

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

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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 kritikal 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 klasik 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)
ρ_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
$C_{M\alpha/4}$	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)
ν	Viscosity(m^2/s)
F_{ND}	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.

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