DDS 161-2
PROPULSION SHAFT FAIRINGS

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, DC 20362-5101

DESIGN DATA SHEET
DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND

DDS 161-2
26 August 1987

PROPULSION SHAFT FAIRINGS

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161-2-a. References

(a) NAVSEA Report 6136-75-162. Establishment of the Design Practice for Shaft Fairing Shape and Dimensions.
(b) NAVSEA 804-5959321 Coupling Covers and Fairwaters for Propulsion Shafts

161-2-b. Introduction

This design data sheet is issued to provide a standard procedure for the design of propulsion shaft fairings or fairwaters. Fairings for the following areas are covered:

- Exposed shaft couplings
- After end of the stern tube or bossing
- Forward and after ends of intermediate shaft struts
- Forward end of the strut barrel of the main shaft strut

These areas are defined in the Coupling Covers and Fairwaters type drawing, reference (b).

Data is presented only for the Elliptical, Parabolic, Hyperbolic (EPH) section. The shapes described in this DDS apply only to shafts whose axes are generally aligned with the direction of flow. For shafts that are not aligned with the direction of flow, the designer will have to resort to model tests and analyses.

The shape and dimensions of the fairings are based on the recommendations of reference (a). For most designs, the fairing proportions can be determined without extensive calculations. The section offsets can either be proportioned from a table or calculated directly from a formula.

The structural and construction details are described in the type drawing, reference (b). Drawings of coupling covers and fairwaters should be prepared in accordance with the requirements listed in the Design Notes on sheet 1 of the type drawing. The requirements for surface finish and fairness are defined in the Detail Notes on sheet 1 of the type drawing.

161-2-c. Definitions

Coupling cover - A fairing covering the coupling flanges on a propeller shaft.

Fairwater - A fairing extending from either a bossing or a strut barrel used to reduce resistance and cavitation.

Strut barrel - The propeller shaft bearing housing supported by the shaft struts.

161-2-d. Symbols and Abbreviations

A, B - constants used in equation for long fairwater c - chord length of an EPH section

D_S - diameter of propeller shaft

L - length of combined coupling cover and fairwater

L_C - length of coupling cover

L_F - length of fairwater

L_N - Distance from nose of coupling cover to point of zero slope on strut barrel

L_T - distance from tail of coupling cover to point of zero slope on strut barrel

M - slope at the end of the strut barrel

R - fairwater end radius formed by round stock

R_1 - EPH section leading edge radius

R_2 - EPH section trailing edge radius

t - maximum thickness of a comple EPH half section

T_B - strut barrel thickness less water clearance = $T_S - T_W$

T_C - maximum thickness of a coupling cover

T_F - fairwater thickness

T_S - maximum thickness of strut barrel

T_W - clearance to allow water circulation through strut bearings

x - longitudinal distance along x-axis from forward end

X_T - distance along the x-axis to the point of tangency between coupling cover and fairwater

y - lateral distance along y-axis from centerline

y_0 - constant used in equation for long fairwater

Y_T - thickness of coupling cover at point of tangency

α - angle of shortened coupling cover leading (or trailing) edge

θ_T - slope at the point of tangency (X_T, Y_T)

161-2-e. General Design Principles

Propulsion shaft fairings must be designed to insure minimum cavitation and resistance. This can be best accomplished with the use of an EPH section. Reference (a) indicates that the desired fairing shape is defined by a surface of revolution by an EPH section around the shaft.

The EPH section used in this DDS is shown in Figure 1. It is half of a full EPH section divided along its longitudinal axis. The surface of revolution is generated by rotating the section about a cylinder (the propeller shaft) as shown in Figure 2. The coupling cover thickness is equal to the thickness of the EPH half section.

The shaft fairings and coupling covers should be designed to be as short as possible and still maintain the required thickness to chord ratio, which governs form resistance. By minimizing the length, the wetted surface is reduced and frictional resistance penalties are minimized.

The continuity of the fairing surface is important. There should be no abrupt changes in the surface that might cause turbulence. Therefore, whenever two surfaces meet, (i.e. the fairwater and the strut barrel) the slopes should be the same. This will help reduce the likelihood of turbulence. There should be no knuckles or reverses in curvature of any of the surfaces.

161-2-f. Fairing Conditions

There are eight different fairing conditions. All of the conditions use either a complete EPH section or portions of an EPH section. Each of the conditions has its own computational procedure. The numbering of each of the conditions corresponds to the numbering used on the type drawing, reference (b).

Condition 1 is the complete EPH section for separate coupling covers.

Condition 2 is a partial EPH section with a modified nose for coupling covers.

Condition 3 is a partial EPH section formed by a modified coupling cover and a fairwater from a strut barrel.

Condition 4 is a partial EPH section used as a fairwater nose for a strut barrel.

Condition 5 is a partial EPH section used as a fairwater tail for a strut barrel or bossing.

Conditions 6 and 7 are fairwaters extending from either a bossing or strut barrel to a shortened coupling cover.

Condition 8 is for a rope guard between the propeller hub and the main strut barrel.

161-2-g. EPH Section

The EPH section is composed of portions of an ellipse, parabola and hyperbola (see Figure 1). The equations of the EPH section are:

ellipse: $[1 - (x/c)/0.43613]^2 + (y/t)^2 = 1, \; 0 \leq x/c \leq 0.43613$

parabola: $\frac{1}{2}[(x/c)/0.43613-1]^2 + (y/t) = 1, \; 0.43613 \leq x/c \leq 0.87226$

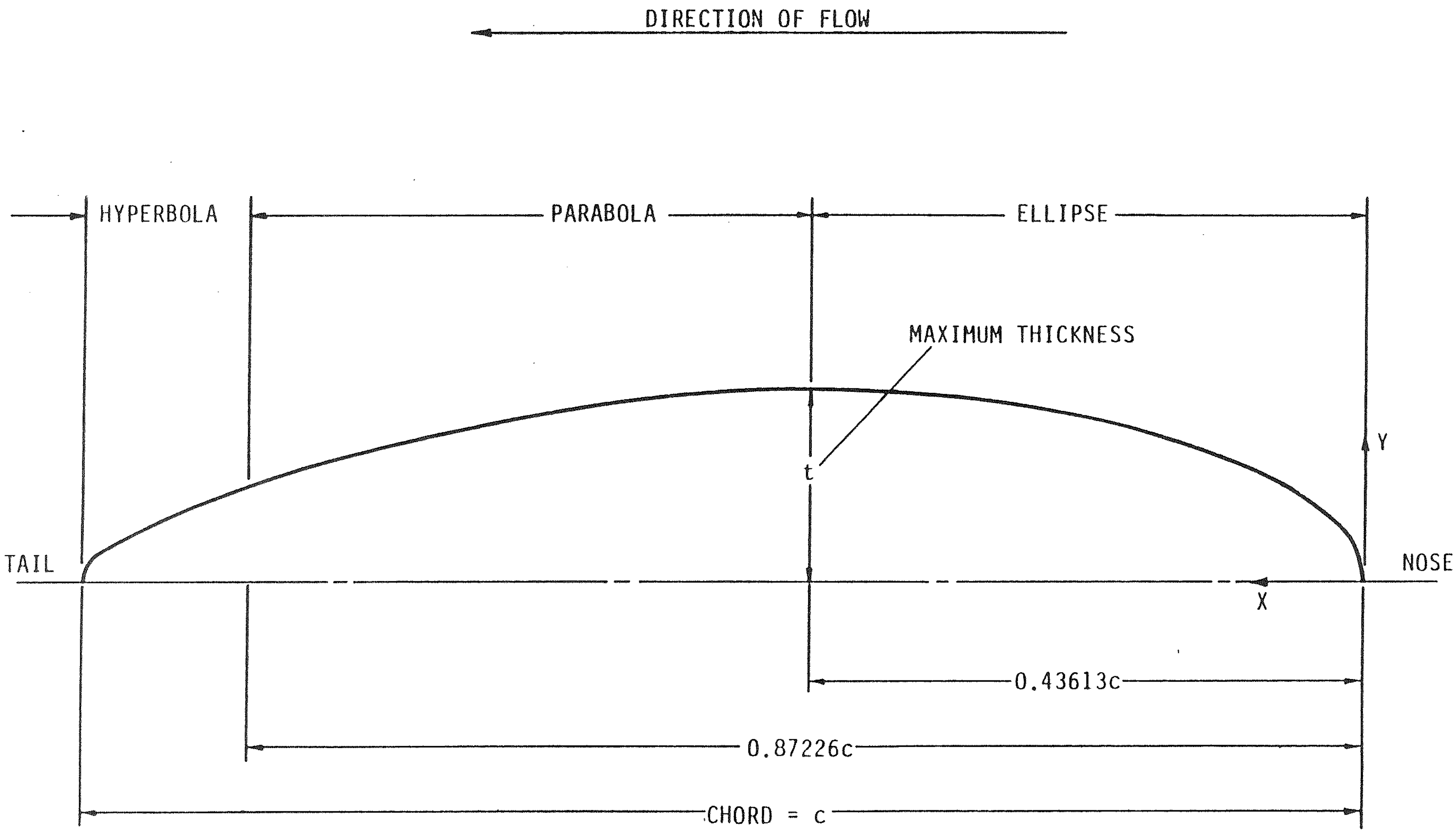
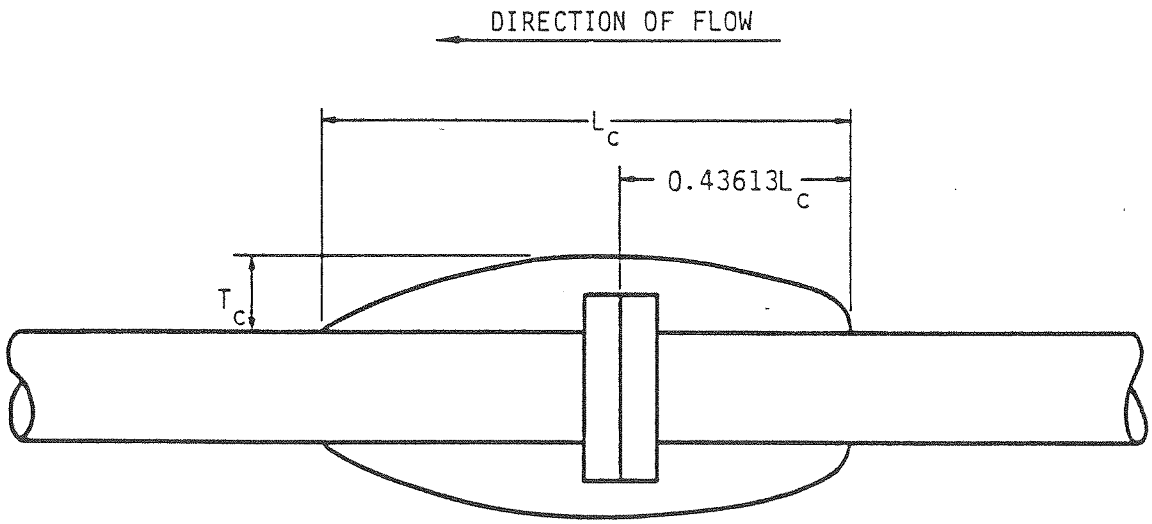


FIGURE 1- EPH SECTION



L_c = COVER LENGTH

T_c = COVER THICKNESS

$$7.0 \le \frac{L_c}{T_c} < 12.0$$

FIGURE 2- COUPLING COVER (CONDITION 1)

$$\text{hyperbola: } [1 + (1 - x/c)/0.30839]^2 - 4(y/t)^2 = 1, \quad 0.87226 \leq x/c \leq 1$$

The EPH section has satisfactory cavitation characteristics and structural properties.

The extreme nose and the extreme tail of the EPH section are defined by the radius of a circle due to hydrodynamic considerations. The equations are given in paragraph 161-2-h. A table of offsets for the EPH section is given in Table 1.

161-2-h. Nose and Tail Radii

The radius of a circle is used to define the extreme leading and trailing edges of the EPH section for hydrodynamic considerations. The radii used are:

Leading Edge Radius: $R_1 = 2.2928\ (t^2/c)$

Trailing Edge Radius: $R_2 = 0.8108\ (t^2/c)$

161-2-i. Coupling Cover (Condition 1)

The coupling cover uses the complete EPH half section as a body of revolution around the shaft. The thickness of the section is determined by the shaft and flange diameter (see Figure 2). The cover thickness, T_c, must allow for the thickness of the cover structure. The desirable length, L_c, of cover is seven to less than twelve times the cover thickness. The length of the cover should be kept as short as possible in accordance with paragraph 161-2-e.

Using the values of T_c and L_c, the offsets of the section can be found using Table 1. This process is demonstrated in the sample calculations, paragraph 161-2-r.

161-2-j. Short Nose Coupling Cover (Condition 2)

The short nosed coupling cover would typically be used in conjunction with a fairwater aft of a bossing or shaft strut. The use of the coupling cover and strut fairwater, as opposed to a long trailing edge fairwater, is dictated by the relative position of the shaft coupling to the strut barrel or bossing. If possible, the coupling cover and fairwater combination should be used, as they do not require as heavy scantlings as used in a long fairwater.

The short nosed coupling cover uses the tail of the EPH section and a modified nose (see Figure 3). The section thickness is determined as for the standard coupling cover. The maximum section thickness does not have to be directly over the coupling.

The length of the nose section will depend on the clearance available and cover structure. The nose should be kept as short as possible. A nominal clearance should be allowed between the bolt heads and the cover structure (2.5 to 5.0 cm). The shortest cover can be attained if the strut barrel or bossing forward is a parabolic-hyperbolic section. The coupling cover, fairwater and strut barrel should form a continuous and fair section with no knuckles or reversals in curvature.

TABLE 1 - Offsets for EPH Half Section

x/c	y/t	x/c	y/t	x/c	y/t
0.010	0.2129	0.400	0.9966	0.750	0.7410
0.025	0.3337	0.43613(a)	1.0000	0.800	0.6520
0.050	0.4649	0.450	0.9995	0.850	0.5497
0.100	0.6372	0.500	0.9893	0.87226(b)	0.5000
0.150	0.7547	0.550	0.9659	0.900	0.4341
0.200	0.8408	0.600	0.9294	0.950	0.2960
0.250	0.9044	0.650	0.8798	0.975	0.2054
0.300	0.9500	0.700	0.8170	0.990	0.1284
0.350	0.9803				

Leading edge radius: $R_1 = 2.2928\ (t^2/c)$

Trailing edge radius: $R_2 = 0.8108(t^2/c)$

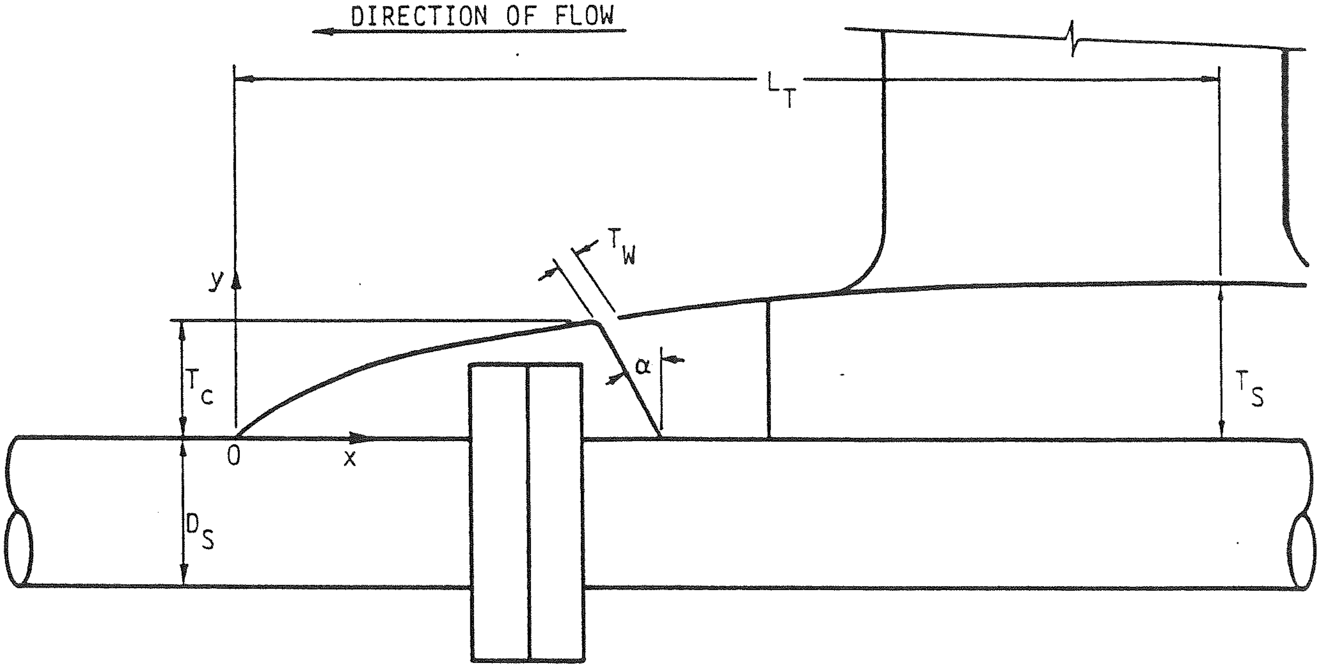
(a) Junction of ellipse and parabola

(b) Junction of parabola and hyperbola

Ellipse: $y/t = \sqrt{1 - (1 - 2.29289x/c)^2}$ for $0 \leq x/c \leq 0.43613$

Parabola: $y/t = 1 - \frac{1}{2}(2.29289x/c - 1)^2$ for $0.43613 \leq x/c \leq 0.87226$

Hyperbola: $y/t = \frac{1}{2}\{[1 + 3.24265(1 - x/c)]^2 - 1\}^{\frac{1}{2}}$ for $0.87226 \leq x/c \leq 1.$



L_T - DISTANCE FROM TAIL OF COUPLING COVER TO THE POINT OF ZERO SLOPE ON THE STRUT BARREL

T_S - MAXIMUM THICKNESS OF STRUT BARREL, OCCURS AT POINT OF ZERO SLOPE

T_c - MAXIMUM COUPLING COVER THICKNESS

T_W - WATER CLEARANCE, AT LEAST 1.5cm

D_S - SHAFT DIAMETER, INCLUDING SHAFT SLEEVE

α - ANGLE OF NOSE OF COUPLING COVER, TYPICALLY 30^o.

FIGURE 3- SHORT NOSED COUPLING COVER AND FAIRWATER (CONDITION 2)

The offsets for the tail section can be determined using the following formulae:

Hyperbolic Part:

$$y/T_S = \tfrac{1}{2}\sqrt{[1 + (1 - 0.43613)/(0.30839)x/L_T]^2 - 1}$$

$$y/T_S = \tfrac{1}{2}\sqrt{[1 + (1/0.546917)x/L_T]^2 - 1}$$

$$y/T_S = \tfrac{1}{2}\sqrt{(1 + 1.82843x/L_T)^2 - 1}$$

Where:

$0 \leq x/L_T \leq 0.22654$

x and y are defined in Figure 3

L_T = length of the hyperbolic, parabolic section. Includes cover, fairwater and strut barrel.

T_S = maximum strut barrel thickness.

Parabolic Part:

$$y/T_S = 1 - \tfrac{1}{2}[(1 - 0.43613)/(0.43613)]^2(1-x/L_T)^2$$

$$y/T_S = 1 - \tfrac{1}{2}(1/0.773458)^2\ (1 - x/L_T)^2$$

$$y/T_S = 1 - 0.83579(1 - x/L_T)^2$$

Where:

$0.22654 \leq x/L_T \leq 1.0$

x, y, L_T, T_S are defined above

The length to thickness ratio is limited as follows:

$3.94709 \leq L_T/T_S \leq 6.76644$

The origin for these equations is at the tail of the coupling cover at the outside surface of the shaft.

The nose of the coupling cover is formed by intersecting the EPH section with a line inside the EPH section. This is most easily done graphically. The angle of the line forming the nose is typically 30° from the vertical. As previously stated, sufficient clearance should be allowed between the bolt head and the coupling cover. The point of intersection between the 30° line and EPH section should be radiused to prevent turbulence. A table of offsets and the equations used to generate the offsets, for the complete coupling cover is shown in Table 2. Use of the table is demonstrated in a sample calculation in paragraph 161-2-r.

TABLE 2 - Offsets for a Short Nosed Coupling Cover

x/L_T	y/T_S	x/L_T	y/T_S
0.00	0.0000	0.55	0.8308
0.01	0.0961	0.60	0.8663
0.05	0.2186	0.65	0.8976
0.10	0.3159	0.70	0.9248
0.15	0.3949	0.75	0.9478
0.20	0.4651	0.80	0.9666
0.22654(a)	0.5000	0.85	0.9812
0.25	0.5299	0.90	0.9916
0.30	0.5905	0.95	0.9979
0.35	0.6469	0.975	0.9995
0.40	0.6991	0.99	0.9999
0.45	0.7472	1.00	1.0000
0.50	0.7911		

(a) Junction of parabola and hyperbola

This section may be intersected at any point to form the nose of the coupling cover. The intersection will usually be in the parabolic portion of the section.

Hyperbola: $y/T_S = \frac{1}{2}\sqrt{(1 + 1.82843x/L_T)^2 - 1}$

for $0 \leq x/L_T \leq 0.22654$

Parabola: $y/T_S = 1 - 0.83579\,(1 - x/L_T)^2$

for $0.22654 \leq x/L_T \leq 1.0$

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The design of the fairwater is covered in paragraph 161-2-o.

161-2-k. <u>Short Tail Coupling Cover and Fairwater - Strut to Coupling Cover (Condition 3)</u>

The short tailed coupling cover is used in conjunction with a fairwater forward of a shaft strut (see Figure 4). The use of this arrangement, instead of a fairwater, is dictated by the position of the shaft coupling relative to the strut barrel. In general, a coupling cover and fairwater combination are preferable to a long fairwater for structural considerations. The scantlings of the long fairwater will be heavy since it is a cantilevered structure. Whereas, this combination requires only a short fairwater, which will not have as large structure as the long fairwater.

The short tailed coupling cover is designed first using part of a complete coupling cover (see Figure 5). A complete coupling cover is designed as in paragraph 161-2-i. The thickness of a coupling cover, T_c, is limited by the strut barrel diameter, T_s:

$$T_c \leq 0.80\ T_s$$

The coupling cover tail section is truncated by intersection with a cone. The tail section is determined most easily graphically. The cover is intersected by a line, typically at an angle of 30 degrees from the vertical. The angle can be adjusted to suit the clearance available between the shaft coupling and the strut barrel. The point of intersection should be chosen so that sufficient clearnance is allowed between the cover structure and the coupling bolt heads (2.5 to 5.0 cm). The intersection point should be radiused rather than sharp edged. The coupling cover length should be kept as short as possible.

The fairwater section is described by a portion of an ellipse. The ellipse is tangent to a point on the elliptical section of the coupling cover. The fairwater forms a continuous section with the coupling cover. The point of tangency of the fairwater and the coupling cover can occur almost anywhere along the elliptical portion of the coupling cover. The point of tangency is taken as 25% of the length of a complete coupling cover aft of the leading edge (X_T = 0.25c).

The offsets of the fairwater are generated using the following equation:

$$y = -y_o + \sqrt{(T_s + y_o)^2 - A(L_N - x)^2}$$

Where:

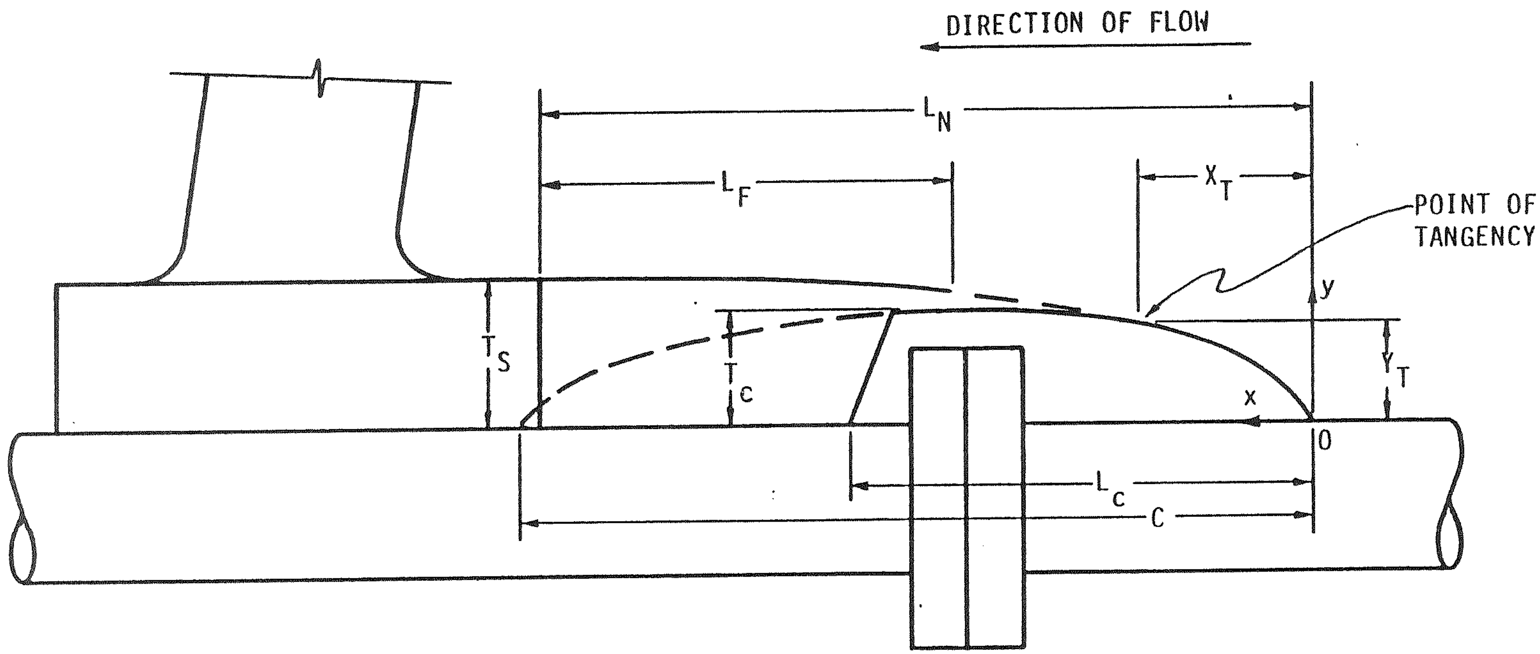
$$A = \Theta_T\ (y_T + y_o)^2\ /\ (L_N - x_T)$$

$$y_o = (By_T + y_T^2 - T_s^2)\ /\ (2T_s - B - 2y_T)$$

$$B = \Theta_T(L_N - x_T)$$

$$y_T = T_c[1-(1-x_T/0.43613c)^2]^{\frac{1}{2}}$$

Θ_T = slope at point of tangency



NOTE: LOWER HALF OF COUPLING COVER, FAIRWATER AND STRUT BARREL WERE LEFT OUT FOR CLARITY

C - CHORD LENGTH OF IMAGINARY EPH HALF-SECTION

L_N - LENGTH OF COUPLING COVER AND FAIRWATER

L_F - LENGTH OF FAIRWATER

X_T - DISTANCE FROM ORIGIN TO POINT OF TANGENCY OF FAIRWATER

T_C - MAXIMUM THICKNESS OF COUPLING COVER

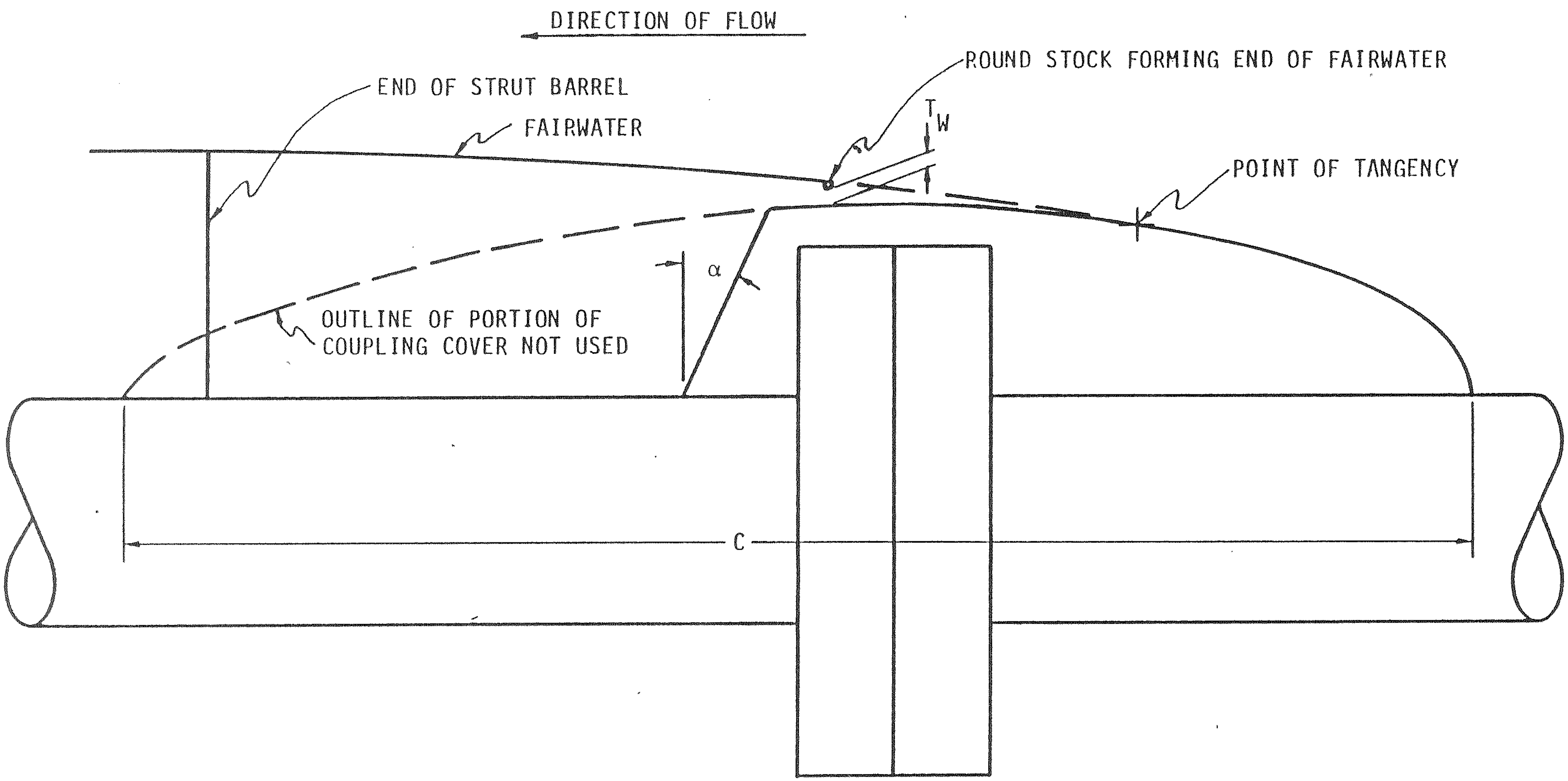
T_S - STRUT BARREL THICKNESS

L_c - LENGTH OF COUPLING COVER

Y_T - COVER THICKNESS AT POINT OF TANGENCY

FOR DETAILS OF FAIRWATER LEADING EDGE SEE FIGURE 5

FIGURE 4 - LONG FAIRWATER AT FORWARD END OF A STRUT BARREL (CONDITION 3)



T_W - WATER CLEARANCE, DISTANCE FROM OUTSIDE OF COUPLING COVER TO INSIDE OF ROUND STOCK FORMING FAIRWATER LEADING EDGE

α - ANGLE OF TAIL OF COUPLING COVER, TYPICALLY 30 DEGREES

C - LENGTH OF IMAGINARY EPH HALF SECTION

FIGURE 5- SHORT TAIL COUPLING COVER AND FAIRWATER (CONDTION 3)

$$\Theta_T = (T_c/0.43613c)(1-x_T/0.43613c) \left[1-(1-x_T/0.43613c)^2\right]^{-\frac{1}{2}}$$

x_T, T_s, L_N, c, T_c are defined in Figure 4.

These equations only apply where: $L_N \geq c\ T_s/T_c$. Otherwise a fairwater should be used. The x-axis of the coordinate system (as defined in Figure 4) is the outside diameter of the propeller shaft. The origin is at the leading edge of the coupling cover.

The length of the fairwater, L_F, is determined by the clearance between the fairwater and cover. The clearance will be defined by the bearing requirements, but should be at least 1.5 cm to admit water to the strut bearing.

The above equation can also be used for fairwaters attached to curved strut barrels. The terms in the equation are redefined in Figure 6. The equation is used to define the offsets of both strut barrel and fairwater. A detailed design example appears in paragraph 161-2-r.

161-2-l. Fairwater, Leading Edge (Condition 4)

The leading edge fairwater is used on the forward end of a strut barrel. The strut barrel may either be cylindrical or curved. The shortest fairwater results when the strut barrel is curved. If the strut barrel is curved, the entire fairwater and forward portion of the strut barrel assembly should be the elliptical portion of an EPH section.

The leading edge fairwater for a strut barrel consists of only the elliptical portion of an EPH section. The thickness of the fairing is determined by the strut barrel diameter, the shaft diameter and the water clearance. The fairwater must form a continuous surface with the strut barrel (see Figure 7). For a curved strut barrel, only a portion of the elliptical section is used for the fairwater. The slope of the leading edge of the barrel must be known so that a fair section may be generated. The slope of the fairwater must equal the slope of the barrel at their intersection. The length of the fairwater is determined using the following:

$$L_F = (-B \pm \sqrt{B^2 - 4AC})/2A$$

Where,

L_F = length of fairwater

T_B = maximum strut barrel thickness, less water clearance

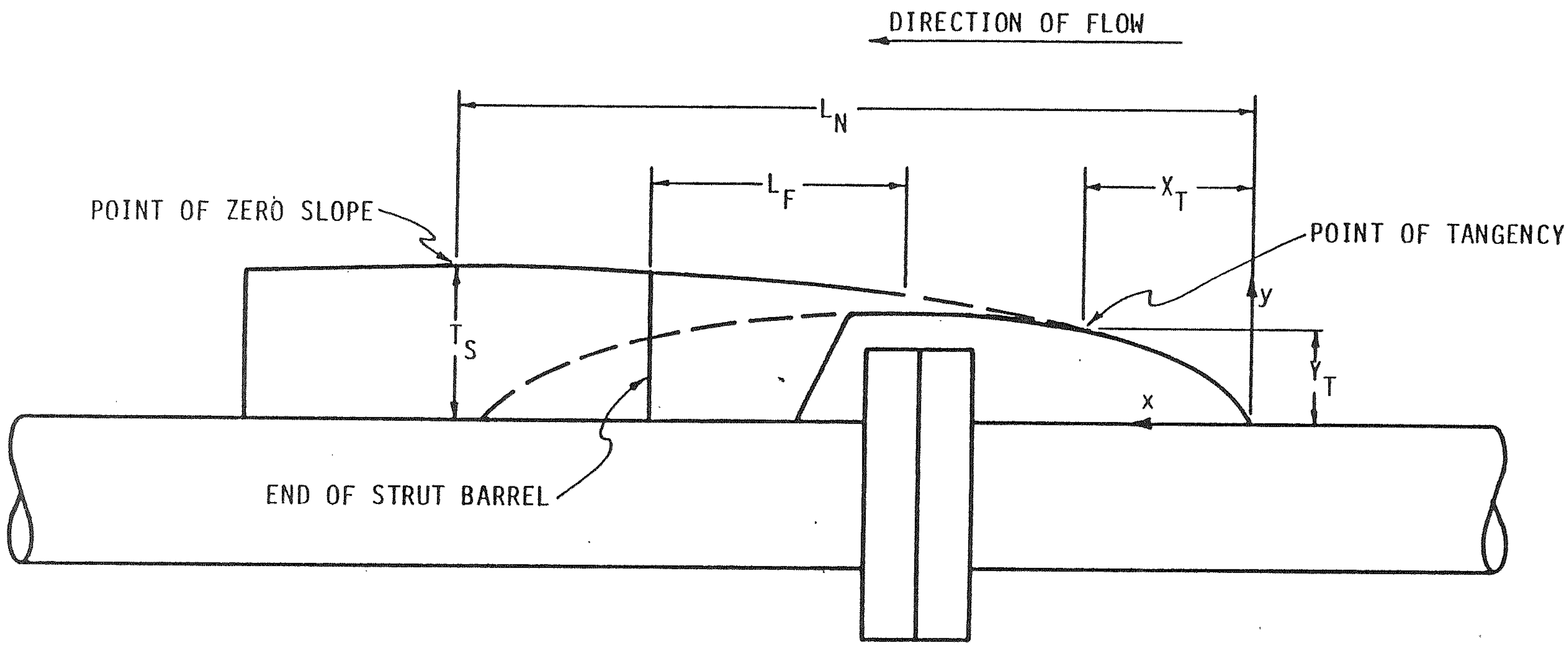
$A = (M^2a^2 + T_B{}^2a^4)$

$B = -(2T_B{}^2a^3 + 2aM^2)$

$C = a^2T_B{}^2$

$a = 1/L_N$

M = slope at the leading edge of the strut barrel



NOTE: LOWER HALF OF COUPLING COVER, FAIRWATER, AND STRUT BARREL WERE LEFT OUT FOR CLARITY. STRUT ARM NOT SHOWN FOR CLARITY.

L_N - DISTANCE FROM STRUT BARREL MAXIMUM SECTION TO ORIGIN

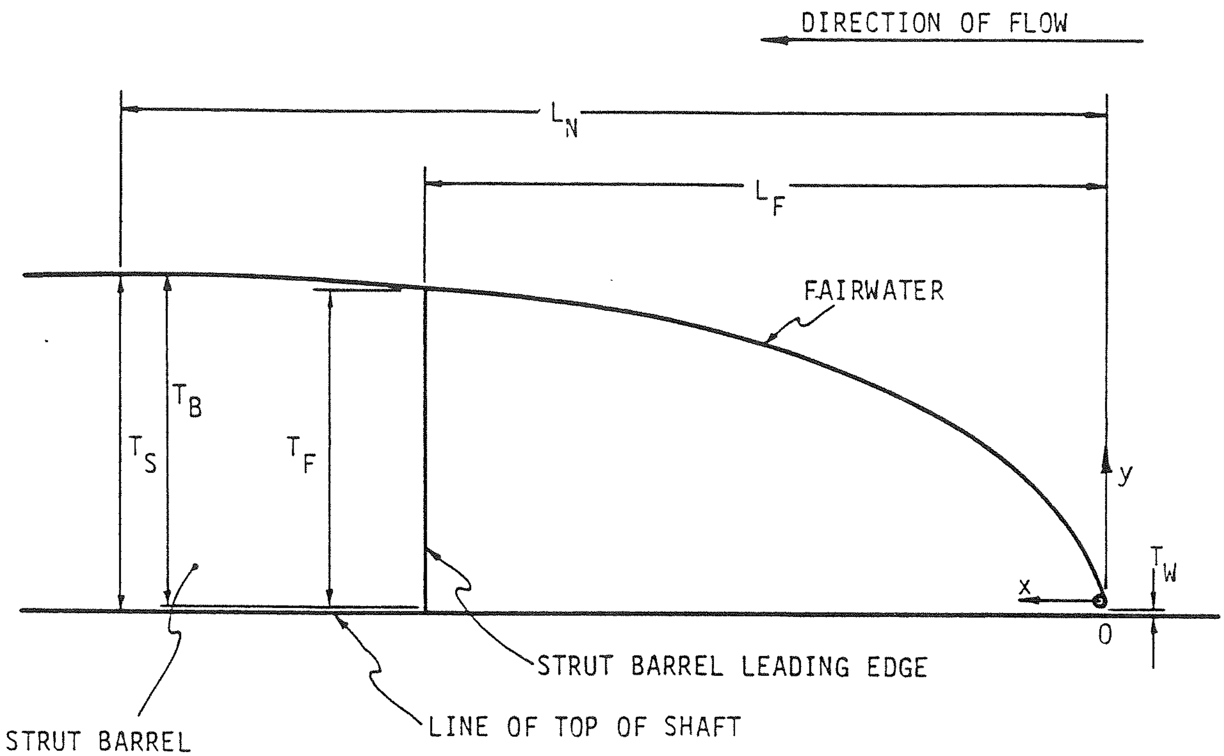
L_F - LENGTH OF FAIRWATER

X_T - DISTANCE FROM ORIGIN TO POINT OF TANGENCY OF FAIRWATER

T_S - MAXIMUM STRUT BARREL THICKNESS

Y_T - COVER THICKNESS AT POINT OF TANGENCY

FIGURE 6 - LONG FAIRWATER AT FORWARD END OF A CURVED STRUT BARREL (CONDITION 3)



L_N - DISTANCE FROM FAIRWATER NOSE TO POINT OF ZERO SLOPE

L_F - LENGTH OF FAIRWATER

R - LEADING EDGE RADIUS FORMED BY ROUND STOCK, TYPICALLY 1.25cm

T_F - FAIRWATER THICKNESS

T_W - WATER CLEARANCE, AT LEAST 1.5cm

T_S - MAXIMUM STRUT BARREL THICKNESS, POINT OF ZERO SLOPE

T_B - STRUT BARREL THICKNESS, LESS WATER CLEARANCE = $T_S - T_W - R$

FIGURE 7- LEADING EDGE FAIRWATER (CONDITION 4)

L_N = distance from fairwater nose to point of zero slope

$L_F = L_N$ for a cylindrical strut barrel

The distance, L_N, must be selected for the fairwater and is limited as follows:

$$3.05291 \leq L_N, T_B \leq 5.23356$$

The fairwater should be kept as short as possible to minimize frictional resistance.

The offsets for the fairwater can be generated by using either Table 3 or the equation below:

$$y/T_B = \sqrt{2(x/L_N) - (x/L_N)^2} \qquad \text{for } 0 \leq x/L_N \leq L_F/L_N$$

Where: y, T_B, x, L_N, L_F are defined in Figure 7.

The origin for this equation is at the nose of the fairwater and it applies to both curved and cylindrical barrels.

Clearance must be allowed between the shaft and the fairwater. The clearance should be sized in accordance with bearing requirements and at least 1.5 cm.

A design example appears in paragraph 161-2-r.

161-2-m. Fairwater, Trailing Edge (Condition 5)

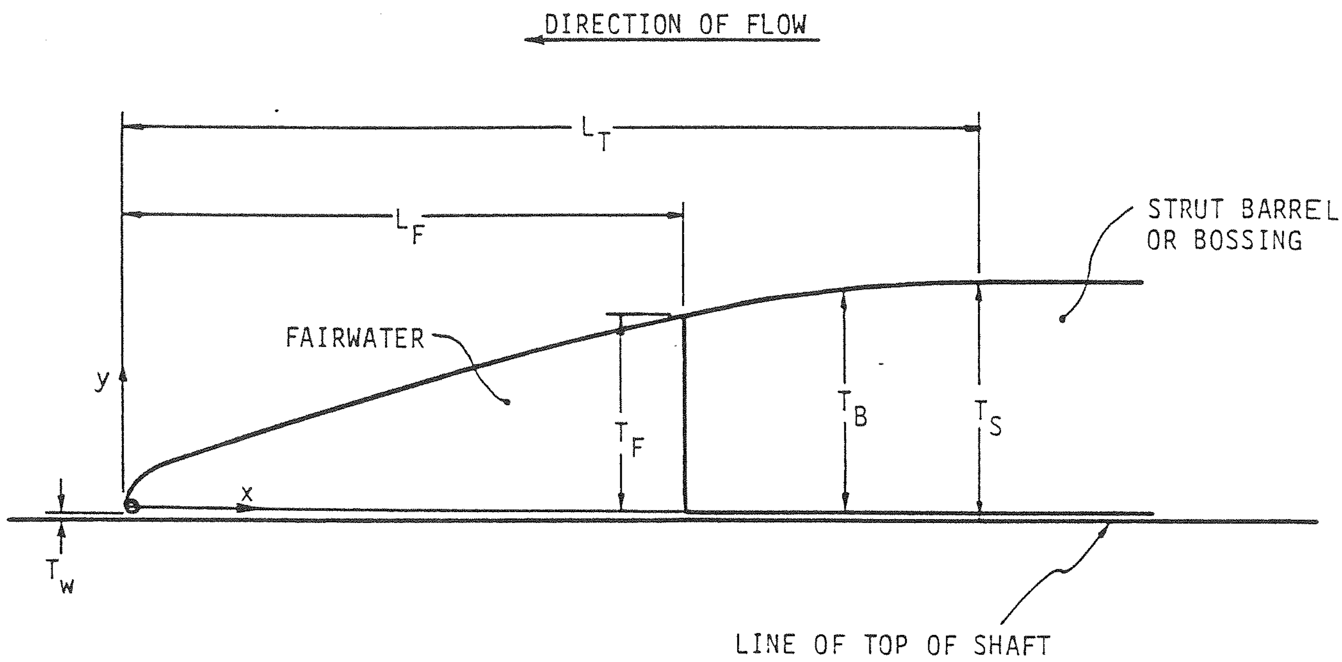
The trailing edge fairwater is used on the after end of a strut barrel or bossing. The strut barrel or bossing may be either cylindrical or curved. The shortest fairwater results when the bossing or barrel is curved. When using a curved strut barrel the entire fairwater and strut barrel should be an EPH section. When a bossing is curved, the bossing and fairwater will form the after portion of an EPH section.

The trailing edge fairwater for a strut barrel or bossing consists of only the parabolic and hyperbolic portions of an EPH section. The thickness of the fairwater is determined by the strut barrel and propeller shaft diameter, (see Figure 8). The fairwater must form a continuous surface with the strut barrel. For a curved strut barrel, only a portion of the parabolic and hyperbolic portion is used for the fairwater. The slope of the trailing edge of the barrel must be known so that a fair section may be generated. The slope of the fairwater must equal the slope of the strut barrel at their intersection. The length of the fairwater is determined using one of the following formulae:

For the hyperbolic portion, slope, $M \geq 1.29290\ T_B/L_T$

$$L_F = (-B + \sqrt{B^2 - 4AC})/2A$$

Where,



L_T - DISTANCE FROM POINT OF ZERO SLOPE TO TAIL OF FAIRWATER

L_F - LENGTH OF FAIRWATER

R - TRAILING EDGE RADIUS FORMED BY ROUND STOCK, TYPICALLY 1.25cm

T_F - FAIRWATER THICKNESS

T_W - WATER CLEARANCE, AT LEAST 1.5cm

T_S - MAXIMUM STRUT BARREL THICKNESS, POINT OF ZERO SLOPE

T_B - STRUT BARREL THICKNESS, LESS WATER CLEARANCE = $T_S - T_W - R$

FIGURE 8- TRAILING EDGE FAIRWATER (CONDITION 5)

$A = 4M^2a^2 - T_B{}^2a^4$

$B = 8M^2a - 2a^3T_B{}^2$

$C = -T_B{}^2a^2$

L_F = length of fairwater

T_B = maximum strut barrel thickness, less water clearance

M = slope at end of strut barrel

$a = 1.82843/L_T$

L_T = length of tail section from point of zero slope

The limits on length to thickness ratio are:

$3.94709 \leq L_T/T_B \leq 6.76644$

For the parabolic portion, slope, $M \leq 1.29290\ T_B/L_T$

$L_F = L_T - ML_T{}^2/a^2T_B$

When the slope is greater than 1.29290 T_B/L_T the intersection occurs in the hyperbolic portion of the EPH section. When the slope is less than 1.29290 T_B/L_T the intersection occurs in the parabolic section. The second formula may be used to determine the length of a fairwater from a cylindrical barrel. The slope is zero for this case. The offsets for the fairwater can be generated by using either Table 3 or the equations below:

For the hyperbolic part:

$y/T_B = \frac{1}{2}\ \sqrt{(1 + 1.82843x/L_T)^2 - 1}$

Where, $0 \leq x/L_T \leq 0.22654$

x, L_T, y, T_B are defined in Figure 8.

For the parabolic part:

$y/T_B = 1 - 0.83579(1 - x/L_T)^2$

Where,

$0.226542 \leq x/L_T \leq L_F/L_T$

x, L_T, y, T_B, L_F are defined as above

Clearance for water circulation must be allowed between the shaft and the fairwater. The clearance should be equal to the water intake clearance.

When a trailing edge fairwater and a leading edge fairwater are combined with a curved strut barrel, the entire assembly should form a complete EPH

TABLE 3 - Strut Fairwaters

Leading Edge (Condition 4)

x/L_N	y/T_B	x/L_N	y/T_B
0.00	0.000	0.50	0.8660
0.05	0.3122	0.55	0.8930
0.10	0.4359	0.60	0.9165
0.15	0.5268	0.65	0.9367
0.20	0.6000	0.70	0.9539
0.25	0.6614	0.75	0.9682
0.30	0.7141	0.80	0.9798
0.35	0.7599	0.85	0.9887
0.40	0.8000	0.90	0.9950
0.45	0.8352	0.95	0.9987
		1.00	1.0000

$$y/T_B = \sqrt{2x/L_N - (x/L_N)^2}$$

Trailing Edge (Condition 5)

x/L_T	y/T_B	x/L_T	y/T_B
0.00	0.0000	0.45	0.7472
0.05	0.2186	0.50	0.7911
0.10	0.3159	0.55	0.8308
0.15	0.3949	0.60	0.8663
0.20	0.4651	0.65	0.8976
		0.70	0.9248
0.2265(a)	0.5000	0.75	0.9478
		0.80	0.9666
0.25	0.5299	0.85	0.9812
0.30	0.5905	0.90	0.9946
0.35	0.6469	0.95	0.9979
0.40	0.6991	1.000	1.0000

(a) Junction of hyperbola and parabola

$$y/T_B = \tfrac{1}{2}\sqrt{(1 + 1.82843\ x/L_T)^2 - 1} \qquad 0 \le x/L_T \le 0.22654$$

$$y/T_B = 1 - 0.83579(1 - x/L_T)^2 \qquad 0.22654 \le x/L_T \le 1$$

section (see Figure 9). In this case the length of the fairwaters will be determined by the strut barrel length, strut barrel thickness and the desired chord to thickness ratio.

A design example appears in paragraph 161-2-r.

161-2-n. Fairwater - Strut Barrel Aft End or Bossing to Coupling Cover - Long (Condition 6)

The long fairwater is used on the after end of either a strut barrel or bossing to form a fair section with a coupling cover. The fairwater extends from the barrel to the coupling cover and is formed by a portion of an ellipse. The section formed by the ellipse and the EPH section is a continuous curve (see Figure 9). The ellipse is tangent to the parabola at the point of intersection of the curves.

The first step of the design process is the design of a short nosed coupling cover (Condition 2). The standard cover from paragraph 161-2-j should be used. The thickness of the coupling cover is limited by the strut barrel or bossing diameter.

$$T_C \leq 0.80\ T_S$$

The long fairwater is used only if the distance between the bossing and the leading edge of the coupling cover is less than six times the strut barrel thickness. Condition 5 should be used otherwise with a separate coupling cover (Condition 1).

The point of tangency of the fairwater and the coupling cover can occur almost anywhere along the parabolic section of the coupling cover. The point of tangency is taken as 30% of the cover length forward of the trailing edge.

The offsets of the fairwater are generated by using the following equation:

$$y = -y_o + \sqrt{(T_S + y_o)^2 - A(L - x)^2}$$

Where:

$$A = \theta_T \sqrt{(y_T + y_o)/(L - x_T)}$$

$$y_o = (By_T + y_T^2 - T_S^2)/(2T_S - B - 2y_T)$$

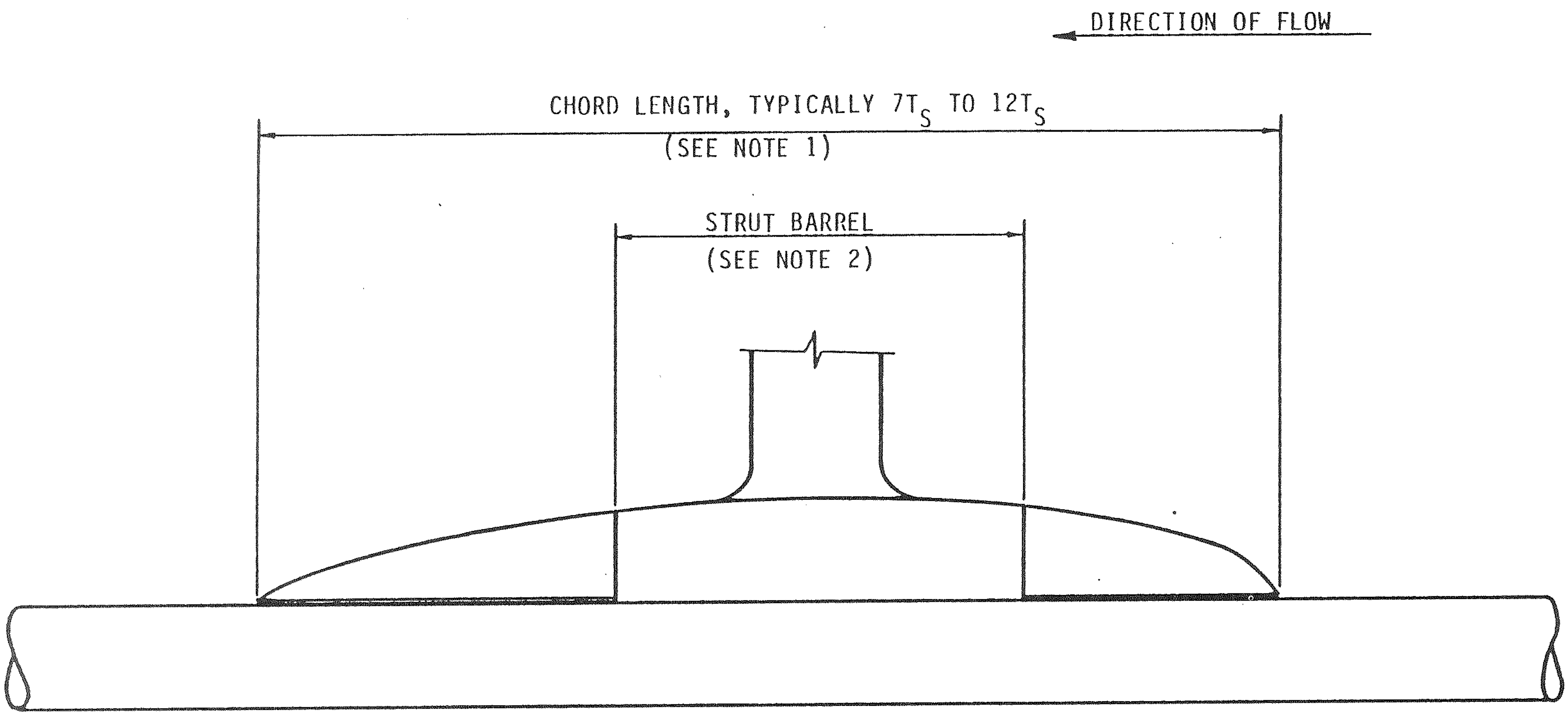
$$B = \theta_T(L - X_T)$$

$$y_T = T_C\{1 - 0.5[(L_C - x)/(0.43613L_C) - 1]^2\}$$

$$\theta_T = T_C/(0.43613L_C)[(L_C - X_T)/(0.43613L_C) - 1]$$

x_T, T_S, L, L_C, T_C are defined in Figure 10.

The x-axis of the coordinate system (as defined in Figure 10) is the outside diameter of the propeller shaft. The origin is at the trailing edge of the coupling cover.



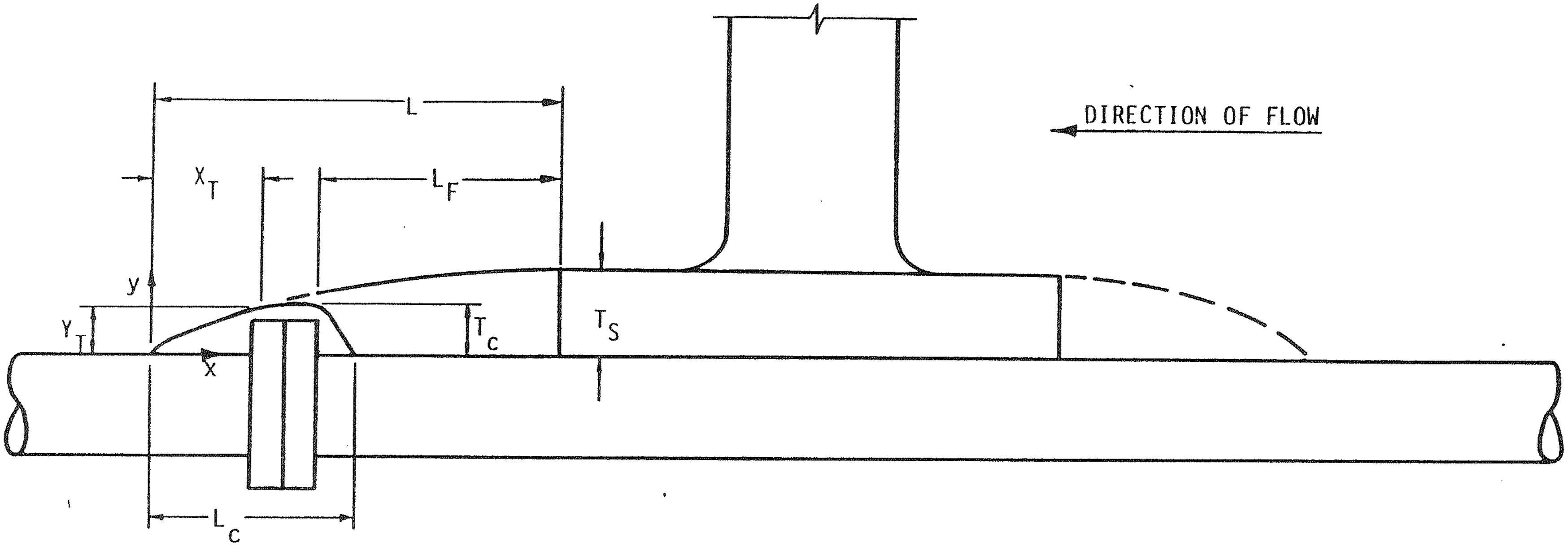
NOTES:

1. THE ENTIRE FAIRWATER AND STRUT BARREL ASSEMBLY CAN BE TREATED AS ONE PIECE. THE ENTIRE ASSEMBLY SHOULD FORM AN EPH SECTION. THE CHORD LENGTH IS DETERMINED BY MECHANICAL AND HYDRODYNAMIC CONSIDERATIONS.

2. STRUT BARREL LENGTH AND MAXIMUM DIAMETER ARE DETERMINED BY STRUCTURAL AND MECHANICAL CONSIDERATIONS. SEE DDS 161-1, DATED 13 NOVEMBER 1982 TO DETERMINE SHAFT STRUT CHARACTERISTICS.

3. LOWER HALF OF FAIRWATERS AND STRUT BARREL OMITTED FOR ILLUSTRATIVE PURPOSES.

FIGURE 9- FAIRWATERS FOR A SHAFT STRUT (CONDTIONS 4 AND 5)



NOTE: LOWER HALF OF COUPLING COVER AND SHAFT BARREL WERE LEFT OUT FOR CLARITY

L - LENGTH OF COUPLING COVER AND FAIRWATER

L_F - LENGTH OF FAIRWATER

X_T - DISTANCE FROM ORIGIN TO POINT OF TANGENCY OF FAIRWATER

T_c - MAXIMUM THICKNESS OF COUPLING COVER

T_S - STRUT BARREL OR BOSSING THICKNESS

L_c - LENGTH OF COUPLING COVER

Y_T - COVER THICKNESS AT POINT OF TANGENCY

FIGURE 10- LONG FAIRWATER ON AFT END OF STRUT BARREL OR BOSSING (CONDITION 6)

The length of the fairwater, L_F, is determined by the clearance between the fairwater and the cover. A clearance is required to allow water circulation through the strut bearings. The clearance should be sized in accordance with bearing requirements but not less than 1.5 cm.

A design example appears in paragraph 161-2-r.

161-2-o. Fairwater - Strut Barrel After End or Bossing to Coupling Cover - Short (Condition 7)

The short fairwater is used on the after end of a strut barrel or bossing in conjunction with a short nosed coupling cover (Condition 2) to form a fair section. The use of this arrangement, as opposed to a long trailing edge fairwater, is dictated by the position of the shaft coupling relative to the strut barrel or bossing. The coupling cover, fairwater and strut barrel should form a fair section, preferably part of an EPH section (see Figure 3).

The offsets for the fairwater can be generated using the equations for the coupling cover in paragraph 161-2-j if the coupling cover, fairwater and strut barrel are all part of the same EPH section. However, if the fairwater is of a different shape it will be necessary to match the slope at the after end of the fairwater with that of the coupling cover. The slope at any point of the coupling cover can be determined using the following:

Anywhere along the hyperbolic section:

$$y' = 0.91422(T_S/L_T)[3.65686\,(x/L_T)+3.34316(x/L_T)^2]^{-\frac{1}{2}}\,[1 + 1.82843(x/L_T)]$$

Where,

$0 \leq x/L_T \leq 0.22654$

y' = slope at a distance x from the origin at the tail.

L_T = length of the tail section as shown in Figure 3

T_S = maximum strut barrel thickness as shown in Figure 3

Anywhere along the parabolic section:

$$y' = 1.67158(T_S/L_T)(1-x/L_T)$$

Where,

$0.22654 \leq x/L_T \leq 1.0$

y', T_S, L_T are as defined above.

The slope at the forward end of the fairwater must match the slope of the after end of the strut barrel.

The length of the fairwater is determined by the clearance between the cover and the fairwater. A clearance must be provided for water flow through the strut bearings. It should be in accordance with the bearing requirements but not less than 1.5 cm.

A design example appears in paragraph 161-2-r.

161-2-p. Rope Guard (Condition 8)

The rope guard is a cylindrical plate that extends aft from the strut barrel. A gap is formed between this cylindrical plate and a similar smaller cylindrical plate that extends forward from the propeller hub. The propeller hub ring diameter should be equal to the strut barrel diameter reduced by twice the thickness of the rope guard and the water clearance. The propeller hub ring and the rope guard should overlap at least 7.5 cm. The end clearance of the rope guard to the propeller hub should be sized in accordance with thrust bearing requirements and at least 1.5 cm. The clearance between the propeller hub ring and the strut barrel should be in accordance with the bearing requirements and at least 1.5 cm. See Figure 11.

161-2-q. Surface Smoothness

The contour of the fairwater or coupling cover is very important. Therefore, when they are constructed, the design contour must be maintained. The entire outside surface must be smooth and free from irregularities. All welding must be ground smooth and flush to the contour. No welding spatter, pits or undue roughness is to be permitted. The overall surface finish must be 250 micro-inches or better.

The surface of the fairwaters and coupling covers prior to painting shall have a smoothness consistent with normal surface finish which results from grit blasting. A check for smoothness and fairness shall be made using a wooden batten. When held against the surface, the batten shall exclude a 1.59 mm (1/16 inch) diameter feeler gage everywhere along its length. The surface should be tested at random locations, in the assumed direction of flow, about 0.15 m (6 inches) apart. Where the gap between the surface and the batten is less than 1.59 mm, the slope of the surface locally shall not be greater than 1:10, where measured perpendicular to the surface and parallel to the flow.

161-2-r. Sample Calculations

Sample calculations are provided for all of the conditions described in the previous sections, except for the rope guard. The following data is used in all of the examples:

Shaft O.D.	0.60 m
Flange O.D.	0.90 m
Strut Barrel O.D.	1.25 m

Condition 1: Coupling Cover

The design of the coupling cover starts with the determination of the maximum cover thickness, T_C. To determine T_C, it is necessary to know the depth of the structure that supports the cover. The structure depends on the shaft

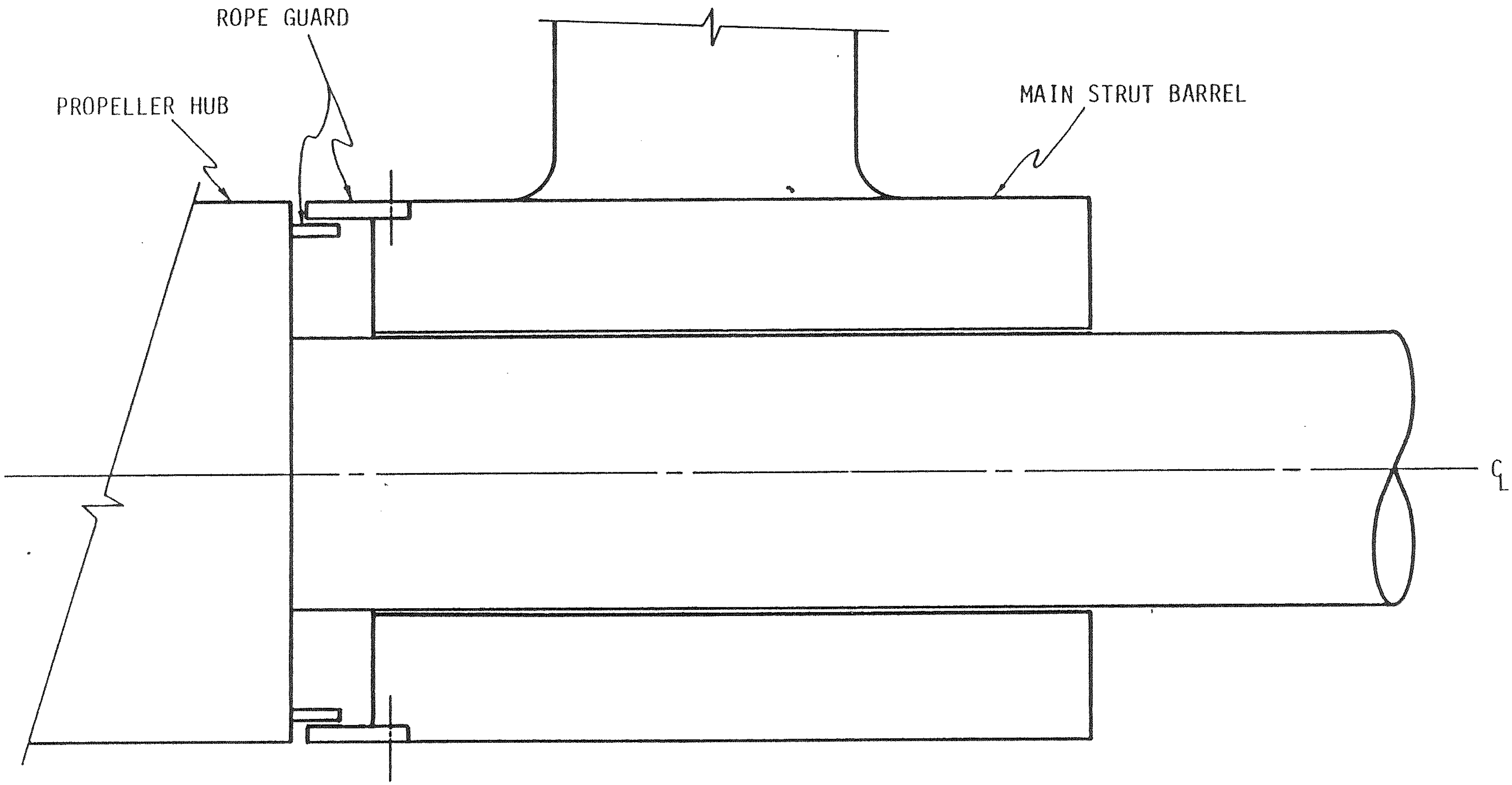


FIGURE 11- ROPE GUARD (CONDITION 8)

and flange diameters. A first estimate of the cover thickness, including structure, can be made using the following formula:

$$T_C = 5/3\,[(D_F - Ds)/2]$$

Where:

T_C = coupling cover thickness, including structure

D_F = flange outside diameter

D_S = shaft outside diameter

This formula is only an approximation and a more detailed analysis should be used to determine the actual structure. Use of this formula gives:

$$T_C = 5/3\,[(0.90 - 0.60)/2]$$

$$T_C = 0.25 \text{ m}$$

To minimize the frictional resistance penalty the cover length should be kept as short as possible (see paragraph 161-2-c). Selecting the lower limit on length to thickness ratio from paragraph 161-2-g, gives:

$$L_C = 7\ T_C = 1.75 \text{ m}$$

Knowing, L_C and T_C it is possible to generate offsets using either the equations in paragraph 161-2-g or the offsets in Table 1. In Table 1, $t = T_C$.

The section of maximum thickness is positioned over the joint where the two flanges meet. This point is 0.763 m aft of the nose of the coupling cover. The offsets for this example are given in Table 4.

<u>Conditions 2 & 7: Short Nosed Coupling Cover and Short Fairwater</u>

Two examples using a short nosed coupling cover and a short fairwater will be demonstrated in this example. The first will demonstrate a cylindrical strut barrel and the second a curved strut barrel. Both examples will cover the design of the cover and the fairwater.

<u>Cylindrical Barrel</u>

To design the coupling cover and fairwater, additional information is needed. The size of the coupling and its position relative to the strut barrel are needed. The following additional information is assumed for the example:

Distance from strut barrel to coupling	0.40 m
Coupling width	0.30 m
Bolt head width	0.05 m

All of the above information is shown in Figure 12 for clarity.

TABLE 4 - Offsets for Example Coupling Cover (Condition 1)

x (m aft of nose)	y (m above surface of shaft)
0.000	0.0000
0.175	0.1593
0.350	0.2102
0.525	0.2375
0.700	0.2492
0.763	0.2500
0.875	0.2473
1.050	0.2324
1.225	0.2043
1.400	0.1630
1.575	0.1085
1.750	0.0000

Nose Radius = 2.2928 (t^2/c)

= 0.0819 m

Tail Radius = 0.8108 (t^2/c)

= 0.0290 m

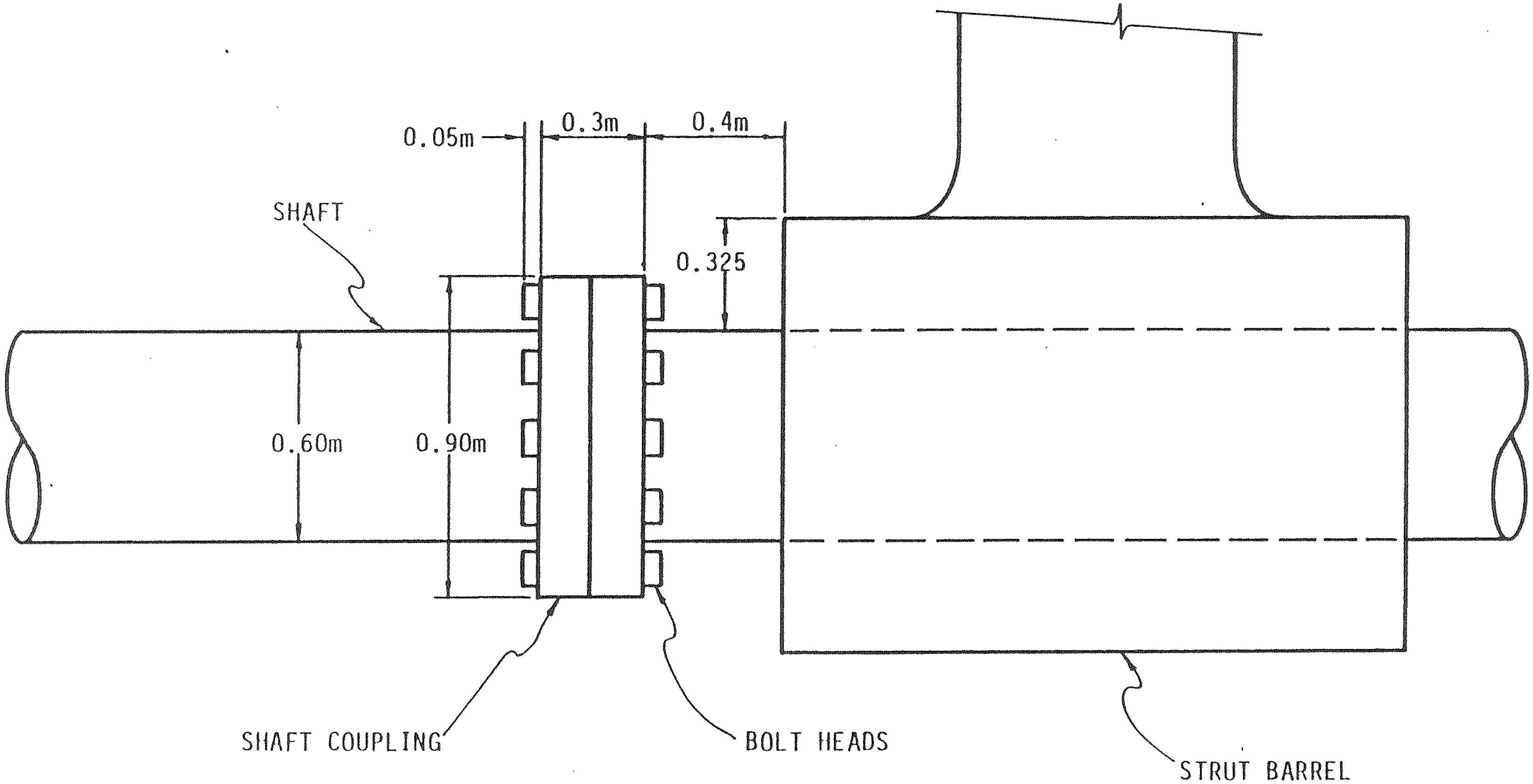


FIGURE 12- SAMPLE STRUT BARREL AND SHAFT COUPLING

The limits on the equations found in paragraph 161-2-j indicate that the length of the coupling cover and fairwater is between 1.2828 m and 2.1991 m ($3.94709 \leq L_T/T_S \leq 6.76644$) for T_S = 0.325m. To minimize frictional resistance the cover and fairwater length should be as short as possible.

The thickness of the coupling cover must be determined. The scantlings used in the example for Condition 1 to determine cover thickness will be used here. The structure and clearance to be used are 0.10 m in depth. This depth will be added to the outside of the shaft coupling. The section formed by the coupling cover and fairwater must have at least this diameter at the after end of the shaft coupling to allow for the cover structure. The cover at this point must be at 0.25 m thick when measured from the outside diameter of the shaft:

$$\text{Thickness} = (D_F + 2(\text{Clearance}) - D_S)/2$$

$$= (0.90 + 2(0.10) - 0.6)/2$$

$$= 0.25 \text{ m}$$

This point is located 0.7 m aft of the strut barrel.

From the limits on section length previously established the length of the section, L_T, is assumed to be 1.30 m. The thickness of the strut barrel, T_S, is 0.325 m (see Figure 12).

The equation for the parabola will be used to check for clearance, at the after end of the coupling cover:

$$x/L_T = (1.30 - 0.70)/1.30 = 0.46154$$

$$y/T_S = 1 - 0.83579(1 - x/L_T)^2$$

$$y/T_S = 0.75767$$

$$\text{Since } T_S = 0.325 \text{ m}$$

$$y = 0.246 \text{ m}$$

Obviously, this is not adequate because $y < 0.25$m. The cover length, L_T, will be increased to 1.35 m and the process repeated.

$$x/L_T = (1.35\text{m} - 0.70\text{m})/1.35\text{m} = 0.48148$$

$$y/T_S = 0.77529$$

$$y = 0.252 \text{ m}$$

Since, $y > 0.25$ m, the length of the section is adequate. This length can be used to generate the offsets for the section using either Table 2 or the equations. The offsets appear in Table 5. The nose of the coupling cover starts 1.05 m forward of the trailing edge of the cover and is at an angle, α, of 30^o to provide sufficient clearance for the bolt heads.

TABLE 5 - Offsets for Example Short Nosed Coupling Cover and Fairwater (Cylindrical Barrel) - Conditions 2 and 7

x (m)	y (m)
0.00	0.0000
0.10	0.0874
0.20	0.1274
0.30	0.1607
0.3058(a)	0.1625
0.40	0.1905
0.50	0.2173
0.60	0.2412
0.70	0.2620
0.80	0.2799
0.90	0.2948
1.00	0.3067
1.05 (b)	0.3116
1.10 (c)	0.3157
1.20	0.3216
1.30	0.3246
1.35	0.3250

(a) Junction of hyperbola and parabola.

(b) Nose of coupling cover starts here.

(c) Fairwater starts here. T_W is 0.05 m.

Curved Barrel

This example uses all of the same initial data as for the cylindrical barrel except that the strut barrel diameter is a minimum of 1.25 m and the distance between the strut barrel and shaft coupling is only 0.30 m. The length of the strut barrel is 2.40 m.

To design the coupling cover and fairwater, it will also be necessary to design the strut barrel so that a fair section is designed. The preferred section would be the parabolic-hyperbolic portion of an EPH section. The minimum strut barrel diameter will be found at the after end of the strut barrel and the maximum diameter, T_C, will be found farther forward. An examination of Table 2 indicates that in the first quarter of its length the parabolic-hyperbolic section attains nearly 53% of its height. In the second quarter it increases to 79% and then to almost 95% in the third. Therefore, to minimize length without making an unnecessarily thick section the end of the strut barrel should be at about 0.75 L_T. The coupling cover scantlings are assumed to be the same as the previous example. Therefore, at a point 0.6 m aft of the strut barrel, the section must be 0.25 m above the shaft.

If the end of the strut barrel is at 0.75 L_T, using Table 2 gives the following:

$$\text{at } x/L_T = 0.75,\ y/T_S = 0.9478 \text{ and } y = 0.325\text{m}$$

Therefore,

$$T_S = 0.325\text{ m}/0.9478$$

$$T_S = 0.3429\text{ m}$$

To minimize the length of fairwater and coupling cover L_T/T_S should be as near to the lower limit as possible (3.94709). The clearance needed over the shaft at the coupling is 0.25 m, which gives:

$$y/T_S = 0.25\text{m}/0.3429\text{m} = 0.7291$$

therefore $0.40 < x/L_T < 0.45$ (from Table 2). A rough estimation gives x/L_T = 0.44. Having taken the end of the strut barrel at 0.75 L_T and the distance between the two points is 0.60 m, we have

$$L_T = 0.60\text{m}/(0.75 - 0.44) = 1.94\text{ m}$$

Therefore: $L_T/T_S = 1.94/0.3429$

$$= 5.66$$

Using L_T = 1.94 m and T_S = 0.3429 m and the equations in paragraph 161-2-j, then

$$y = 0.2530\text{ m} \quad \text{at } x = (x/L_T)L_T = 0.44\text{x}1.94\text{m} = 0.854\text{m}$$

The parabolic section ends at $(1 - 0.75)L_T$ = 0.485 m forward of the end of the strut barrel. Forward of this the strut barrel is cylindrical. A table of offsets for this section is given in Table 6. The nose is designed as in the previous example.

Condition 3: Short Tailed Coupling Cover and Fairwater

The design of a short tailed coupling cover and fairwater will be demonstrated in two examples. The first will demonstrate a cylindrical strut barrel and the second a curved strut barrel.

Cylindrical Barrel

In order to design the coupling cover and fairwater, information will be needed on the dimensions of the strut barrel and coupling. The following dimensions are known:

$T_s = 0.325$ m
$T_w = 0.015$ m

Distance from strut barrel to aft end of coupling = 1.4 m.

Shaft Diameter	0.60 m
Coupling Width	0.30 m
Coupling Diameter	0.90 m

This information is shown in Figure 13.

The coupling cover must be designed before the fairwater. The maximum allowable cover thickness is taken from paragraph 161-2-k:

$Tc \leq 0.8T_s$
$Tc \leq 0.8\ (0.325\text{m})$
$Tc \leq 0.260\text{m}$

Since the coupling cover designed for Condition 1 has a thickness of 0.25m, it will be used for this example. It will truncated by intersection with a 30 degree line at a point 1.000m aft of the nose. The offsets for the cover appear in Table 7. The length of the EPH half section, c, is 1.75m. The cover length, Lc, is 1.137m. The nose of the cover is 0.763m forward of the shaft flange joint.

The point of tangency between the cover and the fairwater is:

$x_T = 0.25c$
$= 0.25\ (1.75\text{m})$
$= 0.4375\text{m}$

The equation in paragraph 161-2-k will be used to define the fairwater surface.

$$y = -y_o + \sqrt{(T_s + y_o)^2 - A(L_N - x)^2}$$

The following constants were used to find A, y_o, B, y_T and θ_T:

$x_T = 0.4375\text{m}$

TABLE 6 - Offsets for Example Short Nosed Coupling Cover, Fairwater and Curved Strut Barrel - Conditions 2 and 7

x (m)	y (m)
0.00	0.0000
0.20	0.1101
0.40	0.1623
0.4395(a)	0.1714
0.60	0.2062
0.80	0.2439
1.00	0.2756
1.20	0.3012
1.205 (b)	0.3018
1.21 (c)	0.3023
1.40	0.3207
1.455 (d)	0.3250
1.50	0.3282
1.60	0.3341
1.80	0.3414
1.94 (e)	0.3429

(a) Junction of hyperbola and parabola

(b) Nose of coupling cover starts here.

(c) Fairwater starts here. T_W is 0.05 m.

(d) Junction of fairwater and strut barrel

(e) Start of cylindrical strut barrel

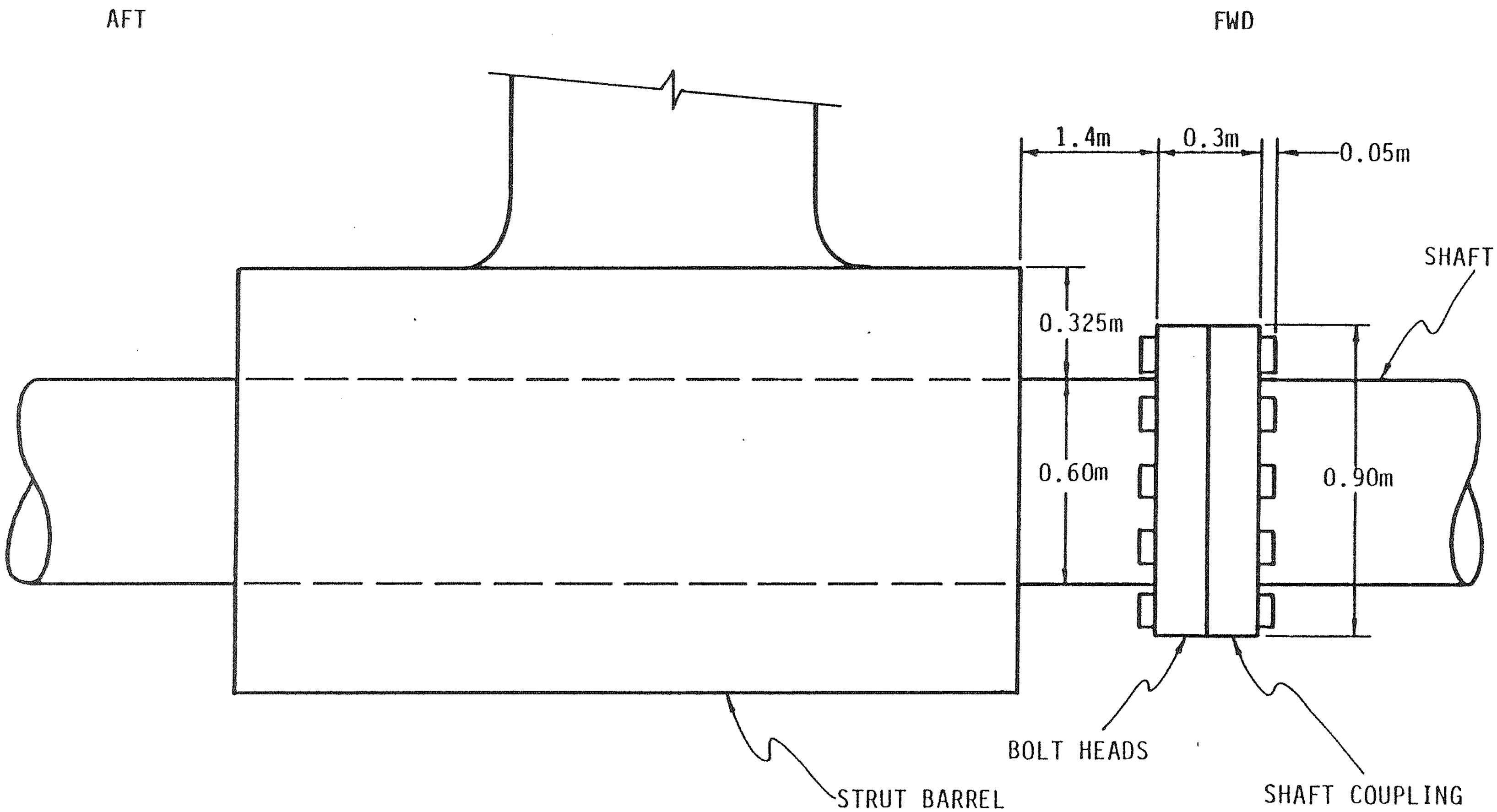


FIGURE 13- INFORMATION FOR SAMPLE SHORT TAILED COUPLING COVER AND FAIRWATER

TABLE 7 - Offsets for Short Tailed Coupling Cover Example (Condition 3)

x (meters)	y (meters)
0.000	0.0000
0.100	0.1237
0.200	0.1687
0.300	0.1987
0.400	0.2199
0.500	0.2347
0.600	0.2442
0.700	0.2492
0.800	0.2497
0.900	0.2460
1.000(a)	0.2380
1.100	0.0648
1.137	0.0000

(a) Intersection of EPH section by cone, $\alpha = 30^{\circ}$.

$T_S = 0.325m$

$L_N = 2.313m$

$c = 1.75m$

$T_C = 0.25m$

From paragraph 161-2-k:

$y_T = T_C \left[1 - (1-x_T/0.43613\ c)^2\right]^{1/2}$

$= 0.2261$

$\theta_T = (T_C/0.43613c)(1-x_T/0.43613c)\ \left[1-(1-x_T/0.43613c)^2\right]^{-1/2}$

$= 0.1546$

$B = \theta_T\ (L_N - x_T)$

$= 0.2899$

$yo = (B\ y_T + y_T^2 - T_S^2)/(2T_S - B - 2y_T)$

$= -0.1199$

$A = \theta_T\ (y_T + y_0)/(L_N - x_T)$

$= 0.00875$

Therefore:

$y = 0.1199 + \sqrt{0.0421 + 0.00875\ (2.313 - x)^2}$

The offsets for the fairwater are shown in Table 8.

The length of the fairwater is determined from the clearance necessary for water circulation. The clearance for water circulation for this example is taken as 0.015m. The reinforcing bar at the leading edge is assumed to have a radius of 0.0125m. Therefore, the end of the fairwater occurs where there is 0.040m of clearance between the cover and the fairwater (see Figure 14).

Curved Barrel

This example is very similar to the previous example. All of the initial information remains the same except the distance from the strut barrel to the coupling is only 0.5m. Also, the minimum strut barrel thickness will be found at the forward end of the strut barrel and the maximum thickness, Ts, will be found farther aft. A minimum barrel thickness of 0.305m is assumed.

A portion of the strut barrel will be designed in this example so that a fair section is generated. The coupling cover, fairwater and part of the

TABLE 8 - Offsets for Leading Edge Fairwater from a Straight Strut Barrel (Condition 3)

x (meters)	y (meters)	x (meters)	y (meters)
0.4375	0.226	1.500	0.310
0.450	0.228	1.600	0.314
0.500	0.235	1.700	0.317
0.600	0.248	1.800	0.319
0.700	0.259	1.900	0.321
0.800	0.268	2.000	0.323
0.900	0.277	2.100	0.324
1.000	0.284	2.200	0.325
1.100	0.291	2.300	0.325
1.200	0.297	2.313	0.325
1.300	0.302		
1.400	0.306		

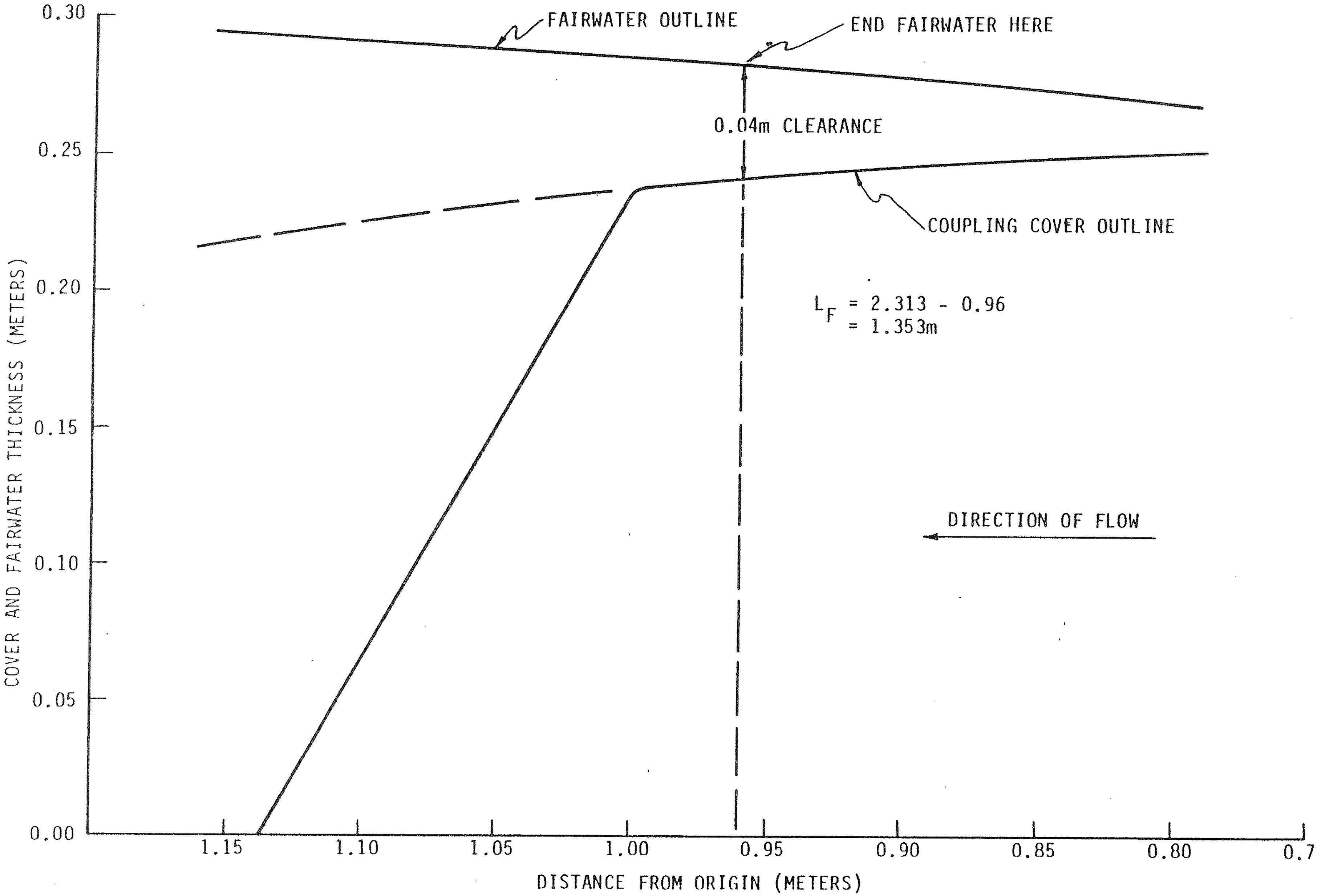


FIGURE 14- LEADING EDGE FAIRWATER TO COUPLING COVER (CONDTION 3)

strut barrel will all be formed from the elliptical portion of an EPH section.

The coupling cover designed in the previous example will be used again. The offsets for the coupling cover appear in Table 7.

The point of tangency between the coupling cover and the fairwater is:

$$x_T = 0.25c$$

$$= 0.25\ (1.75m)$$

$$x_T = 0.4375m$$

$$y_T = T_c \sqrt{1-(1-x_T/0.43613c)^2}$$

$$y_T = 0.2261m$$

The leading edge of the strut barrel is located 1.413m aft of the origin. At this point the ellipse forming the fairwater and strut barrel must be at least 0.305m above the shaft surface.

An estimation of the distance from the origin to the point of maximum strut barrel thickness, L_N, must be made. It will be assumed for the example that L_N = 2.30m. The following constants are used to find A, y_o, B, and Θ_T:

$$x_T = 0.4375m$$

$$T_s = 0.325m$$

$$L_N = 2.30m$$

$$c = 1.75m$$

$$T_c = 0.25m$$

From paragraph 161-2-k:

$$\Theta_T = (T_c/0.43613c)\ (1-x_T/0.43613c)\ [1-(1-x_T/0.43613c)^2]^{-\frac{1}{2}}$$

$$= 0.15458$$

$$B = \Theta_T\ (L_N - x_T)$$

$$= 0.28791$$

$$y_o = (By_T + y_T^2 - T_s^2) / (2T_S-B-2y_T)$$

$$= -0.11754$$

$$A = \Theta_T(y_t + y_o) / (L_N - x_t)$$

$= 0.00901$

The equation describing the fairwater is

$$y = 0.11754 + \sqrt{0.04304 - 0.00901\,(2.3 - x)^2}$$

At the leading edge of the strut barrel (x = 1.413m) the thickness is 0.307m. Since the minimum required thickness was 0.305m, the length is adequate. If the section was not adequate it would have been necessary to adjust L_N and recalculate the equation. The offsets for the fairwater and strut barrel appear in Table 9. The end of the fairwater would be determined as in the last example.

Condition 4: Fairwater, Leading Edge

The fairwater must form a continuous surface with the barrel of the strut to which it is attached. The maximum diameter of the fairwater is equal to the strut barrel diameter for a cylindrical barrel less the clearance to allow water flow to the strut bearings. Therefore, the fairwater thickness is:

$$T_F = (\text{Strut O.D} - D_S)/2 - T_W - R$$

$$T_F = (1.25\text{ m} - 0.60\text{ m})/2 - 0.0275\text{m} - 0.0125\text{m}$$

$$= 0.285\text{ m}$$

The length to thickness ratio is selected from the range given in paragraph 161-2-1 but kept as low as possible. For the example a ratio of 4 was selected. The length of the fairwater is:

$$L_F = 4\,T_C$$

$$= 1.140\text{ m}$$

Using T_F and L_F, the offsets for the fairwater can be determined by using either Table 4 or the equation in paragraph 161-2-1. The offsets for the fairwater are shown in Table 10.

Condition 5: Fairwater, Trailing Edge

The diameter of the fairwater is equal to the strut barrel diameter, for a cylindrical barrel, as a continuous surface must be formed. The fairwater must allow for circulation through the strut barrel by leaving clearance for the water to escape. The thickness of the fairwater is:

$$T_F = (\text{Barrel O.D.} - D_S)/2 - T_W - R$$

$$= (1.25\text{ m} - 0.60\text{ m})/2 - 0.0275\text{m} - 0.0125\text{m}$$

$$= 0.285\text{ m}$$

The length to thickness ratio is selected from the range given in paragraph 161-2-m. The length of the fairwater (assuming $L_F/T_F = 5.17$) is:

TABLE 9 - Offsets for Leading Edge Fairwater and Curved Strut Barrel (Condition 3)

x (meters)	y (meters)	x (meters)	y (meters)
0.4375	0.226	1.413(a)	0.307
0.500	0.235	1.500	0.311
0.600	0.248	1.600	0.314
0.700	0.259	1.700	0.317
0.800	0.268	1.800	0.319
0.900	0.277	1.900	0.321
1.000	0.284	2.000	0.323
1.100	0.291	2.100	0.324
1.200	0.297	2.200	0.325
1.300	0.302	2.300	0.325
1.400	0.307		

(a) Junction of fairwater and strut barrel

TABLE 10 - Example Leading Edge Fairwater Offsets (Condition 4)

x (m)	y (m)
0.000	0.000
0.114	0.124
0.228	0.171
0.342	0.206
0.456	0.228
0.570	0.247
0.684	0.261
0.798	0.272
0.912	0.279
1.026	0.284
1.140	0.285

Origin is located 0.04m above the shaft.

$L_F = 5.17\ T_C$

$= 1.473m$

Using L_F and T_F, the offsets of the fairwater can be generated from either Table 4 or the equations in paragraph 161-2-m. The offsets for the fairwater are shown in Table 11.

<u>Conditions 4 and 5: Fairwaters on a Curved Barrel</u>

This example demonstrates the design of a strut barrel and leading and trailing edge fairwaters. The preferred shape for this assembly is an EPH section as shown in Figure 9.

The strut barrel length is assmued to be 2.40m and the minimum barrel thickness is assumed to be 0.325m. The water clearance, T_W is 0.0157m and the radius is 0.0125m. Therefore $T_B =$ 0.322m.

Limits must be established for both chord length and section thickness of the assembly. The chord length is already limited by section thickness ($7.0 \leq c/T_B \leq 12.0$) but there may be additional limits due to interference with the hull or strucutrual considerations. For example, it is assumed there are no additional limits on chord length, but section thickness shall not be greater than 045m. Therefore, the ratio of minimum barrel thickness to maximum thickness is limited to:

$y/T_B = 0.295/0.45$

$= 0.6556$

The minimum barrel thickness is assumed to occur at both ends of the strut barrel. Examination of Table 1 indicates that if y/t = 0.75 the strut barrel will extend from about x/c = 0.15 to about x/c = 0.75, so that the barrel length will be approximately 0.6c. Knowing the strut barrel length gives an approximation of chord length:

$c \simeq 2.4m/0.6$

$c \simeq 4.0m$

The maximum section thickness is:

$T_B = 0.295m/0.75$

$T_B = 0.3933\ m$

The chord to thickness ratio is:

$c/T_B \simeq 4.0/0.3933$

$\simeq 10.17$

This ratio is acceptable, therefore, the design example may be completed using the maximum section thickness of 0.3933 m. The exact chord length will have to

TABLE 11 - Example Leading Edge Fairwater Offsets (Condition 5)

x (m)	y (m)
0.000	0.000
0.147	0.090
0.295	0.133
0.442	0.168
0.589	0.199
0.737	0.225
0.884	0.247
1.031	0.264
1.178	0.275
1.326	0.283
1.473	0.285

NOTE: The origin on a trailing edge fairwater is at the after end of the fairwater 0.04 m above the shaft.

be determined using the equations for an ellipse and a parabola given in paragraph 161-2-g. Using these equations will give the exact position along the chord (x/c) for the ends of the strut barrel.

Ellipse:

$$x/c = 0.43613[1 - \sqrt{1 - (y/t)^2}]$$

for $y/t = 0.75$

$$x/c = 0.1477$$

Parabola:

$$x/c = 0.43613 [1 + \sqrt{2(1 + y/t)}]$$

$$x/c = 0.7445$$

The barrel length expressed in terms of x/c is:

$$x/c = 0.7445 - 0.1477$$

$$= 0.5968$$

Therefore:

$$c = x/0.5968$$

$$= 2.4 \text{ m}/0.5968$$

$$= 4.02 \text{ m}$$

The offsets for the entire section are given in Table 12. The origin of the coordinate system is at the nose of the leading edge fairwater which is located 0.03 m above the shaft.

Condition 6: Fairwater - Bossing to Coupling Cover - Long

The coupling cover must be designed before the fairwater. The cover thickness may not be more than 80% of the barrel thickness ($T_c \leq 0.80Ts$). The maximum cover thickness is:

$$(T_c)_{max} = 0.80 (0.325)$$

$$= 0.260 \text{ m}$$

Since, the coupling cover design for Condition 1 has a thickness T_c = 0.25m, it will be used in this example. The length of the coupling cover from the example is 1.75 m. The leading edge of the cover is assumed to be 1.5 m from the strut barrel (less than the $6T_s$ allowed by paragraph 161-2-n).

TABLE 12 - Offsets for Example, Fairwaters on a Curved Barrel

x (m)	y (m)
0.00	0.0000
0.25	0.2024
0.50	0.2750
0.594 (a)	0.2950
0.75	0.3225
1.00	0.3552
1.25	0.3767
1.50	0.3892
1.75	0.3933
2.00	0.3894
2.25	0.3775
2.50	0.3576
2.75	0.3297
2.994 (b)	0.2948
3.00	0.2939
3.25	0.2500
3.50	0.1981
4.00	0.0355
4.02	0.0000

(a) Leading-edge fairwater to strut barrel junction.

(b) Trailing-edge fairwater to strut barrel junction.

R_1 = 0.1069 m

R_2 = 0.0378 m

The point of tangency between the cover and the fairwater is:

$$x_T = 0.30\ L_c$$
$$= 0.30\ (1.75)$$
$$= 0.525 \text{ m forward of the trailing edge.}$$

The equation in paragraph 161-2-n, will be used to define the fairwater surface:

$$y = y_o + \sqrt{(T_s - y_o)^2 - A(x_o - x)^2}$$

The following constants are used:

$$T_c = 0.25 \text{ m}$$
$$L_c = 1.75 \text{ m}$$
$$L = 3.25 \text{ m}$$
$$T_s = 0.325 \text{ m}$$
$$x_T = 0.525 \text{ m}$$

Therefore:

$$y_T = 0.2042 \text{ m}$$
$$\theta_T = 0.1982$$
$$B = 0.5401$$
$$y_o = 0.15531$$
$$A = 0.00356$$

$$y = 0.15531 + \sqrt{(0.325 - 0.15531)^2 - .00356(3.25 - x)^2}$$

The offsets for the fairwater appear in Table 13.

The length of the fairwater is most easily found by graphical methods. The coupling cover is drawn to scale and the fairwater section is projected onto the drawing. The end point of the fairwater is determined by the clearance between the cover and the fairwater. In this case the clearance is 0.03 m. See Figure 15.

TABLE 13 - Offsets for Example Trailing Edge Fairwater to Coupling Cover (Condition 6)

x (m)	y (m)
0.525	0.2042
0.600	0.2171
0.700	0.2306
1.000	0.2592
1.500	0.2891
2.000	0.3078
2.500	0.3190
3.000	0.3243
3.250	0.3250

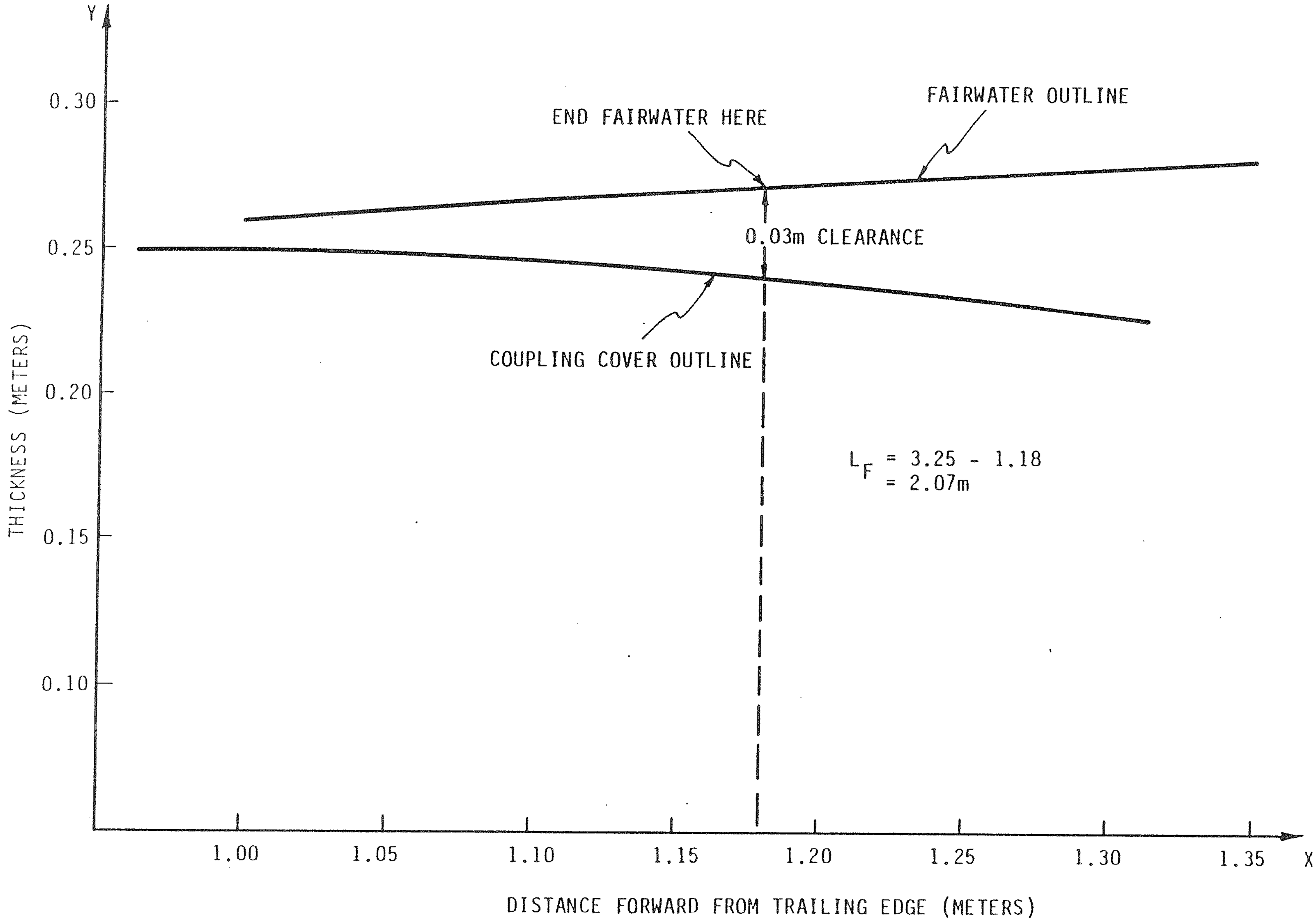


FIGURE 15- TRAILING EDGE FAIRWATER TO COUPLING COVER