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HIGH SPEED MARINE CRAFT 1990
KRISTIANSAND, NORWAY.

DESIGN TOOL FOR HIGH SPEED SLENDER CATAMARANS

BY

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INTRODUCTION.

Performance prediction tools for use in preliminary design exist for planing and round bilge monohulls, surface effect ships and hydrofoils, but no published prediction tool exists for catamarans. This is remarkable in that catamarans have become by far the leading type of commercial high speed craft. As of mid 1989 there were 263 catamarans compared to 215 hydrofoils (the previous leading type of high speed craft). Approximately 25 companies in 12 countries are now involved in catamaran construction, with Norway being the leading producer.

MARINTEK, Ocean Laboratories in Trondheim, Norway, has since 1987 tested a large number of catamaran designs both in calm water and in head/following seas. Model to full scale correlation for high speed catamarans has been developed based on extensive full scale experiments. This unique amount of emphirical data makes it possible to present a simple tool for preliminary design, speed-powering predictions as well as seakeeping assessment of high speed slender catamarans.

SLENDER CATAMARAN CHARACTERISTICS.

The slender catamaran is characterized by having extremely slender, symmetric hulls without utilizing much planing effects. The craft thus operates esentially as a displacement vessel and is the most effective concept for passenger transport at speeds up to Froude Number of about $Fn=1.1, (Fn=V/\sqrt{g \cdot L},\ V(m/s))$.

This concept has been well received by commercial operators as market share of the total number of high speed ferries has grown from 13% in 1971-75 to an expected 40% in 1991-95 (Fig. 1 of ref. 1).

A large number of slender catamarans has been tested at MARINTEK, Ocean Laboratories. All models in scale 1:10 or 1:12.5. The models cover the length displacement ratio $L/\Delta^{1/3}$ = 5.75 to 7.5. Typical main characteristics for good designs are:

- (a) Straight V-formed transverse sections in forebody with total angle of entrance 12 to 16 degrees. $\{6 < i_e < 8\}$
- (b) Minimum hull beam closely related to machinery installation.
- (c) Round bilges along the entire hull.
- (d) Transom width equal to the midship, and transom depth reduced compared to the midship section.
- (e) Longitudinal center of gravity (cg.) approx. 5% of Lpp aft of midship.
- (f) Wet-tunnel width minimum 1/3 of the craft beam. $\bar{c} = \frac{c}{2L} > 0,5$

The position of the center of gravity is the primary design parameter, together with the length/displacement ratio and wet-tunnel height. ? width

- The cg. should not be placed too far aft. Large aft body volume and deep stern plate gives relatively large increase in wave resistance. This effect is considerable for cg. positions more than 7.5% of Lpp aft of midship.

- The cg. should not be placed forward of 2.5% aft of midship in order to ensure that too large negative trim angles are avoided in following sea.

The combination of slender forebody, a forward position of cg. and operation in even moderate following seas with speed of wave propagation close to ship speed has resulted in hazardous effects such as green water and bow diving. These effects are effectively studied in model tank tests and MARINTEK highly recommends that all high-speed vessel concepts are tested to assess the risk of bow down diving tendencies in following seas.

The optimal position of cg. is a function of aft body design, type of propulsion system, use of trim flaps, service speed and above water bow design. The above water bow design influences both the seakeeping performance in head seas and the safety qualities in following seas.

In general a running trim of 0.5 to 1.0 degree will be optimal at design speed and the slender catamaran should be designed to run at this trim without the use of trim flaps.

Ride quality in waves is mainly determined by the magnitude and frequency of the vertical accelerations. The vertical acceleration of catamarans is closely related to ship speed, length-displacement ratio and height of wet-tunnel. Rules for Light Craft allows a 1 "g" maximum cg. acceleration limit for structural design purposes. Statistically this corresponds to a 0.33 "g" RMS-value. As a "rule of thumb" the slender catamaran wet-tunnel height measured 10% of Lpp aft of the forward perpendicular should be at least 0.85 * Hs (Hs = design significant waveheight) to meet the DnV requirement for a speed corresponding to a Froude Number = approx. 0.60.

SLENDER CATAMARAN DESIGN AND SPEED CALCULATION

The above mentioned factors must be taken into account when designing slender catamarans. A detailed design process will give basic ship parameters however, relevant basic dimensions can be determined by regression analysis of data from existing craft. MARINTEK High-Speed Data-Base gives these basic dimensions normalized to craft length between pendiculars (L_{PP}). The ratio L_{OA}/L_{PP} is typically 1.1.

FIGURE 2 gives the ratio between L_{PP} and B_{OA}. As can be seen the ratio increases by increasing length.

FIGURE 3 gives the ratio between L_{PP} and design displacement. $L_{PP}/\Delta^{1/3}$ is the most sensitive factor related to resistance and speed. Resistance curves are thus given for ratios in the range 5.75 to 7.5.

FIGURE 4 gives the ratio between L_{PP} and lightweight displacement. Lightweight excludes fuel, oil, water, crew etc.

FIGURE 5 gives typical slender catamaran wetted surface, excluding stern plate area. The total ship resistance is proportional to the wetted surface and a "mean line" is given as representative for modern slender catamaran designs. This ratio is proposed to be used in the presented speed calculation method when no detailed design is available.

FIGURE 6 gives Data-Base information on the ratio between passenger capacity and total main deck area.

The design process is an iteractive one, composed of two key activities:

* Synthesis - the development of feasible design alternatives based upon traditional parametric studies.
* Analysis - the assessment and comparison of the performance and transport economy of these feasible design alternatives.

The method by wich the synthesis and analysis activities take place is decided by the designer. The following quick calculation method requires a set of basic parameters, which can either be established by the above given figures or by a detailed design process.

The effective horsepower (P_E) for the ship is calculated from:

(1) $P_E = 0.00686 V R_T$

where:

R_T = total resistance for ship in kp.

V = ship speed in knots.

(2) $R_T = 13.84 \cdot C_T V^2 S + R_{AA}$

where:

C_T = total resistance coefficient for the ship.

S = wetted surface area in m^2 (Ref. fig.5 or design data).

R_{AA} = air resistance in kp.

(3) $C_R = C_F + \Delta C_F + C_R$

where:

C_F = frictional resistance coefficient

ΔC_F = roughness allowance equal to 0.0005, corresponding to a hull roughness of approx. 150 mμ in the maximum speed range.

ITTC 1959 ship-model correlation line gives:

(4) $C_F = \frac{0.075}{(\log Rn - 2)^2}$

where:

Rn = Reynolds Number = $0.433 \cdot V \cdot L_{WL} \cdot 10^6$.

FIGURE 7 C_R is established by comprehensive studies of model test data and ship-model correlation. The results from these investigations are made available in one figure permitting easy readoff.

(5) C_R = Residuary Coefficient is given in FIGURE 7.

Some major assumptions should be recognized:

* Ship-model correlation as a function of length displacement ratio is included.
* Ship-model correlation related to interaction between propulsion system and hull interaction is included in the given total propulsive coefficients.
* Conventional aft body, without propeller tunnel is assumed.
* Optimal running trim related to resistance is assumed.
* Air resistance correlation is included.

Air resistance is calculated by the fomulae:

(6) $R_{AA} = 0.012 V^2 A_V$

where:

A_V = projected frontal area of superstructure.

An air drag coefficient of 0.70 is assumed representative based on wind tunnel tests.

The SHAFT HORSEPOWER (P_S) is finally calculated by:

(7) $P_S = P_E / \eta_{tot}$

The ship-model correlation studies at service speed included both propeller and waterjet propulsion systems. Applying the data the following propulsive coefficients are to be used. Losses along the shafting is included.

* Waterjet propulsion	η_{tot} = 0.62 - 0.64
* Propeller with inclined shaft	η_{tot} = 0.64 - 0.65
* Propeller with aft body tunnel	η_{tot} = 0.70 - 0.74
* Z-Drive	η_{tot} = 0.68 - 0.70

SLENDER CATAMARAN SEAKEEPING PERFORMANCE.

A given high-speed craft must withstand two forcing functions in order to accomplish their mission, the man-induced demands on the craft and the prevailing environmental factors. Experience shows that certain actions by the operator of high-speed craft can lead to major or even hazardous effects. This implies that more seakeeping data is needed on these craft so operational limits can be established for comfort and safety reasons.

It is the objective of the designer to minimize the adverse impact and degradation of craft performance caused by sea environment and to ensure comfortable ride in normal operation and craft survival under extreme sea and operational conditions. High-speed craft seakeeping performance assessment must include specific model or full scale testing, however, in preliminary design prior to such testing, numerical and emphirical methods for preliminary evaluation of motions and accelerations have been developed at MARINTEK.

A numerical method based on theoretical calculation for predicting steady hydrodynamic forces and wave induced motions for high-speed catamarans is presented in ref.2. The main difference between this method and the conventional strip theory approach is that it incorporates in a rational way the important wave systems generated at high speed by the craft itself.

By using this improved method MARINTEK is able to predict RMS-values and extreme values of motions, accelerations, slamming loads, global dynamic loads and added resistance due to waves for slender catamarans in any sea state.

In the present paper a simple emphirical method based on extensive model test results is presented. Slender catamaran seakeeping performance is mainly dependant on size of craft, length displacement ratio and speed. Relevant Data-Base information on pitch and center of gravity accelerations (RMS-values) are presented for speed range up to Froude Number 1.0. Pierson-Moskowitz spectra waves are assumed.

FIGURE 8 gives the vertical center of gravity accelerations (RMS-values) for the same speed and displacement ranges. It is seen that unlike pitch (fig.7) accelerations are decreased by increasing the length to displacement ratio.

CONCLUSION.

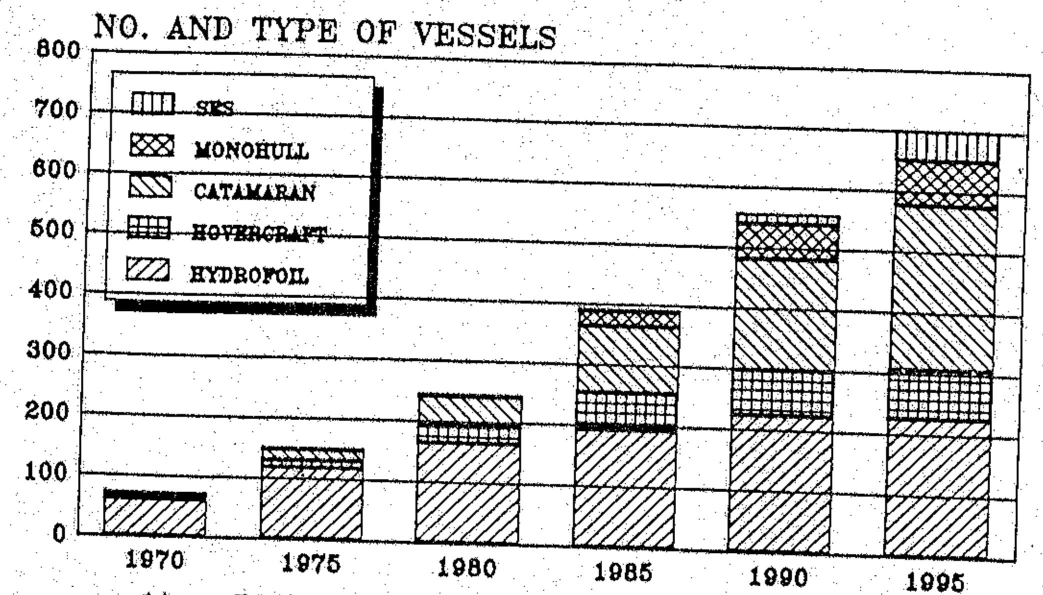
An easily used tool for preliminary slender catamaran hull design; selection of basic hull parameters speed calculation and seakeeping assessment is presented. The method can be used throughout the design process. The Data-Base Figures can be used to establish a starting configuration as well as assessing the specific ship design as it evolves.

The design process can easily be transformed to a computer program or be used in a standard PC-Data-Sheet system.

REFERENCES:

1. NTNF High Speed Craft Project: Report MV-11.22690, May 1989 "Summary of High-Speed Craft Statistics."
2. NTNF High Speed Craft Project: Report MV-11.24898, March 1990 "Seakeeping of High-Speed Catamarans".

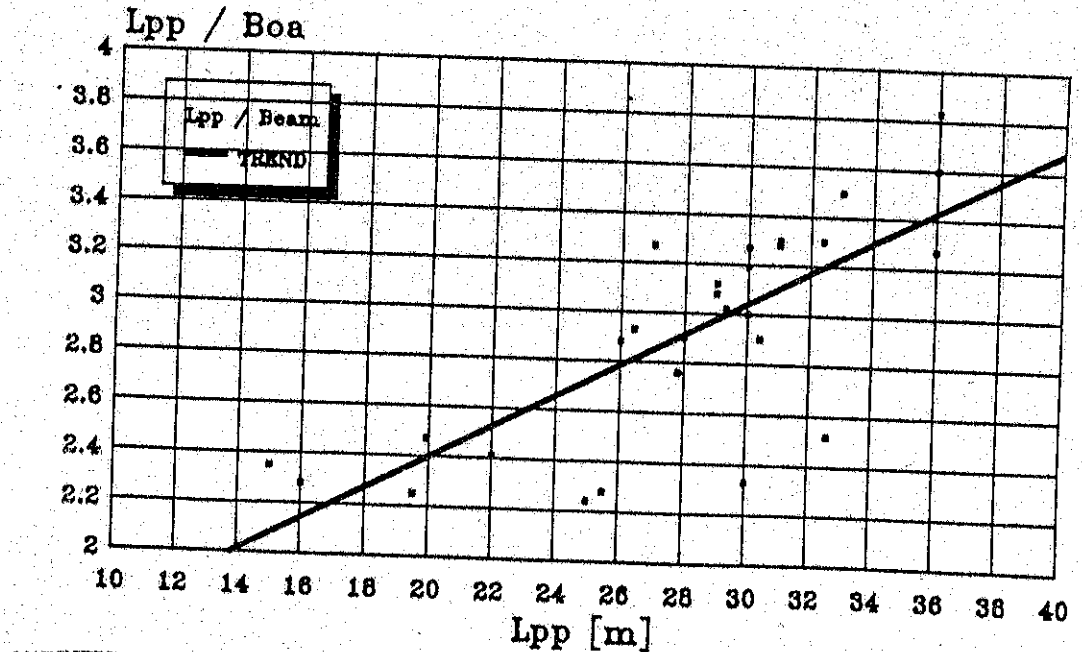
FIGURE 1
HSMV's BUILT & DELIVERED 1965–1995



** > 50 PASSENGERS & > 25 KNOTS SPEED **

(PARAMILITARY CRAFT EXCLUDED)

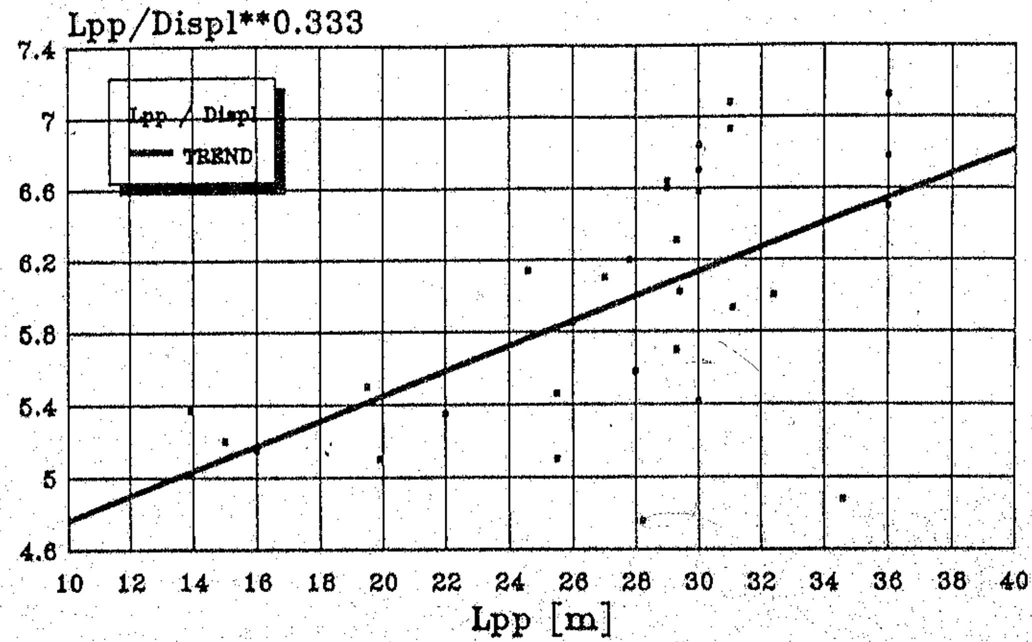
FIGURE 2
LENGTH – BEAM RATIO



MARINTEK DATABASE

Lpp/Boa = 0,064 Lpp + 1,105

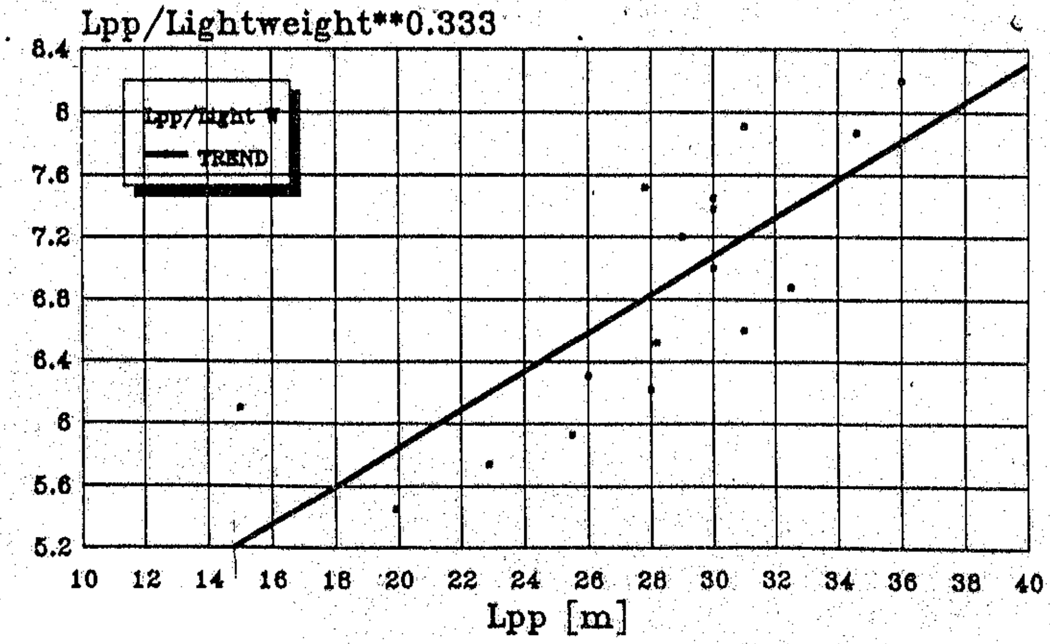
FIGURE 3
LENGTH – DISPLACEMENT RATIO



MARINTEK DATABASE

Lpp/LW^0.33 = 0,0681 Lpp + 4,08

FIGURE 4
LENGTH – LIGHTWEIGHT RATIO



MARINTEK DATABASE

Lpp/LW^0.33 = 0,124 Lpp + 3,340

FIGURE 5
WET AREA – LENGTH RATIO

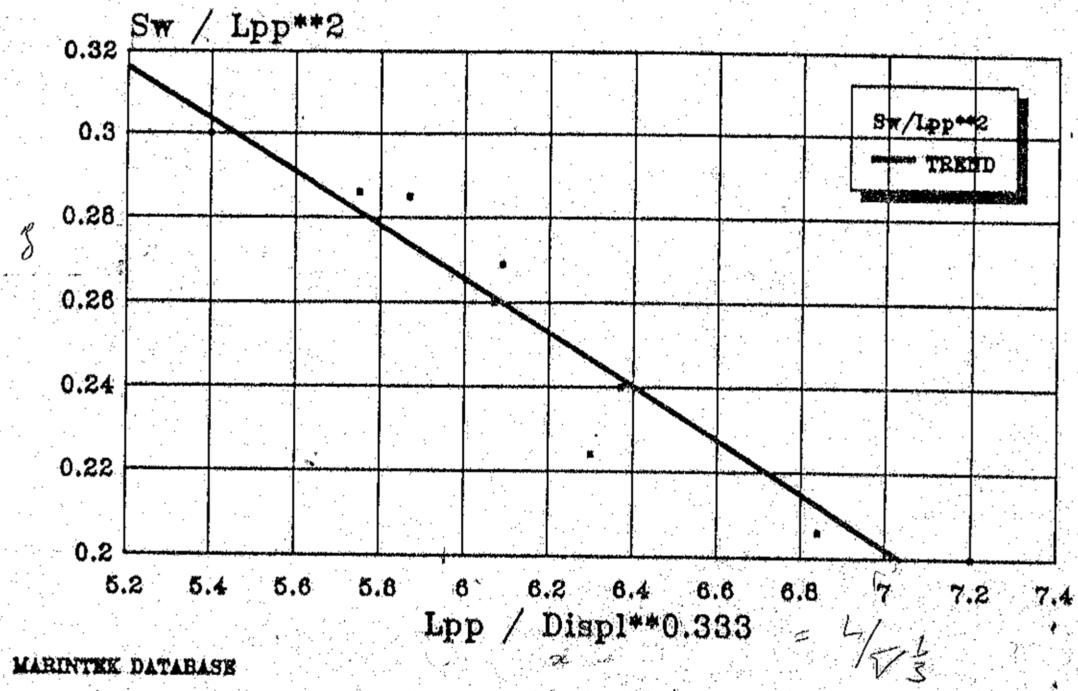


FIGURE 6
PASSENGER CAPACITY

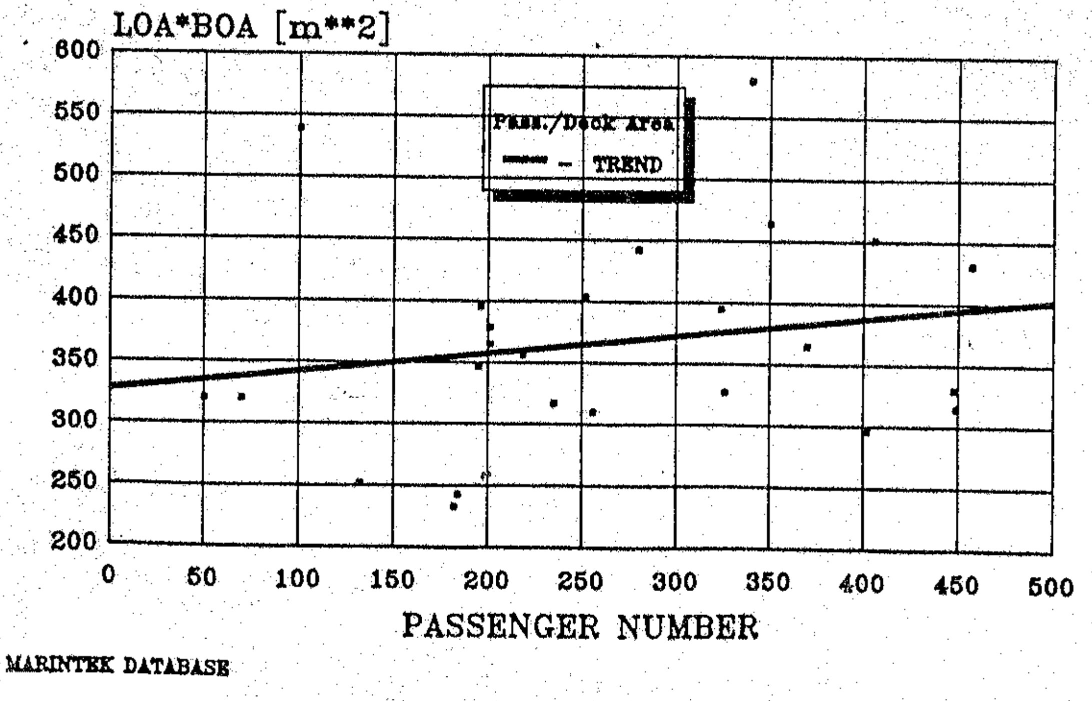
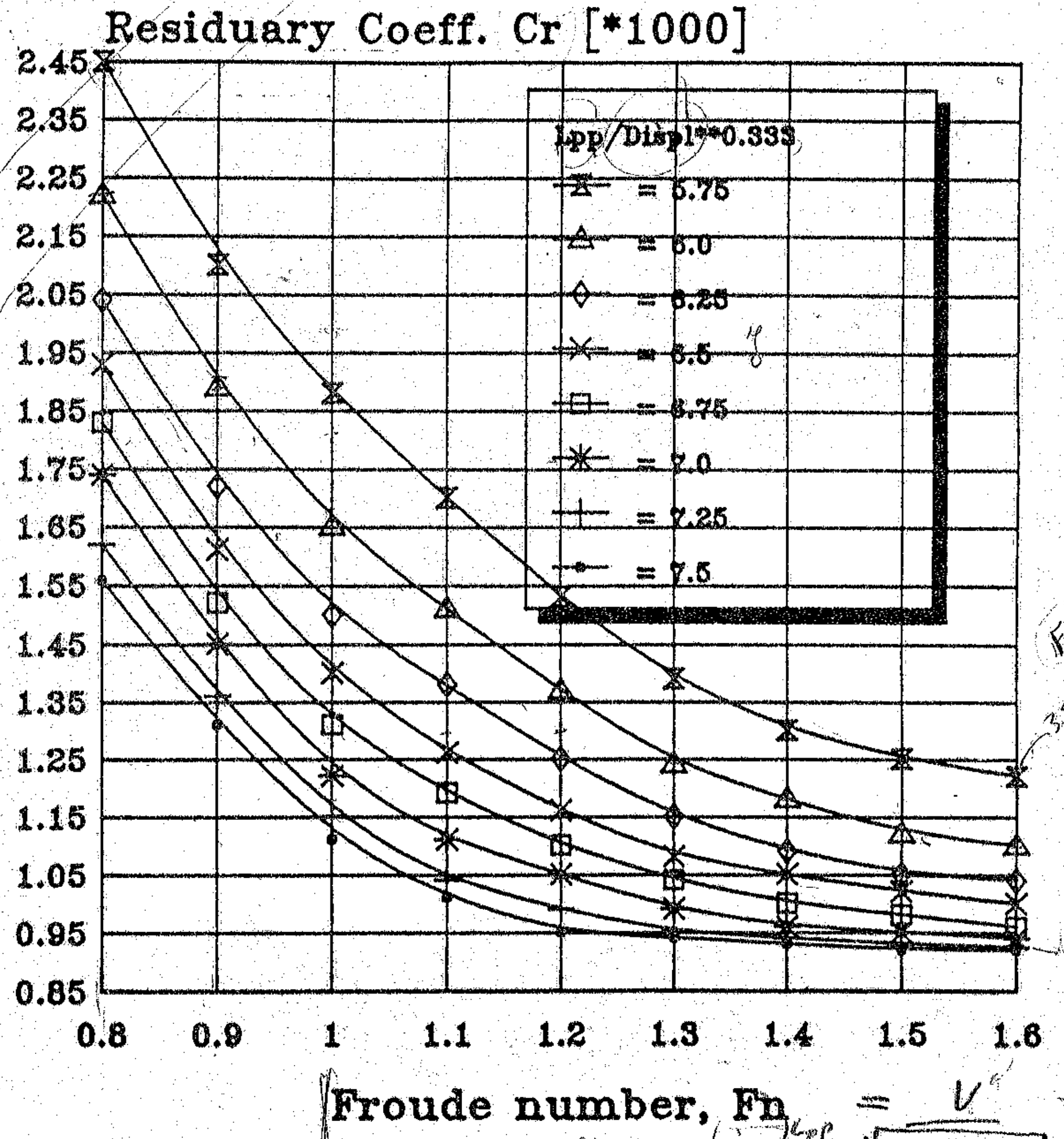


FIGURE 7
RESIDUARY COEFFICIENT



MARINTEK DATABASE

$Fn = \frac{V}{\sqrt{g L_{WL}}}$

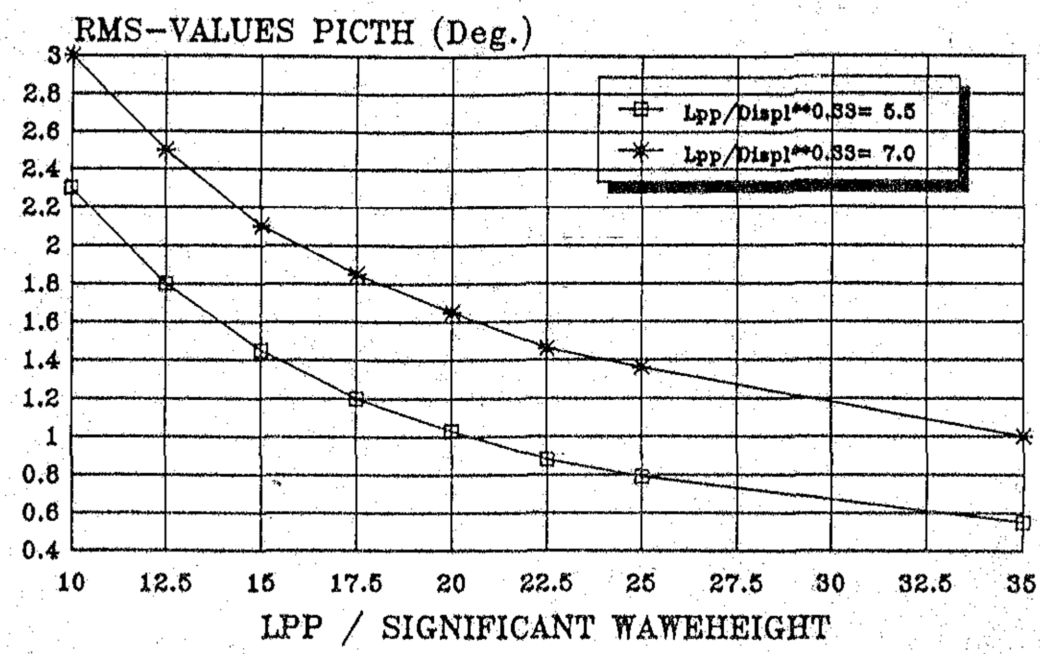
Fn_L

$Fn_{\nabla} = \frac{V}{\sqrt{g L_{pp}}} \cdot \sqrt{\frac{L_{pp}}{\nabla^{1/3}}}$

$L_{pp} = L_{WL}$

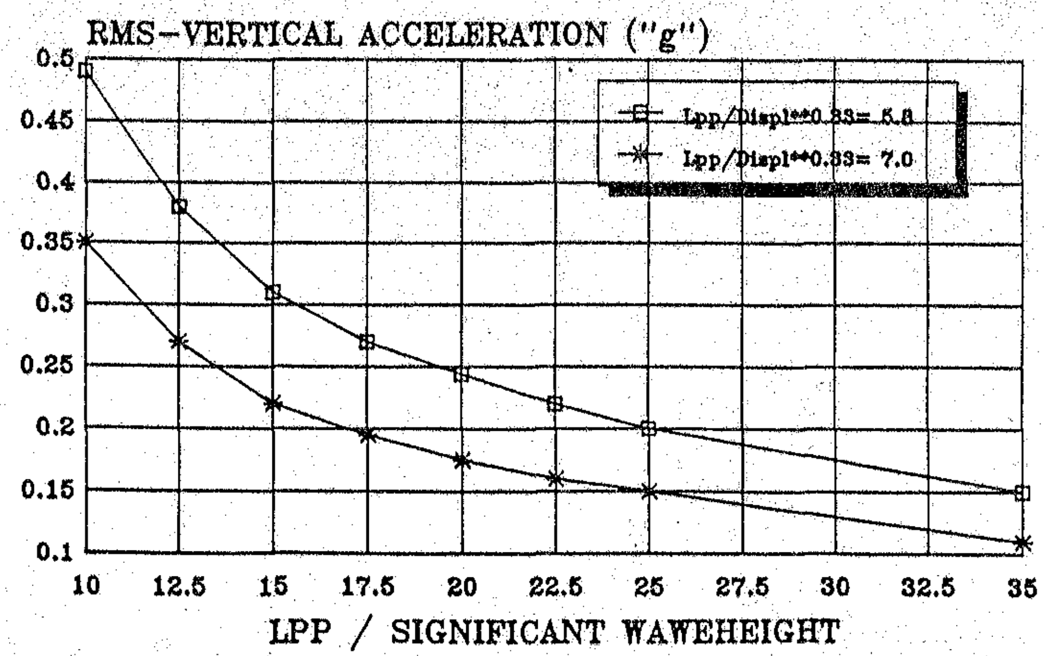
$Fn_{\nabla} = Fn_L \cdot \sqrt{\frac{L_{pp}}{\nabla^{1/3}}}$

FIGURE 8
SEAKEEPING – PITCH MOTION



MARINTEK DATABASE

FIGURE 9
SEAKEEPING – VERT.ACC CG.



MARINTEK DATABASE