ADVANCEMENTS IN HYDRODYNAMIC DESIGN BY SYSTEMATIC TANK TESTING OF INNOVATIVE HULL SHAPES FOR A 28FT DAY RACER CATAMARAN

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ABSTRACT

An intensive tank tests program was carried out during 3 sessions conducted at the A.N.A.S.T facility with 1/5th scale single hull models towed at speeds covering a range of Froude numbers from low subcritical 0.225 to medium supercritical 1.3. The model was free to pitch and heave, but yaw and roll were locked in with constant drift and heel. This program aimed primarily at studying the effects of including longitudinal asymmetry and semi-planing shapes inside an innovative approach for hull design of catamaran sailboat. Key parameters as slenderness ratio (LWL/BWL), bow half-entry angles, keel line relative camber, deflecting chine widths have driven the evolution of hydrodynamic design for 4 different hull shapes which finally led to a final candidate, fitted on the TECHNI 28 Leman’s lake M2 day racer.

1. INTRODUCTION

The whole of the studies which were undertaken within the framework of the program described here were dedicated to assess the potentialities of innovative hull shapes in bringing significant hydrodynamic improvements to a 28 ft day racer catamaran concept belonging to the Swiss M2 class: the Techni 28 project. The main features of the actual boat are:

- Overall Lpp (including spinnaker pole): 10 m
- Hull length : 8.54 m (28 ft)
- Empty weight (without sails and crew) : 425kg
- Crew weight (3 on board) : 240 kg
- Racing displacement racing: 7250 Newton
- Beam without external ladders : 6.1 m (20ft)
- Overall beam (with ladders) : 8.54 m (28ft)
- Total upwind sail area : 83 sq.meters
- Downwind max sail area : 140 sq.meters
- Maximum righting moment: 37750 N.m
- Maximum sustainable Side Force : 5150 N
- Side Force / Racing weight Ratio: 0.71
- Sailarea / weight Ratio upwind: 115 sq.m / ton
- Sailarea / weight Ratio upwind: 193 sq.m / ton
- Maximum upwind speed: 13.2 kts
- Upwind average Froude Number: 0.66
- Maximum downwind speed : 27.6 kts
- Downwind average Froude Number: 1.15

The main idea which leads the design trends for hull shapes was to integrate characteristics of planing motorboat catamarans in order to be able to benefit from the effects of dynamic lift and to limit the penalties induced by dynamic sinkage, while preserving a level of acceptable drag when riding into the subcritical Froude domain. The last subject is of great concern as various attempts has failed in trying to apply planing shapes principles to sailing multihulls, one of the most well-known being Yves Parlier’s “Hydraplaneur-Mediatis”
fitted with floatplanes amas which was suffered from low average speed during transatlantic races despite quite high top speeds (+38 kts).

So, huge efforts were put on the careful integration of typical basic features of powercats planing hull shapes with CAD systematic refinements, always keeping in mind that installation of hard chine and steps will have not to induce unacceptable drag growths at low speeds regime of Techni 28 (5 to 10 knots of boat speed). To be able to check this level of hydrodynamic risk, round bilge hulls candidates with similar performance goals were used as contenders during comparative tank testing sessions.

2. HYDRODYNAMIC THEORY DRIVING HULL DESIGN

The genesis of hull shapes was driven by a quite new principle of coupling inclusion of lateral asymmetry in multihull amas like in Hobie Cat 16 or Prindle 16 designs with semi-planing sections, (i.e. the CAD work constraints obviously get rid of a longitudinal symmetry plane that make starboard external shell a mirror image of the portboard one). Indeed, the great majority of the powercats hulls are simply based on this principle of a central tunnel deduced from a spacing on the 2 sides of a V-bottom hard chines planing hull, with bottom dihedral angles going from 15 to 30° on to avoid unbearable high levels of slamming pressure and vertical acceleration. By doing this, it could be expected 4 major potential advantages:

- improving the hull side force generation which is here trigonometrically linked to the dynamic lift
- riding with a dynamic lift component which compensates partially dynamic sinkage
- reducing with dihedral the increase of slamming loads brought by the use of hard-chine hulls
- using lateral spray rails and low half-entry angles \( \theta \) which reduce both bow spray

2.1 HULL LINES

2 main families of hulls for the Techni 28 floats have been designed in an attempt to combine the 4 goals quoted over here. A total of 6 different contenders were built and tested at the A.N.A.S.T. facility at University of Liège (Belgium).

2.1 (a) Asymmetric Round Bilge Hulls: D02 & E021

D02 figures :

- L.O.A = 8.538 m
- L.W.L = 8.461 m
- B.W.L = 0.534 m
- Displacement = 7'250 N
- L.C.B. (52.2% aft LWL)
- L.C.F (55.1% aft LWL)
- \( C_H = 0.49 \)
- \( C_P = 0.66 \)
- \( C_{WP} = 0.79 \)
- \( S_{Waterplane} = 3.554 \text{ sq.m} \)
- \( S_{MW0} = 6.4 \text{ sq.m} \)
- Camber of LP = 0.49
- L/B ratio = 15.14
- D/L ratio = 34.09
- BMT = 5.216 m

2.1 (b) Asymmetric Hard Chine: V303, N38 & W30

V303 figures :

- L.O.A = 8.538 m
- L.W.L = 8.461 m
- B.W.L = 0.515 m
- Displacement = 7'250 N
- L.C.B. (51.6% aft LWL)
- L.C.F (55.1% aft LWL)
- \( C_H = 0.46 \)
- \( C_P = 0.63 \)
- \( C_{WP} = 0.79 \)
- \( S_{Waterplane} = 3.554 \text{ sq.m} \)
- \( S_{MW0} = 6.7 \text{ sq.m} \)
- L/B ratio = 15.14
- D/L ratio = 34.09
- BMT = 5.216 m
2.2 HYDRODYNAMIC EVALUATION OF (SIDE FORCE / DRAG) RATIO

Quick efficient assessments of the hydrodynamic benefits that could be expected when relying on hull side force generation have been made by means of slender body’s hydrodynamics. As the amas are canted towards the symmetry plane of the whole boat, hulls run without heel effects. No appendage is fitted in tank testing as high aspect ratio daggerboards have been identified as to trig low induced drag interferences with hulls.

Techni 28 initial hulls are asymmetric (round-bilge D02 and hard-chined V303) and have full displacement drafts when she lifts off completely upwind ama, between Tc V303 = 0.254 m and Tc D02 = 0.248 m and lateral plane area A_LP V303 = 1.371 sq.m to A_LP D02 = 1.322 sq.m. This means for the geometrical aspect ratios of lateral planes, respectively:

\[
\frac{A_{LP\ V303}}{A_{LP\ D02}} = \frac{(0.254)^2}{1.371} = 0.0471 \quad \text{and} \quad \frac{A_{LP\ D02}}{A_{LP\ D02}} = \frac{(0.248)^2}{1.322} = 0.0465
\]

These geometrical aspect ratios must be multiplied by a Froude dependant factor which describes the influence of free surface effects over effective span \( T_{eff} \) from the very low Froude case to the high FN one. Effective hull span and effective aspect ratio resume obviously the actual 3D side-force induced drag of the isolated hull.

\[
T_{eff} = \sqrt{AR_{eff} A_{LP}} \quad \text{and} \quad AR_{eff} = \frac{C_s^2}{\pi C_{Induced\ Hull}}
\]

Doubling the geometrical aspect ratio at near zero Froude numbers FN (mirror image or double model with equivalent infinitely rigid sea surface) to merely its value for FN higher than 0.5 without any parasitic ventilation or cavitation phenomenon. Several authors studied this evolution, like Keuning & Sonnenberg (1998) who proposed a linear variation of effective draft with Froude or Schlager & Teeters (1993) who deduce from PACT ACC data a decreasing Gaussian behaviour of \( T_{eff} \) for 0.3 < FN < 0.45. After several extensive CFD + tank studies carried out on slender boats, specially on ACC boats and D35 cats, a satisfactory expression was found by us on to provide good mean values:

\[
\frac{T_{eff}}{T_{geometrical}} = 1 + 0.414 e^{-4FN^2}
\]

The side force coefficient versus leeway angle \( \beta \) for symmetrical hull concepts can be calculated for the range of aspect ratios valid for single fully-loaded hull by the sum of linear lift and vortex lift components for very low aspect ratio bodies:

\[
C_{SF\ Hull}\beta = \frac{\pi}{2} AR_{eff} \sin \beta + 1.75 \sin^2 \beta \cos \beta \quad \text{for round-bilge}
\]

\[
C_{SF\ Hull}\beta = \frac{\pi}{2} AR_{eff} \sin \beta + 3 \sin^3 \beta \cos \beta \quad \text{for hard-chine}
\]

For the induced drag coefficients, as underlined by Hoerner in “Fluid Dynamic Drag”, the linear part reveals maximum flow deflection only given by front lifting body, therefore inducing half of the normal induced angle. The induced drag coming from the free side vortex suction, like on a delta wing, is obtained when multiplying the vortex lift by \( TAN\ \beta \):

\[
C_{D1\ Hull}\beta = \frac{\pi}{4} AR_{eff} \sin^2 \beta \cos \beta + 1.75 \sin^2 \beta \quad \text{for round-bilge}
\]

\[
C_{D1\ Hull}\beta = \frac{\pi}{4} AR_{eff} \sin^2 \beta \cos \beta + 3 \sin^3 \beta \quad \text{for hard-chine}
\]

Classically, other coefficients relative to the remaining components of hull drag use different reference areas:

- zero FN wetted area of the fully loaded ama for friction and wave resistance \( C_{Df} \) and \( C_w \)
- transom underwater dry area for the transom drag \( C_{DTr} \)

In a first approximation for (SF/D) assessments, we neglect at FN = 0.6 the lowest components: wave drag and transom drag, which were seen to merely change with low leeway angles.

The dominant component of the isolated hull is friction drag, which must include a side-force dependence factor accounting for the dynamic pressures increases and spiralling of hull wetted area streamlines. The friction coefficient relative to lateral plane area \( A_{LP} \) is thus given by, average mean hull wetted area being \( S_{mw0} = 6.4 \) sq.m for a round bilge D02-like, but symmetrized, concept at racing load and \( S_{mw0} = 6.7 \) sq.m for an hard-chine symmetric M2 hull. The Prohaska factor being approached at a reasonable level by \( k_hull = 1.5 \) [ (BWL + T) / 2 LWL \( )^{1.5} \sim 0.015 \) and the friction coefficient by the well-known ITTC 57 formula.

\[
C_{D\ friction\ LP} = \left( \frac{S_{mw0}}{A_{LP}} \right) \left[ 1 + k_{hull} \left( 1 + \frac{C_{SF}^2}{16} \frac{0.075}{\log_{10} Re_{hull} - 2} \right) \right]
\]

First, side force versus pure induced drag ratios of isolated symmetric candidate hulls are plotted versus leeway angle \( \beta \) for the average upwind case (\( V_{boat} = 11.7 \) kts ), effective aspect ratios being around 1.15 times \( \text{AR}_{geometric} = \frac{\text{SF}}{\text{CD}_{hull}} \). The potential flow performances of an asymmetrical daggerboard of \( \text{AR}_{def} = 5 \) have been also put for comparison purposes.
This graph shows clearly that, until leeway angles of $\beta = 2.5^\circ$ have been reached, the symmetrical hulls are better non-viscous potential flow lifters when (SF/ Di) matters than an NACA 64-312 asymmetric daggerboard of $A_{\text{D eff}} = 5$.

Now, taking into account viscous effects, hull friction represents a penalty that is acting whatever the level of hull SF could be. If the effective global (SF/ $D_{\text{total}}$) is considered, it leads still to a neat gain under $\beta = 2.5^\circ$ in front of non-lifting hulls provided that the friction drag of the slender hull begins doesn’t grow quickly, which happens only for $\beta > 8^\circ$.

Of course, quest for improved (SF/D) ratios is essential to get the best ($V_{\text{boat}}/TWS$) ratios, but, indeed, the sailing catamaran designer must not forget the whole process of VPP equilibrium upwind. So, as boom angle is actually limited to boat longitudinal axis and as a catamaran fitted with symmetric amas is compulsory forced to keep this optimum $+2.5^\circ$ leeway angle on to get the best efficiency, sails encounter lower effective angles of attack AOA.

Detailed VPP studies conclude that slightly less driving force comes from the rig when the cat is running at more than $\beta = +0.5^\circ$ relatively to the straight running attitude at $\beta = 0^\circ$.

We can also notice that, in general, global (SF/$D_{\text{total}}$) ratio of $A_{\text{D eff}} = 5$ asymmetrical daggerboards, fitted with more cambered sections like E 407 or NACA 64-412, increases versus the previous NACA 64-312 option and that a E407 $A_{\text{D eff}} = 5$ daggerboard works optimally around $0.5^\circ$ of leeway.

For all the reasons quoted above, it looks obvious that, even if sharing SF between a small percentage of hulls SF and a majority of daggerboard SF is the optimum choice, the leeway running angle have to be very low for optimum VMG. So, seeking for the combination of these 2 trends, early design choices have been conducted towards putting asymmetry in the cat’s hull in such a way that an optimum leeway angle of $\beta = +0.5^\circ$ will arise truly at upwind case equilibrium.

- D02 hull has an effective lateral camber of 2.43 %, meaning that the leeway angle at which SF nullify is $\beta = -2.2^\circ$.
- V302 hull has an effective lateral camber of 2.92 %, meaning that the leeway angle at which SF nullify is $\beta = -2.65^\circ$.

2.2 DYNAMIC LIFT VERSUS SINKAGE

Every critical or supercritical boat (ability to go to FN = 0.5 and beyond) has to cope with a severe penalty which contributes to the abrupt rising of the drag between FN = 0.4 and 0.8, the hydrodynamic suction which pulls down the hull into the water. This phenomenon is well-known and called the dynamic sinkage. It increases effective displacement severely, contributes to dynamic wetted
area growth and can even induce pressure drag if it forces the hull to pitch up. Generally, it can be linked to the level of downwards curvature of the mean camberline of hull buttocks. Hull acts as the upper cambered shell of a very low aspect ratio wing which is turned upside-down.

Inversely, if the hull waterplane is put on incidence relatively to incoming water flow, it generates a slender body lift which pulls up the hull out of the water. Lift is influenced the same way as side force by free surface effects that prevent static pressure deltas to be established between near underwater zones and ambient atmospheric pressure.

A good approximation of the counteracting dynamic sinkage and dynamic lift is brought by:

\[
\frac{D_{\text{w}} F}{\frac{1}{2} \rho \omega_{\text{w}} \omega_{\text{w}} A_{\text{w}}} \approx \frac{5}{\frac{1}{2} \rho \omega_{\text{w}} A_{\text{w}}} \left( \frac{T_{\text{buttock}}}{LWL} - \frac{\pi}{2} \frac{BWL}{LWL} \sin \tau \right) \left( 1 + 0.414 e^{-0.09 P} \right)
\]

(7)

\(T_{\text{buttock}}\) is the mean camber draft of buttock lines and \(\tau\) is the pitch angle, positive when bow is up.

Every hull which runs at critical Froude regime (0.5 < FN < 0.75) could then obey to 2 very distinctive behaviours if it is pushed harder:

a) fighting efficiently against dynamic sinkage with dynamic lift, extenuating added wetted area and being able to ride over the high pressure bow zone extended to amidships, this hull can go to high supercritical regimes

b) being sucked down further, especially if buttock curvature is too high or front positive slope is too small, phenomenon emphasized if the hull pitches down for this to cause trim to fall down and lift with. This type of hull rarely goes to high supercritical Froude and exhibits steep total drag risings if FN > 0.7

2.3 BOTTOM DIHEDRAL ANGLE FOR SLAMMING REDUCTION

Dihedral angles for hard chine hulls have been chosen with help from some analytical formulae. These deal with vertical acceleration that is generated at the CG location when running in regular waves with a planing hull having a mean bottom deadrise angle equal to \(\beta\) are:

(8)

This acceleration ratio is expressed in numbers of:

\(g\) = earth gravity acceleration (9.81 m.s\(^{-2}\))

\(H_w\) = significant wave height in meter (from 0.05 to 0.2 m for small chops)

\(B\) = mean wetted beam

\(\tau\) = effective trim angle in degrees = real incidence of planing bottom relatively to sea level

\(\beta\) = deadrise angle in degrees

\(V_B\) = boat speed in meters / seconds

\(\Delta\) = weight fraction which loads the planing surface in Newton

Hoggard & Jones:

\[
\frac{\partial^2 Z}{\partial t^2} \approx 7 \left( \frac{H_w}{B} \right) \left[ 1 + \left( \frac{\tau}{\beta} \right)^{0.25} \right] \frac{F_v}{\sqrt{\rho g L}} \left( 1 - \sin \beta \right) \cos \beta^2
\]

(9)

\(F_v\) : Volumetric Froude number, calculated as

\[
F_v = \frac{V_B}{\sqrt{g V^{1/3}}}
\]

\(L\) is the mean wetted length

\(\nu\) : volume of sea water equivalent to the weight fraction which loads the planing surface \(\nu = \frac{\Delta}{\rho g}\) in cubic meters.

2.4 SPRAY RAILS AND HALF ENTRY ANGLE FOR DYNAMIC WETTED AREA

On high speed supercritical ships, one of the major concerns after dynamic sinkage is bow spray which increases dramatically dynamic wetted area. The remaining value of viscous drag included in residuary resistance when static wetted area is kept for calculating friction drag diverges if it happens (conventional splitting of hull drag component).

A mean to accurately calculate this added wetted area is to consider analytical parabola-like expressions describing the bow wave and proposed by Delhommeau, Guilbaud & Noblesse (2007)

Simpler expression of \(Z_b\), the bow wave maximum elevation has been proposed by Noblesse & Al. (2005) :

\[
Z_b = \frac{V_{\text{float}}^2}{g} \tan i_k \frac{2.2}{1 + F_D \cos i_k} F_D = \frac{V_{\text{float}}}{\sqrt{g D_{\text{bow}}}}
\]

(10)

The Froude number \(F_D\) is based on bow foot local draft.
The occurrence of bow spray is a phenomenon which is thus directly connected to the water dynamic pressure at bow and the bow half-entry angle. The frontal projected areas cause high submarine stagnation pressures which raise a spray root. This sheet of green water climbs abruptly along hull sides up, is deflected backwards and finish by breaking down because of steep wave internal instabilities. Muller-Graf (1991 & 1997) intensively studied an Advanced Spray Rail System (ASRS) which was able to cut off total resistance of round-bilge hulls by 12%. The author gives also advices on slender hulls with \((L/B) > 5.4\) and underlines the fact that only one spray rails is sufficient for drag reduction purpose. The Techni 28, following these requirements, have been equipped with one rank of deflecting chines on both sides which play the role of spray rails.

3. ANALYSIS OF TANK TESTS RESULTS

3.1 REFERENCE FRAME

Reference trigonometric frame provided by A.N.A.S.T. engineers have been used to analyze the tank tests results with:
- 0X axis directed + frontward
- 0Y axis directed + port board
- 0Z axis directed + upwards

On the experimental setting, the asymmetrical hulls were 1/5th scaled-down models of the starboard hulls of Techni 28

3.2 CORRELATIONS BETWEEN HULL LINES AND SIDE FORCE

Side Force has been divided by water dynamic pressure, lateral plane area to get the \(C_{SF} = CY\) coefficients:

On the upper part of this graph are plotted the \(C_{SF}\) from slender body theory.

In fact, models, especially V303, the hard chine first design with a twisted planing bottom, are generating a drifting force that moves the boat sideward in the same direction as rig Side Force, instead of counteracting it!

Among all the results got from these tank tests sessions, these seem at first glance, the most amazing ones.

In an effort to understand what could be the cause of this odd hydrodynamic behaviour, we extract the corresponding values of yawing moment \(M_z\) (counted positive if the boat luffs, negative if she bears away).
Clearly, as yawing moments are mostly negative, except if V303 is put a positive angle of +2° of leeway, it indicates that the drifting penalizing force have its effective CoE located on the forebody of the boat, ahead of the CG / LCB of the hull. For V303 indeed, it is obvious that dynamic pressure trigs the negative bear away tendency as Mz < 0 diverges on a quadratic-like curve when riding at +20 knots. So, we can basically conclude that the negative SF, Ry < 0, comes from hydrodynamic suction, probably a submarine vortex as it seems very intense.

As we examined what could be the paths of the hull shell streamlines at the bottom on the hull, we discover that these paths converge on the sharp keel line on the immersed forebody and probably separate on it. This bottom boundary layer separation on a curved knife-like crest having an incidence versus incoming flow generates a vortex which is probably at the source of the negative Mz and SF penalty. When hull are set at positive leeway angles, the flow realigns a little bit with the sharp forebody keel line and the phenomenon vanishes.

This first conclusion guide the design of second generation of hard chine hulls, N038, the high (L/B) one, and W030, the low (L/B), which were carefully drawn erasing any warp on the keel line or nearby chines on to be sure to avoid parasitic boundary layers separation.

This first round of keel line shape optimization ends in the effective suppression of negative SF and negative Mz which is shown just here under on this graph. N038 design is, at least, even able to generate a positive SF of 30 kgf = 294 N.
3.3 DYNAMIC SINKAGE AND DYNAMIC LIFT

Before taking a look at the effective dynamic sinkage of the hulls, we must consider the evolution of the pitch angle (dynamic planing boat trim °) which drives heavily the generation of the dynamic lift component which counteracts the suction induced by negative buttocks curvature (in 0z sense, convexity downward).

It can be noticed that, despite their high slenderness ratio (L/B = 16), the hull behaves very similarly as planing NPL, SSPA or NORDSTROM semi-planing series. There is indeed a steep rising of the pitch angle when they begin to reach the critical zone (FN=0.525), with an abrupt climbing to \( \tau = +0.8^\circ \) stabilized at FN = 0.6, when the hull ride in a regime where transverse waves extinct quickly, divergent waves begin to fall down and 3/4 of hull length is submitted to high pressures that lift up the boat partially (intermediate supercritical regime).

Beyond FN = 0.8, pitch angle decreased slowly. This is mainly due to the fact that as fore body static pressures increasing at the square of speed and as bow wave elevation is also rising creating local dynamic wetted area too, the pressure and friction drag grow severely on the first 1/3 LWL of the hull and this create a pitch down My moment.

V303 pitches down more seriously the D02 because of the suction effect of fore keel line vortex and the drag associated with it, 2 physical sources which add together their detrimental effect on My.

Also, despite some author’s hypotheses, spray rails bring no obvious effects on pitch attitude, their impact is rather noticeable on drag by cutting dynamic wetted area.

It appears clearly that dynamic sinkage could be described after going through into supercritical regimes (FN > 1), as the balance between antagonists dynamic lift and suction from the downward curvature of buttocks. However, under FN = 1 sinkage is driven widely by interaction with the divergent waves field and the building up of low static pressures under the last 1/3 length of the hull, which also depend first on rear body buttocks angulations and, secondly, on transom width, immersion and section shape.

These conclusions led to the exploration of positive trim settings on next generation hulls N038, E021 and W030.

As it can be seen, putting the hulls at +1 to +1.5° ("cabré") can reduce significantly dynamic sinkage and so, dynamic added wetted area. Generally, if trim is sufficiently low, it allows a global reduction of drag as friction drag cut-off is bigger than pressure drag increase.
DYNAMIC VERTICAL FORCE COEFFICIENTS $C_z$ FOR FIRST GENERATION HULLS
(NEGATIVE = generating DYNAMIC SINKAGE)

BOAT SPEED $V_{BOAT}$ AT FULL SCALE (KNOTS)

EVOLUTION of PERCENTAGE of DYNAMIC SINKAGE

BOAT SPEED $V_{BOAT}$ AT FULL SCALE (KNOTS)
3.4 PITCHING MOMENTS

The pitching moments $M_y$ are always negative (Bow up attitude) and they become more and more with speed, this is inherently safe for a sailing multihull because the diving moment from the rig increases too with boat speed.

Semi-planing hard-chine V303 hull show better abilities to maintain the effective longitudinal center of vertical dynamic lift forward than the round bilge D02. Spray rails effects go inversely as common sense would have guessed, bringing no additional lift, but a small amount of local pressure drag which makes the hull to dive with 23% less bow up pitching moment.

3.5 DIFFERENT FEATURES INFLUENCING DRAG EVOLUTION

As standard process to set up an naval hydrodynamic analysis, the drag has been cut out in 2 major components:

- a friction drag, commonly deduced from ITTC 57 $C_{friction} +$ Prohaksa factor and static mean wetted area
- a residuary drag, gathering globally, as usual :
  - pure wave drag
  - pressure drag induced by dynamic lift as on planing boat theory (Savitsky or Shuford)
  - transom drag due to the lack of Archimedeian thrust on dry “immersed” transom
  - additional wetted area due to sinkage
  - spray drag

After extraction of the friction component and calculation of model ITTC 57 $C_{friction \ 1.5}$, the residuary is kept away and supposed nearly constant with scale. The real scale actual boat friction coefficient $C_{friction \ full-scale}$ is then classically used to establish the real boat friction drag.

The main features of the correlations between hull shape and drag are:

a) addition of spray rails on D02 allows a 13.5 % reduction in total drag between 20 and 23 kts
b) boats which are able to start planing can reduce effectively drag by wetted area cutting
c) trimming up narrow hulls lead to same effectiveness as using wide hulls
d) absence of convexity in bow front wedge is equally important as low $i_e < 7^\circ$
\[ R_{x \text{ total full-scale boat}} = \left[ \frac{R_{\text{residual model}}}{\Delta_{\text{model}}} \right] \Delta_{\text{full-scale boat}} + \frac{1}{2} \rho_{\text{water}} U_{\text{Full-scale Boat}}^2 S_{\text{mg}}{\text{0 Full-scale}} C_{f \text{ full-scale}} \] 

(11)

4. CONCLUSIONS

The analysis of the whole of the results of the tank tests, carried out during 3 sessions different to the A.N.A.S.T. from Liege, showed that it is possible to obtain drag reductions and increases in bow-up trimming moment by promoting planing behaviours on hull shapes with slender ratio between \( 12 < (L/B) < 16 \), typically semi planing hard chine or “U” round bilge and fitted with:

- lateral chines with laterally prominent steps which play the role of spray rails
- low \( \lambda \) diminishing the bow wave elevation

Nevertheless, other innovating elements which equipped its experimental hulls appeared penalizing because in particular of parasitic swirls, of separation on underwater lines bilges. Longitudinal asymmetry (relative to \( x_0z \) symmetry) of the hull, especially appeared as however does not have more beneficial influence on hydrodynamic total (Lift/Drag) ratio, compared to a symmetrical hull equipped with advanced round-bilge “U” shapes.

5. REFERENCES


