ENGINEERING APPROXIMATION OF MAXIMUM ACCELERATIONS EXPERIENCED BY PLANING CRAFT IN ROUGH WATER

by

John K. Roper

This research was sponsored by the Naval Ship Systems Command Exploratory Development Research Program SF 35421009 and prepared under Office of Naval Research Contract N00014-67-A-0202-0014, NR052-419/9-18-68 (Code 458)

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Approved

Daniel Savitsky
Assistant Director
ABSTRACT

An engineering procedure is presented for estimating the maximum impact accelerations experienced by planing craft in irregular head seas. General agreement between calculated and model test results indicates that the proposed method is realistic. The procedure should be particularly useful during preliminary design.

Keywords
Planing Hulls
Impact Accelerations
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**NOMENCLATURE**

- \(a\): Horizontal distance from LCG
- \(b\): Beam
- \(C_{L_0}\): Total lift coefficient, zero deadrise = \(f(C_{T}, \beta)\)
- \(C_{L_{OD}}\): Dynamic lift coefficient, zero deadrise = \(0.012 \cdot 1.1 \cdot \lambda_{o}^{1/2}\)
- \(C_{L_B}\): Total lift coefficient, deadrise surface = \(A/qb^2\)
- \(C_{L_{BD}}\): Dynamic lift coefficient, deadrise surface = \(f(C_{L_{OD}}, \beta)\)
- \(C_v\): Speed coefficient = \(\dot{x}/\sqrt{gb}\)
- \(g\): Acceleration due to gravity
- \(H_w\): Wave height
- \(a\): Wave particle velocity, vertical, at surface
- \(i\): Mass moment of inertia
- \(L\): Total lift
- \(L_B\): Buoyant lift
- \(L_D\): Dynamic lift
- \(LCF\): Centroid of chine planform area forward of transom
- \(LCG\): Center of gravity location forward of transom
- \(x\): Effective wetted length forward of transom
- \(x_C\): Projected chine length
- \(x_w\): Wave length
- \(M\): Applied moment
- \(n\): Incremental load factor
- \(q\): Dynamic pressure = \(\dot{x}^2(p/2)\)
- \(T_w\): Wave period
- \(V\): Speed, knots
- \(\dot{x}\): Horizontal velocity
- \(\dot{y}\): Vertical velocity
\[ \gamma \]  Vertical acceleration

\[ \dot{z} \]  Velocity, relative to adjacent fluid, of planing body normal to its keel

\[ \beta \]  Deadrise angle

\[ \Delta \]  Gross weight

\[ \ddot{\theta} \]  Angular acceleration

\[ \lambda \]  Effective wetted length to beam ratio

\[ \rho \]  Mass density

\[ \tau \]  Trim angle

\[ \phi \]  Wave slope (maximum)

**Subscripts**

\[ o \]  Denotes smooth water operation

\[ \text{max} \]  Denotes rough water operation

\[ \text{CG} \]  Denotes center of gravity

\[ \theta \]  Denotes angular motion
INTRODUCTION

Research in the area of hydrodynamic impact has been carried out mainly by the aerodynamicist in his studies of landings of water-based aircraft and recently by the hydrodynamicist in his studies of ship slamming. Numerous theoretical developments have been published and a great deal of experimental data on hydrodynamic impact exists in the various publications associated with these two technological disciplines. A brief study was undertaken to review the existing information on hydrodynamic impact and to extract therefrom those results particularly applicable to the design of high speed planing craft. In the course of this review, an empirical procedure was formulated which allowed for reliable engineering estimates of the maximum impact accelerations experienced by planing craft in rough water. It was believed that this procedure would be of immediate direct benefit to the small craft designer and, consequently, the emphasis of the present report is on a description of this engineering procedure and includes a comparison of computed and measured rough water accelerations obtained in model tests at the Davidson Laboratory.


BACKGROUND

Some of the earliest studies of the phenomenon of hydrodynamic impact were initiated by aircraft designers concerned with the determinations of hull impact loads for seaplanes alighting upon a smooth water surface. Analytical and experimental investigations of hydrodynamic impact were continuously pursued during the period when seaplanes were a viable component of aviation. As a consequence, an extensive technical literature was developed which is generally available in NACA (now NASA) reports.

For the most part, seaplane impact theories deal mainly with the case of constant deadrise surfaces alighting upon a smooth water surface at a fixed trim angle such that the initial contact between hull and water is at the transom-keel intersection and the maximum impact load occurs prior to chine immersion. These conditions are typically representative of most seaplane landings. Well-documented reviews of seaplane
Impact theory have been prepared by Mayo\(^1\) and Monaghan\(^2\). In essence, these papers describe the impact process as the transfer of momentum from an impacting hull to an "added mass" of water which is directly associated with the hull during its contact with the water and to the "added mass" shed into the wake as the hull moves forward. The expression for the time rate of change of momentum between hull and added mass components then describes the differential equation of motion governing the impact. It is apparent then that this Impact theory is dependent upon a proper definition of the form of added mass and, as a result, a substantial research effort has been directed to this end (von Karman\(^3\), Wagner\(^4\), Pabst\(^5\), Milwitzky\(^6\) among others). The added mass is defined for two-dimensional sections normal to the keel which are then integrated over the wetted length of the hull and corrected by an aspect-ratio correction developed by Pabst\(^5\) to provide for a three-dimensional estimate of the total added mass in contact with the hull. This is the usual procedure used in seaplane impact theory and must be limited to the chines-dry impact of a constant deadrise hull.

More comprehensive impact theories dealing with heavily loaded, high length-beam ratio warped hulls were being developed for both smooth and rough water impact conditions when water-based aircraft research was essentially terminated. This new approach, which consists in exploiting the fact that planing is a particular case of impact, would have been of particular advantage to the planing hull. It can be applied to any hull shape for which planing data are available whether or not the chines are immersed and is not limited to prismatic surfaces. Stelner\(^7\) used this approach to obtain a correlation between planing data and one of the empirico-theoretical virtual mass expressions using limited data mostly confined to the chines dry condition. Brown\(^8\) and Smiley\(^9,10,11,12\) exploit, to varying degrees, the concept that impact characteristics may be predicted from planing data. In both cases, the basic equations of motion governing the smooth water Impact of a hull are formulated, integrated, and adapted to the prediction of smooth water impact loads and motions from planing equations. Since this work was carried out prior to the development of modern high speed computers, the analytical solutions are dependent
upon the application of special tabulated mathematical functions which make the use of the computational procedure extremely tedious. This method for impact calculations should be reactivated and extended to the case of planing hull operation in waves. This extension was not possible within the limited scope of the present study.

Analytical studies of the impact process establish the form of relation between the impact force; the mass of the planing hull and its geometry; and the relative approach conditions between hull and wave; i.e., hull trim, hull velocity (horizontal and vertical components), position in wave. These approach conditions are statistically related and can only be determined from analysis of operational experiences. At the present time, there is insufficient information to describe realistic combinations of approach parameters to be used with impact theory. These operational conditions require much further study.

ENGINEERING APPROXIMATION OF MAXIMUM ACCELERATIONS

The actual case of a planing craft operating in an irregular sea state is a most difficult problem for precise analysis. As previously noted, the basic impact theory requires further development; and among the unknown, moreover, are the hull trim and velocities at the time of impact and the geometry and relative position of the local wave surface against which the hull impacts. In recent years, however, a moderate amount of experimental data has been collected on the behavior of planing hulls in waves. One of the more complete works is a report by Chey on model tests of a series of six patrol boats in smooth and rough water. In that report, numerous plots of angular and center-of-gravity accelerations are presented for round and hard chine hulls in several irregular seas. It was believed that, by a combination of present understanding of the fundamentals of impact theory, full scale and model test observations of planing hulls in waves, and a judicious set of approximations, an engineering procedure for estimating maximum accelerations on planing hulls could be established to at least be applicable within the range of available experimental data. Accordingly, the following assumptions and approximations have been made to represent the impact process and the hull-wave contact conditions at the time of maximum hull acceleration.
A) Hydrodynamic Representation of the Impact Process

1) The planing hull is subjected to both dynamic and buoyant pressures during the planing and impact process. In steady planing, the dynamic lift ($L_D$) and the buoyant lift ($L_B$) can be obtained from planing lift equations such as given by Savitsky.

2) For a given trim angle, the dynamic pressures are taken to be proportional to the square of the velocity, $\dot{z}$, normal to the keel of the body relative to the adjacent fluid. This assumption is similar to that made by Smiley and Brown where hydrodynamic impact and planing are shown to be related. Then, $\ddot{z}$ is equal to the sum of the normal component of the hull's vertical velocity ($\ddot{z}$), the normal component of the hull's horizontal velocity $\dot{x}$, and the normal component of the vertical velocity of the wave ($\dot{h}$). This relationship can be written as:

$$\ddot{z} = \dot{x} \sin \tau + \dot{y} \cos \tau + \dot{h} \cos \tau$$

where $\tau$ is the hull trim relative to level water.

3) All other conditions being equal, the hydrodynamic lift ($L_D$) is equal to the product of the average bottom pressure and the wetted bottom area. The wetted area is proportional to the mean wetted length ($l$). Actually, as can be seen from Figure 10 of Ref. 14, a linear relation between planing lift and mean wetted length-beam ratio is realistic for the range of speed coefficients ($2.0 \leq C_V \leq 6.0$) and mean wetted length-beam ratios ($1.5 \leq \lambda \leq 4.0$) typical for planing hulls. Thus

$$L_D \approx (\ddot{z})^2(l)$$

4) For pure planing in smooth water (subscript o), the vertical velocity of the craft ($\dot{y}_o$) and the velocity of the water ($\dot{h}_o$) are both zero. The trim ($\tau_o$) and corresponding effective wetted length ($l_o$) are functions of the basic characteristics of the craft (beam, weight, center of gravity location, deadrise, and speed). Thus

$$\ddot{z}_o = \dot{x} \sin \tau_o$$

$$\tau_o = f(b, \Delta, LCG, B, \dot{x})$$

$$l_o = f(b, \Delta, LCG, B, \dot{x})$$
The smooth water equilibrium condition shown in Figure 1 can be evolved by applying the procedures of Ref. 14.

8) Relative Hull-Wave Contact Conditions at Time of Maximum Hull Acceleration (Figure 2)

1) In rough water (subscript max.) the maximum hydrodynamic lift ($L_{\text{D, max}}$) occurs in head seas at the time of maximum chine immersion ($t_{\text{max}}$) and at the time when the vertical velocity ($\dot{y}_{\text{max}}$) of the hull is essentially zero.

2) Observations of full-scale and model planing craft in waves indicate that, at maximum acceleration, the mid-length of the craft encounters the mid-flank of an oncoming wave and there is an increase in the trim of the craft ($\tau_{\text{max}}$) to equal the maximum slope ($\varphi_{\text{max}}$) of the wave.

3) The length of the wave in contact with the hull is assumed to move vertically with maximum wave orbital velocity, that is:

$$h_{\text{max}} = \frac{\pi H_w}{T_w}$$

where $T_w = \text{wave period}$

$h_w = \text{wave height}$

Combining conditions (1), (2) and (3) above, the maximum velocity normal to the full keel and the time of maximum acceleration in a wave is given by

$$\dot{z}_{\text{max}} = \dot{x} \sin \varphi_{\text{max}} + h_{\text{max}} \cos \tau_{\text{max}}$$

where

$$\tau_{\text{max}} = \varphi_{\text{max}} \text{ or } \tau_0 \text{ (whichever is larger)}$$

$$\tan \varphi_{\text{max}} = \frac{\pi H_w}{T_w}$$

$$h_{\text{max}} = \frac{\pi H_w}{T_w}$$

and

$$\cos \tau_{\text{max}} \approx 1$$

In these expressions, $T_w$, $H_w$, and $\varphi_{\text{max}}$ are the wave length, height and maximum slope respectively. For irregular head seas, Table 1 can be used to define these quantities as a function of wind speed or sea state.
Relative to the magnitude of the hull wetted length and the time of maximum acceleration, it is assumed that for the case when \( \ell_w \) is large relative to the hull length, the maximum effective wetted hull length \( \ell_{\text{max}} \) is equal to the projected chine length \( \ell_c \) as shown in Figure 2. In relatively shorter waves, the forebody of the craft extends beyond the wave crest and the maximum effective length is reduced to \( \ell_c/2 + \ell_w/8 \) or \( 3\ell_w/8 \). Thus:

\[
\ell_{\text{max}} = \ell_c \text{ or } \left( \frac{\ell_c}{2} + \frac{\ell_w}{8} \right) \text{ or } \frac{3}{8} \ell_w \text{ (whichever is smallest)}
\]

C) Maximum Accelerations During Hull Impact in Waves

1) The ratio of maximum dynamic lift in rough water to the hydrodynamic lift during smooth water planing can be expressed as

\[
\frac{L_{D\text{max}}}{L_{D\text{o}}\text{max}} = \left( \frac{\ell_{\text{max}}}{\ell_{\text{o}}} \right)^2 = \left( \frac{x_{\text{max}} + h_{\text{max}}^{\text{max}}}{x_{\text{o}} \cdot \sin \theta_{\text{max}}} \right)^2 = \left( \frac{\ell_{\text{max}}}{\ell_{\text{o}}} \right)^2
\]

2) The ratio of maximum buoyant lift in rough water impact to buoyant lift during smooth water planing is taken to be

\[
\frac{L_{B\text{max}}}{L_{B\text{o}}\text{max}} = \frac{\ell_{\text{max}}}{\ell_{\text{o}}}
\]

3) Using the basic characteristics of the craft (beam, weight, center of gravity location, deadrise, and speed), Ref. 14 can be used to calculate the dynamic lift \( L_{D\text{o}}\) and the buoyant lift \( L_{B\text{o}}\) during smooth water planing. Then

\[
L_{D\text{o}} = f(b, \Delta, \text{LCG}, \beta, \chi) \\
L_{B\text{o}} = \Delta - L_{D\text{o}}
\]

4) Applying conditions (1), (2) and (3) above, the maximum total lift in rough water \( L_{\text{max}} \) can be computed:

\[
L_{\text{max}} = L_{D\text{o}} \left( \frac{L_{D\text{max}}}{L_{D\text{o}}\text{max}} \right) + L_{B\text{o}} \left( \frac{L_{B\text{max}}}{L_{B\text{o}}\text{max}} \right)
\]

and the maximum center of gravity acceleration \( \dot{y}_{\text{CG\max}} \) is
The corresponding load factor is

\[ n_{CG_{\text{max}}} = \frac{\gamma_{CG_{\text{max}}}}{g} - 1 \]

5) In rough water, it is assumed that the maximum total lift \( L_{\text{max}} \) acts at the centroid (LCF) of the chine planform area. Thus, the maximum applied pitching moment about the center of gravity can be written

\[ M_{\text{max}} = L_{\text{max}}(\text{LCF} - \text{LCG}) \]

6) The mass moment of inertia \( I \) of the craft about its center of gravity is approximately

\[ I = \left( 0.25 \frac{L_c}{g} \right)^2 g \]

Thus, the maximum angular acceleration \( \ddot{\theta}_{\text{max}} \) is

\[ \ddot{\theta}_{\text{max}} = \frac{M_{\text{max}}}{I} \]

and the associated linear acceleration \( \gamma_{\theta} \) at any distance \( a \) from the center of gravity is

\[ \gamma_{\theta} = \ddot{\theta}_{\text{max}} a \]

and the corresponding incremental load factor at any distance, \( a \), from the center of gravity is then

\[ n_{\text{max}} = \frac{\gamma_{\theta}}{g} + \frac{\gamma_{CG_{\text{max}}}}{g} - 1 \]

D) Summary of Engineering Procedure for Estimating Maximum Accelerations

1) Given:

Planing craft characteristics
\( \Delta, b, \ell_c, \text{LCG}, \text{LCF}, \beta, \dot{x}, I \)

Wave characteristics
\( H_w, \ell_w, T_w \)

2) Objective:

Estimate maximum center of gravity and angular accelerations.
3) Procedure:

\[ L_D^O = f_1(\Delta, b, LCG, B, \dot{x}) \]  
from Ref. 14

\[ L_B^O = \Delta - L_D^O \]  

\[ \tau^O = f_2(\Delta, b, LCG, B, \dot{x}) \]  
from Ref. 14

\[ t^O = f_3(\Delta, b, LCG, B, \dot{x}) \]  
from Ref. 14

\[ \tan \phi_{\text{max}} = \frac{H_w}{t_w} \]

\[ H_{\text{max}} = \frac{H_w}{t_w} \]

\[ t_{\text{max}} = t_c \text{ or } \left( \frac{t_c}{2} + \frac{t_w}{3} \right) \text{ or } \frac{3t_w}{5} \quad \text{whichever is smallest} \]

\[ \tau_{\text{max}} = \phi_{\text{max}} \text{ or } \tau^O \quad \text{whichever is largest} \]

\[ L_D^\text{max} = L_D^O \left[ \frac{\dot{x} \sin \tau_{\text{max}} + H_{\text{max}}}{\dot{x} \sin \tau^O} \right] \left[ \frac{t_{\text{max}}}{t^O} \right] \]

\[ L_B^\text{max} = L_B^O \left[ \frac{t_{\text{max}}}{t^O} \right] \]

\[ L^\text{max} = L_D^\text{max} + L_B^\text{max} \]

\[ \gamma_{CG}^\text{max} = \frac{(\Delta/g)}{} \]

Also:

\[ H_{\text{max}} = (LCF - LCG)L_{\text{max}} \]

\[ I = (0.25t_c)^2/C\Delta/g \]

\[ \dot{\theta}_{\text{max}} = \frac{H_{\text{max}}}{I} \]

It may be that some of the previous assumptions which comprise this engineering procedure can be individually questioned. Nonetheless, it will be demonstrated that the synthesis of these elemental approximations does indeed compose a satisfactory engineering computational procedure which provides values of maximum accelerations that are in good agreement with model test results. This will be demonstrated in the following section of the report entitled "Verification." It is recommended that further study of the impact problem be pursued to establish a vigorously forward design procedure applicable for a wide range of impact conditions.
VERIFICATION

The proposed method has been employed to predict the center of gravity and angular accelerations of three hard chine hulls in a variety of irregular sea conditions. The calculated accelerations are compared with experimental model data reported by Chey.\textsuperscript{15}

Detailed calculations for the average and $1/10$ highest accelerations at the center of gravity and bow are illustrated in Tables 2, 3 and 4 as a function of speed for head sea operation in sea state 3 and 5. The calculations are for Model 4928 and for sea state characteristics as described in Ref. 15. In particular, the hull and sea state properties are as follows:

Hull Characteristics (Model 4928, Ref. 15)
\[ \Delta = 55,000 \text{ lbs. (Full scale values)} \]
\[ I_c = 42 \text{ ft.} \]
\[ b = 14 \text{ ft.} \]
\[ LCG/b = 1.29 \]
\[ \theta_{av} = 17.5^\circ \]
\[ C_v = V/ gb = V/21.2 \]
\[ LCG = 18.05 \text{ ft.} \]
\[ LCF = 19.05 \text{ ft.} \]
\[ l = 200,000 \text{ ft.-lbs.-sec.}^2 \]
\[ a = 13.45 \text{ ft. (from LCG to bow accelerometer)} \]

Sea State 5 Characteristics (as reported in Ref. 15)
\[ H_{av} = 5.5 \text{ ft. (Full scale values)} \]
\[ T_{av} = 6.0 \text{ sec.} \]
\[ h_{av} = \frac{mH_{av}}{T_{av}^2} = 2.88 \text{ ft.-sec.}^{-1} \]
\[ \omega_{av} = \frac{gT_{av}}{C_H} = 184.5 \text{ ft.} \]
\[ \phi_{av} = \tan^{-1} \frac{H_{av}}{\omega_{av}} = 5.4^\circ \]
Sea State 3 Characteristics (as reported in Ref. 15)

\[ H_{1/10} = 9.4 \text{ ft.} \]
\[ h_{1/10} = 4.92 \text{ ft.-sec.}^{-1} \]
\[ \varphi_{1/10} = 9.1 \text{ degrees} \]

Sea State 3 Characteristics (as reported in Ref. 15)

\[ H_{av} = 2.47 \text{ ft.} \quad (\text{Full scale values}) \]
\[ T_{av} = 4.5 \text{ sec.} \]
\[ h_{av} = 1.72 \text{ ft.-sec.}^{-1} \]
\[ l_w = 104 \text{ ft.} \]
\[ \varphi_{av} = 4.14^\circ \]
\[ H_{1/10} = 4.42 \text{ ft.} \]
\[ h_{1/10} = 3.09 \text{ ft.-sec.}^{-1} \]
\[ \varphi_{1/10} = 7.63 \text{ degrees} \]

Table 2 presents the results of calculations for the smooth water performance as a function of speed from 15 to 45 ft/sec. Presented in Table 2 are the equilibrium trim angle (\(\tau_o\)); the equilibrium mean wetted length-beam ratio (\(\lambda_o\)) and the dynamic (\(L_D\)) and buoyant (\(L_B\)) components of planing lift force. Table 3 presents the details of the computations and results for the center-of-gravity acceleration (both average and 1/10 highest) as a function of speed for sea states 3 and 5. Table 4 considers the bow accelerations for similar test conditions.

Comparisons between computed and measured accelerations are given in Figures 3 through 10. It can be seen that the agreement between computed and measured accelerations is reasonably good—at least for engineering design purposes. In general, the computed accelerations appear to be somewhat higher than measured values, especially at speeds in excess of approximately 35 knots. Similar calculations and comparisons have been made for hull forms 4929 (\(\beta_{av} = 19^\circ\)) and 2387 (\(\beta_{av} = 19^\circ\)) described in Ref. 15. The agreement between computed and measured results is equally favorable; detailed comparisons are therefore not presented in this report.
A brief study was made of the effects of trim change and loading change on the average center-of-gravity acceleration for Model 4928 planing at 30 knots in a sea state 5. It was found that a 50% increase in trim resulted in a 90% increase in acceleration while a 50% increase in loading resulted in a 25% decrease in acceleration. These results are qualitatively in agreement with the conclusions of Savitsky and Fridsma, thus further confirming the applicability of the proposed engineering computational procedure.

CONCLUSIONS

General agreement between calculated and experimental results indicates that the proposed method for computing maximum accelerations of planing craft during rough water operation is realistic. Since the method is easy to apply and requires no knowledge of the detailed craft characteristics, this procedure should be particularly useful during preliminary design.
REFERENCES


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*For hurricane winds (wind above 50 knots), sea is very rough, white caps rare, areas of wave length 10 m or more are seen.
### Table II. Calculations for Smooth-Water Performance

(Model 4928, Ref. 15)

<p>| ( \Delta ) | ( b ) | ( V ) | ( x ) | ( q ) | ( C ) | ( L ) | ( C_{1p} ) | ( C_{2p} ) | ( C_{1q} ) | ( C_{2q} ) | ( C_{1d} ) | ( C_{2d} ) | ( C_{1b} ) | ( C_{2b} ) | ( C_{1d} ) | ( C_{2d} ) | ( L_{d} ) | ( L_{b} ) |
| 55,000 | 14 | 15 | 25.4 | 645 | 0.435 | 1.29 | 1.2 | 2.9 | 0.075 | 17.5 | 0.51 | 6.8 | 5.7 | 0.139 | 0.105 | 13,300 | 41,700 |
| 20 | 33.8 | 1.140 | 0.245 | 1.59 | 2.4 | 0.039 | 0.30 | 7.9 | 6.55 | 0.147 | 0.11 | 24,600 | 20,400 |
| 25 | 42.25 | 1.786 | 0.157 | 1.98 | 2.15 | 0.027 | 0.20 | 7.41 | 6.2 | 0.13 | 0.10 | 35,000 | 20,000 |
| 30 | 50.7 | 2.570 | 0.109 | 2.39 | 1.95 | 0.022 | 0.14 | 6.36 | 5.36 | 0.1065 | 0.08 | 46,300 | 14,700 |
| 35 | 59.2 | 3.500 | 0.08 | 2.79 | 1.90 | 0.02 | 0.11 | 5.5 | 4.71 | 0.091 | 0.064 | 43,500 | 11,100 |
| 40 | 67.6 | 4.570 | 0.0613 | 3.19 | 1.85 | 0.019 | 0.087 | 4.57 | 3.98 | 0.0737 | 0.049 | 44,000 | 11,000 |
| 45 | 76 | 5.780 | 0.0486 | 3.59 | 1.80 | 0.018 | 0.074 | 4.11 | 3.61 | 0.0664 | 0.042 | 47,500 | 7,500 |
| 15 | 25.4 | 13,300 | 41,700 |
| 20 | 33.8 | 24,600 | 30,400 |
| 25 | 42.25 | 35,000 | 20,000 |
| 30 | 50.7 | 40,300 | 14,700 |
| 35 | 59.2 | 43,500 | 11,100 |
| 40 | 67.6 | 44,000 | 11,000 |
| 45 | 76 | 47,500 | 7,500 |</p>
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**Table 11. Calculations for CG Accelerations**

(Model 4928, Ref. 15)

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<th>( R = \left( \frac{V_{\text{m}}}{\text{data}} \right) )</th>
<th>( \frac{A}{\sqrt{V_{\text{m}}}} )</th>
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<td>( 2.88 )</td>
<td>( 2.92 )</td>
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<tr>
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<td>( 2.88 )</td>
<td>( 2.92 )</td>
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<td>( 2.88 )</td>
<td>( 2.92 )</td>
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<table>
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<th>( y )</th>
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</table>
### Table IV. Calculations for Bow Accelerations

*(Model 4928, Ref. 15)*

| V  | LCF | LG | LCF-LG | L<sub>max</sub> | (L<sub>CF</sub>-LGC) | L<sub>max</sub> | a | f<sub>max</sub> | g | a | f<sub>max</sub> | g | a | f<sub>max</sub> | g | a | f<sub>max</sub> | g |
|----|-----|----|--------|---------------|----------------|---------------|---|----------------|---|---|----------------|---|---|----------------|---|---|----------------|---|---|
| 15 | 19.05 | 18.05 | 1.00 | 107,200 | 107,200 | 200,000 | 0.536 | 13.45 | 0.224 | 0.95 | 1.174 | Sea State 5 | Head Seas | Average | Avg. 1/10 Highest |
| 20 | 132,000 | 132,000 | 0.66 | 0.276 | 1.40 | 1.676 |
| 25 | 157,900 | 157,900 | 0.79 | 0.35 | 1.87 | 2.20 |
| 30 | 183,600 | 183,600 | 0.816 | 0.383 | 2.37 | 2.753 |
| 35 | 227,500 | 227,500 | 1.14 | 0.475 | 3.14 | 3.615 |
| 40 | 293,800 | 293,800 | 1.47 | 0.613 | 4.34 | 4.953 |
| 45 | 358,500 | 358,500 | 1.79 | 0.748 | 5.52 | 6.260 |
| 15 | 1.00 | 216,200 | 216,200 | 200,000 | 1.08 | 13.45 | 0.451 | 2.94 | 3.39 |
| 20 | 255,000 | 255,000 | 1.275 | 0.533 | 3.64 | 4.173 |
| 25 | 324,900 | 324,900 | 1.625 | 0.679 | 5.24 | 5.919 |
| 30 | 484,600 | 484,600 | 2.42 | 1.02 | 7.80 | 8.82 |
| 35 | 617,500 | 617,500 | 3.065 | 1.29 | 10.25 | 11.54 |
| 40 | 807,800 | 807,800 | 4.04 | 1.69 | 13.70 | 15.39 |
| 45 | 1,004,500 | 1,004,500 | 5.02 | 2.10 | 17.25 | 19.35 |
| 15 | 1.00 | 66,300 | 66,300 | 200,000 | 0.337 | 13.45 | 0.138 | 0.205 | 0.343 |
| 20 | 82,800 | 82,800 | 0.414 | 0.173 | 0.505 | 0.678 |
| 25 | 97,800 | 97,800 | 0.489 | 0.204 | 0.78 | 0.984 |
| 30 | 111,100 | 111,100 | 0.555 | 0.232 | 1.02 | 1.62 |
| 35 | 116,700 | 116,700 | 0.583 | 0.244 | 1.12 | 1.364 |
| 40 | 129,400 | 129,400 | 0.647 | 0.270 | 1.35 | 1.62 |
| 45 | 155,100 | 155,100 | 0.775 | 0.324 | 1.82 | 2.144 |
| 15 | 1.00 | 108,400 | 108,400 | 200,000 | 0.542 | 13.45 | 0.226 | 0.97 | 1.196 |
| 20 | 127,200 | 127,200 | 0.636 | 0.266 | 1.31 | 1.576 |
| 25 | 162,600 | 162,600 | 0.813 | 0.339 | 1.96 | 2.299 |
| 30 | 233,300 | 233,300 | 1.166 | 0.486 | 3.24 | 3.726 |
| 35 | 300,200 | 300,200 | 1.50 | 0.626 | 4.46 | 5.086 |
| 40 | 397,400 | 397,400 | 1.985 | 0.83 | 6.22 | 7.05 |
| 45 | 499,100 | 499,100 | 2.50 | 1.04 | 8.09 | 9.13 |
FIG. 1 SMOOTH WATER PURE PLAINING
FIG. 2 ROUGH WATER MAXIMUM LOAD CONDITION
FIG. 3
MODEL 4928
SEA STATE 5, HEAD SEAS
AVERAGE CG ACCELERATIONS

INCREMENITAL LOAD FACTOR \sim \frac{\text{g}}{\text{s}}

SPEED \sim \text{KNOTS}
FIG. 4
MODEL 4928
SEA STATE 5, HEAD SEAS
AVERAGE 1/10 HIGHEST CG ACCELERATIONS

INCREMENTAL LOAD FACTOR ~ g's

SPEED ~ KNOTS

CALCULATED
EXPERIMENTAL
FIG. 5
MODEL 4928, HEAD SEAS
SEA STATE 5, AVERAGE BOW ACCELERATIONS
FIG. 6. MODEL 4928, SEA STATE 5, HEAD SEAS, AVERAGE 1/10 HIGHEST BOW ACCELERATIONS.

INCREMENTAL LOAD FACTOR ~ 0.1
SPEED ~ KNOTS

CALCULATED
EXPERIMENTAL
FIG. 7
MODEL 4928
SEA STATE 3, HEAD SEAS
AVERAGE CG ACCELERATIONS

R-1437
FIG. 9
MODEL 4928
SEA STATE 3, HEAD SEAS
AVERAGE 1/10 HIGHEST CG ACCELERATIONS

INCREMENTAL LOAD FACTOR ~ g's

CALCULATED

EXPERIMENTAL

SPEED ~ KNOTS
FIG. 10
MODEL 4928
SEA STATE 3, HEAD SEAS
AVERAGE 1/10 HIGHEST CG ACCELERATIONS

R-1437

CALCULATED

EXPERIMENTAL

INCREMENTAL LOAD FACTOR ~ 0.6

SPEED ~ KNOTS
An engineering procedure is presented for estimating the maximum impact accelerations experienced by planing craft in irregular head seas. General agreement between calculated and model test results indicates that the proposed method is realistic. The procedure should be particularly useful during preliminary design.
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Planing Hulls
Impact Accelerations