LONGITUDINAL STABILITY AND MOTION OF TRIMARAN WING IN GROUND EFFECT MODEL DURING TAKE-OFF

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DEDICATION

I dedicate this knowledge to:

My beloved father and mother
Development of science and technology
Welfare of all people in the world

“Nothing is impossible in this world; keep trying, learning and seeking blessing from The God until the end of your life”

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ABSTRACT

Wing in Ground Effect is a relatively new concept in transportation technology. It is more efficient than conventional aircraft and quicker compared to conventional marine vehicles. However WIG is still not widely use as a public transportation. One of the criteria to be fulfilled is stability. Longitudinal stability of WIG craft is still of concern to the designer and the solutions are being investigated. Instability of a small WIG craft occurs when aerodynamic-hydrodynamic phase changes into pure aerodynamic phase during the take-off. In this research, investigations were conducted to determine the longitudinal static and dynamic stability effect of Trimaran WIG craft during takeoff and to verify the factors affecting its stability. Two parameters considered are aerodynamic and hydrodynamic characteristics. The investigation resorts to vortex lattice method and examines the effects of flat ground and end plate on the performance of aerodynamic characteristic of the WIG craft. Planing hull has been chosen for the hull shape of the WIG craft due to higher speed takeoff. The hydrodynamics of prismatic planing surfaces, presented by Savitsky, is used to calculate the hydrodynamic characteristic. Numerical result is compared to the experimental results and against published data. The Static Stability Margin (SSM) for longitudinal static stability of Trimaran WIG model has been investigated and using the classical aircraft motion modification and calculating the aerodynamic, hydrostatic and hydrodynamic forces, the complete equation of motion that uses a small perturbation assumption for WIG during take-off has been derived and solved. Finally, dynamic stability for Trimaran WIG during take-off has been investigated and analyzed using Routh-Hurwitz Stability Criterion and Control Anticipation Parameter (CAP).

ABSTRAK

Kenderaan ‘Wing in Ground’ (WIG) merupakan konsep yang berbanding baru dalam teknologi pengangkutan. Ia lebih cekap dari pesawat konvensional dan lebih pantas berbanding kendaraan air konvensional. Walau bagaimana, WIG masih tidak boleh digunapakai sebagai kenderaan pengangkutan awam. Salah satu kriteria yang perlu dipenuhi adalah kestabilan. Kestabilan melintang kenderaan WIG masih menjadi perhatian para pereka dan penyelesaianya sedang dikaji. Masalah kestabilan kenderaan WIG yang kecil berlaku semasa pertukaran fasa aerodinamik-hidrodinamik kepada fasa aerodinamik sepenuhnya ketika berlepas. Di dalam penyelidikan ini, penyiasatan telah dijalankan untuk menentukan pengaruh kestabilan melintang statik dan dinamik model kenderaan trimaran WIG semasa berlepas dan mengesahkan faktor yang mempengaruhinya. Dua parameter yang dipertimbangkan ialah ciri aerodinamik dan ciri hidrodinamik. Kajian telah memilih kaedah kisi ‘*vortex lattice’* dan memilih kesan tanah rata dengan hujung plat kepada prestasi ciri aerodinamik dan ciri hidrodinamik kenderaan WIG. ‘*Planing hull*’ telah dipilih sebagai bentuk badan kenderaan trimaran WIG disebabkan perlunya kelajuan yang tinggi untuk ia berlepas. Ciri Hidrodinamik permukaan prismatic untuk ‘*planing hull*’ yang dibentangkan oleh Savitsky telah digunakan untuk mengira ciri-ciri hidrodinamik. Keputusan analisis berangka dibandingkan dengan keputusan uji kaji dan data yang telah diterbitkan. Margin Kestabilan Statik (SSM) untuk kestabilan statik membujur model kenderaan trimaran WIG telah dikaji. Dan dengan menggunakan modifikasi pergerakan asas pesawat udara dengan mengira aerodinamik, hidrostatik dan daya hidrodinamik, persamaan lengkap pergerakan yang menggunakan andaian perturbasi kecil, telah diterbitkan dan diselesaikan untuk kenderaan WIG semasa ia berlepas. Akhirnya,kestabilan dinamik Trimaran WIG semasa berlepas telah dikaji dan telah dianalisis menggunakan Kriteria Stabiliti Routh-Hurwitz dan Faktor Kawalan Antisipasi (CAP).

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LIST OF ABBREVIATIONS

WIG	Wing In Ground Effect
CDGE	Chord Dominated Ground Effect
SDGE	Span Dominated Ground Effect
PIV	Particle Image Velocimetry
LDA	Laser Doppler Anemometry
RANS	Reynolds Average Navier-Stokes
VLM	Vortex Lattice Method
BEM	Boundary Element Method
SPM	Surface Panel Method
DHMTU	Department of Hydro-Mechanics of the Marine Technical University
CFD	Computational Fluid Dynamics
ACH	Aerodynamic Center in Height
ACP	Aerodynamic Center in Pitch
SSM	Static Stability Margin
WISES	Wing in Surface effect Ship
AOA	Angle of Attack
LOA	Length over all
BOA	Breadth over all
B	Hull breadth
LST-UTM	Low Speed Wind Tunnel University technology Malaysia
ABB	Allan Bradley
HCH	Hydrodynamic Centre in Heave
AAMV	Aerodynamically Alleviated Marine Vehicle
HCH	Hydrodynamic Centre in Pitch
COG	Centre of Gravity
SPPO	Short Period Pitch Oscillation

Phugoid	Long Period Pitch Oscillation
CAP	Control Anticipation Parameter
EDF	Electric Ducting Propeller
NACA	National Advisory Committee for Aeronautics
COG	Centre Of Gravity
MATLAB	language programming
FORTRAN	language programming
vortex	spinning, often turbulent, flow of fluid
chord	long of the wing
span	width of the wing
hull	body of ship
fuselage	body of airplane
tail	small wing at
EHP	small wing at
RULM	Rectilinear Uniform Level Motion

LIST OF SYMBOLS

Aerodynamic

A	*aspect ratio (b/c)*
b	*wing span (m)*
c	*Chord length (m)*
C_M	*moment coefficient* $(=L/0.5\rho AU^2_\infty)$
C_L	*lift coefficient* $(=L/0.5\rho AU^2_\infty)$
C_D	*drag coefficient* $(=D/0.5\rho AU^2_\infty)$
C_{Di}	*induced drag coefficient*
h/c	*ground clearance*
h_e/c	*endplate ratio*
N	*maximum number of element panel*
c_c	*cord along trailing leg of elemental panel (m)*
α	*angle of attack* $(^0)$
ϕ	*dihedral angle* $(^0)$
σ	*ground influence coefficient*
φ	*endplate influence coefficient*
ψ	*sweep Angle* $(^0)$
ρ	*air density*
Γ	*vortex strength*
F	*influence function geometry of single horshoe*
S	*wing area* (m^2)
U	*free stream velocity (m/s)*
u	*backwash velocity (m/s)*
v	*sidewash velocity (m/s)*

w	*downwash velocity (m/s)*
r_1 , r_2	*vector distance*
h/c	*ratio height ground into chord*
h/b	*ratio height ground into span*
a	*angle of attack*
e	*downwash angle at the tail wing*
z	*damping ratio*
q	*pitch angle*
n	*root of the speed subsidence mode*
w	*frequency*
alt	*lift curve slope of the tail wing*
x,y,z	*distance along X,Y,Z*
X_{ac}	*distance center of aerodynamic from leading edge*
X_{cg}	*distance center of gravity from leading edge*
X_h	*distance center of height from leading edge*
$\overline{X}.\overline{Y}.\overline{Z}$	*body-axis system for plan form*
$\hat{X},\hat{Y},\hat{Z}$	*wind axis system*
$\hat{x},\hat{y},\hat{z}$	*distance along* $\hat{X},\hat{Y},\hat{Z}$
x,y,z	*distance along X,Y,Z*
X,Y,Z	*axis system for horsoe vortex*
X_{ac}	*distance center of aerodynamic from leading edge*
X_{cg}	*distance center of gravity from leading edge*
X_h	*distance center of height from leading edge*
X_H	*distance center of hydrodynamic pitch from leading edge*
$\frac{\partial X}{\partial h}$	*derivatives height into surging*
$\frac{\partial Z}{\partial h}$	*derivatives height into heaving*
$\frac{\partial M}{\partial h}$	*derivatives height into pitching*
Sref	*reference area*

Subscript

U	*backwash*
V	*sidewash*
w	*downwash*
n	*index for elemental panel*
H	*hydrodynamic pitch*
OGE	*out ground effect*
IGE	*in ground effect*
E	*with endplate*
WE	*without endplate*

Hydrodynamic

LOA	*length over all*
LWL	*length water line on (hydro)static condition*
b	*chine beam (average) or beam of planing surface measured between the chine(BPa)*
Ä	*displacement mass or vertical load on water*
∇	*displacement volume*
h	*vertical depth of trailing edge of boat (at keel) below level water surface or depth of keel @ transom*
LCG	*location of the longitudinal centre of gravity , forward of transom*
VCG	*vertical centre of gravity, above baseline*
p	*number of propellers*
r	*number of rudders*
V_s	*boat forward planing velocity or horizontal velocity of planing surface*
b	*deadrise angle (degrees) - average, usually taken @ 0,5 Lp*
e	*propeller shaft line inclination relative to the baseline (or keel line)*
t	*trim (angle between planing bottom and horizontal)*
C_V	*speed coefficient*
FN_∇	*volume Froude number*

C_f	*Schoenherr frictional drag coefficient based on Reynolds number*
ÄC_f	*friction coefficient allowance for roughness of planing surface or Correlation Allowance, Savitsky used CA = 0.0004 & ITTC recommends CA = 0.003 for this friction line.(CA)*
CL_0	*Lift coefficient @ zero deadrise*
CL_β	*lift coefficient with deadrise surface*
L_P	*projected length of chine from transom to bow profile*
L_K	*Projected wetted keel length*
L_C	*Projected wetted chine length measured from transom to spray root (stagnation line) intersection with chine (excluding spray)*
L_M	*Mean wetted length of pressure Area*
B_X	*beam max*
λ	*or LM/b; mean wetted length / beam ratio*
Ä$_\lambda$	*Effective increase in friction area length beam ratio due to spray contribution to drag*
L_{CP}	*longitudinal location of centre of pressure from trailing edge (i.e.transom)*
C_P	*Centre of pressure*
N	*Resultant of pressure (hydrodynamic) and buoyancy (hydrostatic) forces assumed acting normal to hull bottom*
A_P	*projected planing bottom area (excluding external spray strips) or total bottom pressure area*
S_w	*principal wetted surface area (bounded by trailing edge, chines and heavy spray line)*
S_S	*area wetted by spray*
f	*perpendicular distance off shaft line to Centre of Gravity (CG)*
a	*the perpendicular distance between frictional drag-force component Df and CG*
f_a	*Distance between Appendage Drag Da (assumed as acting parallel to keel line) and CG*
g	*acceleration due to gravity (or gravitational constant) = 9.81 m/s2*
R_N	*Reynolds number*
n	*Kinematic viscosity of fluid (salt water @ 20° = 1*10-6)*

V_M	*Average water bottom velocity over the pressure area*
q	*Angle between the keel (centreline) and*
	the outer edge of spray area measured in plane of bottom
ñ	*specific weight of water (or mass density of water)*
D_f	*Frictional Drag-force component along bottom of surface*
D_a	*Appendage Drag (assumed as acting parallel to keel line)*
T	*Propeller thrust along shaft line*
d	*Diameter of shaft or bossing*
c	*distance between N (pressure force applied to centre of pressure)*
	and CG measured longitudinally from transom stern and normal to N
RT	*total resistance*

Dynamic Stability and motion

F_a	*Aerodynamic force*
F_h	*Hydrodynamic force*
F_c	*Control force*
F_d	*disturbance force*
F_g	*gravitational force*
F_p	*Propulsion force*
F_0	*equilibrium state of force*
F'	*perturbation from datum*
$\dot{u}$	*surge displacement*
$\dot{q}$	heave displacement, positive downward
$\dot{w}$	pitch rotation, positive bow up
A	*mass matrix*
B	*damping matrix*
C	*restoring matrix*
D	*influence height into aerodynamic force*
I	*moment inertia*

Superscript

a	*related to aerodynamics*
h	*related to hydrodynamics*
‘	*perturbation value*

Subscript

0	*value at the equilibrium state*
h	derivative with respect to height

Experiment formula

Y_w	*width of wake*
q	*local dynamic pressure*
$q\infty$	*free stream*
C_{mLE}	*moment coefficient from leading edge*
$x(dc)$	distance from leading edge (or other selected reference point)
$\frac{\Delta P}{q}$	*pressure difference at each location*
P_a	*pressure at inlet*
P_b	*pressure at outlet*
Y	*error every airspeed*

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CHAPTER 1

INTRODUCTION

1.1 Background and problem statement

Moving marine vehicles at high speed has been one of the biggest challenges faced by naval architects and hydrodynamic researcher over the years especially after the invention of aircraft, much thought have been given to find different methods that can move ships quickly, Wing In Ground Effect (WIG) Craft is the most successful one in terms of gaining high speed. The phenomenon of ground effect was observed by many researchers since early in the birth of aviation. The advantages of using a high speed craft in ground condition are commonly acknowledged by reduce drag and increase lift. Wieselsberger [0], Reid [0] and Carter [0], hypothetically and experimentally was analyzed the influence of the ground on aerodynamics wings. Analysis of experimental drag of wing with endplate shown effect endplate in aerodynamic characteristic has investigated by Hemke [0]. Absolutely, ground clearances and endplate ratio have influence in static stability margin (SSM). Kumar [0,0], Irodov [0], Zhukov [0], and Staufenbiel [0,0], Chun, and Chang [0], all of them tell about the problem of longitudinal stability in ground condition, where position aerodynamic centre in pitch (ACP) and position aerodynamic in height (ACH) was influenced from the scenery of the longitudinal stability every comparative position. Plentiful studies have been conducted analyzing the influence of the ground effect on wing performance. However, few largely disregarded. Rozhdestvensky [0] presents a summation of research investigating the influence of wing profile and platform on the positioning of the two aerodynamic centers.

All problems above tell us about longitudinal static stability and longitudinal dynamic stability during cruise which means that only aerodynamic affects the stability. However, the stability problem that often occurs on the small WIG craft is when WIG's phase change from hydrodynamic-aerodynamic phase into pure aerodynamic phase during take-off. Collu et al [0] has been tried to solve advance mathematical framework for the longitudinal stability of a high-speed craft with planing hull and aerodynamic surfaces. Eventually, a complete kinematics model is been developed. Their observation illustrates a mathematical method for performance Aerodynamically Alleviated Marine Vehicle (AAMV) in dynamic condition. That vehicle was designed to take advantage of combination aerodynamic forces and hydrodynamic force in high speed craft to get fuel efficiency and to reach further and with a greater payload.

There are similarities between an AAMV with a WIG, when the WIG in phase "aero-hydro" during take-off. Not only the aerodynamic force that worked when she takeoff, but both of aerodynamic force and hydrodynamic force that worked at that moment. In this research, observations were performed to determine aerodynamic characteristic of NACA 6409 dihedral rectangular wing (50-50) of aspect ratio 1-1.5 with taper 0.8. The observation were conducted using vortex lattice method and investigating the influence of "*flat ground*" and endplate on enforcement of a trimaran WIG for relative ground clearances of $0.01 < h/c < 0.2$, with ratio endplate $0.015 < he/c < 0.1$ on angles of attack between 0 and 8°. Planing hull has been chosen for the Wig as high speed is necessary to takeoff .In 1964; a comprehensive paper that summarized previous experimental studies on the hydrodynamics of prismatic planing surfaces was presented by Savitsky. He presented a method for application of these results for the design of moving ships. Besides, many laboratories and research centers have conducted hydrodynamic studies on several fundamental planing hull phenomena. All numerical result will be validated with experimental results or other published work.

After that, the old concept Static Stability Margin (SSM) was modified by adding hydrodynamic factor. Thus, SSM during takeoff will be presented with the new configuration with three criteria, first, " *the position Aerodynamic centre in Pitch (ACP) should be located downstream of the position Aerodynamic Centre in Height (ACH)* ", second, "*the position of center of gravity (COG) of the craft should be located upstream of the aerodynamic center of pitch (ACP)"* and third, "*the position Aerodynamic Centre in Height (ACH) should be located upstream of Hydrodynamic center in Pitch (HCP)"*. The classical aircraft motion has been modified by calculating the aerodynamic force, hydrostatic and hydrodynamic forces, using a small perturbation assumption the full equations of motion WIG during takeoff are derived and solved.

1.2 **Purpose and objective of the study**

The major aim of this investigate is to overpass this problem by investigating a new configuration equation of motion WIG by calculating the equal importance of aerodynamic and hydrodynamic forces in small-disturbance composition. The arithmetical model of this framework was developed to investigate the longitudinal static stability and longitudinal dynamic stability of a trimaran WIG during take-off.

1.3 Scope of this study

i. To estimate aerodynamic characteristic trimaran WIG using vortex lattice method with criteria; NACA 6409 dihedral rectangular wing, aspect ratio 1.25, taper 0.8.
ii. To investigate influence of "*flat ground*" and "*endplate*" on the performance of a trimaran WIG for several ground clearances, with ratio endplate 0.06 on angles of attack between 0 and 8°.
iii. To calculate hydrodynamic characteristic of prismatic planing surfaces using Savitsky method.
iv. To validated the numerical results by experiment or publish work or commercial software.
v. To arrange Static Stability Margin (SSM) criteria on WIG trimaran for investigate longitudinal static stability WIG trimaran during takeoff.
vi. To arrange configuration equation of motion by calculating the equal importance of aerodynamic and hydrodynamic forces in small-disturbance composition for investigate longitudinal dynamic stability WIG trimaran during takeoff.

1.4 Significance of the study

The significance of this study is to investigate longitudinal static stability and dynamic stability of a trimaran WIG model during take-off. Where we should be to calculate aerodynamics characteristic and hydrodynamics characteristic using numerical equation and compare these calculation with experimental data or commercial software.

1.5 Thesis outline

This thesis is managed into seven chapters. There are:

The first chapter provides about the background and problem statement of the study, purpose and objective of the study, scope of the study, significant of the study. Finally, thesis managing is presented.

The second chapter tells about literature review; history of vehicles on ground condition, aerodynamic characteristic of vehicles on ground condition, hydrodynamic of ground effect vehicles, longitudinal static stability of ground effect vehicles, and dynamic stability of ground effect vehicles.

Chapter three provides the research methodology of longitudinal stability and dynamic motion WIG trimaran during takeoff, where the stages of research are initial design model, computational calculation, experimental work, comparison and analysis of computational results with experiments or other published researchers, longitudinal static and dynamic stability.

Chapter four propose mathematical modeling of aerodynamic characteristic wing in ground effect using vortex lattice methods, effect ground effect on lift coefficient, effect endplate on lift coefficient, hydrodynamic wing in ground effect using Savitsky methods, analysis static stability ground effect with new configuration static stability margin, and last on this chapter try propose new configuration equation motion of a trimaran wing in ground effect during take-off for analysis Routh-Hurwitz criteria and Criteria for public transportation(CPT).

Chapter five provides procedure experiment in wind tunnel test at Low Speed Tunnel (LST) UTM and free running test.

Chapter six provides comparison results of computational calculation and experimental, also analytical results

Chapter seven presents the conclusion and suggestion which can be used for further research.

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