Jurnal
Teknologi

Full Paper

COMPUTATIONAL FLUID DYNAMICS INVESTIGATION ON THE OUTER WING OF FLYING BOAT REMOTE CONTROL MODEL

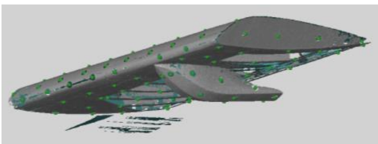
Article history
Received
16 February 2015
Received in revised form
18 March 2015
Accepted
1 August 2015

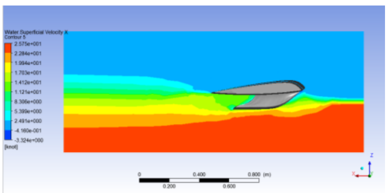
S. Syamsuar[a], E. B Djatmiko[b], A. S Mujahid[c], Erwandi[d], Subchan[e]

[a]Doctoral Candidate of Marine Tehnology, Faculty of Marine Technology, Tenth of November Institute of Technology, Surabaya, Indonesia
[b]Professor in Offshore Hydrodynamics, Faculty of Marine Technology, Tenth of November Institute of Technology, Surabaya, Indonesia
[c]Staff on Indonesian Hydrodynamics Laboratory, Agency for the Assessment and Application of Technology, Surabaya, Indonesia
[d]Staff on Indonesian Hydrodynamics Laboratory, Agency for the Assessment and Application of Technology, Surabaya, Indonesia
[e]Vice Director of National Robotics Centre, Tenth of November Institute of Technology, Surabaya, Indonesia

*Corresponding author
sayutisyamsuar@yahoo.com
or
sayuti.syamsuar@bppt.go.id

Graphical abstract





Abstract

The experiment of Wing in Surface Effect craft A2B and A2C B type for (1 - 2) seaters prototype are the background of this research. The aerodynamic, hydrodynamic, thrust and weight data of these prototypes were already investigated. The best ratio of Thrust per Weight is around 0.4 from this experience to fulfill the liftoff condition from the water surface. The step position on the hull as the theoretical prediction of Wing in Surface Effect craft is made (2 to 10)^{0} from center of gravity, c.g location to the step position. These formulas have been used to designing the Flying Boat remote control model. The whole process to build the remote control model is shown on this paper. The investigation of the outer wing of Flying Boat remote control model had been done to elaborate the aerodynamic and hydrodynamic characteristic. Included the laser photo camera tracking to 3 D model and Computational Fluid Dynamics analysis have been done also. The three dimensions (3 D) figures are evaluated by CATIA software and then these data results were transfer to the input of CFx Computational Fluid Dynamics (CFD) software. The meshing, pressure distribution and forces distributions during hydro planing of outer wing and pontoon of Flying Boat remote control model have been analyzed by CFx Computational Fluid Dynamics software. The Z force on the outer wing and pontoon showed a good result.

Keywords: Thrust per weight ratio, wing in surface effect craft, flying boat, and step position

1.0 INTRODUCTION

Two phenomena were occurred when a wing approaches the ground. Ground effect is the term used for both effects which is sometimes confusing. The two phenomena are sometimes referred to as span dominated and chord dominated ground effect. The former results in a reduction of induced drag (D) and the latter in an increase of lift (L). The overall effect is the increment of the L/D ratio. This ratio measured the efficiency of an aircraft which can be expressed as the amount of power (thrust) that is required to propel an aircraft of a certain weight. Since thrust is equal to drag and weight is equal to lift in stationary flight, this efficiency also expressed the L/D ratio. As the L/D of a wing increases with decreasing ground clearance the craft becomes more efficient in ground effect [10].

There is not enough space for the vortices to fully develop when a wing is approaching the ground. Therefore the amount of "leakage" of pressure from the lower side is less and the vortices become weaker. The vortices are also pushed outward by the ground; apparently the effective aspect ratio of the wing becomes higher than the geometric aspect ratio. This is a common way to account for span wise ground effect. Theory of Wieselsberger has found this in the 1920's by applying Prandtls lifting line theory. From this theory it follows that induced drag reduces to approximately 50% at a ground clearance of 10% of the wingspan [11].

The background of this paper is to know the power to weight ratio of Wing in Surface Effect craft B type and the center of gravity, c.g position during hydro planing. The data are become from experimental analysis. The 180.0 HP of Textron Lycoming O 360 engine series power were not enough for 1.000 kg weight of Wing in Surface Effect craft (1-2) seaters A2B prototype B type. The A2B (1-2) seaters prototype has been tested at Pantai Carita on Bojonegara in Banten Province, Indonesia. The aerodynamic lift and hydrodynamic resistance with the power on the Wing in Surface Effect craft of A2B prototype B type are not enough to counter the weight of craft during high speed hydro planing. Muhammad, H [15] was calculating the aerodynamic lift and drag coefficients of reverse delta wing configuration by using DATCOM software. The hydrodynamic data of water resistance was calculated by Maxsurf software. Jamaluddin, A [14] calculate the hydrodynamic resistance of 8 seaters model by using Maxsurf software. The hydrodynamic 3 (three) dimension model has been tested on the towing tank in Surabaya. The thrust engine is measured from static thrust measurement. The weight and balance of Wing In Surface Effect prototypes are measured by weighting to know the maximum takeoff weight and the centre of gravity, c.g position. The flight performance requirement of Wing in Surface Effect craft A2B and A2C B type prototypes due to the forces interaction between hull, pontoons, reverse delta wing, weight acting on the center of gravity, c.g position during hydro planing have been calculated in 2007. The thrust measurement, weight and balance measurement of the second prototype of Wing in Surface Effect craft A2C B type with 430.0 kg Maximum Takeoff Weight (MTOW) and the 115.0 HP power engine have been analyzed in 2012. The ratio of Thrust per Weight is around 0.4. The step position calculation is known by measured from the Z axis to center of gravity, c.g position (imaginary) and made the angle (2 to 10)^0 to the step position on the hull of Flying Boat remote control model. The overweight problem on the Wing In Surface Effect A2B B type (1-2) seaters prototype is tail heavy but the A2C prototype still in the c.g limitation [8].

The numerical analysis had been performed on the outer wing of Flying Boat remote control model. The aerodynamic and hydrodynamic characteristic of the model during hydro planing will be presented. This configuration is choice to design the adaptive control in surface effect. The application of adaptive control design is conducting to solve the Pilot workload on the Wing In Surface Effect craft. Here is one of the other solutions to answer the coastal transportation means operating in calm water conditions in Indonesia.

2.0 THEORY

The surface effect on the upper of water surface become from the wing tip vortex (vortices blocked by the ground). The Figure 1 is the effective Span during free flight and near in surface effect [11].

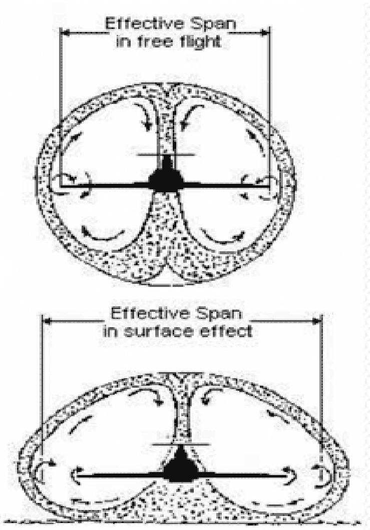


Figure 1 The effective span during free flight and nearby surface effect[11]

The flight performance about the aerodynamic and hydrodynamic characteristic of Wing in Surface Effect craft B type during hydro planing were use as background analysis on this paper.

The aerodynamic and hydrodynamic theoretical prediction of Wing in Surface Effect craft has been used in this research [14]. Several data of the aerodynamic model are calculated by using software DATCOM [15] to known the aerodynamic coefficients versus angle of attack (α). The towing tank test model is to known the water resistance versus Froude number, F_r of Wing in Surface Effect craft B type Lippisch configuration.

CFD solvers are based on the finite volume method. The fluid region is decomposed into a finite set of control volumes. General conservation (transport) equations for mass, momentum, energy, species, etc. are solved on this set of control volumes. Continuous partial differential equations (the governing equations) are discrete into a system of linear algebraic equations that can be solved on a computer. The method is to known the surface effect phenomenon by using computational fluid dynamics. The response that will be known is by using adaptive control surface effect during flight testing of Flying Boat remote control model. The CFD was use on the Flying Boat remote control model to know the pressure distribution, meshing, isometric and the air velocity streamline, etc.

2.1 Forces Distribution

The forces distribution during hydro planing are located at centre of gravity, c.g position and centre of buoyancy, c.b along the body axis of the Wing in Surface Effect craft [8] is showed in Figure 2.

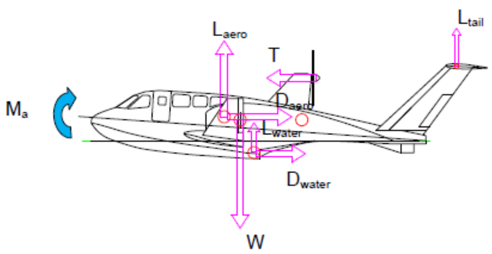


Figure 2 The forces distribution on the Wing in Surface Effect craft B type during hydro planing[8]

2.2 The Aerodynamic Lift of Wing

The aerodynamic lift (L) and the aerodynamic drag (D) are the components of the resultant aerodynamic force on the wing perpendicular and parallel to the velocity vector [11] is presented in Figure 3. They satisfy the relations are shown in equation below:

$$L = \frac{1}{2} C_L \rho S V^2 \qquad (1)$$

$$D = \frac{1}{2} C_D \rho S V^2 \qquad (2)$$

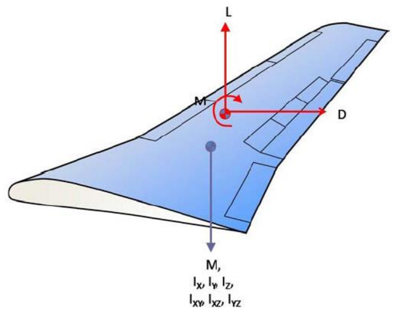


Figure 3 The lift, drag and moment of aerodynamic on the wing surface[11]

2.3 The Resistance (Hump Drags) of the Hull

The comparison of Resistance versus Speed regimes [7] of Hull of Seaplane and Planing Boat is showed in Figure 4.

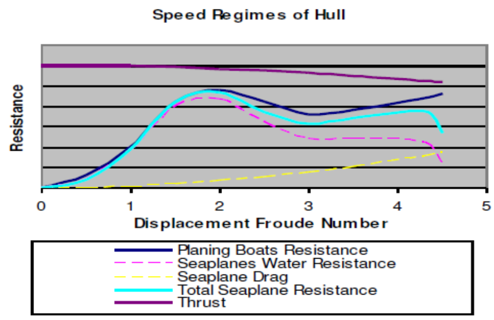


Figure 4 The resistance versus Speed[7]

2.4 Notation and Sign Convention of Hydrodynamic Force

The mathematical model convention and description of marine system [12] is showed in Table 1 and depicted in Figure 5.

Table 1 Notation for marine vessels[12]

Degree of Freedom (DOF)		Force/ Moment	Linear/ Angular velocity	Positions/ Euler angles
1	surge	X	u	x
2	sway	Y	v	y
3	heave	Z	w	z
4	roll	K	p	Φ
5	pitch	M	q	θ
6	yaw	N	r	φ

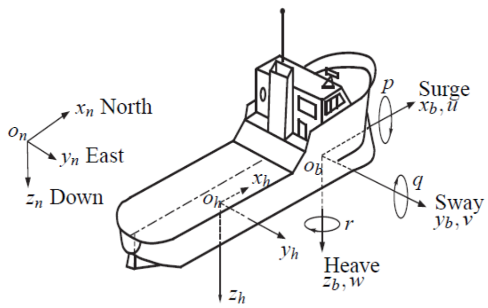


Figure 5 Notation and sign conventions for ship motion[12]

This frame is usually considered when the vessel travels at a constant average speed (which also includes the case of zero speed); and therefore, the wave-induced motion makes the vessel oscillate with respect to the h frame. This frame is considered inertial.

2.5 Step Position

The determination of step position on the hull of Flying Boat remote control model is measured from the angle around (2 to 10)^0 between Z axis to the center of gravity, c.g position and to the step position. While the center of buoyancy, c.b lied in front of center of gravity, c.g position. The illustration of the concept of longitudinal stability [8] is showed in Figure 6.

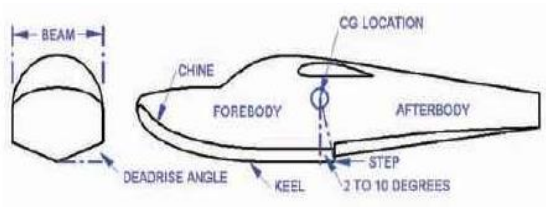


Figure 6 Step position determinations on the hull of the Flying Boat[8)]

2.6 Computational Fluid Dynamics

General conservation (transport) equations (3) for mass, momentum, energy, species, etc. are solved on this set of control volumes [16]:

$$\frac{\partial}{\partial t}\int_V \rho\phi dV + \oint_A \rho\phi V.dA = \oint_A \Gamma\nabla\phi.dA + \int_V S_\phi dV \quad (3)$$

Unsteady + Advection = Diffusion + Generation

2.7 Power to Weight ratio

The current Seaplanes do have competitive advantages over past planing boats for transporting people over medium distances. Modern passengers demand faster service and today they are high speed ferries that travel at more than 40 knots [7]. It can be seen in Figure 7.

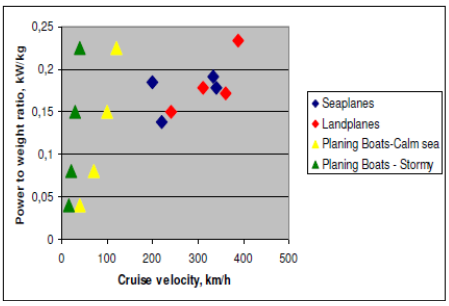


Figure 7 Power to weight ratio versus cruise velocity for planing boats and Seaplane[7)]

3.0 PAPER REVIEW

For discrete of the computational domain, an unstructured type of grid with quad elements was selected by T. Abramowski [10]. The grid for the airfoil moving in free air is presented in Figure 8.

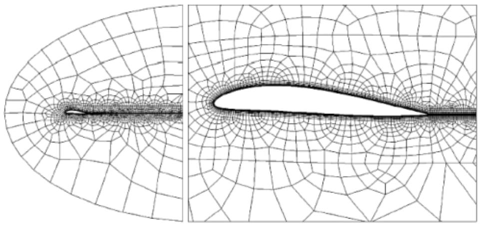


Figure 8 Grid applied for airfoil moving in free air[10)]

The Flying Boat remote control model has been developed to verification the adaptive control system connecting to the control surfaces (elevator, aileron, and rudder) deflection during ground effect altitude. The T/W ratio around 0.4 and step position criteria of wing in surface effect craft A2B B type prototype are applied on the Flying Boat remote control model.

3.1 Wing In Surface Effect Craft Prototype

The Wing In Surface Effect A2B and A2C B type reverse delta wing Lippisch configuration (1-2) seaters prototypes with Clark Y airfoil on the wing [8] are showed in Figure 9 and Figure 10. The progresses of these 2 prototypes experimental are not finished in this time [8]. These Wing In Surface Effect craft Lippisch configuration research program are sponsored by Indonesia Government.

Figure 9 The Wing In Surface Effect craft A2B prototype

Figure 10 The Wing In Surface Effect craft A2C prototype

The discussions on this topic are:

- Ever since the very first experimental Wing In Surface Effect A2B B type vehicles have been built in the thirties longitudinal stability has been recognized as a very critical design factor.
- If it were not designed properly Wing In Surface Effect craft B type show a potentially dangerous pitch up tendency when leaving (strong) ground effect. The water resistance is bigger than normally. This is the problem in longitudinal stability. Powerboats sometimes show the same tendency, when they meet a wave or a wind gust they may suddenly flip backwards.
- The wing in surface effect B type experience will be inspired to build the C type prototype.

3.2 Flying Boat Remote Control Model

The power used on the Flying Boat Remote Control model is around 5.5 HP engine with 25.0 kg maximum takeoff weight. The wing uses NACA 23012 airfoil, the Horizontal Tail Plane (HTP) is use the NACA 0010 and the Vertical Tail Plane (VTP) is uses NACA 0012 on the root and NACA 0010 on the wingtip. The results of this research are fulfilling the adaptive control investigation of the full configuration of the Flying Boat remote control model during surface effect. The model is a handmade without special tool. The fuselage, wing and horizontal tail plane are built by wood. The processes how to build the model are showed in Figure 11, Figure 12, Figure 13 and Figure 14.

Figure 11 The composite material

Figure 12 The Airfoil composition

Figure 13 The Pontoon configuration

Figure 14 The Fuselage

The remote control model full configuration is showed in Figure 15. This program has been started since 2012 in Serpong and Surabaya, Indonesia.

Figure 15 The Flying Boat remote control model.

The aerodynamic and hydrodynamic problems were solved by using computational fluid dynamics.

4.0 THE DATA ANALYSIS OF FLYING BOAT REMOTE CONTROL MODEL

This paper is made some recommendations due to the Wing In Surface Effect craft prototype reverse delta wing Lippisch configuration experience as background of the research. The first recommendation is about the flight testing of Wing in Surface Effect craft A2C B type prototype Lippisch configuration [5]. The second one is about the design of Flying Boat remote control model with rectangular wing configuration. These recommendations are fulfill the Thrust per Weight ratio 0.4 and the step position criteria. The three dimension of wing and hull of Flying Boat remote control model have been measured by using the laser tracking photo camera. The Figure 16 is the laser photo camera laser tracking process. Figure 17 is the result of outer wing drawing.

Figure 16 The outer wing and pontoon with the marker during photo camera laser tracking process

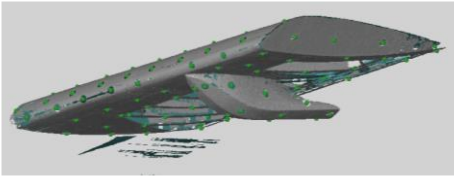


Figure 17 The 3 (three) view drawing of outer wing and pontoon of Flying Boat remote control model

After the dimensions of the model are fed on the computer that gave the solid line on the drawing of CATIA. The three views drawing of the model will be imported to the computer system on the computational fluid dynamics.

The aerodynamic and hydrodynamic analyses of the outer wing with the pontoon have been done by CFD. Outer wing model, geometry, meshing and isometric as input data are showed in Figure 18, Figure 19, Figure 20 and Figure 21.

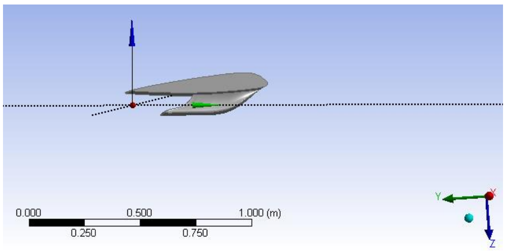


Figure 18 Outer wing and pontoon model in CFD

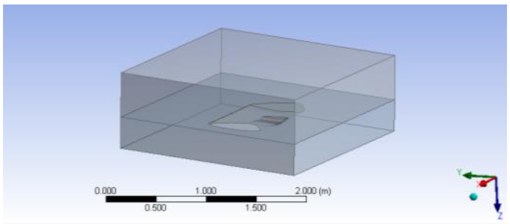


Figure 19 Geometry in CFD

Figure 20 is the meshing of the outer wing and pontoon of Flying Boat remote control model and Figure 21 is the isometric.

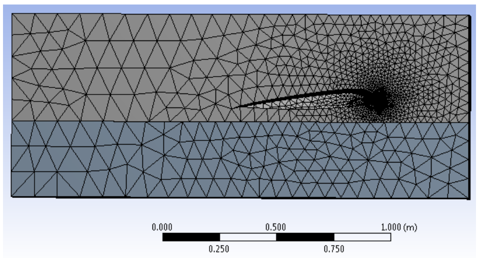


Figure 20 Meshing on the outer wing and pontoon

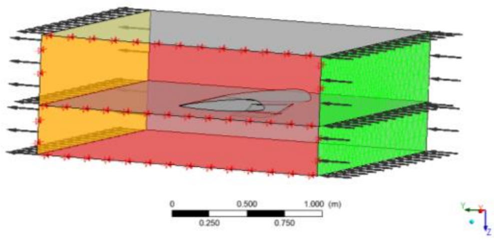


Figure 21 Isometric on the outer wing and pontoon

Parameters in Figure 21 are:

Inlet	:	speed 25 knots
Outlet	:	pressure 0 Pa
Wall	:	no slip wall, smooth wall
Symmetry	:	free slip wall
Half geometry	:	half geometry

The Figure 22 is the result of Air Pressure distribution, and the Figure 23 is the result of Water Pressure Distribution on the outer wing and pontoon.

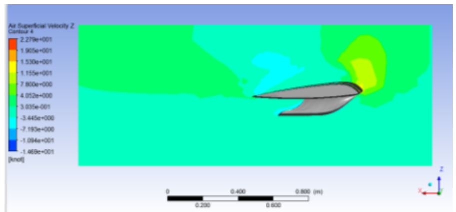


Figure 22 The result of Air Pressure Distribution on the outer wing and pontoon

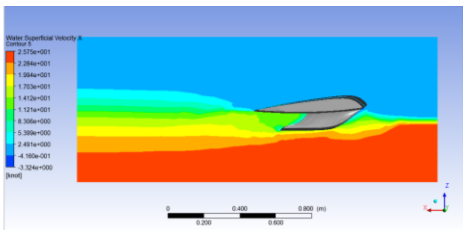


Figure 23 The result of Water Pressure Distribution on the outer wing and pontoon

Figure 24 is the result of Air Velocity Streamline of the outer wing and pontoon. Figure 25 is the result of Water Velocity Streamline on the outer wing and pontoon.

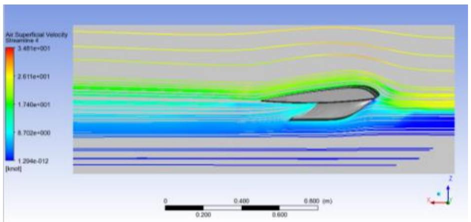


Figure 24 The result of Air Velocity Streamline on the outer wing and pontoon

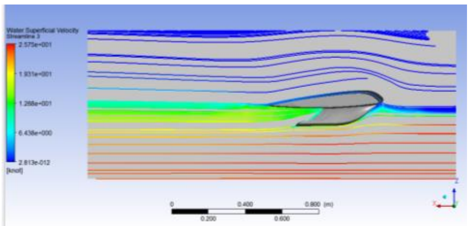


Figure 25 The result of Water Velocity Streamline on the outer wing and pontoon

Figure 26 is the result of Air Velocity Vector of the outer wing, and Figure 27 is the result of Water Velocity Vector of the outer wing and pontoon.

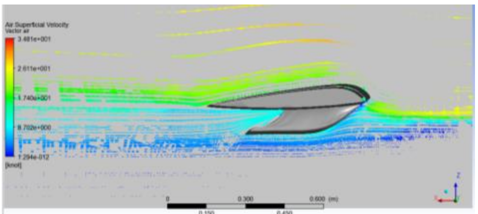


Figure 26 The result of Air Velocity Vector on the outer wing and pontoon

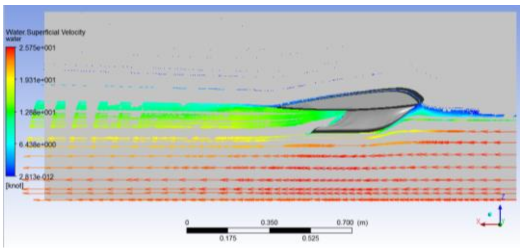


Figure 27 The result of Water Velocity Vector on the outer wing and pontoon

Figure 28 is the result of Force (Z lifting) distribution on the outer wing and pontoon of Flying Boat remote control model.

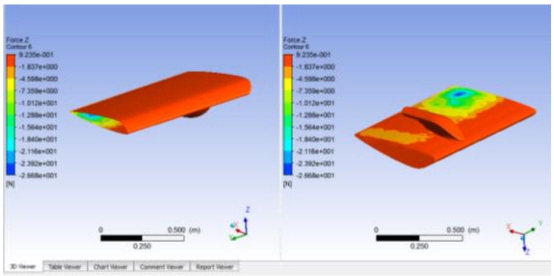


Figure 28 The Force (Z lifting) distribution on the outer wing and pontoon

5.0 CONCLUSIONS

The study of computational fluid dynamics on the Flying Boat remote control model carried out some conclusion:

- The Thrust (HP) per Weight (kg) ratio was used around 0.4 to build the Flying Boat remote control model. In the next research of Flying Boat Remote Control model, it is utilize for the maximum power than normally of Seaplane. This power will be used during aborted landing.
- The Z axis, center of gravity, c.g and step position on the Flying Boat remote control model made the angle between (2 to 10)^0. The maximum value 0.9235 Newton of forces is distributed on the leading edge of the outer wing and pontoon.
- The computational fluid dynamics results are the Pressure Distribution, Air Velocity Streamline and Air Velocity Vector during hydro planing on the outer wing and pontoon showed a good results. The air and water flow of simulation on the model are smoothly.
- The Z forces during hydro planing are calculated by Computational Fluid Dynamics (CFD) software on the outer wing and pontoon of Flying Boat remote control model has a good result. The aerodynamic lift could enough to carry out the Flying Boat Remote Control model from the water surface. The aerodynamic and hydrodynamic characteristic phenomena of outer half wing and pontoon model during hydro planing in speed between (0 to 25) knots have the maximum aerodynamic lift (0.9235 Newton) on the leading edge of outer wing. This value will be increase with adding of speed.

NOMENCLATURE

m	mass of WISE-craft
MTOW	Maximum Takeoff Weight
V	airspeed of WISE-craft
α	angle of attack
β	side slip angle
φ, θ, ψ	Euler angle (roll, pitch and yaw)
CFD	Computational Fluid Dynamics
C_D	Aerodynamic drag coefficient
C_L	Aerodynamic lift coefficient
C_{LF}	Aerodynamic lift coefficient of the tail

C_l	Aerodynamic rolling moment coefficient
C_n	Aerodynamic yawing moment coefficient
C_m	Aerodynamic pitching moment coefficient
ρ	air density
I_x, I_y, I_z	Inertial moment in the x, y and z axes
c	Mean Aerodynamic Chord length
S	wing area/ planform
b	wing span
g	Gravitation acceleration
T	Thrust
n	North position in navigation frame
e	East position in navigation frame
d	Down position in navigation frame
u	Surge velocity in body frame (X body axis); Velocity coordinate
v	Sway velocity in body frame (Y body axis); Velocity coordinate
w	Heave velocity in body frame (Z body axis); Velocity coordinate
p	Roll rate in body frame
q	Pitch rate in body frame
r	Yaw rate in body frame
q_∞	dynamic pressure
C	chord length
c.g	center of gravity
W	Weight
MAC	Mean Aerodynamic Chord
kN	kilo Newton
Fn	Froude Number
L	Aerodynamic Lift
D	Aerodynamic Drag
DOF	Degree of Freedom

Acknowledgement

The authors would like to thank the Ministry of Research Technology and High Education of Republic Indonesia, Head of Agency for the Assessment and Application of Technology for the financial support towards conducting the study. The authors also express their earnest gratitude to head and staffs of System Transportation Division. The colleague in Pondok Cabe Home Industry, Mr. Djubair OD, and Mr. Karyawan as conceptual designed in aerodynamic laboratory, Puspiptek, Serpong. Ir. Teddy A. Lubis, M. Eng. as Head of MEPPO Laboratory, Puspiptek, Serpong and especially to Mr. Nur Muhamad Fuad & Dede Sumantri. Dr. Taufiq A. Setyanto as Head of Indonesia Hydrodynamic Laboratory, Surabaya.

References

[1] Anderson, John. D Jr. 1995. *Computational Fluid Dynamics, The Basics with Applications*. Department of Aerospace Engineering, University of Maryland, Mc. Graw Hill, Inc., New York.

[2] Graham Taylor. 2003. Re-defining Sea Level: The Hoverwing Wing In Ground Effect Vehicle, Fischer Flugmechanik/ AFD Airfoil Development GmbH, Germany. *Paper for the Hovercraft Society, Air Cushion Technology Conference & Exhibition*, England.

[3] Ikeda Yoshiho, Katayama Toru. 2000. Porpoising Oscillations of a Very High Speed Marine craft, Department of Marine System Engineering, Osaka Prefecture University.

[4] Maurizio Collu, Minno H Patel. 2008. Florent Trarieux, A Mathematical Model to Analyze the Static Stability of Hybrid (Aero-Hydrodynamically Supported) Vehicles, *Presented At The 8 Th. Symposium On High Speed Marine Vehicle*, Naples.

[5] Maurizio Collu, Minno H Patel, Florent Trarieux. 2007. A Unified Mathematical Model for High Speed Hybrid (Air and Water borne) Vehicles. Cranfield University, United Kingdom.

[6] Odd M. Faltinsen. 2005. *Hydrodynamics of High Speed Marine Vehicles*. Norwegian University of Science and Technology, Cambridge University Press.

[7] Plamen Roglev. 2013. *Multidisciplinary Design Optimization of Amphibious Aircraft of Unconventional Aerodynamic Configurations*. Po. Box 26, 4001, Plovdiv, Bulgaria.

[8] S. Syamsuar, E. B. Djatmiko, P. A. Wilson, Erwandi, Subchan. 2013. The Flight Performance Criteria for Adaptive Control Design during Hydro Planing and Ground Effect Altitude for Wing In Surface Effect craft. *International Review of Mechanical Engineering (I.R.E.M.E)*. 7(4): 633-645. ISSN 1970-8734, Praise Worthy Prize S.r.l.

[9] Thor I. Fossen. 2005. A Non-linear Unified State Space Model for Ship Maneuvering and Control In Seaway. Department of Engineering Cybernetics, Norwegian University of Science and Technology, Norway.

[10] Tomasz Abramowski. 2007. Numerical Investigation of Airfoil in Ground Proximity, Faculty of Maritime Technology, Technical University of Szczecin, *Journal of Theoretical and Applied Mechanics*. Warsaw.

[11] Tom Benson. 2005. *Downwash Effect on Lift*. Glenn Research Center, NASA.

[12] Tristian Perez, O N Smogeli, T I Fossen, and A J Sorensen. 2006. *An Overview of the Marine Systems Simulator (MSS): A Simulink Toolbox for Marine Control Systems*. Centre for Ships and Ocean Structures, Department of Marine Technology, Trondheim, Norway

[13] The University of Adelaide Australia. 2007. *Wing in Ground Effect (WIG) aircraft Aerodynamics*, School of Mechanical Engineering Mech. Eng. 3016 Aaeronautical Engineering.

[14] Jamaluddin, A. 2004. *Analisa dan Pengujian Hidrodinamika Kapal Bersayap (WISE 10)*. Indonesian Hydrodynamic Laboratory.

[15] Muhammad, H. 2005. *Technical Report*, *Design Configuration*, *Preliminary Design*, Part I-A WiSE Aerodynamic Prediction based on DATCOM, LPPM ITB, Bandung.

[16] Ansys Training Manual. 2009. *Chapter 1 Introduction to CFD/ CFX*. Inc. Proprietary.