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Mechanisms and Factors Affecting Microbubble Drag Reduction in Ship

Issac Thomas[1], Rejith G Krishnan[1], Saloop T S[1], Vishnu M Mohan[1]
[1](Department of mechanical engineering, College of engineering Munnar, India)

Abstract: *Drag is a mechanical force generated by a solid object moving through a fluid. For drag to be generated, the solid body must be in contact with the fluid. Drag is generated by the difference in velocity between the solid object and the fluid. Drag acts in the direction opposite to the direction of motion of the body. Microbubbles is a drag reduction device that reduces skin friction of a solid body moving in water by injecting small bubbles into the turbulent boundary layer developing on the solid body. Its application is confined to the ships, especially large ships. Ships such as tankers play a major role in marine transportation. They are very large and move very slowly. They are especially suited to microbubbles application. With the development of the Microbubbles technology almost 20-80% drag reduction is possible. In this paper we study about different drag reduction mechanisms and factor affecting net power saving in large ship.*
Keywords*: Drag, Microbubbles, Net power saving, Skin friction*

I. Introduction

Drag is a mechanical force generated by a solid object moving through a fluid. For drag to be generated, the solid body must be in contact with the fluid. If there is no fluid, there is no drag. Drag is generated by the difference in velocity between the solid object and the fluid. There must be motion between the object and the fluid. If there is no motion, there is no drag. Drag acts in the direction opposite to the direction of motion of the body. A body moving through a fluid experiences a drag force, which is usually divided into two components: frictional drag (sometimes called viscous drag) and pressure drag (sometimes called form drag or profile drag).

Frictional drag comes from friction between the fluid and the surfaces over which it is flowing. This friction is associated with the development of boundary layers. Pressure drag comes from the eddying motions that are set up in the fluid by the passage of the body. This drag is associated with the formation of a wake, which can be readily seen behind a passing boat. When the drag is dominated by viscous drag, we say the body is streamlined, and when it is dominated by pressure drag, we say the body is bluff. Whether the flow is viscous-drag dominated or pressure-drag dominated both depends entirely on the shape of the body. A streamlined body looks like a fish, or an airfoil at small angles of attack, whereas a bluff body looks like a brick, a cylinder, or airfoil at large angles of attack. For streamlined bodies, frictional drag is the dominant source of air resistance. For a bluff body, the dominant source of drag is pressure drag. For a given frontal area and velocity, a streamlined body will always have a lower resistance than a bluff body.

Reduction in ship resistance has been one of the crucial parts of R&D by naval architects over the last few decades. The drag reduction technology can be extensively applied to many industrial fields such as hydraulic machines, oil well operations, pumping systems, pipe line systems, oil line, automobiles, aircrafts, submarines, ships, etc. It was reported that the fluid frictional drag accounts for as much as 60-70% of the total drag for cargo ship, and about 80% of that for a tanker, thus there is a strong demand for the reduction in the fluid frictional drag, especially in the marine transportation business.

Currently, in order to reduce the skin frictional drag of the fluid, many drag-reducing techniques have been developed, including microgrooves, coatings, addictive injections (such as polymer, surfactant and micro-bubbles), active blowing or suction, electromagnetic excitation and an acoustic excitation. Of many drag reducing techniques, the drag reduction technology by micro-bubble is paid more attentions due to obvious advantages such as environmental friendships, easy operations, low costs and high saving of energy. It was reported that the drag reduction by micro-bubbles is able to achieve a drag reduction rate as high as 80% which points out that even a relatively small reduction of the total drag can result in a substantial fuel saving for both commercial and naval ships for shortened transit time.

II. Skin Friction

It is defined as friction at the surface of a solid and a fluid in relative motion. Skin friction drag is a component of parasitic drag that occurs depending on the type of flow over the body (laminar or turbulent). Just like any other form of drag, the coefficient of skin friction drag is calculated with equations and measurements depending on the flow and then added to coefficients of other forms of drag to calculate total drag.

The calculation of skin friction drag is heavily based on the Reynolds number of the body. For reference, Reynolds number (Re) is calculated with;

$$Re = \frac{VL}{\upsilon} \tag{1}$$

Where:
V is the velocity of the flow
L is the length of the body that the flow travels across
υ is the kinematic viscosity of the fluid

Now that Reynolds number is known, the coefficient of skin friction drag can be calculated.

Laminar flow;

$$C_f = \frac{1.328}{\sqrt{Re}} \tag{2}$$

Also known as the Blassius Friction law

Turbulent flow;

$$C_f = \frac{0.455}{\log(Re)^{2.58}} \tag{3}$$

Also known as the Schlichting empirical formula

The skin friction coefficient, C_f, is defined by;

$$C_f = \frac{\tau_w}{\frac{1}{2}\rho U_\infty^2} \tag{4}$$

Where τ_w is the local wall shear stress, ρ is the fluid density and U_∞ is the free-stream velocity (usually taken outside of the boundary layer or at the inlet)

III. Micro bubble

Micro bubbles are bubbles smaller than one millimeter in diameter, but larger than one micrometer. Micro bubbles is a drag reduction device that reduces skin friction of a solid body moving in water by injecting small bubbles into the turbulent boundary layer developing on the solid body. But at the same time the energy needed for injecting bubbles at the hull bottom is not small because large ships have large water depth against which the bubbles have to be injected. Therefore it is important to reduce the amount of injected air in order to put micro bubbles into practical use. Ships such as tankers play a major role in marine transportation. They are very large and move very slowly. They are especially suited to micro bubbles application. One reason that they are suited is that their skin friction drag component occupies about 80% of the total drag. The drag of a ship that moves on the water consists of two components, i.e., wave-making drag and skin frictional drag.

The wave-making drag component of such a ship is very small because they move very slowly. Another reason that they are suited is in their shape. Their shape is like a box, except for bow and stern regions. They have a wide flat bottom, and the bubbles injected at the bottom near the bow stay close to the hull bottom by buoyancy while they are carried by flow all the way to the stern. Thus the injected bubbles can cover the whole hull bottom efficiently.

IV. Micro-Bubble Characteristics

Over the years, many studies have been done in order to reduce skin friction. Usage of micro bubbles is the most promising way as a drag reduction, therefore the characteristics of micro bubbles that would give an optimum impact on skin friction reduction should be figured out.

4.1 Bubble size

The bubble size is one of the major factors influencing frictional resistance. Bubbles of a few millimeters in diameter can increase the frictional resistance. It is happened possibly because of the turbulence generated by the bubble wake. When micro-bubbles are ejected through a hole or porous plate, the bubble size is decided by the main flow velocity and the air flow rate, and not by the size of the hole.

The research works have pointed out that the bubble size is a critical factor; the drag reduction can be attained only when the bubble diameter is less than about 1 mm; and the drag reduction rate is generally higher when the bubble diameter is smaller.

The researchers also indicated that the size of the bubbles as an alternative important parameter for drag reduction. The diameter of the bubbles affects their trajectories and consequently, their concentration and location in the boundary layer.

4.2 Location of micro-bubble injection

Micro bubble injection location is one of the important parameters that need to be considered in reviewing the effectiveness of skin friction reduction by micro bubbles. Researchers have established an experiment on high speed vessel model to test the efficiency of micro bubbles on resistance reduction. The micro bubble injector position is showed in Figure 1. The results showed that the location of micro bubbles injection behind the mid ship (position 3) is the best location to achieve the most effective drag reduction and has caused about 6-9% of drag reduction. Below are the descriptions of injection position made by them. Position 1 is at front of mid ship, position 2 at mid ship and position 3 at aft of mid ship.

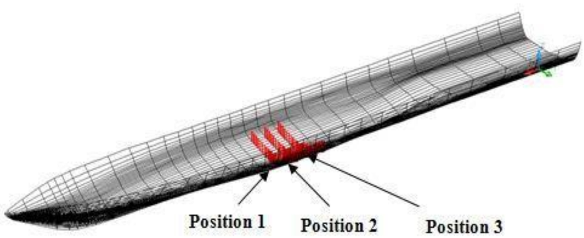

Figure 1 Lines plan and micro bubble injector position

These positions were investigated and compared regarding the influence of micro bubble injection.

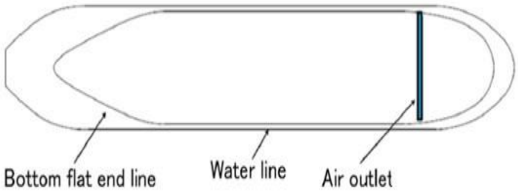

Figure 2 Location of air outlet viewed from the bottom

The location of micro-bubbles injection behind the mid-ship section is the best location to get effective drag reduction. A possible explanation of the phenomenon is the reduction of turbulence intensity caused by micro bubble which increases the effective viscosity of the water- bubble mixture.

V. Discussions on Skin Friction Reduction Mechanisms of Micro bubbles

Some possible mechanisms for skin friction reductions effects are discussed below

5.1. Mechanism 1: Density effect

Perhaps the most obvious among the possible mechanisms for skin friction reduction by micro bubbles, is the density effect. When air bubbles are present, the density of mixture decreases, and according to the shear stress representation;

$$\tau = \mu \frac{du}{dy} - \rho UV \quad (5)$$

The second term i.e. the Reynolds stress decreases because ρ decreases. The liquid surface area through which the first term acts also decreases. The well known phenomenon that signifies skin friction reduction is obtained when clusters near a solid wall bubble support this mechanism.

5.2. Mechanism 2: Increase of effective viscosity

It has been proven very early that small bubbles or minute particles in liquid increases the effective viscosity of liquid. Though the increase of effective viscosity increase the first term of equation;

$$\tau = \mu \frac{du}{dy} - \rho UV \quad (6)$$

And if this decreases the second term significantly, the shear stress τ decreases.

In order for this mechanism to work the, bubbles must be small. In micro bubble experiment micro bubbles with diameter ranging from 0.5mm to 1mm are observed, but there is a possibility that much smaller bubbles contribute to this effect. If this effect is important in skin friction reduction mechanism, there is a chance to increase the skin friction reduction without increasing the amount of air injected.

5.3. Mechanism 3: Turbulence effect

Test conducted on plates have shown that bubbles increase turbulence but decrease the Reynolds shear stress i.e. correlation between the two velocity fluctuation components becomes smaller with bubbles. It is not clear why this occurs.

VI. Application of Micro Bubbles in Ships

First an equation for the net power saving of a full scale ship is derived by considering the skin friction reduction by micro bubbles and the power needed to inject them. Second, issues on the practical application of micro bubbles to ships are discussed. Finally, the net power saving value is considered using available experimental results and typical specifications of a full scale ship.

VII. Equations For Net Power Saving

We assume that a ship runs at speed U with power W_0, "0" denoting the non-bubble condition, and by injecting bubbles the ship runs at the same speed U with different, hopefully reduced, power W;

$$W_0 = D_0 U, W = DU \tag{7}$$

where D_0, D: ship's drag. (–ΔD) and (–ΔW) the drag and power reductions, are related as;

$$(-\Delta W) = (-\Delta D)U \tag{8}$$

Where;

$$\Delta W \cong W - W_{0,}\ \Delta D \cong D - D_0 \tag{9}$$

Let D_F be the frictional drag and define;

$$r_f \cong D_{fb}/D \tag{10}$$

Let D_{Fb} be the frictional drag of the surface covered with bubbles. The ratio D_{Fb} / D should be approximately equal to;

$$r_s \cong S_b/S \tag{11}$$

where

S: wetted surface area of the ship,

S_b: surface area covered with bubbles,

but by selecting the S_b location near the bow we can expect, using a parameter $m_b > 1$;

$$D_{fb}/D = r_f r_s m_b \tag{12}$$

Since the drag reduction occurs only in D_{Fb},;

$$D_0 - D = D_{fb0} - D_{fb} \tag{13}$$

In order to estimate the net drag reduction effect, one should subtract the power needed for bubble injection from the power gain due to drag reduction. The pumping power W_{pump} is expressed as;

$$W_{pump} = (\rho g z + p)Q \tag{14}$$

where

ρ: water density,

g: gravity acceleration,

z: water depth at injection point,

p: dynamic pressure at injection point,

Q: volumetric air injection rate.

By introducing non-dimensional parameters;

$$C_Q \equiv Q/US_b : volumetic\ air\ coefficient \tag{15}$$

$$r_z \equiv \frac{z}{L} : water\ depth\ ratio(L : ship\ length) \tag{16}$$

$$F_n \equiv U/\sqrt{gL} : Froude\ number \tag{17}$$

$$C_p \equiv p/\frac{1}{2}\rho U^2 \tag{18}$$

W_{pump} is expressed as;

$$W_{pump} = \frac{1}{2}\rho U^3 S_b C_Q (\frac{2r_z}{F_n^2} + C_p) \tag{19}$$

Finally the net power saving ratio r_{nps} is expressed as;

$$r_{nps} \equiv \frac{(-\Delta W) - W_{pump}}{W_0} \tag{20}$$

$$= r_s[r_f m_b \left(1 - \frac{D_{fb}}{D_{fb0}}\right) - \frac{C_Q}{C_{D0}}\left(\frac{2r_z}{F_n^2} + C_p\right)] \tag{21}$$

where D_0 has been non-dimensionalized as;

$$C_{D0} \equiv D_0 \Big/ \frac{1}{2} \rho U^2 S \quad (22)$$

For example, r_{nps} =0.05 means 5% net power saving. It is the purpose of microbubbles studies to maximize this parameter.

VIII. Issues on the Application of Micro bubbles to Ships

8.1. $(1 - D_{Fb} / D_{Fb0})$

This parameter represents the reduction of the frictional drag by micro bubbles and therefore is the most important. It is not the local value but the integrated value over the entire surface covered with bubbles.The frictional drag in that area to be covered with bubbles in the non-bubble condition was estimated using the Schoenherr experimental formula shown below;

$$\log\left(R_e C_{F_{Sch}}\right) = 0.242 log10 \Big/ \sqrt{C_{F_{Sch}}} \quad (23)$$

The reason for the higher decay of the skin friction reduction effect at the higher speed is suspected to be the higher diffusion of the bubbles away from the wall by the higher turbulence intensity and/or smaller bubble size.

8.2. r_s

We should efficiently cover a wide surface area with bubbles.

8.3. r_F

The wave-making drag, the other major drag component, increases quadratically with speed, and therefore the smaller the speed, the greater $\mathbf{r_F}$ becomes, and the better-suited to microbubbles. With a displacement type ship such as a large tanker at the cruising speed of 14 knots (7m/sec), $\mathbf{r_F}$ reaches 0.8.

8.4. C_Q / C_{D0}

We should minimize the air volume for a given skin friction reduction.

8.5. r_z / F_n^2

This ratio, being equal to gz/U^2, means that the pumping power reduces quadratically with speed, so higher the speed, the better the performance. Note that the skin friction reduction effect decreases with speed at the same time. It would also be possible to reduce $\mathbf{r_z}$ by utilizing the downward flow near the bow.

8.6. C_P

By choosing the location for bubble injection or designing the local shape, one can reduce C_P and thus improve the net power gain.

8.7. Hull form

The hull form of a large tanker is regarded suitable for micro bubbles, because it's flat and very wide bottom will help the bubbles injected at the bow stay close to the bottom by buoyancy. It is also important to consider effects of non-horizontal surface, pressure gradient and surface curvature.

8.8. Sea water

Bubbles generated in sea water are in general smaller than those in fresh water with which almost all the laboratory experiments were carried out. This will affect the trajectories and the skin friction reduction effect.

IX. Conclusion

The frictional resistance forms an integral part of total resistance of displacement ship of medium and low speed. Since the frictional resistance depends on the hull form of ship it is very difficult to decrease on existing ship, thus air lubrication using micro bubbles proves to be a promising technology for further investigation. As discussed above many researchers have been struggled to investigate the effectiveness of micro bubbles on ships. Yet, there are a lot of questions could not get the exact answer about the mechanisms and factors which affect and control drag reduction using micro bubbles. Further research should be continued to enable the development of modification of turbulent boundary layer and thus increasing the ship efficiencies.

Reference

[1] McCormick, M.E. and Bhattacharyya, R., 1973, "Drag Reduction of a Submersible Hull by Electrolysis", *Naval Engineers Journal, Vol.85, No.2, pp. 11-16.*

[2] C. Merkle,. and S. Deutsch:"Drag Reduction in Liquid Boundary Layers by Gas Injection", *Progress in Astronautics and Aeronautics vol.123, AIAA.*

[3] Guin M.M., Kato, H., Maeda, M., and Miyanaga, M., 1996, "Reduction of Skin Friction by Microbubbles and Its Relation with Near-WallBubble Concentration in a Channel", *Journal of Marine Science and Technology, Vol. 1, No. 5, pp. 241-254.*

[4] Takahashi,T. et al.,1997,"Streamwise Distribution of the Skin Friction Reduction by Microbubbles", *J. of the Society of Naval Architects of Japan, vol.182, pp.1-8*.

[5] Y. Kodama,et al.,:"Experimental study on microbubbles and their applicability to ships for skin friction reduction.", *International Journal of Heat and Fluid Flow21 ,2000.*

[6] Kato, H., Iwashita, T., Miyanaga, M., Yamaguchi, H, 1998, "Effect of Microbubble Cluster on Turbulent Flow Structure", *IUTAM Symp. on Mechanics of Passive and Active Flow Control, Gottingen, Germany, pp.1-6*.

[7] Watanabe, O. et al.,1998,"Measurements of Drag Reduction by Microbubbles Using Very Long Ship Models", *J. of Soc. Naval Architects, Japan, vol.183, pp.53-63.*

[8] T. Takahashi et al.:"Experimental Study on Drag Reduction by Microbubbles Using a50m-long Flat Plate Ship", *2nd International Symposium on Turbulence and Shear Flow Phenomena (TSFP-2), June, 2001*.

[9] Lu, J., Fernandez, A., and Tryggvason, G. 2005. *The Effect of Bubbles on the Wall Drag in a Turbulent Channel Flow*. *Phys. Fluids*. 17: 95–102.

[10] Merkle, C. L. and Deutsch, S. 1992. Microbubble Drag Reduction in Liquid Turbulent Boundary Layers. Appl. Mech. Rev. 45(3): 103–27.