# TOMS EFFECT AND WALL ROUGHNESS AS A MEANS TO CONTROL TURBULENT BOUNDARY LAYER IN SEA TRIAL SIMULATION

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*Abstract* We report the experimental data on novel approach to provide the hydrodynamic similarity between sea trials and towing tanks experiments and to reproduce the full-scale movement of ships and underwater vehicles at high Reynolds numbers ( $\mathrm{Re} \sim 10^9$ ) in towing tanks (at $\mathrm{Re} \sim 10^6$ ) in terms of some hydrodynamic factors by means of polymer drag reduction.

It is obviously important in ship design to ensure the propulsion, tactical and technoeconomic characteristics. For that, it is necessary to know with reasonable accuracy the resistance of water to movement under sea trial conditions and the characteristics of flow near hull, including ones in boundary layer and viscous wakes. Such parameters are determined on the basis of model experiments in towing tanks. The complete dynamic similarity in turbulent flow around smooth surfaces of a ship and its model is achieved while satisfying the two criteria of similarity: Froude $\mathrm{Fr}$ and Reynolds $\mathrm{Re}$ numbers. Traditionally, in a towing tank only the equality of Froude numbers can be realized so the traditional approach is related to the methods of partial modelling when the hypothesis of independence of the wave and viscous resistances is taken. The first one is found directly from the results of model tests and the second one as well as the charactericties of viscous flow (boundary layer and wake) is corrected using the semi empirical boundary layer theory, i.e. the problem of scale effects occurs.

A well-known example of using polymer additives is the control of turbulent boundary layers. It also concerns the problems for movement of surface and underwater vehicles in fluid and, in particular, energy consumption decrease because of reducing hydrodynamic friction of hull by injection of their solution on ship shell. In present work, dilute solutions of high molecular weight polymers are used quite differently – for simulating the flow around vehicles corresponding to full-scale Reynolds numbers ( $\mathrm{Re} \sim 10^9$ ) in towing tanks ( at $\mathrm{Re} \sim 10^6$ ), i.e. for creating the hydrodynamic similarity between sea trials and model experiments. The selected results of experimental substantiation are, e.g., in [1]. In this paper, such experimental study is extended and more detailed. We give comparable analysis the data on velocity profiles and local skin-friction coefficient for the pipe flow facility [1], towing tanks [2] and sea trials. So, approximately 30% drag reduction corresponds to Reynolds numbers that more on the order of magnitude (Fig. 1). Surface roughness leads to higher skin friction in contrast the action of polymer additives. Varying these experimental conditions (Fig. 2) allows simulating the sea trials under lower Reynolds numbers in towing tanks with the desired characteristics in terms of some hydrodynamic factors. We discuss different variants of creating a friction stress distribution equidistant to distribution along ship length in pure water. We give recommendations for practical usage of the approach in towing tanks with discrete injection of polymer solution into boundary layer of vehicle models.

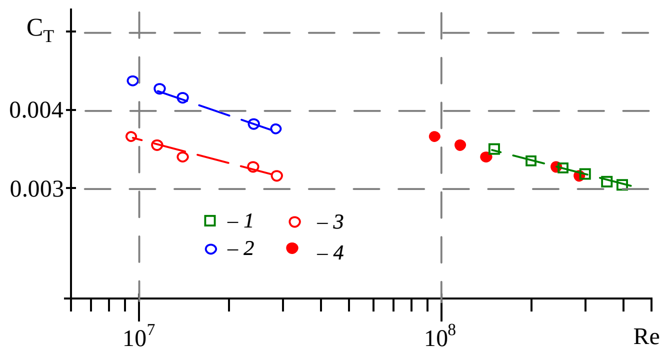


**Figure 1.** Dependence of total resistance coefficient on $\mathrm{Re}$: 1 – sea trials, underwater vehicle; 2 – towing tank, UV model; 3 – towing tank, UV model, polymer drag reduction ~ 30%; 4 – shift in Re on the order of magnitude for the case 3.

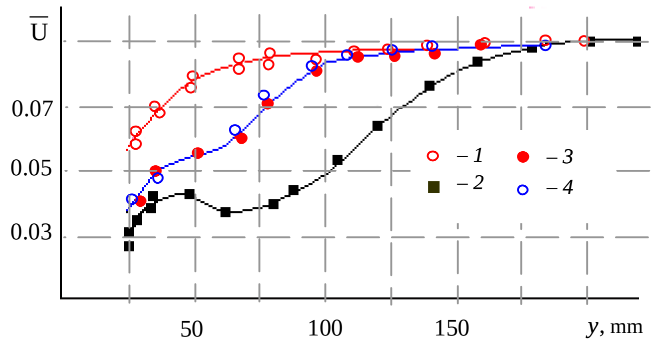


**Figure 2.** Velocity scaled on ship model velocity around the propeller disc: 1 – smooth surface, WSR-301 solution, concentration ~ $6{\cdot}10^{-4}$ %; 2 – rough surface, water; 3 – rough surface, WSR-301 solution, concentration ~ $4.5{\cdot}10^{-4}$ %; 4 – smooth surface, water.

## References

[1] I. Elyukhina, and A. Khomyakov. Simulating the full-scale sea trials in the towing tanks using polymer drag reduction. *Journal of Physics: Conference Series* **318**: 092013, 2011.
[2] http://www.ksri.ru.