Ocean Engineering 101 (2015) 47–57

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Prediction of planing hull side forces in yaw using slender body oblique impact theory

Michael Gorts Morabito *

Naval Architecture and Ocean Engineering Department, United States Naval Academy, 590 Holloway Road, MS 11D, Annapolis, MD, 21402 USA

ARTICLE INFO

Article history:
Received 19 July 2014
Accepted 5 April 2015
Available online 21 April 2015

Keywords:
Planing hull
Maneuvering
Water impact
Vertical and oblique water entry
Moving body

ABSTRACT

Recent advances in the slender body theory and computational methods have enabled the study of asymmetric and oblique impacts of wedges on a flat free surface. These two-dimensional oblique impact predictions are often used for studies of wave slam loadings, as well as observations of the asymmetric formation of the spray jets. In the present study, an existing zero gravity, inviscid two-dimensional oblique impact model is applied to the three-dimensional planing case using slender body theory, producing estimates of planing hull side force as a function of yaw angle. Plots are generated to predict the side force generated by planing surfaces as a function of speed, beam, wetted length, trim angle and yaw angle. The resulting predictions are compared with previously published and new measurements of planing hull side forces during steady drift tests. The comparisons are used to establish recommended limitations of the method and provide insight into future work.

Published by Elsevier Ltd.

1. Introduction

Within the last fifteen years, there has been increasing development in the field of two-dimensional wedge impact predictions. Much of this development has centered on developing theoretical and computational procedures to include arbitrary shaped sections as well as oblique and asymmetric impacts. These studies have been useful for exploring the effects of asymmetric impact of spray formation (Judge et al., 2004), as well as estimating slamming pressures on offshore structures (Gu et al., 2014). In the present study, solutions for the constant velocity oblique impact of a two-dimensional wedge are related to the problem of planing at a steady drift angle. Prediction of steady drift forces provides an essential building block for future six degree-of-freedom planing hull maneuvering models using asymmetric and oblique impact theory. The primary purpose of this study is to determine if this new method shows promise, and to identify areas for improvement.

Fig. 1 shows the geometry of a typical planing hull with beam, b keel wetted length, L_K and deadrise β operating at a trim angle τ. Aft of the bow, this planing hull has constant beam and deadrise and straight buttock lines, making these sections a “prismatic planing hull.” At planing speed, a pile-up of water, known as a “wave rise” occurs near the intersection of the water surface with the hull. This intersection is termed as the “spray root.” The maximum pressures on the planing hull occur in the spray root region. Two distinct spray patterns are formed, the “whisker spray” which is a thin sheet of spray that leaves a hull at an angle equal to the reflection of the free stream about the spray root line and the “main spray” which is a heavy, dense spray emanating from the intersection of the spray root line with the chine. This main spray is formed as a result of high pressure gradients between the pressure along the spray root line and the atmospheric pressure at the chine. In two-dimensional approaches for analyzing planing hulls (2D+T), the fluid motion is confined to planes perpendicular to the keel and centerplane, shown in Fig. 2. In 2D+T approaches, it is not possible to have spray directed forward, therefore flat plates, and other low-deadrise hulls, in which the whisker spray is directed forward, cannot be accurately predicted using 2D+T approaches. Fig. 2 also shows typical planing hull pressure distributions in transverse planes. Section AA shows a section across the spray root region and the corresponding pressure distribution, which peaks just inboard of the spray root. Section BB shows a pressure distribution aft of the spray root. The pressure is substantially reduced. In classical, self-similar 2D+T approaches, such as Wagner (1932), it is not possible to predict the pressure distribution aft of the intersection of the spray root with the chine; however more recent work, such as Vorus (1996) allow for this.

Fig. 3 shows a representation of the typical 2D+T strip theory of planing. The hull passes through a fixed observation plane. Within that plane, the motion of the hull appears to be analogous to the constant velocity immersion of a wedge. This concept was first developed by Von Karman (1929) who estimated the forces

* Tel.: +1 410 293 6428; fax: +1 410 293 2219.
E-mail address: morabito@usna.edu

http://dx.doi.org/10.1016/j.oceaneng.2015.04.014
0029-8018/Published by Elsevier Ltd.

Nomenclature

Hull geometry

b beam (m)
β deadrise (deg)
L_K keel wetted length (beams)
T transom draft (m)
t section draft (m)

Physical constants

g gravitational acceleration (m/s^2)

Forces and moments

K roll moment positive starboard side down (N-m)
Y side force positive to starboard (N)
Z vertical force (N)
Subscript 2D denotes two-dimensional section properties

Distances

x longitudinal distance positive forward of the intersection of the level water with the keel
y transverse distance to starboard of centerline
z vertical distance below level water surface

Angles

ψ yaw angle positive bow to starboard (deg)
τ trim angle positive bow up (deg)

Velocities

U velocity in x direction of boat (m/s)
u velocity in x direction of 2D section (m/s)
v velocity in y direction of 2D section (m/s)
w velocity in z direction 2D section (m/s)

Coefficients

C_Z 3-D lift coefficient, $C_Z = \frac{Z}{(1/2)\rho U^2 b^2}$
C_Y 3-D side force coefficient, $C_Y = \frac{Y}{(1/2)\rho U^2 b^2}$
C_K 3-D roll moment coefficient, $C_K = \frac{K}{(1/2)\rho U^2 b^2}$
$C_{Z\ 2D}$ 2-D lift coefficient, $C_{Z\ 2D} = \frac{Z_{2D}}{(1/2)\rho w^2 b}$
$C_{Y\ 2D}$ 2-D side force coefficient, $C_{Y\ 2D} = \frac{Y_{2D}}{(1/2)\rho w^2 b}$
$C_{K\ 2D}$ 2-D roll moment coefficient, $C_{K\ 2D} = \frac{K_{2D}}{(1/2)\rho w^2 b}$
C_V beam Froude number, $C_V = \frac{U}{\sqrt{gb}}$

on the impacting wedge by added mass considerations. Wagner (1932) extended this to include the wave-rise, a pile-up of water that increases the wetted width beyond the calm water intersection. In addition to steady planing resistance predictions (Savander et al., 2002), the 2D+T methodology has been used in many different applications. Mayo (1945) and Milwitzky (1948) explored the problem of impacts of seaplanes on water during landing. Zarnick (1978) developed a prediction method for the vertical plane motions of planing hulls in regular waves, later extended a number of times to include irregular waves, gravity effects and roll (Sebastiani et al., 2008). The canonical wedge impact problem at the center of these methodologies has been studied to a great extent with increasingly accurate theoretical and numerical procedures. Recent studies by Fairlie-Clarke and Tveitnes (2008) and Tveitnes et al. (2008) have included gravity effects which allow the slender body theory to be extended to lower speeds.

Fig. 4 shows a representation of a yawed planing hull passing through a fixed observation plane. As the hull passes through the observation plane, it appears as a wedge impacting at both a vertical and a horizontal velocity. Recently, there have been an increasing number of researchers studying the problem of asymmetric impact of two-dimensional wedges from analytical and

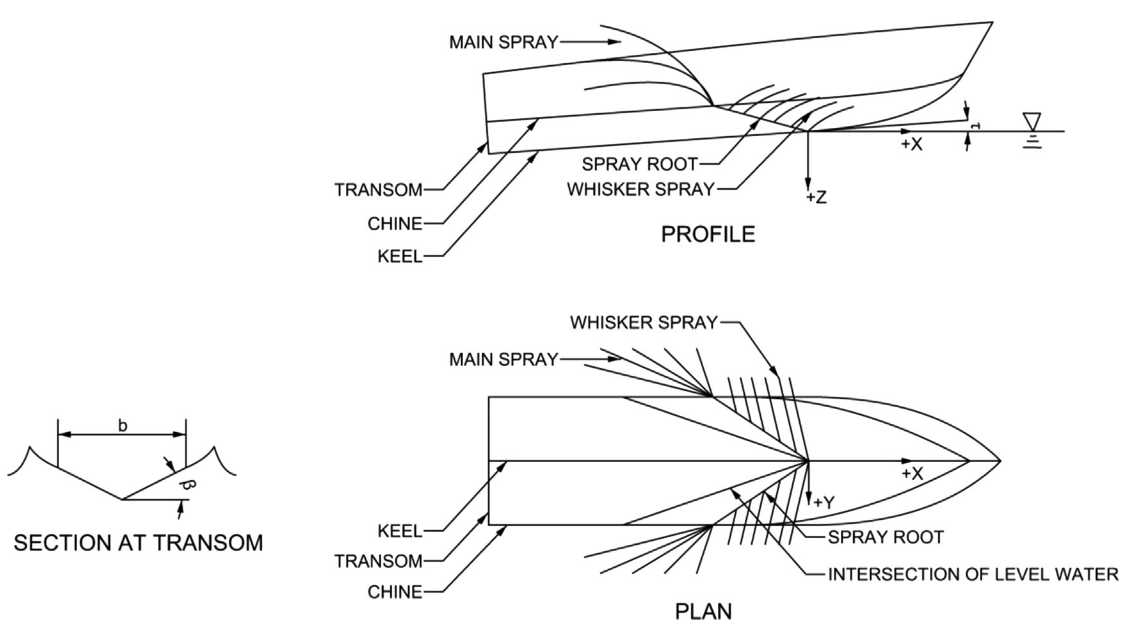

Fig. 1. Planing hull geometry.