OPTIMIZATION OF CATAMARAN DEMIHULL
FROM WAVE RESISTANCE STAND POINT

by

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ABSTRACT

A computer program developed by Drs. Pien and Strom-
Tejsen, intended to optimize the source distribution on a
submerged surface so that they will generate a ship-like
body, with a minimal wave resistance, have been attempted
by Naval Engineer Joe Fuller Grable to be adapted to the
catamarans. His program has been developed up to the point
where the coefficients of the optimal source distribution
based on a set of constraints regarding the shape of the
water plane and on a design Froude number, have been cal-
culated. The author improved that program and adapted it
to a new program designed to compute the shape of the cata-
maran generated by optimal source distribution and there-
fore to give a practical interpretation to what have been
so far only an abstract source distribution. Using such a
program like a subroutine, the author has developed a com-
puter program intended to find a catamaran satisfying a
set of design requirements (displacement, hull spacing and
speed) with a minimum wave resistance. In order to accom-
plish this goal a systematic variation of the design Froude
number has been provided and for each design Froude number,
does exist a systematic variation of the constraints re-
garding the water plane. It is interesting to note that
the optimal source distribution generated by a given set of
constraints regarding the water plane, is not necessarily
an optimal source distribution in respect with distributions
generated by any other set of constraints. Therefore for
each Froude number must exist an optimal set of constraints
with property that the ship generated under these constraints satisfies the design requirements and has a minimum wave resistance. The computer program developed by the author will find the optimal set of constraints for each Froude number and will print out the shape, the length and the wave resistance coefficient of the ship generated by the optimal constraints. The wave resistance coefficients of that ship at other speeds than the design speed are also computed and printed out for both the design hull spacing and for infinite hull spacing so that the user can compute the interference factor for each speed. Finally from these ships, each one the best for one Froude number, the ship with smallest wave resistance coefficient will be considered the optimal ship and the length of that ship is considered the optimal length. Of course, this is an ambiguous way of defining the optimal ship, but that is why the user has available the length of the optimal ship and the wave resistance coefficient at both design and infinite spacing so that one can compute the absolute value of wave resistance and the interference factor and then can define the optimal ship according with his own criteria and preferences.

The program has been provided with an alternative which once the optimal ship has been defined, will develop a systematic variation of the hull spacing until the optimal hull spacing for the optimal length (Froude number) has been found and printed out. The alternative of finding the optimal length and that of finding the optimal hull spacing work independently and used carefully by a naval architect will help in finding a virtually optimal solution in spite of the fact that optimization of the length is based on a given hull spacing and optimization of the hull spacing is based on a given ship length. Theoretically a simultaneous optimization is possible, but it has been considered by the author that such a program will require an extremely worthless, long computation time.

A sample of output and some diagrams are presented to give a representation of how the wave resistance coefficient and the interference factor are changed for different Froude numbers or different hull spacing.
Acknowledgements

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INTRODUCTION

At the first glance, catamarans are an impressive kind of ship, and their appearance usually will produce a legitimate question: "Why have they been built like that?" Usually, a monohull ship is better than a catamaran, due to the fact that it has a smaller wetted surface and therefore a smaller frictional resistance, and it is also simpler from structural point of view. For this reason, the catamarans have been ignored for a long time until some new tasks have been created by the life of our technological society and which seem to create difficulties for a monohull ship in its competition with the catamarans. Such cases are the need for transportation of goods having a large volume and a small weight, i.e., a bulk with a small specific weight, which will end up with a ship having a too small transverse stability. Another case is the result of the fact that naval architects will prefer to design a ship almost totally submerged with the exception of a very small tower used for navigation and for air supply for engines, because such a ship will have a smaller wave resistance; yet, due to the fact that it will have a very small water plane area, the stability will be too small and the combination of two such ships resulting in a catamaran, if the trouble
with having more wetted surface would be eliminated, will be again of interest. Therefore, the advantage of a catamaran over a monohull ship is not a natural characteristic and that is why it has to be created and defeated. By this, it is understood that one should not expect to find a catamaran shape with a smaller resistance than a monohull ship, but, we have to minimize the resistance of a catamaran at least up to the point where the disadvantage of having a greater resistance is small enough so that it could be balanced by the advantage of having a greater stability.

In order to accomplish this task, one has to break down the total resistance of a catamaran and to see where is the point at which something could be done to create the advantage of the catamaran. For instance, the frictional resistance, according with F. H. Todd (4) accounts for eighty to eighty-five percent of the total resistance for slow-speed ships and decreases up to fifty percent of the total resistance of high-speed ships, and yet the catamaran offers the opportunity to reduce only the wave resistance of a ship which is quite less than fifty percent of the total resistance of a ship. One method of reducing the wave resistance of a catamaran is to design a very long and therefore slender demihull.
Regarding to this method, the linearized wave theory could possibly lead one to believe that if combined beams and displacements of two slender demihulls were equal to the beam and displacement of a conventional hull of the same length, the wave making resistance will be fifty percent that of a single hull.

Several authorities, notably J. T. Everest in his discussion of (6), and R. Rasaki, T. Takahei, and J. L. Moss in (7) show that this is not correct, with the exception of very fine hull forms at high Froude numbers and cannot be applied to the fuller forms of conventional hulls. Everest, using the results of a model test has shown that, in fact, the fifty percent reduction in wave making resistance could be as little as twenty percent.

The remaining area of exploration for a substantial decrease of wave making resistance, quite narrow by now, is that of wave train interference associated with a fat, short ship and therefore with a small wetted surface so that the percentage of total resistance (the wave resistance), subjected to the wave train interference to be quite substantial.

The theoretical work of K. Yokoo and R. Tasaki (2) in 1951 and K. Eggers (3) in 1955 have emphasized the way in this respect, demonstrating the favorable effect which
the interference factor of one demihull's wave train will have on the other. In their discussion of reference (1) Tejsen and P. C. Pien indicate that the wave making resistance can be reduced by forty percent at certain Froude numbers in the range of 0.25 to 0.40 where the wave making resistance is a significant part of the total resistance. So far, one can easily realize that the wave resistance of a catamaran depends on speed-length ratio as well as on the spacing between the demihull, but there is another important factor and that is the hull form. Initially the catamarans have been designed with demihulls symmetrical in respect with their center plane, but model tests have demonstrated many of the unfavorable aspects of asymmetrical flow associated with symmetrical hulls; among these are the increased flow velocities and the increased wetted areas between the two demihulls which give greater frictional resistance, the disruption of smooth flow along the turn of the bilge and subsequent cross-flow across the bottom, the higher water level between the hulls and resulting interference with the cross structure, and the increased possibility of boundary layer separation because of the greater adverse pressure gradient forms between the hulls. Yet, they theoretically predicted benefits of wave train cancellation between the interior and exterior waves
of the same amplitude. Therefore, a symmetrical flow is required, and to obtain it, each demihull must be cambered to give a symmetrical wave pattern.

Turner and Taplin (1) built and tested an asymmetrical design in an attempt to reduce the wave building between the two demihulls. The demihulls they designed had the side facing inboard, perfectly flat and that, as they recognized, will induce some lifting force and therefore more drag. Initially, they hoped that by moving the demihulls into closer proximity, some lift and therefore some drag will be reduced, but the experimental data shows that, moving the demihulls closer would have a very little effect on drag diminishing, and that asymmetrical hulls would have unacceptable high resistance. Something has been overlooked here and that is the fact that the best shape of the inboard sides is not a flat one because the flow must adjust to the angle of entrance so that the streamlines entering the area between the two demihulls to be no longer straight, but curved outboard relative to each hull. At the same time each demihull must be cambered in such a way as to give a symmetrical wave pattern. The chamber depends on spacing, design speed, and hull dimensions. In order to satisfy these requirements, the following method has been used in this thesis:
Find an optimal distribution of water sources along of center plane of each demihull which, if would be taken alone in an infinite flow will generate a symmetrical demihull, then solve the differential equations for streamlines of such a demihull taking into account the presence of the other demihull. In this case, we will obtain asymmetrical demihulls with a profile following exactly the flow of the fluid under the presence of two liquid bodies and which in their turn have adjusted their shape according to the given physical situation (the presence of uniform flow and of the other demihull).

By this it is understood that the contraction in the cross sectional area between the two demihulls initially resulting in an asymmetrical change in water velocity and pressure associated with a venture effect is allowed to influence the shape of the liquid body accordingly and therefore when a real solid body with such a shape will be built, the rise in water level between the demihulls and water flow under the turn of the bilges and across the bottom of the two demihulls as they are suggested in (8) will be in our case substantially diminished. For this reason we should not be surprised if bringing the demihulls too close together the computer program will give some streamlines starting from interior part of the
demihull, which will be deviated outward when they get to the middle of the ship.

It is yet understood that due to viscosity which is not taken into account here, these effects will not be totally destroyed so that we will have some increase in water level between the hulls which would have an effect on the frictional resistance, and some other effects as the increased fluid velocity between hulls which as K. Egger suggested in (3) will also lead to an increase in frictional resistance. In fact we wouldn't expect even a symmetrical flow but it would be much closer to a symmetrical one than in case of two interfering symmetrical demihulls. Finally will be the effect of wave reflection between hulls, and losses due to wave breaking at the centerline of the catamaran where the interior wave training from the demihulls will meet. The weight of these effects, overlooked in this program can be evaluated only after some experimental results will be compared with theoretical results given by computer.
The Basic Approach of Using Source Distribution to Generate Ship Hulls

The idea of computing the wave resistance of a ship by computing the wave resistance of source sink distribution which will generate a body with the same shape like the actual ship is quite old, but it is very difficult to find mathematical expressions for such a distribution which has to fit a given hull shape. In recent years, Professor Inui has suggested that it is easier to start with a given source-sink distribution and to find out what the hull looks like. In his approach the source distribution is given all over a flat plate surface, which if it is submerged in an uniform flow having the speed of the ship, will generate a ship body, having the surface with these sources and sinks, placed in the center plane of the ship.

Such a source distribution can be represented as:

\[ M(\xi, \zeta) = f_1(\xi)f_2(\xi) \] with \( -1 \leq \xi \leq 1 \) and \( -t \leq \zeta \leq 0 \),

where \( \xi \) and \( \zeta \) are the nondimensional coordinates on the flat plate in the forward and upward direction, respectively.

In 1963, Dr. Pao C. Pien and Wilburn L. Moore (11) have emphasized the advantages and the disadvantages of this approach. They have emphasized that the hull form
represented by such a distribution cannot be a practical one for a regular ship because $B/H$ ratio will be always less than 2. Other limitations are that the keel line sags and both of end profiles are vertical lines. The biggest limitation yet came from the fact that having just one flat surface with sources distributed on, there is no interference effect on waves generated by these sources and therefore there is no way of optimization.

The main difference between Inui's and Dr. Pien's approach (11), developed later by Dr. Pien and Dr. Strom-Tejsen (10) is consisting in the fact that now the sources are no longer distributed on a flat surface along of the center plane, but on a closed surface symmetrical in respect with center plan of the ship as it is shown in Figure 1.

![Figure 1](image-url)
Such a surface can be represented by

$$\eta = \pm f(\xi, \zeta)$$

where \(\xi\) and \(\zeta\) are the coordinates of a rectangular coordinate system with the original at the midship on the undisturbed free surface. All dimensions used here are normalized in respect with half length of the ship. The \(\xi\)-axis is positive in the forward direction and the \(\eta\)- and \(\zeta\)-axes are positive to port and upward respectively. They suggested

$$f(\xi, \zeta) = B_\eta [1 - (1-a-b)\xi^{2n} - a\xi^{2n} - b\xi^n]$$

which represents in fact a vertical strut-like surface with beam \(B_\eta\) and its water plane controlled by parameters \(a, b, n\).

The singularity distribution on the \(\eta\)-surface has been given in term of strength per unit velocity of a moving ship and it has been expressed as:

$$M(\xi, \zeta) = M_1(\xi, \zeta) + M_2(\xi, \zeta)$$

with

$$M_1(\xi, \zeta) = \sum_{i=1}^{4} \sum_{j=1}^{5} a_{ij} \frac{\xi}{|\xi|} \xi^j \zeta^{i-1} = \sum_{i=1}^{4} E_i$$
\[ M_2(\xi, \zeta) = \sum_{i=5}^{8} \sum_{j=1}^{5} b_{ij} \xi^j \zeta^{i-1} = \sum_{i=5}^{8} E_i \]

where \( M_1(\xi, \zeta) \) represents the source-sink distribution, and \( M_2(\xi, \zeta) \), the doublet distribution and

\[ E_i = (a_{i1} \xi + a_{i2} \xi^2 + a_{i3} \xi^3 + a_{i4} \xi^4 + a_{i5} \xi^5) \zeta^{i-1}. \]

Sometimes to generate a bulbous hull we can use a line source and line doublet distribution:

\[ E_9 = \sum_{j=0}^{3} s_j \xi^j \]

\[ E_{10} = \sum_{j=0}^{3} d_j \zeta^i \]

Once a decision has been made upon the singularity distribution, we can compute at least theoretically the speed components \( u, v, w \), at any given point \((x, y, z)\) in space and by solving the differential equation of the streamlines:

\[
\frac{dy}{dx} = \frac{v}{v+u}, \quad \frac{dz}{dx} = \frac{w}{w+u}
\]

(4)

where \( U \) is the speed of the ship, we can find the shape of the hull.
In order to compute the wave resistance of that ship, it is assumed that every element of \( \eta \)-surface is in fact an elementary source moving beneath the free surface and therefore generating a three dimensional surface wave system which according with Havelock (15) will produce a surface elevation:

\[
\zeta_s(x,y) = \zeta_w(x,y) + \zeta(x,y)
\]

with

\[
\zeta_w(x,y) = \frac{MK_o}{\pi U} \int_0^\alpha \sec^3 \theta e^{-K_o \zeta \sec^2 \theta} \cos R \cos \theta \, d\theta. \tag{5}
\]

where

\[
R = K_o \sec^2 \theta[(x-\xi) \cos \theta + (y-\eta) \sin \theta]
\]

\[
\alpha = \arctan \left( \frac{-X}{Y} \right)
\]

\[
K_o = \frac{g}{U^2} = \frac{1}{2F^2_n}
\]

M = source strength

U = speed of advance

\( \theta \) = angle between wave direction and x-axis.

The term \( \zeta_w(x,y) \) represents a free-wave system that causes the wave resistance and \( \zeta_l(x,y) \) is a local disturbance, existing only in the vicinity of a point source and having no contribution to the wave resistance.
If one defines \( R_0 = x \cos \theta + y \sin \theta \)
\[ P = \xi \cos \theta + \eta \sin \theta \]
then \( R = K_0 \sec^2 \theta (R_0 - P) \) and therefore
\[
\cos R = \cos(K_0 P \sec^2 \theta) \cos(K_0 R_0 \sec^2 \theta) \\
+ \sin(K_0 P \sec^2 \theta) \sin(K_0 R_0 \sec^2 \theta) \tag{6}
\]
If (6) is used in (5) we have:
\[
\zeta_M(x, y) = \int_{-\frac{\pi}{2}}^{\alpha} a_c(\theta) \cos(K_0 R_0 \sec^2 \theta)d\theta \\
+ \int_{\frac{\pi}{2}}^{\alpha} a_s(\theta) \sin(K_0 R_0 \sec^2 \theta)d\theta \tag{7}
\]
where
\[
a_c(\theta) = \frac{MK_0}{\pi U} \sec^3 \theta e^{K_0 \zeta \sec^2 \theta} \cos(K_0 P \sec^2 \theta) \tag{8}
\]
\[
a_s(\theta) = \frac{MK_0}{\pi U} \sec^3 \theta e^{K_0 \zeta \sec^2 \theta} \sin(K_0 P \sec^2 \theta) \tag{9}
\]
For a point doublet the amplitude functions
\[
a_c(\theta) = -\frac{MK^2}{\pi U} \sec^4 \theta e^{K_0 \zeta \sec^2 \theta} \sin(K_0 P \sec^2 \theta) \tag{10}
\]
\[ a_s(\theta) = \frac{MK^2}{\pi U} \sec \theta \ e^{K_0 \zeta \sec^2 \theta} \cos(K_0 \rho \sec^2 \theta) \] (11)

The wave resistance of a point source will be:

\[ r = \pi p U^2 \int_0^{\pi/2} \{ [a_c(\theta)]^2 + [a_s(\theta)]^2 \} \cos^3 \theta d\theta \] (12)

and for the whole surface singularity distribution, the wave resistance will be:

\[ R_w = \pi p U^2 \frac{\pi}{2} \{ [A_c(\theta)]^2 + [A_s(\theta)]^2 \} \cos^3 \theta d\theta \] (13)

where because \( \eta = \pm f(\xi, \zeta) \)

\[ A_c(\theta) = \frac{1}{2} \sum_{i=1}^{4} \sum_{j=1}^{4} a_{ij} \frac{K_0}{\pi} \sec^2 \theta \int \int \frac{\xi_j \zeta^{i-1}}{\eta_s} \] (14)

\[ x \ e^{K_0 \zeta \sec^2 \theta} \cos(\xi_a + b \eta) + \cos(\xi_a - b \eta) \] \( d\xi d\zeta \)

or

\[ A_c(\theta) = \sum_{i=1}^{4} \sum_{j=1}^{5} a_{ij} \frac{K_0}{\pi} \sec^2 \theta \int \int \frac{\xi_j \zeta^{i-1}}{\eta_s} \] (15)

\[ x \ e^{K_0 \zeta \sec^2 \theta} \cos b \eta \cos \xi_a \] \( d\xi d\zeta \)
and similarly

$$A_s(\theta) = \sum_{i=1}^{4} \sum_{j=1}^{5} a_{i,j} \frac{K_o}{\pi} \sec^2 \theta \int_{\eta_s} \int_{\zeta_s} \xi_j \zeta^{i-1}$$  

$$\times e^{K_o \sec^2 \theta} \cos b \eta \sin a \xi \, d\eta \, d\xi$$  

(16)

where \( a = K_o \sec \theta \)

\( b = K_o \tan \theta \sec \theta \)

In fact (13) is giving only the wave resistance caused by surface source-sink distribution i.e., the contribution of \( E_1 + E_2 + E_3 + E_4 \), but in this program the possibility of a linear source and doublet distribution has been provided in order to improve the shape of the ship. They are distributed according with:

$$E_9 = \sum_{j=0}^{3} s_j \zeta^j$$  for sources and

$$E_{10} = \sum_{j=0}^{3} a_j \zeta^j$$  for doublets located at \( \zeta = \pm 1 \),

at the center plane of the demihull.

Their contribution to the wave resistance can be computed by an expression similar to (13) and in fact it is computed in this computer program, and the difference
is that $A_c(\theta)$ and $A_s(\theta)$ are obtained from a linear integration along of a vertical line from zero to a draft specified by user at $\xi = \pm 1$ and the integrand $a_c(\theta)$ and $a_s(\theta)$ will be given by (8) and (9) for the linear source distribution and by (10) and (11) for a linear doublet distribution.

No provision has been made in this program for a surface doublet distribution i.e., for $E_5, E_6, E_7, E_8$.

Because we don't mind if a round-bottom demihull inconvenient only for a monohull ship, will be obtained, no doublet and sink distribution have been provided on the bottom of the ship.
Derivation of Catamaran From Monohull Ship
Generated by Singularities Distribution

The reason for a minute description of the general approach of using singularities in order to generate monohull ships is that once that being understood it can be very easily adapted for catamarans. In fact in order to generate a catamaran one has only to tear apart those two symmetrical halves of \( \eta \)-surface shown in Figure 1 and to carry them outward up to the distance called demihull spacing, \( d \), which is in fact the distance from the longitudinal axis of symmetry of a catamaran to the center plane of a domihull (see Figure 2). The demihull spacing \( d \), shown in Figure 2 is only one example but usually we have to indicate the distance at each extreme of only one demihull.

![Diagram](image-url)

FIGURE 2.
Now the singularities placed on each face of $\eta$-surface will generate a demihull. Of course, the fact that $\eta$-surfaces have their concavity oriented toward the axis of symmetry of the catamaran, it doesn't imply that the catamaran demihull must be concave too. Usually their interior line will be less convex than the exterior line of waterline but that is O.K. if one takes into consideration that we don't want symmetrical demihulls for reasons mentioned in the introduction.

Due to the fact that in linear wave theory we can apply the method of superposition, formula (13) given in the previous section can be applied for catamaran without any alternation except that if before $\eta$-surface was given by $+f(\xi, \zeta)$ and if each half of $\eta$-surface has been maintained parallel to its old position, then it becomes now $\eta = +f(\zeta, \xi)$ +d.

Apparently idea of placing the faces of $\eta$-surface so that each one to generate a demihull can normally arise the question if this doesn't return back to Professor Imui's idea of generating ships by a distribution of singularities along of a flat plate, a method with a lot of limitations as it has been mentioned in introduction. The answer is that such limitations no longer bother us when it comes to catamaran; for instance, we don't want $B/H \leq 2$ because the
stability of the catamaran is no longer a function of water plane of a demihull alone but it depends on hull spacing too. Also, \( B/H < 2 \) as well as the fact that keel line sags is not going to influence the space available for storage, because the storage space is mainly on the deck, between demihulls. On the contrary, with the exception of some limitations on draft, the deeper are the singularities, the smaller will be the surface effect. As a matter of fact in this program we went further, accepting even a \( \eta \)-surface like a flat plate and creating a special alternative of the computer program for this case, which has the big advantage that a lot of integrals otherwise solved only by special numerical methods, have been solved analytically and the computer time for that case is less by a factor of twenty.
The Optimization of Singularity Distribution

When we talk about optimization of singularity distribution, we have in mind to minimize the wave resistance

\[ R_w = \pi \rho U^2 \int_0^\pi \left[ (a_c)^2 + (a_s)^2 \right] \cos^3 \theta d\theta \]

in respect with parameters \( a_{ij} \) included in \( a_c \) and \( a_s \) given by (14) and (15), and this is a simple problem of maximum or minimum, i.e., compute \( \frac{\partial R}{\partial a_{ij}} \) and put the condition that \( \frac{\partial R}{\partial a_{ij}} = 0 \).

In this way we will get a set of linear equations in term of \( a_{ij} \) and we can solve it, but the trivial solution of this system of equation will be \( a_{ij} = 0 \) which is meaningless for our problem. In order to avoid this trouble we use same constraints as have been suggested in references (10), (11), (16) with exception that because the optimization is made in this program for the total singularity distribution and not only for forebody along the constraint \( \int_0^1 E_1 d\xi = B_1 \) is not used. This has been possible because the \( E_1 \) are in fact symmetrical functions in respect with origin \( \xi = 0 \) and therefore because the ship is a closed solid body \( \int_{-1}^{+1} E_1 d\xi \) must be always zero.
Yet, there are two other constraints used and they are:

\[ \int_0^1 E_1 \kappa g dg = V_i \]  \hspace{1cm} (17)

\[ E_i(1) = T_i \]  \hspace{1cm} (18)

where \( V_i \) and \( T_i \) are in fact the constraints for optimization of wave resistance and physically they will influence the shape of the hull or more specifically the shape of the waterline. The bigger is \( V_i \), for instance, probably the more concentration of sources we will have toward the bow if \( T_i \) has been set high enough to allow that, and therefore we will get a fuller ship. If \( V_i \) is big but \( T_i \) is small, the only way to get a big \( V_i \) will be to have a bigger source distribution toward the midship which will generate a ship with a fine entrance, but with a continuously enlarging body up to the midship. In other words, in this case the water plane coefficient will be very small, and no parallel body will be expected. If these parameters are not carefully selected, i.e., if they are not compatible we can get funny shapes like ships strangulated toward the midships, etc. As a guide rule, it has been observed from experimental results of the computer program that \( T_i \) should vary from \( V_i \) up to \( \frac{3}{2} V_i \), but of course, this is not rigorous because in optimiza-
tion procedure we have a range of variation for each constraint and each value of one constraint from its own range has to be associated with each value from the range of variation for the other constraint.

Specifically, the optimization of singularity distribution which is just one step in this more complex process of optimization of the demihulls can be described as follows.

Consider that \( \int E_1 \, d \xi \) has been solved so that (17) and (18) can be expressed as

\[
\begin{bmatrix}
\frac{1}{3} & \frac{1}{4} \\
1 & 1
\end{bmatrix}
\begin{bmatrix}
a_{11} \\
a_{12}
\end{bmatrix}
= 
\begin{bmatrix}
-\frac{1}{5} & -\frac{1}{6} & -\frac{1}{7} & 1 & 0 \\
-1 & -1 & -1 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
a_{13} \\
a_{14} \\
a_{15} \\
V_1 \\
T_1
\end{bmatrix}
\]  
(19)

or in a restraint form

\[
\mathbf{C}_L \mathbf{A}_L = \mathbf{C}_R \mathbf{A}_R
\]  
(19a)

which is closer to the symbols used in the program attached to this work.

Compute \( R_w \) using (13) and then replace \( a_{11}, a_{12} \) with an equivalent expression in terms of \( a_{13}, a_{14}, a_{15}, V_1, T_1 \) resulting from (19). Finally \( R_w \) will be a func-
tion of only $a_{13}$, $a_{14}$, $a_{15}$ and if one computes

$$\frac{\partial R}{\partial a_{ij}} \quad J = 3, 4, 5 \text{ and imposes } \frac{\partial R}{\partial a_{ij}} = 0 \quad (20)$$

will result a system of 3 equations with 3 unknowns which can be solved for $a_{13}$, $a_{14}$, $a_{15}$ and finally we can find $a_{11}$, $a_{12}$.

This will be the solution for coefficients $a_{ij}$ so that the wave resistance of the singularity distribution expressed in term of these coefficients to be minimum.

This procedure is repeated for each $E_i \ i = 1, 2, 3, 4$. As one can easily see from the methodology described above, we have found optimal set of parameters $a_{ij}$ for a given set of constraints but for a complete optimization we have to find out what is the set of constraints corresponding to the ship with the smallest wave resistance, i.e., to find an optimal set of constraints and this is the topic of the next section.
Finding the Optional Form of a Catamaran Demihull for a Given Set of Requirements

In an attempt to make this program as close as it is possible to the real life, i.e., to make it useful to a naval architect, even at the stage when he has only very little information about the required design of the catamaran, the program has been conceived in such a way that the only information required to set the requirements for optimization are the displacement, the speed of the catamaran and the range of variation for the constraints regarding the optimization of the singularities distribution, i.e., the range of variation for $V_1$ and $T_1$ used in (17) and (18). It is also required to mention a range of variation for Froude's number (indirectly the range of variation for the length of the catamaran), and the design hull spacing, when the length of the ship is to be optimized, or a range of variation for hull spacing and a design Froude number when the hull spacing is to be optimized. The first alternative is called "mode 1". The second one is called "mode 2".

The flow chart for this program at a microlevel is given in Figure 3, and some comments on each step specified there are given below:
1. Loop over $i = 1, 2, 3, 4$ using constraints $\sum_{i=1}^{4} a_{i,j} = Y_i, i = 1, 4$ to find the coefficients $a_{i,j}$ of the optimal singular distribution and compute the wave resistance $R_m$.

2. Find the stagnation point of this singular distribution and the length of the ship $L_1$ associated with their stagnation point.

3. Compute the volume.

4. Pick up next set of constraints $Y_i, i = 1, 4$.

5. If the range of variation for $Y_i, i = 1, 4$ is exhausted, yes. Store the source distribution and the ship with the smallest $R_m$.

6. Go to the next $Y_i, i = 1, 4$.

7. If the range of $F_n$ is exhausted, yes. Go to the next $F_n$.

8. Stop if $F_n$ is not exhausted, no.
Step 1. Loop over \( i = 1, 2, 3, 4 \), using constraints

\[
\int_0^1 E_i(\xi) \, d\xi = V_i \quad \text{and} \quad E_i(1) = T_i
\]

to find the coefficient \( a_{ij} \) of the optimal singularity distribution and compute the wave resistance \( R_w \). This step has been described in "The Optimization of Singularity Distribution" and has been developed by the author on the framework of an older program written by Naval Engineer Joe F. Grable who had it adapted from a program originally developed by Dr. Pien and Strom-Tejsen (11).

In addition to what has been said in the previous section, it is important to mention that \( \eta \)-surface given by (1) must be chosen in such a way as to make (15) and (16) integrable, i.e., must be a function of \( \eta \) only as it is given in (2).

Now \( A_c(\theta) \) for instance, can be written as:

\[
A_c(\theta) = \sum_j \sum_i a_{ij} \frac{K_0 \sec^2 \theta}{\pi} \int_{\xi}^{\xi_j} \cos[b \eta(\xi)]
\]

\[
x \cos a \xi \xi \int_{\xi}^{\xi_j} e^{-K_0 \sec^2 \theta} d\xi
\]

where

\[
\int_{\xi}^{\xi_j} \cos[b \eta(\xi)] \cos a \xi \xi
\]
denoted by $x_i$, $i = 1, 2, 3, 4$, is a function of $\xi$ only and can be solved numerically. The new alternative of this section in the program developed by author has one option which is automatically used for the particular case when $\eta$ is a flat plate and $x_{ic} = \cos b_\eta \int_0^1 \cos a_\xi d\xi$ is already solved analytically so that it saves a lot of computer time.

The other part of $A_c(\theta)$, namely $z_j = B\int_{-T}^T \zeta \sin \theta d\zeta$ with $B = K_0 \sec^2 \theta$ and $T = \text{depth of } \eta$ surface can always be solved analytically so that finally

$$A_c(\theta) = \frac{\sec \theta}{\pi} \sum_j \sum_i a_{ij} x_{ic} z_j$$  \hspace{1cm} (21)$$

$$A_s(\theta) = \frac{\sec \theta}{\pi} \sum_j \sum_i a_{ij} x_{is} z_j$$  \hspace{1cm} (22)$$

where

$$x_{is} = \int_0^1 \zeta \cos \left[b_\eta(\zeta) \sin(a, \zeta) d\zeta$$

and finally

$$R_w = \frac{\rho v^2}{\pi} \int_0^\pi \left( \sum_j \sum_i x_{ic} z_j \right)^2 + \left( \sum_j \sum_i x_{is} z_j \right)^2 \cos \theta d\theta$$  \hspace{1cm} (23)$$
This integral has been solved numerically using a Gaussian quadrature but in the new alternative of this step of the computer program the increment of $\theta$ is automatically computed by computer so that the losses due to the fact that the integrand has a very sophisticated variation, to be minimized. Due to the fact that $x_{ic}, x_{is}, z_j$ do not depend on $V_1$ and $T_1$, they are saved in computer and used for the whole range of variation of $V_1, T_1$ for a given Froude number. This also saves a substantial amount of computer time.

**Step 2.** Find the stagnation point of this singularity distribution and the length of the ship $L_1$, associated with their stagnation point. To find this stagnation point, we have to be able to compute the speed generated by a given singularity distribution at a given point $P(x, y, z)$.
a) For the source-sink distribution if the sources located on the element $d\eta_s$ with its centroid of coordinates $(\xi, \eta, \zeta)$, would be considered just a point source of strength $Q = M(\xi, \eta, \zeta)d\eta_s$ located at $R(\xi, \eta, \zeta)$, then the speed modulus generated by such an elementary source at point $P(x, y, z)$ along of radius $\vec{r}$ of length $RP$, will be

$$dV = \frac{Md\eta_s}{4\pi r^2}$$

(24)

Next by integration over all $\eta$-surface the component of the speed $V$ will be given by:

$$u_{ss} = \frac{1}{4\pi} \int \int_{\eta_s} \frac{M(\xi, \eta, \zeta)}{r^2} \cos \alpha d\eta_s$$

$$v_{ss} = \frac{1}{4\pi} \int \int_{\eta_s} \frac{M(\xi, \eta, \zeta)}{r^2} \cos \beta d\eta_s$$

$$w_{ss} = \frac{1}{4\pi} \int \int_{\eta_s} \frac{M(\xi, \eta, \zeta)}{r^2} \cos \gamma d\eta_s$$

where $\alpha, \beta, \gamma$ are the direction cosines of vector $\vec{r}$.

If

$$\eta_s = B_\eta[1-(1-a-b)\xi^3n - a\xi^{2n} - b\xi^n] = f(\xi)$$

Then

$$\frac{3\eta_s}{\xi} = -B_\eta[3n(1-a-b)\xi^{3n-1} + 2na \xi^{2n-1} + nb \xi^{n-1}]; \frac{\delta\eta_s}{\delta\xi} = 0$$
and

\[ u_{ss} = \frac{1}{4\pi} \iint \frac{M(\xi, \zeta)}{r^2} \frac{x-\xi}{r} p \, d\xi d\zeta \]  
(25)

\[ v_{ss} = \frac{1}{4\pi} \iint \frac{M(\xi, \zeta)}{r^2} \frac{y-\eta}{r} p \, d\xi d\zeta \]  
(26)

\[ w_{ss} = \frac{1}{4\pi} \iint \frac{M(\xi, \zeta)}{r^2} \frac{z-\zeta}{r} p \, d\xi d\zeta \]  
(27)

where \( P = \sqrt{(1 + \frac{\partial \eta}{\partial \xi})^2 + (\frac{\partial \eta}{\partial \zeta})^2} = \sqrt{1 + (\frac{\partial \eta}{\partial \xi})^2} \)

and \( p d\xi d\zeta = d\eta_s \).

Finally because \( r^2 = (x-\xi)^2 + (y-\eta)^2 + (z-\zeta)^2 \) the speed component will be:

\[ u_{ss} = \frac{1}{4\pi} \iint \frac{\sum_{i=1}^{4} \sum_{j=1}^{5} a_{ij} |\xi|^{j-1} (x-\xi) P \, \text{sign}(\xi) \, d\xi d\zeta}{\left[ (x-\xi)^2 + (y-\eta)^2 + (z-\zeta)^2 \right]^{3/2}} \]  
(28)

\[ v_{ss} = \frac{1}{4\pi} \iint \frac{\sum_{i=1}^{6} \sum_{j=1}^{5} a_{ij} |\eta|^{j-1} (y-\eta) \, \text{sign}(\xi) \, d\xi d\zeta}{\left[ (x-\xi)^2 + (y-\eta)^2 + (z-\zeta)^2 \right]^{3/2}} \]  
(29)

\[ w_{ss} = \frac{1}{4\pi} \iint \frac{\sum_{i=1}^{4} \sum_{j=1}^{5} a_{ij} |\zeta|^{j-1} (z-\zeta) P \, \text{sign}(\xi) \, d\xi d\zeta}{\left[ (x-\xi)^2 + (y-\eta)^2 + (z-\zeta)^2 \right]^{3/2}} \]  
(30)
where
\[
\eta = B_\eta [1-a-b] \xi^{2n} - a \xi^{2n} - b \xi^n
\]
and
\[
P = \sqrt{1 + \left( \frac{\partial \eta}{\partial \xi} \right)^2}
\]
with
\[
\frac{\partial \eta}{\partial \xi} = -B_\eta [3n(1-a-b) \xi^{3n-1} + 2na \xi^{2n-1} + nb \xi^{n-1}]
\]
and sign \( (\xi) = \frac{|\xi|}{\xi} \).

b) For a linear source distribution located at \( \xi = \pm 1 \) and at the center plane of the demihull:

\[
u_{1s} = \frac{1}{4\pi} \int_{T_{ls}}^{0} \frac{\sum_{j=0}^{3} s_j \xi^j (x+1) d\xi}{[(x+1)^2 + (y-\eta_{ls})^2 + (z-\zeta)^2]^{3/2}}
\]
(31)

\[
u_{1s} = \frac{1}{4\pi} \int_{-T_{ls}}^{0} \frac{\sum_{j=0}^{3} s_j \xi^j (y-\eta_{ls}) d\xi}{[(x+1)^2 + (y-\eta_{ls})^2 + (z-\zeta)^2]^{3/2}}
\]
(32)

\[
u_{1s} = \frac{1}{4\pi} \int_{-T_{ls}}^{0} \frac{\sum_{j=0}^{3} s_j \xi^j (z+1) d\xi}{[(x+1)^2 + (y-\eta_{ls})^2 + (z-\zeta)^2]^{3/2}}
\]
(33)

where \( T_{ls} \) is the lowest point of the linear source distribution and \( \eta_{ls} \) is \( \eta \) the coordinate of the vertical linear source distribution. Usually that should have the magnitude of the demihull spacing.
c) For linear doublet distribution, the potential
flow $\Phi = \frac{ux}{r^3}$ has been used, together with

$$u = \frac{\partial \phi}{\partial x}, \quad v = \frac{\partial \phi}{\partial y}, \quad w = \frac{\partial \phi}{\partial z}$$

As a result the components of the speed generated by a
doublet element of strength $\mu$ are:

$$u_{ld} = \mu \frac{r^2 - 3x(x + 1)}{r^5}$$

$$v_{ld} = \mu \frac{-3x(y - \eta_{ld})}{r^5}$$

$$w_{ld} = \mu \frac{-3x(z - \zeta)}{r^5}$$

where $\mu = E_0(\zeta) d\zeta$, $\eta_{ld}$ is the coordinate of the vertical
linear doublet distribution, $r^2 = (x + 1)^2 + (y - \eta_{ld})^2 + (z - \zeta)^2$.

By integration along of the line of distribution, the fol-
lowing expressions will be obtained:

$$u_{ld} = \int_{-\tau_{ld}}^{\tau_{ld}} \frac{\sum d_j \zeta^j [(r^2 - 3x)(x + 1)]}{r^5} d\zeta$$

(34)

$$v_{ld} = \int_{-\tau_{ld}}^{\tau_{ld}} \frac{\sum d_j \zeta^j [(3x(y - \eta_{ld})]]}{r^5} d\zeta$$

(35)
\[ w_{ld} = \int_{-T_{ld}}^{0} \sum_{j=0}^{3} \frac{d_j \zeta^i [-3x(z-\zeta)]}{r^5} d\zeta \] (36)

To find the speed \( u, v, w \) at any given point we have to add the contribution of each kind of singularity distribution:

\[
\begin{align*}
\bar{u} &= u_{ss} + u_{ls} + u_{ld} \\
\bar{v} &= v_{ss} + v_{ls} + v_{ld} \\
\bar{w} &= w_{ss} + w_{ls} + w_{ld}
\end{align*}
\]

and this implies to solve expressions 28 - 36 again and again for every single point. The computer program developed by author is solving these integrals in two alternatives:

a) for a general case when \( \eta \) surface is a function of \( \zeta, \zeta \) and the Gaussian quadrature is used, but that takes too much computer time for computation of the streamlines, and for this reason, the author doesn't recommend the use of this alternative for a complete optimization procedure; yet, it can be used to find the optimal solution for only one Froude number, i.e., when beside the design speed and the displacement, the length of the ship is known too.
b) The second alternative has been provided for the case when \( \eta \) surface is a flat plate, i.e., \( \frac{\partial \eta}{\partial \xi} = 0 \) and the ship is symmetrical in respect with the midship. In this case, the contribution of surface source can be computed as:

\[
u_{ss} = \frac{1}{4\pi} \sum_{i=1}^{4} \sum_{j=1}^{5} \int_{-T}^{0} a_{ij} \zeta^{i-1} d\zeta \int_{-1}^{1} \frac{g^{j}(x-\xi) d\xi}{[(x-\xi)^2 + (y+\eta)^2 + (z-\zeta)^2]^{3/2}}
\]

\[
v_{ss} = \frac{1}{4\pi} \sum_{i=1}^{4} \sum_{j=1}^{5} \int_{-T}^{0} a_{ij} \zeta^{i-1} (y-\eta) d\xi
\]

\[
x \int_{-1}^{1} \frac{g^{j} d\xi}{[(x-\xi)^2 + (y-\eta)^2 + (z-\zeta)^2]^{3/2}}
\]

\[
w_{ss} = \frac{1}{4\pi} \sum_{i=1}^{4} \sum_{j=1}^{5} \int_{-T}^{0} a_{ij} \zeta^{i-1} (z-\xi) d\zeta
\]

\[
x \int_{-1}^{1} \frac{g^{j} d\xi}{[(x-\xi)^2 + (y-\eta)^2 + (z-\zeta)^2]^{3/2}}
\]

If we define \( X = (x-\xi) \), then \( \xi = x-X \) and \( d\xi = -dX \)

Consequently,
\[ u_{ss} = -\frac{1}{4\pi} \sum_{i=1}^{4} \sum_{j=1}^{5} \int_{-T}^{0} a_{ij} \xi_i \zeta_j \frac{x-1}{x+1} \frac{(x-x)\xi \zeta}{(x^2+a^2)^{3/2}} \] (37)

\[ v_{ss} = -\frac{1}{4\pi} \sum_{i=1}^{4} \sum_{j=1}^{5} \int_{-T}^{0} a_{ij} \xi_i \zeta_j (y-\eta) \frac{x-1}{x+1} \frac{(x-x)\xi \zeta}{(x^2+a^2)^{3/2}} \] (38)

\[ w_{ss} = \frac{1}{4\pi} \sum_{i=1}^{4} \sum_{j=1}^{5} \int_{-T}^{0} a_{ij} \xi_i \zeta_j (z-\zeta) \frac{x-1}{x+1} \frac{(x-x)\xi \zeta}{(x^2+a)^{3/2}} \] (39)

where \( a = (y-\eta)^2 + (z-\zeta)^2 \).

If in expressions given above \((x-x)\xi\) is expanded, we will end up with a summation of integrals each of type

\[ I_k = \frac{x^k \zeta}{(x^2+a)^{3/2}} \quad \text{where} \quad k = 0, 1, 2, 3, 4, 6. \]

These integrals can be solved analytically and their solution is given below:

\[ I_0 = \frac{1}{a}(-t) \]

\[ I_1 = -\frac{1}{s} \]

\[ I_2 = -\frac{1}{t} - \frac{1}{2} \ln \left| \frac{t-1}{t+1} \right| \]

\[ I_3 = s + a \left( \frac{1}{s} \right) \]

\[ I_4 = -a \left[ -\left( \frac{1}{t} \right) - \frac{3}{4} \ln (1-t) + \frac{1}{4} \left( \frac{1}{1-t} \right) + \frac{3}{4} \ln |1+t| - \frac{1}{4} \left( \frac{1}{1+t} \right) \right] \]
\[ I_5 = \left( \frac{s^3}{3} \right) - 2a(s) - a^2 \frac{1}{s} \]
\[ I_6 = a^2 \left[ -\left( \frac{1}{t} \right) - \frac{15}{10} \ln \left| \frac{t-1}{t+1} \right| - \frac{7}{8} \frac{t}{t^2-1} + \frac{1}{4} \frac{t}{(t^2-1)^2} \right] \]

where
\[ t = \sqrt{x^2 + a} \quad \text{and} \quad s = \sqrt{x^2 + a} \]

Using these integrals in expressions 37 - 39 after they have been expanded, they could be integrated analytically in respect with \( \xi \) and the only part of integration remained to be solved by Gaussian quadrature is the integration in respect with \( \zeta \). Due to this method the computer time for the second alternative has been dropped down by a factor of 20 and so the computer program can be used for a complete optimization over a quite wide range of Froude numbers.

Once we have method to compute \( u, v, w \), at any given point \( P(x, y, z) \), finding the stagnation point is just a matter of systematic research in neighborhood of the bow until is found a point having \( u = U \) and \( v \approx 0 \). Here \( U \) is the speed of the ship and is coming against of \( x \) axis so that when \( u = U \), the total component of the speed along of \( x \) axis is zero.
Step 3. Compute the Volume $V_1$ of the catamaran. This implies first of all to find the streamlines and to do this job the equation of the streamline $\frac{dv}{dx} = \frac{v}{-U+u}$, $\frac{dz}{dx} = \frac{w}{-U+u}$ has to be solved. The numerical solution of this equation has been found in this program using Kutta Merson method. Because $u$, $v$, $w$, has to be computed according to this method, in four intermediate points for each new point of a streamline, and because the demi-hull is not symmetrical in respect with $X$ axis and therefore, we have to compute the effects in both sides of a demi-hull, this is the part consuming the most of the computer time. Once the streamline have been found numerically, they are used to compute the volume which is a relatively easy job.

It is important to mention that the free surface has been materialized by a wall, and therefore in our computer program it is considered that always exist a mirror image of the singularity distribution and when the speed is computed at a given point the contribution of these mirror images are encountered too. Therefore, all integrals computing the speed components have been evaluated from $-T$ to $T$ instead of $-T$ to zero.
Step 4. Store the singularities distribution with the smallest wave resistance \( R_w \) and the ship associated with them. This means that if the ship computed at Step (3) has a volume close to the required volume we check its wave resistance against the smallest wave resistance we have found so far. If the last ship has a higher wave resistance, we ignore it and try to generate another one using another set of constraints \( T_i, V_i \). If the last ship has the smallest wave resistance from all ship generated so far, we store this ship, for comparison with the future ships to be generated.

The program keeps the best ship for the current Froude number and the current optimal ship, i.e., one with smallest wave resistance no matter of Froude number. When the range of variation of constraints \( T_i, V_i \), is exhausted for a given Froude number, the computer also calculates and prints out the coefficient of wave resistance of the best ship for that Froude number, over a whole range of speeds. In fact, these speed will cover the range of variation for \( F_n \) read in computer, but at this time given that the length of the ship is known, each \( F_n \) will be associated with a speed. In this way for the best ship for a given \( F_n \), we can plot the variation of wave resistance coefficient vs. \( F_n \).
Step 5. What is going to be the next set of constraints $T_i, V_i$? It depends on what happened to the previous set of constraints, but to understand this, it is necessary to mention that we have to read in computer the lower and the upper limit of variation for each parameter. Because between $V_i$ and $T_i$ must be a certain degree of compatibility* (otherwise we will get impractical ships like strangled at midship, etc.) and because for each Froude number the value of the feasible set of constraints $V_i, T_i$ is substantially changed, the limits read in computer and shown in Figure 5 as $V_0, T_0, V_f, T_f$ are used only for the first Froude number, then they are increased according to a function schematically shown in Figure 5 where $V_{io}, T_{io}$ are the lower limits for a given Froude number and $V_{io}, T_{io}$ are the upper limits.

*One example of constraints $V_i, T_i$ is given in Table 1 for a catamaran of 25,000 tons/demihull.
Normally, for each Froude number in Figure 5, will correspond a set of four values: \( V_{io}, T_{io}, V_{if}, T_{if} \) which according with a parameter read in computer called NINT (number of intervals) will generate a mesh with

\[
\Delta T = \frac{T_{if} - T_{io}}{NINT}, \quad \Delta V = \frac{V_{if} - V_{io}}{NINT}
\]

An example of such a mesh for NINT = 5 is shown in Figure 6.

Note that in Figure 6, the intersection of axis is not the origin \( V_i = 0, T_i = 0 \).

![Figure 6](image)

Now for each \( T_{ij} (j = 0, 1, 2, \ldots, \text{NINT}) \), starting with \( V_{io} \) the computer will vary \( V_i \) until a feasible ship will be found. Yet if \( V_{io} \) generates a too large ship,
there is no sense to try \( V_{i1} \) because that will generate even a bigger ship. In that case, both \( T_{ij} \) and \( V_{10} \) (but \( V_{10} \) only for that \( T_{ij} \)) will be decreased proportionally until a too small, or a feasible ship is obtained. If a too small ship has been obtained, then the computer will increase the current value of \( V_i \) with \( \Delta V_i \) until a too large ship is obtained. Then \( V_i \) is decreased with \( \Delta V_i \). \( \Delta V_i \) is divided by two and now \( V_i \) is increased with this new \( \Delta V_i \). This process goes so until a feasible ship is obtained. Then same procedure is repeated for the next \( T_{ij} \) up \( T_{if} \).

In the attached program, the user has a choice to search for the optimal ship over all range \( T_{10} - T_{if} \) or to find a feasible ship for \( T_{10} \) only, for each Froude number. In the last alternative, the control parameter for this choice NMK(1,7) called NOTI must be set equal to 1, otherwise it must have the value 2.

Reason for this alternative is that after more experimental runs of the computer program turns out that usually the ship with the finest angle of entrance \( T_i \) has the smallest wave resistance and therefore if we are looking for a ship with smallest wave resistance, it is not worth to try other ships with a blunt bow. On the other hand the ships with a fine entrance will not always have a very attractive form so that the user have the choice to use the program according with his needs and preferences.
Step 6 is "go to the next Froude number" and apparently this doesn't require any other comments. Yet, this is happening only when the computer program works in "mode 1", i.e., the optimization of Froude number and indirectly the optimization of the length of the ship.

When the user is asking the computer program to work in "mode 2", i.e., the optimization of hull spacing, at Step 6, one should read, "go to the next hull spacing", because then the hull spacing is changed and the Froude number stays constant.
Interference Factor

If finding out the optimal form of catamaran demihull has not been very easy job, it turns out that the interpretation of the result is not quite easy too. In fact, is really difficult to compare a catamaran with a monohull ship because of their different advantages; even if they will have the same displacement, catamarans fulfill requirements which monohulls cannot; large areas, unusually high transverse stability, the capability to handle large loads at the center of the ship, etc. On another hand to compare a catamaran wave resistance directly with that of monohull having the same total displacement using linearized wave theory would not be fair because as it has been mentioned in the introduction, the linear wave theory will predict an unwarranted advantage to the catamarans.

Some researchers [1] have defined an "Interference Factor" I.F. as follows:

\[ I.F = \frac{R_{RS} - 2D_{RS}}{2D_{RS}} \]

where \( R_{RS} \) = total catamaran wave resistance
\( D_{RS} \) = demihull wave resistance
\( D_{RS} \) being equal to the total catamaran wave resistance at infinite separation, divided by 2.
This definition seems to make sense especially in our case, when it is assumed that due to the fact that the shape of the demihull has the freedom to take the form imposed by the presence of the other demihull, the flow is always virtually symmetrical. That is why this definition for I.F will be used in the analysis of our results:
Results

Page 53-59. Sample of computer output, the basis for Figure 7, 8, 9.

Figure 7. Demihull Graphical Representation
Figure 8. Source Distribution
Figure 9. Wave Resistance Coefficient vs. Froude Number for a Design Froude Number of 0.35
Figure 10. Wave Resistance Coefficient vs. The Design Froude Number for a Speed of 25 kts.
Figure 11. Interference Factor vs. Froude Number for Three Different Hull Forms Having a Hull Spacing of 0.25
Figure 12. Interference Factor vs. Hull Spacing for Three Different Hull Forms At The Speed of 25 kts.
Figure 13. Interference Factor vs. Froude Number for Different Hull Spacings And a Design Froude Number of 0.325
FIG. 9
WAVE RESISTANCE COEFFICIENT VS. FROUDE NUMBER
FOR A DESIGN FROUDE NUMBER OF 0.35
WAVE RESISTANCE COEFFICIENT VS. THE DESIGN FROUDE NUMBER FOR A SPEED OF 25 KTS.

$C_w = R_w / \frac{1}{2} \rho V^2 L^2 \times 10^{-3}$

FIG. 10
FIG. 11 WAVE RESISTANCE INTERFERENCE FACTORS FOR THREE DIFFERENT HULL FORMS WITH HULL SPACING .25
**DEMIHULL DISPL=25,000 T, V=42FT/SEC, FR. NO.=0.35 , SPACING OPTIMIZATION**

<table>
<thead>
<tr>
<th>NG</th>
<th>NGS</th>
<th>LINES</th>
<th>NINT</th>
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**AND THE LENGTH OF 451.47 FEET IS GIVEN BELOW**
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| 0.026 | -0.050   | 0.047    | -0.031|          |
| 0.018 | -0.154   | 0.039    | -0.040|          |
| 0.015 | -0.054   | 0.031    | -0.045|          |
| 0.012 | -0.053   | 0.026    | -0.048|          |

| 0.931 |          |          | 0.931 |          |
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| 0.031 | -0.062   | 0.058    | -0.038|          |
| 0.023 | -0.066   | 0.049    | -0.049|          |
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| 0.11  | -0.167   | 0.073    | -0.169|          |

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AND THE DISPLACEMENT IS 24748.25 TONS

$T_1 \quad V_1$

$4.35699940 \quad 5.11499893$

DEMIHULL DISPL=25,000 T, $V=42ET/SEC$, $F_0$, $M_1=0.35$, SPACING OPTIMIZATION

VALUES OF $N_{XM}, N_{MS}, N_{MD}, N_{NT}$

1 2 2 2 1 0 0

VALUES OF $A_{EN}, A_{PP}, PC(1), PC(2)$

0.0 2.00000 0.20000

VALUES OF $B_1, A_1, A_2, T_1, D_1, S_1, L_1, F_1, F_2$

0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

VALUES OF $F_0, F_1, F_2, F_3, F_4, F_5, F_6, F_7, F_8, F_9$

0.35000 0.0 2.00000 2.00000 42.20000 1.00000 0.100025 0.00000 0.01000

VALUES OF $C_{RR}, C_{SH}, F_{PP}, B_{PC}$

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VALUES OF SURFACE SOURCE DISTRIBUTION COEFFICIENTS

$0.372631384E+01 \quad 0.35048922E+02 \quad -0.34136261E+02 \quad 0.4550708E+02 \quad -0.46059708E+02$

VALUES OF LINE SOURCE DISTRIBUTION COEFFICIENTS

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VALUES OF LINE DOUBLET DISTRIBUTION COEFFICIENTS

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<td>0.9489118E-01</td>
</tr>
</tbody>
</table>

### List of Wave Making Resistance Coefficient, Forebody Alone

<table>
<thead>
<tr>
<th>Wave Making Coefficient</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
<th>Value 4</th>
<th>Value 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25151041E-03</td>
<td>0.24563406E-03</td>
<td>0.23851846E-03</td>
<td>0.39023301E-03</td>
<td>0.96366974E-03</td>
<td>0.88243443E-03</td>
</tr>
<tr>
<td>0.51194087E-03</td>
<td>0.51194087E-03</td>
<td>0.28466573E-03</td>
<td>0.45665470E-03</td>
<td>0.96366974E-03</td>
<td>0.88243443E-03</td>
</tr>
<tr>
<td>0.13135931E-02</td>
<td>0.16317798E-02</td>
<td>0.17864397E-02</td>
<td>0.17864397E-02</td>
<td>0.17864397E-02</td>
<td>0.17864397E-02</td>
</tr>
</tbody>
</table>

### List of Wave Making Resistance Coefficient, Symmetrical Ship

<table>
<thead>
<tr>
<th>Wave Making Coefficient</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
<th>Value 4</th>
<th>Value 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10066186E-02</td>
<td>0.98251412E-03</td>
<td>0.95405430E-03</td>
<td>0.15610203E-02</td>
<td>0.38547684E-02</td>
<td>0.35298318E-02</td>
</tr>
<tr>
<td>0.36296509E-02</td>
<td>0.20478480E-02</td>
<td>0.11386415E-02</td>
<td>0.1267012E-02</td>
<td>0.35298318E-02</td>
<td>0.35298318E-02</td>
</tr>
<tr>
<td>0.52540898E-02</td>
<td>0.65268017E-02</td>
<td>0.71453999E-02</td>
<td>0.35298318E-02</td>
<td>0.35298318E-02</td>
<td>0.35298318E-02</td>
</tr>
</tbody>
</table>

### Surface Source Distribution

<table>
<thead>
<tr>
<th>X</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
<th>Value 4</th>
<th>Value 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>5.120</td>
<td>10.201</td>
<td>11.913</td>
<td>11.516</td>
<td>9.939</td>
</tr>
<tr>
<td>0.9</td>
<td>5.120</td>
<td>10.201</td>
<td>11.913</td>
<td>11.516</td>
<td>9.939</td>
</tr>
<tr>
<td>0.8</td>
<td>5.120</td>
<td>10.201</td>
<td>11.913</td>
<td>11.516</td>
<td>9.939</td>
</tr>
<tr>
<td>0.7</td>
<td>5.120</td>
<td>10.201</td>
<td>11.913</td>
<td>11.516</td>
<td>9.939</td>
</tr>
<tr>
<td>0.5</td>
<td>5.120</td>
<td>10.201</td>
<td>11.913</td>
<td>11.516</td>
<td>9.939</td>
</tr>
</tbody>
</table>

The optimal ship for the given set of constraints has the length of 451.47 feet and the hull spacing of 0.20.  
End job reached through program control.
Discussion of Results

Discussion of Computer Output.

The sample of computer output attached to this thesis is purposely limited only to one design Froude number in order to show a complete output with a minimum number of pages. The most significant informations provided in this sample of output are plotted in Figure 7, 8, 9. Due to the fact that the user of this computer program has a large variety of options, the sample given here is only one of outputs generated by this computer program. This program encounters other cases of secondary importance like the case when the user wants to test the compatibility of a set of constraints for optimization of source distribution, when the estimated time for a job is over, no streamlines are computed, the range of variation for the constraints on source distribution didn't allow the computer to find any feasible ship, etc., and for each of these cases there is a specific output. In case of a successful run the informations printed out are given in such a form as to make them easily available for study and decision making; in case of incompatible input data, the informations are of nature such as to help the user to understand what is going wrong and therefore to be able to take a proper corrective action.
Discussion of Figure 7.

Figure 7 is a graphical representation of a demihull forebody of a 50,000 tons catamaran (25,000 tons/demihull) having a speed of 25 knots and a design Froude number of 0.35 i.e., a length of 451.67 feet. Due to the fact that the ship is a symmetrical one, there is no reason for after-body to be represented there. In the version attached to this thesis, the computer program is designed only for symmetrical ships, but it has been written in such a way that it can be easily adapted for forebody alone. The author didn't consider the symmetry a limitation because one can use this program to get qualitative informations about the wave resistance vs. the shape of forebody and after-body and later when comes to a practical design, only has to attach a parallel body at the midship. In fact in practical life due to viscosity which is not encountered here, the body of the ship will get thicker toward the stern and in order to avoid that, the shape of the demihull given by computer should be slightly altered. Also, until a modification of this program will be made to check for the symmetry of the flow in respect with midline of the water planes, alterations of demihulls given by computer will be necessary; especially for those cases where some streamlines starting on inner side of a demihull are
deviated outward by the time where they are getting close to the midship. In the case of the ship plotted in Figure 7, no line source or doublet have been used, but if one wants to get a bulbous bow or to change the line of the keel, they can feel free to make use of such singularities.

Discussion of Figure 8.

Figure 8 represents the surface source distribution used to produce the ship given in Figure 7. The profile of such a line depends on absolute value of the constraints $V_1$, $T_1$ used at optimization of source distribution as well as on their ratio. Where $T_1$, i.e., the value of source distribution at $\xi = 1$ is a very small number of order of 0.1, the ratio $\frac{V_1}{T_1}$ can't usually be less than 1, because some sinks will appear in positive side of $\xi$ axis and that will generate a ship strangled at the midship. This ratio can and must increase later for higher order of magnitude of $V_1$, $T_1$, in order to get some parallel body at the midship.

Discussion of Figure 9.

Figure 9 is a plot of wave resistance coefficient defined as $C_w = R_w / \frac{1}{2} \frac{L^2}{U^2} C_U^2 L^2$, vs. Froude number, for the ship plotted in Figure 7. Qualitatively it doesn't
differ too much from a similar diagram for monohull ships except for the fact that the "hump" at \( F_n = 0.29 \) which seems to be unusually high and therefore can possibly make difficult to reach the advantage of the following hollow at \( F_n = 0.35 \). Looking from another end, one can say that the hollow of this diagram is unusually deep and therefore what usually is a negligible advantage for monohull ships seems to be promising for catamarans. Of course, some experimental results will make clear if this is only a mirage or a real fact, and experiments are now possible because the shape of the demihull associated with this source distribution is known.

**Discussion of Figure 10.**

Figure 10 is a plot of wave resistance coefficient defined as \( C_w = R_w / \frac{1}{2} \rho U^2 L^2 \) vs. the design Froude number for a speed of 25 knots. It warns us that even if the interference factor is more favorable for shorter ships, as one can see in Figure 11, we have to take into account that there is a substantial increase in absolute value of wave resistance coefficient where it passes from very fine ships to very full ships.
Discussion of Figure 11.

Figure 11 represents the plot of interference factor for three different hull forms with a hull spacing of 0.25. It turns out that the interference factor unfortunately not very large for the case plotted here, is higher for the shortest ship, i.e., the ship with a design Froude number of 0.35. If we take into consideration, that for full ships the wave resistance represents quite a substantial part of wave resistance, now we can see that they also have the largest interference factor so that we can fully use the advantage of catamarans for this kind of ships.

A qualitative conclusion resulting from this chart is the fact that the full form does not have only a secondary effect on interference factor, but rather a very important one. It is worth to note that unfavorable I.F.'s at Froude number slightly below the design Froude number will present powering problems to the designer.

Discussion of Figure 12.

Figure 12 represents the interference factor vs. hull spacing for three different hull forms (for three different design Froude numbers). This is a completion of Figure 11 showing the influence of the design Froude number on interference factor, but it also shows the fact that for different lengths the optimal
interference factor occurs at different hull spacings. In other words the optimum demihull spacing decreases with increasing Froude number. The conclusion resulting from here is that once we have got the optimal length of the ship using the computer program in "mode 1", it makes sense to run the program once again in "mode 2" with the optimal set of constraints only, but to find the optimal hull spacing for optimal length.

Discussion of Figure 13.

Figure 13 is a plot of interference factor vs. Froude number for different hull spacing and a design Froude number of 0.325. The conclusion resulting from this diagram is essentially the same as that resulting from Figure 12, but from practical stand point here, it can be formulated as follows: if one starts decreasing the hull spacing, it turns out that the optimal speed is increasing with an increasing value of optimal interference factor until hull spacing reaches 0.2. Then the value of optimal interference factor is decreasing sharply beyond the hull spacing equal .15 and suddenly increases again in neighborhood of .1, but for a smaller speed. The optimal hull spacing seems to be for this case, between .2 and .25.
Conclusions

The interference factor is a function of speed/length ratio, hull spacing and the shape of the hull. This triple dependence makes worth on optimization program and such program has been successfully set up and tested by author. While the interference factor is helpful to us, to see the interference effect of the catamaran for design purposes, wave resistance coefficient seems to be more relevant. For this reason the wave resistance coefficient has been choosen to be the function to be optimized in the computer program attached to this thesis.

The catamarans have a significant interference factor (-28 for a case studied by author and there are other cases where even a higher interference factor can be obtained), but it also appears that usually the hollow of such a diagram is shaded by high humps which to be overpassed may require a substantial reserve of power. On other hand, the ships having the highest interference factor and therefore, the ships offering the best chance to a catamaran to show up its advantage of wave interference are the full ships, with a very deep draft and with a large absolute value of wave resistance coefficient. That is why the advantage of catamarans have to be evaluated specifically for each case and weighted against the design requirements.
Recommendations

If in the past one couldn't drive on experiment with catamarans generated by water sources, it was because we didn't know the shape of the demihull generated by these sources. Now this problem being solved there is no reason why one should not get into some experiments to check the validity of the conclusions resulting from this theory. Another recommendation is that of modifying this program to check the symmetry of the flow around of a demihull and that is not going to be a difficult job due to the structure of the program. The criteria to be used for that will be to compute the speed at two points one of each side of the demihull but of the same \( \zeta \) and \( \zeta \) ordinate and make sure that the speed has the same value by proper adjustment of the parameters of \( \eta \) surface. This will be especially useful for the case of very small hull spacing when the deformation of water body generated by sources, is not enough to create a transverse pressure-equilibrium.
APPENDIX A

DEFINITIONS OF THE INPUT
This program has been written in FORTRAN G language and it requires 260 K of memory. It can be used with WATFIV compiler only if the card MAIN0285 and MAIN5500 calling for subroutine TIMING are taken out. A description of the input data is given below:

NJOBS is punched on the first input data card and indicates the number of jobs to be expected by compiler. Each of these jobs must have the following set of input data:

TITLE is an identification and page shifting device used in the printing out of data. It can be anything that takes up less than seventy-two spaces. Format (18A4).

INFIN is a parameter indicating if the wave resistance coefficient for infinite spacing is desirable or not. When INFIN = 0, no wave resistance coefficient for infinite spacing is desirable. Otherwise INFIN should be different by zero. INFIN is the last parameter punched on card "Specification for gaussian quadrature".
Specification for Gaussian Quadrature.

The number of subinterval length is defined by the NGS value, and the number of Gaussian stations in each subinterval is given by NG, NG = 10, NGS = 10 are recommended.

\[
\begin{align*}
\text{NG} &= \\
\text{NGS} &= \\
\text{LINES} &= \\
\text{JTIME} &= \\
\text{INFIN} &= 
\end{align*}
\]

LINES = The number of the streamlines on each side of a demihull.

NINT = The number of intervals in the range of variation for constraints \( T_1, V_1 \).

JTIME = A time bigger than the time expected for one's job, which comes into play only when the job exceeds the expected time. To allow the computer to use the advantage of JTIME, the time punched on JCL should be 1-2 minutes, bigger than JTIME. At JTIME, the computer will print out a set of informations regarding the evolution of the program so far and then will stop. This is to avoid the trouble the user will get in, when the time specified on JCL is over, and the job stops without any information.
### Abscissa Values

<table>
<thead>
<tr>
<th>G(1,1)</th>
<th>G(1,2)</th>
<th>G(1,3)</th>
<th>G(1,4)</th>
<th>G(1,5)</th>
<th>G(1,6)</th>
<th>G(1,7)</th>
<th>G(1,8)</th>
<th>G(1,9)</th>
<th>G(1,10)</th>
<th>G(1,11)</th>
<th>G(1,12)</th>
<th>G(1,13)</th>
<th>G(1,14)</th>
<th>G(1,15)</th>
</tr>
</thead>
</table>

### Weight Factors

<table>
<thead>
<tr>
<th>G(2,1)</th>
<th>G(2,2)</th>
<th>G(2,3)</th>
<th>G(2,4)</th>
<th>G(2,5)</th>
<th>G(2,6)</th>
<th>G(2,7)</th>
<th>G(2,8)</th>
<th>G(2,9)</th>
<th>G(2,10)</th>
<th>G(2,11)</th>
<th>G(2,12)</th>
<th>G(2,13)</th>
<th>G(2,14)</th>
<th>G(2,15)</th>
</tr>
</thead>
</table>

**FORMAT (6F12.8)**

The abscissa values and the weight factors used in the Gaussian formula should not be separated, therefore G(2,1) should follow G(1,NG). Check that the number of stations correspond to the NG value stated above.
SPECIFICATION OF GEOMETRY

DEN - End of integration in X direction. If the hull is symmetrical, or if only the forebody calculation is required, DEN = 0.

ARP - This gives the origin for the weighted free wave amplitudes (both sine and cosine). If one wished to see what effect a certain line source and/or line doublet (bulbous bow) distribution had on the wave amplitude, setting ARP = 1 would put the origin of the amplitude printout at the bow. Thus the effect of the line source and/or line doublet distribution would not be masked by the surface source distribution. The printout is for design Froude number.

PC(1) - Forebody demihull hull spacing, measured at the bow, and is the half distance between hulls divided by the half length of the ship. (centerplane to centerplane).

PC(2) - Afterbody demihull hull spacing. Measured at the stern. Half distance between hulls divided by half ship length. (centerplane to centerplane).

\[
\begin{align*}
\text{DEN} &= \\
\text{ARP} &= \\
\text{PC(1)} &= \\
\text{PC(2)} &= 
\end{align*}
\]
SPECIFICATION FOR LOGIC

NXM - If NXM = 0, no surface source distribution is to be read in. If NXM ≠ 0, surface source distribution is to be read in.

NDS - If NDS = 0, no line source or line doublet distribution is to be read in. If NDS ≠ 0, the distribution is to be read in.

MODE = 1 Optimize the length.
MODE = 2 Optimize the hull spacing.
TEST ≠ 0 The program will stop after the first ship so that the user could get an idea about the magnitude of constraints $T_i$, $V_i$. For optimization TEST should be zero.

NBD - Number of constraints when optimizing hull form. For this program it can be only 2 or 0.
NDB = 0 no optimization is performed, but it is expected to read in a singularity distribution to compute the wave resistance.

NP - Equivalent to N in the ETA surface equation. NP = 2 has been found satisfactory.

NOTI = 1 Only one angle of entrance $T_{io}$, will be used for each Froude number.

NOTI = 2 All range of variation for $T_i$ will be used for each Froude number.
NOVOL - If NOVOL = 0, no hull shape, or volume will be computed; only the optimization of source distribution will be performed and the wave resistance coefficient will be printed out. In this case, one can use dummy subroutines instead of actual subroutines for OFSET, SPEED and VOLUME; that means that all executable statements from these subroutines should be taken out.

DEBUG ≠ 0 The matrices used at optimization of source distribution will be printed out.

\[
\begin{align*}
NXM &= \text{NMK}(I, 1) = \\
NDS &= \text{NMK}(I, 2) = \\
MODE &= \text{NMK}(I, 3) = \\
TEST &= \text{NMK}(I, 4) = \\
NBD &= \text{NMK}(I, 5) = \\
NP &= \text{NMK}(I, 6) = \\
NOTI &= \text{NMK}(I, 7) = \\
NOVOL &= \text{NMK}(I, 8) = \\
DEBUG &= \text{NMK}(I, 9) = 
\end{align*}
\]

FORMAT (918)
GEOMETRIC AND SPEED INPUTS

BM - Beam in eta eg'n
AC - "a" value in eta eg'n
BC - "b" value in eta eg'n
T - "t" = draft of eta surface

DESP - Hull spacing decrement. It is not used when the length is optimized.

SPLIM - Lower limit for hull spacing. It is not used when the length is optimized.

F1 - Lower limit of range of variation for Froude number.

FD - Froude number increment

F2 - Upper limit of range of variation for Froude number.

FDN - Design Froude number except for optimization of length when this number is not used at all.

CM - Cosine multiplier

PT - Weighted wave amplitudes printed if PT ≠ 0

V - The design speed of the ship in ft./sec.

TSD - Multiplier if line source/doublet present

DEFFN - One can use different range of variation for $F_n$ at length optimization and at the wave resistance computation for optimal length. The range of variation for $F_n$ at wave resistance computations is that determined by $F_1$ to $F_2$. At length optimization DEFFN is subtracted from $F_2$. 
DISPL - Displacement in thousands of tones of one demi-hull, or half the displacement of monohull if hull spacing, PC(1) has been set to zero.

TB - Depth of line source, doublet.

BM = CMK(1, 1) =
AC = CMK(1, 2) =
BC = CMK(1, 3) =
T  = CMK(1, 4) =
DESP = CMK(1, 5) =
SPLIM = CMK(1, 6) =
P1  = CMK(1, 7) =
FD  = CMK(1, 8) =
F2  = CMK(1, 9) =
FDN = CMK(1,10) =
CM  = CMK(1,11) =
SM  = CMK(1,12) =
PT  = CMK(1,13) =
V   = CMK(1,14) =
TSD = CMK(1,15) =
DEFFN = CMK(1,16) =
DISPL = CMK(1,17) =
TB  = CMK(1,18) =
CM } - The cosine component of both diverging and
SM transverse waves are cancelled for a symmetrical
ship.

TSD - Multiplier if Line source/doublet present. If at
bow alone, TSD = 1. If at bow and stern of sym-
metrical ship, TSD = 2. If not symmetrical, value
determined by degree of phase shift between bow and
stern sources and/or doublets.

TB - The draft of line sources/doublet distribution.
LINE SOURCE AND LINE DOUBLET DISTRIBUTION

TO BE SPECIFIED IF NDS ≠ 0

\[
\begin{align*}
S(I, 1) &= \quad & D(I, 1) &= \\
S(I, 2) &= \quad & D(I, 2) &= \\
S(I, 3) &= \quad & D(I, 3) &= \\
S(I, 4) &= \quad & D(I, 4) &= \\
S(I, 5) &= \quad & D(I, 5) &= \\
\end{align*}
\]

FORMAT (5F14.8) FORMAT (5F14.8)

\[
\begin{align*}
E_9 &= S(I,1) + S(I,2) \zeta + S(I,3) \zeta^2 + S(I,4) \zeta^3 \\
E_{10} &= D(I,1) + D(I,2) \zeta + D(I,3) \zeta^2 + D(I,4) \zeta^3
\end{align*}
\]

Cosine and sine multiplier valid for line source and line doublet distribution.

<table>
<thead>
<tr>
<th>Symmetric</th>
<th>Bow Alone</th>
</tr>
</thead>
<tbody>
<tr>
<td>cosine multiplier</td>
<td>CCB</td>
</tr>
<tr>
<td>sine multiplier</td>
<td>SSB</td>
</tr>
</tbody>
</table>

FBP(1) forebody location of line source
BPC(1) forebody location of line doublet

\[
\begin{align*}
CCB (I) &= \\
SSB (I) &= \\
FBP (I) &= \\
BPC (I) &= \quad \text{FORMAT (9F8.5)}
\end{align*}
\]
CONSTRANTS ON $E_1$, $E_2$, $E_3$ and $E_4$

SPECIFIED IF NBD $\neq 0$

\[
\begin{array}{ccc}
\text{FORMAT (9F8.5)} & \text{FORMAT (9F8.5)} \\
\hline
V_0 & T_0 \\
\hline
Zi(1,1) = & Zi(2,1) = \\
Zi(1,2) = & Zi(2,2) = \\
Zi(1,3) = & Zi(2,3) = \\
Zi(1,4) = & Zi(2,4) = \\
\end{array}
\]

\[
\begin{array}{ccc}
\text{FORMAT (9F8.5)} & \text{FORMAT (9F8.5)} \\
\hline
V_f & T_f \\
\hline
Zf(1,1) = & Zf(2,1) = \\
Zf(1,2) = & Zf(2,2) = \\
Zf(1,3) = & Zf(2,3) = \\
Zf(1,4) = & Zf(2,4) = \\
\end{array}
\]

No restraints can be used when optimizing $E_9$ and $E_{10}$. One example of reasonable values for $V_o$, $T_o$ for a 50,000 ton catamaran (i.e., 25000 tons/demihull and 25 knots speed is given in Table 1.
TABLE 1
Example of Reasonable Constraint Values for a Catamaran of a 25,000 tons/demihull.

<table>
<thead>
<tr>
<th>$F_n$</th>
<th>0.21</th>
<th>0.225</th>
<th>0.25</th>
<th>0.275</th>
<th>0.325</th>
<th>0.325</th>
<th>0.35</th>
</tr>
</thead>
<tbody>
<tr>
<td>LENGTH</td>
<td>1382.64</td>
<td>1092.46</td>
<td>884.89</td>
<td>731.31</td>
<td>614.51</td>
<td>523.60</td>
<td>451.40</td>
</tr>
<tr>
<td>$V_o$</td>
<td>0.16</td>
<td>0.28</td>
<td>0.56</td>
<td>0.93</td>
<td>1.59</td>
<td>2.68</td>
<td>4.35</td>
</tr>
<tr>
<td>$T_o$</td>
<td>0.16</td>
<td>0.33</td>
<td>0.64</td>
<td>1.23</td>
<td>2.1</td>
<td>3.6</td>
<td>5.5</td>
</tr>
<tr>
<td>$V_f', T_f$</td>
<td>0.5</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>3.0</td>
<td>5.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>
SPECIFICATION FOR OPTIMIZATION SCHEME

IL(1) ≠ 0 \( E_1 \) should be optimized
IL(2) ≠ 0 \( E_2 \) should be optimized
IL(3) ≠ 0 \( E_3 \) should be optimized
IL(4) ≠ 0 \( E_4 \) should be optimized

SPECIFY NUMBER OF TERMS IN \( E_1, E_2, \) ETC.

If \( KN(1) = 4 \), then \( E_1 \) contains four terms. In this program
\( KN(1) = 5 \), e.g.,

\[
E_1 = (a_{11} \xi + a_{21} \xi^2 + a_{31} \xi^3 + a_{41} \xi^4) \xi^0
\]

\[
\text{KN}(1) = \\
\text{KN}(2) = \\
\text{KN}(3) = \\
\text{KN}(4) = \\
\text{KN}(5) = \\
\text{KN}(6) = \\
\text{KN}(7) = \\
\text{KN}(8) = \\
\text{KN}(9) = \\
\text{KN}(10) = \\
\]

FORMAT (9I8)
**Specify Surface Source Distribution**

*To be read in if $\text{NXM} \neq 0$*

Surface Source Distribution

$$M(\xi, \zeta) = \sum_{i=1}^{4} \sum_{j=1}^{5} \text{XMBB}(I,J) \xi^{j} \zeta^{i-1}$$

or

$$M(\xi, \zeta) = E_1 + E_2 + E_3 + E_4$$

<table>
<thead>
<tr>
<th>$\text{XMBB}(1,1)$</th>
<th>$\text{XMBB}(1,2)$</th>
<th>$\text{XMBB}(1,3)$</th>
<th>$\text{XMBB}(1,4)$</th>
<th>$\text{XMBB}(1,5)$</th>
</tr>
</thead>
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FORMAT (5F14.8)  FORMAT (5F14.8)  FORMAT (5F14.8)  FORMAT (5F14.8)
APPENDIX B

LISTING OF THE COMPUTER PROGRAM
PROGRAM FOR OPTIMIZATION OF CATAMARAN DEMIHULLS FROM WAVE RESISTANCE STAND-POINT

DOUBLE PRECISION CKSE, CKSFIX

DIMENSION U(2,15), S1(2,9), D(2,9), ZE(6,9), XM(6,9), CK(1,3,1),
1 ABD(350), ACC(350), ASS(350), ACS(350), ASLS(350), ACSL(350), ACSL(350),
2 ASL(350), ACTH(350,6), ASTH(350,6), Z(2,7), ZB(2,7), CCB(2), SS3(2),
3 FBP(2), ECL(2), ECO(2), TOS(2), ACLD(350), CCLD(350), CL(20,20),
4 WRT(50), FKF(50), DFF(350), CCL(2,2), DFT(2), PC(2), BPC(2),
5 GCR(0,5), XZ(11,21), SBX(15), DXB(15), THD(350), IL(20), KN(20),
6 BB(15,10), ZZ(3,4), ZP(3,4), ZF(3,4),
7 XM(6,9), WRFB(50), WRGTS(50), NCM(2,9), CMK(2,18), TITLE(18),
8 XBB(15,10), XLINE(2,11,50), YLINE(2,11,50), COMM(100,11),
9 ETAFIX(11,11), KSEFIX(11,11), FIX(11,11), NS(11), NC(11), NB(11),
A XES(25), YRES(11,11), ZRES(11,25), XRES(11,25), ZLINE(2,11,50), NQ(3,3),

DIMENSION RXMM(6,9), RASTH(350), RACTH(350,6), XREX(100),

DIMENSION CSR(5), CSN(5), CSL(5), CSLN(5), CCB(2),

DIMENSION UNOFF(5,200), UMM(200), AAREA(50), RAREA(50), ZF1(4),

COMMON/ARCT/ CMK, NCM, PC, DNE, FBP, BPC, S, D, LINES, RED, IL,

COMMON/BRCT/ G, COMMON, NG, USH, NS, NB, NC, SHPL,

COMMON/CRCT/ NR, KSEFIX, ETAFIX, FIX, TENOMS, TENOMD, XREX,

COMMON/DRCT/ XMMB, XMSS

XS(1, KSE) = 1. / A / A * SIN(A * KSE) - KSE / A * COS(A * KSE)
XS(2, KSE) = 1. / A / A * COS(A * KSE) + KSE / A * SIN(A * KSE)
XS(2, KSE) = - KSE * KSE / A * COS(A * KSE) + 2. / A * X(1) (KSE)
XS(2, KSE) = - KSE * KSE / A * SIN(A * KSE) - 2. / A * X(1) (KSE)
XS(3, KSE) = - KSE ** 3 / A * COS(A * KSE) + 3. / A * X(2) (KSE)
XS(4, KSE) = - KSE ** 3 / A * SIN(A * KSE) - 3. / A * X(2) (KSE)
XS(4, KSE) = - KSE ** 4 / A * COS(A * KSE) + 4. / A * X(3) (KSE)
XS(4, KSE) = - KSE ** 4 / A * SIN(A * KSE) - 4. / A * X(3) (KSE)
XS(5, KSE) = - KSE ** 5 / A * COS(A * KSE) + 5. / A * X(4) (KSE)
XS(5, KSE) = - KSE ** 5 / A * SIN(A * KSE) - 5. / A * X(4) (KSE)
A = COS(X, Y, D) = X*D/(X*Y)
AREA(X, Y, D) = ABS CIS(X, Y, D) / 2. * (X-Y) + Y*D/2.
READ(5, 2170) NJDBS
DO 2250 NJBS=1,NJGBS
C
C READ IN VALUES AND INITIALIZE
C
READ(5,60) TITLE
PRINT 350
WRITE(6,70) TITLE
KUNTS=0
SCOE=0.
SMALL=10.*X60
RVOL=0.0
KONT=0
READ(5,10) WORDS
WRITE(6,10) WORDS
10 FORMAT(20A4)
READ(5,2170) NG,NGS,LINES,NINT,TIME,INF
WRITE(6,2170) NG,NGS,LINES, NINT,TIME,INF
ISTART=0
ISTOP=0
JTIME=JTIME*6000
CALL TIMING(ISTART)
ZN=FLOAT(NINT)
READ(5,10) WORDS
WRITE(6,10) WORDS
READ(5,2200) ((G(I,J),J=1,NG),I=1,2)
DO 30 I=1,2
DO 20 J=1,9
G(I,J)=0.
D(I,J)=0.
20 CONTINUE
30 CONTINUE
DO 50 I=1,4
DO 40 J=1,5
XABB(I,J)=0.
XABBB(I,J)=0.0
XMLS(I,J)=0.
CONTINUE
CONTINUE
CCB(1)=0.
CCB(2)=0.
SSB(1)=0.
SSB(2)=0.
FBP(1)=0.
FBP(2)=0.
BPC(1)=0.
BPC(2)=0.
READ(5,10) WORDS
WRITE(6,10) WORDS
READ(5,2160) DEN,ARP,PC(1),PC(2)
WRITE(6,2160) DEN,ARP,PC(1),PC(2)

FORMAT(18A4)
READ(5,10) WORDS
WRITE(6,10) WORDS
READ(5,2170) (NMK(1,J), J=1,9)
NMX,NDS,NBD,NP,NTEST
WRITE(6,2170) (NMK(1,J), J=1,9)
NDS=NMK(1,2)
MODE=NMK(1,3)
TEST=FLOAT(NMK(1,4))
NBD=NMK(1,5)
NUM1=NMK(1,7)
DEBUG=FLOAT(NMK(1,9))
IF(NBD.EQ.0) ISWICH=5
DBT(1)=1.
DBT(2)=1.
READ(5,10) WORDS
WRITE(6,10) WORDS
READ(5,2180) (CMK(1,J), J=1,18)
BM, AC, BC, T, DDF, DDE, FL, FD, F2, FDN, CM, SM, PT, TSD, TB
WRITE(6,2180) (CMK(1,J), J=1,18)
READ(5,10) WORDS
WRITE(6,10) WORDS
READ(5,2160) CCB(1), SSB(1), FBP(1), BPC(1)
WRITE(6,2160) CCB(1), SSB(1), FBP(1), BPC(1)
FBP(2)=-FBP(1)
BPC(2)=-BPC(1)
DESP=CMK(1,5)
IF(MODE.EQ.2) PC(1)=PC(1)+DESP
RPC1=PC(1)
SPLIM=CMK(1,6)-0.0001
DDISP=CMK(1,17)*1000.
IF(PC(1).EQ.0.0) DDISP=2.*DDISP
bM=CMK(1,1)
VSHIP=CMK(1,14)
DEFFN=CMK(1,16)
DELELF=CMK(1,8)+0.005
C ODELF IS INCREMENT OF FROUDE NUMBER AT OPTIMIZATION
UPERF=CMK(1,9)-DEFFN
C
C TEST TO SEE IF FOREBODY LINE SOURCE AND LINE DOUBLET DATA ARE
C TO BE READ IN
C
IF(NMK(1,2))80,100,80
80 READ(5,2190) (S(1,J), J=1,4)
READ(5,2190) (D(1,J), J=1,4)
WRITE(6,2190) (S(1,J), J=1,4)
WRITE(6,2190) (D(1,J), J=1,4)
DO 90 J=1,4
S(2,J)=-S(1,J)
90
DO 120 J=1,NBD
D(2,J)=D(1,J)
C
C TEST TO SEE IF CONSTRAINTS ARE TO BE READ IN
C
100 IF(NMK(1,5))110,140,110
110 DO 120 J=1,NBD
READ(5,10) WORDS
WRITE(6,10) WORDS
READ(5,2160) (ZI(J,L),L=1,4)
WRITE(6,2160) (ZI(J,L),L=1,4)
READ(5,10) WORDS
WRITE(6,10) WORDS
READ(5,2160) (ZF(J,L),L=1,4)
WRITE(6,2160) (ZF(J,L),L=1,4)
CONTINUE
READ(5,10) WORDS
WRITE(6,10) WORDS
READ(5,2170) (IL(J),J=1,10)
WRITE(6,2170) (IL(J),J=1,10)
READ(5,10) WORDS
WRITE(6,10) WORDS
READ(5,2170) (KN(J),J=1,10)
WRITE(6,2170) (KN(J),J=1,10)
M=1

C
C INSERTION OF CONSTRAINTS
C
DO 130 K=1,5
CL(I,K)=1./FLOAT(K+2)
CL(2,K)=1.
CL(3,K)=1./FLOAT(K+1)
C THIS MAKES SENSE ONLY IF DEN=-1
IF(DEN.GE.0) GO TO 130
CL(I,K)=2.*CL(I,K)
130 CONTINUE
NO=NBD
C
C TEST TO SEE IF FOREBODY SURFACE SOURCE DATA IS TO BE READ IN
C
140 IF(NMK(1,1))150,160,150
150 READ(5,2190) ((XMBB(I,J),J=1,5),I=1,4)
WRITE(6,2190)((XMBB(I,J),J=1,5),I=1,4)
FGS=FLOAT(NGS)
NMK(2,2)=0.
C TEST TO SEE IF AFTERBODY DATA SHOULD BE READ IN
C
IF(DEN)170,220,220
170 WRITE(6,180)
180 FORMAT(21H AFTERBODY INPUT DATA)
READ(5,2170) (NMK(2,J),J=1,9)
WRITE(6,2170) (NMK(2,J),J=1,9)
READ (5,2160) (CMK(2,J),J=1,18)
WRITE(6,2160) (CMK(2,J),J=1,18)
READ (5,2160) CCB(2),SSB(2),FBP(2),BPC(2)
WRITE(6,2160) CCB(2),SSB(2),FBP(2),BPC(2)
C TEST TO SEE IF AFTERBODY LINE SOURCE AND LINE DOUBLET DATA ARE TO BE READ IN
C
IF(NMK(2,2))190,200,190
190 READ (5,2190) (S(2,J),J=1,4)
WRITE(6,2190) (S(2,J),J=1,4)
READ (5,2190) (D(2,J),J=1,4)
WRITE(6,2190) (D(2,J),J=1,4)
C TEST TO SEE IF AFTERBODY SURFACE SOURCE DATA ARE TO BE READ IN
C
200 IF(NMK(2,1))210,220,210
210 READ (5,2190) ((XMSS(I,J),J=1,5),I=1,4)
WRITE(6,2190) ((XMSS(I,J),J=1,5),I=1,4)
220 CONTINUE
C
C INSERTION OF FOREBODY AND AFTERBODY LENGTHS
C
TDS(1)=1.
TDS(2)=-1.
T=CMK(1,4)
KF=1
IDEFRO=0
F=CMK(1,7)
FDN=CMK(1,10)
IF(NBD.EQ.0) GO TO 600
REZ=F-UDLF
C
C START LOOPING OVER EACH FROUDE NUMBER
C
230 GO TO (240,250),MODE
240 F=REZ+UDLF
REZ=F
PG(1)=KPC1
PG(2)=PG(1)
GO TO 260
250 PG(1)=KPC1
PG(3)=PG(1)-DESP
PG(2)=PG(1)
KPC1=PG(1)
F=CMK(1,10)
260 I$WICH=0
REZ=F
IDEFRO=0
KONIF=KONIF+1
ISAVE=0
MOREM=1
SHIPL=((VSHIP/F)**2)/32.2
VSHIP=VSHIP
PROP=(SHIPL/2.)**3
DISPL=35.*DDISP/P REP
SMALLF=10.**60
DO 270 I=1,4
ZD(1,I)=(ZF(1,I)-ZI(1,I))/ZN
ZD(2,I)=(ZF(2,I)-ZI(2,I))/ZN
270 CONTINUE
IF(MODE.EQ.2) GO TO 310
IF(KONIF.EQ.1) GO TO 310
DO 280 I=1,4
ZI(2,1)=ZE(2,1)*ODELF/0.0135+0.08
ZF(2,1)=ZF(2,1)+28.*ODELF*FLOAT(KONTF)
280 CONTINUE
290 DO 300 I=1,4
  ZI(1,I)=ZE(1,I)*ODELF/0.0152+0.05
  ZF(I,1)=ZF(I,1)+28.*ODELF*FLOAT(KONTF)
300 CONTINUE
310 GO TO(320,330),MODE
320 IF(F.LT.UPERF) GO TO 540
  IF(NMK(1,8).EQ.0) GO TO 2230
  GO TO 520
330 IF(PC(1).GT.SPLIM) GO TO 540
  IF(NMK(1,8).EQ.0) GO TO 2230
  GO TO 520
340 IF(SMALLF.GT.10.**59) GO TO 520
  WRITE(6,350)
350 FORMAT(1H1)
  WRITE(6,360) RFPC,RLRF
360 FORMAT(I8,'THE SHIP WITH SMALLEST WAVE RESISTANCE FOR SPACING OF ',
      "AND THE LENGTH OF ',F7.2,' FEET IS GIVEN BELOW',/
      "L1X,F7.3,'I8X,'AND THE LENGTH OF ',F7.2,' FEET IS GIVEN BELOW',/
      "WRITE(6,370)
370 FORMAT(/,22X,'FLOATING LINE ')
  WRITE(6,410)
  WRITE(6,380)
380 FORMAT(18X,'Y',11X,'X',10X,'Y',/
      DO 390 I=1,NUR
      WRITE(6,400) YREST(2,1,I),XREST(1),YREST(1,1,I)
390 CONTINUE
400 FORMAT(10X,3F11.3)
  WRITE(6,410)
410 FORMAT(/,12X,'PORTSIDE',18X,'STARBOARD',/
      WRITE(6,420)
420 FORMAT(11X,'Y',10X,'Z',5X,'X',6X,'Y',10X,'Z',/
      DO 440 J=2,NUR
      WRITE(6,430) XREST(J)
430 FORMAT(/,21X,F10.3,/)
DD 440 I=1,LINES
WRITE(0,450) YREST(2,1,J),ZREST(2,1,J),YREST(1,I,J),ZREST(1,I,J)  MAIN1435
440  CONTINUE  MAIN1440
450  FORMAT(1X,4F12.3)  MAIN1445
WRITE(0,460)  MAIN1450
460  FORMAT(/,9X,'AREA OF CROSS-SECTION',//)  MAIN1455
DO 470 I=1,NOR  MAIN1460
470  WRITE(0,480) XREST(I),RAREA(I)  MAIN1465
480  FORMAT(4X,F8.3,4X,F10.5)  MAIN1470
RDISPL=RDISPL*PROP/35.  MAIN1475
WRITE(0,490) SMALLF, RDISPL  MAIN1480
490  FORMAT(/,1X,'THE COEFFICIENT OF WAVE RESISTANCE FOR THIS SHIP IS  MAIN1485
1',E13.5,',/,' AND THE DISPLACEMENT IS ',F13.2,' TONS',//)  MAIN1490
PRINT 500  MAIN1495
500  FORMAT(8X,'TI',12X,'VI')  MAIN1500
WRITE(0,2190) ZRAA,ZRBB  MAIN1505
ISWICH=5  MAIN1510
ISAVE=0  MAIN1515
F=CMK(1,7)  MAIN1520
KF=1  MAIN1525
CMK(1,10)=FROUDF  MAIN1530
FDN=FROUDF  MAIN1535
SHIPL=RLFRF  MAIN1540
NMK(1,1)=1  MAIN1545
DU 510 I=1,4  MAIN1550
DU 510 J=1,5  MAIN1555
XMBB(I,J)=RXMBB(I,J)  MAIN1560
510  CONTINUE  MAIN1565
NBD=0  MAIN1570
GO TO 600  MAIN1575
520  IF(SMALL.GT.10.**59) GO TO 2260  MAIN1580
WRITE(6,350)  MAIN1585
WRITE(6,350) RLFR, RPC  MAIN1590
530  FORMAT(1X,'THE OPTIMAL SHIP FOR THE GIVEN SET OF CONSTRAINTS HAS THE LENGTH OF ',F7.2,' FEET',/,' AND THE HULL SPACING OF ',F7.2)  MAIN1595
GO TO 2230  MAIN1600
540 DO 550 I=1,4
    ZD(2,I)=ZF(2,I)-Z1(2,I)/ZN
550 ZE(2,I)=Z1(2,I)-ZD(2,I)
      SCUEF=0.0
560 DO 570 I=1,4
    ZE(2,I)=ZE(2,I)+ZD(2,I)
    ZO(1,I)=(ZF(1,I)-Z1(1,I))/ZN
    ZE(1,I)=Z1(1,I)-ZD(1,I)
    ZF1(I)=ZF(1,I)
    IF(ZE(2,I).GT.ZF(2,I)) GO TO 340
570 CONTINUE
    M=1
      KONTM=0
580 ZE(1,M)=ZE(1,M)+ZD(1,M)
      IF(ZE(1,M).LE.ZF(1,M)) GO TO 590
      GO TO (340,560),NOTI
590 IF(KONTM.GT.12) GO TO 560
      IF(ZE(1,M).LT.ZF1(M)) GO TO 600
      ZE(1,M)=ZE(1,M)-ZD(1,M)
      ZD(1,M)=ZD(1,M)/2.
      ZE(1,M)=ZE(1,M)+ZD(1,M)
600 N5=KN(M)-NBD
    DO 620 I=1,2
      DU 620 J=1,2
    DO 610 J=1,5
      CCL(I,J)=0.
610 DU 620 J=1,5
      CCR(I,J)=0.
620 CONTINUE
C INDICATES WHICH ELEMENT IS OPTIMIZED
C
LI=IL(M)
LJ=LJ
LIJ=LJ-4
IF(LI.J.LE.0) GO TO 630
LI=LJ
C GENERATE MATRICES FOR COEFFICIENT SOLUTION

630 DO 640 J=1,NBD
     DO 640 K=1,NBD
640 CCL(J,K)=CL(J,K)
     DO 650 K=1,N5
     KL=K+NBD
650 CCR(J,K)=-CL(J,KL)
     CCR(1,N5+1)=1.
     CCR(2,N5+2)=1.
     IF(NBD-1)670,670,660
660 CALL TEJSEN (CCL,NBD,CCR,5,Q,1D)
     GO TO (690,2020),1D
670 DO 680 K=1,5
680 CCR(1,K)=CCR(1,K)/CCL(1,1)
     CONTINUE
C

700 R=.5/(F+F)
     IF(M.EQ.1) WRC=0.0
     IF(ISAVE.NE.0) GO TO 720
     DO 710 I=1,350
     DO 710 J=1,6
     RASTH(I,J)=0.
     RACTH(I,J)=0.
710 CONTINUE
720 DO 740 I=1,350
     ASSS(I)=0.0
     ACSS(I)=0.
     ACCL(I)=0.
     ASS(I)=0.
     ASLS(I)=0.
     ACLS(I)=0.
     ASLO(I)=0.
     ACLUD(I)=0.
     CONTINUE
DO 730 J=1,6
ASTH(I,J)=0.
ACTH(I,J)=0.
730 CONTINUE
740 CONTINUE
DO 750 I=1,3
CSK(I,1)=0.
DO 750 J=1,3
CSL(I,J)=0.
750 CONTINUE
WK=0.
WRF=0.
WKS=0.
CGSR=0.

C INITIAL THETA AND DELTA THETA VALUE.

C
UTETA=0.0
JA=0
DO 1280 IE=1,106
IF(IE.EQ.1) GO TO 760
UTETA=TETALM
760 DARG=FLOAT(IE)*1.5708
TETALM=(-R*PC(1)+SQRT(PC(1)*R*R*PC(1)+4.*DFD*DARG))/2./DARG
TETALM=AR SIN(TETALM)
DFD=(TETALM-UTETA)/3.
IF(IE.LT.3) DFD=DFD/2.
IF(IE.EQ.1) DFD=DFD/4.
IF(IE.EQ.1) DN=-DFD
770 DN=DN+DFD
IF(DN.LT.TETALM) GO TO 780
DN=TETALM
GO TO 1280
C
C JA COUNTS THETA ANGLE
C
C
C
C
BEGIN CALCULATION OF AC(THETA) AND AS(THETA)

780
CB=COS(DN)
JA=JA+1
ACB(JA)=CB

CURRENT THETA AND DELTA THETA VALUE

THDN(JA)=DN
OFF(JA)=DFD
IF(ISAVE.NE.0) GO TO 1150

FOLLOWING SETS UP INTEGRATION INTERVAL IN X DIRECTION.

A=R/GB
B=A/GB
V=-B*CMK(1,4)
W=1./V
E=EXP(V)

ANALYTIC PART OF SURFACE SOURCE INTEGRATION TO DEPTH T OVER FOREBODY

Z(1,1)=1.-E
Z(1,2)=-1./B*(1.-W)*CMK(1,4)*E
Z(1,3)= 2./B/B-((W-1.)*2.*W+1.)*CMK(1,4)**2*E
Z(1,4)=-6./B/B/B-((W-1.)*6.*W+3.)*W-1.)*CMK(1,4)**3*E
Y=EXP(-B*CMK(1,18))
YZ=-1./B/CMK(1,18)

ANALYTIC PART OF LINE SOURCE AND LINE DOUBLET INTEGRATION TO DEPTH T OVER THE FOREBODY

ZB(1,1)=1.-Y
ZB(1,2)=-1./B*(1.-YZ)*CMK(1,18)*Y
IF(LJ.GT.3) GO TO 1050
IF(DEN.LT.0.) GO TO 830
IF(CMK(1,1).EQ.0.0) GO TO 1010

830 X=TDS(1)
840 I=1
850 I=2
860 XBAR=ABS(X/TDS(1))

C
C SLOPE OF ETA SURFACE. PURPOSE OF THE FOLLOWING IS TO CHOOSE A DX
C SUCH THAT THE PERIOD OF THE THETA FUNCTION IS GREATER THAN DX.
C
C DFER=DBK*(-3.*EN*(1.-AC-BC)*XBAR**(3*N-1)-2.*EN*BC*XBAR**(2*N-1)+A
1-EN*AC*XBAR**(NP-1))
ADEC=ABS(DFER)
DX=-FQS/ADER
IF(DX.LT.-.3) DX=-.3
XE=X+DX
IF(XE.LT.DEN) XE=DEN
DX=X-XE

C
C BEGIN THE GAUSSIAN LOOP.
C
C DO 1000 KG=1,NG
C GQ IS THE X COORDINATE.
C GQ=X-DX*G(1,KG)
I=1
870 IF(GQ)870,880,880
880 I=2
890 DO=TDU(1)
890 QQ=GQ/DST
CM=CMK(1,11)
SM=CMK(1,12)
T=CMK(1,4)
TB=CMK(1,18)
IF(QQ)1000,1000,890
QK=QQ*A
FF=QQ**NMK(1,6)
TE=CMK(1,1)*(1-((1.-CMK(1,2)-CMK(1,3))*FF+CMK(1,2))*FF+CMK(1,3))
1*FF+PC(1)
BATA=TE*ATD
QNS=SIN(BATA)
QNC=COS(BATA)
SNQ=QNS*G(2,KG)*DX
CNQ=QNC*G(2,KG)*DX
CPS=COS(QR)
SEQ=SIN(QR)

C
CALCULATION OF AC(THETA) AND AS(THETA) FOR SOURFACE SOURCE.
C
IF(NMK(1,1))900,960,900
900 GO TO (910,930),1
C
C FOREBODY
C
910 DO 920 L=1,4
FM=((XMBB(L,5)*QQ+XMBB(L,4))*QQ+XMBB(L,3))*QQ+XMBB(L,2))*QQ+
1XMBB(L,1))*QQ
CST=FM*Z(I,L)*CNQ/DST
ACSS(JA)=ACSS(JA)+CEQ*CST
920 ASSS(JA)=ASSS(JA)+SEQ*CST
GO TO 950
C
C AFTERBODY
C
930 DO 940 L=1,4
FM=((XMSS(L,5)*QQ+XMSS(L,4))*QQ+XMSS(L,3))*QQ+XMSS(L,2))*QQ+
1XMSS(L,1))*QQ
CST=FM*Z(I,L)*CNQ/DST
ACSS(JA)=ACSS(JA)+CEQ*CST
940 ASSS(JA)=ASSS(JA)+SEQ*CST
950 CONTINUE
IF(NBD.980,1000,970)

C BUILDUP OF MATRIX IF DISTRIBUTION E1-E8 IS TO BE OPTIMIZED STEP 1

970 IF(GQ).1000,980,980
980 IF(LIJ,.GT.,0) GO TO 1000
DO 990 K=1,5
QQN=QQ**K*CNQ/DST
SON=QON*SEQ*SM
CON=QON*CEQ*CM
RACTH(JA,K)=RACHT(JA,K)+CON*Z(1,LI)
990 RASTH(JA,K)=RASTH(JA,K)+SON*Z(1,LI)
1000 CONTINUE
C END OF GAUSSIAN LOOP.
C
X=XE
100 IF(X-DEN).1050,1050,840
C
C GO BACK AND INCREASE X
C
1010 IF(CM.EQ.,0,0) GO TO 1030
RASTH(JA,1)=(XC1(1,1)-XC1(0,1))*QNC*CM*Z(1,LI)
RASTH(JA,2)=(XC2(1,1)-XC2(0,1))*QNC*CM*Z(1,LI)
RASTH(JA,3)=(XC3(1,1)-XC3(0,1))*QNC*CM*Z(1,LI)
RASTH(JA,4)=(XC4(1,1)-XC4(0,1))*QNC*CM*Z(1,LI)
RASTH(JA,5)=(XC5(1,1)-XC5(0,1))*QNC*CM*Z(1,LI)
1030 CONTINUE
IF(NBD.NE.0) GO TO 1050
ASSS(JA)=0.0
DO 1040 L=1,4
  DU 1040 K=1,5
1040 ASSS(JA)=ASSS(JA)+RASTH(JA,K)*XMBB(L,K)/SM
1050 IF(NBD.NE.0) GO TO 1120
DU 1030 I=1,2
IF(NMK(I,2).NE.1080,1080,1060
C C RESISTANCE CAUSED BY LINE SOURCE AND LINE DOUBLET CALCULATIONS
C WHEN VALUES ARE KNOWN
C 1060 TWP=6.2832
  INTE=(A*FBP(I))/TWP
  ARG=A*FBP(I)-FLOAT(INTE)*TWP
  SEQ=SIN(ARG)
  CEQ=COX(ARG)
  BATA=PC(I)*ATD
  INEH=BATA/TWP
  BATA=BATA-FLOAT(INEH)*TWP
  CNQ=COX(BATA)
  DU 1070 L=1,4
  CST=S(I,L)*ZB(I,L)*CNQ*DBT(I)
  S(I,8)=S(I,8)+CEQ*CST
  S(I,9)=S(I,9)+SEQ*CST
  CST=D(I,L)*ZB(I,L)*CNQ*A
  D(I,8)=D(I,8)-SEQ*CST
  D(I,9)=D(I,9)+CST*CEQ
1070 D(I,9)=D(I,9)+CST*CEQ
1080 CONTINUE
C C SUMMATION OF RESISTANCE CAUSED BY SURFACE SOURCE, LINE SOURCE AND
C LINE DOUBLET
C C AC1=ACSS(JA)
AC2=(S(I,8)+D(I,8))*CCB(I)+(S(2,9)+D(2,9))*CCB(2)
AS2=(S(I,9)+D(I,9))*SSB(I)+(S(2,9)+D(2,9))*SSB(2)
ACC(JA)=AC1*CM+AC2
ACCF=AC1+Si(1,8)+D(1,8)
AS1=ASSS(JA)
ASS(JA)=AS1*SM+AS2
ASSF=AS1+Si(1,9)+D(1,9)
ASSG=AS1+Si(1,9)+D(1,9)*2.
ALLD(JA)=D(1,8)+D(2,8)
ASLD(JA)=D(1,9)+D(2,9)
ACLs(JA)=Si(1,8)+S(2,8)
ASLS(JA)=Si(1,9)+S(2,9)

C
C VALUES OF WAVE RESISTANCES
C
IF(JA.EQ.1) GO TO 1090
WRJ=WRN
WRFU=WRFN
WSO=WRSN
1090 WRN=(ACC(JA)*ACC(JA)+ASS(JA)*ASS(JA))*ACB(JA)
WRFN=(ACCF*ACCF+ASSF*ASSF)*ACB(JA)
WSN=(ASSG*ASSG)*ACB(JA)
IF(JA.EQ.1) GO TO 770
IF(SIG(1,WRO).EQ.SIG(1,WRN)) GO TO 1100
WR=WR+ARE(A(WRO,WRN,DFD)
GO TO 1110
1100 WR=WR+(WRO*WRN)*DFC(JA)/2.
1110 WRF=WRF+(WRFU+WRFN)*DFC(JA)/2.
WRS=WRS+(WSO+WRSN)*DFC(JA)/2.
GO TO 770
1120 IF(LJ=8)1150,1150,1130
C
C BUILDUP MATRIX FOR OPTIMIZATION OF E9, E10 STEPl
C
1130 BSS=SEQ*CNQ
BCC=CEQ*CNQ
DO 1140 J=1,4
RASTH(JA,J)=BSS*SSB(1)*ZB(1,J)

M1N3235
M1N3240
M1N3245
M1N3250
M1N3255
M1N3260
M1N3265
M1N3270
M1N3275
M1N3280
M1N3285
M1N3290
M1N3295
M1N3300
M1N3305
M1N3310
M1N3315
M1N3320
M1N3325
M1N3330
M1N3335
M1N3340
M1N3345
M1N3350
M1N3355
M1N3360
M1N3365
M1N3370
M1N3375
M1N3380
M1N3385
M1N3390
M1N3395
M1N3400
M1N3405
M1N3410
\begin{verbatim}
1140  RACTH(JA,J)=BCC*CGB(1)*ZB(1,J)
C
C BUILDUP MATRIX FOR OPTIMIZATION OF E1-E10 STEP 2
C
1150  DO 1160 K=1,5
       ACH(JA,K)=RACTH(JA,K)
       ASTH(JA,K)=RASTH(JA,K)
1160  CONTINUE
       DO 1170 K=1,NBD
       DO 1170 J=1,NBD
       KJ=NS+J
       ASS(JA)=ASS(JA)+CCK(K,J)*ZE(J,LJ)*ASTH(JA,K)
1170  ACC(JA)=ACC(JA)+CCK(K,J)*ZE(J,LJ)*ACTH(JA,K)
       DO 1180 J=1,N5
       KL=NBD+J
       ASTH(JA,KL)=ASTH(JA,KL)+ASTH(JA,K)*CCK(K,J)
1180  ACH(JA,KL)=ACTH(JA,KL)+ACTH(JA,K)*CCK(K,J)
       CONTINUE
       IN=N5
       IF(JA.EQ.1) GO TO 1200
       CCSK=CCSKN
       1200  CSSRN=(ACC(JA)*ACC(JA)+ASS(JA)*ASS(JA))*ACB(JA)
       IF(JA.EQ.1) GO TO 1210
       CCSR=CSSR+(CSK+CSSRN)*DFF(JA)/2.
1210  DO 1270 JB=1,IN
       NH=NBD+JB
       IF(JA.EQ.1) GO TO 1220
       CSRO(NH)=CSR(NH)
       1220  CSR(NH)=(ACC(JA)*ACTH(JA,NH)+ASS(JA)*ASTH(JA,NH))*ACB(JA)
       IF(JA.EQ.1) GO TO 1240
       IF(SIGN(1.,CSRO(NH)).EQ.SIGN(1.,CSR(NH))) GO TO 1230
       CSR(JB,1)=CSR(JB,1)-AREA(CSR(NH),CSR(NH),DFD)
       GO TO 1240
1230  CSR(JB,1)=CSR(JB,1)-(CSRO(NH)+CSR(NH))*DFF(JA)/2.
1240  DO 1270 JD=1,IN
       ND=JD+NBD
\end{verbatim}
IF(JA.EQ.1) GO TO 1250
C SLN(NH,ND)=C SLN(NH,ND)
1250 C SLN(NH,ND)= (ACTH(JA,NH)*ACTH(JA,ND)+ASTH(JA,NH)*ASTH(JA,ND))*
LAG(JA)
IF(JA.EQ.1) GO TO 1270
IF(SIGN(1,C SLN(NH,ND)) .EQ. SIGN(1,C SLN(NH,ND))) GO TO 1260
C SL(JB, JD)=C SL(JB, JD)+AREA(C SLN(NH,ND),C SLN(NH,ND),DFD)
GO TO 1270
1260 C SL(JB, JD)=C SL(JB, JD)+(C SLN(NH,ND)+C SLN(NH,ND))*OFF(JA)/2.
1270 CONTINUE
GO TO 770
1280 CONTINUE
C INTEGRATION IS COMPLETED.
C JJ=JA
IF(NBD)1740,1340,1740
1290 NMK(1,1)=0
IF(SMALL.LT.WRC) GO TO 1300
SMALL=WRC
RVOL=VOL
RPG=PC(1)
FRJUDE=F
RLFR=SHIPL
ZKA=ZE(1,M)
ZRB=ZE(2,M)
1300 IF(SMALLF.LE.WRC) GO TO 1330
SMALLF=WRC
KDISPL=VOL
FRUDF=F
RFPC=PC(1)
RLFRF=SHIPL
ZKAA=ZE(1,M)
ZRB0=ZE(2,M)
DU 1310 I=1,4
DU 1310 J=1,5
RXMBB(I,J)=XMBB(I,J)
CONTINUE
NOR=NS(1)
DO 1320 J=1,NOR
XRIST(J)=XLINE(1,1,J)
KAREA(J)=AAREA(J)
DO 1320 I=1,LINES
YREST(I,1,J)=YLINE(1,1,J)
YREST(2,I,J)=YLINE(2,1,J)
ZREST(I,1,J)=ZLINE(1,1,J)
ZREST(2,I,J)=ZLINE(2,1,J)
CONTINUE
1330 NB0=NMK(1,5)
DELTA=MU(1,M)
GO TO (340,350), NOTI
C THESE NUMBERS ARE DIVIDED BY 2 FOR SAME REASON AS WRC IS DIVIDED BY 2
1340 WRCI(KF)=WRI/6.2832/2.
WRFIA(KF)=WRI/6.2832/2.
WRCI(KF)=WRI/6.2832/2.
FKF(KF)=F
IF(CMK(1,13))1350,1470,1350
1350 FDF=AABS(F-CMK(1,10))
IF(FDF-.001)1350,1470,1470
1360 DO 1380 JA=1,JJ
EXA=ACBJA*5/3.1416
ACC(JA)=ACC(JA)*EXA
ASS(JA)=ASS(JA)*EXA
ACSA(JA)=ACSA(JA)*EXA
ASSA(JA)=ASSA(JA)*EXA
ACD(JA)=ACD(JA)*EXA
ASD(JA)=ASD(JA)*EXA
ACD(JA)=ACD(JA)*EXA
ASD(JA)=ASD(JA)*EXA
IF(ARP)1380,1350,1370
1370 AARP=R/ACBJA*ARP
CARP=COS(AARP)
SARP=SIN(AARP)
ACCT(JA)=ACCT(JA)*CARP
ASS(JA)=ASS(JA)*SARP
AGSS(JA)=AGSS(JA)*CARP
ASS(JA)=ASS(JA)*SARP
ALSF(JA)=ALSF(JA)*CARP
ASLS(JA)=ASLS(JA)*SARP
ACLQ(JA)=ACLQ(JA)*CARP
ASLD(JA)=ASLD(JA)*SARP
WRITE(6,70) TITLE
1360 CONTINUE
WRITE(6,1390) FDN,ARP
1390 FORMAT(5DH WEIGHTED FREE WAVE AMPLITUDES AT FROUDE NUMBER = F8.5, MAIN4015
125H CENTER OF ORIGINE AT X = F8.5)
WRITE(6,1400) SM,SSB(1),CCB(1)
IF(DEN.GE.0.0) GO TO 1410
WRITE(6,1400) SM,SSB(2),CCB(2)
1400 FORMAT(34H MULTIPLICATION FACTORS SM=F6.3,7H SSB=F6.3,8H MAIN4040
1 CCB=F6.3)
1410 WRITE(6,1420)
1420 FORMAT(60H SINE COMPONENTS TIMES ONE AND A HALF POWER OF COSINE THMAIN4055
1 ETA /)
WRITE(6,1430)
1430 FORMAT(64H THETA IN TOTAL SURFACE LINE MAIN4070
1 LINE,/, 266H DEGREES COMPONENT SOURCE SOURCE DOUBL MAIN4080
3ET,)
WRITE(6,2210) (THDN(J),ASS(J),ASSS(J),ASLS(J),ASLD(J), J=1,JJ)
WRITE(6,1440)
1440 FORMAT(39H COSINE COMPONENTS TIMES ONE AND A HALF POWER OF COSINE MAIN4100
1 ETA /)
WRITE(6,1450) CM,CCB(1),SSB(1)
IF(DEN.GE.0.0) GO TO 1450
WRITE(6,1450) CM,CCB(2),SSB(2)
1450 FORMAT(34H MULTIPLICATION FACTORS CM=F6.3,7H CCB=F6.3,8H MAIN4125
1 SSB=F6.3)
WRITE (6, 1430)  
WRITE (6, 2210) (THDN(J), ACC(J), ACSS(J), ACLS(J), ACLD(J), J=1, JJ)  
F=F+CMK(1, 8)  
IF (IDEFRU.NE.0) GO TO 1495  
IF (F-CMK(1, 9)) 1480, 1480, 1490  
KF=KF+1  
GO TO 700  
1490 IDEFRU=1  
F=REZ  
GO TO 700  
1495 IF (NMK(1, 8).NE.0) WRITE (6, 350)  
WRITE (6, 70) TITLE  
WRITE (6, 1500)  
1500 FORMAT (55H VALUES OF NXM, NDS, NBD, NP, NTEST)  
WRITE (6, 2170) (NMK(1, J), J=1, 9)  
IF (DEN.GE.0.) GO TO 1510  
WRITE (6, 2170) (NMK(2, J), J=1, 9)  
1510 WRITE (6, 1520)  
1520 FORMAT (54H VALUES OF DEN, ARP, PC(1), PC(2))  
WRITE (6, 2160) DEN, ARP, PC(1), PC(2)  
WRITE (6, 1530)  
1530 FORMAT (1X, 'VALUES OF BM, AC, BC, T, DESP, SPLIM, F1, FD, F2')  
WRITE (6, 2160) (CMK(1, J), J=1, 9)  
IF (DEN.GE.0.) GO TO 1540  
WRITE (6, 2160) (CMK(2, J), J=1, 9)  
1540 WRITE (6, 1550)  
1550 FORMAT (55H VALUES OF FDN, CM, SM, PT, TSD, T8)  
WRITE (6, 2160) (CMK(1, J), J=10, 18)  
IF (DEN.GE.0.) GO TO 1560  
WRITE (6, 2160) (CMK(2, J), J=10, 18)  
1560 WRITE (6, 1570)  
1570 FORMAT (54H VALUES OF CCB, SSB, FBP, BPC)  
WRITE (6, 2160) CCB(1), SSB(1), FBP(1), BPC(1)  
WRITE (6, 2160) CCB(2), SSB(2), FBP(2), BPC(2)  
WRITE (6, 1580)  
1580 FORMAT (51H VALUES OF SURFACE SOURCE DISTRIBUTION COEFFICIENTS)
WRITE(6,2180) ((XMBB(I,J),J=1,5),I=1,4)
WRITE(6,2180) ((XMSJ(I,J),J=1,5),I=1,4)
WRITE(6,1590)

1590 FORMAT(48H VALUES OF LINE SOURCE DISTRIBUTION COEFFICIENTS)
WRITE(6,2180) (S(I,J),J=1,4)
WRITE(6,2180) (S(2,J),J=1,4)
WRITE(6,1600)

1600 FORMAT(49H VALUES OF LINE DOUBLET DISTRIBUTION COEFFICIENTS)
WRITE(6,2180) (D(I,J),J=1,4)
WRITE(6,2180) (D(2,J),J=1,4)
WRITE(6,1610)

1610 FORMAT(24H LIST OF FROUDE NUMBERS)
WRITE(6,2180) (FKF(J),J=1,4)
WRITE(6,1620)

1620 FORMAT(44H LIST OF WAVE MAKING RESISTANCE COEFFICIENTS)
WRITE(6,2180) (WRCT(J),J=1,4)
VULM=0.
BEAM=0.
DO 1630 LB=1,4
XLB=FLOAT(LB)
DO 1630 K=1,5
XLK=FLOAT(K)
BEAM=BEAM*XMBB(LB,K)/XLB/(XLK+1)
VULM=VULM+XMBB(LB,K)/(XLB*(XLK+2))
VULM=VULM**2
IF(RVOL.NE.0.0) VLOM=RVOL
DO 1640 J=1,4
WRCT(J)=WRCT(J)/VLOM
WRITE(6,1650)

1650 FORMAT(53H LIST OF SPECIFIC WAVE MAKING RESISTANCE COEFFICIENTS)
WRITE(6,2180)(WRCT(J),J=1,4)
IF(JEN)230,1650,1660
WRITE(6,1670)

1660 WRITE(6,1670)

1670 FORMAT(53H LIST OF WAVE MAKING RESISTANCE COEFFICIENTS, FOREBODY ALONE)
WRITE(6,2180) (WRCTB(J),J=1,4)
WRITE(6,1680)
1680 FORMAT(54H LIST OF WAVE MAKING RESISTANCE COEFF. SYMETRICAL SHIP) MAIN4475
WRITE(6,2180) (WRCTS(J),J=1,KF) MAIN4480
WRITE(6,1990) MAIN4485
WRITE(6,1690) MAIN4490
1690 FORMAT(2X,'X','X','6X,'1.0','5X,'0.9','5X,'0.8','5X,'0.7','5X,'0.6','5X,'0.5' MAIN4495
Y=CMK(1,4)/FLOAT(LINES-1) MAIN4500
DO 1730 I=1,LINES MAIN4505
Y=Y-CMK(1,4)/FLOAT(LINES-1) MAIN4510
X=1.1 MAIN4515
DO 1710 J=1,11 MAIN4520
X=X-0.1 MAIN4525
XZ(I,J)=0.0 MAIN4530
DO 1700 L=1,4 MAIN4535
1F(L.EQ.1) ZL=1 MAIN4540
1F(L.EQ.1) GO TO 1700 MAIN4545
2L=2Y***(L-1) MAIN4550
1700 XZ(I,J)=XZ(I,1)+((XMBB(L,5)*X+XMBB(L,4))*X+XMBB(L,3))*X+XMBB(L,2) MAIN4555
1))**X+XMBB(L,1)**X**ZL MAIN4560
1710 CONTINUE MAIN4565
WRITE(6,1720) Y,(XZ(I,J),J=1,11) MAIN4570
1720 FORMAT(1X,F5.3,1X,11(F7.3,1X)) MAIN4575
1730 CONTINUE MAIN4580
NMK(1,1)=0 MAIN4585
NB0=NMK(1,5) MAIN4590
1F(NB0.EQ.0) GO TO 2230 MAIN4595
1F(PC(1).EQ.3.) GO TO 230 MAIN4600
1F(1FIN.EQ.0) GO TO 230 MAIN4605
PC(1)=3 MAIN4610
PC(2)=PC(1) MAIN4615
1DEFRU=0 MAIN4620
GO TO 2010 MAIN4621
1740 IF(DEBG.EQ.0.0) GO TO 1760 MAIN4625
WRITE(6,1750) MAIN4630
1750 FORMAT(38H SINGULARITY DISTRIBUTION COEFFICIENTS) MAIN4635
WRITE(6,2220) MAIN4640
1760 FORMAT(1X,S17.15) MAIN4645
C SOLVE FOR OPTIMUM SINGULARITY DISTRIBUTION.

1760 CALL TEJSEN(CSL,IN,CSR,1,Q,ID)
GOTO(1770,2020),ID
1770 IF(LI-5)1780,1840,1860
1780 L=LI
   DO 1790 K=1,5
      XMIB(L,K)=0.
   CONTINUE
   DO 1800 K=1,N5
      KJ=NBD+K
      XMIB(L,KJ)=CSR(K,1)+XMIB(L,KJ)
   CONTINUE
      DO 1820 K=1,NBD
      DO 1810 J=1,N5
         XMIB(L,K)=CCR(K,J)*CSR(J,1)+XMIB(L,K)
   CONTINUE
      DO 1820 J=1,NBD
      DO 1810 J=N5+J
         XMIB(L,K)=XMIB(L,K)+CCR(K,KJ)*ZE(J,LI)
   CONTINUE
      DO 1830 J=1,5
         SCUEF=SCUEF+XMIB(M,J)
      CONTINUE
      IF(SCUEF.LT.0.0) GOTO 290
   CONTINUE
1840 GO TO 1830
1850 S(L,KJ)=CSR(K,1)
   IF(DEBUG.EQ.0.0) GOTO 1880
   WRITE(6,2180) (S(I,J),J=1,4)
   GOTO 1880
1860 GO TO 1870
1870 D(L,KJ)=CSR(K,1)
   IF(DEBUG.EQ.0.0) GOTO 1880
   WRITE(6,2180) (D(I,J),J=1,4)
1880 CONTINUE
   WRK=0.
DO 1920 J=1, JJ
  WAC=0.
  WAS=0.
  DO 1890 K=1, IN
    KJ=NBD+K
    WAC=WAC+CSR(K,1)*ACTH(J,KJ)
    WAS=WAS+CSR(K,1)*ASTH(J,KJ)
    WAC=WAC+ACC(J)
    WAS=WAS+ASS(J)
  IF(J.EQ.1) GO TO 1900
  WKJ=WKN
  1900
    WRN=(WAC+WAC+WAS)*ACB(J)
  IF(J.EQ.1) GO TO 1920
  IF(SIGN(1.,WKD).EQ.SIGN(1.,WRN)) GO TO 1910
  WR=WK+AKEA(WKD,WRN,ACB(J))
  GO TO 1920
  1910
    WR=(WRN+WKD)*DFJ/2.+WR
  1920 CONTINUE
    WR=WWR/6.2832+WRC
  C IT CAN BE SHOWN THAT RW=RO*VR*2*WRC; IF CW IS DEFINED SO THAT
  C RW=0.5*VR*2*VR*2*CW, THEN AS A RESULT OF THESE TWO RELATIONS
  C CW=VR*VR/L*2, BUT L=2 THEREFORE CW=WRC/2
    WRC=WRC/2.
  IF(NMK(1,3).EQ.0) WRITE(6,1930) F,PC(1),WRC,ZE(1,M),ZE(2,M)
  1930 FORMAT(1X,'FROUDE NO.=',F5.3,' HULL SP.=',F5.2,' WAVE RESIST.
        LCoeff.=',E11.3,'/1X,' VI=',F5.3,' T1=',F6.3)
  C
  C
    IF(DEBUG.EQ.0,0) GO TO 2000
    PRINT 1940
  1940 FORMAT(LUX,'LIST OF MATRICES USED FOR CALCULATION OF OPTIMAL COEFF.
        L1CLIENTS')
    WRITE(6,2180) ((CSR(J,K),J=1,IN),K=1,IN)
    WRITE(6,2180) (CSR(J,1),J=1,IN)
    WRITE(6,2180) CCSR
  DO 1950 I=1,II
  1950
SXB(I)=0.
DXX(I)=0.
DU 1950 J=1,21
XZ(I,J)=0.
CONTINUE
1950  CONTINUE
Y=-0.11
DU 1960 KZ=1,11
Y=Y+.01
DU 1960 L=1,4
ZL=Y*(L-1)
SXB(KZ)=SXB(KZ)+ZL*S(1,L)
DXX(KZ)=DXX(KZ)+ZL*D(1,L)
X=L.1
DU 1960 KX=1,21
X=X-0.1
IF(XLT.DEN) GO TO 1960
KX=KX
1960  XZ(KZ,KX)=XZ(KZ,KX)+(X(XMBB(L,5)*X+XMBB(L,4))*X+XMBB(L,3))*X+XMBB
WRITE(6,1970)
WRITE(6,1970)
1970  FORMAT(26H LINE SOURCE DISTRIBUTION )
WRITE(6,2180) (SXB(J),J=1,11)
WRITE(6,1980)
WRITE(6,1980)
1980  FORMAT(27H LINE DOUBLET DISTRIBUTION )
WRITE(6,2180) (DXX(J),J=1,11)
WRITE(6,1990)
WRITE(6,1990)
1990  FORMAT(29H SURFACE SOURCE DISTRIBUTION )
WRITE(6,2180) (XZ(J,K),K=1,KK),J=1,11)
2000  M=M+1
IF(M.EQ.05) GO TO 2010
IF(M.EQ.0) GO TO 2000
GO TO (280,600),M0REM
2010  N0D=0
NNK(I,1)=1
M=1
IF(NMK(1,8) .NE. 0) GO TO 2040
ISWICH=5
ISAVE=0
F=CMK(1,7)
KF=1
NMK(1,1)=1
NBD=0
GO TO 600

2020 WRITE(6,2030)
2030 FORMAT(27H THIS MATRIX IS SINGULAR- I8)
GO TO 580
2040 CALL OFFSET(XLINE,YLINE,ZLINE)
   IF(IRED.EQ.7) GO TO 2280
   ISAVE=ISAVE+1
   MUKEM=1
   DO 2050 I=2,4
   IF(IL(I).NE.0) ISAVE=0
   2050 CONTINUE
   VOL=0.
   IF(IRED.EQ.0) GO TO 2070
   WRITE(6,2170) IRED
   NMK(1,1)=0
   NBD=NMK(1,5)
   KONTM=KONTM+1
   IF(IRED.EQ.3) GO TO 580
   DO 2060 I=1,4
   ZE(I,1)=ZE(I,1)-ZD(I,1)
   ZD(I,1)=ZD(I,1)/2.
   ZE(I,1)=ZE(I,1)+ZD(I,1)
   2060 CONTINUE
   MUKEM=2
   GO TO 600
2070 CALL VOLUME(XLINE,YLINE,ZLINE,VOL,AAREA)
   IF(TEST.EQ.0.0) GO TO 2120
   PRINT 370
   PRINT 2080
2080 FORMAT(6X,'X',12X,'Y',12X,'Z',/)        MAIN5370
  DU 2090 MKL=1,2     MAIN5375
  NO=NS(1)           MAIN5380
  DU 2090 I=1,NO     MAIN5385
  WRITE(6,2200) XLINE(MKL,1,I),YLINE(MKL,1,I),ZLINE(MKL,1,I)  MAIN5390
2090 CONTINUE      MAIN5395
  PRINT 2100        MAIN5400
2100 FORMAT(6X,'THE OFFSETS AT EACH CROSS-SECTION',/)  MAIN5405
  DU 2110 J=2,NO    MAIN5410
  WRITE(6,2170) J   MAIN5415
  DU 2110 I=1,LINES MAIN5420
  WRITE(6,2200) XLINE(1,I,J),YLINE(1,I,J),ZLINE(1,I,J),XLINE(2,I,J),  MAIN5425
  YLINE(2,I,J),ZLINE(2,I,J)        MAIN5430
2110 CONTINUE      MAIN5435
  PRINT 2320        MAIN5440
  WRITE(6,2180)DISPL,VOL,ZE(1,M),ZE(2,M),WRC     MAIN5445
  GO TO 2340        MAIN5450
2120 KNTM=KNTM+1    MAIN5455
  DIF=DISPL-VOL     MAIN5460
  releu=ABS(DIF)/DIF MAIN5465
  KNTS=KNTS+1       MAIN5470
  UUJFF(1,KNTS)=DISPL MAIN5475
  UUJFF(2,KNTS)=VOL  MAIN5480
  UUJFF(3,KNTS)=ZE(1,M) MAIN5485
  UUJFF(4,KNTS)=ZE(2,M) MAIN5490
  UUJFF(5,KNTS)=WRC  MAIN5495
  CALL TIMING(ISTOP) MAIN5500
  ITIM=ISTOP-ISTART MAIN5505
  MYTIME(KNTS)=ITIM  MAIN5510
  IF(ITIM.GT.JTIME) GO TO 2300 MAIN5515
  RATIO=ABS(DIF)/DISPL MAIN5520
  IF(RATIO.LT.0.05) GO TO 1290 MAIN5525
  ND=NMK(1,5)       MAIN5530
  NMK(1,1)=0        MAIN5535
  IF(RELEU.EQ.1.0) GO TO 580 MAIN5540
  IF(KNTM.GT.1) GO TO 2140 MAIN5545
DO 2130 I=1,4
   ZE(2,I)=ZE(2,1)-ZE(2,1)/8.
   ZE(1,I)=ZE(1,1)-ZE(1,1)/8.
2130 CONTINUE
   MOREM=2
   KOUTM=0
   GO TO 600
2140 DO 2150 I=1,4
   ZFL(I)=ZE(I,1)-0.0000001
   ZE(I,1)=ZE(I,1)-ZD(I,1)
   ZD(I,1)=ZD(I,1)/2.
   ZE(I,1)=ZE(I,1)+ZD(I,1)
2150 CONTINUE
   MOREM=2
   GO TO 600
2160 FORMAT(9F8.5)
2170 FORMAT(9I8)
2180 FORMAT(5E19.8)
2190 FORMAT(5F14.8)
2200 FORMAT(5F12.8)
2210 FORMAT(F9.9,3X,F13.4,3X,F31.8)
2220 FORMAT(1X,'AFTER OPTIMIZATION OF E","I2)
2230 WRITE(6,2240)
2240 FORMAT(1X,'END OF JOB REACHED THROUGH PROGRAM CONTROL')
2250 CONTINUE
   GO TO 2340
2260 PRINT 2270
2270 FORMAT(1X,'NO SUITABLE SHIP CAN BE FOUND IN ALLOWED RANGE FOR MAINS')
   CONTINUE
   GO TO 2300
2280 WRITE(6,2290)
2290 FORMAT(1X,'SPEED U IS NEGATIVE, INCREASE VALUE OF Z1(M,1)')
   GO TO 2340
2300 WRITE(6,2310)
2310 FORMAT(1X,'THE TIME IS OVER, SOME RELEVANT PARAMETERS ARE GIVEN BY MAINS')
   CONTINUE
   GO TO 2300
2320 WRITE(6,2340)
2330 FORMAT(1X,'AMONG THEM IS GIVEN THE TIME ')
WRITE(0,2320)
2320 FORMAT(7X,'REQUIRED VOL',6X,'ACTUAL VOLUME',12X,'ZE(1,M)',12X,'ZE(MAIN5735'
12,M)',4X,'WAVE RESIST. COEFF.')
DO 2330 J=1,KONTS
    WRITE(0,2180) (OOGFF(K,J),K=1,5)
    WRITE(0,2170) MYTIME(J)
2330 CONTINUE
2340 CONTINUE
STOP
END
SUBROUTINE TEJSEN(A,N1,B,M1,INDEX,ID)
C MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS
C
C DOUBLE PRECISION A,B,PIVOT,T,DABS,AMAX,SWAP
C DIMENSION A(N1,N1),B(N1,M1),INDEX(N1,3)
C EQUIVALENCE (IROW,JROW),(ICOLUMN,JCOLUMN),(AMAX,T,SWAP)
C
C INITIALIZATION
C
M=M1
N=N1
DETERM=1.0
DO 10 J=1,N
10 INDEX(J,3)=0
DO 200 I=1,N
C
C SEARCH FOR PIVOT ELEMENT
C
AMAX=0.0
DO 60 J=1,N
20 IF(INDEX(J,3)-1)20,60,20
IF(INDEX(K,3)-1)30,50,280
30 IF(AMAX-DABS(A(J,K)))40,50,50
40 IROW=J
ICOLUMN=K
AMAX=DABS(A(J,K))
50 CONTINUE
60 CONTINUE
INDEX(ICOLUMN,3)=INDEX(ICOLUMN,3)+1
INDEX(I,1)=IROW
INDEX(I,2)=ICOLUMN
C
C INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
C

IF(IROW-ICOLUMN)=70,110,70
70 DETERM=DETERM
DO 80 L=1,N
SWAP=A(IROW,L)
A(IROW,L)=A(ICOLUMN,L)
80 A(ICOLUMN,L)=SWAP
IF(M)=110,110,90
90 DO 100 L=1,M
SWAP=B(IROW,L)
B(IROW,L)=B(ICOLUMN,L)
100 B(ICOLUMN,L)=SWAP
C
C DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
110 PIVOT=A(ICOLUMN,ICOLUMN)
DETERM=DETERM*PIVOT
A(ICOLUMN,ICOLUMN)=1.0
DO 120 L=1,N
120 A(ICOLUMN,L)=A(ICOLUMN,L)/PIVOT
IF(M)=150,150,130
130 DO 140 L=1,M
140 B(ICOLUMN,L)=B(ICOLUMN,L)/PIVOT
C
C REDUCE NON-PIVOT ROWS
C
150 DO 200 L=1,N
IF(L1-ICOLUMN)=160,200,160
160 T=A(L1,ICOLUMN)
A(L1,ICOLUMN)=0.0
DO 170 L=1,N
170 A(L1,L)=A(L1,L)-A(ICOLUMN,L)*T
IF(M)=200,200,180
180 DO 190 L=1,M
190 B(L1,L)=B(L1,L)-B(ICOLUMN,L)*T
200 CONTINUE
C INTERCHANGE COLUMNS
C
DO 230 I=1,N
L=N+1-I
IF(INDEX(L,1)-INDEX(L,2))210,230,210
210 JROW=INDEX(L,1)
JCOLUMN=INDEX(L,2)
DO 220 K=1,N
SWAP=A(K,JROW)
A(K,JROW)=A(K,JCOLUMN)
A(K,JCOLUMN)=SWAP
220 CONTINUE
230 CONTINUE
DO 260 K=1,N
IF(INDEX(K,3)-1)240,250,240
240 ID=2
GO TO 270
250 CONTINUE
260 CONTINUE
ID=1
270 RETURN
280 ID=2
GO TO 270
END
SUBROUTINE OFFSET(XNEXT,YNEXT,ZNEXT)
C WRITTEN BY GEORGE PCPESCU AUGUST 10, 1972
C THIS SUBROUTINE WILL CALCULATE THE STREAMLINES GENERATED BY A
C GIVEN WATER SOURCE DISTRIBUTION IN A STEADY FLOW
C DOUBLE PRECISION XR, YR, XR
C REAL KSE, KSEFIX
C DIMENSION CMK(2,18), NMK(2,9), G(2,15), PC(2), COMMON(100,11)
C DIMENSION XNEXT(2,11,50), YNEXT(2,11,50), NS(11), NC(11), NB(11)
C DIMENSION XMHB(6,9), XMSS(6,9), FBP(2), BPC(2), S(2,9), D(2,9)
C DIMENSION AK(4), AM(4), ETAFIX(11,11), KSEFIX(11,11), TFIX(11,11)
C DIMENSION XX(50), XREX(100), ZNEXT(2,11,50), IL(20)
C COMMON/ ARCT/ CMK,NMK,PC, DEN, FBP, BPC, S, D, LINES, IRED, IL
C COMMON/ BRCT/ G, COMMON, NG, USHIP, NS, NB, VG, SHIPL
C COMMON/ CRCT/ NR, KSEFIX, ETAFIX, TFIX, TENOMS, TENOMD, XREX
C COMMON/ DRCT/ XMHB, XMSS
C DO 10 I=1, 100
C DO 10 J=1, 11
C COMMON(I,J)=0.
C CONTINUE
C DO 20 I=1, 11
C DO 20 J=1, 50
C XNEXT(I,1,J)=0.0
C XNEXT(2,1,J)=0.0
C YNEXT(I,1,J)=0.0
C YNEXT(2,1,J)=0.0
C ZNEXT(I,1,J)=0.0
C ZNEXT(2,1,J)=0.0
C XX(J)=0.0
C CONTINUE
C RDEN=0EN
C IREC=0
C NLINF=LINES
C IF(LINES.NE.1) GO TO 30
C DELTAV=CMK(1,4)
C GO TO 40
C 30 DELTAZ=CMK(1,4)/(FLOAT(LINES)-1.)
NR=1
KSEFIX(1,1)=1.
ETAFIX(1,1)=PC(1)

C THE GAUSSIAN QUADRATURE IS USED TO INTEGRATE OVER ETA SURFACE.
C AS A RESULT THE CONTINUOUS SOURCE DISTRIBUTION ON ETA SURFACE IS
C REPLACED BY A DISCONTINUOUS EQUIVALENT SOURCE DISTRIBUTION WHICH IS
C THEN DIVIDED BY 4*PI. THE NEW NAME OF THESE SOURCES IS "COMMON".
C YET IF ETA IS A FLAT PLATE THIS IS NOT NECESSARY, AND GO TO 160.
IF(CMK(1,1),EQ,0.0) GO TO 160
IF(DEN,NE,0.0) GO TO 70
DO 50 I=1,9
NMK(2,I)=NMK(1,I)
50 CONTINUE
DO 60 I=1,18
CMK(2,I)=CMK(1,I)
60 CONTINUE
FBP(2)=FBP(1)
BPC(2)=BPC(1)
DEN=-1.0
NMK(2,1)=0
IA=1
TKSE=1.0
DELKSE=0.2
ISWICH=1
GO TO 90
IA=2
ISWICH=-1
90 A=CMK(IA,2)
B=CMK(IA,3)
N=NMK(IA,6)
N1=6*N-2
N2=5*N-2
N3=4*N-2
N4=3*N-2
N5=2*N-2
BETA=CMK(IA,1)
Q = 1. - A * B  
EN = FLOAT(N)  
E = BETA * BETA * EN * EN  
C1 = 9. * E * Q * Q  
C2 = 12. * E * A * C  
C4 = 4. * E * A * B  
C5 = E * B * B  
TG = (PC(1) - PC(2)) / 2.  
TGT = 0.  
IF (DEN, LT, 0.) TGT = (CMK(2, 4) - CMK(1, 4)) / 2.

100  
DO 150 KG = 1, NG  
KSE = TKSE = DELKSE * G(1, KG)  
FF = KSE**NMK(IA, 6)  
ETA = BETA * (1. - (((1. - A - B) * FF - A) * FF - B) * FF) + PC(1) - TG * (1. - KSE)  
ETAFIX(NR, KG) = ETA  
KSEFIX(NR, KG) = KSE  
TFIX(NR, KG) = CMK(1, 4) + (1. - KSE) * TGT  
TFIX(NR, KG) = TFIX(NR, KG)  
RADIC = 1. + C1 * (KSE**N1) + C2 * (KSE**N2) + C3 * (KSE**N3) + C4 * (KSE**N4) + C5 * (KSE**N5)  
RADIC = SORT(RADIC)  
FACTOR = G(2, KG) * RADIC / 12.5664 * DELKSE  
M = (NR - 1) * NG + KG  
XREX(M) = KSE  
DO 150 K = 1, NG  
ZETA = TFIX(NR, KG) * G(1, K)  
IF (ZETA, LT, TFIX(NR, KG)) GO TO 150  
DO 140 I = 1, 4  
JA = I - 1  
IF (JA, EQ, 0.) GO TO 110  
ZPOWER = ABS(ZETA)**JA  
GO TO 120

110  
ZPOWER = 1.  
120  
PKSE = (ABS(KSE)**J)**TSWITCH  
DO 140 J = 1, 5
AIJ=XMBB(I,J)
IF((NMK(2,1).EQ.0).AND.(DEN.GT.0.0))GO TO 130
IF(IA.EQ.2) AIJ=XMSS(I,J)

130 COMMON(M,K)=COMMON(M,K)+AIJ*PKSE*ZPOWER
140 CONTINUE
COMMON(M,K)=COMMON(M,K)*FACTOR*G(2,K)*(-TFIX(NR,KG))
150 CONTINUE

NR=NR+1
TKSE=TKSE-DELKSE
AREST=TKSE-DELKSE-0.000002
IF(AREST.LE.DEN) DELKSE=TKSE-DEN
IF(TKSE.LE.DEN) GO TO 160
IF(ISWICH.LT.1) GO TO 100
IF((TKSE-0.00001).LT.0.0) GO TO 80
GO TO 100

C IN ORDER TO APPLY RUNGE-KUTTA METHOD THE STAGNATION POINT FOR EACH STREAMLINE IS TO BE FOUND

160 NR=NR-1
YA=EAFIX(1,1)
YB=PC(1)
IF(EAFIX(1,1).GT.PC(1)) GO TO 170
YA=PC(1)
YB=EAFIX(1,1)

170 ZO=DELTAZ
YC=YA
YCC=YC
IF(YC.GT.0.4) YCC=0.8/2.2
DEN=RDEN

WRITE(6,250)((COMMON(I,J),I=1,100),J=1,2)
DD 440 I=1,LINES
ZO=7C-DELTAZ
REST=1000.
RXV=C.
RYV=C.
YR=YC+.01
DELTAY=0.01
KONTY=0
DEF=1000.

180  DELTAX=0.01
XR=1.06+10.*(-8)
YR=YR-DELTAY
KONTY=KONTY+1
IF(KONTY.GT.15) GO TO 330

190  KONT=0
200  XR=XR-DELTAX
KONT=KONT+1
IF(KONT.LT.20) GO TO 210
IF(KONTY.NE.1) GO TO 320
RXV=KSEFIX(1,1)
RXR=RXV
RYV=YC
GO TO 340

210  CALL SPEED(1,XR,YR,20,I,U,V,W)
DEF=U-USHIP
IF(KONT.EQ.1) GO TO 220
IF(U.LT.UREST) GO TO 250

220  UREST=U
IF((DEF.EQ.0.) GO TO 630
IF((DEF.GT.0.) .AND. (KONT.EQ.1)) GO TO 230
RATIO=ABS(DEF/USHIP)
IF((RATIO.GT.0.01)) GO TO 260
IF((DEF.GT.0.)) GO TO 240
IF((YR.EQ.YC).AND.(XR.LT.KSEFIX(1,1))) GO TO 240
GO TO 200

230  XR=XR+0.06
GO TO 190

240  XR=XR+DELTAX
DELTAX=DELTAX/3.
UREST=0.
GO TO 200

250  XR=XR+1.5*DELTAX
DELTAX=DELTAX/3.
UREST=0.
GO TO 200
26C IF(XR.LT.1.02) GO TO 270
IREC=5
GO TO 680
27C CALL SPEED(XR, YR, ZO, I, U, V, W)
DEF=V/U
IF(ABS(DEF).GT.REST) GO TO 280
REST=ABS(DEF)
ARXV=XR
ARYV=VR
28C IF(V.GE.0.) GO TO 290
RXV=XR
RYV=VR
29C IF(KCNTY.NE.1) GO TO 300
RXR=XR
30C IF(APS(DEF).LT.0.02) GO TO 340
IF(V.LE.0.) GO TO 310
GO TO 180
31C YR=VR+DELTA
DELTA=DELTA/3.
GO TO 180
32C IF(REST.NE.1000.) GO TO 310
IF(YR.GE.(YR-0.05)) GO TO 180
YR=V+DELTA
DELTA=DELTA/3.
GO TO 180
C THE POINTS OF STREAMLINES HAVING THE STAGNATION POINT FOUND ABOVE
C ARE NOW COMPUTED USING RUNGE-KUTTA METHOD
33C IF(REST.EQ.1000.) GO TO 630
34C IF(RXV.EQ.0.) RXV=ARXV
IF(RYV.EQ.0.) RYV=ARYV
DIFF=VC-ARY
YR=YR+DIFF+0.002
XR=XR+0.001
DAN=DEN+0.0001
XNEXT(1,I,1)=XR+0.001  
ZNEXT(1,I,1)=Z0       
ZNEXT(2,I,1)=Z0       
do 430 LA=1.2          
ZR=ZC                 
DELTA=0.001          
if(la.eq.2) delta=-0.001   
ynext(la,i,1)=yc+delta  
kont=0                
mont=0                
go to 370             
35c                
xr=xr+0.0005          
go to 370             
36c                
yc=yc+delta          
mont=mont+1           
if(mont.lt.5) go to 370  
ired=7                
go to 680             
37c                
do 410 JK=1.40         
j=jk+1                
deltax=-0.1          
if(jk.le.6) deltax=-0.05    
if(jk.lt.4) deltax=-0.001*float(jk) 
if(kont.eq.1) deltax=dan-xr  
call speed(2,xr,yc,zr,1,u,v,w) 
if((jk.eq.1).and.(u.gt.uship)) go to 350  
if((jk.eq.1).and.((v*delta ).lt.0.0)) go to 360 
if(la.eq.1) go to 380  
if(jk.gt.7) go to 380  
if(jk.eq.1) go to 380  
yk=0.55*(ynext(1,i,jk-1)-ynext(1,i,jk))*4.*ycc  
dif=ynext(la,i,jk)-ynext(la,i,jk-1)  
if(dif.lt.yk) go to 380  
yr=yk+ystor  
ynext(la,i,jk)=yr      
call speed(2,xr,yc,zr,1,u,v,w)
DO 390 L=1,3
DEF=U-USHIP
IF(ABS(DEF) .LT. C .00001) GO TO 360
F=V/DEF
C=W/DEF
AK(L)=DELTAX*F
AM(L)=DELTAX*C
IF(L.EQ.3) GO TO 390
X=XR+0.5*DELTAX
Y=YR+0.5*AK(L)
Z=ZR+0.5*AM(L)
CALL SPEED(Z,X,Y,Z,I,U,V,W)
CONTINUE
X=XR+DELTAX
Y=YR+AK(3)
Z=ZR+AM(3)
CALL SPEED(Z,X,Y,Z,I,U,V,W)
DEF=U-USHIP
IF(ABS(DEF) .LT. 0.00001) GO TO 360
F=V/DEF
C=W/DEF
AK(4)=DELTAX*F
AM(4)=DELTAX*C
XNEXT(I,I,J)=XR+DELTAX
YNEXT(I,I,J)=YR+1./6.*(AK(1)+2.*AK(2)+2.*AK(3)+AK(4))
IF(JK.GT.3) GO TO 400
IF((LA.EQ.1) .AND. (YNEXT(LA,I,J) .LT. YNEXT(LA,I,JK))) GO TO 360
400
ZNEXT(LA,I,J)=ZR+1./6.*(AM(1)+2.*AM(2)+2.*AM(3)+AM(4))
YSTCR=YNEXT(LA,I,JK)
XR=XR+DELTAX
YR=YNEXT(LA,I,J)
ZR=ZNEXT(LA,I,J)
IF((XR+DELTAX) .GE. (DAN+.02)) GO TO 410
KONT=KONT+1
IF(KONT.GT.1) GO TO 420
CONTINUE

OFST 2530
OFST 2540
OFST 2550
OFST 2560
OFST 2570
OFST 2580
OFST 2590
OFST 2600
OFST 2610
OFST 2620
OFST 2630
OFST 2640
OFST 2650
OFST 2660
OFST 2670
OFST 2680
OFST 2690
OFST 2700
OFST 2710
OFST 2720
OFST 2730
OFST 2740
OFST 2750
OFST 2760
OFST 2770
OFST 2780
OFST 2790
OFST 2800
OFST 2810
OFST 2820
OFST 2830
OFST 2840
OFST 2850
OFST 2860
OFST 2870
OFST 2880
42C  XR=RXV+0.001  OFST2890
      YR=RYV-0.001  OFST2900
43C  CONTINUE  OFST2910
      NS(I)=J  OFST2920
44C  CONTINUE  OFST2930
      Y=YC
      DO 460  I=1, LINES  OFST2940
      N0=NS(I)  OFST2950
      DO 450  JK=1, NO  OFST2960
      YNEXT(1, I, JK)=YNEXT(1, I, JK)-Y  OFST2970
      YNEXT(2, I, JK)=Y-YNEXT(2, I, JK)  OFST2980
45C  CONTINUE  OFST2990
46C  CONTINUE  OFST3000
C  THE POINTS OF THE STREAMLINE COMPUTED ABOVE ARE USED FOR INTERPOLATION  OFST3010
C  SO THAT THE STREAMLINES WILL BE COMPUTED AT EACH VERTICAL  OFST3020
C  CROSS-SECTION IN DEMIHULL AND THESE WILL BE IN FACT THE OFFSETS OF  OFST3030
C  THE DEMIHULL.
      DO 470  I=1, 100  OFST3040
      DO 470  J=1, 11  OFST3050
      COMMON(I, J)=0.0  OFST3060
50C  CONTINUE  OFST3070
      RMAX=YNEXT(1, I, 1)  OFST3080
      RMIN=YNEXT(1, I, 7)  OFST3090
      DO 480  I=1, LINES  OFST3100
      IF(YNEXT(1, I, 1).GT.RMAX)  RMAX=YNEXT(1, I, 1)  OFST3110
      IF(YNEXT(1, I, 07).LT.RMIN)  RMIN=YNEXT(1, I, 07)  OFST3120
480  CONTINUE  OFST3130
      DELBCW=(RMAX-RMIN)/6.  OFST3140
      X0DW=RMIN  OFST3150
      DELTA=DEL BCW  OFST3160
      X=RMAX  OFST3170
      DO 490  I=1, LINES  OFST3180
      NR(I)=0  OFST3190
      NC(I)=1  OFST3200
49C  CONTINUE  OFST3210
      DO 560  K=1, 50  OFST3220

DO 530 I=1,LINES
ND=NS(I)
NA=NC(I)
DO 500 JA=NA,ND
J=J+1
IF(XNEXT(1,I,J).LT.X) GO TO 510
50C CONTINUE
GO TO 530
51C IF(J.EQ.1) GO TO 530
IF(NB(I).NE.0) GO TO 520
IF(J.EQ.2) NB(I)=K
52C L=J-1
NC(I)=J
DEF=XNEXT(1,I,L)-XNEXT(1,I,J)
DIF=YNEXT(1,I,L)-YNEXT(1,I,J)
DIFZ=ZNEXT(1,I,L)-ZNEXT(1,I,J)
DELTA=XNEXT(1,I,L)-X
C **COMMON** IS USED FOR TEMPORARY STORAGE OF THE OFFSETS
COMMON(K,I)=YNEXT(1,I,L)-DELTA*DIFF/DEF
XNEXT(2,I,K)=ZNEXT(1,I,L)-DELTA*DIFFZ/CEF
N=K+50
NM=K+25
IF(YNEXT(2,I,L)-YNEXT(2,I,J)
DIFZ=ZNEXT(2,I,L)-ZNEXT(2,I,J)
COMMON(N,I)=YNEXT(2,I,L)-DELTA*CIF/DEF
XNEXT(2,I,NM)=ZNEXT(2,I,L)-DELTA*DIFFZ/DEF
530 CONTINUE
XX(K)=X
IF((X-DELTA).LT.(X+BOO)) DELTA=(RMIN-DEN)/9.
IF((X-DELTA).GT.(DEN+0.04)) GO TO 550
L=K+1
N=L+50
NM=L+25
XX(L)=DEN
DO 540 I=1,LINES
\[\text{NO} = \text{NS}[i]\]
\[\text{COMMON}(l, i) = \text{YNEXT}(1, i, \text{NO})\]
\[\text{COMMON}(n, i) = \text{YNEXT}(2, i, \text{NO})\]
\[\text{XNEXT}(2, i, l) = \text{ZNEXT}(1, i, \text{NO})\]
\[\text{XNEXT}(2, i, \text{NM}) = \text{ZNEXT}(2, i, \text{NO})\]
\[\text{NS}[i] = \text{L}\]

540 \text{ CONTINUE}
550 \text{ GO TO 570}
560 \text{ X = X - DELTA}
566 \text{ CONTINUE}
570 \text{ DO 580 I = 1, LINES}
\text{DO 580 J = 1, 50}
\text{XNEXT}(1, i, j) = 0.0
\text{YNEXT}(1, i, j) = 0.0
\text{ZNEXT}(1, i, j) = 0.0
\text{YNEXT}(2, i, j) = 0.0
\text{ZNEXT}(2, i, j) = 0.0
580 \text{ CONTINUE}
\text{DO 610 I = 1, LINES}
\text{DO 610 J = 1, 50}
\text{YNEXT}(1, i, j) = \text{COMMON}(j, i)
\text{IF}(j, \text{GT}, 25) \text{ GO TO 590}
\text{ZNEXT}(1, i, j) = \text{XNEXT}(2, i, j)
\text{GO TO 600}
590 \text{ NM =} -25
\text{ZNEXT}(2, i, \text{NM}) = \text{XNEXT}(2, i, j)
600 \text{ N =} J + 50
\text{YNEXT}(2, i, j) = \text{COMMON}(n, i)
610 \text{ CONTINUE}
\text{DO 620 I = 1, LINES}
\text{DO 620 J = 1, 50}
\text{XNEXT}(2, i, j) = 0.0
\text{XNEXT}(1, i, j) = XX(J)
\text{XNEXT}(2, i, j) = XX(J)
620 \text{ CONTINUE}
\text{GO TO 680}
630 PRINT 640
TREC=3
640 FORMAT(1X,'THE STAGNATION POINT COULD NOT BE FOUND ')
WRITE(6,650) KONTY, U, V, DEF, REST, DELTAY, XR, YR
650 FORMAT(1X,13,7E13.5)
PRINT 670
660 FORMAT(1X,7E15.7)
670 FORMAT(1X,'THE SOURCES DISTRIBUTION IS GIVEN BELOW ')
WRITE(6,660)((COMMON(I,J), I=1,100), J=1,LINES)
680 RETURN
END
SUBROUTINE SPEED(MODE, X, Y, Z, KL, U, V, W)

C THIS SUBROUTINE COMPUTES THE SPEED GIVEN BY SURFACE SOURCES, LINE

C SOURCES AND DOUBLETS AT A POINT OF COORDINATES X, Y, Z.

C DOUBLE PRECISION AX, AY1, AY2, R1, R2, RATIO1, RATIO2, X, Y, DSGRT

C DOUBLE PRECISION DLG, AZETA, ZER0, MINS1, PLONE, DABS

C DOUBLE PRECISION G1, G2, G3, G4, G5, G6, G7, T

C REAL KSE, FIX, KSE1U, KSE2U, KSE3U, KSE4U, KSE5U, KSE1V, KSE2V, KSE3V, KSE4V

1 KSE5V, KSE

DIMENSION G(2,15), COMMON(100, 11), ETAFIX(11, 11), KSEFI X(11, 11)

DIMENSION TFIX(11, 11), BPC(2), S(2, 9), D(2, 9), PC(2), CMK(2, 18), NMK(2, 19), FBP(2), NS(11), NC(11), NB(11), XREX(100), IL(20)

DIMENSION XMBA(6, 9), XMSS(6, 9)

COMMON/ARC/ CMK, NMK, PC, DEN, FBP, BPC, S, D, LINES, IRED, IL

COMMON/BRC/ G, COMMON, NG, USHIP, NS, NR, NC, SHIPL

COMMON/CRC/ NR, KSEFIX, ETAFIX, TFXI, TENOMS, TENOMD, XREX

COMMON/DRC/ XMBA, XMSS

G1(T) = 1.0 / A / T

G2(T) = 1.0 / T

G3(T) = 1.0 / T - 0.5 * DLOG(DABS((T - 1.0) / (T + 1.0)))

G4(T) = T + A / T

G5(T) = -A * (1.0 / T - 0.75 * DLOG(DABS(1.0 - T)) + 0.25 / (1.0 - T) + 0.75 * DLOG(DABS(T)))

G6(T) = T ** 3 / 3 - 2 * A * T - A * A / T

G7(T) = A * A / T - 15 / 16 * DLOG(DABS((T - 1.0) / (T + 1.0))) - 7.0 / 8.0 * T / (T ** 1.0 - 1.0)

G(T) = G1(T) + 0.25 * T / (T ** 1.0 - 1.0) / (T ** 1.0 - 1.0)

U = 0.

V = 0.

W = 0.

C COMPUTE THE CONTRIBUTION OF SURFACE SOURCES TO THE SPEED AT POINT

C OF COORDINATES X, Y, Z

C WHEN ETA IS A FLAT PLATE USE A SPECIAL ALTERNATIVE STARTING AT 110

IF(CMK(1, 1) .EQ. 0.0) GO TO 50

SIGN = C.000001

RLIM = 0.1E-39

IF(MODE .EQ. 2) RLIM = 0.1E-10

IF(MODE .EQ. 2) SIGN = C.001

SPED0010

SPED0020

SPED0030

SPED0040

SPED0050

SPED0060

SPED0070

SPED0080

SPED0090

SPED0100

SPED0110

SPED0120

SPED0130

SPED0140

SPED0150

SPED0160

SPED0170

SPED0180

SPED0190

SPED0200

SPED0210

SPED0220

SPED0230

SPED0240

SPED0250

SPED0260

SPED0270

SPED0280

SPED0290

SPED0300

SPED0310

SPED0320

SPED0330

SPED0340

SPED0350

SPED0360
DO 40 N=1, NP
DO 40 KG=1, NG
KSE=KSEFX(N, KG)
ETA=ETAFX(N, KG)
T=TFIX(N, KG)
AX=(X-KSE)*(X-KSE)
AY1=(Y-ETA)*(Y-ETA)
AY2=(Y+ETA)*(Y+ETA)
M=(N-1)*NG+KG
DO 40 K=1, NG
DO 30 LZ=1, 2
TT=1.
IF(L7.EQ.2) TT=-1.
ZETA=TT*T**G(1, K)
10 AZ=(Z-ZETA)*(Z-ZETA)
R1=AX+AY1+AZ
R2=AX+AY2+AZ
AR1=DSQRT(R1)
AR2=DSQRT(R2)
R1=R1*AR1
R2=R2*AR2
IF(R1.GT.RLIM) GO TO 20
ZETA=ZETA-0.001*SIGN
GO TO 10
20 RATIO1=COMCNR(M, K)/R1
RATIO2=COMCNR(M, K)/R2
U=U+(RATIO1+RATIO2)*(X-KSE)
IF(MODE.EQ.1) GO TO 30
V=V+(RATIO1*(Y-ETA)+RATIO2*(Y+ETA)
W=W+(RATIO1+RATIO2)*(Z-ZETA)
30 CONTINUE
40 CONTINUE
GO TO 90
50 ETA=PC(1)
DO 80 KD=1, 2
IF(KC.EQ.2) ETA=-PC(1)
G4D=G4M1+G41-2.*G40
G5U=G51-G5M1
G5D=G5M1+G51-2.*G50
G6U=G61-G6M1
G6D=G6M1+G61-2.*G60
G7U=G71-G7M1
KSE1U=X*G2U-G3U
KSE2U=X**X*G2D-2.*X**G3D+G4D
KSE3U=X**X*G2U-3.*X**X*G3U+3.*X**G4U-G5U
KSE4U=X**4*G2D-4.*X**3*G3D+6.*X**X*G4D-4.*X**G5D+G6D
KSE5U=X**5*G2U-5.*X**4*G3U+10.*X**3*G4U-10.*X**X*G5U+5.*X**G6U-G7U
KSE1V=X*G1U-G2U
KSE2V=X**X*G1D-2.*X**G2D+G3D
KSE3V=X**3*G1U-3.*X**X*G2U+3.*X**G3U-G4U
KSE4V=X**4*G1D-4.*X**3*G2D+6.*X**X*G3D-4.*X**G4D+G5D
KSE5V=X**5*G1U-5.*X**4*G2U+10.*X**3*G3U-10.*X**X*G4U+5.*X**G5U-G6U
DO 60 I=1,4
IF(I.LT.1).EQ.0 GO TO 60
U=U+XMBB(I,1)*KSE1U+XMBB(I,2)*KSE2U+XMBB(I,3)*KSE3U+XMBB(I,4)*KSE5U
14U+XMBB(I,5)*KSE5U*(DABS(ZETA))**((1-I))**G(2,KG)
V=V+XMBB(I,1)*KSE1V+XMBB(I,2)*KSE2V+XMBB(I,3)*KSE3V+XMBB(I,4)*KSE5V
14V+XMBB(I,5)*KSE5V*(DABS(ZETA))**((1-I))**G(2,KG)*(Y-ETA)
W=W+XMBB(I,1)*KSE1V+XMBB(I,2)*KSE2V+XMBB(I,3)*KSE3V+XMBB(I,4)*KSE5V
14V+XMBB(I,5)*KSE5V*(Z-ZETA)*(DABS(ZETA))**((1-I))**G(2,KG)
60 CONTINUE
70 CONTINUE
80 CONTINUE
90 IF(NMK.I.EQ.0) GO TO 120
C 6.2832 IS FOR 12.5464, BECAUSE THE INTERVAL OF INTEGRATION IS 2*C
U=-U/6.2832*CMK(1,4)
V=-V/6.2832*CMK(1,4)
W=-W/6.2832*CMK(1,4)
90 IF(NMK(I,2).EQ.0) GO TO 120
C COMPUTE THE CONTRIBUTION OF LINE SOURCE TO THE SPEED AT POINT OF
C COORDINATES X,Y,Z
ETA=PC(1)
DO 110 KD=1,2
110 CONTINUE
SPED1090
SPED1100
SPED1110
SPED1120
SPED1130
SPED1140
SPED1150
SPED1160
SPED1170
SPED1180
SPED1190
SPED1200
SPED1210
SPED1220
SPED1230
SPED1240
SPED1250
SPED1260
SPED1270
SPED1280
SPED1290
SPED1300
SPED1310
SPED1320
SPED1330
SPED1340
SPED1350
SPED1360
SPED1370
SPED1380
SPED1390
SPED1400
SPED1410
SPED1420
SPED1430
SPED1440
IF (KC.EQ.2) ETA=-PC(1)
DO 100 KG=1,NG
ZETA=-CMK(1,18)+2.*CMK(1,18)*G(1,KC)
AZETA=DBS(ZETA)
ZZETA=ZETA*ZETA
DO 100 IA=1,2
KSE=FBP(IA)
TENOMS=(S(IA,1)*AZETA+S(IA,2)*ZETA+S(IA,3)*AZETA*ZZETA+S(IA,4)*ZZETA)/12.56
1ETA=ZETA)*G(2,KG)*2.*CMK(1,18)/12.56
AX=(X-KSE)*(X-KSE)
AY1=(Y-ETA)*(Y-ETA)
AZ=(Z-ZETA)*(Z-ZETA)
R1=AX*AY1+AZ
RATIO1=TENOMS/R1/DSORT(R1)
U=U+RATIO1*(X-KSE)
V=V+RATIO1*(Y-ETA)
W=W+RATIO1*(Z-ZETA)
C COMPUTE THE CONTRIBUTION OF DOUBLETS TO THE SPEED AT POINT OF
C COORDINATES X,Y,Z
KSE=BPC(IA)
TENOMD=(D(IA,1)*AZETA+D(IA,2)*ZETA+D(IA,3)*AZETA*ZZETA+D(IA,4)*ZZETA)/12.56
1ETA*ZZETA)*G(2,KG)*2.*CMK(1,18)
R1=AX*AY1+AZ
R2=DSORT(R1)
RATIO1=TENOMD/(R1**3)
U=U+RATIO1*[R1*R2-3.*R2*(X-KSE)**2]
V=V+RATIO1*(-3.*X*R2*(Y-ETA))
W=W+RATIO1*(-3.*X*R2*(Z-ZETA))
100 CONTINUE
110 CONTINUE
120 U=U+USHIP
V=V+USHIP
W=W+USHIP
RETURN
END
SUBROUTINE VOLUME(X, Y, Z, VOL, AREA)
DIMENSION X(2, 11, 50), Y(2, 11, 50), AREA(50), Z(2, 11, 50), IL(2C)
DIMENSION CMK(2, 18), NMK(2, 9), PC(2), FBP(2), BPC(2), S(2, 9), L(2, 9)
COMMON/ARC/ CMK, NMK, PC, DENS, FBP, BPC, S, D, LINES, IRED, IL
LM=LINES-1
10 DO 10 J=1, 50
   AREA(J)=0
   CONTINUE
10 DO 40 J=1, 50
   KONT=0
   DO 30 I=1, LM
      AREA(J)=AREA(J)+(Y(1, I, J)+Y(1, I+1, J))*Z(I, I, J)-Z(I, I+1, J))/2.
      IF((Y(2, I+1, J)<0.) AND.(KONT.EQ.0)) GO TO 20
      AREA(J)=AREA(J)+(ABS(Y(2, I, J))+ABS(Y(2, I+1, J)))*Z(2, I, J)-Z(2, I+1, VOL=0.0
      CONTINUE
30 VOL=0.0
   DO 50 I=1, 49
      VOL=VOL+1, AREA(I)+AREA(I+1)*(X(1, I, I)-X(1, I+1))/2.
50 CONTINUE
   IF(DENS.EQ.0.) VOL=2.0VOL
RETURN
END
DEMIHJLL DISPL=25,000 T, V=42FT/SEC, FR. NO.=0.30 , SPACING OPTIMIZATION 04,30,73

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COEFFICIENTS OF GAUSSIAN QUADRATURE

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DEN ARP PC(1) PC(2)

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SPECIFICATION FOR LOGIC

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GEOMETRIC AND SPEED INPUT

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CCB(1) SSB(1) FBP(1) BPC(1)

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ZF(1,1) ZF(1,2) ZF(1,3) ZF(1,4)

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LI(2,1) LI(2,2) LI(2,3) LI(2,4)

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ZF(2,1) ZF(2,2) ZF(2,3) ZF(2,4)

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SAMPLE OF INPUT DATA
APPENDIX C REFERENCES


