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APPLICABILITY OF THE DOUGLAS COMPUTER PROGRAM TO HULL PRESSURE PROBLEMS

by

Stephen B. Denny

HYDROMECHANICS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

October 1963 Report 1786

PRNC-TMB-648 (Rev. 3-63)

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NOMENCLATURE

C_p	Nondimensional pressure coefficient
$(C_p)_b$	Pressure coefficient at a desired point on the bolster
$(C_p)_h$	Pressure coefficient for the hull at the point of attachment
p	Local stream total static pressure
p_b	Local stream pressure on the bolster
p_∞	Free stream total static pressure
p_{b_∞}	Free stream pressure (approaching the bolster)
p_v	Vapor pressure of the fluid
V	Local stream velocity
V_∞	Free stream velocity
V_T	Tangential velocity at the point of attachment on the parent body
$V_{\infty b}$	Free stream velocity approaching the bolster
v_t	$\frac{V_T}{V_\infty}$
ρ	Density of the fluid

ABSTRACT

Presented here are the results of several investigative runs of the Douglas Aircraft Company computer program for the "calculation of nonlifting potential flow about arbitrary three-dimensional bodies." This report designates areas where the program can be used with confidence to predict pressures and velocities on surface ship hull configurations and, in addition, offers a concise computer input scheme. By comparison with experiment, it was found that although there are no analytic allowances in the program for free-surface or boundary layer effects, the velocity and pressure predictions of the program are quite dependable in the forefoot area of a hull.

INTRODUCTION

As the complexity of hull forms increases, so do the problems of conducting flow studies. And yet these investigations such as the determination of cavitation characteristics, are of mounting importance both in designating areas of the hull plating where erosion might occur and in determining accompanying noise which might interfere with the operation of acoustical detection systems. Sonar domes, having combinations of high aspect ratios and acute curvatures, harbor sensitive equipment that can ill-afford either of these flow liabilities.

Problems arise in conducting flow studies at model scale; first, in the lengthy and expensive task of equipping the model with pressure measuring or flow visualization devices and, second, in getting reliable measurements on a scale model. Obviously, a versatile computer program for the calculation of flow about three-dimensional bodies is a good step toward the alleviation of the dependence upon model tests. Such a program exists and was formulated by the Douglas Aircraft Company[1] under the Bureau of Ships Fundamental Hydromechanics Program, NS 715-102, administered by the David Taylor Model Basin.

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[1] References are listed on page 7.

This report presents the results of a number of exploratory calculations with this computer program to test its applicability in predicting pressures on ship hulls. Other examples of interest can be found in References 2 and 3 pertaining to the axisymmetric and the arbitrary three-dimensional cases.

To determine the extent of the free surface and boundary layer effects, a comparison was made between calculated and experimentally measured pressures on a destroyer hull-sonar dome configuration. In the forefoot area where the boundary layer is thin, the calculated pressures closely approximated the experimental pressures.

The program was then used to determine the cavitation characteristics on an aircraft carrier's sonar dome. These results were compared with another run of the same hull differing only by two attached bolsters located above and below the sonar windows. The bolsters were "half-pipes" in shape, and were to serve as guards during anchor handling. The comparison of the two runs, while not substantiated by experimental results, is noteworthy in that it shows the program's handling of relatively small appendages which, if scaled to model size, would be diminutive. An investigation was also made to determine whether or not three-dimensional appendages could be handled independently and their effective influence superimposed on parent hulls; that is, to combine the bare hull pressure distribution with the pressure distribution obtained on an appendage which is affixed to a flat plate and placed in a free stream.

Appendix A is presented to aid future users of the Douglas Program in preparing the input and in interpreting the output. For a thorough coverage of both the theory and the input logic, one should consult Reference 1.

OUTLINE OF THE COMPUTER PROGRAM

Appendix A will give some insight into the formalities of using the program. The following description is necessary in understanding the method of approach used in the calculations of this report.

Input for the program consists of: a network of point offsets which geometrically describe the body; specification of unit onset flows; and some standard convergence criteria. The body may be completely arbitrary in shape or have 1, 2, or 3 planes of symmetry. These plans of symmetry are designated by the use of control cards and only the basic one-half, one-fourth, or one-eighth portion of the body need be input. The origin of the coordinate axes must be located on the plane or planes of symmetry.

The offset points lie in assigned, but not necessarily parallel, rows and columns on the body. Four adjacent points, while not usually lying in the same plane, govern the formation of plane quadrilaterals whose size and normal vectors are the basis for the computations. The concentration of points in an area should be determined by the shape. Naturally, more points would be needed to define a surface with a good deal of curvature than would be needed for a flat or near-flat surface.

There does exist a geometric means of compensating for the effect of an existing free surface. Since theoretically, the body is to be submerged in an unbounded fluid, then to duplicate free surface effects, it would be necessary to extend the hull into some irregular shape which would create a flow pattern identical to the wave profile on the hull. The determination of such an additive shape would be practically impossible. It is far simpler to mirror the body about the design waterline and establish conditions which correspond to those at zero Froude number. The hulls investigated in this study were run with two planes of symmetry: the design waterline, i.e., the zero Froude number case, and the centerline profile plane.

A flow is designated positive if its direction is from plus to minus along a coordinate axis. If this flow is input with unit magnitude, a valid nondimensional pressure coefficient is printed directly in the final output; should the inflow velocity be input with other than unit magnitude, the print out of the velocities is correct and only the pressure coefficient is in error.

The nondimensional pressure coefficient served as the most convenient means for comparison of data and it is important in the calculation of speeds at which cavitation occurs. C_p may be written,

$$C_p = \frac{p - p_\infty}{1/2 \rho V_\infty^2} = 1 - \left(\frac{V}{V_\infty} \right)^2 \qquad [1]$$

where, p = local stream total static pressure,

p_∞ = free stream total static pressure,

V_∞ = free stream velocity,

V = local stream velocity,

ρ = density of the fluid.

At cavitation inception the local total static pressure is equal to vapor pressure, p_v, and V_∞ , the velocity at which cavitation would occur for a given C_p, may be written

$$V_\infty = \left[\frac{p_v - p_\infty}{1/2 \rho C_p} \right]^{1/2} \qquad [2]$$

CALCULATIONS AND RESULTS

The first computer run had as subject a destroyer sonar dome with approximately one-hundred input points in the dome area; the remainder of the ship was represented by widely spaced points. Agreement between the calculated and experimental data was very poor and presumably a finer mesh of offset points was needed in order to adequately describe the acute curvature of the form in the sonar dome area. A second run was made in which about three-hundred input points described the area previously defined by only one-hundred, and the remainder of the hull was represented in the same fashion as the first run.

Figure 1 is a photograph of the destroyer sonar dome and the final grid of offset points. The locations of the pitot tubes at which the experimental measurements were made are also shown and numbered from 1 to 56. Figures 2 through 4c show the comparisons of the calculated results and the experimental data and the good agreement which justifies further use of the program for similar cases.

To determine how much of the hull must actually be input into the program, a truncated version of the destroyer hull was run. It included the dome and the hull only for the length of the dome. It was found that this portion, representing only about 30 percent of the length of the ship, gave calculated data in the forefoot area that compared to the experimental data equally as well as runs in which the entire ship was included.

The second subject for calculations was the dome area of an aircraft carrier. The problem was to find the effect on flow velocities in the forefoot area should bolsters be added above and below the sonar windows (Figure 5).

Offset points for a shortened version of the aircraft carrier hull were input into the program. Two runs were made and pressure distributions were obtained for the hull both with and without the protective bolsters. The C_p curves for the hull geometry which included the bolster offsets displayed fluctuations at the bolster location at every station aft of the forward perpendicular for the length of the bolsters. Figures 6, 7, and 8 show the calculated results for both cases, with bolsters and bare hull, for longitudinal stations at increasing distances from the forward perpendicular. Figure 9 has the plots of the C_p curves for both cases along the waterlines where the pressure coefficients were observed to be consistently low.

The principle of superposition was first investigated for the aircraft carrier hull in ahead motion. It was hoped that the observed pressure fluctuations at the bolsters were caused primarily by the transverse component of flow across the bolsters, induced by the ahead motion of the hull. It was found by calculation, however, that the longitudinal velocity component was far more significant than the transverse component in determining pressures and that this approach to the problem was unsatisfactory for ahead motion. To further test the principle of superposition, the program was applied to a simpler case, that of pure transverse flow across the bolsters as shown in Figure 10. This would correspond to a pure heaving motion of the hull. The pressure distribution for the bolster shape was obtained by a short program calculation for a two-dimensional cross section of the bolster affixed to a flat plate and subjected to a uniform free stream. In superimposing flows it is assumed that the free stream velocity approaching the bolster in the flat plate case should be taken equal to the tangential flow velocity on the bare hull at the points of bolster attachment. On the basis of this assumption, it is shown in Appendix B that the total pressure coefficient, C_p, for the superposition case, may be written

$$C_p = (C_p)_h + (v_t)^2 \cdot (C_p)_b \qquad [3]$$

When comparisons were made, considerable differences were observed between the pressure distribution superimposed on the bare hull and the pressure distribution obtained when the combined geometry of bolsters and hull was entered into the program. Figure 10 shows the bare hull pressure distribution, the combined hull-bolster distribution, and the result of superposition. Obviously, the bolster produces a sizeable influence on the streamline approaching the bolster which results in a reduction of the velocities in the area adjacent to the bolsters and a corresponding increase in pressures over those of the bare hull in that area. The minimum pressures predicted by the superposition method appear to be more conservative for the prediction of cavitation velocities. This method is also faster and less expensive and may be used to find the final flow characteristics when the influence of additive configurations and the flow characteristics of a parent body are known.

CONCLUSIONS

Good agreement was obtained between pressures found experimentally on a destroyer dome and the pressures for the same dome calculated by the Douglas Computer Program. On the basis of this comparison, it is believed that one can obtain with this program satisfactory predictions of the pressures or velocities in the forefoot region of other surface ship hulls.

Had pressure measurements been available for points closer to the free surface and had a comparison been made between the corresponding experimental and calculated pressures, there would probably have been poorer agreement. It was feared that even at the depths at which pressures were measured in the destroyer case, the wave effects would prove the program useless for the calculation of flow about the body. It is concluded, however, on the basis of the good correlation between the calculated and experimental results in this case, that the combined wave and viscosity effects were negligible.

A fair approximation of the influence of an additive configuration on the flow field of a bare hull can be made by superimposing onto the pressure field of the bare hull the pressure distribution of the appendage. This pressure distribution can be obtained with a machine calculation for a two- or three-dimensional appendage on a flat plate subjected to transverse flow; the two-dimensional calculation is possible, as in the bolster case here, if the appendage is of near uniform cross-section and of sufficient length to place the ends of the appendage well out of the area of interest.

For regions close to the free surface, where wave effects are important, and regions further aft on the hull, where viscosity effects are important and the boundary layer well developed, no conclusions can be drawn from the present study. An additional study to determine the viscous effect is being undertaken. Since the program can calculate velocities at off-body points, calculations will be made for a destroyer to compare calculated and measured velocities in the planes of its propellers.

REFERENCES

1. Hess, John and Smith, A.M.O., "Calculation of Nonlifting Potential Flow about Arbitrary Three-Dimensional Bodies," Douglas Aircraft Co. Report No. E.S.-40622 (Mar 1962).

2. Hess, John, "Calculation of Potential Flow about Bodies of Revolution Having Axes Perpendicular to the Free Stream Direction," Douglas Aircraft Co. Report No. E.S.-29812 (Oct 1960).

3. Smith, A.M.O., and Pierce, Jesse, "Exact Solution of the Neumann Problem. Calculation of Noncirculatory Plane and Axially Symmetric Flows About or Within Arbitrary Boundaries," Douglas Aircraft Co. Report No. E.S.-26988 (Aug 1958).

APPENDIX A

Explanation of the Input Schemes

The body is represented by a grid of points located in rows and columns on the body. Two consecutive points in one column and two adjacent points in an adjoining column form pseudo-quadrilaterals the diagonals of which are crossed and the resultant vector is considered normal to the body surface and of magnitude proportional to the area of the quadrilateral. By setting the normal velocity equal to zero at the "null"* point in each of the quadrilaterals, a host of boundary conditions and hence, simultaneous equations are formed. The velocity contributions of adjoining elements to the total calculated velocity at a null point are governed by two formulae, one of which is considerably more accurate for near points than the other. The choice of which relation is used is decided by the magnitude of the ratio of the distance of the point at which the summation is being made to the centroid of the contributing element and the maximum diagonal of the element. Therefore it is good practice to keep the input point spacing as uniform as possible, the quadrilateral elements uniform in area, and consequently, prevent irregularities from appearing in the calculation.

The input points are entered such that to an observer in the fluid, as the columns increase to the right, the rows must increase upward. In short, if the direction of increasing columns is crossed into the direction of increasing rows, the resultant is an outward normal to the body.

Conveniently, to avoid having an excessively large number of points in any row or column, the body can be divided into sections. The row and column arrangements are independent from section to section; that is, while boundary points must be repeated, they may be considered a row of one section and a column in the other (Figure 11). Obviously the rows or columns need not and cannot remain parallel within all sections, and though they

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* Null point - a point near the centroid of the plane quadrilateral element at which the element induces no velocity in its own plane.

cannot cross, they may terminate in a single point common to both, and hence, a triangle rather than a quadrilateral is formed. Under all circumstances the body must be closed. For example, the line of intersection with a plane of symmetry must be completely composed of line segments which are sides of defined quadrilaterals or triangles.

Figure 11 shows a sketch of a geometric section. The coordinates would be entered on the input sheet from the point (1,1) (Column 1, point 1) to the right and then from (2,1) to the right, etc. The significance of the dual position possibilities is: since the N = 3 column has five points, then the N = 4 column must have five points to close the body (i.e., perform calculations for the triangular element). To do this the fifth point (4,5) of Column N = 4 is given identically the coordinates of point (4,4) or (3,5). The same rule applies for N = 5 except that it must have only four points to close the body (again performing calculations for a triangular element.)*

As was stated earlier, the direction of flow is input; and as the program is set up now, it must be of unit magnitude for the pressure coefficient to have meaning. Also, if the inflow is along one of the coordinate axes, the flow calculations can be made for inflow along the other two axes with only a small additional amount of computer time.

If the points are judiciously chosen, it is not probable that any cases will arise in the near future in which the storage of the computer is taxed. None of the problems reported here used over 85 percent of the memory available, yet some ran for as long as four hours.

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* Note: It is important to notice that there exists a discrepency between the conventional m-rows, n-columns idea. The number columns N = 1, N = 2, etc., are <u>L(M)</u> on the input sheets.

Storage capacities are as follows:

Maximum Number of Basic Elements

Type of Case	IBM 704	IBM 7090
Nonsymmetric	800	675
One Symmetry Plane	670	650
Two or Three Symmetry Planes	545	550

Therefore the Effective Number of Elements are:

Type of Case	IBM 704	IBM 7090
Nonsymmetric	800	675
One Symmetry Plane	1340	1300
Two Symmetry Planes	2180	2200
Three Symmetry Planes	4360	4400

The Maximum Number of Input Points

Type of Case	IBM 704	IBM 7090
Nonsymmetric	1250	1125
One Symmetry Plane	1540	1300
Two or Three Symmetry Planes	1300	1100

The preparation of the input sheets (Figure 12) should be as follows:

(1) X, Y, Z are the coordinates of the point in decimal values. Since all computations are dimensionless, it is important to check the consistency of all offsets. Each line on the input sheet defines one point and the values are entered from the left immediately following the sign.

(2) N, M: N is the number of columns in a section; it is entered only at the beginning of each section. M is the number of points in each column and is entered at the first point of each column.

(3) L(X) is merely the point number; it is a positive, consecutive, increasing integer throughout the input.

(4) L(N) is the number of the section. It is entered only at the first point of the new section and is a positive, consecutive, increasing integer throughout the input.

(5) L(M) is the number of the column; it is entered at the first point of the column and is a positive, consecutive, increasing integer throughout the input, i.e., the series does not begin over at a new section.

Figure 12 is a sample input sheet. Notice that the 83rd input point is the beginning of a new section and consequently the beginning of a new column. N = 9 means that there are nine columns in the section, M = 8, that the first column has eight points in it; L(N) = 2, that it is the second section and L(M) = 9, that the point is the beginning of the ninth column (i.e., the first section had eight columns.)

EXPLANATION OF OUTPUT

After only a small percentage of machine time has passed, certain geometrical properties of the quadrilateral elements are printed out (Figure 13a). This pause in the machine procedure and print out aids the checking of input before lengthy, expensive computations take place. If the null point is outside of the quadrilateral, or if the iterative procedure does not converge, the integers 1 or 2, respectively, will be printed in the right-hand margin.

The quantities listed in Figure 13a are: the integers N & M, which are the column and row location of the point to which the element is associated; the coordinates (X, Y, Z) of the four input points are used to form the element; the components (NX, NY, NZ) of the unit normal vector; the coordinates of the null point in the reference coordinate system; the common projection distance, D, of the four input points into the plane of the element; the maximum diagonal, T, and the area of the quadrilateral, A.

The final output (Figure 13b) is a print out of:

M, N	The identifying integers of the element,
NPX, NPY, NPZ	The coordinates of the null point in the reference coordinate system,
VT	Magnitude of the total flow velocity at the null point,
VTSQ	The square of the total flow velocity,
CP	The nondimensional pressure coefficient,
VX, VY, VZ	The components of the total flow velocity at the null point,
DCX, DCY, DCZ	The direction cosines of the total flow velocity vector,
NX, NY, NZ	The components of the unit normal vector,
VN	The total normal velocity,
SIG	The value of the surface source density on the element.

APPENDIX B

Formula Derivation for the Superposition of an Appendage Contribution to an Existing Pressure Field

Bare Hull

$$(C_p)_h = \frac{p - p_\infty}{1/2 \quad V_\infty^2}$$

$$\text{or} \quad p - p_\infty = 1/2 \rho V_\infty^2 (C_p)_h$$

Bolster Alone

$$(C_p)_b = \frac{p_b - p_{\infty b}}{1/2 \rho V_{\infty b}^2}$$

$$\text{or} \quad p_b - p_{\infty_b} = 1/2 \rho V_{\infty_b}^2 \cdot (C_p)_b$$

Assume

$$p_{\infty_b} \approx p \qquad V_{\infty_b}^2 \approx V_T^2$$

$$\therefore \quad p_b - p = 1/2 \rho V_T^2 (C_p)_b$$

$$p_b - p_\infty = 1/2 \rho \left[(C_p)_b \cdot V_T^2 + (C_p)_h \cdot V_\infty^2 \right]$$

$$= 1/2 \rho V_\infty^2 \left[(C_p)_h + v_t^2 (C_p)_b \right]$$

$$C_p = (C_p)_h + v_t^2 \cdot (C_p)_b$$

where:

$$v_t = \frac{V_T}{V_\infty}$$ (Some percentage of inflow velocity)

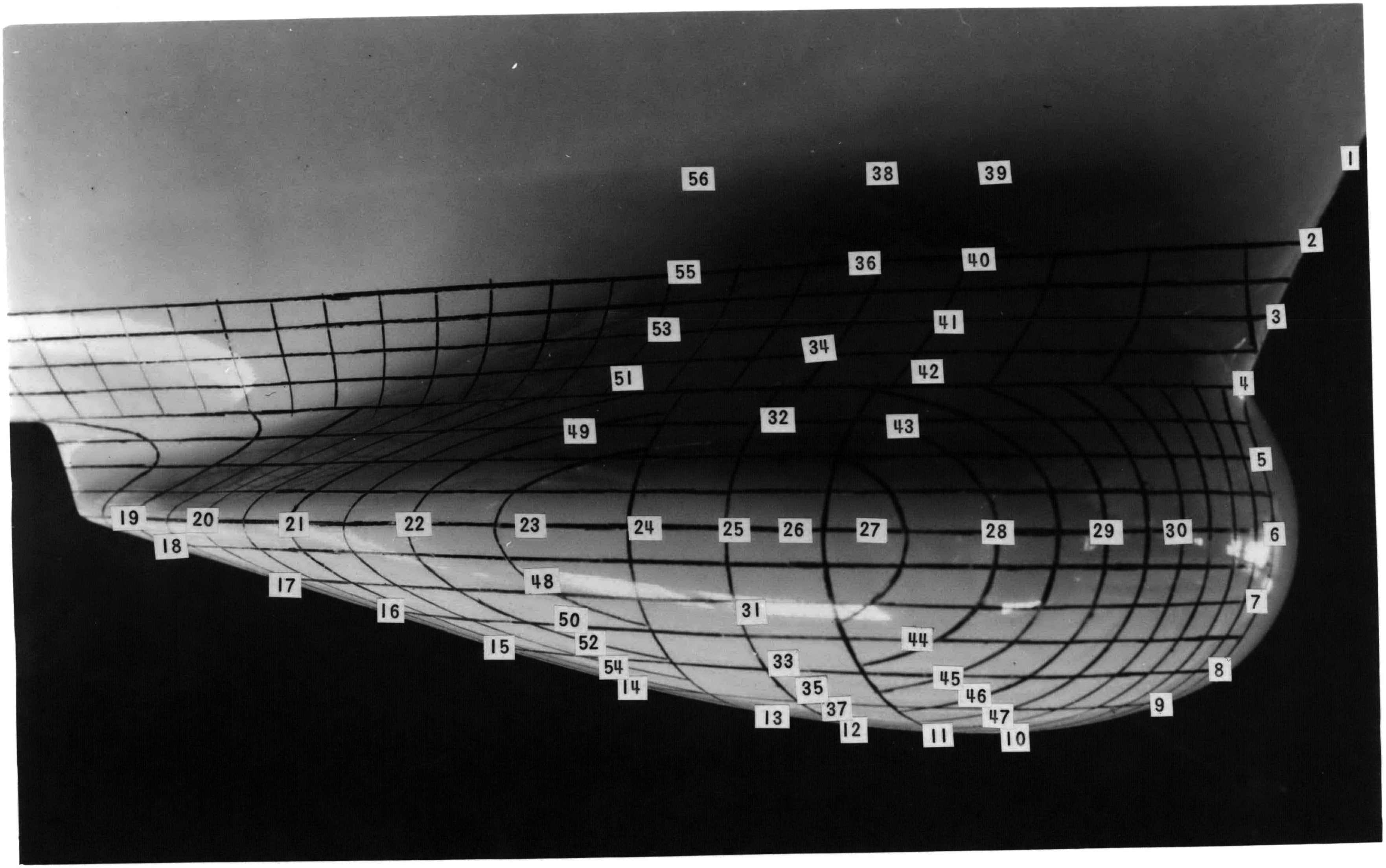

Figure 1 - Pitot Tube Locations and the Division of the Destroyer Dome Area into Quadrilateral Surface Elements

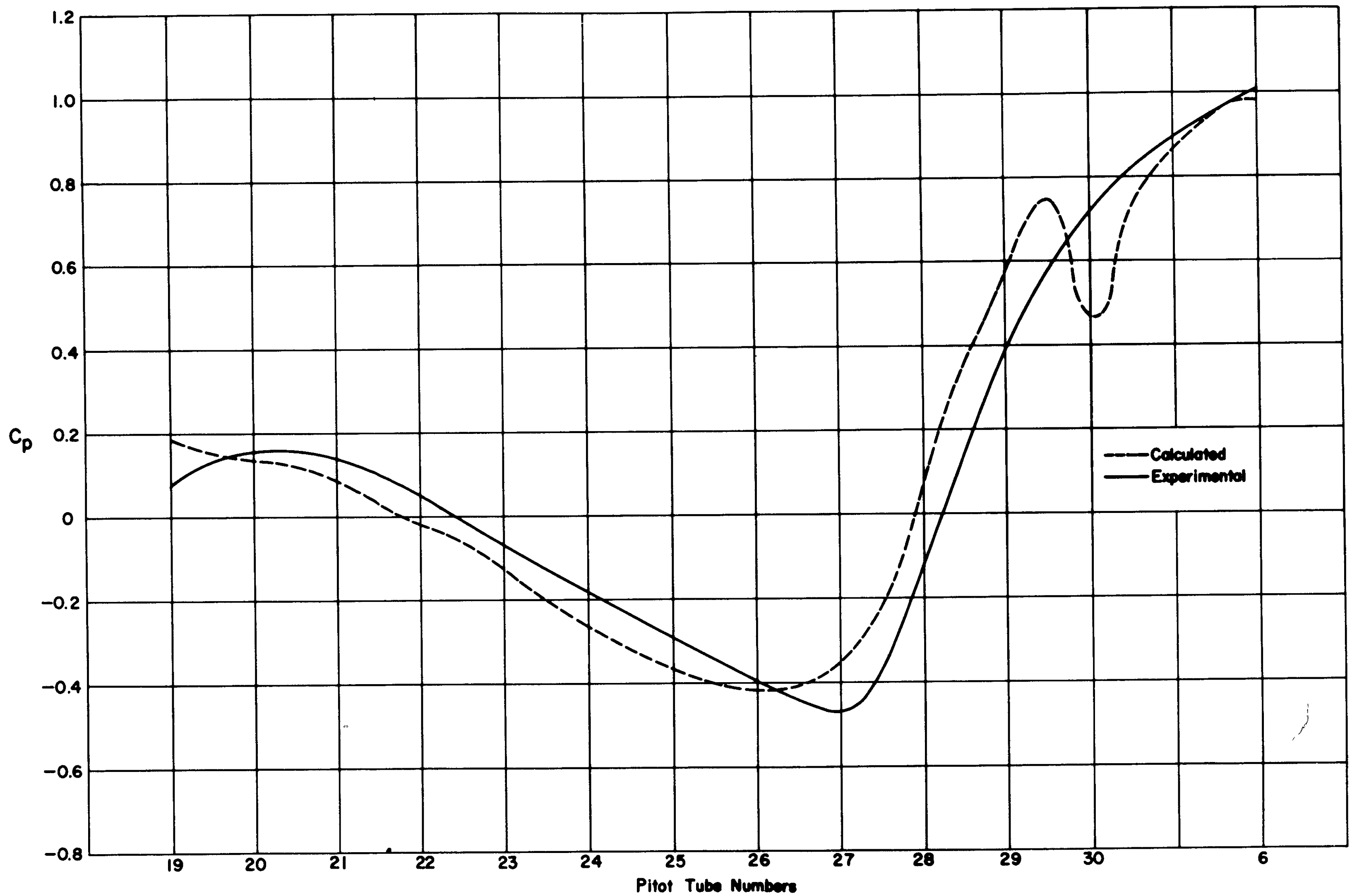

Figure 2 - Plot of C_p along the Waterline at the Maximum Horizontal Section (Destroyer Dome)

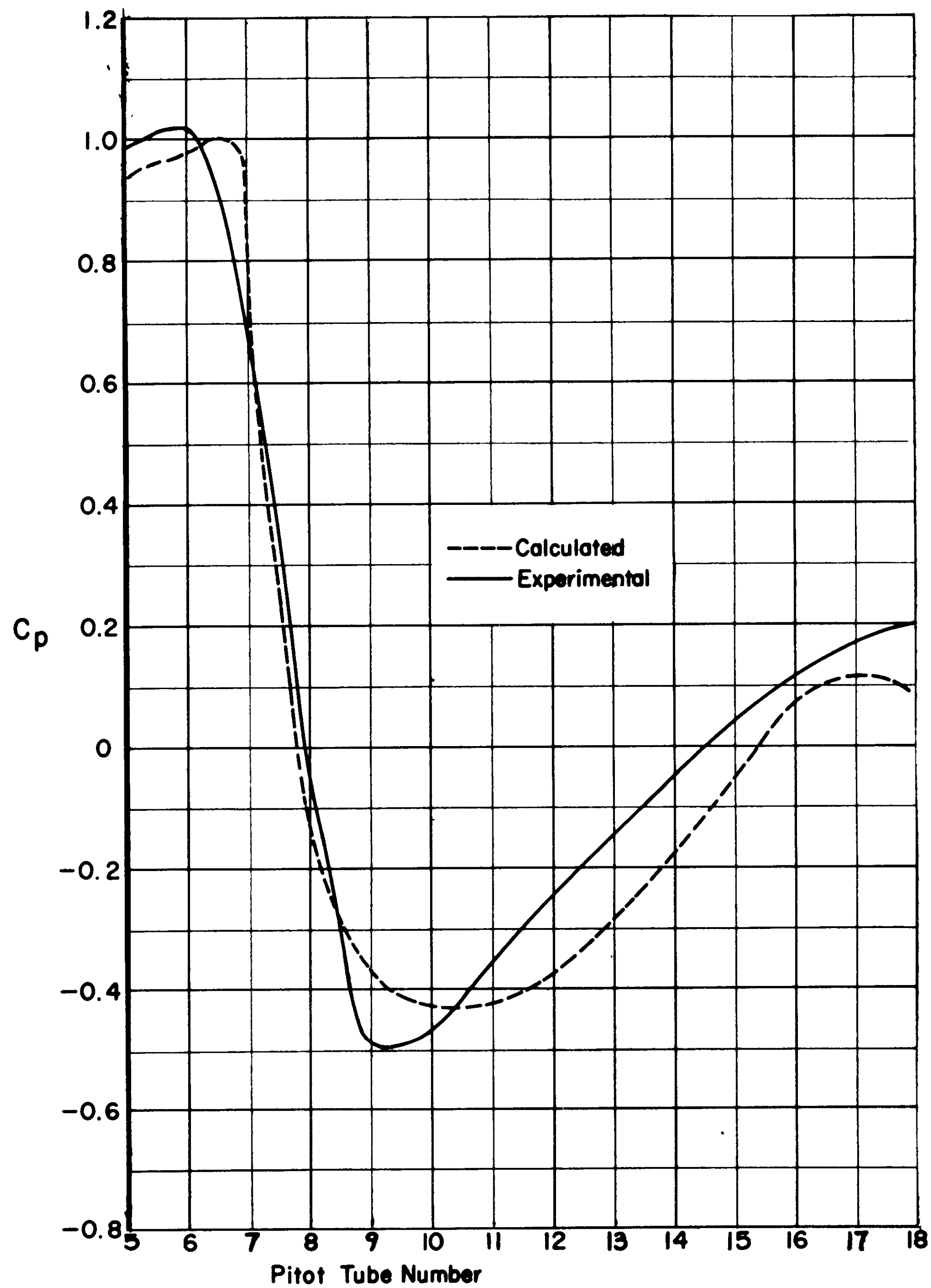

Figure 3 - Plot of C_p along the Profile Line of the Destroyer Dome

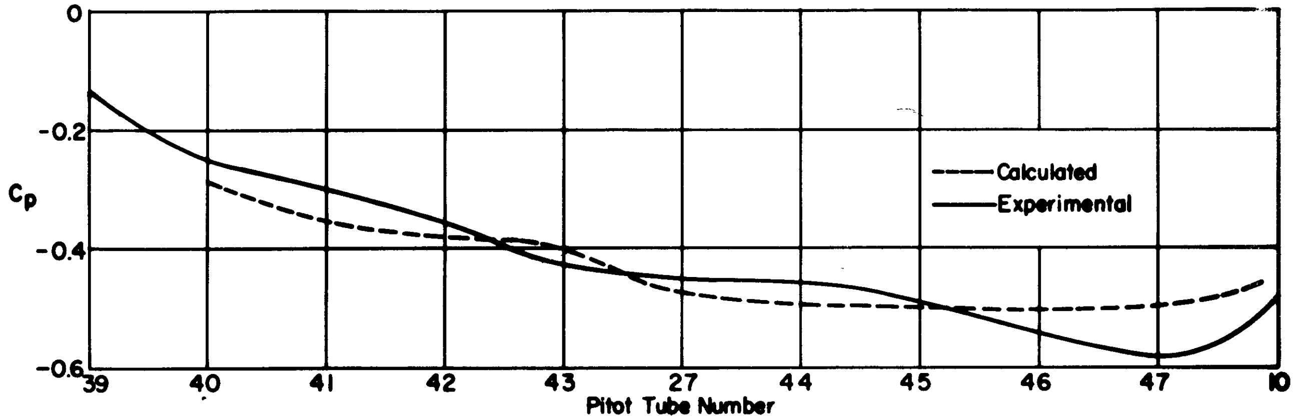

Figure 4a- C_p at the Transverse Plane Forward of the Maximum Thickness Section (Destroyer Dome)

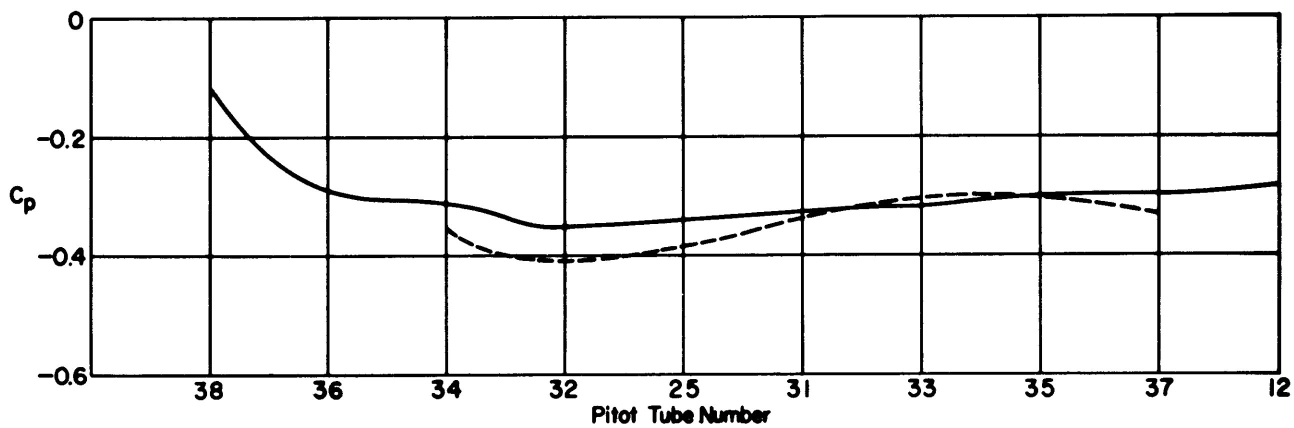

Figure 4b- C_p at the Maximum Thickness Section

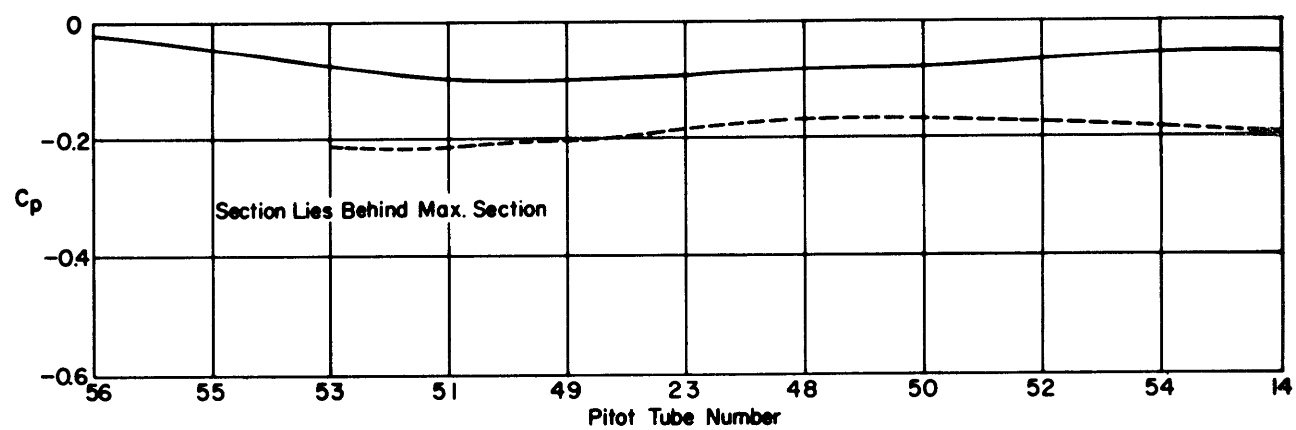

Figure 4c- C_p at the Transverse Plane Aft of the Maximum Thickness Section

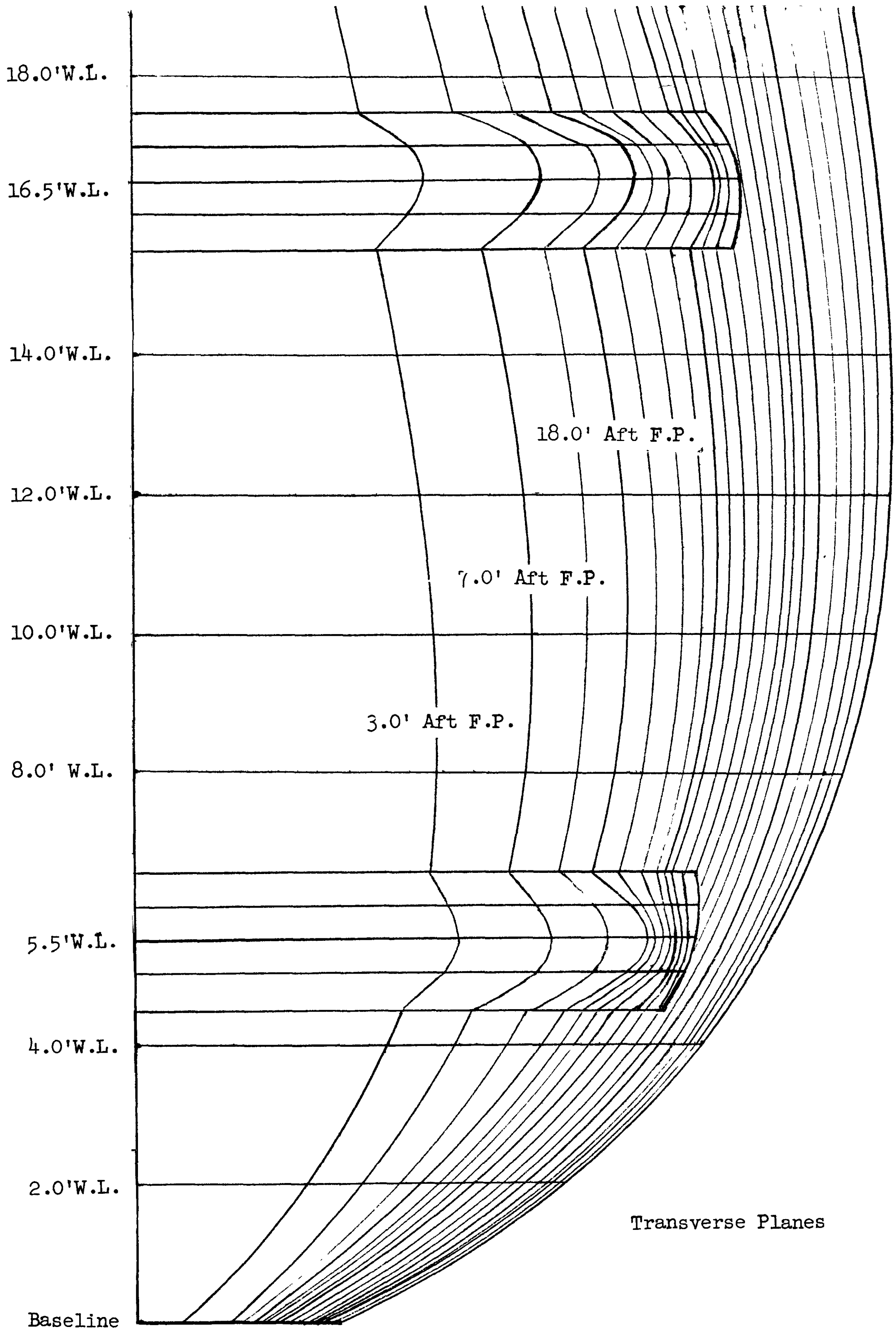

Figure 5 - Sketch of Bolster Arrangement on the Aircraft Carrier Dome

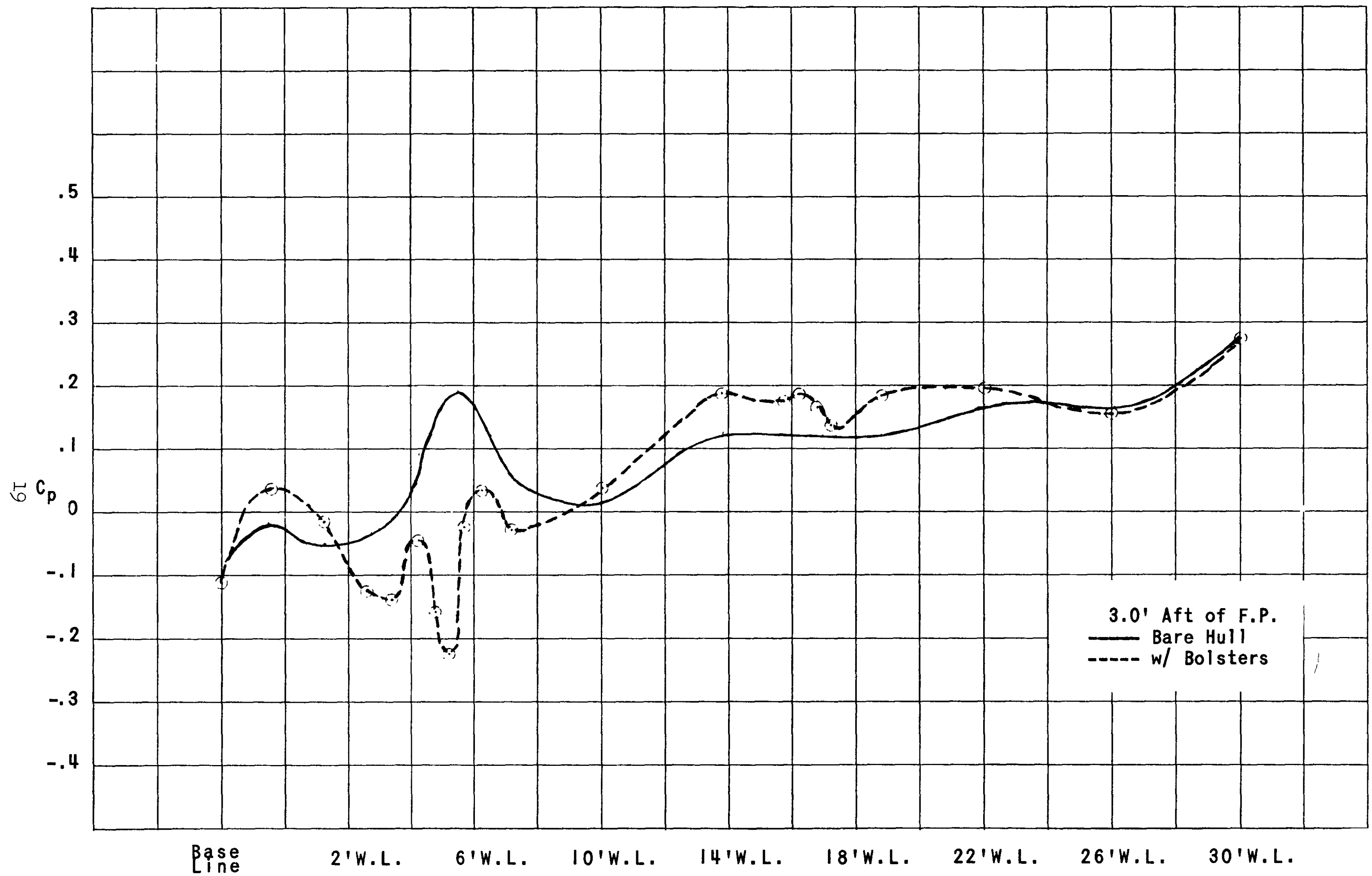

Figure 6 - C_p, Transverse Plane 3.0 Feet Aft of F.P.

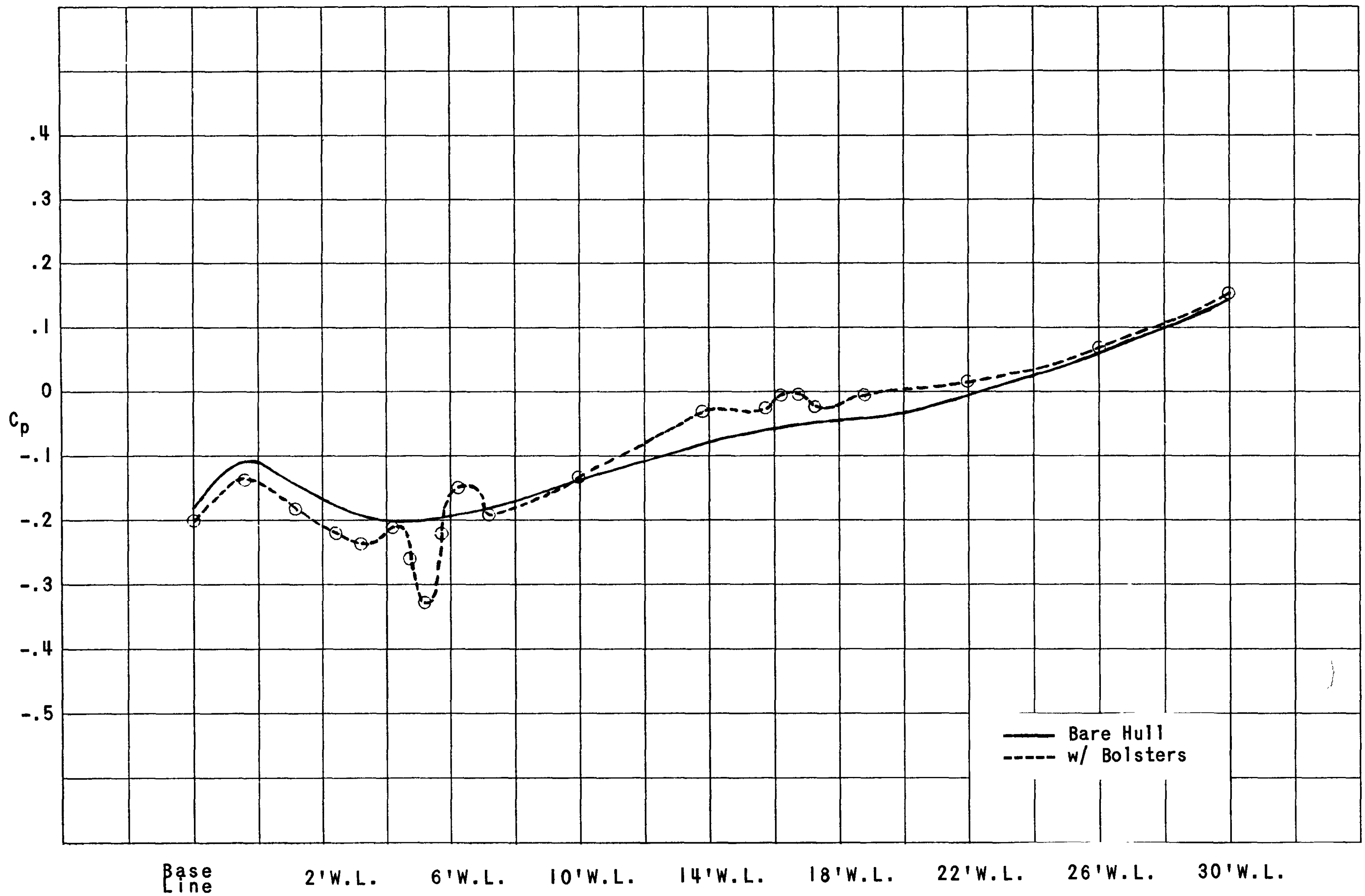

Figure 7 - C_p, Transverse Plane 5.0 Feet Aft of F.P.

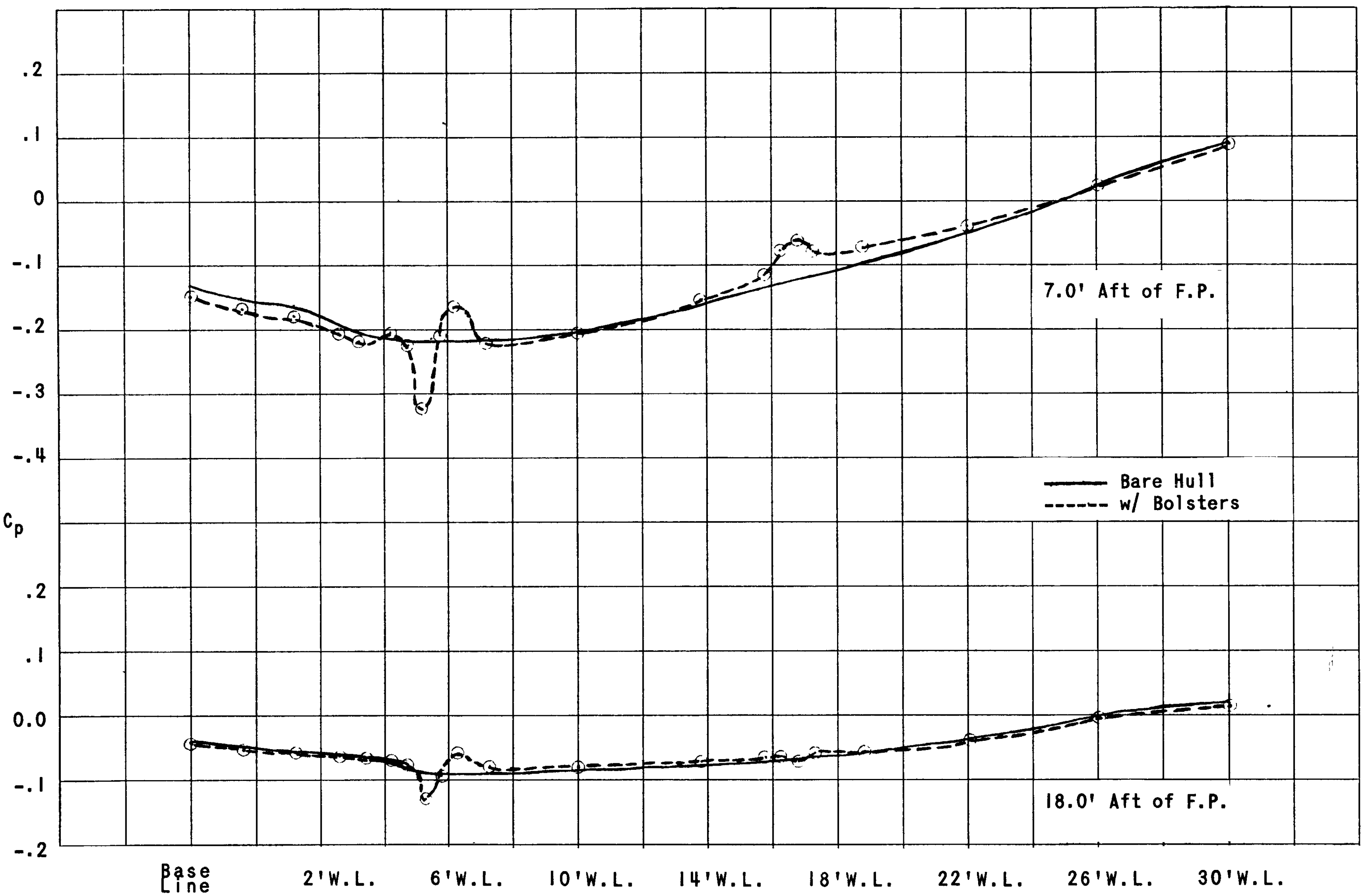

Figure 8 - C_p, Transverse Planes 7.0 and 18.0 Feet Aft of F. P.

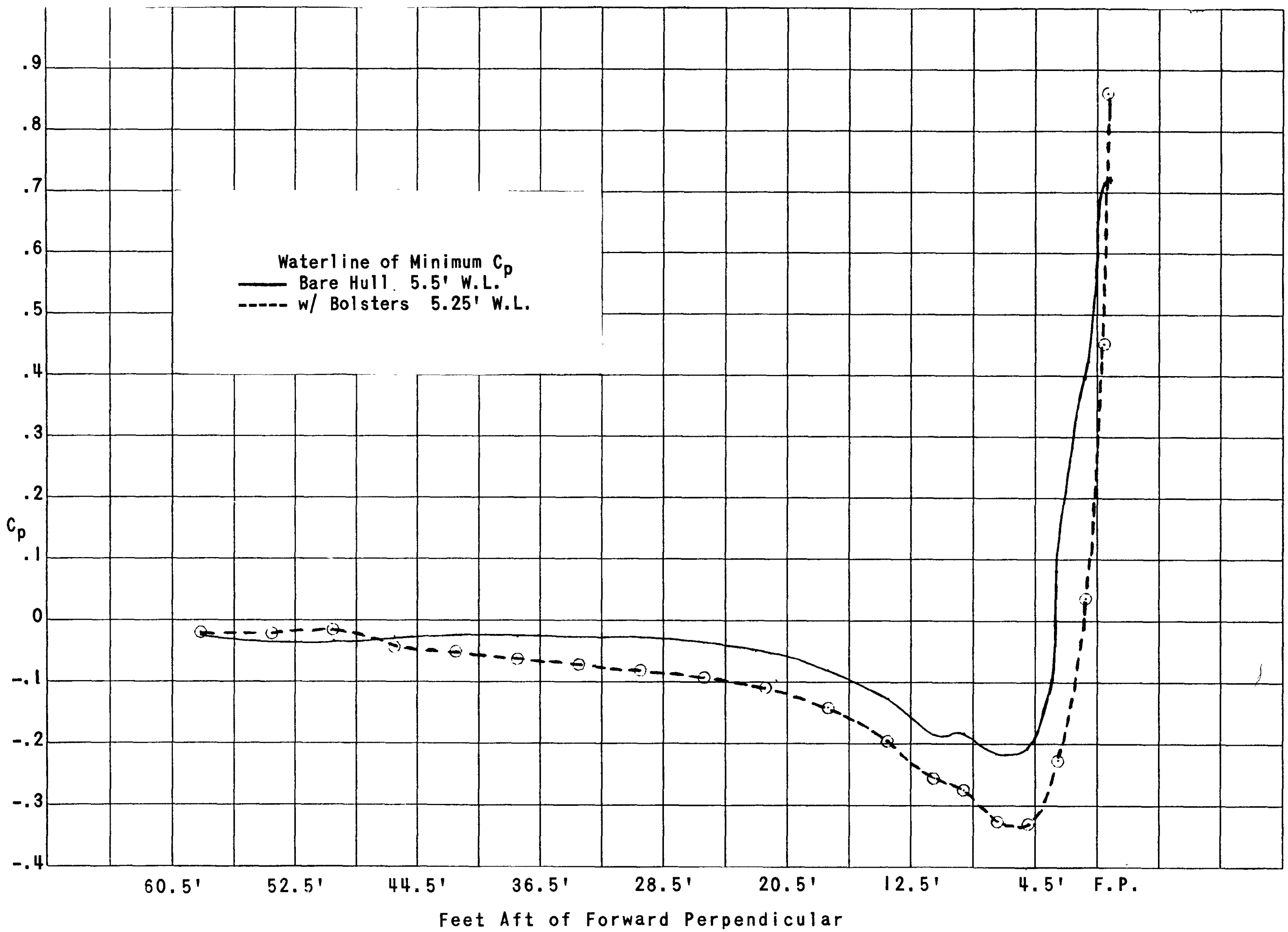

Figure 9 - Waterline of Minimum C_p

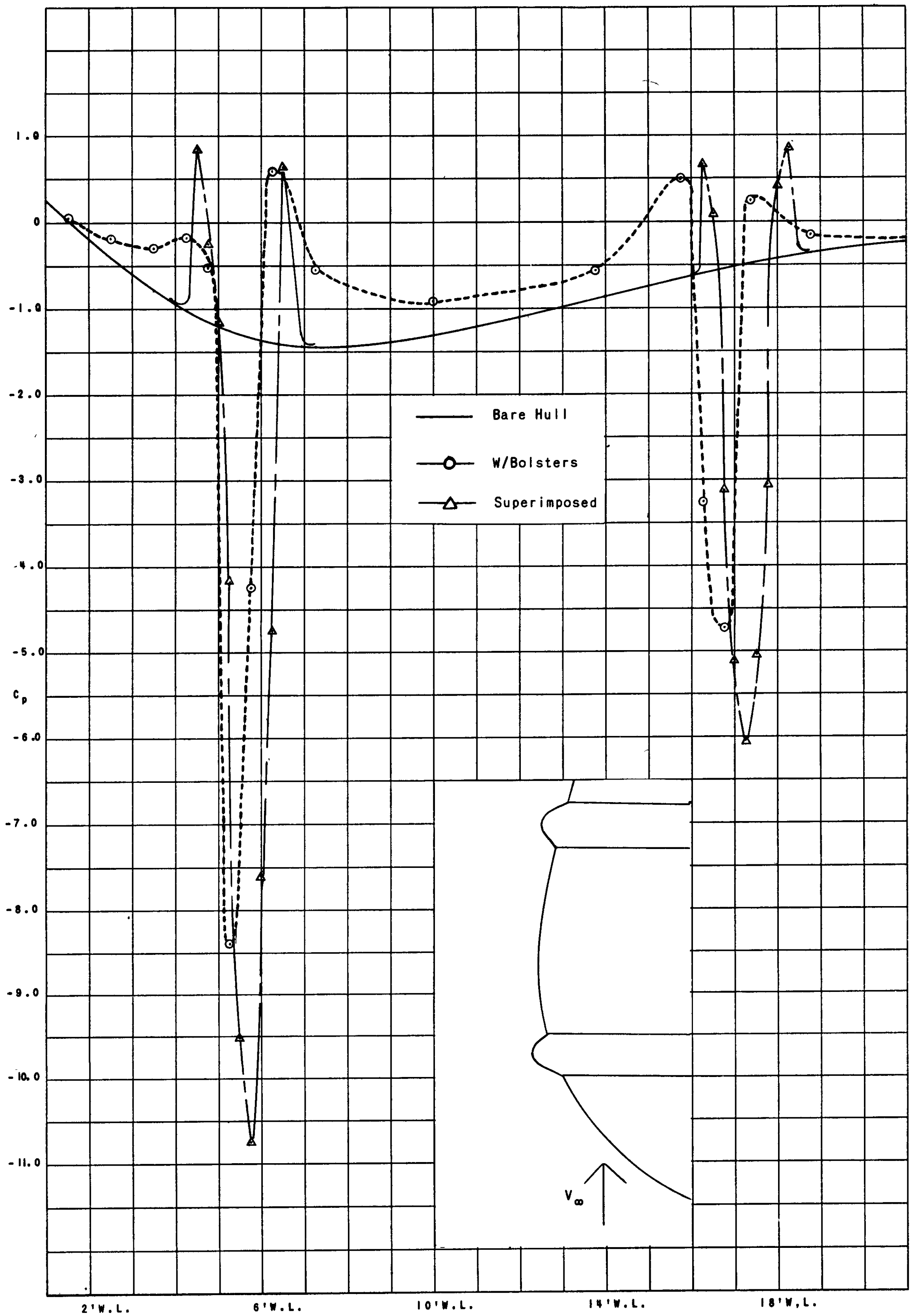

Figure 10- Plot of C_p for Pure Transverse Flow Across the Bolsters

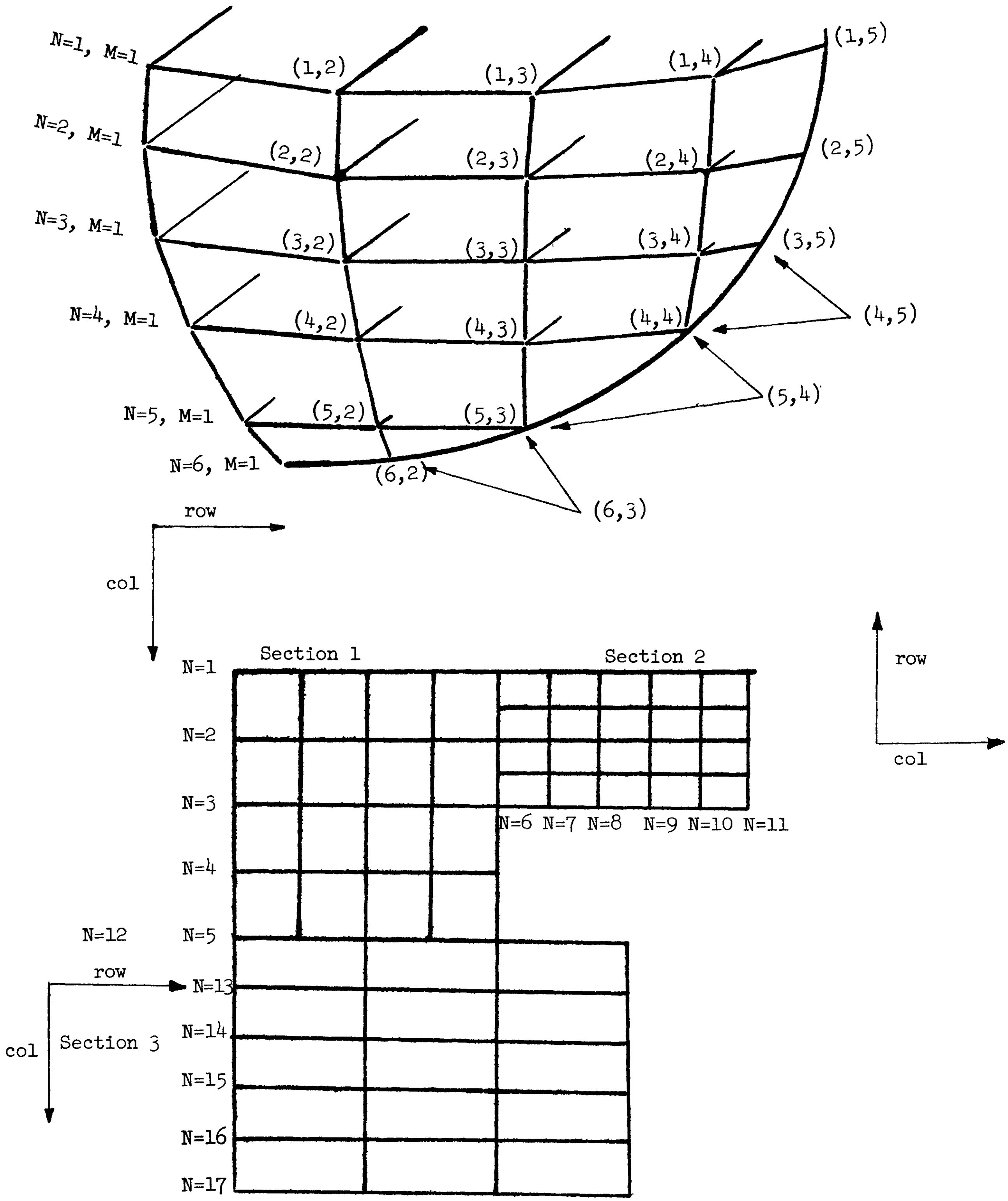

Figure 11- Samples of Some Valid Input Grid Configurations

COORDINATES OF INPUT POINTS
V150 SERIES - THREE DIMENSIONAL POTENTIAL FLOW

±	X	±	Y	±	Z	N	M	L(X)	L(N)	L(M)	
1	2–12	13	14–24	25	26–36	37–40	41–44	45–48	49–52	53–56	57–72
-	129.0	-	9.0		0.0			80			
-	135.74	-	8.05		0.0			81			
-	142.48		0.0		0.0			82			
	0.0		0.0	-	10.57	9	8	83	2	9	
	0.0	-	7.6	-	9.513			84			
	0.0	-	9.87	-	8.456			85			
	0.0	-	11.39	-	7.399			86			
	0.0	-	12.425	-	6.342			87			
	0.0	-	13.625	-	4.228			88			
	0.0	-	14.05	-	2.114			89			

Figure 12- Sample of Input Form

PROGRAM V150 DOUGLAS AIRCRAFT COMPANY
EL SEGUNDO DIVISION

CASE NO.		SONAR DOME PRES DISTRIBUTION						00000000
N	M	X	X	X	X	NX	NPX	D
		Y	Y	Y	Y	NY	NPY	T
		Z	Z	Z	Z	NZ	NPZ	A
1	1	.000000	1.075000	1.075000	.000000	-.967298	.537080	.2494 -01
		.000000	-4.315000	-3.920000	.000000	-.252543	-2.057475	.4924 01
		.000000	.000000	-2.114000	-2.114000	-.023594	-1.053438	.8999 01
	2	1.075000	7.813000	7.813000	1.075000	.131078	4.436200	-.1514 -01
		-4.315000	-3.380000	-3.047000	-3.920000	-.976995	-3.666547	.7175 01
		.000000	.000000	-2.114000	-2.114000	-.168224	-1.056995	.1458 02

Figure 13a- Sample of First Output

CASE NO.		NEUMANN PROB 3-D			000000000000	A FLOW	PAGE 2
N	M	NPX	VT	VX	DCX	NX	VN
		NPY	VTSQ	VY	DCY	NY	SIG
		NPZ	CP	VZ	DCZ	NZ	
2	7	10.099608	1.02913167	-1.02817035	-.99906589	.04312290	.00000004
		-13.869335	1.05911201	-.04370775	-.04247051	-.99176780	.00567654
		-1.056994	-.05911201	-.00820936	-.00797697	-.12056970	
3	1	16.829495	1.01868562	-1.01864463	-.99995975	.00343818	.00000017
		-3.553479	1.03772043	.00783624	.00769250	-.14709753	-.00126062
		-10.041596	-.03772043	-.00470637	-.00462004	-.98911603	

Figure 13b- Sample of Second Output

INITIAL DISTRIBUTION

Copies		
9	CHBUSHIPS	
	3	Tech Lib (Code 210-L)
	1	Appl Res (Code 340)
	1	Prelim Des (Code 420)
	3	Hull Des (Code 440)
	1	Lab Mgt (Code 320)
1	CHBUWEPS	
	1	Library (DLI-3)
3	CHONR	
	2	Fluid Dyn Br (Code 438)
	1	Library (Code 740)
1	CDR, USNOTS, Pasadena Annex	
1	SUPT, USNAVPGSCOL	
1	DIR, ORL	
1	ADMIN, Maritime Admin	
20	DDC	
1	SNAME	
1	HD, Dept NAME, MIT	
1	Hydro Lab, CIT	
1	DIR, Iowa Inst of Hydraulic Res	
1	DIR, St. Anthony Falls Hydraulic Lab	
1	DIR, Davidson Lab, SIT	
1	HD, Dept NAME, Univ of Mich	
1	ADMIN, Inst of Nav Arch, Webb	
1	DIR, Inst of Eng Res, Univ of Calif	
1	Electric Boat Div, Groton	
1	NNS & DDC	

1 Douglas Aircraft Co

1 Bath Iron Works

1 Gibbs and Cox

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2. Ship hulls--Hydrodynamic characteristics--Mathematical analysis
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