data required for this model are the moment of inertia and shear area of the girder at specified cross-sections along the ship. If these data are unavailable, it may be necessary to compute them from the ship's plans. The general theory involved in computing them is over

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S/N 0102-014-6601

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NSWC/WOL/TR 77-26 28 January 1977

Calculation of Moment of Inertia and Shear Area of a Ship Cross-Section

When calculating the whipping motions of a surface ship caused by an underwater explosion, it is necessary to have a structural model of the ship in finite element form. Among the input data required for this model are the moment of inertia and shear area of the girder at specified cross-sections along the ship. If these data are unavailable, it may be necessary to compute them from the ship's plans. The general theory involved in computing them is described as is a simple computer program written to expedite the calculation.

Julius W. Enig

JULIUS W. ENIG
By direction

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1. INTRODUCTION

1.1. The concepts of moment of inertia and shear area are fundamental to any discussion of the strength of materials or to the load bearing capability of a structure. In particular, the design of ships requires a knowledge of these quantities in order to compute the longitudinal strength. This is essential to determining whether the girder is sufficiently strong to carry the imposed weight of the ship, its stores and on-board equipment. Standard procedures for computing these quantities have been developed. These are described in reference 1. The purpose of this NSWC/WOL/TR is to describe the general principles involved and how they have been implemented by computerization.

2. THEORY

2.1. In longitudinal strength calculations of a ship, simple beam theory is assumed to hold, reference 2. That is to say, a ship, for purposes of strength considerations, may be likened to a hollow, nearly rectangular, girder. Therefore, the equations derivable from simple beam theory may be used to make calculations for the strength of such a beam of known cross-section, reference 3. Because the girder may be considered to be a beam with a known cross-sectional area A, those simple relations which may be found in any text book on engineering mechanics may be applied to it; for example, see reference 4. However, for convenience, the relevant relations are rederived in the sections below.

2.2. Consider a beam with the arbitrary cross-section shown in Figure 2.1. The total area A can be found by integration as follows:

$$A = \int_A da. \tag{2.1}$$

The distance $\bar{y}$ to the centroid C of the area is obtained from

$$\bar{y} = \int_A y_x da / \int_A da \tag{2.2}$$

where it is understood by the symbol A beneath the integral signs that the integrations must be carried out over the entire area A.

---

1. DDS 9290-8. "Longitudinal Strength Calculations," Design Data Sheet, Department of the Navy, Bureau of Ships, 27 Dec 1950, Unclassified.
2. "Principles of Naval Architecture," revised edition published by the Society of Naval Architects and Marine Engineers, 1967.
3. T. C. Gillmer, "Modern Ship Design," United States Naval Institute, Annapolis, Maryland, Copyright 1970.
4. S. P. Timoshenko and J. M. Gere, "Mechanics of Materials," D. Van Nostrand Company, Copyright 1972.

The numerator of Equation 2.2 is known as the first moment of the area with respect to the x_x-axis and will be denoted by the symbol Q_x. Thus,

$$Q_x = \int_A y_x da. \tag{2.3}$$

2.3. Before continuing, it is necessary to introduce the concept of neutral axis. If a beam is bent, some of the fibers in the beam will be in compression while others will be in tension. However, there will exist some surface within the beam such that all fibers lying in this surface are neither in compression nor in tension. This surface is referred to as the neutral surface and its intersection with any cross-sectional plane of the beam is called the neutral axis of the cross-section. The moment of inertia of a cross-section of a girder used in longitudinal strength calculations is the moment of inertia with respect to the neutral axis of the cross-section. The moment of inertia of an area with respect to an axis in the plane of the area is related to the moment of inertia with respect to a parallel centroidal axis by the Parallel Axis Theorem. To obtain this theorem, consider the area shown in Figure 2.1. Assume that the point C is the centroid of the area and that the x and y axes are through the centroid. The x_x and y_x axes are parallel to the x and y axes and have their origin at any point 0. Then, by definition, the moment of inertia of the area with respect to the x_x axis is

$$I_x = \int_A y_x^2 \, da = \int_A (y + \bar{y})^2 \, da \tag{2.4}$$

or,

$$I_x = \int_A y^2 \, da + 2\bar{y} \int_A y da + \bar{y}^2 \int_A da. \tag{2.5}$$

The first integral on the right hand side of Equation 2.5 is the moment of inertia about the centroidal x-axis, I_c; the second integral vanishes because the x-axis passes through the centroid; and the third integral is the area A of the figure. Therefore, Equation 2.5 may be reduced to the form

$$I_x = I_c + \bar{y}^2 A. \tag{2.6}$$

It will not be proved here but it may be shown, reference 4, that the neutral axis passes through the centroid, hence, if I_{NA} represents the moment of inertia with respect to the neutral axis, we have from Equation 2.6,

$$I_{NA} = I_x - \bar{y}^2 A. \tag{2.7}$$

This equation may be used to find the moment of inertia with respect to the neutral axis given the moment of inertia I_x with respect to the arbitrary x_x-axis where

$$I_x = \int_A y_x^2 \, da. \tag{2.8}$$

2.4. The procedure to be used is the following. Choose any arbitrary axis parallel to the baseline of the ship girder cross-section of interest (see Figure 3.1). Let this axis be the x_x-axis. Indeed, the baseline itself may be chosen as this arbitrary axis. Now, compute the cross-sectional area A from Equation 2.1, the first moment Q_x of the area about this axis from Equation 2.3 and finally the moment of inertia I_x from Equation 2.8. The distance $\bar{y}$ between this arbitrary axis and the neutral axis may be found from Equation 2.2 which, for simplicity, may be rewritten as

$$\bar{y} = Q_x/A. \tag{2.9}$$

Finally, use Equation 2.7 to obtain the desired moment I_{NA} about the neutral axis.

2.5. The calculation of the area of a cross-section effective in shear, A_s, is a difficult problem where the cross-section does not have a geometrically simple shape. Such is the case for ship girder cross-sections. Several formulae for computing the shear area of ship cross-sections have been proposed in the literature. Hicks, reference 5, discusses these. For our purposes, the following formula, derived from considerations of simple beam theory, is used to obtain the shear area, namely

$$A_s = \frac{I_{NA}\, t}{M}. \tag{2.10}$$

The quantity I_{NA} is obtained from Equation 2.7, M is the first moment of the area above the neutral axis, and t is the sum of the thicknesses of all continuous side shell plating intersected by the neutral axis. By continuous, it is meant that the plating

5. A. N. Hicks, "The Theory of Explosion Induced Ship Whipping Motions." NCRE Report R579, (1972).

extends longitudinally at least 1/20 of the water line length of the ship. As an illustration, if we refer to Figure 3.1, we see that the neutral axis of the cross-section of the girder intersects the E-strake which we know from Equation 3.1 to be 0.5 inches thick. But the neutral axis intersects the E-strake of both sides of the girder, hence t is the sum of the thicknesses of both E-strakes or 1 inch. The quantity M may be calculated from

$$M = \int_{A'} y \, da \tag{2.11}$$

where the integral extends only over the area A' of the cross-section above the neutral axis.

3. READING SHIPS' PLANS

3.1. In order to carry out the calculations, it is necessary to have suitable ship's plans. Such plans are provided by inertia sections. These are cross-sections of the girder which show only those structural elements which effectively contribute to the longitudinal strength. These are typically provided for up to 15 stations along the ship. Figure 3.1 is a typical inertia section taken at station [illegible] a ship. The reading of inertia sections requires a knowledge of terms used by naval architects. Some of the more common of these are discussed below.

3.2. The following notations are commonly encountered:

L - refers to an inner-bottom longitudinal. These are normally sequentially numbered from the keel, e.g., L-1, L-2, etc.

CVK - Center vertical keel. A major strength element.

P and/or S - port and/or starboard. Used to mark those items found only on the port and/or starboard side of the ship cross-section. An area of plating enclosed by a triangle marked P and/or S means that it is not effective for strength purposes and should be omitted from strength calculations.

A,B,C, etc. - these are used to label the various plating elements (commonly referred to as strakes) that make up the shell (outer portion of hull) and the inner-bottom. These are labeled sequentially from the keel. The strake labeled "G" in Figure 3.1 is often called the sheer strake and the deck (main) plate connected to it is called the stringer strake.

FK - Flat keel. A flat plate welded to the CVK extending along the length of the ship.

℄ - Center-line. The axis of symmetry of the cross-section.

\$ - denotes a welded seam. These define the extent of various strakes.

Plating thicknesses are given in pounds, denoted # per square foot of plating. Using the density of steel, the thickness of a given plate whose weight is W #/ft sq is,

$$\text{thickness (in)} = W/40.8. \qquad (3.1)$$

For example, the A strake of the inner-bottom which entends from the top of the CVK to the first welded seam is labeled "A" - 20.4 #. Its thickness is therefore 1/2 inch. Longitudinals which may be I-beams, T-beams, etc. are identified by two dimensions and a weight. For example, the main deck longitudinals in Figure 3.1 are labeled,

8" x 4" x 15 # I-T.

The 8" is the nominal depth of the section while 4" is the nominal flange width. Figure 3.2 defines the basic properties of an I-beam. The notation I-T means that one flange has been cut off this I-beam to make it a T-beam. Sometimes the I-beam is cut at the center of the web to make a shorter T-beam. If this were done with the beam used in the example above, it would probably be identified as,

4" x 4" x 15 # I-T.

The nominal dimensions are then used to obtain the dimensions of the beam from a handbook on structural design. The necessary dimensions needed are the depth of the section, the flange width, flange thickness and web thickness. Another structural element that might be encountered in reading ship's plans is the angle, denoted by the symbol ∠. Angles are also identified by two dimensions and a weight. For example, referring to Figure 3.1, we see an angle between the sheer strake and the stringer strake labeled

6" x 6" 24.2 #.

The dimensions refer to the lengths of the sides of the angle and its weight may be used to obtain its cross-sectional area by again using the density of steel. The area is equal to the weight, 24.2 #. divided by the factor 3.41. This will yield the area in in. sq.. Thus, in general, a cross-section of a girder may be reduced to 3 general elements, i.e., plates, beams and angles.

4. APPLICATION

4.1. As we have seen, the calculation of the moment of inertia and shear area of a ship cross-section, in principle. involves the evaluation of certain integrals. In practice, this must be done by replacing the integrals by finite sums. For each finite element making up the girder, its moment of inertia about an arbitrary axis, call it i, consists of two moments of inertia. The first is its moment about an arbitrary axis, i_x, and the second is its moment of inertia about its own axis, i_o. In the limit of vanishingly small areas, i_o approaches zero. Consider Figure 4.1. Suppose a small area of plating is represented by the rectangular element of area ab rotated by an angle ϕ with respect to an arbitrary axis $\overline{xx}$. We can compute its moment of inertia about the rotated x'-axis then transform this to obtain the moment about the x-axis. If we do this, using the law of tensor transformations, we find that,

$$i_{NA} = \frac{1}{12} ab(b^2\cos^2\phi + a^2\sin^2\phi) + ab\, y_x{}^2 - \overline{y}(ab) \qquad (4.1)$$

where y_x is the perpendicular distance from the arbitrary x-axis to the centroid of the area and $\overline{y}$ is the distance between this arbitrary x-axis and the true neutral axis. If we identify,

$$i_x = ab\, y_x^2 \qquad (4.2)$$

and,

$$i_o = \frac{1}{12} ab(b^2\cos^2\phi + a^2\sin^2\phi) \qquad (4.3)$$

we have,

$$i_{NA} = (i_x + i_o) - \overline{y}^2(ab) \qquad (4.4)$$

or,

$$i_{NA} = i - (ab)\,\overline{y}^2 \qquad (4.5)$$

which is the Parallel Axis Theorem, Equation 2.6. The total moment of inertia of the plating about the neutral axis is the sum of all the i_{NA}'s. The moment of inertia of beams is obtained by calculating the area of the beam's cross-section from the four beam dimensions mentioned previously and multiplying this by the square of its distance from the arbitrary $x_{\overline{x}}$axis. Its moment about the neutral axis may then be obtained from the Parallel Axis Theorem. The same thing is done with angles. Thus, we neglect i_o for beams and angles since they are quite small. All of these calculations have been reduced to a form suitable for use in a computer program. The input is described in the next section.

5. PREPARATION OF COMPUTER INPUT

5.1. As previously pointed out, the structural elements that make up the girder may be grouped into three categories. These are plates, angles and scantlings (I,J,T-beams). The purpose of this section is to describe how the data needed for the computer program is to be obtained. The tools required are the inertia sections, a ruler (preferably divided into units of approximately 1/50 inch), dividers and a drafting machine for measuring angles. It is most convenient if the reading operation is carried out on a drafting table but this is not essential. Adjust the machine so that the base line of the inertia section (see Figure 3.1) is the zero degree reference and the CVK is the ninety degree reference. All angles should be positive and between zero and ninety degrees.

5.2. Plating elements must be divided up into rectangles sufficiently small that their cross-sectional area is accurately approximated by a rectangle of area equal to length times thickness. For decks, bulkheads, strakes, etc. that have little or no curvature, a rectangle of much longer length will suffice than for those which have a great deal of curvature and which must, therefore, be divided into rectangles of shorter lengths. The thickness will be obtained from the plating's weight via Equation 3.1. Two other quantities are required for calculating the inertia of the plating. These are the perpendicular distance of the centroid of the plate element from an assumed (arbitrary) neutral axis (D)* and the angle (PHI) in degrees that the elemental rectangle makes with this assumed neutral axis ANA, which is parallel to the base line. Since all lengths and distances are in arbitrary units, scale factors must be determined from the inertia section drawing in order to convert the units to feet or inches as appropriate. This can be done by determining the number of units in some known distance on the drawing, for example the depth of the section from main deck to keel.

5.3. Angles have a cross-sectional area that is obtained from the weight per linear foot of length according to the rule discussed in Section 3.1 supra. Since the moment of inertia of the angle about its own neutral axis (i_o) is small in comparison with its moment about the ANA, only two quantities are required for inertia calculations for angles. These are the weight per linear foot (WA) (obtained from the angle's identification on the drawing) and the perpendicular distance between its centroid and the ANA, call it (DA). This distance will be in arbitrary units. Similarly, for scantlings, we need only determine the beam's nominal, identifying, dimensions and weight (WS), and the perpendicular distance of its centroid from the ANA, call it (DS). It is important to determine the type (TYPE) beam that is being considered. These may be identified as I-beams, J-beams and T-beams (two types). A J-beam is simply an I-beam with one end of the flange cut off. J-beams

*See Table 6.1 for meaning of Fortran Symbols are identified on drawings by the symbol J . As previously mentioned, I-beams may have a flange cut off to form a T-beam (referred to herein as a T-flange, TF) or they may be cut in the center of the web to form a T-beam (referred to herein as a T-web, TW). The four dimensions of the I-beam necessary to compute its cross-sectional area are the section depth (SD), width of the flange (WF), thickness of the flange (TF) and thickness of the web (TW). These data are sufficient for the calculations carried out by the computer program described in the next section.

6. INPUT DATA SPECIFICATIONS

6.1. The input data listed below in Table 6.1 is required. Fortran symbols, formats, units (if any) and comments are included.

Table 6.1

FORTRAN SYMBOL	FORMAT	UNITS	COMMENTS
SCALEF,SCALEI	2F10.0	ft./unit in./unit	scale factors for converting units to length
NP, NA, NS	3I5	-,-,-,	respectively, the number of plate rectangles, angles, scantlings that make up section
W,L,D,PHI	4F10.0	lb,units units, deg.	weight/ft. sq. of plate, length of elemental rectangles, distance from centroid to ANA, angle with ANA made by the rectangle (see Figure 4.1)
WA,DA	2F10.0	lb., units	weight/ft. of the angle and distance from centroid to ANA
SD,WF,TF,TW, DS,TYPE	5f10.0	in.,in.,in., in., units,-	sect. depth, flange width, thickness, web thickness, distance from centroid to ANA, beam type

6.2. A few additional comments are in order. First, the determination of the centroid of the plate rectangles, angles and scantlings is not critical. On some inertia sections, the centroid of scantlings is indicated. If it is not, its position may be estimated by considering how it will be shifted by the removal of either a flange or part of the web and the flange. Second, when reading inertia sections, it is useful to prepare data sheets appropriate for recording the requisite data. These should be labeled with the section number, ship, date and number of plate elements, angles or scantlings. Finally, it should be noted that although the computer program is set up to read data for an entire ship cross-section, it is necessary, because of the symmetry, to read only one-half of the cross-section. When digitizing the data, it is necessary to punch one card and then this card may be duplicated. Remember, however, that in a few instances there may be P and/or S asymmetries in the plating. This has been discussed in Section 3.2.

7. COMPUTER PROGRAM AND OUTPUT

7.1. The computer program that carries out the longitudinal strength calculations is written in Fortran. A listing is provided as Appendix A. All necessary scaling is done internally so that it is unnecessary to convert lengths and distances to real lengths and distances externally.

7.2. The program computes the moment of inertia and static moment about an arbitrary assumed neutral axis and then uses the Parallel Axis Theorem to obtain the moment about the true neutral axis. It also computes the total cross-sectional area of the strength elements that make up the section. The calculations are carried out in stages. First the contribution of plating is considered, then the angles are added, then the effect of the scantlings is considered. The cross-sectional area, moment of inertia and static moment are printed out at these three stages. This is useful in comparing the relative contributions of these types of structural elements. Also printed out is the distance between the true neutral axis and the assumed neutral axis. The cross-sectional area, moment of inertia, static moment and distance between true and assumed neutral axis are denoted respectively by SUMA, SUMI, SUMQ, and DG. After obtaining the final totals for these, the program computes the thickness of plating on the neutral axis (H), the moment of the area above the neutral axis (MA) and uses Equation 2.10 to obtain the shear area (ASHR). The units of output quantities are given in Table 7.1.

Table 7.1

OUTPUT VARIABLE	DIMENSION	COMMENTS
L,T,A,D,PHI,IO	in.,in.,in. sq., ft.,deg.,in.sq.-ft.sq.	The length, thickness and area of the elemental rectangles that make up the plating, distance of centroid from ANA, the angle made by the rectangles with respect to the ANA, and the moment of inertia of the rectangle about its own axis.
AA,DA	in.sq.,ft.	cross-sectional area of the angle and distance of centroid from ANA
AS,DS,TYPE	in. sq.,ft.,-	cross-sectional area of the scantling, distance of centroid from ANA, type of beam
SUMA,SUMQ,SUMI	in.sq.,in.sq.-ft., in.sq.-ft.sq.	cross-sectional area of the structural elements, static moment about ANA, moment of inertia about ANA
DG,INA	ft.,in.sq.-ft.sq.	distance between ANA and true neutral axis, moment of inertia of section about the true neutral axis
SA,SQ,MA	in.sq.,in.sq.-ft., in.sq.-ft	area and static moment of area above ANA, moment of area above true neutral axis
H,ASHR	in.,in.sq.	thickness of plating on the neutral axis, shear area of cross-section

A typical data set is included in Appendix A for use in the computer program listed there.

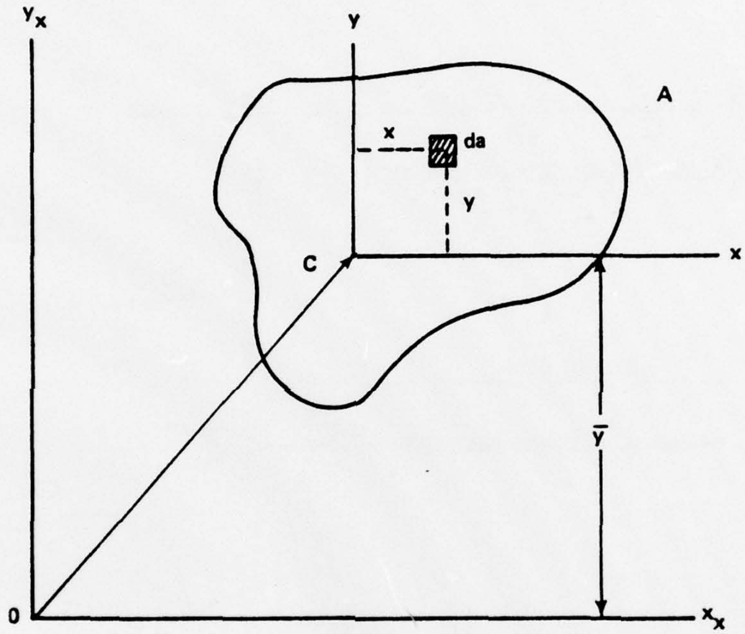

FIG. 2.1 PLANE AREA WITH CENTROID C

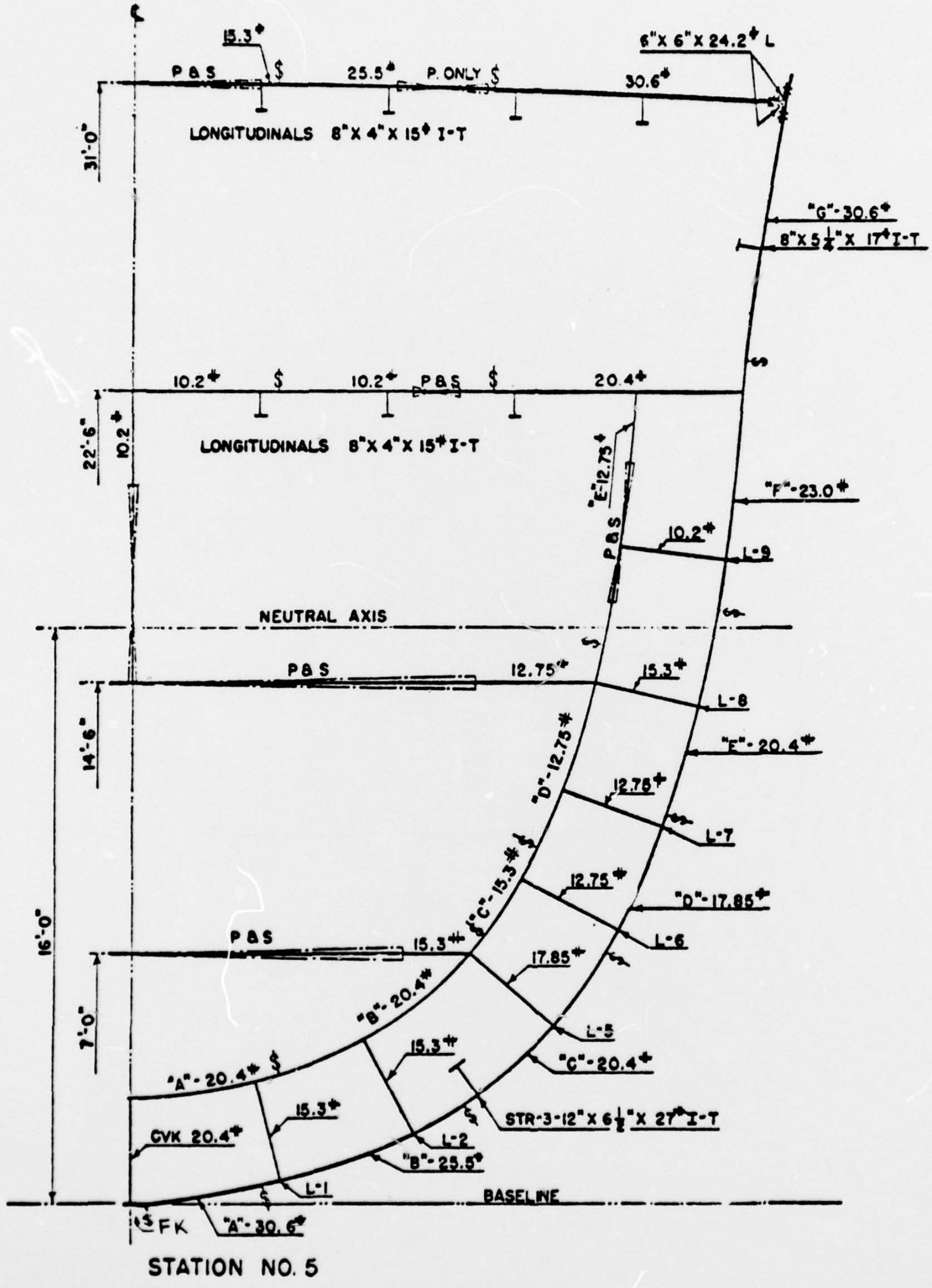

FIG. 3.1 TYPICAL SHIP CROSS-SECTION

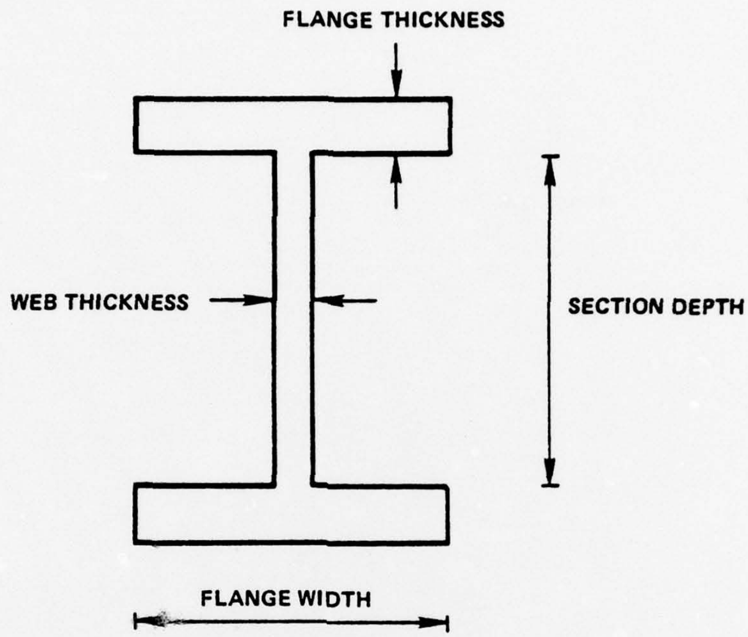

FIG. 3.2 NOMINAL BEAM DIMENSIONS

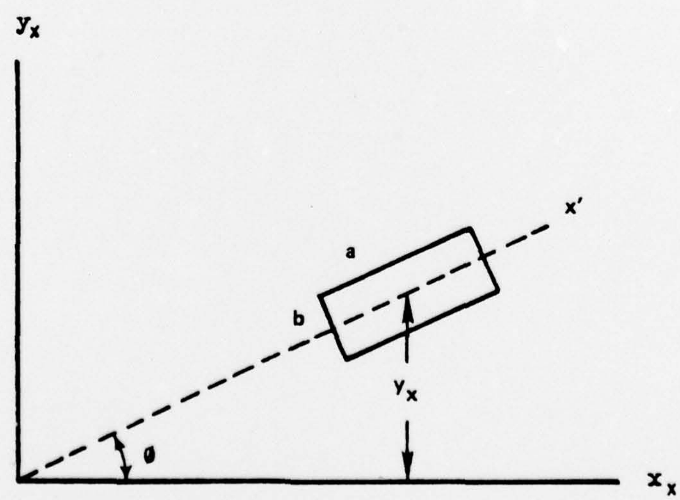

FIG. 4.1 CALCULATION OF MOMENT OF INERTIA IN ROTATED COORDINATE SYSTEM

APPENDIX A

```
      DIMENSION A(200),L(200),D(200),IO(200),T(200),PHI(200),W(200)
      DIMENSION WA(200),DA(200),TYPE(200),AA(200),ASC(200)
      DIMENSION SD(200),WF(200),TF(200),TW(200),DS(200)
      REAL L,IO,INA,MA
      DATA PI/3.1415926/
      READ (5,10) SCALEF,SCALEI
      READ(5,10)YANA
      YANA=YANA*SCALEF
C     YANA IS THE DISTANCE FROM THE KEEL TO THE ASSUMED NEUTRAL AXIS
C     SCALE CONVERTS ARBITRARY UNITS INTO FEET OR INCHES
C     A IS THE ARRAY OF ELEMENTAL AREAS
C     L IS THE ARRAY OF ELEMENTAL LENGTHS
C     T IS THE ARRAY OF ELEMENTAL THICKNESSES
C     D IS THE ARRAY OF DISTANCES BETWEEN THE ELEMENTAL CENTROIDS AND THE
C     ASSUMED NEUTRAL AXIS
C     IO IS THE ARRAY OF MOMENTS OF THE ELEMENTAL AREAS ABOUT THEIR OWN
C     AXIS PARALLEL TO THE ASSUMED NEUTRAL AXIS
C     PHI IS THE ARRAY OF ANGLES THAT EACH ELEMENTAL LENGTH MAKES WITH THE
C     ASSUMED NEUTRAL AXIS
C     W IS THE ARRAY OF PLATE WEIGHTS ASSOCIATED WITH EACH ELEMENTAL AREA
      READ (5,20) NP,NA,NS
C     NP IS THE NUMBER OF PLATE ELEMENTS TO BE READ IN AS DATA
C     NA IS THE NUMBER OF ANGLES TO BE READ IN AS DATA
C     NS IS THE NUMBER OF SCANTLINGS TO BE READ IN AS DATA
      READ (5,10) (W(I),L(I),D(I),PHI(I),I=1,NP)
      SUMA=0.
      SUMQ=0.
      SUMI=0.
C     SA IS THE SUM OF THE AREAS LYING ON OR ABOVE THE ASSUMED NA
C     SQ IS THE SUM OF STATIC MOMENTS OF AREAS LYING ON OR ABOVE THE NA
      SA=0.
      SQ=0.
      WRITE (6,23)
      WRITE (6,21)
      WRITE(6,25)
      DO 40 I=1,NP
      T(I)=W(I)/40.8
      L(I)=L(I)*SCALEI
      A(I)=L(I)*T(I)
      D(I)=D(I)*SCALEF
      SUMA=SUMA+A(I)
      SUMQ=SUMQ+A(I)*D(I)
      TH=PHI(I)*PI/180.
      IO(I)=A(I)/1728.*((T(I)*COS(TH))**2+(L(I)*SIN(TH))**2)
      SUMI=SUMI+A(I)*D(I)*D(I)+IO(I)
      WRITE (6,50) L(I),T(I),A(I),D(I),PHI(I),IO(I)
 40   CONTINUE
      WRITE (6,27)
      WRITE(6,277)
      WRITE (6,50) SUMA,SUMQ,SUMI
      DG=SUMQ/SUMA
```

```
C     DG IS THE DISTANCE BETWEEN THE ASSUMED NEUTRAL AXIS AND THE TRUE
C     NEUTRAL AXIS
      INA=SUMI-SUMA*DG*DG
C     IT IS ASSUMED THAT THE SHIP IS SYMMETRIC ABOUT ITS CENTER LINE
      WRITE (6,28)
      WRITE(6,288)
      WRITE (6,50) DG,INA
      IF (NA.EQ.0)  GO TO 75
      READ (5,10)  (WA(I),DA(I),I=1,NA)
C     WA IS THE ARRAY OF WEIGHTS/FT FOR THE ANGLES
C     DA IS THE ARRAY OF DISTANCES BETWEEN THE ANGLE CENTROIDS AND THE
C     ASSUMED NEUTRAL AXIS
      WRITE (6,24)
      WRITE (6,37)
      WRITE(6,377)
      DO 70 I=1,NA
      AA(I)=WA(I)/3.4109
C     AA IS THE ANGLE AREA IN IN SQ
      DA(I)=DA(I)*SCALEF
      SUMA=SUMA+AA(I)
      SUMQ=SUMQ+AA(I)*DA(I)
      SUMI=SUMI+AA(I)*DA(I)*DA(I)
      WRITE (6,50) AA(I),DA(I)
 70   CONTINUE
      WRITE (6,27)
      WRITE(6,277)
      WRITE (6,50) SUMA,SUMQ,SUMI
      DG=SUMQ/SUMA
      INA=SUMI-SUMA*DG*DG
      WRITE (6,28)
      WRITE(6,288)
      WRITE (6,50) DG,INA
 75   READ(5,12)  (SD(I),WF(I),TF(I),TW(I),DS(I),TYPE(I),I=1,NS)
C     SD IS THE ARRAY OF SCANTLING DEPTHS
C     WF IS THE ARRAY OF FLANGE WIDTHS
C     TF IS THE ARRAY OF FLANGE THICKNESSES
C     TW IS THE ARRAY OF WEB THICKNESSES
C     DS IS THE ARRAY OF DISTANCES BETWEEN SCANTLING CENTROIDS AND THE
C     ASSUMED NEUTRAL AXIS
C     TYPE IDENTIFIES THE SCANTLING AS  I,J, WEB CUT T, OR FLANGE CUT T
      WRITE (6,26)
      WRITE (6,38)
      WRITE(6,388)
      DO 100 I=1,NS
      DS(I)=DS(I)*SCALEF
      IF (TYPE(I).EQ.2HI ) GO TO 105
      IF (TYPE(I).EQ.2HJ ) GO TO 110
      IF (TYPE(I).EQ.2HTW ) GO TO 115
      IF (TYPE(I).EQ.2HTF) GO TO 120
```

APPENDIX A (Cont.)

```
105   AS=SD(I)*WF(I)-(SD(I)-2.*TF(I))*(WF(I)-TW(I))
      GO TO 130
110   AS=SD(I)*WF(I)-.5*(WF(I)-TW(I))*(2.*SD(I)-3.*TF(I))
      GO TO 130
115   AS=.5*(SD(I)*WF(I)-(SD(I)-2.*TF(I))*(WF(I)-TW(I)))
      GO TO 130
120   AS=SD(I)*WF(I)-(SD(I)-2.*TF(I))*(WF(I)-TW(I))-WF(I)*TF(I)
130   ASC(I)=AS
      SUMA=SUMA+ASC(I)
      SUMQ=SUMQ+ASC(I)*DS(I)
      SUMI=SUMI+ASC(I)*DS(I)*DS(I)
      WRITE (6,55) AS,DS(I),TYPE(I)
100   CONTINUE
      WRITE (6,27)
      WRITE(6,277)
      WRITE (6,50) SUMA,SUMQ,SUMI
      DG=SUMQ/SUMA
      INA=SUMI-SUMA*DG*DG
      WRITE (6,28)
      WRITE(6,288)
      WRITE (6,50) DG,INA
C
C     CALCULATION OF THICKNESS OF PLATING ON THE NEUTRAL AXIS AND THE
C     SHEAR AREA OF THE SECTION
      H=0.
      DO 36 I=1,NP
      TH=PHI(I)*PI/180.
      DEL=.5*L(I)*SIN(TH)/12.
      IF (D(I)-DG .LT. 0. .AND. ABS(D(I)-DG) .GT. DEL) GO TO 36
      IF (ABS(D(I)-DG) .GT. DEL) GO TO 35
      H=H+T(I)
      A(I)=T(I)*(.5*L(I)+(D(I)-DG)*12./SIN(TH))
      D(I)=.25*L(I)*SIN(TH)/12.+.5*(D(I)-DG)
   35 SA=SA+A(I)
      SQ=SQ+A(I)*D(I)
36    CONTINUE
      IF(H .NE. 0.) GO TO 39
      NP1=NP-1
      K=1
      DO 1 I=1,NP1
      IF(ABS(PHI(I)) .LT. 10.) GO TO 1
      D=ABS(D(I)-DG)
      IF(D .LE. ABS(D(K)-DG)) K=I
    1 CONTINUE
      H=T(K)*2.
      A(K)=T(K)*(.5*L(K)+(D(K)-DG)*12./SIN(TH))
      D(K)=.25*L(K)*SIN(TH)/12.+.5*(D(K)-DG)
      SA=SA+2.*A(K)
      SQ=SQ+2.*A(K)*D(K)
   39 CONTINUE
   39 CONTINUE
```

APPENDIX A (Cont.)

```
      IF (NA.EQ.0.) GO TO 133
      DO 42 I=1,NA
      IF (DA(I)-DG.LT.0.) GO TO 42
      SA=SA+AA(I)
      SQ=SQ+AA(I)*DA(I)
 42   CONTINUE
 133  DO 57 I=1,NS
      IF (DS(I)-DG.LT.0.) GO TO 57
      SA=SA+ASC(I)
      SQ=SQ+ASC(I)*DS(I)
 57   CONTINUE
      MA=SQ-DG*SA
      ASHR=2.*INA*H/MA
C     ASHR IS THE SHEAR AREA
      ASHR=ASHR*12.
C     ASHR CONVERTED TO SQ.IN.
      DG=YANA + DG
      WRITE (6,22) DG,H,SUMA,ASHR,INA
   10 FORMAT (4F10.0)
 12   FORMAT (5F10.0,A2)
   20 FORMAT (3I5)
   21 FORMAT(//5X*LENGTH*7X*THICKNESS*9X*AREA*6X*DIST. FROM NA*6X*ANGLE*
     17X*TO OWN AXIS*)
   22 FORMAT (/1X, 29HDISTANCE FROM KEEL TO N.A. = ,F8.2, 5H FEET/1X,29H
     1THICKNESS OF PLATE ON N.A. = ,F8.3,7H INCHES/1X,29HAREA OF CROSS S
     1ECTION       = F5.0,11H SQ. INCHES/1X,31HSECTION SHEAR AREA
     1    = ,      F5.0,11H SQ. INCHES/1X,29HSECTION MOMENT OF INERTIA =
     1 ,    F8.0,19HSQ. FEET-SQ. INCHES)
   23 FORMAT(//60X*PLATING*//)
   24 FORMAT(//60X*ANGLES*//)
   25 FORMAT(4X*(INCHES)*7X*(INCHES)*7X*(SQ.IN.)*7X*(FEET)*8X*(DEGREES)*
     13X*(IN.SQ.-FT.SQ.)*/)
   26 FORMAT(//60X*SCANTLINGS*//)
   27 FORMAT(//5X*AREA*10X*MOMENT*9X*INERTIA*)
  277 FORMAT(3X*(SQ.IN.)*5X*(IN.SQ.-FT.)*2X*(IN.SQ.-FT.SQ.)*/)
   28 FORMAT(//1X*DIST. FROM NA*3X*I ABOUT NA*)
  288 FORMAT(6X*(FT)*5X*(IN.SQ.-FT.SQ.)*/)
   37 FORMAT(//5X*AREA*7X*DIST.FROM NA*)
  377 FORMAT(3X*(IN.SQ.)*10X*(FT.)*/)
   38 FORMAT(//5X*AREA*7X*DIST.FROM NA*8X*TYPE*)
  388 FORMAT(3X*(SQ.IN.)*9X*(FT.)*/)
   50 FORMAT(F10.2,5X,F11.3,4X,F11.3,4X,F10.2,5X,F10.2,5X,F12.4,3X)
   55 FORMAT(F10.3,5X,F11.3,11X,A2)
      STOP
      END
```

```
0.156934   1.883212
138.0
  128   60   48
9.          12.         134.        0.
9.          12.         134.        0.
17.5        48.         134.        0.
17.5        48.         134.        0.
30.         49.         132.5       0.
30.         49.         132.5       0.
36.5        34.         131.        0.
36.5        34.         131.        0.
9.          12.5        84.         0.
9.          12.5        84.         0.
12.         50.         84.         0.
12.         50.         84.         0.
12.         50.         81.5        0.
12.         50.         81.5        0.
19.         36.         80.         0.
19.         36.         80.         0.
80.         123.5       28.         0.
80.         123.5       28.         0.
70.         43.         27.5        0.
70.         43.         27.5        0.
28.         9.5         -137.       0.
28.         9.5         -137.       0.
40.         13.         -138.       0.
40.         13.         -138.       0.
28.         48.         -134.5      5.
28.         48.         -134.5      5.
27.         33.5        -134.       4.75
27.         33.5        -134.       4.75
27.         11.         -130.       9.5
27.         11.         -130.       9.5
27.         10.         -127.       16.
27.         10.         -127.       16.
27.         13.5        -124.5      20.3
27.         13.5        -124.5      20.3
27.         11.         -120.       27.4
27.         11.         -120.       27.4
27.         10.         -115.       33.9
27.         10.         -115.       33.9
27.         10.5        -110.       34.
27.         10.5        -110.       34.
27.         12.         -103.5      38.2
27.         12.         -103.5      38.2
25.         10.         -100.       38.5
25.         10.         -100.       38.5
25.         10.         -93.        44.4
25.         10.         -93.        44.4
25.         10.         -87.        48.5
25.         10.         -87.        48.5
```

APPENDIX A (Cont.)

25.	10.	-80.	51.8
25.	10.	-80.	51.8
25.	10.	-73.	53.8
25.	10.	-73.	53.8
25.	10.	-66.5	58.2
25.	10.	-66.5	58.2
25.	10.	-59.5	59.1
25.	10.	-59.5	59.1
25.	10.	-50.5	64.8
25.	10.	-50.5	64.8
25.	10.	-43.	64.9
25.	10.	-43.	64.9
25.	5.5	-36.	66.
25.	5.5	-36.	66.
25.	40.	-13.	88.
25.	40.	-13.	88.
25.	46.5	30.	87.8
25.	46.5	30.	87.8
25.	53.5	76.	87.3
25.	53.5	76.	87.3
35.	32.	116.	87.3
35.	32.	116.	87.3
12.	40.5	-113.5	2.4
12.	40.5	-113.5	2.4
12.	37.	-112.	3.8
12.	37.	-112.	3.8
12.	18.5	-109.	7.8
12.	18.5	-109.	7.8
12.	16.	-105.	17.3
12.	16.	-105.	17.3
15.	16.	-99.	26.8
15.	16.	-99.	26.8
15.	12.5	-92.5	35.4
15.	12.5	-92.5	35.4
15.	10.5	-85.	41.9
15.	10.5	-85.	41.9
15.	11.	-80.	52.3
15.	11.	-80.	52.3
15.	11.	-71.	61.2
15.	11.	-71.	61.2
15.	7.	-63.5	72.6
15.	7.	-63.5	72.6
15.	7.5	-56.5	77.3
15.	7.5	-56.5	77.3
14.	22.	-44.	82.3
14.	22.	-44.	82.3
14.	25.	-20.5	89.5
14.	25.	-20.5	89.5
10.	37.5	6.5	89.4
10.	37.5	6.5	89.4
25.	12.	-115.0	0.
25.	12.	-115.0	0.
12.	20.	-125.5	86.

12.	20.	-125.5	86.
12.	20.	-123.5	85.8
12.	20.	-123.5	85.8
12.	20.5	-123.	87.
12.	20.5	-123.	87.
12.	20.5	-120.	81.9
12.	20.5	-120.	81.9
12.	20.	-115.	69.6
12.	20.	-115.	69.6
12.	20.	-105.	58.5
12.	20.	-105.	58.5
15.	23.	-86.	45.9
15.	23.	-86.	45.9
9.	32.	-58.	32.6
9.	32.	-58.	32.6
9.	43.5	-29.	0.
9.	43.5	-29.	0.
15.	22.5	40.	90.
15.	22.5	40.	90.
10.	31.	64.	90.
10.	31.	64.	90.
12.	14.	-100.	26.9
12.	14.	-100.	26.9
15.	20.	-102.	46.4
15.	20.	-102.	46.4
15.	26.	-127.	90.
15.	26.	-127.	90.
28.7	130.	10.2	79.
28.7	130.	10.2	79.
21.9	26.	9.8	28.
21.9	26.	9.8	28.
6.6	-115.	6.6	-114.
6.6	-115.	6.6	-114.
6.6	-112.	6.6	-111.
6.6	-112.	6.6	-111.
6.6	-106.	7.2	-97.
6.6	-106.	7.2	-97.
7.2	-96.	8.5	-79.
7.2	-96.	8.5	-79.
8.5	-77.	7.2	-42.
8.5	-77.	7.2	-42.
7.2	-28.	6.6	-134.
7.2	-28.	6.6	-134.
6.6	-133.	6.6	-133.
6.6	-133.	6.6	-133.
6.6	-129.	6.6	-123.
6.6	-129.	6.6	-123.
7.2	-113.	7.2	-111.
7.2	-113.	7.2	-111.
8.5	-94.	8.5	-93.
8.5	-94.	8.5	-93.
7.2	-65.	12.	-27.

APPENDIX A (Cont.)

7.2	-65.	12.	-27.		
9.1	-98.	12.	-94.		
9.1	-98.	12.	-94.		
9.8	-118.	10.6	-135.		
9.8	-118.	10.6	-135.		
8.00	5.25	.308	.230	130.	TF
8.00	5.25	.308	.230	130.	TF
7.93	6.5	.398	.245	131.	J
7.93	6.5	.398	.245	131.	J
15.85	6.992	.428	.299	126.	J
15.85	6.992	.428	.299	126.	J
15.85	6.992	.428	.299	128.	J
15.85	6.992	.428	.299	128.	J
7.93	6.5	.398	.245	127.	J
7.93	6.5	.398	.245	127.	J
7.93	6.5	.398	.245	127.	J
7.93	6.5	.398	.245	127.	J
8.00	5.25	.308	.230	80.	TF
8.00	5.25	.308	.230	80.	TF
8.00	5.25	.308	.230	80.	TF
8.00	5.25	.308	.230	80.	TF
8.00	5.25	.308	.230	80.	TF
8.00	5.25	.308	.230	80.	TF
8.00	5.25	.308	.230	80.	TF
8.00	5.25	.308	.230	80.	TF
8.00	5.25	.308	.230	77.	TF
8.00	5.25	.308	.230	77.	TF
8.00	5.25	.308	.230	77.	TF
8.00	5.25	.308	.230	77.	TF
16.	7.0	.503	.307	22.	J
16.	7.0	.503	.307	22.	J
16.	7.0	.503	.307	22.	J
16.	7.0	.503	.307	22.	J
7.93	6.5	.398	.245	101.	J
7.93	6.5	.398	.245	101.	J
7.93	6.5	.398	.245	52.	J
7.93	6.5	.398	.245	52.	J
16.	3.06	.25	.1875	-119.	TW
16.	3.06	.25	.1875	-119.	TW
16.	3.06	.25	.1875	-117.	TW
16.	3.06	.25	.1875	-117.	TW
16.	3.06	.25	.1875	-115.	TW
16.	3.06	.25	.1875	-115.	TW
16.	3.06	.25	.1875	-114.	TW
16.	3.06	.25	.1875	-114.	TW
16.	3.06	.25	.1875	-111.	TW
16.	3.06	.25	.1875	-111.	TW
16.	3.06	.25	.1875	-89.	TW
16.	3.06	.25	.1875	-89.	TW
16.	3.06	.25	.1875	-104.	TW
16.	3.06	.25	.1875	-104.	TW
16.	3.06	.25	.1875	-64.	TW
16.	3.06	.25	.1875	-64.	TW

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