Drag Reduction by Kelvin-Helmholtz Instability

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Drag Reduction by Kelvin-Helmholtz Instability

Yoshiaki Takahashi
R and D Engineering Inc.

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Summary

Ultra fine Microbubble was generated by Kelvin-Helmholtz Instability and was proved to be very effective for ships Drag Reduction, for example, over 10% reduction of total power.

This paper is a subsequent one to previous paper presented at 22nd ONR Symposium held at Washington D.C. in 1998.

In this paper an invention process of WAIP (Winged Air Induction Pipe), over which wing Kelvin-Helmholtz Instability occurs, and actual application results for various size ships, 15m,30m and 80m long ships, are presented with actual total power reduction performance.

1. Preface

Frictional Resistance Reduction (hereafter Drag Reduction) has been one of the major targets of Research and Development of naval architects for a long time since Mr. William Froude in 1870's.

No explicit practical way for Drag Reduction has not been so far invented except smoothening the welding beads and self-polishing paint.

Here is presented a quite practical Drag Reduction by Kelvin-Helmholtz Instability, called WAIP: Winged Air Induction Pipe.

This paper is a subsequent one to the previous paper [1].

2. Essence of Research and Development way in Drag Reduction

In the previous paper presented at 22nd ONR symposium in Washington D.C. in 1998[1], there is described no simple scale factor in Drag Reduction like Froude number in Wave Making Resistance. This fact is easily understood by that Mirobubble size can not be changed after once emitted into water however large or small ship size is changed.

From this understanding, the author selected actual size wing for experiments to invent WAIP. WAIP is a unit to generate Microbubble very less expensive. This WAIP is composed of Wing and Air Induction Pipe (AIP , with compressors if necessary) as shown in Photo1.

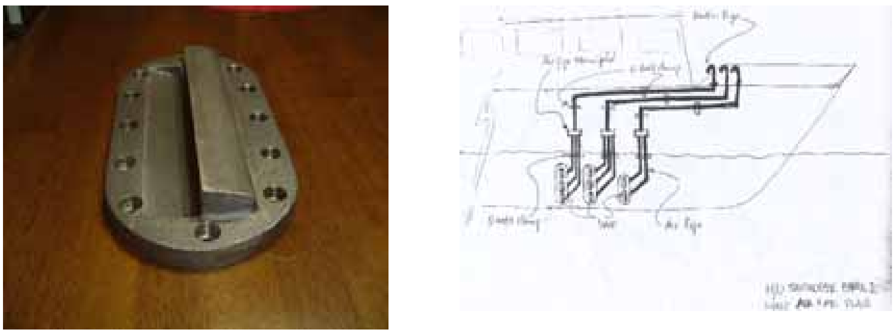

Photo1.WAIP (Cast Iron) and Piping Arrangement Example (Santander Ferry1 case)

3. Need to find out another efficient way to generate Microbubble less expensive

In any adiabatic process, internal energy raise occupies about 71% of all total energy required for compression as follows.

$$\frac{\Delta U}{L_{total}} = \frac{\alpha C_V}{\beta R \,\kappa / (\kappa - 1)} = 0.711$$

$\alpha : 1.3596$

$\beta : 0.0133$

$R : 29.5$

$C_V : 0.718$

$\kappa : 1.4$

This internal energy raise means temperature raise of compressed air and the energy will be instantaneously lost once it touches with sea water, infinitely large heat sink.

Then theoretically adiabatic process efficiency can be said only about 29% for air compression , that is for generating Microbubble.

In addition to this extremely low theoretical efficiency, Microbubble generation by compressor needs also acquisition cost of compressor machine and its driving power.

Of paramount importance is a discovery of finding out another efficient way to generate Microbubble less expensive.

The author acknowledged before that any injected air into water forms bubble. Then air injection into water was tested first of all.

For air injection to water for actual ship, low static pressure portion of a ship, bottom, was considered.

And then acceleration of this negative pressure was tested like Kikumaru [2] by attaching prism like protrusion on the bottom. This prism generated fog like ultra fine about 10 micron Microbubble as shown below Photo2.

Photo2. Kikumaru bottom photo through peeping hole at the stern[2]

Above: without Microbubble, Under: with fog like 10micron Microbubble

But accelerated negative pressure at the rear side of the prism has not so many design parameters except prism height and total prism length.

4. Kelvin-Helmholtz Instability to generate ultra fine 10micron Microbubble

Then comes wing attached to the bottom, above which light fluid, air in this case, comes down directly from atmosphere through AIP and heavy fluid, water in this case, goes very fast to the stern direction. See Photo1 Piping Arrangement Example.

Usually light fluid on heavy fluid is very stable when there is no speed difference at the interface. But once any speed difference occurs at the interface, then comes instability and generates ultra fine 10 micron Microbubble. This phenomenon is called Kelvin-Helmholtz Instabiliy (KHI). Above the Wing, this phenomenon occurs.

This Wing has many design parameters such as Wing shape (ogival, aerofoil etc.), size (chord length and width) , aspect ratio, protrusion height and attack angle. By these parameters best configuration shall be formed. Generated ultra fine 10micron Microbubble is shown in Photo 3(Adventure2 case).

Photo 3. Ultra fine 10micron Microbubble (Adventure2 case)

5. Experiments at the facility in FEL (West Japan Fluid Engineering Laboratory Co.Ltd.)

Combination of Wing parameters was selected through facility tests at FEL.

CWC (Circulating Water Channel: Max. flow velocity is 5.5m/sec, see Photo 4. and Fig.1) in FEL was used for these tests: Various combinations of Wing shape, aspect ratio, protrusion height and attack angle were tested.

Here conceived was Compensation Distance (C/D) concept as a criteria for best selection of these parameters. This C/D means distance of which Drag Reduction of the plate covered with Microbubble is equal to the Drag caused by the Wing itself.

According to this Criteria, the shorter C/D is, the better configuration of Wing it will be.

At this CWC, Drag Reduction and Wing Drag itself should be measured at the same time for C/D definition for each Wing configuration.

The Wing model for these tests was of actual size.

Photo 4. CWC at FEL

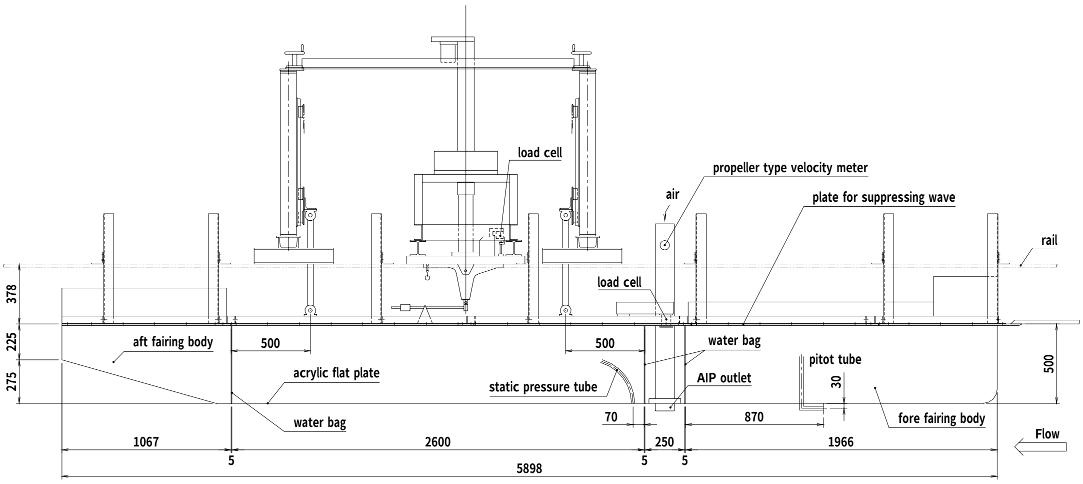

Fig.1 CWC measurement devices

6. WAIP with air compressor

When ship’s draft is too deep and her speed is not so high, air/water interface takes place in the amidst of AIP. In this case, KHI will not occur above the Wing and no ultra fine 10micron Microbuble will be generated.

In this like case, air/water interface should be pushed down above the Wing by small powered compressor and then KHI occurs. This type of WAIP application is called WAIP with air compressor. This phenomenon was also verified at CWC in FEL 2004.

7. Actual sea trials

7.1 Adventure2 at Imari Bay, Japan

Photo 5. Adventure2

Lpp*Bmd*Dmd=12.62*2.7*0.83m, 500ps

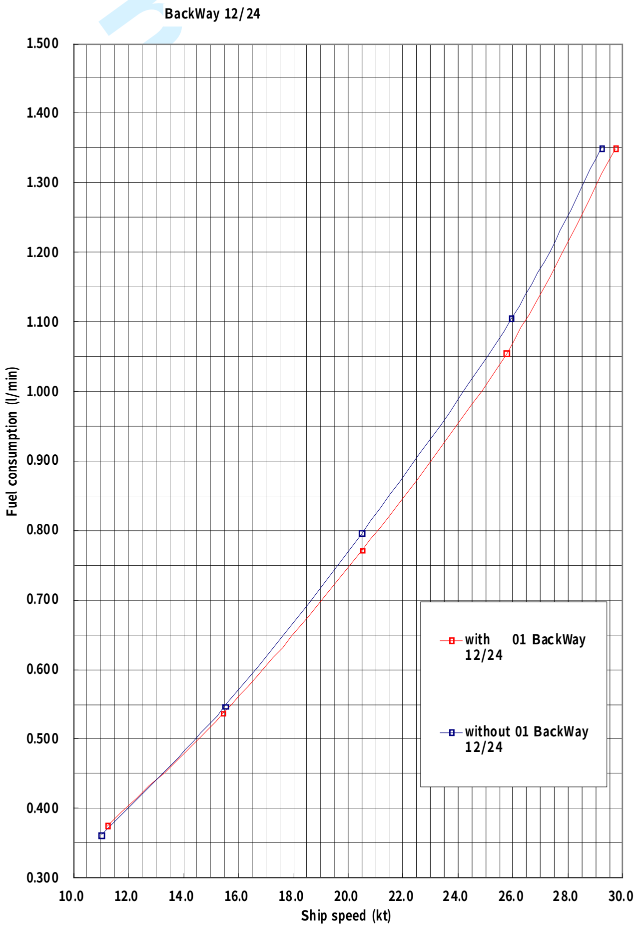

Fig.2 Measured data

About 4% Drag Reduction at 26knots by one WAIP at each side was acknowledged at Imari Bay in December,2002.

7.2 Santander Ferry 1, at Cebu, Philippines

Photo 6. Santander Ferry 1

Lpp*Bmd*Dmd*ps=28.8*5.45*1.55m*700ps

Photo 7. 3-WAIP (Plastic) on P side

Left hand direction : Bow side

Photo 8. All WAIP allocation on P side

Later rearmost 6WAIPs(P and S) were removed.

Left hand direction : Bow side

WAIP allocation was shown in Photo 7 and 8.

10 WAIPs (Plastic) were installed and sea trial was carried out in September, 2004 and actual fuel consumption was measured in February, 2005 as follows in Table 1.

About over 14% Drag Reduction as counted in reduction of fuel consumption was verified by fuel direct consumption measurement as shown in Table 1.

Table 1. Santander Ferry 1 Measured Data

		Go: from Santander to Dumaguete							
		Back: from Dumaguete to Santander							
		All closed		No.2 only open		No.1 only open		All open	
		Go	Back	Go	Back	Go	Back	Go	Back
	Date	on19th Feb.	ditto	ditto	ditto	ditto	ditto	ditto	ditto
	Time	7:41～8:15	9:01～9:35	10:28～10:59	11:56～12:29	13:30～14:03	15:08～15:42	16:35～17:10	18:04～18:35
	Weather/Sea state	Fine/Calm	Fine/Calm	Fine/Calm	Fine/Calm	Fine/W.waves	Fine/W.waves	Fine/W.waves	Fine/Calm
	Elapsed time seconds	550	534	537	513	545	517	517	543
	Total Variable weight tons	3.776	4.231	4.946	3.126	2.801	3.191	2.866	3.451
Starboard	Fuel remained on board	1.566	1.501	1.436	1.371	1.306	1.241	1.176	1.111
side	Persons including passengers	2.210	2.730	3.510	1.755	1.495	1.950	1.690	2.340
Engine	Speed measured knots	11.455	11.798	11.732	12.281	11.560	12.186	12.186	11.602
	Fuel consumption measured littre/ho	101.1	80.5	79.6	72.6	72.2	66.4	77.2	70.9
	Weight corrected with 3.776 tons	-	-	-	-	-	-	-	-
	Speed knots		11.817	11.780	12.252	11.519	12.160	12.146	11.589
	Fuel consumtion littre/hour		80.9	80.6	72.1	71.5	66.0	76.5	70.7
	Averaged fuel consumtion littre/hour		91.0		80.6		71.5		76.5
	Date	on 20th Feb.	ditto	ditto	ditto	ditto	ditto	ditto	ditto
	Time	6:05～6:35	7:10～7:45	8:59～9:30	10:54～11:29	12:04～12:36	13:10～13:45	15:00～15:32	16:07～16:40
	Weather/Sea state	Fine/Swell	Fine/Swell	Fine/W.B'ze	Fine/W.waves	S.cloudy/Caln	S.Cloudy/Calı	Fine/Calm	Fine/Calm
	Elapsed time seconds	549	506	528	522	528	518	501	515
	Total Variable weight tons	3.190	2.553	2.500	3.422	3.044	2.146	2.159	2.951
Portside	Fuel remained on board	1.045	0.993	0.940	0.887	0.834	0.781	0.729	0.676
	Persons including passengers	2.145	1.560	1.560	2.535	2.210	1.365	1.430	2.275
Engine	Speed measured knots	11.475	12.451	11.932	12.069	11.932	12.162	12.575	12.233
	Fuel consumption measured littre/ho	39.0	37.1	40.3	38.7	36.7	27.2	32.9	28.0
	Weight corrected with 3.190 tons	-	-	-	-	-	-	-	-
	Speed knots		12.422	11.902	12.079	11.926	12.117	12.528	12.223
	Fuel consumtion littre/hour		36.8	40.0	38.8	36.6	26.9	32.5	27.9
	Averaged fuel consumption littre/hour		37.9		40.0		36.6		32.5

1. W.waves means one or two white wves at a glance.

2.W.B'ze means Weak Breeze.

3.S.Cloudy means Slightly cloudy.

7.3 New Ferry Misaki equipped with 14 WAIPs (Cast Iron) at Tachibana Bay Japan

Photo 9. New Ferry Misaki

Lpp*Bmd*Dmd*d=68.0*12.3*8.95*3.2m, 4,076ps

In August 2005, New Ferry Misaki sea trial was carried out by Ship Research Center of Japan, one of the governmental authorities in Japan and showed 5.8% Drag Reduction at 18knots, which was very close to estimation calculation result shown in Fig3.

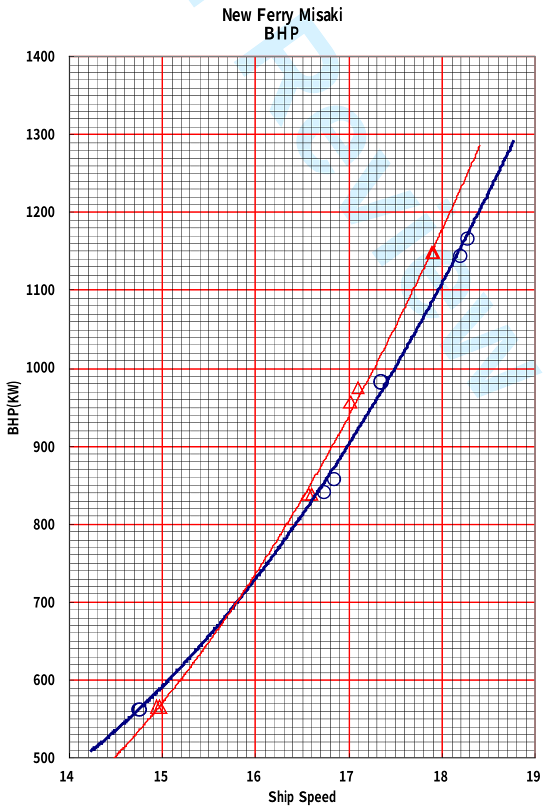

Fig.3 New Ferry Misaki Measured Data

8. Actual application example

Another 20 WAIPs were ordered from New Ferry Misaki owner and fitted to the ship in August 2006.

Photo 10. Another 20 WAIPs fitting

Photo 11. NK is surveying welding

9. Data of power reduction by about 10%

Following data is the summarized New Ferry Misaki Main Engine average fuel consumption change up to 2006 since 2004. From 2004 up to September, 2006, fuel consumption of New Ferry Misaki has been recorded and averaged as in Table2.

Table 2. New Ferry Misaki Main Engine Average Fuel Consumption Change

Number of WAIP fitted	Main Engine Fuel Consumption	
NO WAIP	110.5 4,105.90	Liter/Day
14 WAIPs	103.4 3,842.50	Liter/Day
34 WAIPs	100 3,714.80	Liter/Day

10. Conclusion

By these Facility experiments in FEL and actual sea trials of various size ships, the author could show practical application results of WAIP for effective Drag Reduction by about 10% of total power.

11. References

[1] Y. Yoshida et al "Study on the Mechanism of Resistance Reduction by means of Micro-Bubble Sheet and on Applicability of the Method to Full-scale Ship" presented at ONR symposium, on 13th Aug.1998, in Washington D.C., USA

[2] Y. Takahashi et al "Application of Bubblayer theory to a fishing boat" presented at ONR workshop on GBSSDR (Gas Based Surface Ship Drag Reduction), on 8th October, 1999, at Newport, Rhode Island, USA

Concluded