Prediction of Surface Pressures during Water Impact

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Nomenclature

$C_{D\infty}$ = drag coefficient assuming a constant entry velocity
C_P = pressure coefficient
C_w = wetting factor, h/h'
$\bar{e}_n$ = unit vector normal to the body surface
h = model depth below effective planar surface
h' = model depth below original surface
Δh = increment in depth below the effective planar surface in successive steps
t = time
t^*_m = $V_E t/D$, where t is time measured from initial model impact
t^*_c = $V_E t/d$, where t is the length of time the element centroid has been submerged
V_E = entry velocity
θ_c = cone half angle
θ = entry angle (measured from the horizontal)
ϕ = velocity potential

Theme

A COMMON problem in the design of bodies entering the water at high speeds is the determination of the pressure distribution and loads during water impact. This paper describes an engineering approach for calculating these quantities which is applicable to arbitrary bodies over a wide spectrum of entry conditions. A simplified potential flow model is used which replaces the free surface by a planar one positioned empirically at the splash height. The solution to the potential problem is accomplished using the source-sink distribution technique of Hess and Smith.[1] Body surface pressures are calculated using Bernoulli's Equation and integrated to produce total forces and moments. In support of the development of this predictive technique, pressure measurements are made on obliquely entering disk and ogive cylinder models.

Attempts to analyze the water-entry problem go back to the original work of von Karmen.[2] Comprehensive surveys of this field are provided by May,[3] and Moran.[4] The main thrust of past work relies on potential flow models and uses the concept of added mass which provides only the total load. These theories usually are restricted to simple geometries often entering vertically. The present approach differs from such efforts in several important aspects. Application of Hess and Smith's numerical solution method allows arbitrary bodies to be treated and makes it possible to calculate pressures on the surface of the body. These pressures are themselves of interest and can be integrated to provide both force and moment information.

Contents

Surface pressure measurements are made on obliquely entering vented disk and ogive cylinder models. Both of these bodies were propelled by a pneumatic launcher into the pilot tank at NSWC at an entry angle of 60° and a nominal velocity of 100 fps. An iterative procedure was developed to correct pressures for the finite size of the transducer diaphragm.

The flowfield about the entry body is described by Laplace's Equation. The boundary condition

$$-\nabla\phi\cdot\bar{e}_n = \bar{V}_E\cdot\bar{e}_n \tag{1}$$

is applied on the entry body and $\phi=0$ to the effective planar surface. This surface is assumed to rise at the rate $(C_w - 1)\, V_E \sin\theta$. Pressures are calculated from successive solutions at differing depths using the unsteady Bernoulli Equation which is cast in a reference frame moving with the model

$$C_p = [2\partial\phi/\partial t) - 2\bar{V}_E\cdot\nabla\phi - (\nabla\phi)^2]/V_E^2 \tag{2}$$

The preceding formulation produces pressure and force coefficients which are independent of model scale and entry velocity. The value of these two parameters must be simulated through an appropriate choice of the rate of surface rise (i.e, picking the correct C_w value).

In order to implement the potential flow solution, the nose of the entry body is approximated with a series of planar, quadrilateral elements. Each of these elements is defined by four points or nodes lying on the body surface. The computation proceeds by inserting the model into the water in a series of steps, each at a depth Δh greater than the previous one. At every step, the group of elements comprising the submerged portion of the model is redefined and arranged into a form amenable to the potential flow calculative procedure. The nodes defining a particular element are checked to determine whether they are above or below the water line. Elements with all four nodes above the water surface are discarded whereas those with all four below it are included without change. Elements which are intersected by the water surface are redefined with an upper edge coincident with it. A constant source strength is assumed distributed over the surface of each element, and the value of this strength is determined by satisfying Eq. (1) at the centroid of each element. The boundary condition, $\phi=0$, is satisfied by locating an image of each element of opposite source strength above the water surface.

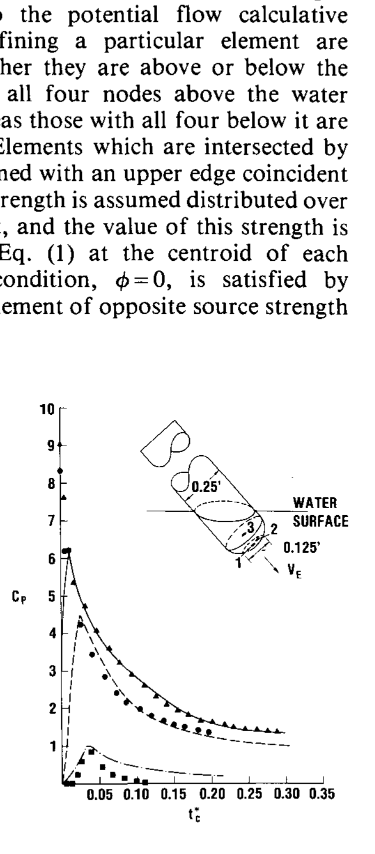

Fig. 1 Calculated and measured pressure-time histories at three different positions on the surface of an ogive cylinder, $\theta=60°$ and $V_E=100$ fps (— measured at positions 1, ▲ calculated at position 1, -- measured at position 2, ● calculated at position 2, — · — measured at position 3. ■ calculated at position 3. Experimental data were taken as a part of the current study.

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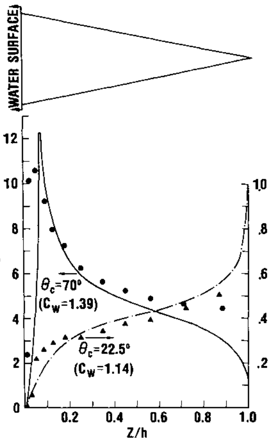

Fig. 2 Measured[5] and calculated pressure as a function of depth on 70° and 22.5° half-angle cones. — measured for a 70° cone, ● calculated for a 70° cone,—·—measured for a 22.5° cone, ▲ calculated for a 22.5° cone.

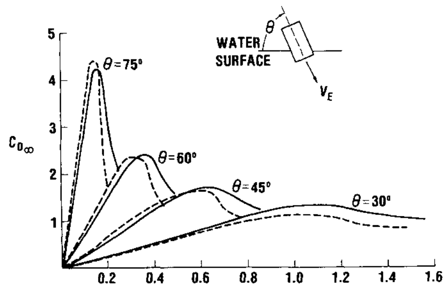

Fig. 3 Calculated[5] and measured drag on a disk cylinder at various entry angles. —experimental data by Baldwin,[5] - -calculated results obtained using $C_w = 1.45$ and a grid covering only the nose of the model.

At each depth the pressure coefficient C_p is evaluated at element centroids using Eq. (2) which is in a body-fixed frame of reference. The quantity $\nabla\phi$ appearing in this equation is determined directly at each depth, but $\partial\phi/\partial t$ must be calculated using the value of ϕ at the same body location in adjacent steps. In most cases this requirement does not pose a problem, since ϕ is calculated at the element centroids which are at fixed locations on the entry body. Defining ϕ_{c_n} to be the value of ϕ at a specific element centroid at step n and using the central difference

$$\frac{\partial\phi}{\partial t} = \frac{\partial h}{\partial t}\frac{\partial\phi}{\partial h} = V_E \sin\theta C_w \left[\frac{\phi_{c_{n+1}} - \phi_{c_{n-1}}}{2\Delta h}\right] \tag{3}$$

The foregoing procedure cannot be applied directly to elements which are intersected by the water surface. Under these conditions, the element centroid location on the entry body changes slightly from step to step and certain approximations must be introduced.

The computational method has been applied to the oblique entry of disk cylinders, ogive cylinders, spheres, and to the vertical entry of cones and spheres. In each case C_w is assigned a value consistent with existing experimental data. The computed pressure coefficients are in good agreement with measurements on the wide variety of bodies studied. The calculated pressures reflect not only basic body geometry but also position on the model surface. The peak pressures tend to be somewhat larger than the measured ones. Fortunately, these act over very small areas and thus do not effect the calculated loads significantly. Typical results are shown in Figs. 1 and 2 for the oblique entry of a tangent ogive and the vertical entry of cones.

The calculated drag is in good agreement with experiment in all of the tested cases, particularly prior to the point of peak loading. Figure 3 provides a comparison between calculated and measured drag on an obliquely entering disk cylinder. The success of the current model indicates that an accurate description of the free surface is not essential in determining the pressures and loads during the flow-forming phase of water entry.

References

[1]Hess, J.L. and Smith, H.M.O., "Calculation of Potential Flow About Arbitrary Bodies," *Progress in Aeronautical Sciences*, edited by D. Kuchemann, 1967, Vol. 8, pp. 1-138, Pergamon Press, New York.

[2]Von Karman, T., "The Impact on Seaplane Floats During Landing," NACA TN 321, Oct. 1929.

[3]May, A., "Forces at Water Impact," Alden Research Laboratories, ARL 119-72/SP, Dec. 1972.

[4]Moran, J.P., "On the Hydrodynamic Theory of Water-Exit and Entry," Therm Advanced Research, TAR-TR 6501, Mar. 1965.

[5]Baldwin, J.L., *An Experimental Investigation of Water Entry*, Ph. D. dissertation, 1972, University of Maryland.