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Determination of Initial Stability and Trim Characteristics for Hydrofoil Small Waterplane Area Ship (HYSWAS)

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I. INTRODUCTION

Hybrid surface ships, in particular HYSWAS, are unique in that substantial portions of their support are provided by both buoyancy and dynamic lift. In addition, since HYSWAS has a respectable waterplane, its support is distributed.

For these reasons, the standard naval architecture stability equations ($\overline{GM}$, trim, etc.) must be modified. This note illustrates the proper means of determining these values. This work is suitable for <u>small angles only</u>.

II. SYMBOLS

H = Buoyant Force

B = Center of Buoyancy at 0° Heel

B_1 = Center of Buoyancy at a Non-Zero Heel Angle

WL = Initial Waterline

WL_1 = Heeled Waterline

P = Hydrodynamic Lift Force

F = Center of Hydrodynamic Lift Force at 0^{0} Heel

F_1 = Center of Hydrodynamic Lift Force at a Non-Zero Heel Angle

θ = Heel Angle

Δ = Displacement of Ship in its Current Condition (=H)

∇ = Volume of Displacement in Current Condition

I_T = Transverse Moment of Inertia of Waterplane

$\overline{BM}$ = Metacentric Radius

$\overline{GM}$ = Metacentric Height

W = Weight of Ship

G = Center of Gravity of Ship

b = Fraction of Lift that is Buoyant

f = Fraction of Lift that is Hydrodynamic

M = Metacenter

RM = Righting Moment

HM = Heeling Moment

III. HULLBORNE STABILITY

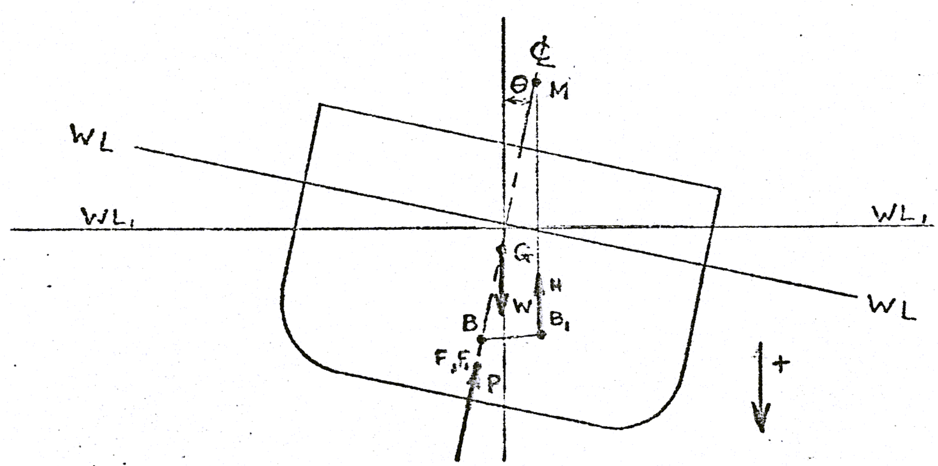
$\overline{GM}_T$ and $\overline{GM}_L$ are calculated in the hullborne case in a manner similar to other ships. One must remember that the ship has three waterplanes -- the two sponsons, and the strut piercing the water. Because the ship has a large beam, the transverse stability is very large -- the ship is stiff in roll. The $\overline{GM}_L$ is similar to that of a conventional ship of this size. Trim and heel for small angles (less than 5^{0}) is similar to that for conventional vessels.

IV. FOILBORNE STABILITY

A. Transverse Stability at Small Angles of Heel

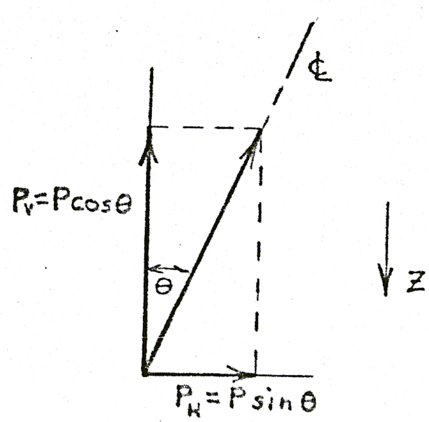
NOTE: For convenience, the accompanying illustrations show a conventional ship with characteristic HYSWAS centers. The center of gravity is assumed to be on the centerline.

The following illustration shows a ship heeled to an angle θ. The center of hydrodynamic lift remains fixed since the foil configuration is assumed to be unchanged. The hydrodynamic lift continues to act along the centerline of the ship.



The buoyancy acts vertically and its center moves.

Examine the sum of vertical forces. $\Sigma Z = 0 = -P \cos\theta - H + W$



(a) $H = W - P \cos\theta$

$$P = f \times W$$

$$H = W - f\,W \cos\theta$$

$$H = W\,(1 - f \cos\theta)$$

Note from equation (a) that the heel angle causes a reduction in vertical hydrodynamic lift. This must be made up by an increase in buoyancy, thus the ship sinks slightly.

Examine the sum of horizontal forces. $\Sigma Y = P \sin\theta$ (neglecting resistance and damping forces).

Examine the resulting moments. Since P goes through G, it produces no moment about G. The only righting moment is that produced by the buoyancy acting vertically.

$$RM = \overline{GM}_T \sin\theta \times H$$

$$= \overline{GM}_T \sin\theta \times W\,(1 - f \cos\theta)$$

$$= \overline{GM}_T \sin\theta\, W - \overline{GM}_T W f \sin\theta \cos\theta$$

For small angles, this approximates to:

$$RM = \overline{GM}_T\, W\,\theta - \overline{GM}_T W f\,\theta = \overline{GM}_T W\,\theta\,(1 - f)$$

The position of M must be determined. This means that the proper means of calculating $\overline{BM}_T$ must be found.

$\overline{BM}_T$, the transverse metacentric radius is normally defined as

$\dfrac{BB_1}{\tan\theta}$: the vertical distance corresponding to the transverse shift in center of buoyancy as the ship heels. Since the foil lift continues to act along the centerline as the ship heels, it contributes nothing to the righting moment. $\overline{BM}_T$ retains the same definition.

$$\overline{BM}_T = \frac{BB_1}{\tan\theta} = \frac{I_T}{\nabla}$$

Since $\nabla = 35 \times \Delta$ and $\Delta = H$

$$\nabla = 35 \times H = 35 \times W\ (1 - f\cos\theta)$$

$$\overline{BM}_T = \frac{I_T}{35 \times W\ (1 - f\cos\theta)}$$

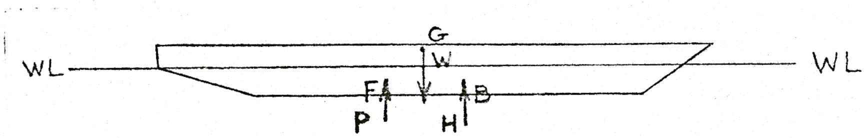
For small angles, $\cos\theta$ is approximately 1

$$\overline{BM}_T = \frac{I_T}{35\ W\ (1 - f)}$$

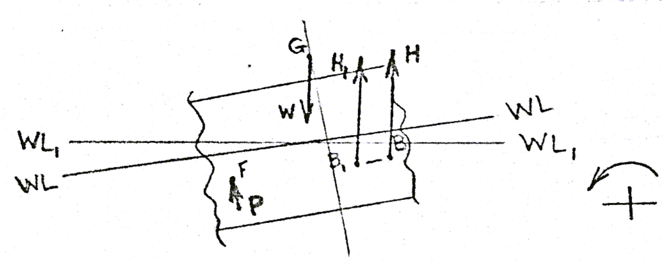
$$\overline{GM}_T = \overline{KB} + \overline{BM}_T - \overline{KG}$$

The $\overline{GM}_T$ would obviously be negative. After some response time, the foils would be activated to correct the heel.

(b) Longitudinal Stability and Trim



In the longitudinal case, the resultant of P and H is such that it acts through G in the untrimmed condition.



When the ship trims, the center of buoyancy will move but the center of foil lift will remain stationary.

In the initial (non-trimmed) case

$$\Sigma M_G = 0$$

$$0 = -\overline{FG} \times P + \overline{BG} \times H$$

horizontal distances

$$\overline{FG} \times P = \overline{BG} \times H$$

In the trimmed case

$$\Sigma M_G = \text{Righting Moment, RM}$$

For small angles:

$$RM = \overline{B_1G} \times H - \overline{F_1G} \times P$$

Since $F = F_1$

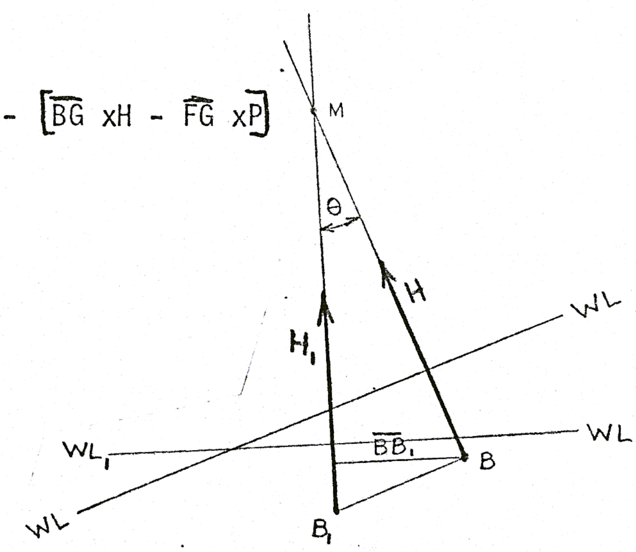
$$RM = \overline{B_1G} \times H - \overline{FG} \times P$$

$$RM = RM - 0$$

$$RM = \overline{B_1G} \times H - \overline{FG} \times P - [\overline{BG} \times H - \overline{FG} \times P]$$

$$RM = [\overline{B_1G} - \overline{BG}] \times H$$

$$RM = \overline{BB_1} \times H$$



$$\overline{BB_1} = \overline{BM_L} \sin\theta$$

$$RM = \overline{BM_L} \sin\theta \times H$$

Note that RM is much larger than if $\overline{GM_L}$ were used.

An example using the longitudinal case will be shown:

Calculate the trim caused by landing a 6.5T helicopter on the landing pad at the stern of a 2000-Ton HYSWAS -- Foilborne.

$I_L = 3.547 \times 10^6 \ FT^4$ about LCF

$\overline{BM}_L = I_L/35\nabla = 3.547 \times 10^6/(35 \times 1400)$

$\overline{BM}_L = 72.4$ ft

Trimming moment = 2 x 6.5 T x 87.6 ft. = 1138.8 ft. tons

The two is for dynamic effect

$TM = RM = \overline{BM}_L \sin\theta \times H \longrightarrow \overline{BM}_L \ \theta \ H$

$1138.8 = 72.4 \times \theta \times 1400$

$\theta = .0112 \text{ rad} = .644^0$

This corresponds to .0112 rad x 180 ft. = 2.02 ft. of trim