CONTRIBUTIONS ON THE PROBLEM OF SHIP VIBRATION, FINAL REPORT

by

Louis Landweber

Sponsored by
Department of Acoustics and Vibration
Naval Ship Research and Development Center
Under Naval Ship Systems Command
Subproject SF 113 1108, Task 1360
Contract Nonr-3271(01) (X)

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Contributions on the Problem of Ship Vibration

Background

At a meeting of the H-11 (Flow Studies) Panel of the Hydrodynamics Committee of the Society of Naval Architects and Marine Engineers, in July 1956, the author was requested to submit a proposal for research on the added mass of a ship vibrating transversely. Since the proposal letter submitted in October 1956 outlined the research program which was actually pursued in the succeeding twelve years, pertinent portions of this proposal are here quoted:

> The now classical papers of Frank M. Lewis (SNAME 1929) and J. Lockwood Taylor (TINA 1930, Phil. Mag. 1930) have furnished a theoretical basis and a practical procedure for estimating the inertia coefficients due to the water when a ship is vibrating vertically. The method is approximate in that it employs the two-dimensional inertia coefficient at each section, with a correction coefficient for the three-dimensionality of the flow based upon an exact solution for an ellipsoid of revolution vibrating in two and three nodes. An unresolved difficulty with respect to the magnitude of this correction coefficient is the large disagreement between the values derived by Lewis and Taylor, the former having assumed vibrations in shear alone, the latter in flexure.
>
> A corresponding theory for the inertia coefficients of ships vibrating horizontally appears to be lacking. The reason for this is that, whereas inertia coefficients for vertical vibrations may be excerpted directly from compilations of such coefficients for bodies completely immersed in a fluid extending to infinity in all directions, the boundary conditions for horizontal vibration lead to a new and difficult problem in potential flow, solutions of which have appeared in the literature for only a few simple geometric forms.
>
> It is proposed to undertake a research program on the added mass of a ship vibrating horizontally, with the following aims:
>
> 1. To devise a method for determining the added mass of a two-dimensional form vibrating horizontally in a free surface.
> 2. To apply the method to families of ship-shape forms.
> 3. To develop corrections for the three-dimensionality of the flow for various modes of vibration, since such corrections will probably not coincide with those for vertical vibrations.

4. To devise an alternative method for obtaining the added mass of a three-dimensional form directly, without recourse to two-dimensional coefficients. If successful, this would also give a more accurate solution for the case of vertical vibrations.

The proposed research was supported by the Society from January 1957 through June 1960. By that time seven papers on ship vibration [1, 2, 3, 4, 5, 6, 7]* had been prepared. A proposal for continuation of this research was then submitted to the Structural Mechanics Division of the David Taylor Model Basin in June 1960 and formally approved in November 1960. Under the latter contract nine additional papers [8, 9, 10, 11, 12, 13, 14, 15, 16] have been written.

Three of the authors of the sixteen papers produced under these contracts, Messrs. E. O. Macagno and L. Landweber, and Mrs. M. Macagno, are staff members of the Iowa Institute of Hydraulic Research. Messrs. C. C. Wu, R. G. Warnock, and A. Pita were graduate students for whom references [4], [13], and [14] served as an M.S. thesis and Ph.D. dissertations respectively.

Contributions to the problem of ship vibrations contained in the aforementioned references may be divided into the following three classifications:

1. Added masses of two-dimensional ship sections.
2. Three-dimensional corrections to strip theory.
3. Three-dimensional theory for vibration in a liquid.

Achievements in each of these categories are summarized below.

1. Added masses of two-dimensional ship sections

The method of "strip theory" requires that the added mass of each double ship section be known. Landweber and Macagno [1, 2] developed expressions for the added masses of such sections vibrating vertically or horizontally at a free surface. The results are given in terms of the coefficients of the Laurent expansion

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* Numbers in brackets indicate references at end of this report.

$$z = \zeta + \frac{a_1}{\zeta} + \frac{a_3}{\zeta^3} + \cdots \tag{1}$$

where a_1, a_3, a_5, $\cdots$ are real numbers, which maps the double ship section in the z-plane into a circle in the ζ-plane. For vertical vibrations the added masses can be expressed very simply in terms of the section area and the coefficient a_1 of (1); for horizontal vibrations the resulting expression is an infinite series involving all the coefficients of (1). Results for a two-parameter family of ship forms, the so-called Lewis forms, obtained from (1) by setting $a_5 = a_7 = \cdots = 0$, are given in [1]; and extended results for a three-parameter family of ship forms, with a_1, a_3, and a_5 in (1) allowed to vary, and $a_7 = a_9 = \cdots = 0$, were presented by Landweber and Macagno [3]. The added-mass formula for horizontal vibrations was found by Wu [4] to yield results in good agreement with experimental values in the case of a horizontally oscillating ogive.

The need for an efficient procedure for determining the coefficients a_i of (1) led to the development of the Bieberbach method, presented by Landweber and Macagno [5]. Results obtained by this method are favorably compared with those by the two- and three-parameter methods [2, 3] by Macagno [6]. More recent, unpublished work indicates that the Bieberbach method may fail for certain sections and that alternative procedures using the Gershgorin integral equation, or iterative procedures for determining the coefficients of (1) more directly, may be preferable. It should be stressed that any of these methods can be used to compute the added masses economically with a high-speed computer, and yields results far superior to that obtained from the two- and three-parameter methods.

2. Three-dimensional corrections to strip theory

In the procedure commonly used to correct the section added-mass coefficients for the three-dimensionality of the flow about a ship form, correction coefficients derived by Frank Lewis [17] from a theoretical analysis for an ellipsoid vibrating vertically in shear are applied. Lewis's results differed appreciably from corresponding ones of J. L. Taylor [18] for vibration with flexure. Macagno and Landweber [7] determined three-dimensional correction coefficients for the case of vertical oscillations for a more general mode of vibration, which includes those of Lewis and Taylor as special cases and accounts for the apparent discrepancy between their results.

Work on the corresponding problem for horizontal vibrations led at first to the solution for the case of rigid lateral oscillations of a spheroid at a free surface [8]. For a half immersed sphere, the added-mass coeficient was found to be given exactly by

$$C_{HS} = \frac{4}{\pi} - 1 \qquad (2)$$

Correction factors for lateral horizontal vibrations of a spheroid in various modes are given by Macagno and Macagno [9]. This procedure assumes the adequacy of a single correction factor for each mode. A comparison of the pressure-force distributions on a vibrating spheroid, derived from strip theory and from three-dimensional potential-flow theory, showed that the method is exact for translatory oscillation, but results in significant errors for flexural vibrations (Macagno [10]).

3. Three-dimensional theory for vibration in a liquid

Predictions of vibration frequencies by the method of strip theory with three-dimensional corrections are in good agreement with experiment at the lower modes, but deviate increasingly at the higher modes. Consequently an alternative procedure was developed in which the body and surrounding fluid are treated as a single dynamical system. Lagrangian dynamical equations, which require the elastic potential energy of the body and the total kinetic energy of body-fluid system, are employed. Although both the body and the fluid are continua, the expressions for the kinetic and potential energies can be discretized to yield expressions as quadratic forms or matrices for the kinetic and potential energies of the system. As was shown by Landweber [11], the natural frequencies are then given by the eigenvalues of the potential energy matrix with respect to an inertia matrix.

This procedure was subsequently applied by Warnock [12, 13] and Pita [14] to obtain the natural frequencies of a circular cylinder of finite length vibrating in a liquid. A procedure for estimating the discretization error and additional comparisons between the results from the two- and three-dimensional theories are given by Landweber [15] for the case of an infinitely long cylinder. Finally, application by Landweber [16] to a submarine form, for which experimental model data on inertial and elastic characteristics and natural frequencies were available, yielded excellent agreement, even at the higher modes. This report also includes a computer program for determining the natural frequencies of arbitrary, elongated bodies of revolution when distributions of the mass and the moduli of elasticity in bending and shear are given. Remaining to be developed is a detailed procedure and computer program for determining the natural frequencies of arbitrary ship forms.

REFERENCES

1. L. Landweber, "Added Mass of Lewis Forms Oscillating in a Free Surface," Proceedings, Symposium on the Behaviour of Ships in a Seaway, Wageningen, The Netherlands, September 1957.

2. L. Landweber and M. Macagno, "Added Mass of Two-Dimensional Forms Oscillating in a Free Surface," Journal of Ship Research, vol. 1, November 1957.

3. L. Landweber and M. Macagno, "Added Mass of a Three-Parameter Family of Two-Dimensional Forms Oscillating in a Free Surface," Journal of Ship Research, vol. 2, March 1959.

4. C. C. Wu and L. Landweber, "Added Mass of Ogival Cylinders Oscillating Horizontally in a Free Surface," Schiffstechnik, vol. 7, no. 37, 1960.

5. L. Landweber and M. Macagno, "Added Masses of Two-Dimensional Forms by Conformal Mapping," Journal of Ship Research, June 1967.

6. M. Macagno, "A Comparison of Three Methods for Computing the Added Mass of Ship Sections," IIHR Report No. 104, April 1967, Journal of Ship Research, December 1968.

7. E. O. Macagno and L. Landweber, "Irrotational Motion of the Liquid Surrounding a Vibrating Ellipsoid of Revolution," Journal of Ship Research, vol. 2, June 1958.

8. L. Landweber and M. Macagno, "Added Mass of a Rigid Prolate Spheroid Oscillating Horizontally in a Free Surface," Journal of Ship Research, March 1960.

9. E. O. Macagno and M. Macagno, "Kinetic Energy of a Liquid Surrounding a Prolate Spheroid Vibrating at Its Free Surface," Journal of Ship Research, March 1961.

10. E. O. Macagno, "Added Mass Distribution of a Spheroid Vibrating at a Free Surface," IIHR Report, May 1963.

11. L. Landweber, "Vibration in an Incompressible Fluid," IIHR Report, May 1963.

12. R. G. Warnock, "Vibration Frequencies of a Circular Cylinder of Finite Length in an Inviscid Fluid," IIHR Report, May 1963.

13. R. G. Warnock, "Added Masses of Vibrating Elastic Bodies," IIHR Report, February 1964.

14. A. Pita, "Vibration Frequencies of a Free-Free Cylindrical Beam of Finite Length Immersed in an Inviscid Fluid," The University of Iowa, Ph.D. Dissertation, August 1967.

15. L. Landweber, "Vibration of a Flexible Cylinder in a Fluid," Journal of Ship Research, September 1967.

16. L. Landweber, "Natural Frequencies of a Body of Revolution Vibrating Transversely in a Fluid," IIHR Report No. 111, August 1968, Journal of Ship Research, June 1971.

17. F.M. Lewis, "The Inertia of the Water Surrounding a Vibrating Ship," Trans. SNAME, vol. 37, 1929.

18. J.L. Taylor, "Some Hydrodynamical Inertia Coefficients," Philosophical Magazine, series 7, vol. 9, 1930.

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13. ABSTRACT

Contributions to three problems of ship vibrations, a) added masses of two-dimensional ship sections (including horizontal vibrations at a free surface), b) three-dimensional corrections to strip theory, c) three-dimensional theory for vibration in a liquid, presented in a series of 16 papers, are briefly summarized. If strip theory is used, it is preferable to determine the added mass of a ship section by conformal mapping than by matching against families of forms (such as the Lewis forms) of known added mass. If natural frequencies at higher modes are required, the three-dimensional vibration theory, which essentially replaces the added-mass vector of strip theory by an added-mass matrix, should be employed.

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