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AMADIFF - A FORTRAN ROUTINE FOR IRREGULAR-FREQUENCY-FREE CALCULATION OF ADDED MASS AND DAMPING OF TWO-DIMENSIONAL FLOATING BODIES BY THE EXTENDED BOUNDARY CON

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May 1995

AMADIFF — A FORTRAN ROUTINE FOR IRREGULAR-FREQUENCY-FREE CALCULATION OF ADDED MASS AND DAMPING OF TWO-DIMENSIONAL FLOATING BODIES BY THE EXTENDED BOUNDARY CONDITION METHOD

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ABSTRACT

The FORTRAN routine AMADIFF (Added Mass And Damping; Irregular-Frequency-Free), which calculates added mass and damping of two-dimensional cylinders floating in the free surface of deep water by the integral equation method using the exact Green function is described. The extended boundary condition method, or the lid method, in which source is distributed along the waterline inside the cylinder as well as on the wetted surface of the cylinder, is used to suppress irregular frequencies.

RÉSUMÉ

Le présent travail décrit le programme FORTRAN AMADIFF (masse augmentée et amortissement; absence de fréquences irrégulaieres); ce programme permet de calculer la masse ajoutée et l'amortissement de cylindres bidimensionnels, flottants à la surface dègagée d'un plan d'eau profond, au moyen de la méthode d'équation intégrale, avec uilisation de la fonction de Green exacte. La méthode étendue des condtions aux limites, ou méthoes du couvercle, qui suppose la répartition des contraites à l'intériequr du cylindre, au niveau de la ligne de flottaison, ainsi que sur toute la surface mouillée de celui-ci, permet de supprimer les fréquences irrégulières.

EXECUTIVE SUMMARY

Since the 1970s, our ability to analyse structures has improved enormously, mainly as a result of the development of advanced finite element techniques. Naval architects have not benefited from these advantages as much as the civil engineering community, due to difficulties in providing sufficiently accurate environmental loading to finite element codes.

DREA is conducting research in environmental loads to help naval architects better exploit modern structural analysis techniques. Ultimately, a suite of computer programs will be available to predict environmental loads and load effects.

Most computer codes for the prediction of environmental loads have a common problem, the existence of irregular frequencies. Irregular frequencies are wave encounter frequencies at which ship motions or environmental loads cannot be predicted because the underlying solution method breaks down at those frequencies. The existence of irregular frequencies has limited the use of codes for prediction of environmental loads by non-expert users, thus contributing to delaying application of better structural analysis method.

This Technical Memorandum describes the development and testing of a method (AMADIFF), which allows calculation of added mass and damping coefficients free of irregular frequencies. AMADIFF is suitable for implementation in two-dimensional seakeeping codes, popularly called strip theory codes. Further work would be required to extend the methodology to the three dimensional case.

TABLE OF CONTENTS

NOTATION

A	submerged cross-sectional area of floating body
a	added mass or moment of inertia per unit length
B	breadth of cylinder at waterline
b	damping coefficient per unit length
C	cylinder contour below calm-water line
C_W	waterline inside body
D	fluid domain outside body
$\mathbf{F}$	force vector
F	generalized force
G	Green's function
g	gravitational acceleration
k	wave number $(= \omega^2/g)$
M	moment vector
$\mathbf{n}$	$= (n_1, n_2)$ unit normal vector to body contour, pointing into body
P.V.	Cauchy principal value
p	hydrodynamic pressure
p^A , p^V	pressure components in phase with displacement and velocity of body, respectively
Q	source strength
Q^C, Q^W	source strength along C and C_W, respectively
Re	real part of a complex variable
s	body motion displacement
S	amplitude of motion
T	draft of cylinder
t	time
V_n	prescribed normal velocity of body
v_y	prescribed normal velocity on waterline inside body
W	waterline outside body
y, z	coordinates of a field point
z_{rc}	z-coordinate of the centre of roll
x	complex variable $(= y + iz)$
η, ζ	coordinates of a source point
ξ	complex variable $(= \eta + i\zeta)$
$\bar{\zeta}$	complex conjugate of ζ
ρ	mass density of fluid
ϕ	velocity potential
ϕ_I, ϕ_D	potentials for incident and diffracted waves, respectively
ω	wave frequency

Subscript

j indices for mode of body motion

$j = 2$ sway (horizontal motion)

$j = 3$ heave (vertical motion)

$j = 4$ roll (rotational motion about z_{rc}, centre of roll)

1. Introduction

This technical memorandum describes the FORTRAN routine AMADIFF (Added Mass And Damping; Irregular-Frequency-Free), which calculates added mass and damping of arbitrary-shaped two-dimensional cylinders floating in the free surface of deep water by the integral equation method ("close-fit" method) without the effect of irregular frequencies. The extended boundary condition method, or the lid method, is used to suppress irregular frequencies. AMADIFF is a modification of DREA's wave diffraction analysis program WADA1 [1]. AMADIFF is intended to be used as part of strip-theory computer codes for ship motions and loads prediction.

To calculate added masses and damping, it is first necessary to solve a boundary-value problem, commonly called the radiation problem, whose governing equation is the Laplace equation; see equations (18)–(22) for the two-dimensional case. The most common approach to solving the radiation problem is the integral equation method, as used by Frank [2]. In this method, the harmonic potential is represented by a single-layer potential using the exact Green's function where the source is distributed along the wetted surface of the cylinder, and a Fredholm integral equation of the second kind for the source strength is derived. The advantages of using this method are: (a) unlike the multipole method, the shapes of bodies that can be dealt with are quite general; and (b) compared with the finite-element method, or even the integral equation method using the free-space Green's function (see, e.g. [3]), it requires less computing time. The disadvantage is that the resulting Fredholm integral equation fails to give a solution at certain critical oscillation frequencies. This is purely a mathematical consequence inherent to the kernel of the integral equation; the physical problem always has a unique solution for any frequency. These critical frequencies at which the integral equation method breaks down are called "irregular frequencies" [4]. Although analytical solution of the integral equation fails at discrete irregular frequencies, the system of algebraic equations that approximate the integral equation becomes ill-conditioned (that is, small changes in the oscillation frequency can lead to arbitrarily large perturbations in the solution) in the vicinity of the irregular frequencies.

John has shown that irregular frequencies can occur "only for sufficiently small frequencies" [4]. He proved that the irregular frequencies of the floating body of draft T oscillating at angular frequency ω are bounded from below by

$$kT \geq 1 \tag{1}$$

where k is the wavenumber defined by $k = \omega^2/g$, g being the gravitational acceleration. As a result, for such stationary bodies as offshore oil rigs, irregular frequencies usually lie outside the range of wavelengths of practical interest, but for ocean-going ships, the wave encounter frequencies may become large even when a ship sails in relatively long wavelengths.

Clearly, there is a need for formulations for calculating the hydrodynamic coefficients that are well-conditioned for all frequencies and do not break down at irregular frequencies. This will increase the utility of ship motions and loads computer codes, whether they be in the frequency domain, such as DREA's SHIPMO, or in the time domain such as TDP1, which is currently under development in-house at DREA.

The mathematical formulation of the linear boundary-value problem is described in Section 2. The solution technique using the Green's function is outlined in Section 3. Descriptions of usage and sample results are given in Sections 4 and 5, respectively.

2. Statement of the Problem

Because AMADIFF is designed to be used as a module in ship motions and loads prediction computer programs, it is convenient to adopt the coordinate system that is compatible with that used in the main program. Figure 1 shows the coordinate system used in AMADIFF. The x-axis points out of the page. The y-axis lies in the calm-water surface. The z-axis points vertically upwards. These are the fixed "equilibrium axes" about which the body executes forced simple harmonic motion. Amplitudes of motion and hence of the generated wave are assumed to be small enough to permit the linearization of the mathematical model. The cylinder is assumed to be of uniform cross section and infinitely long along the x-axis. The cylinder's wetted surface below the calm-water line in the yz-plane is denoted by C, which is assumed to be symmetric about the z-axis. Let $\mathbf{r} = (0, y, z)$ and $\mathbf{R} = (0, y, z - z_{rc})$ be, respectively, the position vectors of a point relative to the origin and the centre of roll in the (x, y, z)-coordinate system. The centre of roll is assumed to be located at $(0, 0, z_{rc})$. The unit normal to C is denoted by $\mathbf{n} = (0, n_2, n_3)$, which points into the body. The domain occupied by water outside the body is denoted by D. Water is assumed to be deep. The calm-water lines inside and outside the cylinder are denoted by C_W and W, respectively. The displacement of the body's simple harmonic motion with angular frequency ω in the j-th mode is described by

$$s_j(t) = S_j e^{-i\omega t} \quad j = 2, 3, 4 \tag{2}$$

where subscript j indicates the mode of motion:

$j = 2$	sway (horizontal motion)
$j = 3$	heave (vertical motion)
$j = 4$	roll (rotatory motion about the centre of roll).

It is to be understood that hereafter the real part of complex expressions involving $e^{-i\omega t}$ is to be taken. Water is assumed inviscid, and its motion irrotational. The latter guarantees the existence of the velocity potential. The velocity potential of the fluid when the body is executing the simple harmonic motion (2) in the j-th mode is assumed to be of the form,

$$\Phi_j(\mathbf{r}, t) = \sum_{k=2}^{4} S_k \phi_k(\mathbf{r}) e^{-i\omega t}, \tag{3}$$

where we allow for the influence of the motion in the j-th mode on the force in the i-th mode for $i, j = 2, 3, 4$. From the linearized Bernoulli's equation, the hydrodynamic pressure p_j induced by the body's motion in the j-th mode is found by

$$p_j(\mathbf{r}, t) = -\rho \frac{\partial \Phi_j(\mathbf{r}, t)}{\partial t}, \tag{4}$$

where ρ is the density of water. Substituting (3) into (4) gives

$$p_j(\mathbf{r}, t) = i\rho\omega \sum_{k=2}^{4} S_k \phi_k(\mathbf{r}) e^{-i\omega t} \tag{5}$$

$$= i\rho\omega \sum_{k=2}^{4} \phi_k(\mathbf{r}) s_k(t), \tag{6}$$

where (2) was used to derive (6). Because ϕ is complex-valued, (6) can be expressed as

$$p_j(\mathbf{r}, t) = -(\omega^2 p_j^A + i\omega p_j^V) s_j(t) \tag{7}$$

$$= p_j^A \ddot{s}_j(t) + p_j^V \dot{s}_j(t), \tag{8}$$

where p_j^A and p_j^V are functions of spatial variables and frequency. Overdots indicate the derivatives with respect to time.

The motion-induced hydrodynamic force $\mathbf{F} = (0, F_2, F_3)$ and rolling moment $\mathbf{M}$ on the body about the centre of roll are given by

$$\mathbf{F}(t) = \int_C p(\mathbf{r}, t) \mathbf{n}(\mathbf{r}) dC, \tag{9}$$

$$\mathbf{M}(t) = \int_C p(\mathbf{r}, t) (\mathbf{R} \times \mathbf{n})(\mathbf{r}) dC. \tag{10}$$

If we write

$$F_4 \equiv |\mathbf{M}|, \tag{11}$$

and

$$n_4 \equiv |\mathbf{R} \times \mathbf{n}| = y n_3 - (z - z_{rc}) n_2, \tag{12}$$

then from (8)–(12),

$$F_i(t) = \sum_{j=2}^{4} \{a_{ij} \ddot{s}_j + b_{ij} \dot{s}_j\}, \qquad i = 2, 3, 4 \tag{13}$$

where

$$a_{ij} = \int_C n_i p_j^A(y, z) dC, \qquad i, j = 2, 3, 4 \tag{14}$$

$$b_{ij} = \int_C n_i p_j^V(y, z) dC, \qquad i, j = 2, 3, 4. \tag{15}$$

In general, the coefficients of proportionality a_{ij} and b_{ij} in (13) are called, respectively, the generalized added masses and damping coefficients in the ith mode caused by sinusoidal motion of unit amplitude in the jth mode. These coefficients satisfy the symmetry relationship

$$a_{ij} = a_{ji}, \quad b_{ij} = b_{ji}. \tag{16}$$

If the cylinder is symmetric about the centerplane, then we have

$$a_{23} = a_{32} = a_{34} = a_{43} = 0. \tag{17}$$

For details, see, for example, [5].

The linear boundary-value problem for the velocity potential ϕ_j for the fluid corresponding to the body's motion in the jth mode is

$$\frac{\partial^2 \phi_j}{\partial y^2} + \frac{\partial^2 \phi_j}{\partial z^2} = 0 \qquad \text{in } D, \tag{18}$$

$$\frac{\partial \phi_j}{\partial z} - k\phi_j = 0 \qquad \text{on } W, \tag{19}$$

$$\lim_{y \to -\infty} \frac{\partial \phi_j}{\partial z} = 0, \tag{20}$$

$$\lim_{y \to \pm\infty} \{\frac{\partial \phi_j}{\partial y} \mp ik\phi_j\} = 0, \tag{21}$$

$$\frac{\partial \phi_j}{\partial n} = V_{nj} \qquad \text{on } C. \tag{22}$$

The condition (21) is the two-dimensional Sommerfeld radiation condition, which ensures that the waves generated by the motion of the body are outgoing. In (22), $\partial/\partial n$ denotes the derivative in the direction of $\mathbf{n}$, and V_{nj} is the normal velocity of the cylinder surface:

$$V_{nj} = -i\omega S_j n_j, \quad j = 2, 3, 4. \tag{23}$$

The boundary-value problem (18)–(22) is called the radiation problem. Incidentally, except for the body-boundary condition (22), the above boundary-value problem is identical to the strip-theory diffraction problem dealt by WADA1 [1], in which $\phi = \phi_I + \phi_D$, with ϕ_I and ϕ_D denoting the velocity potentials of the incident and diffracted waves, respectively, and $V_n = 0$.

3. Solution Technique

The boundary condition method used in AMADIFF for suppressing irregular frequencies is an extension of the source-distribution method. In the source-distribution method, the velocity potential $\phi(y, z)$ is expressed in terms of a distribution of sources of strength $Q(\eta, \zeta)$ on the immersed surface C of the body under the calm water line; that is, for the jth mode of motion,

$$\phi_j(y, z) = \int_C Q_j(\eta, \zeta) G(y, z; \eta, \zeta) dC. \tag{24}$$

The Green's function G is a particular solution of the Laplace equation, which is regular throughout the fluid domain D except at $(y,z) = (\eta,\zeta)$ and directly satisfies the boundary conditions on the free surface (19), on the sea bottom (20), and the radiation condition (21). Because of these properties of G, ϕ defined in (24) satisfies all boundary conditions but (22), which is imposed on the cylinder surface. The source strength Q is determined by the remaining body-boundary condition (22). The function G can be expressed by [6]

$$G(y,z;\eta,\zeta) = \frac{1}{2\pi}\left[\log r - \log r_1 - 2\text{P.V.}\int_0^\infty \frac{e^{k(z+\zeta)}\cos k(y-\eta)}{k-\nu}dk\right] - ie^{\nu(z+\zeta)}\cos\nu(y-\eta), \quad (25)$$

where (y,z) denotes a field point and (η,ζ) a source point,

$$r^2 = (y-\eta)^2 + (z-\zeta)^2, \quad r_1^2 = (y-\eta)^2 + (z+\zeta)^2,$$

and P.V. indicates the Cauchy principal value. Thus, the dependence of ϕ on k is included in (24).

The integral equation resulting from applying the boundary condition (22) to the velocity potential as given by (24) leads to irregular cases for $kT \geq 1$; however, this defect can be overcome by distributing sources not only on C but C_W as well, as shown in [7] and [8]. This formulation, sometimes called the extended boundary condition method [8], or the lid method, is used in AMADIFF. Thus,

$$\phi_j(y,z) = \int_{C\cup C_W} Q_j(\eta,\zeta)G(y,z;\eta,\zeta)dC, \quad (26)$$

and in addition to (19)–(22), the kinematic boundary condition is extended to C_W:

$$\frac{\partial\phi_j}{\partial y} = v_y \qquad \text{on } C_W. \quad (27)$$

Substituting (26) into (22) and (27) yields the following integral equation for Q:

$$-\frac{1}{2}Q_j^C(y,z) + \int_{C_W} Q_j^W(\eta,\zeta)\frac{\partial G(y,z;\eta,\zeta)}{\partial n}dC + \int_C Q_j^C(\eta,\zeta)\frac{\partial G(y,z;\eta,\zeta)}{\partial n}dC = V_n, \quad (28a)$$

for $(y,z) \in C$, and

$$Q_j^W(y,z) + \int_{C_W} Q_j^W(\eta,\zeta)\frac{\partial G(y,z;\eta,\zeta)}{\partial z}dy + \int_C Q_j^C(\eta,\zeta)\frac{\partial G(y,z;\eta,\zeta)}{\partial z}dC = v_y \quad (28b)$$

for $(y,z) \in C_W$. Two equations (28) are simultaneous integral equations for Q^W and Q^C if V_n and v_y on the right-hand side are given. The former is given in (22) as part of the problem, but v_y is undefined in the problem. The latter can be any arbitrary function, but is an even function for symmetric motion and an odd function for anti-symmetric motion [7]. (In AMADIFF, the homogeneous condition, $v_y = 0$ (the rigid-wall condition) is imposed on C_W.) The integral equations (28) are now free of irregular frequencies.

AMADIFF is designed to solve (28) for $kT \geq 1$, but for $kT < 1$, it solves the integral equation resulting from applying the boundary condition (22) to (24). (In the latter case, the integral equation is (28a) without the second term on the left-hand side involving the integral along C_W.) There are three reasons for doing this. First, no irregular cases occur for $kT < 1$; see (1). Second, during the test phase of AMADIFF, the numerical solution of (28) sometimes resulted in minor instability at the very low frequency range, $kT < 0.1$. Third, the numerical solution of (24) requires less computing time, involving as it does fewer segments than does (26).

The integral equations (28) have to be solved by numerical methods. In AMADIFF, the procedures described in [2] are used to evaluate the components of the matrix equation. Thus, the integral equations are discretized using the collocation method, based on piecewise linear approximation of the section contour C. On each segment, source strength Q is assumed constant. The collocation points, or the points at which the unknown values are sought, are taken to be at the midpoint of each segment. On the waterline inside the body, four segments (two segments on each side) are placed. By solving the algebraic equation system that approximates the integral equations (28), the source density Q_j can be determined. Then the velocity potential $\phi(x)$ is found by a direct quadrature via (24) for $kT < 1$, or (26) for $kT \geq 1$.

4. Use of AMADIFF

The calling program must include the following common block statement to pass the data on sectional offsets to subroutine AMADIFF:

COMMON/SECGEO/NP, Y(25), Z(25), ZRC

Subroutine AMADIFF can then be called by:

CALL AMADIFF (IUNIT, OMEG, A22, B22, A33, B33, A44, B44, A24, B24)

Parameters:

(1) Common block SECGEO

NP	Number of offsets: NP $\leq$ 25 (integer)
Y	y-coordinates of offsets on one side of the body (real vector of length 25)
Z	Corresponding z-coordinates (real vector of length 25)
ZRC	z-coordinate of the centre of roll (real)

Note 1: The cylinder contour must be symmetric about the centreplane. The first offset (Y(1),Z(1)) is the intersection of the z-axis and the body contour, and going along in a counter-clockwise direction; the last offset (Y(NP),Z(NP)) is at the intersection of the calm-water line and the body contour on the right half.

Note 2: The number of segments should never be less than six on a half-section contour to ensure sufficient accuracy.
Also, because the source strengths are averaged over each segment, the segment sizes should be made smaller near sharp corners.

Note 3: The computational algorithm in AMADIFF requires that the slope of every segment be positive. For horizontal segments, this difficulty can be easily overcome by giving insignificantly small "artificial" positive slopes to the segments.

(2) **Input**

IUNIT	System of units to be used: (integer)
	IUNIT = 1 MKS system
	IUNIT = 2 FPS system
OMEG	Circular frequency of oscillation (real)

(3) **Output**

A22	Added mass for sway
B22	Damping for sway
A33	Added mass for heave
B33	Damping for heave
A44	Added moment of inertial for roll
B44	Damping for roll
A24	Added mass for sway-roll coupling
B24	Damping for sway-roll coupling

Note 4: These values are all real, dimensional, and for unit length of the cylinder.

Note 5: A24=A42, and B24=B42; see Section 2 above.

A sample calling program for AMADIFF is shown in Appendix A, and sample input for a floating semi-circular cylinder and a rectangular cylinder are shown in Appendix B. Note: For the rectangular cylinder in part (b) in Appendix B, the flat bottom is given an infinitesimal positive slope.

5. Sample Results

The added mass and moment of inertia and damping coefficients calculated by AMADIFF using equation (26) and the usual source-distribution method (USDM) based on equation (24) are compared in Figs. 2–4 for semi-circular and in Figs. 5–7 for a rectangular cylinder of $B/T = 2$. These plots are obtained using the input data shown in Appendix B. Note that AMADIFF is designed for $kT \geq 1$. For $kT < 1$, the calculation is done by the USDM within AMADIFF for the reasons stated in Section 3. One half of the wetted surface is represented by nine straight-line segments for the semi-circular cylinder and 15 segments for the rectangular cylinder. As noted in the foregoing, AMADIFF places two equal-length segments on the waterline inside the cylinder on one side.

For a floating semi-circular cylinder of radius a [7], the two lowest heave irregular frequencies at which the USDM breaks down are $ka \approx 1.818$ and 4.780, and the lowest sway irregular frequency is $kT = ka \approx 3.252$. The corresponding values for a floating rectangular cylinder of $B/T = 2$ [2] are $kT \approx 1.713$ and 4.713 for heave and $kT \approx 3.153$ for sway. Figures 2–7 clearly show that AMADIFF avoids ill-conditioning at, and in the vicinity of, irregular frequencies; however, small differences between the values of a_{jj} and b_{jj} calculated by AMADIFF and those by the USDM are noticeable in the plots. Minor jaggedness of the curves at $kT = 1$ occurs because of the change-over of the formulation between (24) and (28).

Figures 4 and 7 correspond to the cases where the centre of roll is situated at $0.2a$ below the waterline, and on the waterline, respectively. In Fig. 5, the only hint of the second lowest irregular frequency at $kT \approx 4.713$ is minute wiggles in the damping coefficient; no significant effect of ill-conditioning is visible in the added-mass curves.

To calculate added-mass and damping for the the semi-circular cylinder of Appendix B(a) using a VAX 6420 mainframe computer takes about 0.11 CPU seconds per frequency by the USDM and about 0.17 CPU seconds by AMADIFF. For the rectangular cylinder of $B/T = 2.0$ of Appendix B(b), the corresponding CPU times are about 0.36 seconds and about 0.45 seconds, respectively.

6. Concluding Remarks

Using the integral equation method, The FORTRAN program AMADIFF calculates the added mass and damping forces of a two-dimensional cylinder oscillating in the free surface of deep water. The feature of AMADIFF is that the irregular frequencies, which are an inherent weakness in the integral equation method, do not occur. This is accomplished by means of the extended boundary method, or the "lid" method, in which the boundary condition is extended to the waterline inside the body. In some instances, curves of added mass and damping predicted by the lid method and by the usual integral equation method show slight deviation over the frequency range away from the vicinity of irregular frequencies. This matter should be addressed in future studies. AMADIFF is useful in future enhancement of strip-theory ship motions and loads codes, such as DREA'S SHIPMO, and the strip-theory time-domain code currently under development in-house.

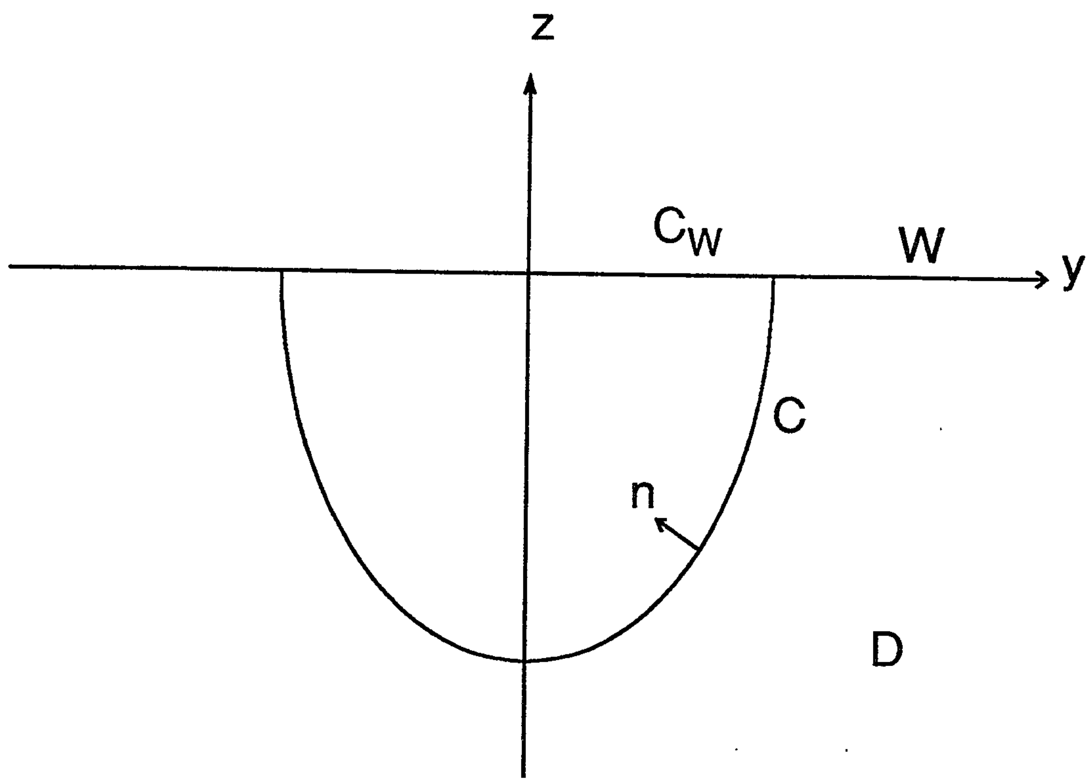

FIG. 1. Coordinate system. Legend: C - cylinder contour; D - fluid domain; W - equilibrium waterline outside the cylinder; C_W - equilibrium waterline inside the cylinder; and **n** - unit normal to the cylinder.

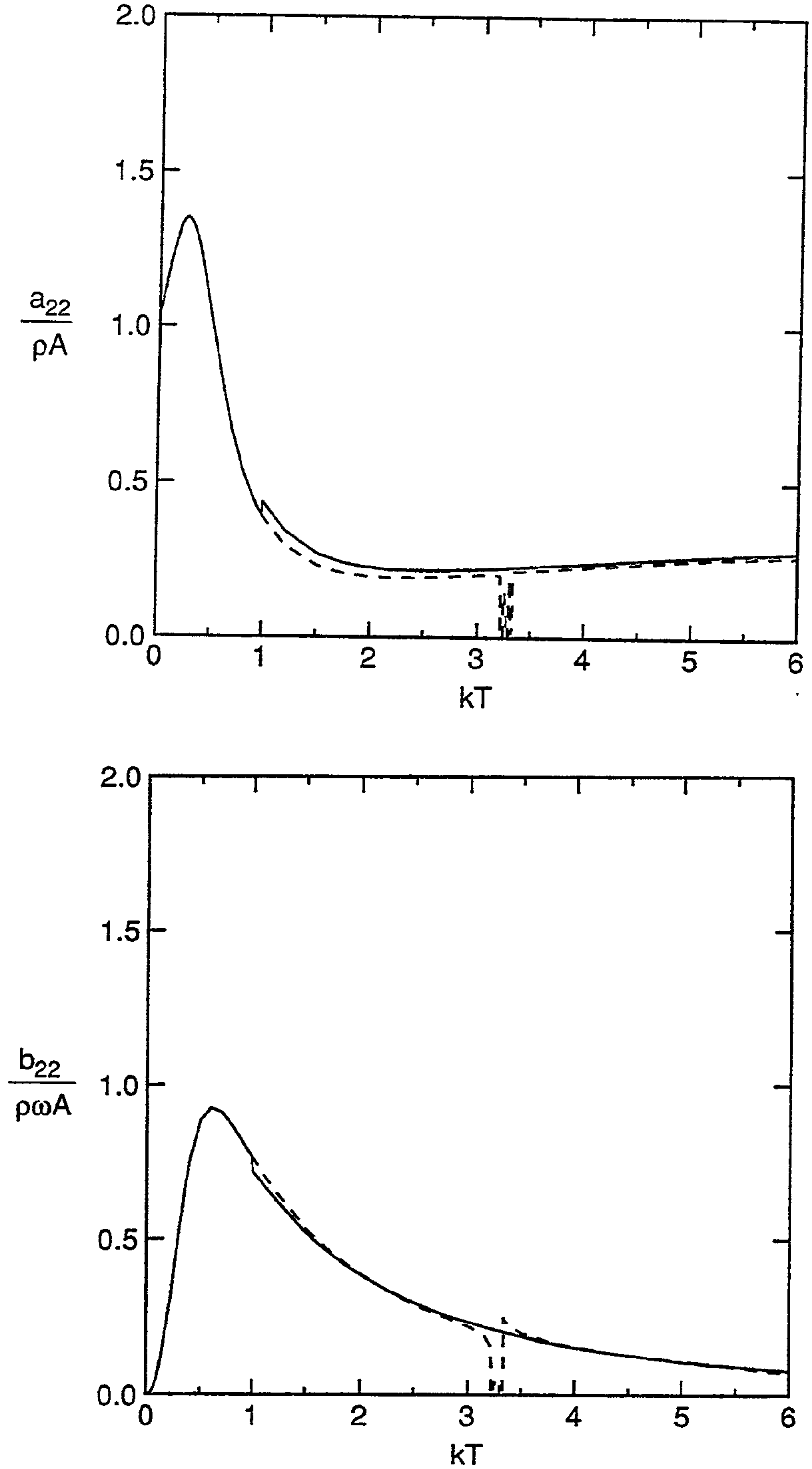

FIG. 2. Sway added mass and damping coefficients for the floating semi-circular cylinder of radius a ($T = a$). Here, $A = \pi a^2/2$: —— AMADIFF; - - - - usual source-distribution method. (18 segments along the wetted surface)

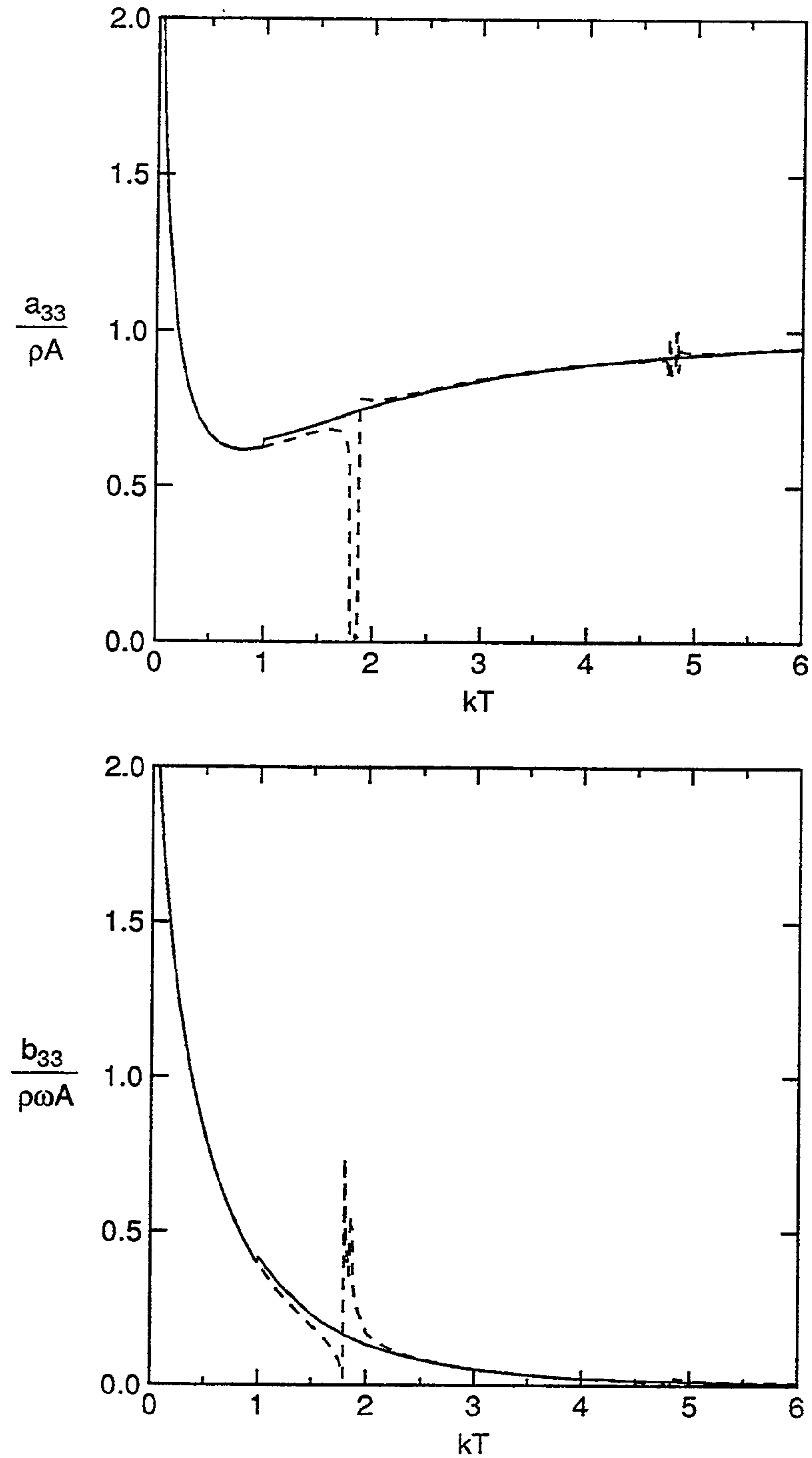

FIG. 3. Heave added mass and damping coefficients for the floating semi-circular cylinder of radius a ($T = a$). Here, $A = \pi a^2/2$: —— AMADIFF; - - - - usual source-distribution method. (18 segments along the wetted surface)

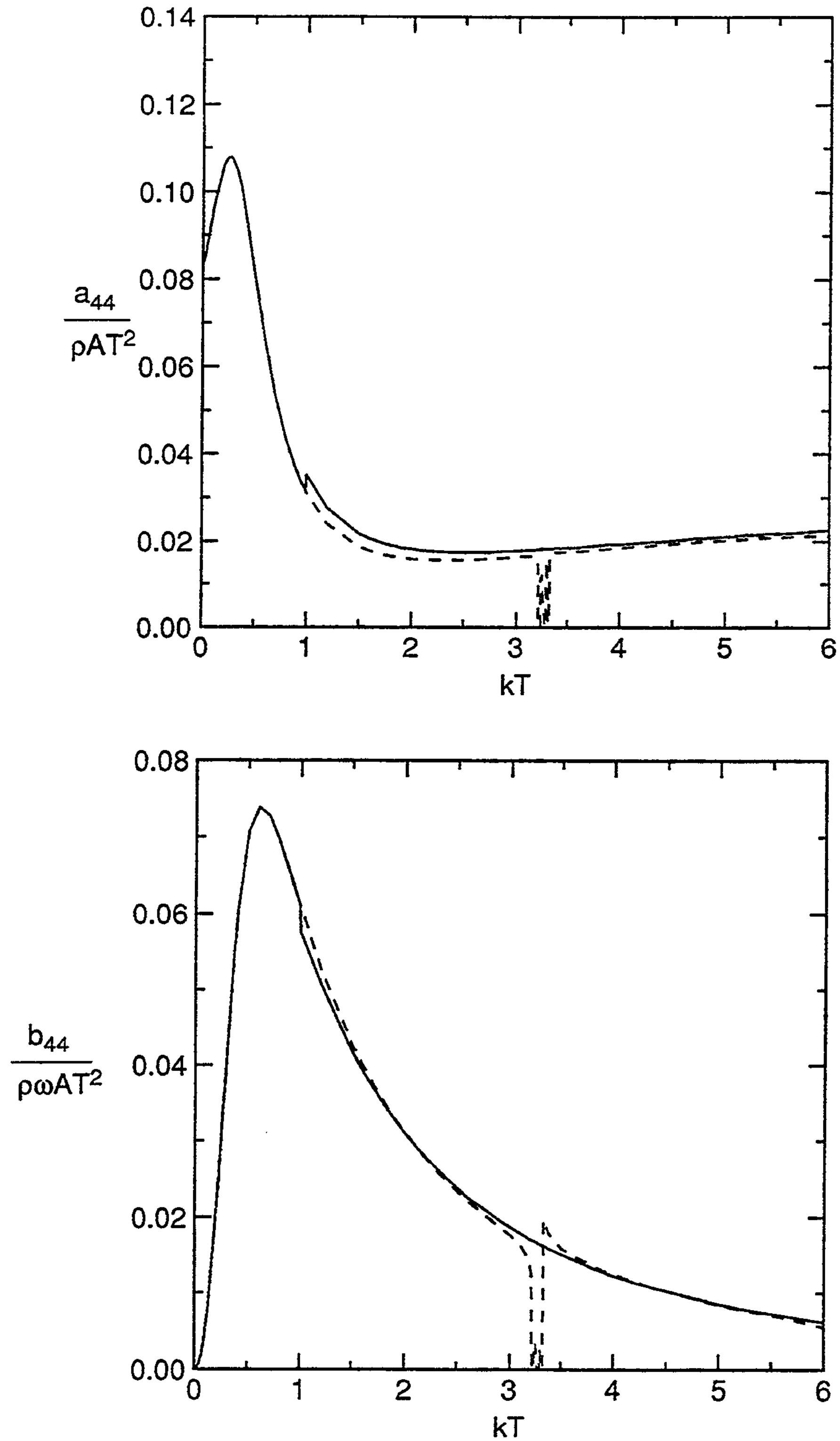

FIG. 4. Roll added moment of inertia and damping coefficients for the floating semi-circular cylinder of radius a ($T = a$). The roll centre is located at $(0, -0.2a)$. Here, $A = \pi a^2/2$: —— AMADIFF; - - - - usual source-distribution method. (18 segments along the wetted surface)

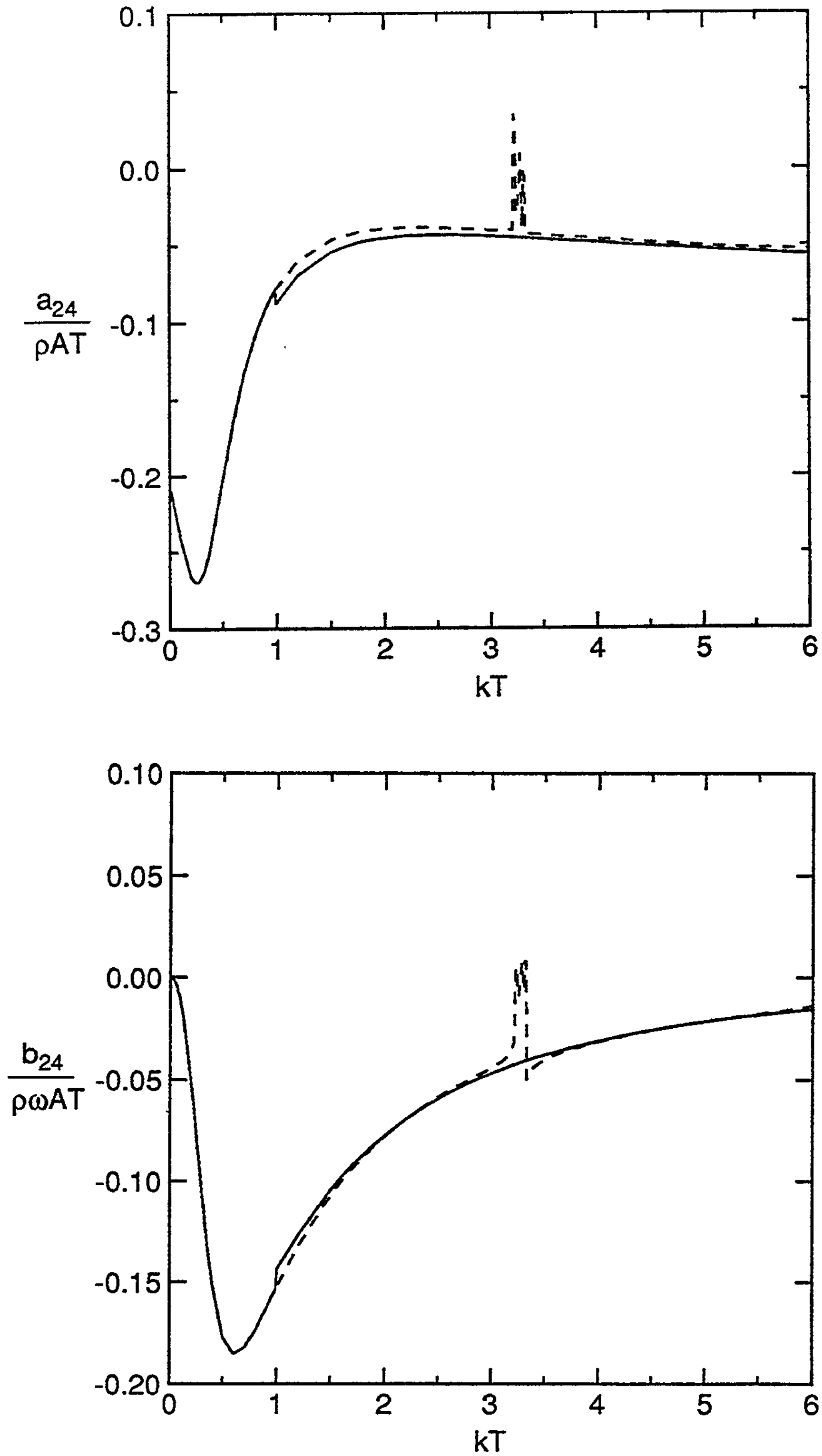

FIG. 5. Sway-roll coupling coefficients for the floating semi-circular cylinder of radius a $(T = a)$. The roll centre is located at $(0, -0.2a)$. Here, $A = \pi a^2/2$: —— AMADIFF; - - - - usual source-distribution method. (18 segments along the wetted surface)

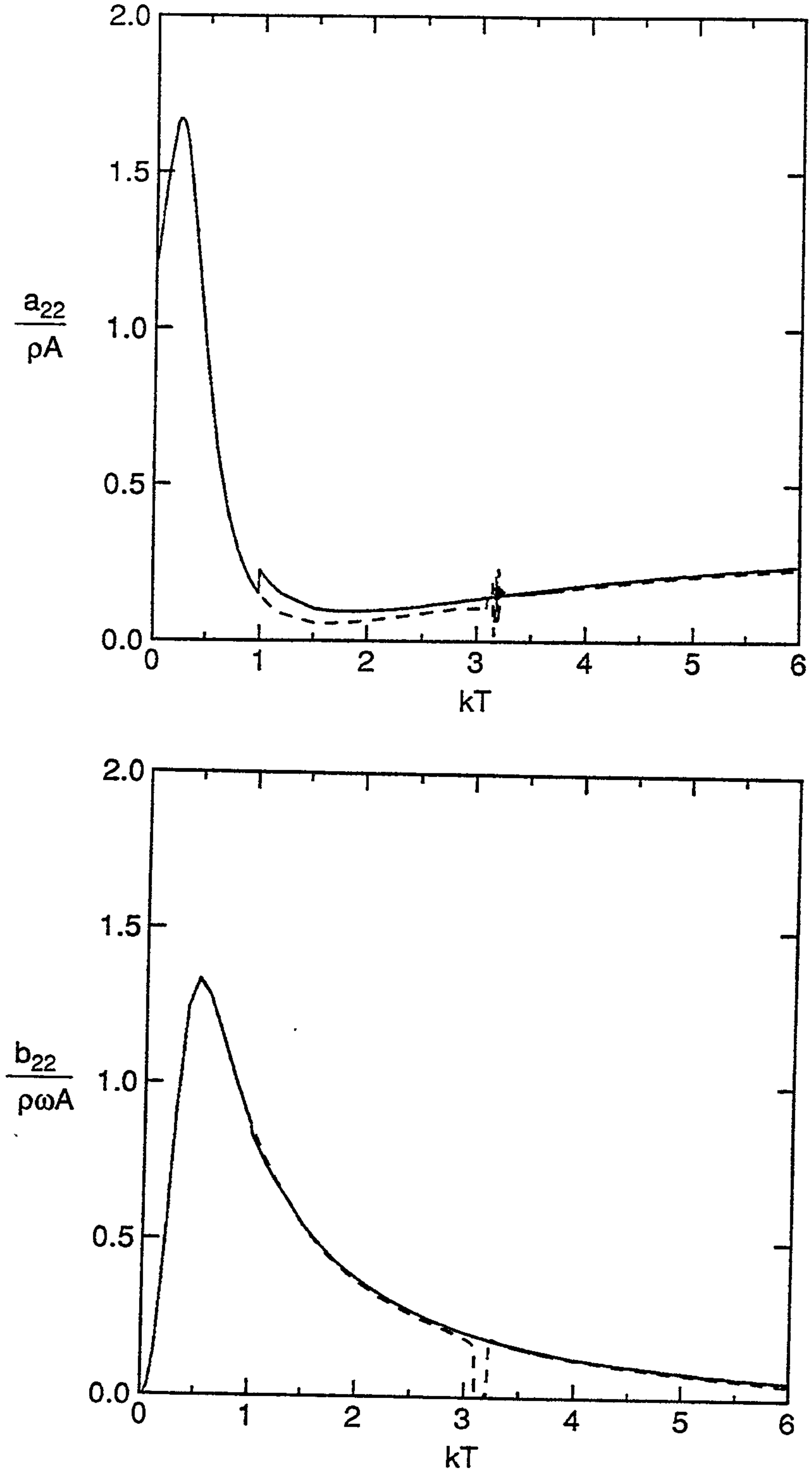

FIG. 6. Sway added mass and damping coefficients for the floating rectangular cylinder of $B/T = 2$. Here, $A = BT$: —— AMADIFF; - - - - usual source-distribution method. (30 segments along the wetted surface)

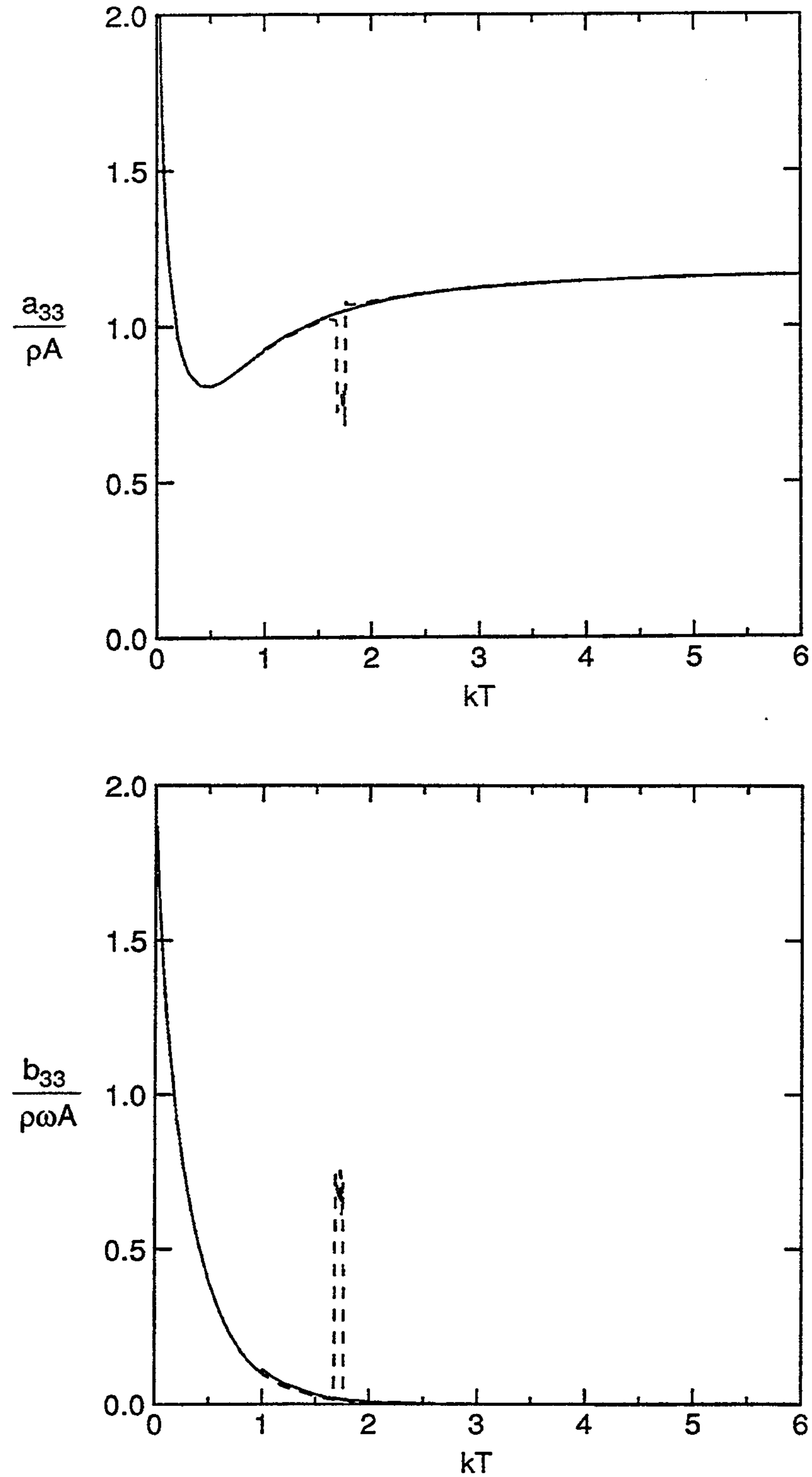

FIG. 7. Heave added mass and damping coefficients for the floating rectangular cylinder of $B/T = 2$. Here, $A = BT$: —— AMADIFF; - - - - usual source-distribution method. (30 segments along the wetted surface)

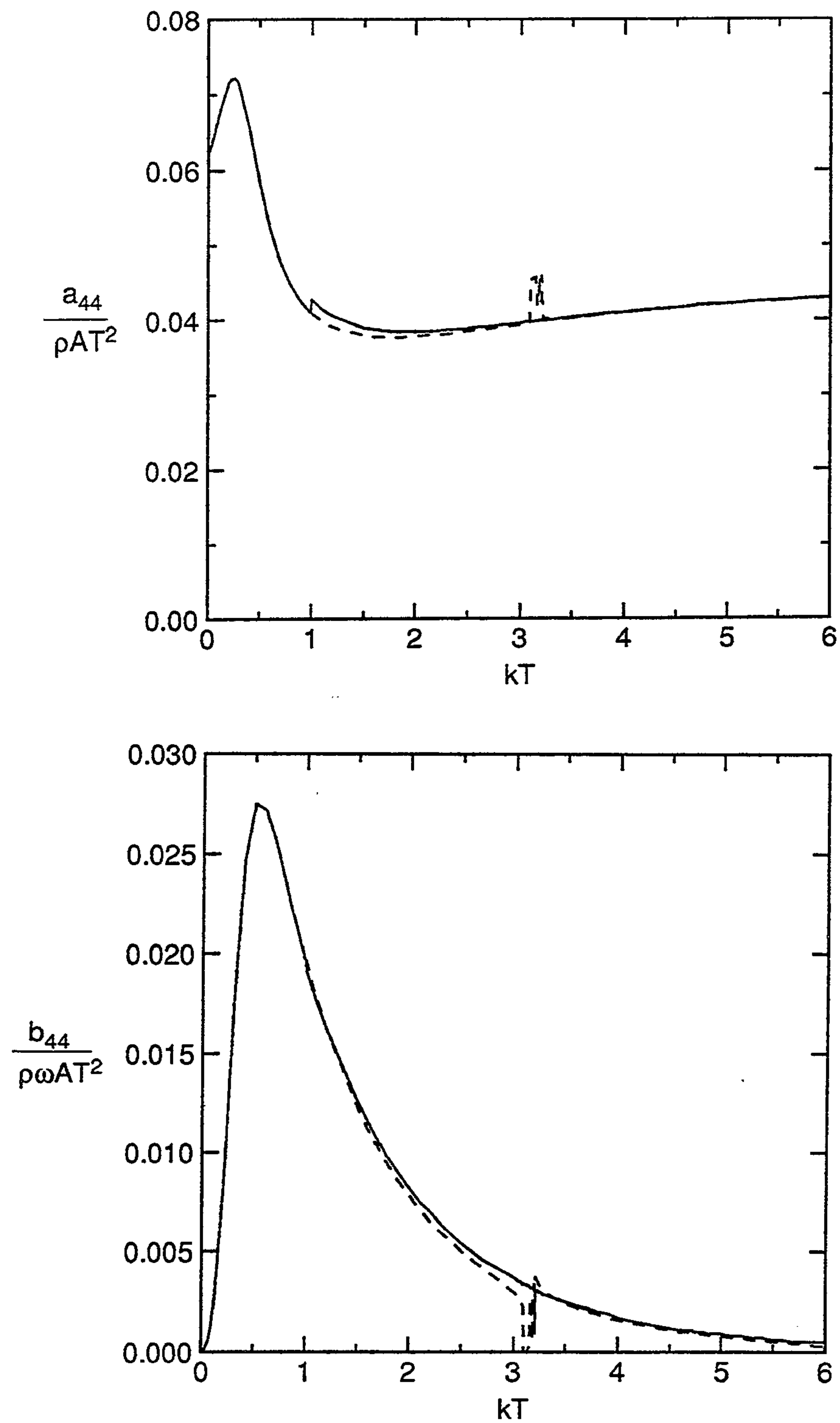

FIG. 8. Roll added moment of inertia and damping coefficients for the floating rectangular cylinder of $B/T = 2$. The roll centre is located on calm waterline. Here, $A = BT$: —— AMADIFF; - - - - usual source-distribution method. (30 segments along the wetted surface)

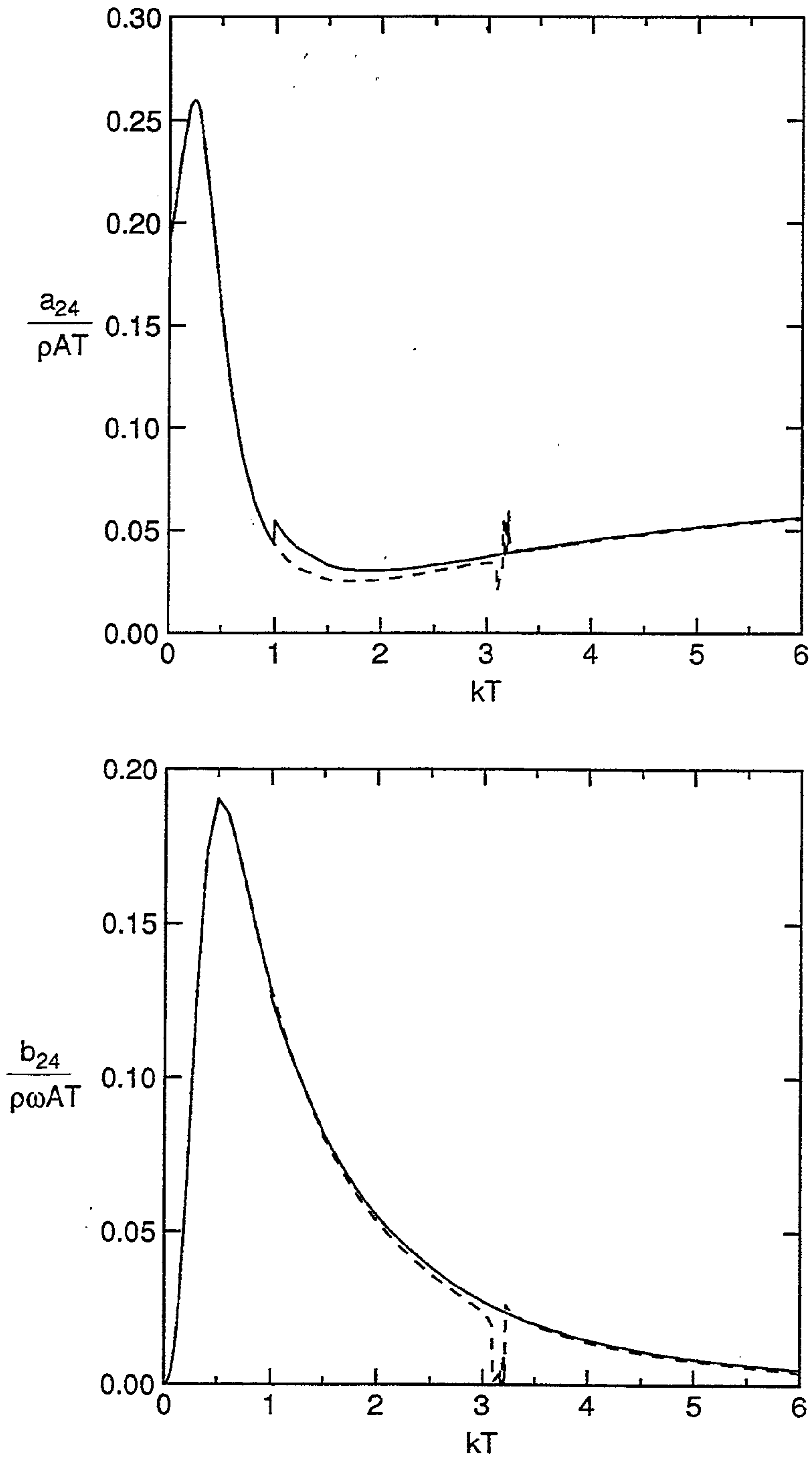

FIG. 9. Sway-roll coupling coefficients for the floating rectangular cylinder of $B/T = 2$. The roll centre is located on calm waterline. Here, $A = BT$: —— AMADIFF; - - - - usual source-distribution method. (30 segments along the wetted surface)

APPENDIX A:
SAMPLE CALLING PROGRAM FOR AMADIFF

A typical calling program is shown below. Note that it is essential to provide the common block SECGEO in the calling program; it is through this common block that the sectional geometry data are passed to AMADIFF. For the description of the parameters, see section 4 (page 6) in the main text. The sample input data file OFFSET.DAT is shown in Appendix B.

```
C           Sample calling program for routine AMADIFF
C           Maximum number of offsets on one-half of the section is 25.
            REAL Y(25),Z(25),ZRC,OMEG
            REAL A22,B22,A33,B33,A44,B44,A24,B24
            REAL OMG(200)
            INTEGER IUNIT,NP,NFREQ
            COMMON/SECGEO/NP,Y(25),Z(25),ZRC
            OPEN(UNIT=5,FILE='OFFSET.DAT',STATUS='OLD')
            READ(5,*) IUNIT
            READ(5,*) NP
            READ(5,*) (Y(I),I=1,NP)
            READ(5,*) (Z(I),I=1,NP)
            READ(5,*) ZRC
            READ(5,*) NFRQ
C           NFRQ is the number of input frequecies (OMEG's).
            READ(5,*) (OMG(I),I=1,NFRQ)
C           An array OMG containes frequecies.
            DO 100 I=1,200
              OMEG=OMG(I)
              CALL AMADIFF (IUNIT,OMEG,A22,B22,A33,B33,A44,B44,A24,B24)
              WRITE(*,'1X,(9F8.4)')OMEG,A22,B22,A33,B33,A44,B44,A24,B24
100         CONTINUE
200         CLOSE(5)
            END
```

APPENDIX B:

SAMPLE INPUT FILES FOR THE DRIVER PROGRAM FOR AMADIFF IN APPENDIX A

(a) Floating semi-circular cylinder of radius 1 m.

```
1
10
0.  .174 .342 .5 .643 .766 .866 .940 .985 1.
-1.  -0.985 -0.940 -0.866 -0.766 -0.643 -0.5 -0.342 -0.174 0.
-0.2
115
0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.10 0.11 0.12 0.20 0.22 0.24
0.26 0.28 0.30 0.32 0.34 0.36 0.38 0.40 0.50 0.60 0.70 0.80 0.85 0.90 0.95
0.97 0.99 1.00 1.20 1.50 1.60 1.70 1.72 1.74 1.76 1.77 1.78 1.79 1.80 1.81
1.82 1.83 1.84 1.85 1.86 1.87 1.88 1.90 2.00 2.10 2.20 2.30 2.40 2.50 2.60
2.70 2.80 2.90 3.00 3.10 3.15 3.20 3.21 3.22 3.23 3.24 3.25 3.28 3.30 3.31
3.32 3.33 3.34 3.35 3.37 3.40 3.50 3.60 3.70 3.80 3.90 4.00 4.20 4.40 4.60
4.70 4.72 4.73 4.74 4.76 4.77 4.78 4.80 4.81 4.82 4.83 4.84 4.86 4.88 4.90
5.00 5.10 5.20 5.30 5.40 5.50 5.60 5.80 5.90 6.00
```

(b) Floating rectangular cylinder (B/T=2.0)

```
1
16
0.  .125 .25 .375 .5 .625 .75 .875 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
-1.0 -0.99998 -0.99997 -0.99996 -0.99995 -0.99994 -0.99993
-0.99992 -0.99991 -0.857 -0.714 -0.571 -0.429 -0.286 -0.143 0.
0.
119
0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.10 0.11 0.12 0.20 0.22 0.24
0.26 0.28 0.30 0.40 0.50 0.60 0.70 0.80 0.85 0.90 0.95 0.97 0.98 0.99 1.00
1.10 1.20 1.50 1.60 1.66 1.67 1.68 1.69 1.70 1.71 1.72 1.73 1.74 1.75 1.76
1.78 1.80 1.90 2.00 2.10 2.20 2.30 2.40 2.50 2.60 2.70 2.80 2.90 3.00 3.05
3.06 3.06 3.07 3.09 3.10 3.15 3.16 3.17 3.18 3.19 3.20 3.205 3.21 3.22 3.23
3.24 3.25 3.26 3.28 3.30 3.40 3.60 3.80 3.40 3.50 3.60 3.70 3.80 3.90 4.00
4.20 4.40 4.60 4.65 4.66 4.67 4.68 4.69 4.70 4.71 4.72 4.73 4.74 4.75 4.76
4.78 4.80 4.90 5.00 5.10 5.20 5.30 5.40 5.50 5.60 5.70 5.80 5.90 6.00
```

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