
HSMV
2017
11th SYMPOSIUM
ON HIGH SPEED
MARINE
VEHICLES
DVD
Naples
25th – 26th
October 2017
ISSN 2532-4888
Proceedings

Influence of Rocker and Twist and the Results of the Delft Systematic Deadrise Series

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Since 1980 the Shiphydromechanics Department of the Delft University of Technology has tested a large number of hard chine planing monohulls all of which were systematic variations on the original parent model as used by Clement and Blount in the 1960's in their systematic research. This entire series of now some 24 different models with varying length to beam ratio and deadrise all together tested in about 350 different conditions with respect to weight and longitudinal position of the center of gravity became known as the Delft Systematic Deadrise Series (DSDS). The latest addition to this series of models was tested in 2014 and consisted of a sub series of models with variation of the "twist" and "rocker" in the aft ship.

The Delft Ship hydromechanics Laboratory of the Delft University of Technology has now decided to make all the data and measurements results of this DSDS available to the public, free of cost, through a website.

This paper describes in short the background and development of the DSDS and the way by which the data can be assessed. Also some results are presented of attempts which have been made to develop an assessment method for the calculation of the resistance, the running trim and the sinkage of an arbitrary planing hard chine monohull making us of the results within the database of the DSDS.

NOMENCLATURE

β	[°]	: Deadrise angle of planing bottom with respect to horizontal plane. Measured at Ord. 10
ε	[°]	: Twist angle, i.e. deadrise at Ord. 10 minus the deadrise at Ord. 0
γ	[°]	: Buttock angle, average centerline angle from Ord. 10 to Ord. 0 with respect to the baseline. Positive for a draft at Ord. 0 greater than draft at Ord. 10
A_P	[m^2]	: Projected planing bottom area, excluding area of external spray strips
$A_p/V^{2/3}$	[-]	: Loading Coefficient
B_{pa}	[m]	: Mean breadth over chines, A_p/L_p
B_{pt}	[m]	: Breadth over chines at transom, excluding external spray strips
B_{px}	[m]	: Maximum breadth over chines, excluding external spray strips
C_{ap}	[%L_p]	: Centroid of planing area, A_p
$d\theta$	[°]	: Running trim angle, relative to its value at zero speed. Positive for bow down.
dZ	[m]	: Sinkage, relative to its position at zero speed. Positive out of water
Fn_∇	[-]	: Froude number based on displacement
g	[m/s^2]	: Gravitational acceleration, 9.81m/s^2
L_c	[m]	: Dynamic wetted length over chine
L_k	[m]	: Dynamic wetted length over keel
L_P	[m]	: Length of projected planing bottom area, length over chines
L_p/B_{px}	[-]	: Length to Beam Ratio
LCG	[%L_P]	: Longitudinal Center of Gravity from Ord. 10
S_{wet}	[m^2]	: Dynamic wetted surface area, measured at speed.
v	[m/s]	: Speed
Δ	[N]	: Weight of displacement
∇	[m^3]	: Volume of displacement

1 INTRODUCTION

Since the Second World War there has been a growing interest in the application of hard chine planing hulls as a method to achieve high speeds over water at a reasonable cost. Reputable systematic research efforts to facilitate the design of such boats were, amongst others, carried out by

Savitsky (Savitsky 1964) and Clement and Blount (Clement & Blount 1963). Savitsky formulated an assessment method for calm water resistance and trim of planing monohulls based on a large database of results obtained with tests with planing wedges. These wedges all had constant deadrise over their entire length. His research yielded a very usable method for assessing the resistance and trim of an arbitrary planing hull in particular also at the higher speeds (Savitsky 1964). Clement and Blount based their method on results of tests carried out at the David Taylor Model Basin with a series of five models with actual planing hull forms with varying length to beam ratio between $L_p/B_{px} = 2.0$ and $L_p/B_{px} = 7.0$ and a deadrise at midships of 12.5 degrees. (Clement & Blount 1963). Their results were published in 1963 and became known as the Series 62. The lines plans of the models used by Clement and Blount are depicted in Figure 1.

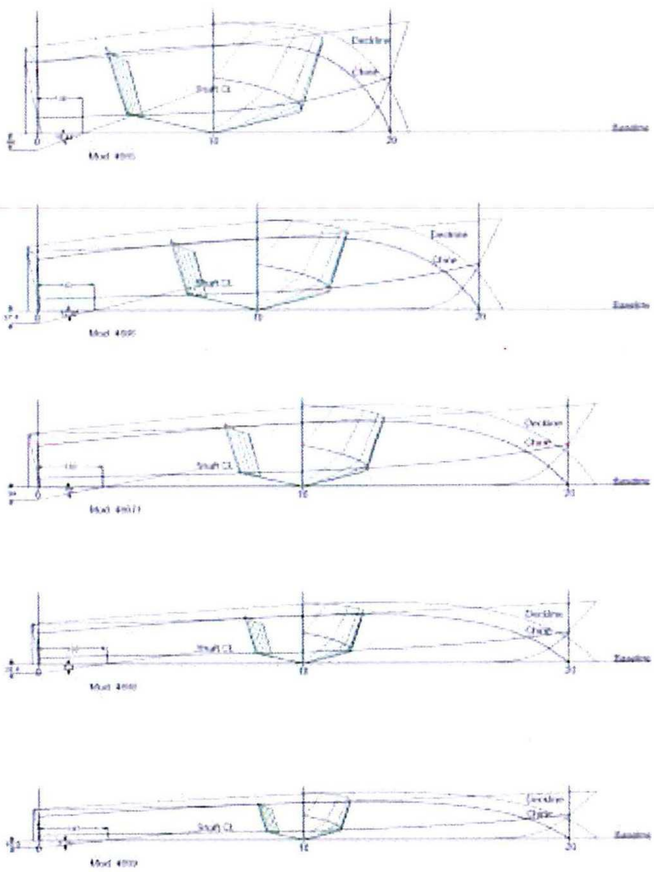

Figure 1: Clement & Blount, 12.5 °degrees deadrise series (1963)

From later research carried out in the 1970's and 1980's on the behavior of planing boats in waves it became evident that in particular the deadrise angle was a paramount parameter for improving the seakeeping behavior of these fast planing boats. Until then the emphasis in the design had been mostly put on minimizing the calm water resistance or maximizing speed. Being able to maintain this high forward speed as long as possible when operating in more exposed areas gradually became more and more of an issue when the operation of these fast planing monohulls shifted from naval to civil applications.

In 1970 J. J. van den Bosch (Bosch 1970) tested two models: one very similar to the Clement parent model and another model with much higher deadrise (i.e. 25 degrees) but further identical to this Clement parent. He tested both models in waves and demonstrated the highly beneficial effect of an increased deadrise on the motions and accelerations: a higher deadrise reduced the peaks in the vertical accelerations in head waves to a large extend and improved the operability of these craft in a seaway.

However a higher deadrise also has a strong influence on the calm water resistance of the boat: i.e. the higher deadrise generally results in a higher calm water resistance. So a compromise between these two, i.e. resistance versus seakeeping, has to be sought. To be able to do this more information on both the effect of the deadrise on resistance as the effect on seakeeping behavior was needed.

To investigate the influence of deadrise on the resistance further Keuning and Gerritsma extended the original series of Clement and Blount in 1982 with identical tests on an additional series of 5 different planing hull forms using the same parent hull shape as Clement and Blount but now having 25.0° of deadrise. Their parent model was derived from the parent hull of Clement and Blount by means of affine transformation techniques (Versluis 1977). In these new hull shapes the deadrise was increased from 12.5 to 25.0 degrees while the vertical projection of the chine area and the hull shape above the chine were kept the same to the Clement and Blount hulls. The lines plans of this 5 new models are depicted in Figure 2. This new series was now tested in the Towing Tank of the Delft University of Technology in the Netherlands. All parametric changes on these new models were identical to those tested by Clement and Blount. However due to physical limitations of the Delft Towing tank the speed range in these new series of tests was now limited to a maximum of $Fn_\nabla = 3.0$, so the speed ranged from $Fn_\nabla = 0.75$ to $Fn_\nabla = 3.0$.

The hard chine planing hull form became increasingly popular as a relatively cheap and reliable concept for fast hull applications also for commercial and patrol ships. The parent hull shape as chosen in the DSDS experiments, based on the original Clement and Blount Series 62 parent hull, was developed a little bit too much with (very) high speeds in mind. For those high speeds a constant deadrise in the aft ship is a good option. However most commercial designs are operating at a larger speed range and are often sailing at relatively much lower speeds.

From dedicated research projects in the 1980's it became evident that applying "twist" and "rocker" in the aft ship had a profound effect on the hydrodynamic performance of hard chine planing hulls. This lead designers to applying this twist and rocker in the aft ship to reduce the calm water resistance at the lower speeds. Furthermore applying twist and rocker in the aft ship enabled the use of larger propeller without protruding these too much below the hull and/or having to deal with too large shaft inclinations.

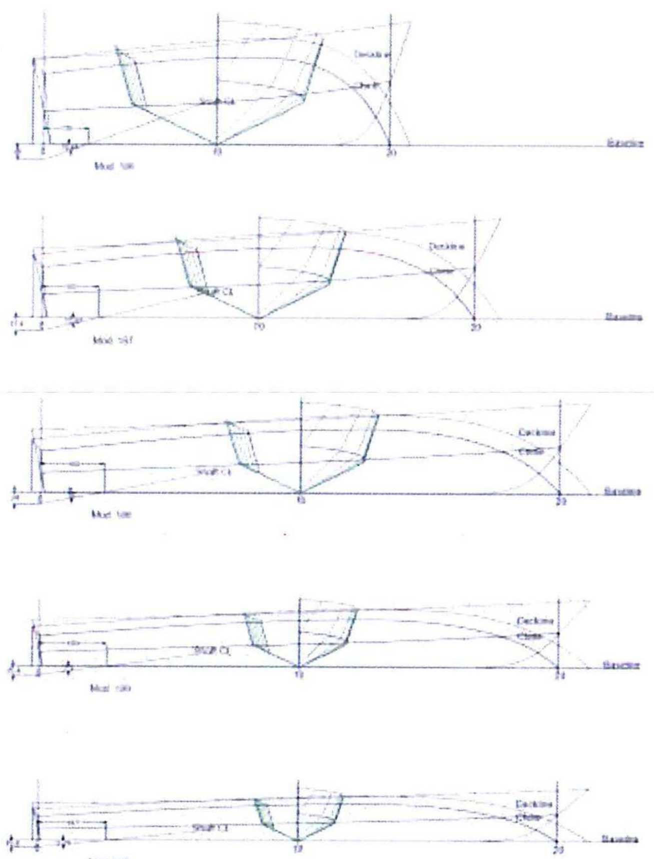

Figure 2: Keuning an Gerritsma, 25.0 ° deadrise series (1982)

To gain more insight in this Keuning e.a. extended their DSDS series in 1986 (Keuning 1986) by testing a small "sub-series" with twist and rocker. In this sub series they used the 25.0° deadrise L_p/B_{px} = 4.09 parent hull as a parent, to investigate the effect of this "twist" and "rocker" in the aft ship on the resistance, sinkage and trim. By doing so it was aimed to derive a "correction" factor for the effect of this twist and rocker, which could then subsequently be applied on the results obtained for the prismatic hulls.

The parameters used to define the twist and the rocker in the aft ship were:

- the twist angle (ε) being the difference in deadrise between the midships and the transom
- the buttock angle (γ). Which is further clarified in Figure 3

Figure 3: Buttock Angle per definition. Negative as shown

The lines plans of these two "twist and rocker" models are depicted in Figure 4.

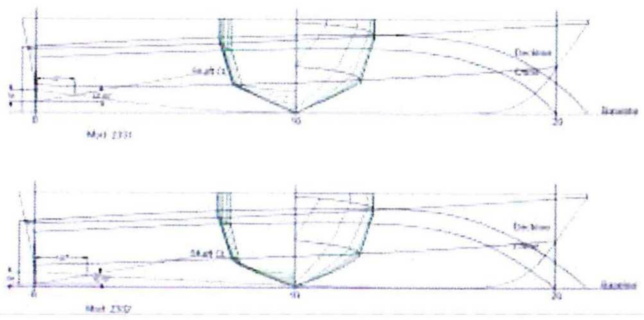

Figure 4: Keuning and Gerritsma, 25.0° deadrise with twist and rocker (1986)

Stimulated by the success of the high deadrise ships for their improved operability in a seaway, Keuning and Gerritsma extended the DSDS database in 1986 once more, now by adding four new models systematically developed from the same parent but now with a (constant) deadrise of 30°. The low L_p/B_{px} ratio boat was omitted from this new series because it was considered to be of little practical use for commercial applications. The lines plans of this 30° series are depicted in Figure 5

The combination of the results of the original Clement and Blount research with the data from the new series tested in Delft now yielded an extensive database containing results on the resistance, trim and sinkage of planing hulls. Using this database a new assessment method for the hydrodynamic performance of planing boats, which can be used in the (early) design phase, could now be developed. This new assessment method makes use of a large number of speed independent polynomial expressions for the calm water resistance, each for a fixed forward speed. A polynomial expression was developed for calm water resistance, the sinkage and the running trim of which the coefficients were determined using least squares regression methods. This assessment method was christened as the "Planing Hull Forms" computer program (i.e. PHF).

The database on which it was based became known as the Delft Systematic Deadrise Series (DSDS). In 1993 J.A. Keuning, J. Gerritsma and P.F. van Terwisga published this method together with the results from the experiments carried out so far (Keuning, Gerritsma & Terwisga 1993)

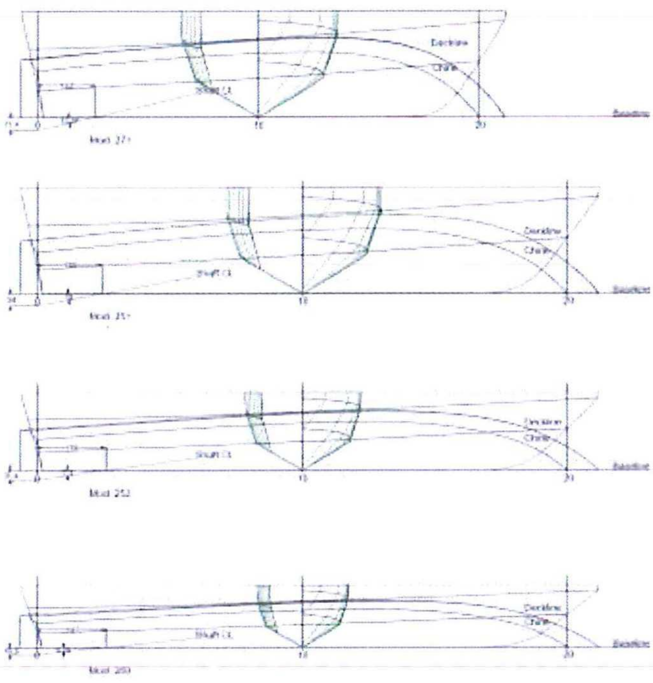

Figure 5: Keuning and Gerritsma, 30° deadrise series(1986)

To achieve a better fit over the entire range of all the deadrise angles used in actual designs and in particular because of the fact that a considerable amount of hard chine planing hulls were now designed around the 20 to 25 degrees of deadrise range, it was decided in 1996 that the DSDS database was to be extended but now with again a similar series of models but now with 19° of deadrise. This was considered desirable to be able to better predict the behavior in the "gap" between 12.5° and 25° of deadrise. The lines plans of this series are depicted in Figure 6. In the PHF assessment method at that time this gap was bridged by assuming linear dependency of the resistance, sinkage and trim on the deadrise angle.

The results of these measurements were added to the DSDS database. So now this data base contained data on systematically tested models with 12.5, 19.0, 25.0 and 30.0 degrees deadrise and with L_p/B_{px} ratio's ranging from $L_p/B_{px} = 2.0$ to $L_p/B_{px} = 7.0$.

Finally also the correction polynomial expression used for introducing the effects of the twist and the rocker on the calm water resistance, trim and sinkage was considered to be based on a too small amount of measurement data to yield accurate results over the larger range of possible applications. So in 2013 it was therefore decided to extend this twist and rocker sub-series once again with additional test on a larger series of models with rocker and twist in the aft ship. Originally twist and rocker was only tested on the $L_p/B_{px} = 4.09$ model but now this was extended with models on more L_p/B_{px} ratios, see Figure 7 on the next page.

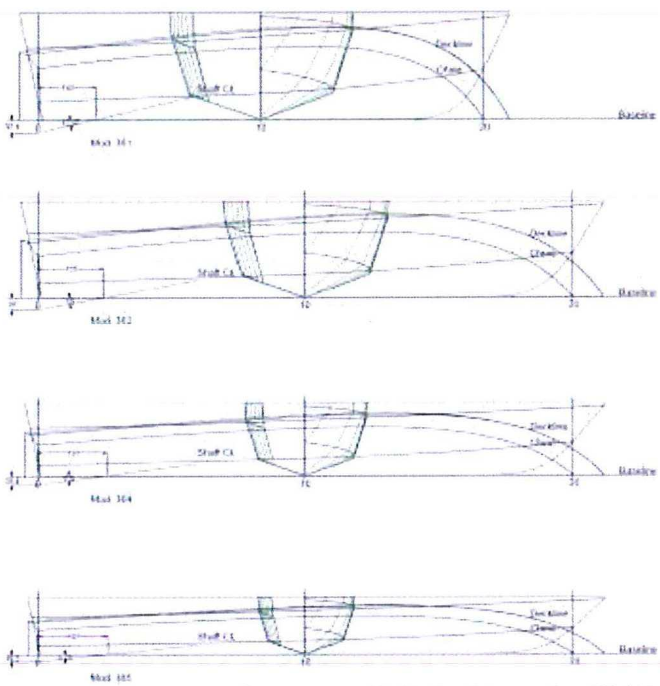

Figure 6: Keuning and Gerritsma 19.0° deadrise series (1996)

The deadrise at midships, however, was still kept the same for all these "twisted" models, i.e. at 25°. The extension of the database was aimed at improving the aforementioned "correction polynomial".

Based on this extended database of the DSDS and now with more data on hull shapes with the possibility to introduce twist and rocker an updated version of PHF has been made.

2 THE DEVELOPMENT OF THE MODELS

The parent model for the entire Delft Systematic Deadrise Series (DSDS) is the Parent model of Clement and Blount from their Series 62. This parent model has a deadrise at midships of 12.5°, a prismatic aft body from midships to transom and a Length to Beam ratio over the chine of L_p/B_{px} = 4.09.

To keep the designs of all the (parent) models used in the DSDS as much identical as possible the following characteristics have been kept the same compared to this parent (as far as the models without twist and rocker are concerned):

- The length and beam over the chine L_p/B_{px}
- The vertical projection of the chine A_p
- The vertical projection of the deck line

- The center line, except in the foremost part where it has been modified to yield the appropriate length over the chine when different deadrise is introduced
- All the models have developable surfaces as hull surfaces (plating)
- The transom slope
- The length of the prismatic aft body

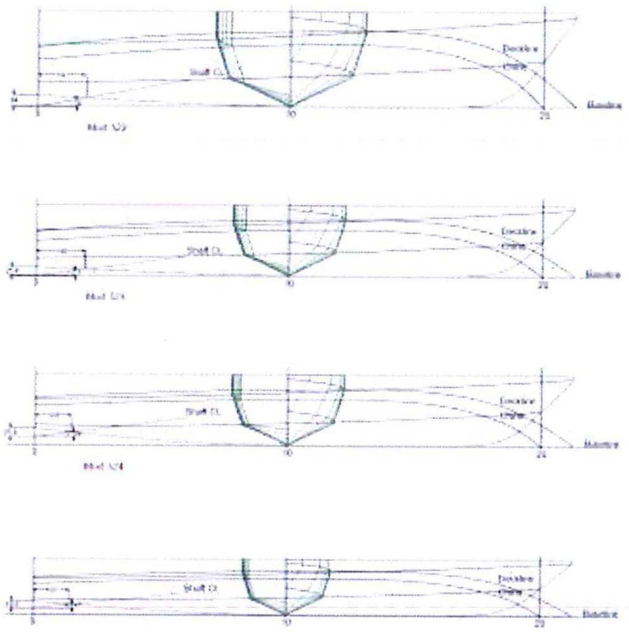

Figure 7: Keuning and Den Ouden, 25.0 ° deadrise parent but now with Twist varied from 10 ° and 20 ° (2013)

The lines plans and body plans of all prismatic parent hull forms are depicted in Figure 8.

In Figure 1, Figure 2 and Figure 4 to Figure 7 the shaft line for all hulls has been depicted. This imaginary shaft line was used to determine the height of the towing point of the models as used in the experiments. The main particulars of all the physical models (24 in total) present in the DSDS are presented together in Table 1, Table 2 and Table 3 here below. All models had spray strips over the entire length of the chine. The bottom of these spray strips was an extension of the bottom of the hull from the transom (ordinate 0) to ordinate 10 (midships) and was horizontal from ordinate 12 to the bow, with a transition region between ordinate 10 and 12. The spray strips had a width of approximately 4 mm. and they had very sharp edges.

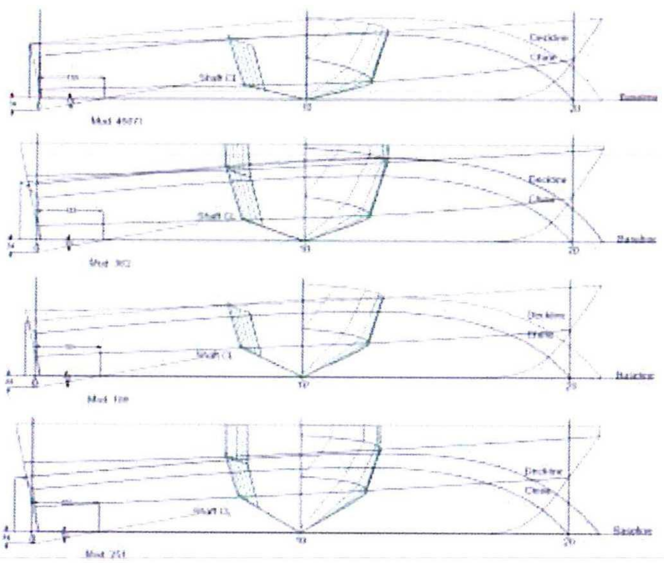

Figure 8: Prismatic Parent Hull Forms of the DSDS

During the entire duration of the testing of the models different materials for model construction have been used, ranging from transparent trovidur plates to glass fiber reinforced polyester with no gelcoat. The hulls were therefore transparent and this enabled "through hull" photography during the tests runs to determine the actual dynamic wetted area of the model, i.e. the wetted area at speed, during each test.

	Model	4665	4666	46671	4668	4669	361	362	363	364
β	[°]	12.50	12.50	12.50	12.50	12.50	19.00	19.00	19.00	19.00
ε	[°]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
γ	[°]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shaft angle	[°]	19.41	12.97	10	7.3	5.75	12.97	10	7.3	5.75
L_P	[m]	1.192	1.825	2.438	2.438	2.438	1.250	1.500	1.500	1.500
B_{PA}	[m]	0.504	0.495	0.305	0.363	0.285	0.340	0.299	0.223	0.175
B_{PX}	[m]	0.596	0.596	0.596	0.443	0.348	0.408	0.367	0.273	0.214
B_{PT}	[m]	0.477	0.422	0.381	0.285	0.224	0.288	0.236	0.175	0.137
L_P/B_{PA}	[-]	2.365	3.690	5.000	7.720	8.560	3.676	5.011	6.737	8.588
L_P/B_{px}	[-]	2.000	3.090	4.090	5.500	7.000	3.060	4.090	5.500	7.000
B_{PX}/B_{PA}	[-]	1.180	1.210	1.220	1.220	1.220	1.200	1.226	1.226	1.225
B_{PT}/B_{PX}	[-]	0.800	0.710	0.640	0.640	0.640	0.706	0.643	0.641	0.640
A_P	[m^2]	0.601	0.903	1.189	0.884	0.695	0.425	0.449	0.334	0.262
C_{AP}	[% L_p]	47.500	48.200	48.800	48.800	48.800	48.08	48.733	48.733	48.667
$A_p/\nabla^{2/3}$	[-]	4 – 8.5	4 – 8.5	4 – 8.5	4 – 8.5	4 – 8.5	4 – 8.5	4 – 8.5	4 – 8.5	4 – 8.5
LCG	[-]	0 – -12	0 – -12	0 – -12	0 – -12	0 – -12	0 – -8	0 – -8	0 – -8	0 – -8
Fn_∇	[-]	0 – 6	0 – 6	0 – 6	0 – 6	0 – 6	0 – 3	0 – 3	0 – 3	0 – 3

Table 1: Model Properties of the DSDS; Clement and Blount (1963) Keuning and Gerritsma (1996)

Model		186	187	188	189	190	271	251	252	260
β	[°]	25.00	25.00	25.00	25.00	25.00	30.00	30.00	30.00	30.00
ε	[°]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
γ	[°]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shaft angle	[°]	19.41	12.97	10	7.3	5.75	12.97	10	7.3	5.75
L_P	[m]	1.000	1.250	1.500	1.500	1.500	1.250	1.500	1.500	1.500
B_{PA}	[m]	0.430	0.342	0.300	0.223	0.175	0.300	0.300	0.223	0.175
B_{PX}	[m]	0.500	0.408	0.367	0.273	0.214	0.367	0.367	0.273	0.214
B_{PT}	[m]	0.400	0.290	0.235	0.175	0.137	0.260	0.235	0.175	0.137
L_P/B_{PA}	[-]	2.372	3.653	5.000	6.726	8.560	4.170	5.000	6.726	8.571
L_P/B_{px}	[-]	2.000	3.064	4.087	5.494	7.010	3.410	4.090	5.500	7.000
B_{PX}/B_{PA}	[-]	1.164	1.192	1.220	1.220	1.220	1.220	1.220	1.220	1.220
B_{PT}/B_{PX}	[-]	0.800	0.711	0.640	0.640	0.642	0.710	0.640	0.640	0.640
A_P	[m^2]	0.430	0.428	0.450	0.335	0.263	0.384	0.450	0.335	0.263
C_{AP}	[% L_p]	47.113	47.879	48.800	48.800	48.800	47.900	48.800	48.600	48.600
$A_p/V^{2/3}$	[-]	4 – 8.5	4 – 8.5	4 – 8.5	4 – 8.5	4 – 8.5	4 – 8.5	4 – 8.5	4 – 8.5	4 – 8.5
LCG	[-]	0 – -12	0 – -12	0 – -12	0 – -12	0 – -12	0 – -8	0 – -8	0 – -8	0 – -8
Fn_∇	[-]	0 – 3	0 – 3	0 – 3	0 – 3	0 – 3	0 – 3	0 – 3	0 – 3	0 – 3

Table 2: Model Properties of the DSDS; Keuning and Gerritsma (1982) and Keuning and Gerritsma (1986)

Model		2331	2332	522	523	524	525
β	[°]	25.00	25.00	25.00	25.00	25.00	25.00
ε	[°]	20.00	20.00	10.00	10.00	20.00	20.00
γ	[°]	-4.93	-2.61	-2.2	-1.69	-3.41	-2.68
Shaft angle	[°]	10	10	10	7.3	7.3	5.75
L_P	[m]	1.500	1.500	1.500	1.500	1.500	1.500
B_{PA}	[m]	0.306	0.303	0.312	0.231	0.237	0.186
B_{PX}	[m]	0.367	0.367	0.367	0.273	0.273	0.214
B_{PT}	[m]	0.320	0.310	0.276	0.202	0.229	0.180
L_P/B_{PA}	[-]	4.900	4.900	4.808	6.503	6.338	8.065
L_P/B_{px}	[-]	4.090	4.090	4.090	5.500	5.500	7.000
B_{PX}/B_{PA}	[-]	1.200	1.200	1.176	1.184	1.154	1.151
B_{PT}/B_{PX}	[-]	0.872	0.844	0.752	0.740	0.839	0.841
A_P	[m^2]	0.459	0.454	0.468	0.346	0.355	0.279
C_{AP}	[% L_p]	48.800	48.800	47.467	47.467	46.667	46.667
$A_p/V^{2/3}$	[-]	4 – 8.5	4 – 8.5	4 – 8.5	4 – 8.5	4 – 8.5	4 – 8.5
LCG	[-]	0 – -12	0 – -12	0 – -12	0 – -12	0 – -12	0 – -12
Fn_∇	[-]	0 – 3	0 – 3	0 – 3	0 – 3	0 – 3	0 – 3

Table 3: Model Properties of the DSDS; Keuning and Gerritsma (1986) and Keuning and Den Ouden (2013)

3 THE EXPERIMENTAL SETUP AS USED IN THE DSDS

In the DSDS great care has been taken over all the years to assure that all the tests have been carried out using the same facilities, following the same procedures, using the same experimental setup and using the same analysis as much as possible

So all the tests in the DSDS have been carried out in the large #1 towing tank of the Delft Ship Hydromechanics Laboratory of the Delft University of Technology. The dimensions of this tank are: length 142 meters, width 4.25 meters and maximum attainable water depth 2.5 meters. The maximum attainable speed of the towing carriage is 7.0 m/sec.

The models were connected to the towing carriage in such a way that they were free to heave (sinkage) and pitch (trim) but restrained in all other modes of motion. The models were connected to the towing carriage by means of a vertical rod free to heave which at the bottom end was connected to the model by means of an pivot. This pivot of this construction that connected the model to the towing carriage was positioned at the intersection of the (assumed) shaft line and the cross section in the Longitudinal position of the Centre of Gravity (LCG). Thus the towing point changed with every change in Longitudinal Centre of Gravity.

A strain gauge type dynamometer was used for measuring the resistance force at the pivot point. The sinkage and the trim of the model were measured in the earlier tests with vertical displacement meters fore and aft of the "wire over potentiometer" type and in the later tests (after 1995) with an optical tracking system. The presented values are averages over at least 10 seconds extending to 20 seconds for the tests with lower speeds.

No turbulence stimulation has been applied on the models and no towing speeds below 1 m/sec have been used.

During each and every run a "through hull" photograph has been taken to enable the determination of the actual wetted surface of the hull at speed (i.e. dynamic wetted area) as well as the wetted length over the centerline (L_k) and the chine (L_c). The dynamic wetted surface has been used in the extrapolation of the measured results to full scale. No form factor has been determined and consequently also not used in the extrapolation procedure. For the extrapolation of all measured data, when applicable, the Froude extrapolation method has been used using the ITTC-57 friction line. For the determination of the characteristic length in the Reynolds number the average of the wetted length over the centerline and the wetted length over the chine has been used.

4 MEASUREMENT SCHEME

The tests program for each sub-series of the DSDS consisted over all possible combinations of the parameter variation shown in Tables 1 to 3 (one should take notice of the fact that the number of combinations of twist, rocker and L_p/B_{px} are limited):

Some of these test conditions appeared to be unrealistic and unworkable for the tests. For instance high displacements with an extreme aft position of the Center of Gravity often caused submergence of the aft deck at rest. These conditions have therefore been omitted from the test program. All test conditions have been kept the same as with the tests carried out by Clement and Blount, except for the forward speed. Due to the limitations of the Delft towing tank the forward speed has been limited to $Fn_\nabla = 3.0$ as a maximum. This is considerably lower than in the Clement and Blount tests. From a practical point of view this was not considered to be a too large restriction because this speed range covers already most commercial applications.

5 RESULTS

Part of this publication is the announcement that the Shiphydromechanics Department of the Delft University of Technology has made all the model geometries, the data and the results of the measurements available through a dedicated website. See the chapter: "RELEASE OF THE RESULTS OF THE DSDS" for more information. These results include also all the results of the latest tests with the sub-series of models with twist and rocker. Therefore no extensive presentation of the results of these tests will be presented in this paper. Some figures however will be presented to demonstrate some of the (measured) effects of the twist and rocker on the resistance, the sinkage and the trim of the models.

These results are depicted below. Please note that all data in these figures is for a deadrise at midships of 25 degrees.

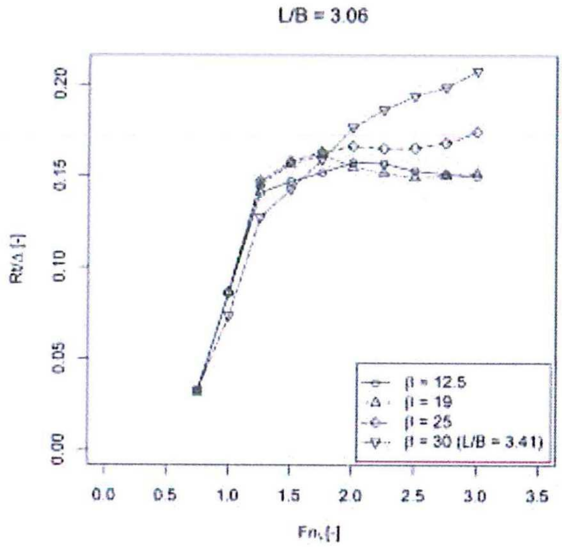

Figure 9: The dependency of calm water resistance on deadrise angle for L_p/B_{px} = 3.06

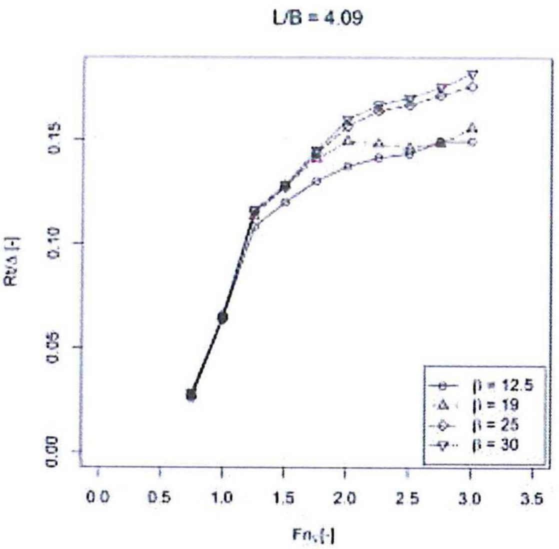

Figure 10: The dependency of calm water resistance on deadrise angle for L_p/B_{px} = 4.09

First of all in Figure 9, 10, 11 and 12 the dependency of the calm water resistance on the deadrise angle is shown for an increasing deadrise from 12.5, to 19.0, 25.0 and 30.0 degrees respectively. The results shown are for four different values of L_p/B_{px} , i.e. L_p/B_{px} = 3.06, L_p/B_{px} = 4.09, L_p/B_{px} = 5.5 and L_p/B_{px} = 7.0 all with a LCG = -4.0

and a weight or loading factor corresponding to $A_p/V^{2/3} = 5.5$. From these plots it is clear that

- The lower deadrise in general has the lowest resistance, i.e. the highest lift
- The earlier supposed linear dependency of the resistance on the deadrise is not valid for the resistance and that the inclusion of the 19.0 degrees of deadrise series in the DSDS data base really makes sense.
- The effect of the deadrise is more pronounced for the lower L_p/B_{px} values, i.e. the effect diminishes for the narrow boats

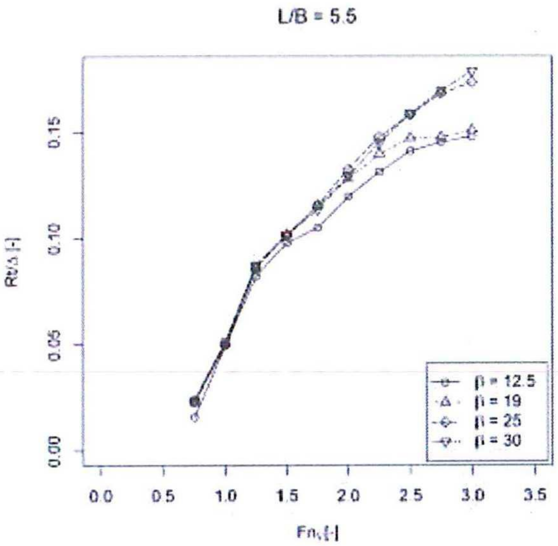

Figure 11: The dependency of calm water resistance on deadrise angle for $L_p/B_{px} = 5.5$

Similar effects, although not all shown here, can be found in the figures showing the dependency of the running trim on the deadrise and L_p/B_{px} ratio. In Figure 13 this relation is shown for a L_p/B_{px} ratio of 4.09.

Also the effect of the twist and rocker in the aft ship and its dependency on the Length to Beam Ratio can now be shown (Figures 14 – 16). These results are all for the model with a midships deadrise angle of 25 degrees, and a L_p/B_{px} ratio of $L_p/B_{px} = 4.09$, $L_p/B_{px} = 5.5$ and $L_p/B_{px} = 7.0$ respectively. A constant LCG of – 4 % and $A_p/V^{2/3}$ of 5.5 is maintained. The twist angle is varied between 0 (i.e. prismatic) 10 and 20 degrees respectively

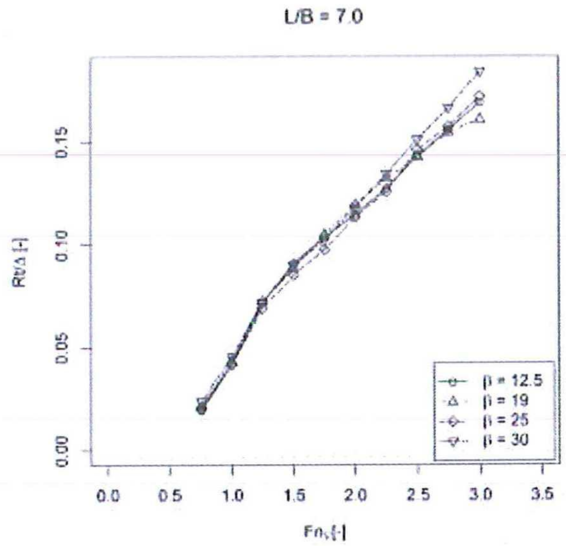

Figure 12: The dependency of calm water resistance on deadrise angle for $L_p/B_{px} = 5.5$

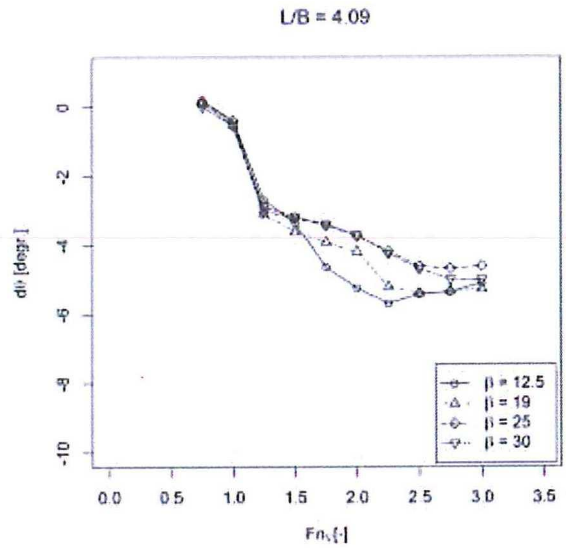

Figure 13: The dependency of the running trim on deadrise angle for $L_p/B_{px} = 4.09$

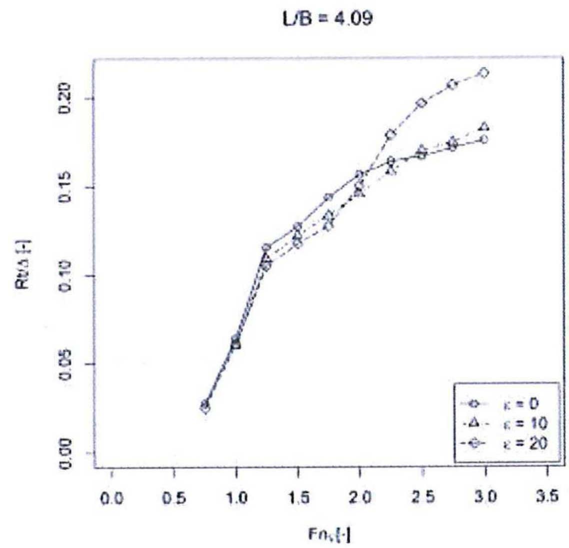

Figure 14: Change in resistance due to twist and rocker for $L_p/B_{px} = 4.09$

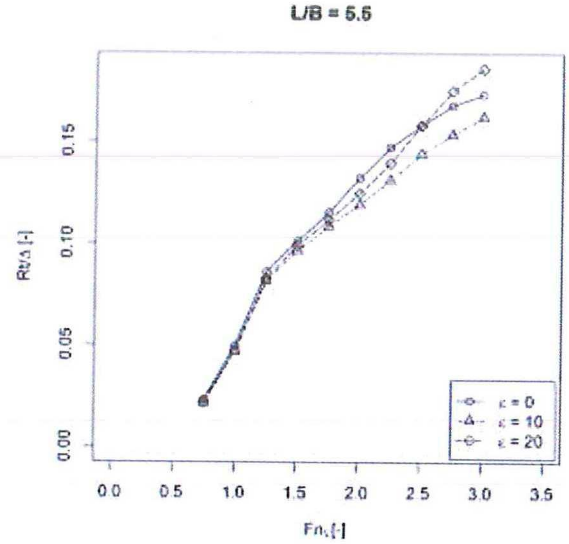

Figure 15: Change in resistance due to twist and rocker for $L_p/B_{px} = 5.5$

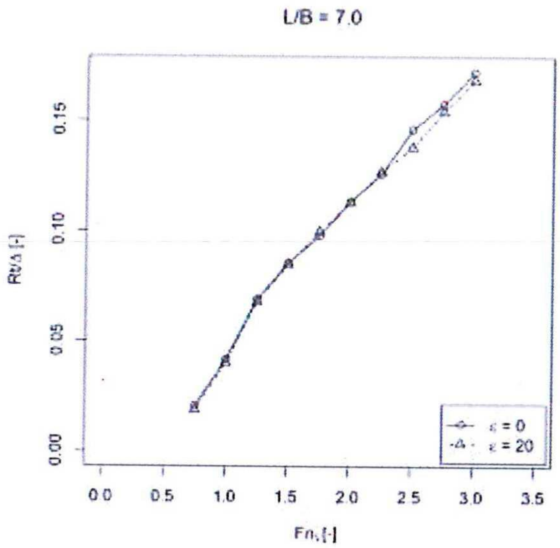

Figure 16: Change in resistance due to twist and rocker for $L_p/B_{px} = 7.0$

From these results it becomes also evident that the effect of twist and rocker is most strongly felt with the low L_p/B_{px} ratio hulls.. This trend is visible both in the effect of deadrise as with the effect of twist and rocker in the aft body: the influence is more pronounced on the more effective hydrodynamic lift generating hull forms. The low L_p/B_{px} ratio hulls are from a hydrodynamic lift generating point of view the hulls with the highest aspect ratio. In the lift analgen the length of the hull equals to the chord of the wing and the beam equals to the span of the wing, so the aspect ratio becomes "beam over length".

A similar trend may be observed from the results of the trim of which only the values for $L_p/B_{px} = 4.09$ are shown in Figure 17,

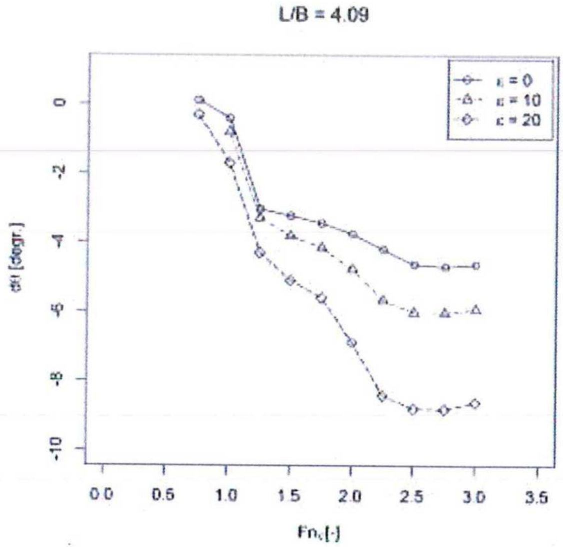

Figure 17: Change in running trim due to twist and rocker for $L_p/B_{px} = 4.09$

6 POLYNOMIAL MODEL FOR ASSESSING THE RESISTANCE, TRIM AND SINKAGE OF AN ARBITRARY HULL

Using the results of the database of the DSDS a new version of the earlier polynomial expressions for the assessment of the resistance, trim and sinkage of an arbitrary planing monohull (Keuning, Gerritsma, Terwisga 1993) has been developed. The aim was an improved prediction for hulls with twist and rocker.

The procedure followed to assess the specific resistance, the running trim and the sinkage of an arbitrary hull, the frictional resistance and the residuary resistance. This deviates from the expressions developed by Gerritsma e.a. previously which were on the total resistance. Because of that the earlier expressions were size dependent and sets of coefficients of the polynomial expressions had to be presented for different weights of displacement.

Now first an expression for the dynamic wetted area of an arbitrary hull had to be developed. Then an expression for the residuary resistance, the running trim and the sinkage for a prismatic hull is approximated using a polynomial expression containing only L_p/B_{px} , $A_p/V^{2/3}$ and *LCG* as the parameters, also to higher orders and in combinations with the other parameters. The expressions used are shown below. Regression techniques are used to determine the values of the various coefficients.

Different from the earlier methods is now also that the deadrise angle is taken into the expressions as a separate parameter. So there are no different regressions applied for each of the deadrise angles separately.

Secondly, a correction polynomial has been formulated to assess the effect of twist and rocker. This effect is accounted for in the present approach as a change (i.e. generally an increase) on the values found for the prismatic hulls. This procedure was adopted because these corrections were only known for the 25 degrees deadrise models. These corrections were consequently assumed to be equal for all the other deadrise angles.

Compared to the polynomials published by Keuning, Gerritsma and Terwisga (Keuning, Gerritsma and Terwisga 1993) the current correction polynomials for the change in resistance, trim and sinkage caused by the application of twist and rocker have been expanded by adding L_p/B_{px} as parameter in the formulation. This was enabled by the extra information gathered by Keuning and Den Ouden in 2013.

The polynomials for resistance, sinkage and trim as well as the correction polynomials for twist and rocker are presented here below. The polynomial expressions used for assessing the trim (dθ) and sinkage ($RCG/\nabla^{1/3}$) are the same as for R_r/Δ presented here below.

Prismatic:

$$\frac{Lw}{\nabla^{\frac{1}{3}}}=a_0+a_1\beta+a_2LCG+a_3\left(\frac{Lp}{Bpx}\right)+a_4\left(\frac{Ap}{\nabla^{\frac{2}{3}}}\right)$$
$$+a_5\left(LCG\cdot\frac{Lp}{Bpx}\right)+a_6\left(\frac{Lp}{Bpx}\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)+a_7\left(\beta\cdot\frac{Lp}{Bpx}\right)$$
$$+a_8\left(\beta\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)+a_9\left(\beta\cdot LCG\right)$$

$$\frac{Swet}{\nabla^{\frac{2}{3}}}=b_0+b_1\beta+b_2LCG+b_3\left(\frac{Lp}{Bpx}\right)+b_4\left(\frac{Ap}{\nabla^{\frac{2}{3}}}\right)$$
$$+b_5\left(LCG\cdot\frac{Lp}{Bpx}\right)+b_6\left(\frac{Lp}{Bpx}\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)+b_7\left(\beta\cdot\frac{Lp}{Bpx}\right)$$
$$+b_8\left(\beta\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)+b_9\left(\beta\cdot LCG\right)$$

$$\frac{Rr}{\Delta}=c_0+c_1\beta+c_2\left(\frac{Lp}{Bpx}\right)+c_3\left(\frac{Ap}{\nabla^{\frac{2}{3}}}\right)+c_4LCG$$
$$+c_5\beta^2+c_6\left(\frac{Lp}{Bpx}\right)^2+c_7\left(\frac{Ap}{\nabla^{\frac{2}{3}}}\right)^2+c_8LCG^2$$
$$+c_9\beta^3+c_{10}\left(\frac{Lp}{Bpx}\right)^3+c_{11}\left(\frac{Ap}{\nabla^{\frac{2}{3}}}\right)^3+c_{12}\left(\beta\cdot\frac{Lp}{Bpx}\right)$$
$$+c_{13}\left(\beta\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)+c_{14}\left(\beta\cdot LCG\right)+c_{15}\left(\frac{Lp}{Bpx}\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)$$
$$+c_{16}\left(\frac{Lp}{Bpx}\cdot LCG\right)+c_{17}\left(\frac{Ap}{\nabla^{\frac{2}{3}}}\cdot LCG\right)$$

Twist and rocker correction:

$$\frac{dLw}{\nabla^{\frac{1}{3}}}=d_0\varepsilon+d_1\gamma+d_2\left(\varepsilon\cdot LCG\right)+d_3\left(\varepsilon\cdot\frac{Lp}{Bpx}\right)$$
$$+d_4\left(\varepsilon\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)+d_5\left(\gamma\cdot LCG\right)+d_6\left(\gamma\cdot\frac{Lp}{Bpx}\right)$$
$$+d_7\left(\gamma\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)+d_8\left(\gamma\cdot LCG\cdot\frac{Lp}{Bpx}\right)+d_9\left(\gamma\cdot LCG\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)$$
$$+d_{10}\left(\gamma\cdot\frac{Lp}{Bpx}\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)$$

$$\frac{dSwet}{\nabla^{\frac{2}{3}}}=e_0\varepsilon+e_1\gamma+e_2\left(\varepsilon\cdot LCG\right)+e_3\left(\varepsilon\cdot\frac{Lp}{Bpx}\right)$$
$$+e_4\left(\varepsilon\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)+e_5\left(\gamma\cdot LCG\right)+e_6\left(\gamma\cdot\frac{Lp}{Bpx}\right)$$
$$+e_7\left(\gamma\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)+e_8\left(\gamma\cdot LCG\cdot\frac{Lp}{Bpx}\right)+e_9\left(\gamma\cdot LCG\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)$$
$$+e_{10}\left(\gamma\cdot\frac{Lp}{Bpx}\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)$$

$$\frac{dRr}{\Delta} = f_0\gamma + f_1\varepsilon + f_2\left(\gamma\cdot\frac{Lp}{Bpx}\right) + f_3\left(\gamma\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)$$
$$+ f_4\left(\gamma\cdot LCG\right) + f_5\left(\varepsilon\cdot\frac{Lp}{Bpx}\right) + f_6\left(\varepsilon\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\right)$$
$$+ f_7\left(\varepsilon\cdot LCG\right) + f_8\left(\gamma\cdot\left(\frac{Ap}{\nabla^{\frac{2}{3}}}\right)^2\right)$$
$$+ f_9\left(\gamma\cdot LCG^2\right) + f_{10}\left(\gamma\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\cdot\frac{Lp}{Bpx}\right)$$
$$+ f_{11}\left(\gamma\cdot\frac{Ap}{\nabla^{\frac{2}{3}}}\cdot LCG\right) + f_{12}\left(\gamma\cdot LCG\cdot\frac{Lp}{Bpx}\right)$$

All the values of the various coefficients for the various polynomials presented here above, i.e. a_n till f_n , are presented in the DSDS data base on the website of which access is presented under Chapter 7 of this paper.

It should be realized that these polynomials are just one example of the many different possibilities to assess the resistance and trim of a arbitrary planing monohull using the results of the DSDS.

By releasing all the results and data of the DSDS, it becomes possible for everyone interested to elaborate and (re)analyse the results and formulate different assessment methods for obtaining better results.

Now all the data of the DSDS is released it is interesting to see what other approaches may yield in this respect.

To validate the approaches used so far the results of an application of the assessment method of both PHF and DSDS on two different planing hulls is depicted in the Figures 12 and 13. The first boat is a 20 meter high speed SAR boat from the Netherlands capable of speeds up to 35 knots and with a hull without any twist and rocker. The second one is a Patrol boat of 35 meter with twist and rocker in the aft ship.

As can be seen from these figures the assessment yields reasonable results and the new data base yields slightly better results than the previous ones.

7 RELEASE OF THE RESULTS OF THE DSDS

The Delft Ship Hydromechanics Laboratory of the Delft University of Technology has decided to release all the data of the Delft Systematic Deadrise Series. This includes the sets of all coefficients necessary for using the various polynomial expressions and all model data, geometries and hydrostatics involved.

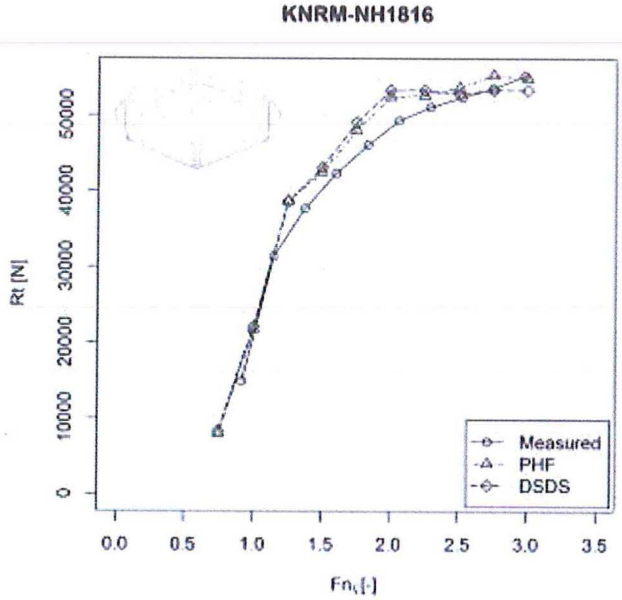

Figure 12: Total resistance prediction of a 20 meter SAR boat using models PHF and DSDS
No twist and rocker

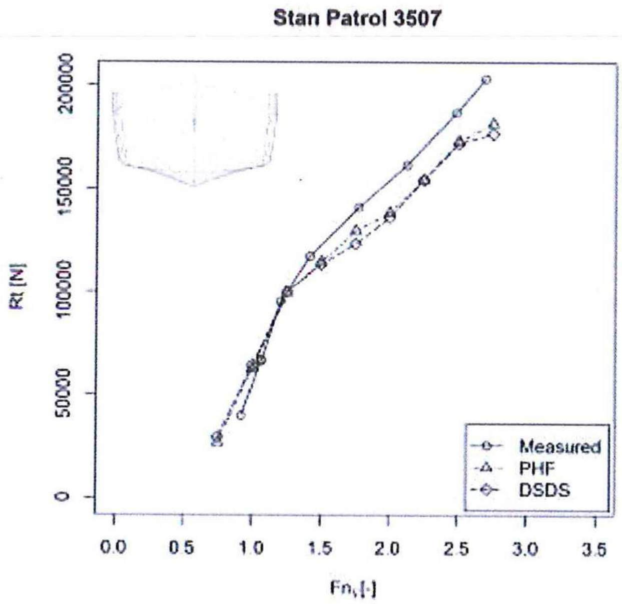

Figure 13: Total resistance prediction of a 35 meter Patrol boat using models PHF and DSDS
15 degrees of twist and 3 degrees of rocker

The aim of the DUT is to present all this data on an easily accessible way to all those interested. A similar procedure has been chosen as the one used previously for distributing all the data of the **Delft Systematic Yachts Hull Series.** All the data becomes available through the release of a dedicated website. This website will be:

http://dsds.tudelft.nl

By doing so any possible addition to or change in the distributed data can be easily handled by the Delft University of Technology. The users will be consequently informed of this by an email.

Access to this website can be obtained by sending an email to the following address:

J.G.denOuden@tudelft.nl

A **user id** and **password** will then be supplied by the DUT which will subsequently give the enquirer access to this website. Additionally some kind of user agreement will have to be signed to guarantee proper use of the data.

From this website all the relevant data can be downloaded

There are no costs involved.

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