# Smart Control of Gas-Liquid Two-Phase Flows for Turbulent Frictional Drag Reduction of Marine Vessels

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Global CO2 emission by marine transports will increase triple 30 years later. Beside it, IMO declared the emission reducing to half by 2050, inferring jumping up required in power efficiency to six times. Is it realistic? We focus on a large technical margin in reducing frictional drag acting on ship hull, which occupies more than 70% in case of large vessels. Our technique is to use air bubbles as lubricator that is designed by three unique flow control schemes combined, which has been successfully applied for several large vessels in the last decade.

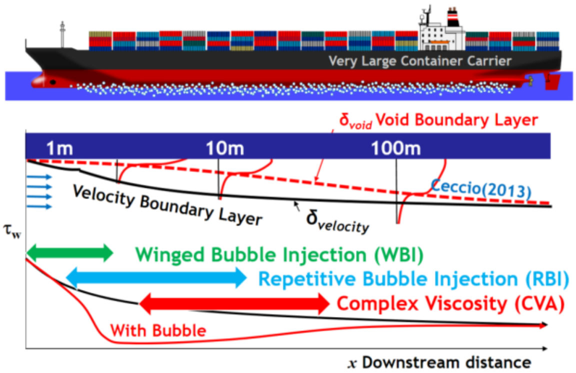


Fig. 1. How to reduce frictional drag of a ship

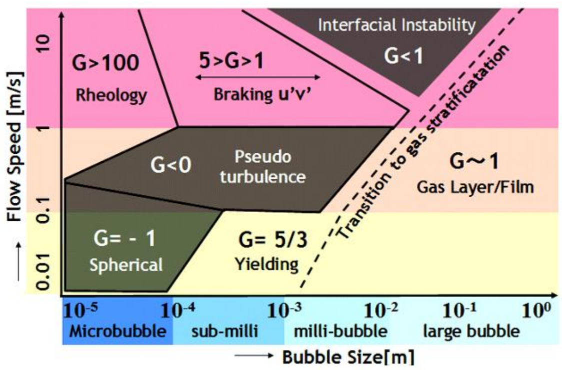


Fig. 2 Mechanism transition diagram of bubble drag reduction

Our concept of smart control originates from the experience how bubble-turbulence interaction was hardly controlled beneath ship hull. Thus, we defined three different types of bubble injection control as shown in Fig. 1. Winged bubble injection (WBI) realizes naturally ventilated bubble injection at ship bottom without installing air compressors/blowers since a hydrofoil introduces air into water around it due to pressure lowering with Bernoulli's effect. Thermal energy loss gets minimized because of pressure decreasing path applied for bubble injection. The principle is advantageous also for fluctuation of relative seawater speed that often increases for large-inertia vessels. Repetitive bubble injection (RBI) is a flow control for bubbles in time domain, which maximizes the downstream drag reduction performance. The technique came from our experimental observation that void wave that naturally stands up downstream always have positive correlation to average drag reduction. With RBI, void fraction of less than 5% in boundary layer can reduce drag. CVA is abbreviation of complex viscosity application, which expects drag reduction by turbulent eddy modulation via complex viscosity nature of bubbly liquids. With CVA, drag reduction can be amplified much effective in comparison with void-drag equilibrium in the inertial regime. These ideas were born from the diagram shown in Fig. 2.

Fig. 3 shows pictures of the vessels to which our technique has been applied. In the worst case we obtained 6% of net energy saving, while the best case was 14% as 32 hydrofoil type of air bubble injector was installed on a coaster (d).


Fig. 3 From fishing boat to very large container carrier

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