Residuary drag estimation for a slender monohull

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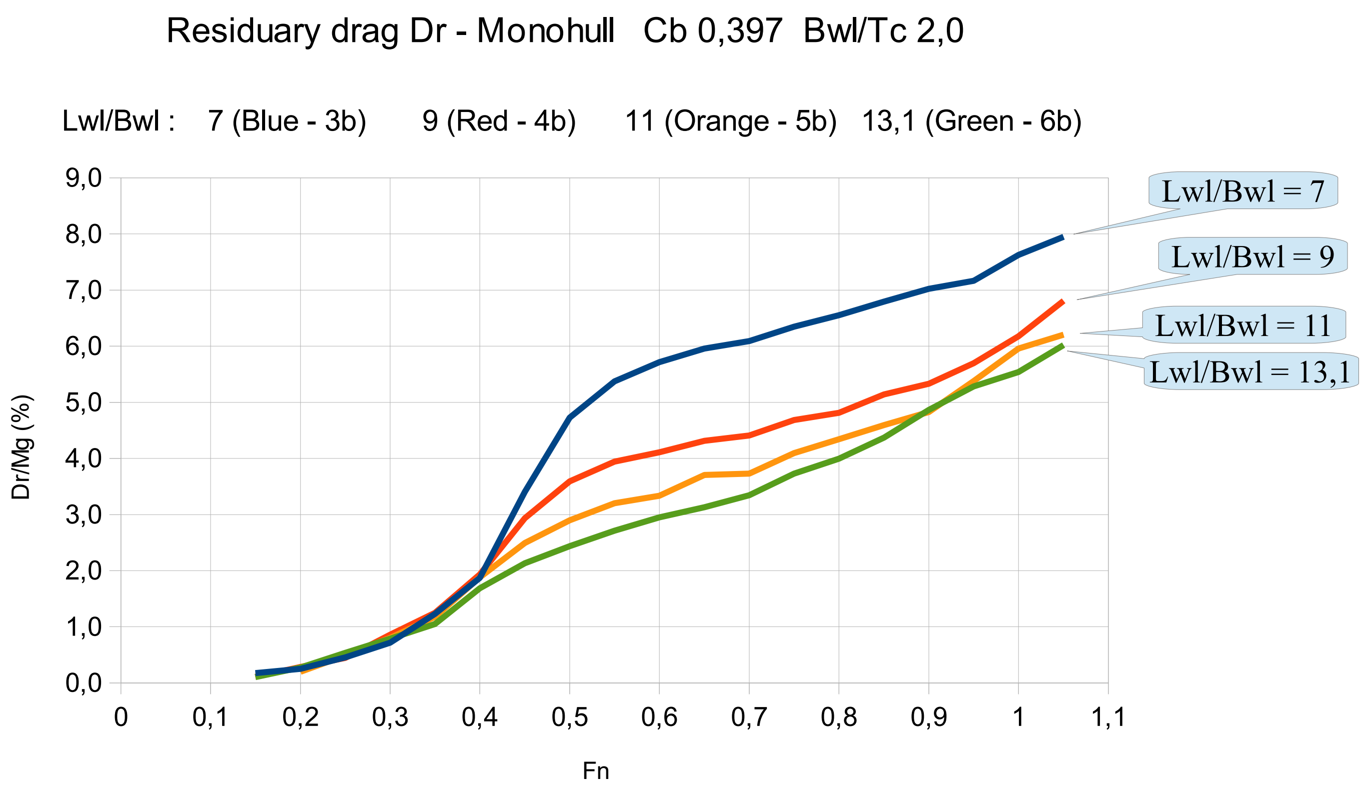
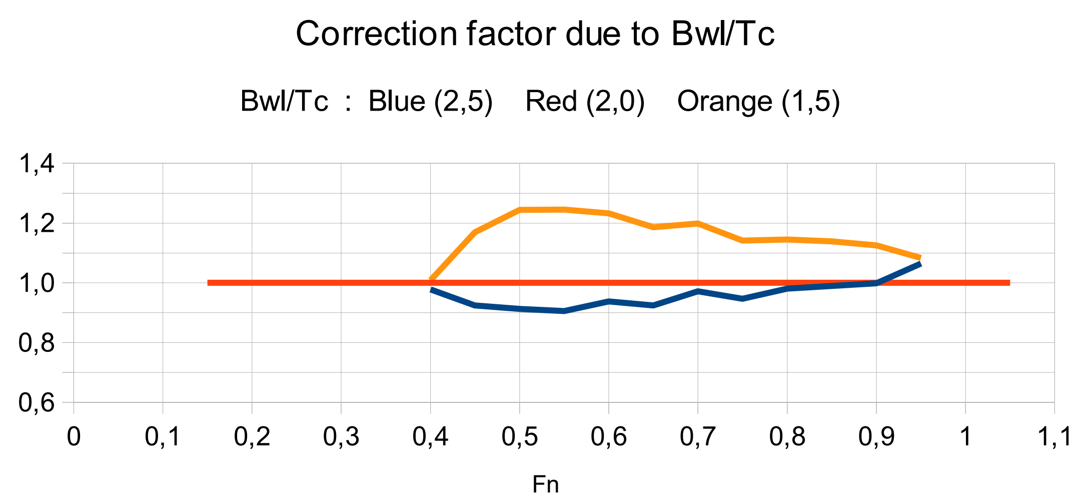
Abstract :
From the towing tank tests of a serie of slender monohull models (Reference and detailed analysis in page 2 and followings), sharing the same block coefficient (Cb ~ 0,4), one can propose this evaluation of the residuary drag component Dr in function of the ratios Lwl/Bwl and Bwl/Tc :

Dr/Mg (%) = Function (Fn, Lwl/Bwl, when Bwl/Tc = 2) * Correction (when Bwl/Tc ≠ 2)

with : Dr : residuary drag ; Mg : weight of the monohull ; Fn : Froude number (based on Lwl)
Lwl : length waterline ; Bwl : beam waterline ; Tc : hull draft

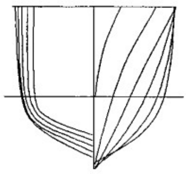




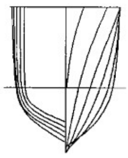
Detailed analysis

The residuary drag of a slender monohull with dimensionless parameters is proposed and discussed, on the basis of a series of models tested in the University Southampton towing tank and reported here below by A.F Molland / University of Southampton and Pat Couser / Bentley systems in january 1994 :
https://www.researchgate.net/publication/284260790_Resistance_experiments_on_a_systematic_series_of_high_speed_displacement_catamaran_forms_Variation_of_length-displacement_ratio_and_breadth-draught_ratio

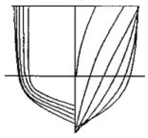
The tested models :



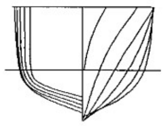
Model: 3b



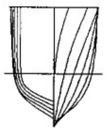
Model: 4a



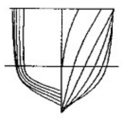
Model: 4b



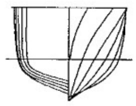
Model: 4c



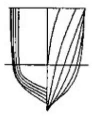
Model: 5a



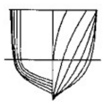
Model: 5b



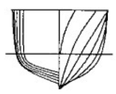
Model: 5c



Model: 6a



Model: 6b



Model: 6c

Model	L (m)	L/B	B/T	L/D^1/3	Cb	Cp	Cm	Sw (m2)	LCB (%Lwl)	>> D(m3)	>> D (kg)
3b	1,6	7,0	2,0	6,27	0,397	0,693	0,565	0,434	-6,4	0,016617	16,62
4a	1,6	10,4	1,5	7,40	0,397	0,693	0,565	0,348	-6,4	0,010108	10,11
4b	1,6	9,0	2,0	7,41	0,397	0,693	0,565	0,338	-6,4	0,010067	10,07
4c	1,6	8,0	2,5	7,39	0,397	0,693	0,565	0,34	-6,4	0,010149	10,15
5a	1,6	12,8	1,5	8,51	0,397	0,693	0,565	0,282	-6,4	0,006646	6,65
5b	1,6	11,0	2,0	8,50	0,397	0,693	0,565	0,276	-6,4	0,006670	6,67
5c	1,6	9,0	2,5	8,49	0,397	0,693	0,565	0,277	-6,4	0,006693	6,69
6a	1,6	15,1	1,5	9,50	0,397	0,693	0,565	0,24	-6,4	0,004777	4,78
6b	1,6	13,1	2,0	9,50	0,397	0,693	0,565	0,233	-6,4	0,004777	4,78
6c	1,6	11,7	2,5	9,50	0,397	0,693	0,565	0,234	-6,4	0,004777	4,78

In the paper in reference the residuary drag of each slender monohull of the series is deduced from the tests and given in Figures 32a, b, c and d , through the resistance coefficient Cr, applied to ½ ρ A u2, in function of Froude Fn. As A (the static wetted surface), u (the speed, known from the Froude number and the lenght L) and the model mass M (known from L/D^1/3 and M = D ρ) , it is possible to convert these curves in the more appropriated adimensional form for such residuary (mostly wave) drag Dr, i.e. Dr/Mg (%) in function of Fn, so showing its independance to Reynolds.

Another point is the parameters used to graduated the various curves in the paper, in apparence they are 3 : Lwl/Bwl, Bwl/Tc, Lwl/D^1/3. But actually, all the models sharing the same block coefficient Cb (= 0,397), when 2 parameters are given, e.g. Lwl/Bwl and Bwl/Tc, the third one Lwl/D^1/3 is fixed through :

$$Lwl/D^{1/3} = [(Bwl/Tc)/Cb]^{1/3} \ (Lwl/Bwl)^{2/3}$$

So the curves presentation can be graduated stating that Cb is common (0,397) and using Lwl/Bwl or Bwl/Tc for the curves graduation.

Lwl/Bwl influence

At first, to demonstrate the approach, here is the Fig.32a of the paper (Residuary drag Dr of the models 3b, 4b, 5b, 6b **at constant Bwl/Tc = 2,0**) and its conversion in curves Dr/Mg (%) in function of Fn :

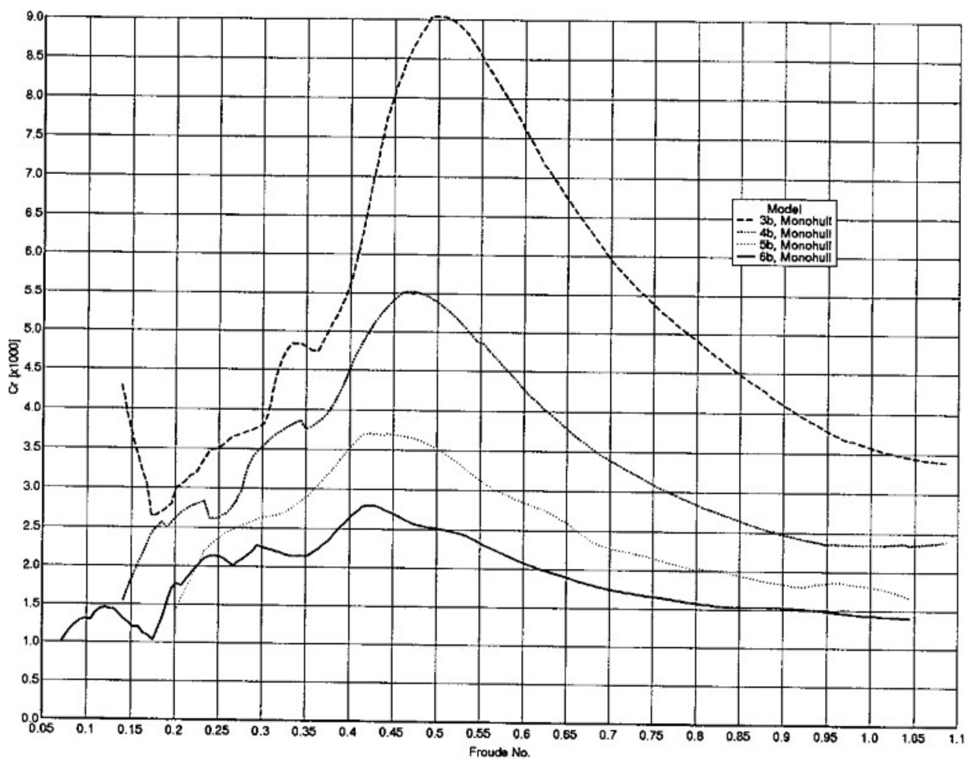
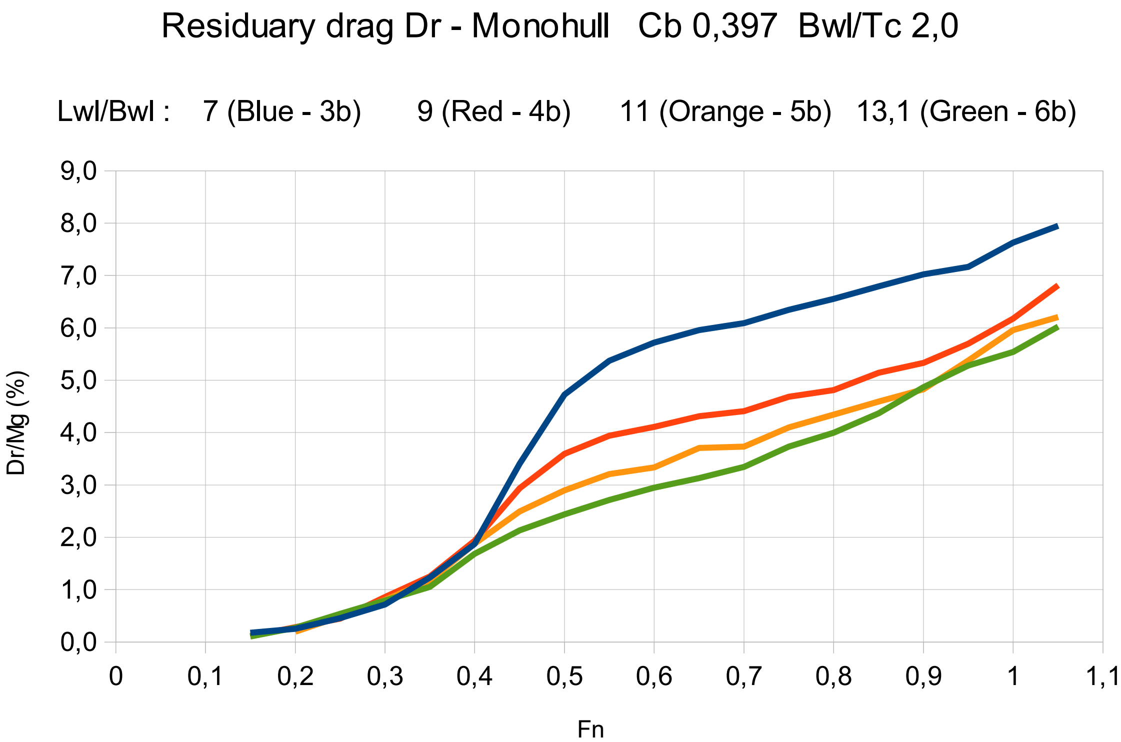
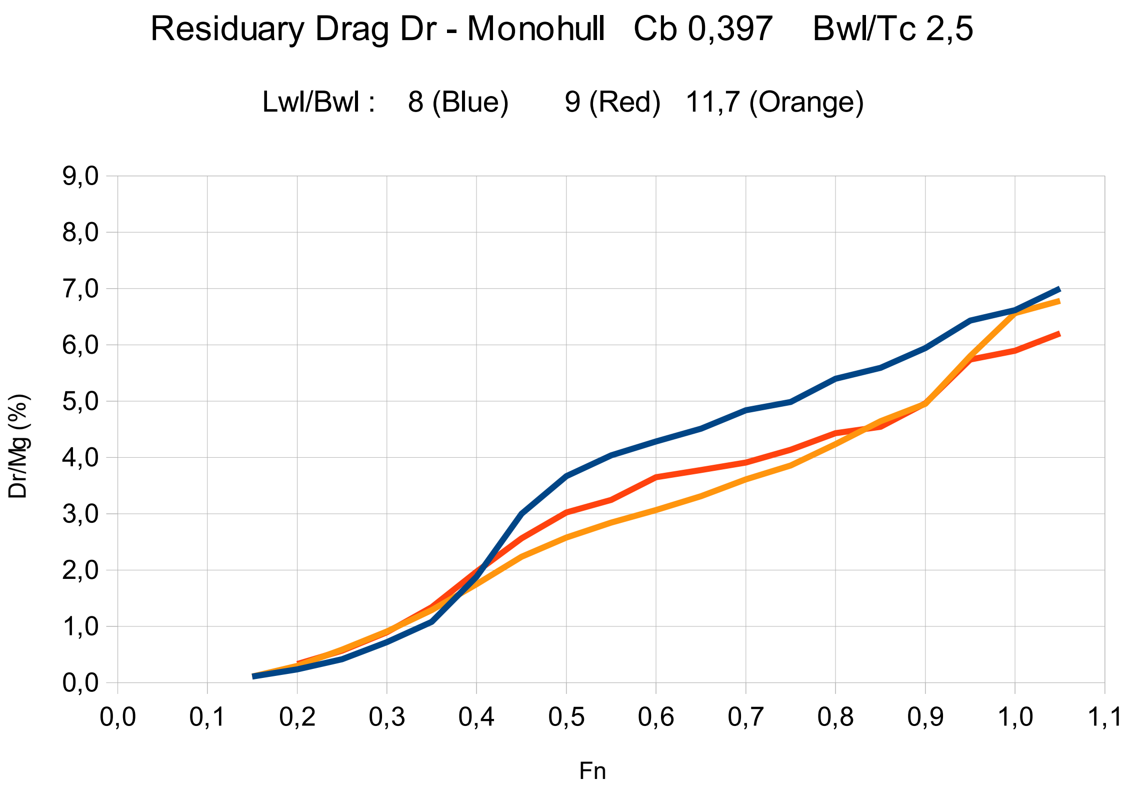


Fig 32a. Residuary Resistance: Models: 3b,4b,5b,6b (Monohull)

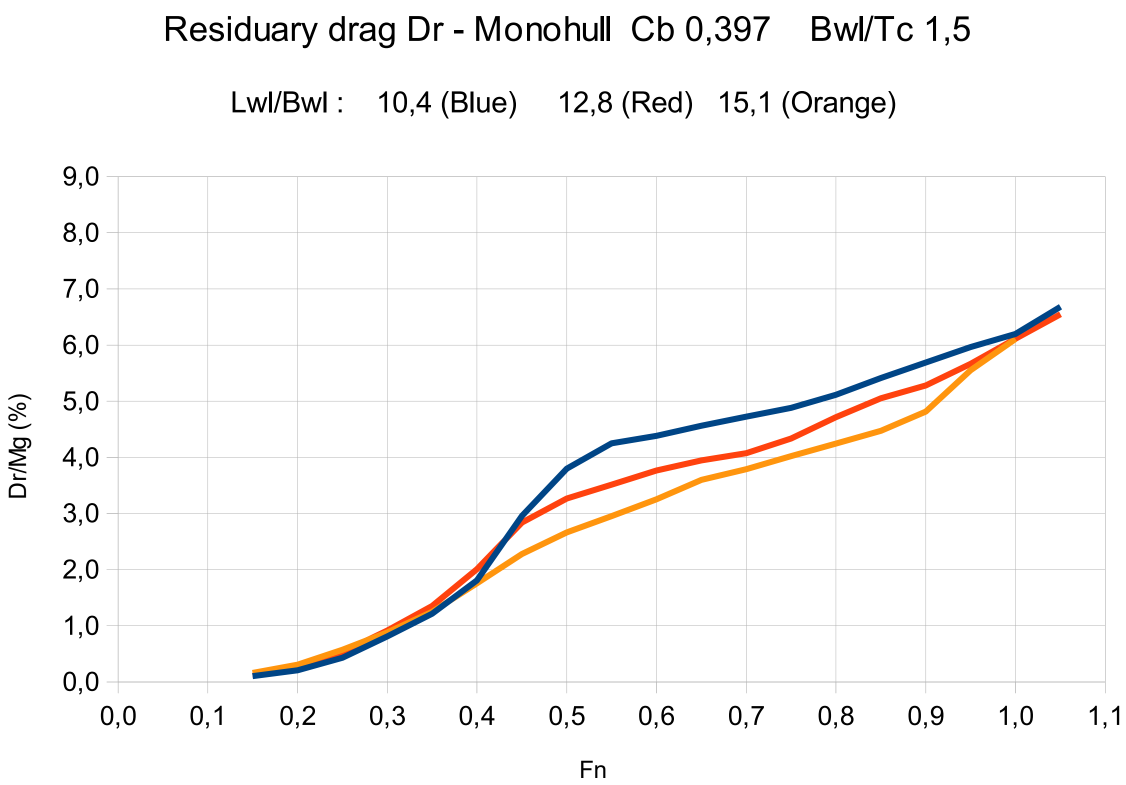


>>> One can see how different the curves appear and the conclusions that can be drawn

Results with models 4c, 5c , 6c , sharing Cb = 0,397 and **Bwl/Tc = 2,5** :
(built from Fig. 32b, 32c and 32d of the paper)



Results with models 4a, 5a , 6a , sharing Cb = 0,397 and **Bwl/Tc = 1,5** :
(built from Fig. 32b, 32c and 32d of the paper)



Comments on these 3 curves for the 3 different Bwl/Tc :

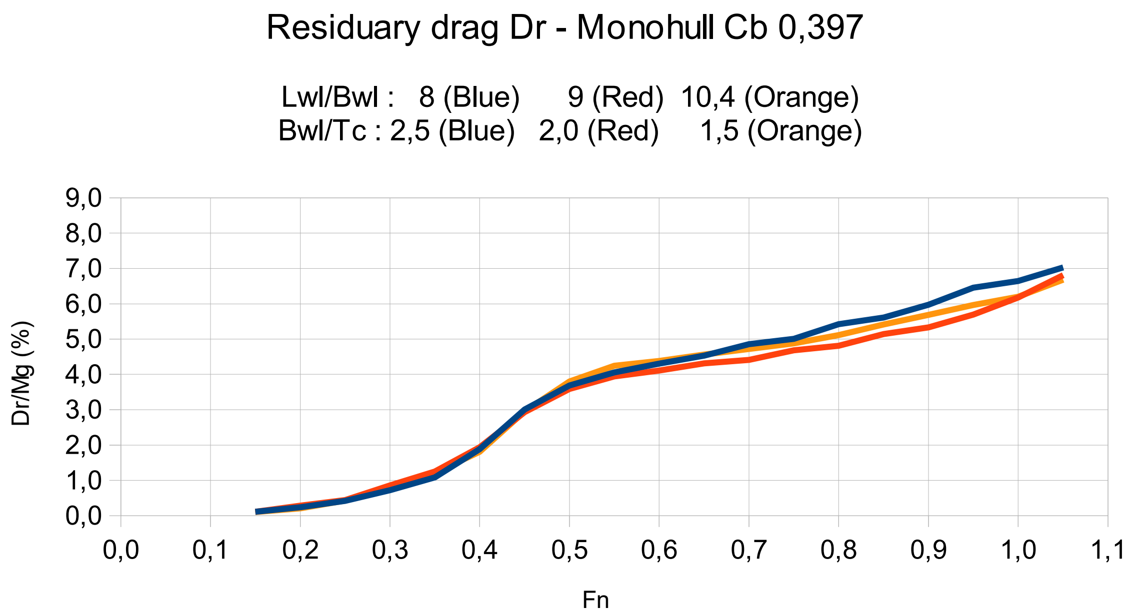
- For Froude < 0,15, Dr is negligeable
- For Froude 0,15 to 0,40 : no clear difference due to the ratio Lwl/Bwl
- For Froude 0,40 to 0,95 : there is a significant graduation of the drag force in the expected order, i.e. the residuary drag decreases when the Lwl/Bwl ratio increases.
- At Froude 0,95 to 1,05 the curves tends to converge to the same drag values.

>>> it seems relevant to aim a Lwl/Bwl > 9 at least to moderate the residuary drag component, an usual recommendation for catamaran hulls.

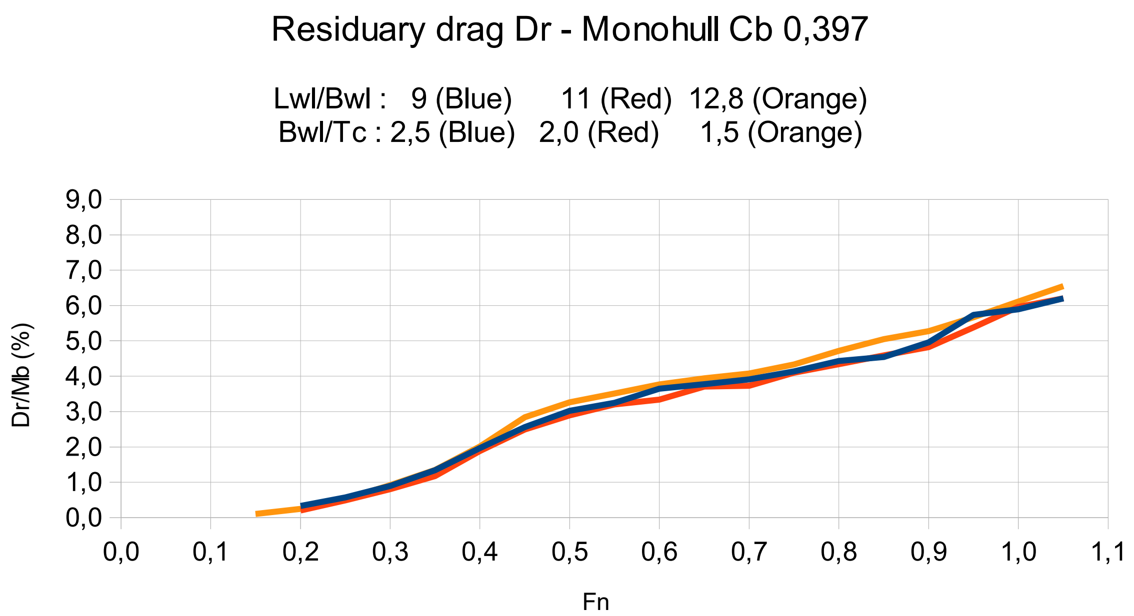
Bwl/Tc influence

To show the influence of Bwl/Tc, the paper propose the Fig. 32b, 32c and 32d but they are not at same Lwl/Bwl which prevent to draw consistent conclusions on the Bwl/Tc influence >>>

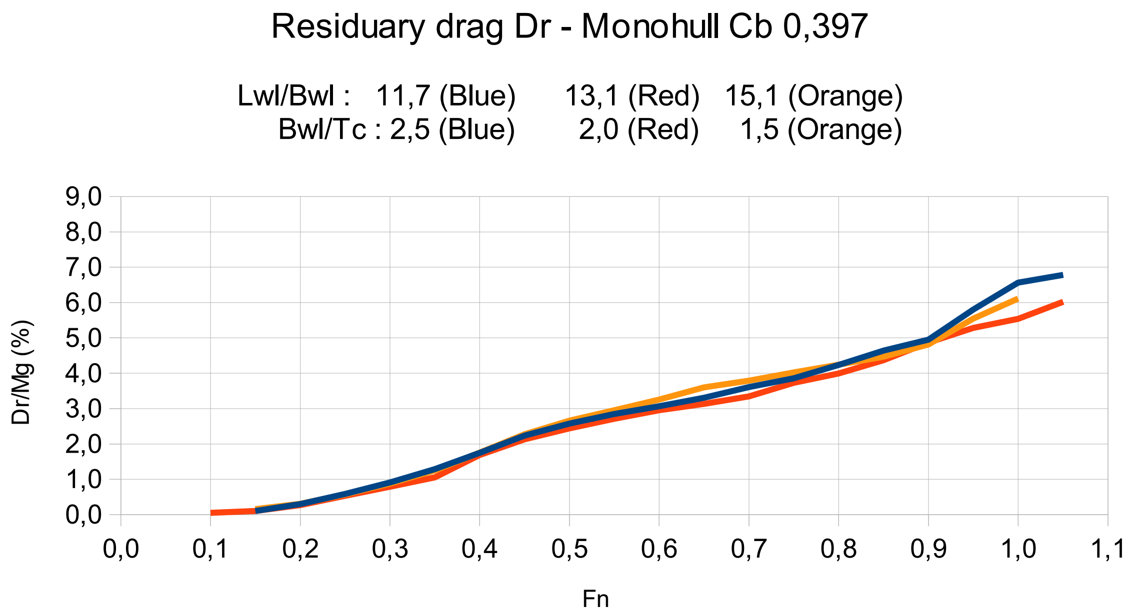
Converted results directly from Fig. 32b with models 4a, 4b , 4c :



Converted results directly from Fig. 32c with models 5a, 5b , 5c :



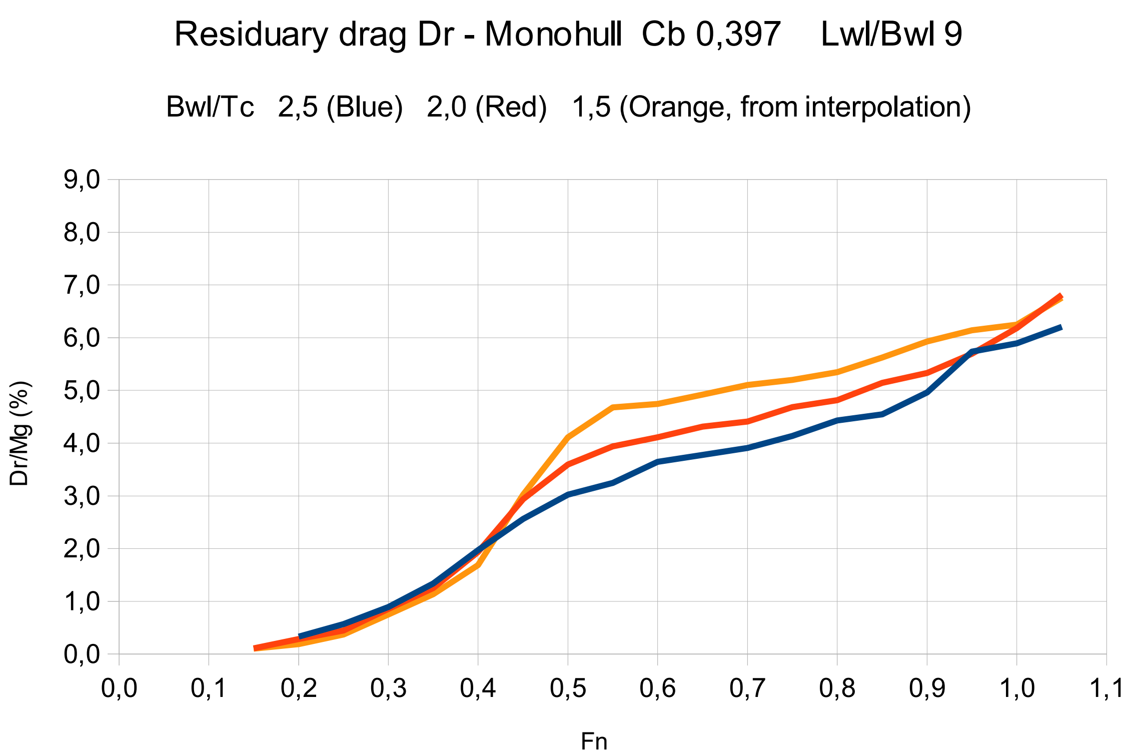
Converted results directly from Fig. 32c with models 6a, 6b , 6c :



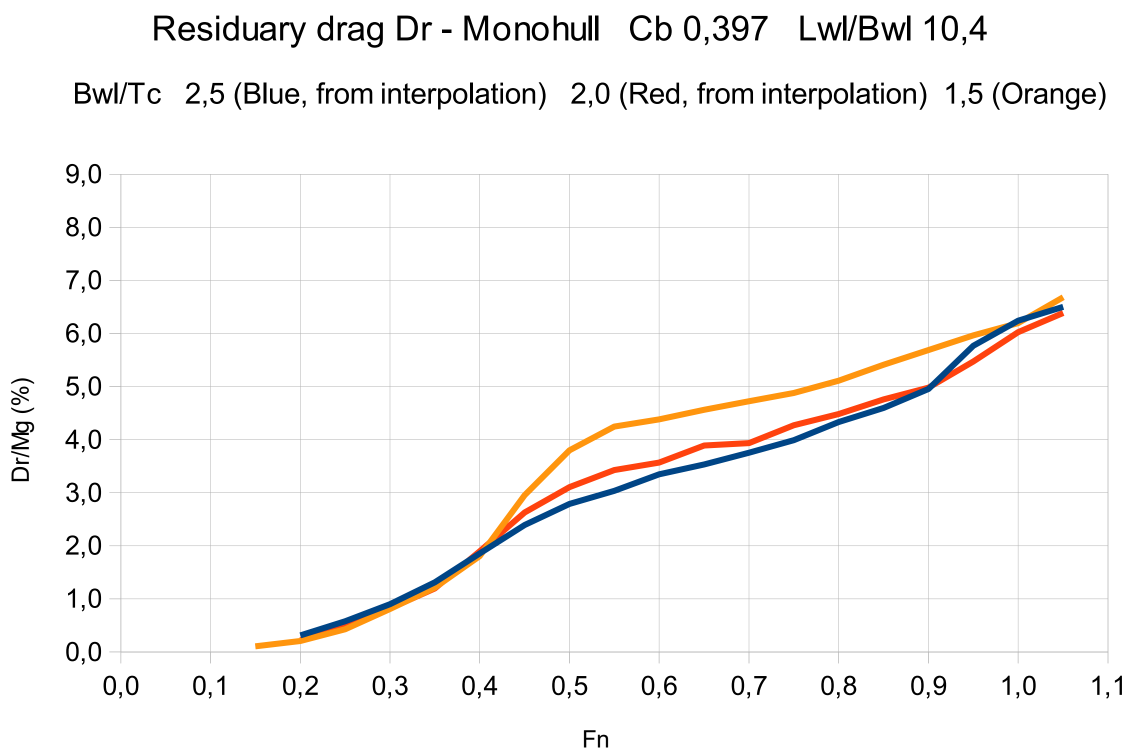
Comments : no apparent differrence but as expected, we cannot draw conclusions on Bwl/tc influence from these figures as the Lwl/Bwl are also variable : e.g. on the figure above how to compare Bwl/Tc 2,5 and 1,5 when associated with Lwl/Bwl with respectively 11,7 and 15,1 ?

>>> So another presentation of the same results is necessary with constant Lwl/Bwl, and it is proposed through some linear interpolation computed from the available data, as close as possible to the real results in order to not loose in consistence and accuracy. That leads to the figures here below, done with 5 different Lwl/Bwl to be sure of the method stability

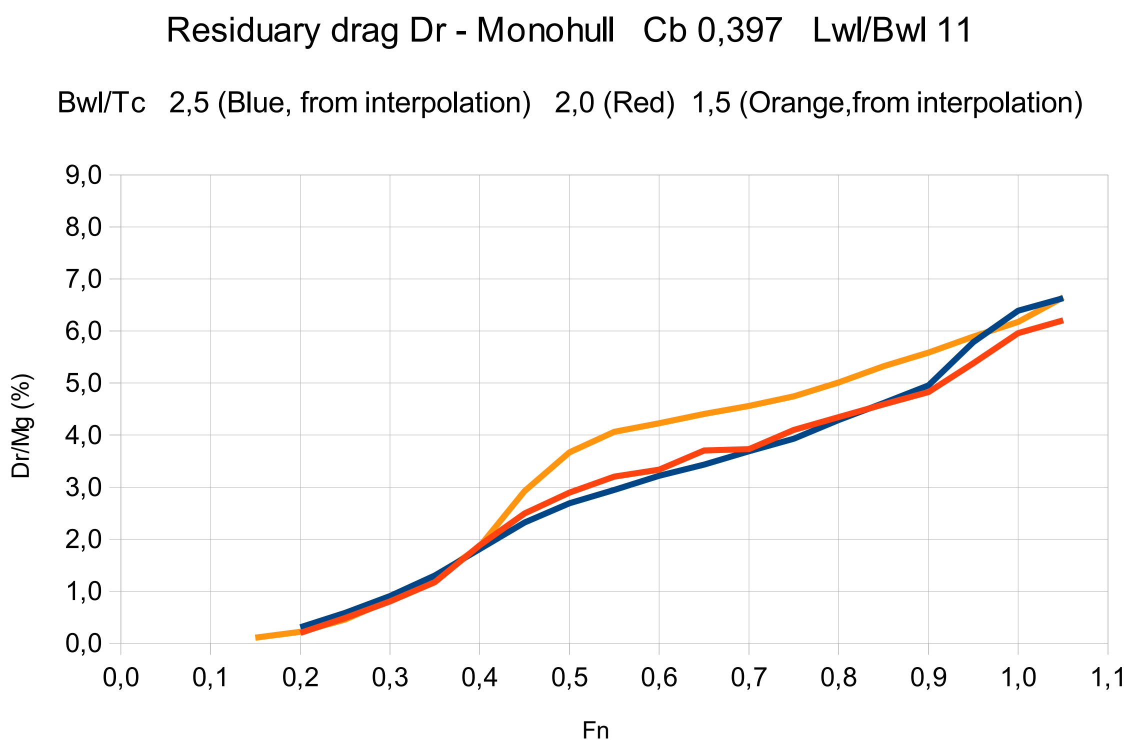
Bwl/Tc influence at Lwl/Bwl = 9



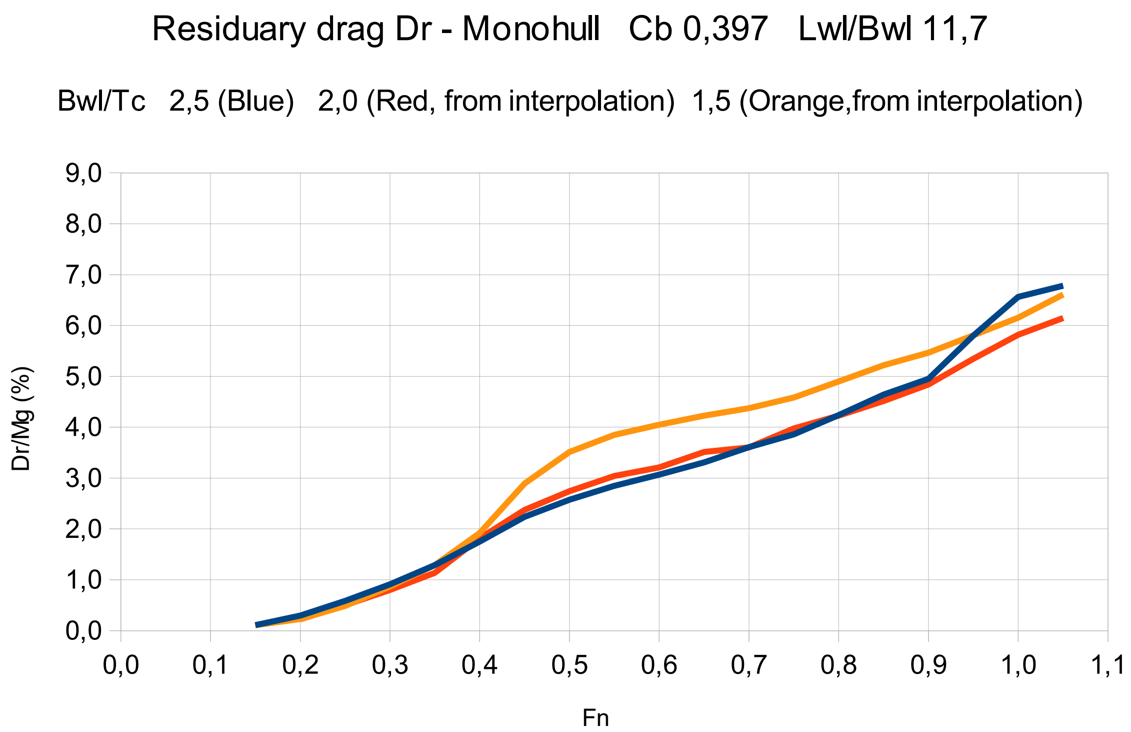
Bwl/Tc influence at Lwl/Bwl = 10,4



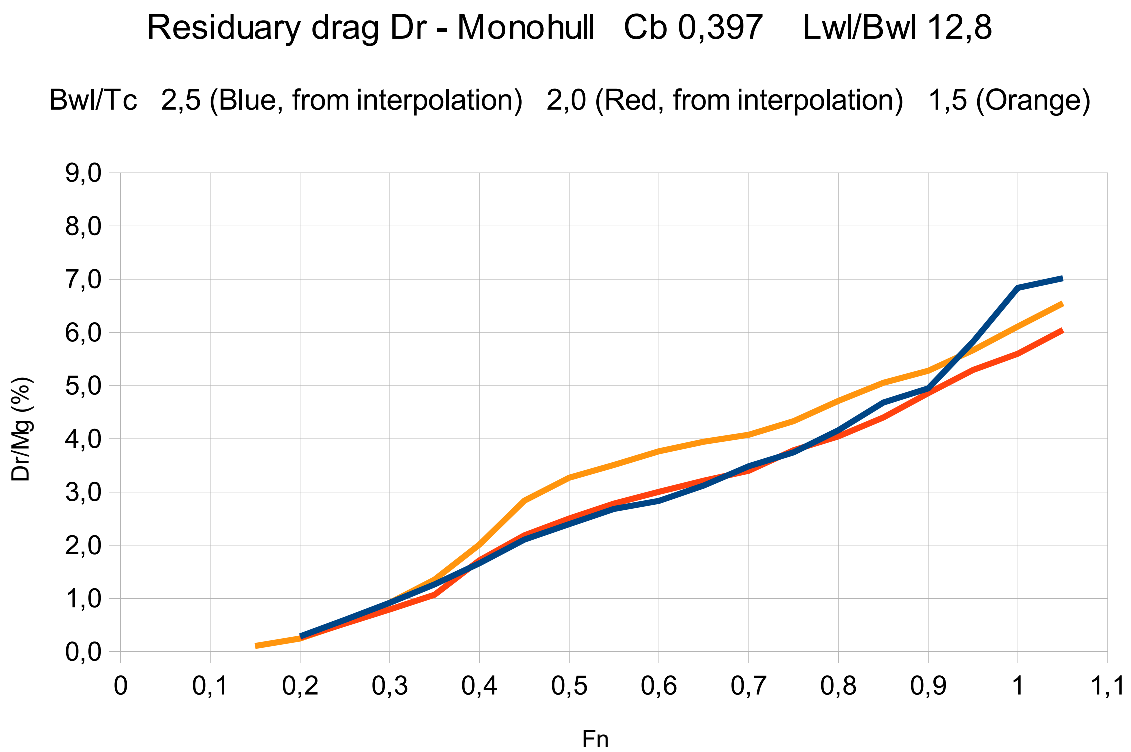
Bwl/Tc influence at Lwl/Bwl = 11



Bwl/Tc influence at Lwl/Bwl = 11,7



Bwl/Tc influence at Lwl/Bwl = 12,8



Comments :

- These curves better show the influence of the Bwl/Tc influence, and with consistence : the trends show similarities for each of the 5 cases.

- The conclusions for Froude < 0,4 and for 0,95 to 1,05 are the same as for the previous comments on Lwl/Bwl influence :
  - For Froude < 0,15, Dr is negligeable
  - For Froude 0,15 to 0,40 : no significant difference
  - At Froude 0,95 to 1,05 the curves tends to converge to the same drag values.
- For Froude 0,40 to 0,95 : the graduation of the drag force shows that Bwl/Tc at 1,5 gives significantly more residuary drag. The drag difference for Bwl/Tc between 2,0 and 2,5 is smaller, except at Lwl/Bwl = 9 where the Bwl/Tc = 2,5 shows a slight advantage.
  >>> in this range of Froude (0,4 to 0,95), a correction factor seems relevant to take into account when Bwl/Tc ≠ 2