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Numerical Experiment of Flow Around a Compound Airfoil

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Numerical Experiment of Flow Around a Compound Airfoil

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Abstract. A numerical simulation around a compound airfoil was performed using the vortex method. The compound airfoil consists of a front airfoil, a fixed wing, and a rear airfoil, and it assumes the rudder of a submarine. As for the shape of the front airfoil and the rear airfoil, NACA0012 was used. Reynolds number was $Re = 3.8\times10^5$. In the numerical simulation, the angle of attack of a front airfoil and a rear airfoil was changed, and the magnitude of the gap between these movable airfoils and the fixed wing was changed. The time history of the fluid force of acting on an airfoil, and the flow pattern were investigated. The total lift was greatly produced, when the front airfoil and rear airfoil attached the same attack angle as the same direction. It was found that the total lift with the large one where the gap between these movable airfoils and the fixed wing is larger can be obtained. It was found that the rear airfoil governs the flow of the compound airfoil.

1. Introduction

The airfoil is a device for generating lift and is an important component in mechanical engineering. Therefore, the performance of airfoils and that of the machine equipped with airfoils have been well researched, and many characteristic tests have been performed [1]. As a method to obtain a large lift, giving an attack angle to an airfoil, speeding up, and making area of an airfoil wide are known. Here, when giving an attack angle to the airfoil, it is cautious of a direction of movement changing. It is the situation which needs a large lift at the time when velocity is late. For example, it is at the time of landing of the airplane and entry into port of the ship. Since the rudder is prepared before the propeller as for the submarine, effectiveness of a rudder worsens rather than the time of the cruise at the time of entry into port. Therefore, the measures which advance effectiveness of the rudder are required.

Yokoi [2] investigated the aspect of the interference flow wheal simulation. Furthermore, Yokoi et. al. [3] performed the numerical simulation of an interference flow about two symmetrical airfoils by which close setting was carried out, and they reported the flow characteristic around those airfoil. Yokoi [4] performed the numerical simulation of flow around an airfoil of tandem arrangement from the layout of the fin of a "tuna", and showed the fluid force characteristics and flow patterns. In tandem arrangement, if the interval of two airfoils is narrowed, they will contact and will become one body. Accordingly, the two airfoils will constitute one total airfoil (compound airfoil). Such the "combined airfoil" is already used also in the airplane or the ship. Since the compound airfoil is promising as an apparatus which obtains a high lift, there are many examples of study [5-9].

In this study, the numerical simulation which used the vortex method about the compound airfoil which arranged the movable airfoil in front and in rear of one fixed wing was performed. As for the movable airfoil, the NACA0012 airfoil type was used. Reynolds number *Re* based on the airfoil chord length was $Re = 3.8\times10^5$. The flow pattern and the fluid force characteristic were investigated.

2. Numerical calculations

2.1. Calculation apparatus
The numerical experiment apparatus was a consisted of simulation software and a notebook type computer (NEC; Lavie) as calculation hardware which are on the market. The soft ware which named "UzuCrise 2D ver.1.1.3 rev.H (College Master Hands Inc., 2006)" is used.

2.2. Calculation method
The method of analyzing the numerical simulation of this study is a vortex method based on the Lagrange analysis. The vortex method is a direct viscid-inviscid interaction scheme, and the emanation of velocity shear layers due to boundary layer separation is represented by introduction of discrete vortices with viscous core step by step of time. The separating shear layers were represented the discreet vortices which were introduced at the separation points. The details of calculation technique of vortex method and accuracy of calculation are shown in references [10] and [11].

2.3. Shape of compound airfoil
The compound airfoil consists of a front airfoil, a fixed wing (stay), and a rear airfoil, and it assumes the rudder of a submarine. The shape of the compound airfoil is shown in figure 1. As for the shape of the front airfoil and the rear airfoil, NACA0012 was used. The full length of the compound airfoil is 3 m, and the length of the movable airfoil is 1 m, respectively. The full length of the compound airfoil is 3 m, and the length of the movable airfoil is 1m, respectively. The gap is set up between the movable airfoil and fixed wing. The movable airfoil (front airfoil and rear airfoil) was divided into 80 panels, over which the vortices were distributed. The fixed wing was divided into 58 panels, over which the vortices were distributed.

2.4. Calculation conditions
Two-dimensional calculations were performed for incompressible and viscous flows. Here, the target object is assumed as the rudder of the submarine, and the velocity at the time of coming alongside the quay is assumed. So, the fluid is water, and the chord length of the airfoil is set as $C = 1.0$ m. Although the cruising speed of the submarine is 20 knots, at the time of coming alongside the quay, the velocity reduces to about 1 knot. So, the main flow velocity U used in the calculation was set as 0.5 m/s. The Reynolds number was set as $Re = 3.8\times10^5$. Every calculation continued to more than non-dimensional time $T = N\Delta t\ U/C = 5$ at intervals of time step $\Delta t = 0.01$ s (N is the number of times of calculation (= 1000 times)). Here, the non-dimension time $T = 5$ is equivalent to 10 seconds in real time. The calculation area was from -2 m to 15 m in x direction, and ±10 m in y direction. The origin was set at lift center which is 1/4 chord length of airfoil from the leading edge. Here for convenience, the front side airfoil was called the 1st airfoil, and the rear side airfoil was called the 2nd airfoil.

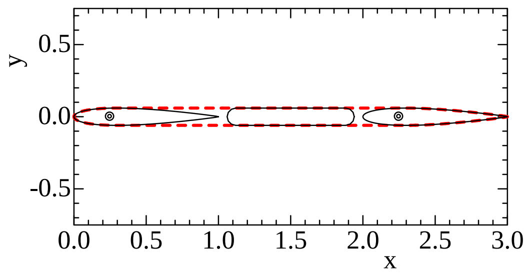

Figure 1. Shape of the compound airfoil; tandem arrangement of a movable airfoil, a fixed wing, and a movable airfoil.

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2.5. Calculation parameters

The main parameter in the numerical experiment was the gap between moving airfoil and fixed wing and the angles of attack of moving airfoils. The gap size is two kinds and is 60 mm and 15 mm. Since it is provided before and after the fixed wing, the length of the fixed wing is changed. The length of those fixed wings is 880 mm, and 970 mm, respectively. There are two kinds of situations of the angle of attack of the movable airfoil. One of which is the case that the angle of attack of both wings is the same. This case is 3 kinds. The combination of the angle of attacks is the following. （α1°, α2°） = (5°,5°), (10°,10°) and (15°,15°). Another is the case where an angle of attack is attached to airfoil of one of the two. This case is 6 kinds. The combination of the angle of attacks is the following. （α1°, α2°） = (0°,5°), (0°,10°), (0°,15°), (5°,0°), (10°,0°) and (15°,0°).

3. Results and discussions

3.1. Performance of fixed wing

The flow pattern and the fluid force characteristic of the fixed wing were investigated. Since the fixed wing was used without the angle of attack, it was carried out about the single fixed wing in the case of having no angle of attack. The flow pattern of the fixed wing and the time history of fluid force are shown in figure 2. In the figure, the length of a fixed wing is the case of 880 mm and 970mm. Although the length of those fixed wings differed, since the shape was the same, it was found that both of flow patterns and fluid force characteristics become the same. The drag coefficient of NACA0012 airfoil in calculation of this technique was C_D = 0.0072, the drag coefficient of this fixed wing is C_D = 0.0035, and it was shown that the fixed wing of this proposal is smaller than NACA0012 type airfoil. It proved that the shape of the fixed wing of the proposal of this is a good shape.

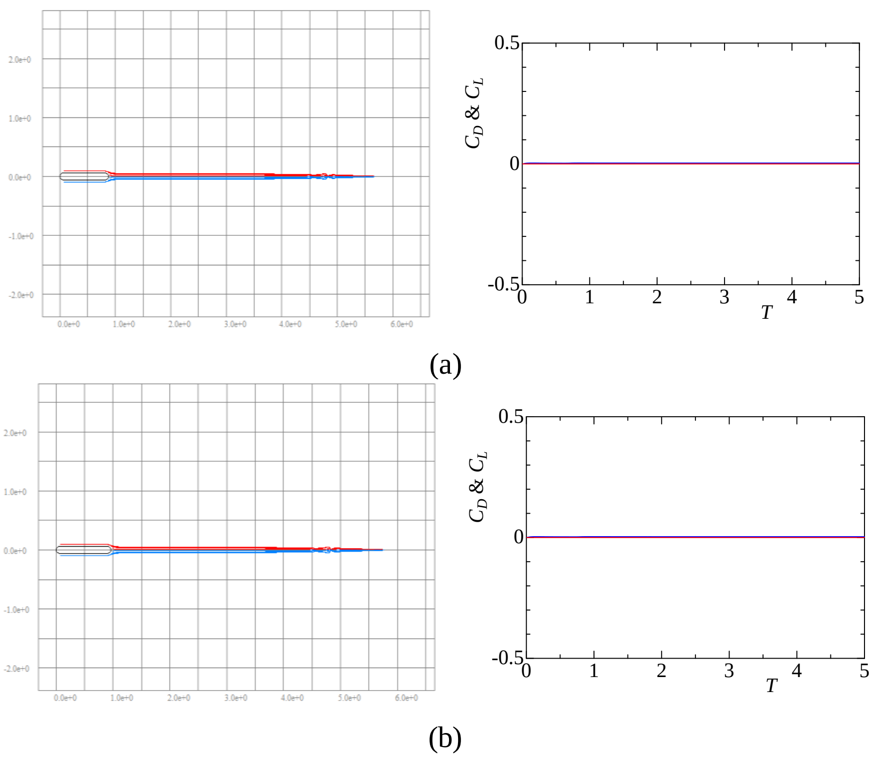

Figure 2. The flow pattern of a fixed wing, and the time history of the fluid force characteristic, (a) the wing length is 880 mm, C_D = 0.0035, C_L = 0.0, (b) the wing length is 970 mm, C_D = 0.0035, C_L = 0.0000.

3.2. Performance of compound airfoil

3.2.1. In the case of same angle of attack. The flow pattern of the compound airfoil and the time history of fluid force are shown in figures 3 and 4. There is no turbulence in the 1st airfoil and the lift is increasing. On the other hand, since there is inflow from the 1st airfoil and the fixed wing in the 2nd airfoil, turbulence has occurred. In the case of 880 mm fixed wing, it is shown that the lift of the 2nd airfoil is smaller than the lift of the 1st airfoil. In the fixed wing, the negative lift has occurred temporarily. When the angle of attack is 15 degrees, the separation bubble is formed by the suction side of the 1st airfoil. In the case of 970 mm fixed wing, although the lift has occurred temporarily in the fixed wing, on the whole, it becomes a negative lift. The lift coefficients in each condition are shown in table 1. Here, the NACA0012 type lift coefficient obtained by this calculation technique was 0.5400 in 5 degrees of angle of attacks, was 1.1831 in 10 degrees of angle of attacks, and was 1.6403 in 15 degrees of angle of attacks. In any case, a total lift is larger than the case of a single NACA0012 type airfoil. When the case of 880 mm fixed wing is compared with the case of 970 mm fixed wing, the one where the gap between the movable airfoil and the fixed wing is larger seems to be convenient for the use.

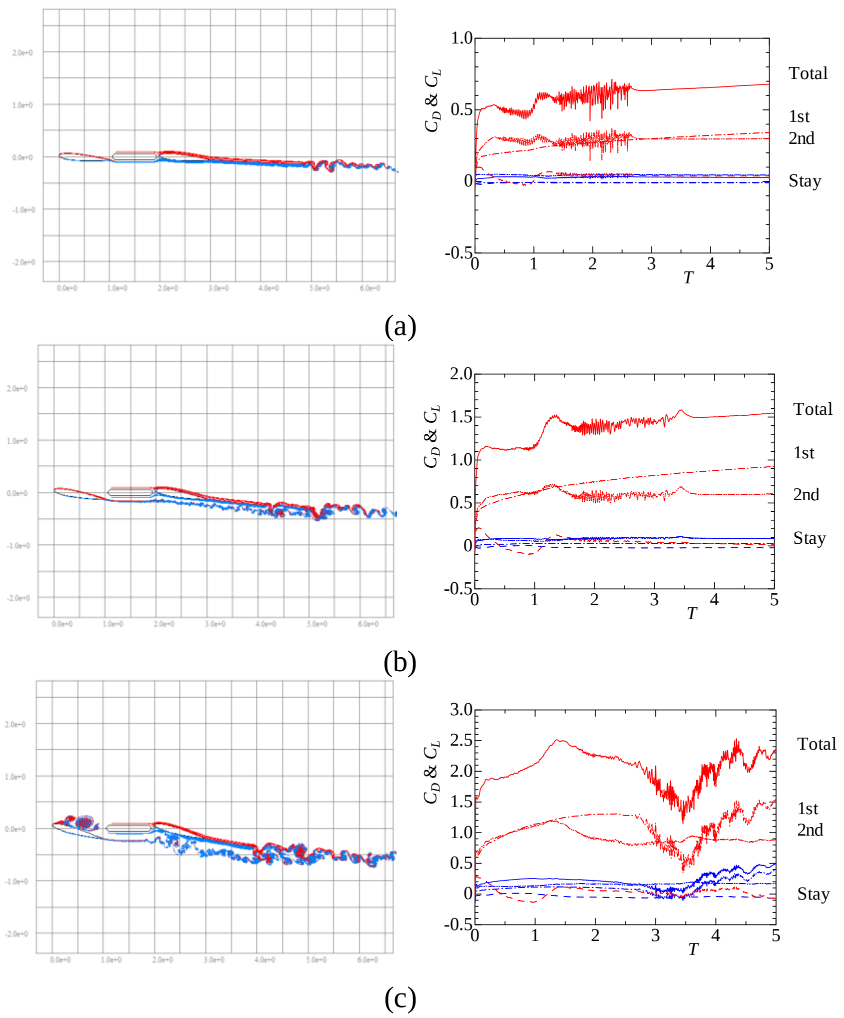

Figure 3. The flow pattern of the compound airfoil and the time history of fluid force, in the case of 880 mm stay (wing) use, (a) (α1, α2) = (5°, 5°), (b) (α1, α2) = (10°, 10°), (c) (α1, α2) = (15°, 15°), the red line shows lift coefficient.

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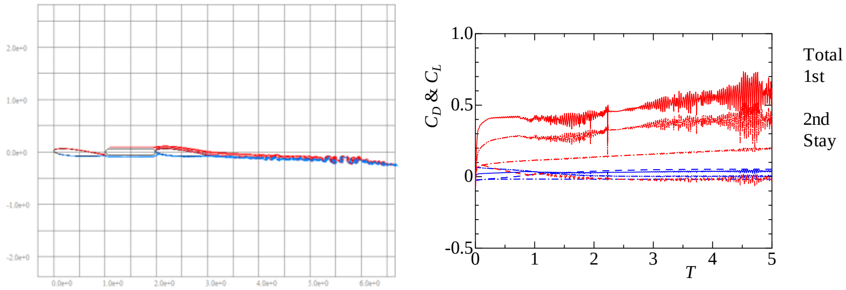
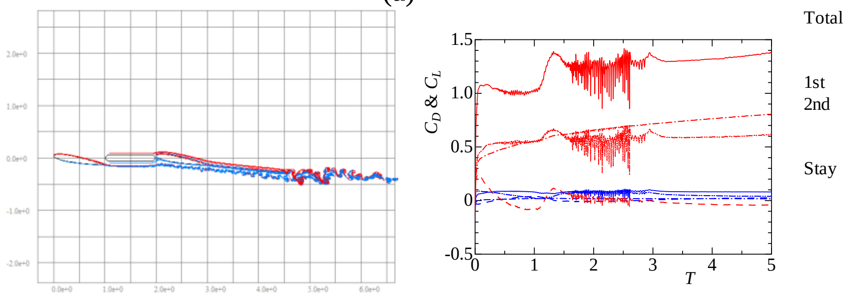


(a)



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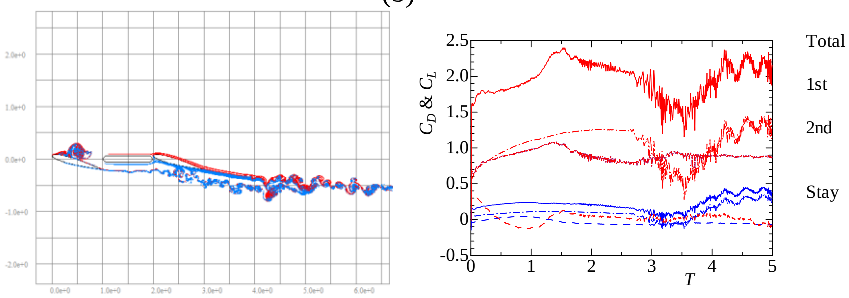


(c)

Figure 4. The flow pattern of the compound airfoil and the time history of fluid force , in the case of 970 mm stay (wing) use, (a) (α1, α2) = (5 °, 5 °), (b) (α1, α2) = (10 °, 10 °), (c) (α1, α2) = (15 °, 15 °), the red line shows lift coefficient.

Table 1. The value of the lift coefficient in each condition in case an angle of attack is in both airfoils, at the time $T = 5$.

Wing type	S880				S970			
(α1,α2)	1st	2nd	stay	total	1st	2n	stay	total
(5, 5)	0.3416	0.2994	0.0382	0.6792	0.1986	0.4280	-0.0097	0.6169
(10, 10)	0.9236	0.6050	0.0154	1.5440	0.8054	0.6163	-0.0420	1.3797
(15, 15)	1.5383	0.8900	-0.0707	2.3576	1.3528	0.8753	-0.0726	2.1555

3.2.2. The angle of attack is attached to one airfoil. This situation has two kinds of cases. The one is the case where an angle of attack is attached to the 1st airfoil. Another is the case where an angle of attack is attached to the 2nd airfoil. The flow pattern of each case and the time history of fluid force are shown in figures 5 and 6. The lift coefficients in each condition are shown in tables 2 and 3. Here, the underlined values in the table are larger than the values for the single airfoil. In the case where an angle of attack is attached to the 1st airfoil, no separation bubble can be seen there be on all airfoils. A negative lift can be seen have occurred in the fixed wing from the time history. It is found that it is smaller than the case where the total lift of the compound airfoil has a single NACA0012 type airfoil. Even when an angle of attack is attached to the 2nd airfoil, no separation bubble can be seen there be on all airfoils. The separation produced in both of the cases at the time of 15 degrees of angle of attacks is not produced. Although there is no angle of attack in the 1st airfoil, the lift has occurred on the 1st airfoils. The lift of the 1st airfoil at the time is smaller than the lift of the 2nd airfoil. Direction of the 2nd airfoil is found seeing synthetically and governing the overall direction of the flow. Although the total lift of the compound airfoil is larger than the case of the NACA0012 type airfoil, the value does not exist more than twice.

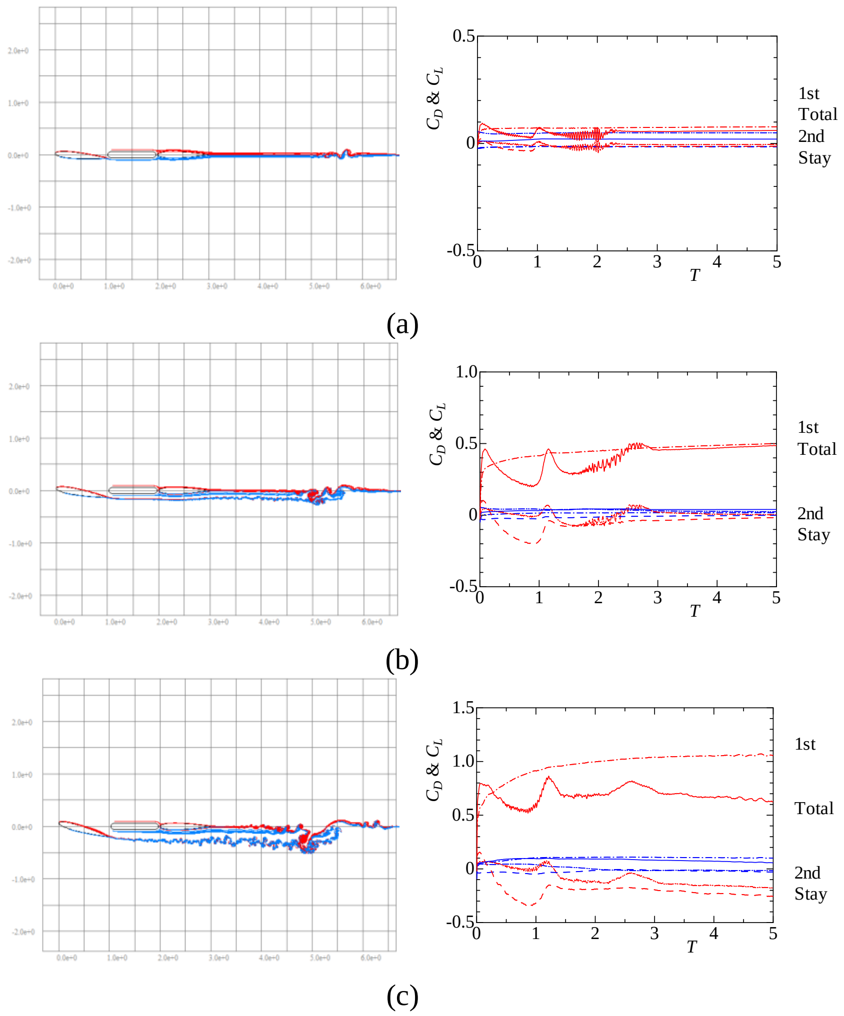
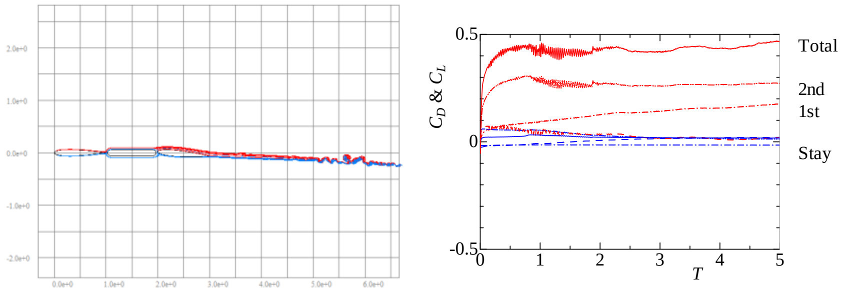
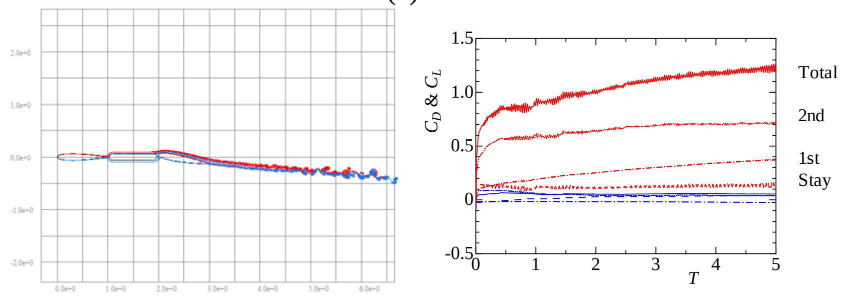


Figure 5. The flow pattern of the compound airfoil and the time history of fluid force, in the case of 880 mm stay (wing) use, in case an angle of attack in the 1st airfoil, (a) α1 = 5 °, (b) α1 = 10 °, (c) α1 = 15 °, the red line shows lift coefficient.



(a)



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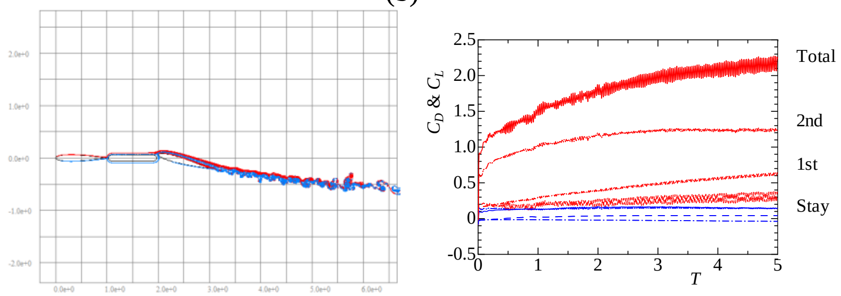

(c)

Figure 6. The flow pattern of the compound airfoil and the time history of fluid force, in the case of 880 mm stay (wing) use, in case an angle of attack in the 2nd airfoil, (a) α2 = 5 °, (b) α2 = 10 °, (c) α2 = 15 °, the red line shows lift coefficient.

Table 2. The value of the lift coefficient in each condition in case an angle of attack is in the 1st airfoil, at the time $T = 5$.

Wing type	S880				S970			
(α1,α2)	1st	2nd	stay	total	1st	2n	stay	total
(5, 0)	0.0781	-0.0046	-0.0127	0.0608	-0.0026	0.0127	-0.1332	-0.1231
(10, 0)	0.4992	0.0033	-0.0171	0.4854	0.4722	-0.1319	0.0479	0.3882
(15, 0)	1.0562	-0.1752	-0.2556	0.6254	1.0082	0.1269	-0.3707	0.7644

Table 3. The value of the lift coefficient in each condition in case an angle of attack is in the 2nd airfoil, at the time T = 5.

Wing type	S880				S970			
(α1,α2)	1st	2nd	stay	total	1st	2n	stay	total
(0, 5)	0.1754	0.2726	0.0192	0.4672	0.1552	0.3558	-0.0271	0.4839
(0, 10)	0.3802	0.7217	0.1579	<u>1.2598</u>	0.1830	0.5759	0.1292	0.8881
(0, 15)	0.6358	1.2461	0.3531	<u>2.2350</u>	0.4768	1.1642	0.2779	<u>1.9189</u>

4. Conclusions

Numerical simulations of initial flow around the compound airfoil with angle of attack were performed by use of the vortex method. The following conclusions were obtained.

(1) In the single test, the fixed wing obtained the drag coefficient lower than the movable airfoil.

(2) Although the total lift of the compound airfoil is larger than the case of the NACA0012 type airfoil, the value does not exist more than twice.

(3) The performance of the compound airfoil of the case where the gap between the movable airfoil and the fixed wing is large is good.

(4) Direction of the 2nd airfoil is governing the overall direction of the flow.

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References

[1] Abbott I H, Doenhoff A E and Stivers L S 1945 *National Advisory Committee for Aeronautics* 824
[2] Yokoi Y 2015 *Applied Mechanics and Materials* **798** 609
[3] Yokoi Y, Nayeri C N and Paschereit C O 2016 *Proc. 7th Int. Conf. on Vortex Models (Rostock)* paper no. Yokoi et.al.
[4] Yokoi Y 2017 *Proc. 8th Int. Conf. on Mechanical and Aerospace Engineering (Prague)* 447
[5] Inumaru N and Kitamura N 1968 *Technical Memorandum of National Aerospace Lab.* TM-140
[6] Tachi K 1988 *The Journal of Japan Institute of Navigation* **98** 25
[7] Jia W, Nakamura Y, Yasuhara M and Kuwabara K 1989 *Trans. of the Japan Scoety for Aeronautical and Space Science* **37-428** 430
[8] Yoshimura Y, Sasaki N and Takekawa M 1997 *Journal of Marine Science and Technology* **181** 191
[9] Hiraoka T and Kajitani H 2003 *Bulletin of Sojo University* **28-1** 141
[10] Kamemoto K 1993 *Japan Society of Computational Fluid Dynamics* **2-1** 20
[11] Kamemoto K 1994 *Japan Society of Computational Fluid Dynamics* **2-2** 28