RESISTANCE OF WING IN GROUND EFFECT CRAFT MODEL DURING TAKE-OFF

Mohammad Mobassher Bin Tofa

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Dedicated

To my mother who is no more in this world

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ABSTRACT

Wing In Ground craft (WIG) is relatively a new concept of transportation. It flies very close to underlying surface that increases lift drag ratio. It is more efficient than aircraft and faster than counterpart marine vessels but high power requirement during take-off is the biggest impediment of its growth. Estimating WIG drag during take-off is difficult as both aerodynamic and hydrodynamic force act together unlike planing hull where hydrodynamic force mainly carries the weight of the craft. The aerodynamic force acts at a specific WIG, depends on speed and characteristics of its wing. Planing hull has been preferred for the wing in ground effect craft to gain higher speed necessary for take-off. In this thesis first, a critical review of the WIG craft has been done after that the work concentrates on the problem of estimating take-off resistance. A mathematical model has been described by modifying Savitsky's method through considering aerodynamic effect along with hydrodynamic effect to estimate the resistance of a classical WIG model during take-off in calm water. WIG and planing craft resistances at different speed are compared to understand the effect of aerodynamic force on resistance during take-off. Wind tunnel test has been performed at Universiti Teknologi Malaysia's (UTM) aeronautic laboratory to investigate aerodynamic characteristics of the wing necessary for considering aerodynamic effect during take-off and free running test of the WIG model has been performed at UTM lake to estimate resistance at different velocities. WIG resistance characteristic curve and free running test results have been used to validate the mathematical model. Generally from the comparison between WIG and planing craft it can be seen that as the speed increases, wetted length ratio, trim, draft at transom, hydrodynamic lift coefficient of WIG craft reduce more drastically than that of planing hull, thus resistance reduces sharply during WIG take-off. It was found that the peak resistance to be 30% lower than that of planing hull. Finally it can be concluded from the results obtained, the proposed mathematical model can be useful to estimate WIG take-off drag and power requirement.

ABSTRAK

Wing *In Ground* (WIG) secara relatifnya merupakan konsep baru dalam pengangkutan. Ianya terbang berhampiran dengan permukaan air yang dapat meningkatkan nisbah daya angkat. Konsep ini dilihat lebih berkesan berbanding pesawat udara dan kapal laut. Bagaimana pun ia memerlukan kuasa yang tinggi semasa berlepas seterusnya menjadi halangan bagi perkembangannya. Penganggaran jumlah rintangan WIG semasa berlepas amat sukar dari segi daya aerodinamik dan hidrodinamik yang bertindak serentak berbanding *planing hull* dimana hanya daya hidrodinamik yang bertindak pada badan pesawat. Daya aerodinamik ini bertindak pada WIG tertentu sahaja, bergantung pada halaju dan ciri-ciri sayapnya. *Planing hull* menjadi pilihan dalam kesan pesawat WIG bagi mendapat halaju yang bersesuaian semasa berlepas. Pada permulaan tesis ini, kajian kritikel mengenai WIG telah dibuat, dimana tumpuan diberikan pada kerja-kerja penganggaran rintangan semasa berlepas. Sebuah model matematik telah dihasilkan melalui pengubahsuaian kaedah Savitsky dengan mempertimbangkan kesan aerodinamik dalam anggaran rintangan sebuah model klasic WIG semasa berlepas di permukaan air yang tenang *(calm water)*. Rintangan WIG dan *planing hull* dibandingkan pada halaju yang berbeza bagi memahami kesan daya aerodinamik terhadap daya rintangan semasa berlepas. Ujian terowong telah dijalankan di makmal aeronautik UTM bagi menyiasat ciri-ciri aerodinamik sayap yang perlu dengan mempertimbangkan kesan aerodinamik semasa berlepas, dan ujian *free running* telah dijalankan di tasik UTM untuk menganggarkan jumlah rintangan pada kelajuan yang berbeza. Lengkung ciri-ciri rintangan WIG dan keputusan *free running test* bagi model WIG digunakan untuk mengesahkan model matematik yang digunakan. Secara umumnya, perbandingan antara WIG dan pesawat *planing hull* telah menunjukkan apabila halaju bertambah, nisbah panjang basah (*wetted length ratio*), trim, drauf pada transom dan pekali angkat hidrodinamik pesawat WIG berkurang secara drastik berbanding *planing hull*. Dengan itu, rintangan untuk WIG berkurang dengan ketara semasa berlepas. Ini menunjukkan rintangan puncak bagi WIG adalah 30% lebih rendah daripada *planing hull.* Kesimpulannya, hasil kajian mendapati model matematik ini boleh diguna pakai untuk menganggarkan daya seretan WIG dan kuasa yang diperlukan untuk berlepas.

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NOMENCLATURES

R_T	Total WIG craft drag
R_{hf}	Hull water friction resistance
R_{hw}	Hull Wave-making drag including the spray drag
R_{sww}	Side buoys Wave-making drag
R_{swf}	side buoys Water friction resistance
R_{aw}	Wave-making resistance caused by air cushion
R_a	Air profile resistance of the whole craft
ρ_a	Air density (Ns/m)
$\boldsymbol{\rho}_w$	Water density (Ns/m)
V_s	Craft speed (m/s)
S_a	Reference area for calculating the air profile drag and lift (m^2)
C	Chord length
b_{at}	Air-tunnel beam(m)

b_h	Hull width(m)
b_{sb}	Side buoys width(m)
C_D	Air profile drag coefficient of the craft model
C_v	speed coefficient
$C_{L\beta}$	Hydrodynamic lift coefficient
l_p	Hydrodynamic pressure point measured from transom(m)
λ_w	Wetted length ratio
D	Draft at transom(m)
S	Wetted surface area(m^2)
C_f	Friction drag coefficient
L_T	Total lift force (kg m/s^2)
L_H	Hydrodynamic lift force (kg m/s^2)
L_A	Aerodynamic lift force (kg m/s^2)
C_L	Aerodynamic Lift coefficient of the WIG craft model
$C_{Mc/4}$	Pitching moment Coefficient
W	Total Weight of the craft(Newton)
X_{CP}	Aerodynamic center of the pressure,

A_{cp}	Distance measured from stern transom to X_{cp}(m)
B	Average breadth of hull(m)
LWL	Load water line(m)
β	Dead rise angle(deg)
υ	Viscosity(m^2/s)
Fn_D	Displacement Froude number

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CHAPTER 1

INTRODUCTION

1.1 Back ground

Wing in Ground effect (WIG) vehicles is quite a new concept of designing fast ship which has vast relevance in numerous areas such as transportation of cargo, tourism, rescue operations, military functions. The ground effect (GE) is a expression that defines a lifting system with a increased lift-to-drag ratio while it cruises just above a surface. WIG craft gives a alternate solution to gain higher speed. Naval Architects always will to design faster marine crafts than previous ones, especially after the aircraft was invented. Traditional mono hull or better known as displacement ship could not keep up with the constant demands for speed. By planing hull and multihull this speed limitation were tried to be broken, also hydrofoils and air cushion vehicles were brought into the business to solve the problem. But none of these craft could break the 100 knots speed limit. Another problem that high speed marine crafts counter is higher power requirement which amplifies the rate of energy expenditure that has negative impact both on economics and environment. Viscous drag due to water friction is main reason behind this high power requirement and speed limitation. So wetted surface area minimization is the apparent answer to these problems, this philosophy was used for hovercraft and hydrofoil. Unfortunately, the sea state restricts the speed and longitudinal stability of a hovercraft also foil cavitations reduces the competency of a hydrofoil. Wing in ground effect craft was designed to solve those problems mentioned earlier.

The development of ground effect craft originated from observations made of the landing performance of aircraft in 1920's. A theoretical understanding of ground effect was achieved soon after, in 1921. Later USA and the USSR, became interested in attempting to exploit the potential benefits of ground effect. 1960's saw a number of experimental craft designed by these countries. The USA abandoned efforts to produce ground effect craft in the mid 1960's as they were more interested in Surface Effect Ship development. Germany began work in the late 1960's using the designs of Alexander Lippisch. However USSR was the undisputed leader, in research and development of WIG up to the late 1980's. Under these circumstances the Ministry of Science, Technology and Innovation (MOSTI) Malaysia is providing fund to develop a WIG, first of its kind here in Malaysia.

As for any craft design power estimation is a must, for WIG its need lot of effort to estimate resistance during take-off. Planing hull has been preferred for the wing in ground effect craft(WIG) to gain higher speed necessary to take-off so it is obvious that WIG shares lot of similarity with high-powered planing crafts but key difference between these two is WIG is held by aerodynamic and hydrodynamic pressure while take-off and aerodynamic pressure during cruise, while the planing craft is carried mainly by the hydrodynamic pressure. Analysis of WIG drag forces is laborious and expensive process as high speed towing tank, wind tunnel test are required .The first trait of WIG drag forces is that its drag becomes very low after the craft has been taken off from the water surface into ground effect, which helps it to gain much higher cruise speed than other marine crafts, also during operation over waves a lesser velocity loss occurs. This is a major plus to the WIG compared to other fast marine craft .Another aspect of WIG drag is a higher primary hump compared with other high-speed craft for example surface effect ship, because of the higher hydrodynamic drag of its (WIG) planing hull during take-off. This research has described a mathematical model to estimate WIG drag during take-off.

1.1 Problem statement

To estimate WIG drag during take-off is difficult as both hydrodynamic lift force and aerodynamic lift force act together, by Savitsky's formula it is relatively easy to calculate planing hull drag but to calculate resistance of planing hull that is effected by aerodynamic force(WIG) is different thing. By analyzing photos of a test tank model wetted length and trim angle can be gained but it is expensive, take-off drag also can be estimated based on similar craft designs which require lot of data. A suitable mathematical model is necessary to include the aerodynamic effect on WIG take-off resistance thus to estimate power requirement during take-off more accurately.

1.3 Research Objective

Objectives of the present research are described as follows:

i. To research aero and hydrodynamic effect on a classical WIG model during take-off
ii. To present a mathematical model to estimate take-off power requirement.
iii. To acquire WIG resistance during take-off by free running test

1.4 Scope of Research

The scope of research concentrated on predicting resistance and finding aerodynamic and hydrodynamic effect on a classical WIG during take-off .Through this research a mathematical model has been presented to estimate WIG resistance during take-off . The wind tunnel results will be used as input to combined aerodynamic effect along with hydrodynamic effect on WIG take-off resistance. The free running test results will be used to verify the output of the mathematical model.

1.5 Research Outline

This study starts with the critical review of the Wing in ground effect (WIG) after that it concentrates on the problem of estimating take-off resistance and aerodynamic influence on take-off resistance, then it presents a mathematical model by modifying Savitsky method to estimate take-off resistance. This research particularly depends on several test, Wind tunnel test and free running test; all of these tests are very challenging to perform. A model (1:6) was chosen to perform free running tests before designing the prototype.

REFERENCES

[1] Rozhdestvensky K.V, 1997, Ekranoplans—the GEMs of fast water transport, Institute of Marine Engineering, London, Vol.109, part 1, page 47–74.

[2] Reeves J.M.L, May 1993, The case for surface effect research, platform applications and development opportunities. NATO–AGARD fluid mechnics panel (FMP) symposium in long range and long range endurance operation of aircraft, session 1A, paper no. 4, page 24–27.

[3] Rozhdestvensky K.V, 2000, Aerodynamics of a lifting system in extreme ground effect. Heidelberg: Springer, page 352.

[4] Rozhdestvensky K.V, November 2008, Wing -in-ground effect vehicles, Progress in Aerospace Sciences 42, page 211–283 (www.siencedirect.com).

[5] Hooker, S., 1982, Wingships: Prospect for High-Speed Oceanic Transport, Jane's All the World's Surface Skimmers, Jane's Information Group Ltd., Coulsdon, Surrey.

[6] Hooker S., June 1989, A review of current technical knowledge necessary to develop large scale wing in surface effect craft, Intersociety advanced marine vehicles conference, Arlington, VA, paper 89-1497-CP 5–7, page 367–429.

[7] Liang Yun, Alan Bliault, Johnny Doo, 2009, WIG Craft and Ekranoplan Ground Effect Craft Technology, chapter 1, page 13, Heidelberg: Springer.

[8] Michael Halloran and Sean O'Meara, February 1999, Wing in Ground Effect Craft Review, The Sir Lawrence Wackett Centre for Aerospace Design Technology Royal Melbourne Institute of Technology, Contract Report CR-9802.

[9] Volkov L.D, Ponomarev A.V, Treschevski V.N, Yushin V.I, 1992, Results of aerodynamic research carried out in Krylov institute in support of design of ekranoplans. International Proceedings of the second international conference on high speed ships.

[10] Maskalik A.I, Rozhdestvensky K.V, Sinitsyn D.N, October 1998, A view of the present state of research in aero and hydrodynamics of ekranoplans, International Proceedings of the symposium on fluid dynamics problems of vehicles operating near or in the air–sea interface. Amsterdam, The Netherlands: Research and Technology Organization, page 5–8.

[11] Liang Yun, Alan Bliault, Johnny Doo, 2009, WIG Craft and Ekranoplan Ground Effect Craft Technology, chapter 7, page 225-254, Heidelberg: Springer

[12] Liang Yun, Alan Bliault, Johnny Doo, 2009 ,WIG Craft and Ekranoplan Ground Effect Craft Technology ,chapter 3, page 102-104, Heidelberg: Springer

[13] Liang Yun, Alan Bliault, Johnny Doo, 2009, WIG Craft and Ekranoplan Ground Effect Craft Technology, chapter 9, page 285-287, Heidelberg: Springer.

[14] Knud Benedict, Nikolai Korne, Michael Meyer, Jost Ebert, 2002, Complex mathematical model of the WIG motion including the take-off mode, Ocean Engineering, Vol. 29, page 315–357.

[15] Lai.C., Troesch.A., 1996, A vortex lattice method for high-speed planning, International Journal for Numerical Methods in Fluids, vol. 22, page 495-513.

[16] Savitsky,D., 1992, Hydrodynamic design of planing hulls, American Society of Naval Engineers, page 1-14.

[17] Muller-Graf, B., 1997, Dynamic stability of high speed small craft, WEGEMT Association Twenty-Fifth School Craft Technology, Athens, Greece: Dept. of Nav. Arch. and Mar. Eng., National Technical University of Athens.

[18] Odd M. Faltinsen, Hydrodynamics of High-Speed Marine Vehicles, 2005 chapter 9, page 342-360, Cambridge university press.

[19] Savitsky,D, 1964, Hydrodynamic design of planing hulls, Marine Technology, **1**, 1, page 71–96.

[20] Daniel Savitsky and P. Ward, 1976, "Brown Procedures for Hydrodynamic Evaluation of Planing Hulls in Smooth and Rough Water" Marine Technology, Vol. 13, No. 4, Oct. 1976, page 381-400.

[21] Ikeda, Y., Yokomizo, K., Hamasaki, J., Umeda, N.,Katayama, T., 1993, Simulation of running attitude and resistance of a high-speed craft using a database of hydrodynamic forces obtained by fully captive model experiments, The Society of Naval Architects of Japan ,Vol. 1, page 583–594.

[22] Clement, E. P., Blount, D. L., 1963, Resistance tests of a systematic series of planing hull forms, SNAME Vol.71, page 201–277.

[23] Keuning, J. A., Gerritsma, J., 1982, Resistance tests of a series planing hull forms with 25 degrees deadrise angle, International. Shipbuilding Progress, Vol. 29, page 222–249.

[24] Keuning, J. A., Gerritsma, J., Terwisga, P. F. van, 1993, Resistance tests of a series planing hull forms with 30 degrees deadrise angle and a calculation method based on this and similar systematic series, International Shipbuilding Progress, Vol. 40, page 333–382.

[25] Doctors, L. J., 2007, A Study of Transom-Stern Ventilation, International Shipbuilding Progress, Vol. 07, page 1-14.

[26] Hui Sun, Odd M. Faltinsen, 2006, The influence of gravity on the performance of planning vessels in calm water , Springer Science &Business Media B.V.

[27] Odd M. Faltinsen, Hydrodynamics of High-Speed Marine Vehicles, 2005 chapter 8, page 301-303, Cambridge university press.

[28] Clement, ESP., and Pope, J.D., 1961, " Stepless and Stepped Planing Hulls - Graphs for Performance Prediction and Design," DTMB Report 1490.

[29] Volker Bertram, Practical Ship Hydrodynamics, 2000, page 1-95, Butterworth-Heinemann Linacre House, Jordan Hill, Oxford.

[30] Morgan, W. B. and Lin, W. C., 1998, Predicting ship hydrodynamic performance in today's world. Naval Engineers J., September, page. 91– 98.

[31] Hess, J. L., 1990, Panel methods in computational fluid dynamics. Annual Review of Fluid Mechanics. Vol. 22, page 255–274.

[32] Kwang Hyo Jung, Ho Hwan Chun, Hee Jung Kim, 2008, Experimental investigation of wing-in-ground effect with a NACA6409 section, Journal of Marine Science and Technology, Vol. 13, page 317–327.

[33] W.H. Mason, 2005, Information for wind tunnel experiment, http://www.aoe.vt.edu/%7Edevenpor/aoe3054/manual/app3/text.html#T6[retrieved October 2010]

[34] Wind tunnel, From Wikipedia, the free encyclopedia, http://en.wikipedia.org/wiki/Wind_tunnel [retrieved October 2010]

[35] "Introduction to UTM low speed wind tunnel facility" Brochure, source: Universiti Teknologi Malaysia (UTM) Aeronautic laboratory.

[36] Eagle tree systems , http://www.eagletreesystems.com/support/Manuals/Pro [retrieved January 2011]

[37] Gee, Nigel, 1999, Future Trends in High Speed Vessels, High Speed Vessels Future Development Conference, Victoria, Canada.