Boats testing in indoor tank

Four singles of different brands were recently tested in an indoor tank (600m long, 16m wide, 7m depth, constant temperature +16°C) at Krylov State Research Centre in Saint-Petersburg, Russia (http://krylov-center.ru/eng/). The boats were:

- Empacher (X10 A115, 2013, 85-100kg);
- Filippi (F14, 2011, 80-95kg);
- Wintech (Medalist, 2014, 75-85kg);
- Nowing (local boat builder, 2014, 75-85kg).

The purposes of the test were to define the drag factors **DF** of each boat using two methods: rowing and towing, and then to find their correlation.

Rowing in the indoor tank

Methods. During the rowing part, a rower of National level (91kg body weight) performed four 200m pieces with increasing stroke rate in each boat equipped with BioRow™ system. Average boat speed **V** was measured by means of timing of the last 150m at every piece. Handle force, oar angles and boat acceleration were measured at each oar at 25Hz, then rowing power **P** and blade efficiency **Ebl** (RBN 2007/12, 2012/06) were derived. Propulsive power **Pprop** was calculated:

$$Prop = P * Ebl \qquad (1)$$

Rowing drag factor was derived in two ways:

1. Gross rowing drag factor DF_{R1} was defined as a ratio to the cube of average speed **Vav** over the cycle:

$$DF_{R1} = Prop / Vav^3 \qquad (2)$$

2. Net rowing drag factor DF_{R2} was defined as a ratio to the average of cubes of the instantaneous boat velocity V_i derived from acceleration during the stroke cycle:

$$DF_{R2} = Prop / average(V_i^3) \qquad (3)$$

The difference between them means that the gross factor includes the excessive energy lost in variation of the boat speed during the stroke cycle, but the net factor doesn't.

Towing measurements

Towing measurements were completely independent from rowing, and all sensors and data processing were provided by the Research Centre. A boat was mounted under a trolley-bridge (56t mass, 4*200kW engines) running on rails on top of the tank. Each boat was tested at two loads 80kg and 90kg, and at two speeds 4 and 5m/s, with three 500m runs at each load-speed combination – 12 runs for each of 4 boats. The drag resistance force R_T, surfacing and trim were measured at 10Hz and averaged over the period of constant speed **V** 20-30s.

Towing drag factor DF_T was derived for every run:

$$DF_T = R_T / V^2 \qquad (4)$$

Results. In rowing measurements, it was found that the highest average rowing power was shown in Fillipi (Table 6 in the Appendix 1 below), **Ebl** and propulsive power (Tables 7-8) were higher in Empacher, but both gross (Table 9) and net drag factors were the lowest in WinTech boat.

| DF_{R2}	Wintech	Empacher	Filippi	Nowing	Average
1	3.079	3.084	3.139	3.144	**3.111**
2	3.000	2.954	3.169	3.262	**3.096**
3	3.007	3.041	3.227	3.016	**3.073**
4	2.936	3.007	3.145	3.172	**3.065**
Aver.	**3.006**	**3.021**	**3.170**	**3.149**	**3.086**

In towing, the drag resistance force (average of three runs, see Appendix 2) was the lowest in WinTech boat:

Table 2. Drag resistance force R_T at towing (N)				
Speed-Load	**WinTech**	**Empacher**	**Filippi**	**Nowing**
4m/c-80kg	48.194	48.622	48.830	48.797
4m/s-90kg	50.779	50.944	51.218	51.579
5m/s-80kg	73.814	74.614	74.351	74.603
5m/s-90kg	77.604	77.998	78.798	78.733
Average	**62.598**	**63.045**	**63.299**	**63.428**

The towing drag factor DF_T has been found the lowest in WinTech boat as well:

DF_T	**WinTech**	**Empacher**	**Filippi**	**Nowing**
4m/c-80kg	2.990	3.025	3.038	3.037
5m/s-80kg	2.929	2.975	2.972	2.974
4m/s-90kg	3.158	3.176	3.191	3.211
5m/s-90kg	3.090	3.112	3.146	3.138
Average	**3.042**	**3.072**	**3.087**	**3.090**

Comparing the drag factors, it was found that all towing factors were lower at higher speed 5m/s (by 5.3% on average). Rowing drag factors also significantly decreased at higher speed in WinTech and Nowing boats, but less in Empacher and Filippi.
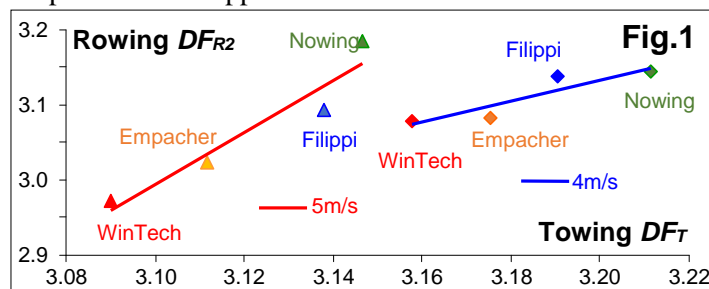
Fig.1

Good correlations were found between rowing and towing DFs (Fig.1, r=0.91 at 4m/s and r=0.95 at 5m/s), which means **the measurements were reliable**. The average rowing net DF_{R2} was 1.6% lower than towing DF_T at similar load 90kg, but the reason is not clear yet.

Summary of the results of rowing and towing measurements: **WinTech boat had the lowest average drag factor**. The given Empacher had 0.78% higher **DF**, Nowing – 2.35% higher and Filippi – 2.95% higher. At the propulsive power 400W (rowing power 508W and time at 2km race about 6:35), above differences in the drag factor would give **the advantage to WinTech boat 1.02s over Empacher, 3.06s over Nowing and 3.84s over tested Filippi.**

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Table 4. Stroke Rate (1/min)

Sample N	Wintech	Empacher	Filippi	Nowing	Average
1	22.0	22.5	22.9	22.8	**22.6**
2	26.4	26.9	26.6	25.7	**26.4**
3	32.1	33.1	31.8	31.9	**32.2**
4	44.1	44.1	39.7	42.5	**42.6**
Average	**31.2**	**31.6**	**30.3**	**30.7**	**30.9**

Table 5. Boat Speed (m/s)

Sample N	Wintech	Empacher	Filippi	Nowing	Average
1	4.03	4.01	4.07	4.06	**4.04**
2	4.34	4.38	4.40	4.17	**4.32**
3	4.68	4.70	4.69	4.74	**4.70**
4	5.55	5.53	5.20	5.20	**5.37**
Average	**4.65**	**4.65**	**4.59**	**4.54**	**4.61**

Table 6. Rowing Power (W)

Sample N	Wintech	Empacher	Filippi	Nowing	Average
1	278.0	260.9	306.9	284.2	**282.5**
2	333.6	327.6	361.8	325.6	**337.2**
3	421.0	427.8	459.3	422.7	**432.7**
4	690.0	688.2	610.1	621.9	**652.6**
Average	**430.7**	**426.1**	**434.5**	**413.6**	**426.2**

Table 7. Blade Efficiency.

Sample N	Wintech	Empacher	Filippi	Nowing	Average
1	76.4%	78.8%	76.2%	78.6%	**77.5%**
2	77.9%	80.8%	79.3%	77.5%	**78.9%**
3	78.3%	79.4%	77.9%	81.4%	**79.3%**
4	79.1%	80.5%	78.9%	78.2%	**79.2%**
Average	**77.9%**	**79.9%**	**78.1%**	**78.9%**	**78.7%**

Table 8. Propulsive power (W)

Sample N	Wintech	Empacher	Filippi	Nowing	Average
1	212.4	205.7	233.7	223.3	**218.9**
2	259.8	264.5	286.9	252.3	**265.9**
3	329.8	339.6	358.0	344.1	**343.0**
4	545.8	554.3	481.2	486.3	**516.7**
Average	**335.6**	**340.4**	**339.2**	**326.4**	**335.4**

Table 9. Gross Drag Factor DF_{R1}

Sample N	Wintech	Empacher	Filippi	Nowing	Average
1	3.256	3.201	3.480	3.329	**3.321**
2	3.189	3.141	3.370	3.471	**3.291**
3	3.223	3.275	3.469	3.229	**3.300**
4	3.190	3.280	3.420	3.464	**3.337**
Average	**3.344**	**3.377**	**3.511**	**3.479**	**3.427**

Table 10. Towing results of Empacher boat

Run N	Towing speed V (m/s)	Drag resistance R_T (N)	Surfacing DT, mm	Trim y (deg)
	Load 80 kg			
1	4.009	48.731	-3.750	0.147
2	4.009	48.567	-4.687	0.145
3	4.009	48.567	-4.117	0.149
	Average	**48.622**	**-4.185**	**0.147**
1	5.003	74.789	-4.687	0.246
2	5.005	74.461	-5.666	0.251
3	5.016	74.592	-5.951	0.228
	Average	**74.614**	**-5.435**	**0.242**
	Load 90 kg			
1	4.002	50.900	-5.543	0.149
2	4.007	50.867	-4.850	0.151
3	4.007	51.064	-4.443	0.151
	Average	**50.944**	**-4.945**	**0.150**
1	5.000	77.911	-6.032	0.246
2	5.006	78.010	-6.155	0.246
3	5.014	78.075	-5.177	0.251
	Average	**77.998**	**-5.788**	**0.248**

Table 11. Towing results of Filippi boat

Run N	Towing speed V (m/s)	Drag resistance R_T (N)	Surfacing DT, mm	Trim y (deg)
	Load 80 kg			
1	4.007	48.468	-3.994	0.158
2	4.010	48.961	-4.198	0.165
3	4.010	49.060	-3.750	0.156
	Average	**48.830**	**-3.981**	**0.160**
1	5.000	74.198	-4.891	0.255
2	5.001	74.757	-7.948	0.246
3	5.003	74.099	-2.527	0.239
	Average	**74.351**	**-5.122**	**0.247**
	Load 90 kg			
1	4.004	51.722	-7.826	0.174
2	4.008	50.802	-0.571	0.151
3	4.008	51.130	-1.101	0.154
	Average	**51.218**		
1	5.003	78.404	-4.647	0.280
2	5.004	78.733	-9.416	0.282
3	5.006	79.258	-7.092	0.316
	Average	**78.798**	**-7.052**	**0.293**

Table 12. Towing results of WinTech boat

Run N	Towing speed V (m/s)	Drag resistance R_T (N)	Surfacing DT, mm	Trim y (deg)
	Load 80 kg			
1	4.008	48.041	-4.117	0.201
2	4.018	48.501	-5.910	0.199
3	4.018	48.041	-6.481	0.181
	Average	**48.194**	**-5.503**	**0.194**
1	5.012	73.672	-5.503	0.285
2	5.022	73.672	-6.196	0.298
3	5.025	74.099	-6.399	0.296
	Average	**73.814**	**-6.033**	**0.293**
	Load 90 kg			
1	4.008	50.604	-4.728	0.208
2	4.008	50.834	-7.296	0.206
3	4.014	50.900	-6.318	0.201
	Average	**50.779**		
1	5.005	77.418	-6.155	0.318
2	5.010	77.681	-7.744	0.318
3	5.019	77.714	-5.992	0.321
	Average	**77.604**	**-6.630**	**0.319**

Table 13. Towing results of Nowing boat

Run N	Towing speed V (m/s)	Drag resistance R_T (N)	Surfacing DT, mm	Trim y (deg)
	Load 80 kg			
1	4.006	48.863	-5.217	0.183
2	4.006	48.863	-3.668	0.172
3	4.014	48.666	-5.421	0.183
	Average	**48.797**	**-4.769**	**0.179**
1	5.006	74.987	-6.807	0.287
2	5.008	74.789	-4.239	0.305
3	5.011	74.034	-5.992	0.287
	Average	**74.603**	**-5.679**	**0.293**
	Load 90 kg			
1	4.004	51.459	-7.296	0.201
2	4.009	51.623	-4.810	0.203
3	4.010	51.656	-6.073	0.196
	Average	**51.579**		
1	5.007	78.470	-5.462	0.314
2	5.007	78.963	-6.888	0.318
3	5.013	78.765	-6.644	0.316
	Average	**78.733**	**-6.331**	**0.316**