Analysis of Lift in a Hovercraft
- Numerical Simulation

Penganalisaan Daya Angkat Hoverkraf
- Simulasi Berangka

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Engineering Campus
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By

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree

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Date ……………………………………………………………….

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This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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Thank you very much. I shall not forget all of your kindness.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

Symbol		Representation
English Symbols		
A	-	Area of triangle
d	-	Size of supply slot
d_s	-	Distance between supply slots
g_x, g_y	-	Pressure gradient respect to *x* and *y*, respectively
h	-	Hovering height
$h_{x,y}$	-	The thickness of air film
i, *j*, *m*	-	Nodes of a triangular element
k	-	Distance between outer most supply slots
l	-	Length between the nodes
N_i, N_j, N_m	-	Shape function
p	-	Pressure
p_a	-	Atmospheric pressure
p_s	-	Supply pressure
p_i, p_j, p_m	-	Nodal potential in *i*, *j* and *m* nodes, respectively
P	-	Power required
t	-	Thickness of the hovercraft hull
V	-	Volumetric flowrate
W	-	Load capacity
x_i, y_i, z_i	-	Nodal coordinates in the *x*, *y* and *z* direction, respectively
Matrix Symbols		
[B]	-	Matrix relating pressure gradient to nodal potential
{*F*}	-	Force vector, load matrix
{g}	-	Gradient matrix
[*k*]	-	Element stiffness matrix
[K]	-	global stiffness matrix
{*P*}	-	Potential function

Greek Symbols

α_i , β_i , γ_i	-	Used to express the shape function
μ	-	Coefficient of dynamic viscosity

Notation of MATLAB Source Code

gcoord	-	Nodal coordinates
lij, ljk, lik	-	Length between nodes
n1, n2, n3	-	1^{st}, 2^{nd} and 3^{rd} connected node for (iel)-th element, respectively
nel	-	Total number of elements
nnode	-	Total number of nodes
xlength	-	Length of the hovercraft in x-axis
ylength	-	Length of the hovercraft in y-axis
xnel	-	Number of element in x-axis
ynel	-	Number of element in y-axis
xnode	-	Number of nodes in x-axis
ynode	-	Number of nodes in y-axis
ynode2	-	Total number of nodes in y-axis
xsize	-	Element size in x-axis
ysize	-	Element size in y-axis
xyzero	-	*x*, *y* coordinates of the origin of the hovercraft dimension
xzero	-	x-coordinate of origin point
yzero	-	y-coordinate of origin point

Other Symbols

$\frac{\delta}{\delta x}, \frac{\delta}{\delta y}$	-	Derivative of a variable with respect to *x* and *y*, respectively
[ ]	-	Denotes a rectangular or a square matrix
{ }	-	Denotes a column matrix
$[\ ]^T$	-	Denotes the transpose of a matrix
$\sum_{i=1}^{e}$	-	Summation of 1^{st} to e^{th} value

ABSTRACT

This final year project report, entitle: 'Analysis of lift in a hovercraft (numerical simulation)', is done by Ho Teik Seng under the supervision of University Sains Malaysia Mechanical School lecturer, Prof. K.N.Seetharamu and guidance from Mechanical School master student 2004/05, Mr Lee Heng Hwa. The analysis is done by using HoverANALYSIS program, which had been written by Mr. Phoon Lam Cheng with the help of MATLAB software. This program is a Finite Element Method based program which compatible to analyze the pressure distribution, load capacity, volumetric flowrate and power required of a hovercraft under certain circumstances. The objectives of this project are to determine the minimum power required for a given lift and the maximum lift for a given power. The specific hovering height, air pressure, number of nodes, number of elements, and other parameters of the hovercraft had been set and analysis carried out to obtain the load capacity, volumetric flowrate and power required for each condition. The effect of number of slots, the way of supply slots placement, distance between supply slots and slot size on to the load capacity, volumetric flowrate and power required have been studied and analyzed. Based on the analysis, the number of supply slots in the hovercraft should be increased in order to obtain minimum power required. However, only 2 supply slots should be installed into the hovercraft with 800mm distance between the supply slots in order to optimize the hovercraft lift.

ABSTRAK

Projek tahun akhir ini bertajuk: Penganalisaan daya angkat hoverkraf (simulasi berangka), adalah disediakan oleh Ho Teik Seng dibawah penyeliaan pensyarah Pusat Pengajian Mekanik Universiti Sains Malaysia, Prof. K.N. Seetharamu dan juga bimbingan daripada siswa ijazah tinggi Pusat Pengajian Mekanik 2004/05, Encik Lee Heng Hwa. Penganalisaan ini telah diselesaikan dengan menggunakan sebuah program bernama HoverANALYSIS yang ditulis oleh Encik Phoon Lam Cheng dengan bantuan perisian MATLAB. Program ini adalah sautu program yang berfungsi berdasarkan Kaedah Unsur Terhingga dan berkemampuan untuk menganalisa penyebaran tekanan, beban yang boleh diangkat, kadar alir isipadu angin, dan kuasa diperlukan oleh hoverkraf dalam keadaan-keadaan tertentu. Objektif projek ini adalah untuk menentukan kuasa minimum yang diperlukan dengan daya angkat tertentu dan juga untuk menetukan daya angkat maksimum yang boleh diperolehi dengan kuasa tertentu dibekalkan. Data seperti ketinggian apungan, tekanan angin, bilangan nod, bilangan unsure, dan parameter-parameter lain dalam hoverkraf ditentukan . Kemudian penganalisaan akan dijalankan demi menperolehi beban yang boleh diangkat, kadar alir isipadu angin, dan kuasa diperlukan untuk setiap situasi tertentu. Kesan-kesan daripada bilangan tiub sumber angin, tempat tiub sumber angin dipasang, jarak antara tiub sumber angin, dan saiz tiub sumber angina ke atas beban yang boleh diangkat, kadar alir isipadu angin, dan kuasa diperlukan telah dikaji and dianalisakan. Daripada penganalisaan yang telah dilakukan, boleh disimpulkan bahawa bilangan tiub sumber angin haruslah ditambahkan demi untuk meminimumkan kuasa yang diperlukan. Walau demikian, hanya 2 tiub sumber angin sahaja harus dipasang ke dalam hoverkraf dengan 800mm jarak antara tiub demi memaksimumkan daya angkat hoverkraf.

CHAPTER 1: INTRODUCTION

1.1 Background and problems of hovercraft lift analysis

Fig 1.1: MicKinJoi - Single person 8Hp hovercraft

Hovercrafts had existed for around 50 years since the production of the first hovercraft, Saunders Roe Nautical One (SR.N1), by Christopher Cockerell in 1950's. But, until today, hovercrafts somehow did not manage to get into the mainstream use of transportation. These are the resultant of several reasons, such as its inability for precise maneuvering, control, its relatively high noise level and its development history (refer to Chapter 2: Literature Review). However, hovercrafts are still a famous vehicle for military, rescue, research and exploration operation, especially those operations which involve wetland or swam. Besides that, many countries are still researching and developing new model and also come out with new concept of hovercraft, such as Seawing (WIG craft) and Aerocon (WIG craft)

A single person 8Hp hovercraft had been designed and fabricated by a team of student from School of Mechanical Engineering, USM in the year 2003/04 under the final year project entitled: 'Hovercraft – Analysis, design and fabrication to move over marshy lands'. They are Mr. Lee Heng Hwa, Mr. Phoon Lam Cheng, and Mr.Lim Jet Khin. Mr. Phoon, who was majoring in hovercraft lift analysis of that project, had written a program with Matlab software to analyze the pressure distribution of the hovercraft by using Finite Element Method. This analysis program was named HoverANALYSIS. However, HoverANALYSIS can only be used to analyze pressure distribution of hovercraft with only 2 supply slots as they design the hovercraft with only 2 supply slots.

1.2 Objectives of this project

This project is to continue past year hovercraft project by analysis the lift in this hovercraft based on the numerical simulation. The three main objective of this project are:

- To come out with a program that can analyze pressure distribution of hovercraft with 3 and 4 supply slots.
- To determine the minimum power required for a given lift, and
- To determine the maximum lift acquired for a given power

1.3 Scope of this project

In order to analyze the hovercraft with more than 2 supply slots, new program had to be come out with as HoverANALYSIS is specially written to analyze hovercraft with only 2 supply slots. Thus, HoverANALYSIS(3slots) and HoverANALYSIS(4slots) had been modified from the original HoverANALYSIS program to run analysis on hovercraft with 3 and 4 slots.

The analysis of hovercraft lift had been carried out by setting a fix value of hovering height, air pressure, number of nodes, number of elements, number of supply slots, and other essential parameters of the hovercraft to obtain the load capacity, volumetric flowrate and power required in each condition. The project had look into the effect of number of slots, the arrangement of supply slots, distance between supply slots, and slot size on to the load capacity, volumetric flowrate and power required to determine the minimum power required and the maximum lift. In this project, all the analysis and studies had been done based on numerical simulation and no experimental methods had been carried out.

CHAPTER 2: LITERATURE REVIEW

The popularity of hovercraft is increasing since the last decade. Although we barely see the usage of hovercraft in our country but hovercrafts are very widely used in western country, such as United State of America and Europe Country. The uses of hovercraft include search and rescue, mass transportation, recreational, research and Military uses.

In English Channel, the hovercraft is used for a long time as passenger ferry to transport passenger, goods, and vehicles. Hovercrafts are very widely used in English Channel regarding to its speed, cargo capacity, and stability. Besides English Channel, it also commonly used in traveling in places such as the Brazilian Amazon river system parks, the mangrove swamp of Bangladesh, the Florida Everglades National Park and the Louisiana wetlands for passenger transportation, research and exploration purposes. Hovercraft does not depend on road conditions and is more accessible than "all terrain" or four wheels drive vehicles. Hence it is also being widely used in many military operations, such as landing troops and equipments, and also rescue operations, involving crossing various terrains.

Hovercraft had being widely used for various kinds of purposes by various organizations. But, which kind of vehicle can be defined as hovercraft and when does it first invented? Based on Encyclopedia Britannica, hovercraft is any of the machines characterized by movement in which a significant portion of the weight is supported by forces arising from air pressures developed around the craft, as a result of which they hover in close proximity to the earth's surface. In other words, a hovercraft is an amphibious vehicle that is supported by a cushion of slightly pressurized air.

The idea of high pressure air jet curtains was developed and the first practical man-carrying hovercraft, Saunders Roe Nautical One (SR.N1), was built in 1950's by Christopher Cockerell, an Englishman who also known as the father of the hovercraft. The hovercraft was classed as "secret" in 1956 with the development contract placed with a British aircraft manufacturer, Saunders Roe. Because of the classification of hovercraft technology after the World War II until 1960's, thus the hovercraft never encourages into the mainstream of vehicle construction companies even after 1960's (this fact was stated in http://www.links999.net). Figure 2.1 shows the photo picture taken by 25th July 1959, when hovercraft SR.N1 first crossed the English Channel after the removal of SR.N1 from secret list in 1958.

Fig 2.1: Christopher Cockerell's Saunders Roe Nautical One (*Source: http://www.hovercraft-museum.org/images/scc21.jpg*)

However, the first recorded design for a hovercraft was in 1716 by Emmanual Swedenborg, a Swedish designer, philosopher and theologian in Sweden's first scientific journal, *Daedulus Hyperboreus* and not in 1950's by Christopher Cockerell. Unfortunately, Swedenborg's project was short-lived and the craft was never built because to operate such a machine required a source of energy that far greater than any available at that time.

In 1870's, Sir John I. Thornycroft, a British Engineer, had built some experimental models on the basis of an air cushion system that would reduce the drag of water on boats and ships. He successfully patented the idea of to create a thin layer of air over the wetted surface of a ship or also known as air-lubricated hulls in 1877. Thornycroft had also developed a number of models with concave hull bottom to contained air bubble forms with cavities but he never solve the problem on how to keep a cushion of air trapped so that it will not escape below the vessel. Therefore, no full scale vessels were built to translate the idea into practice, though the model testing did give favourable results.

In 1882, another idea of reduction of hydrodynamic drag was patented by a Swedish engineer, Gustav de Laval. His experiments of air lubrication for conventional hull form were not successful as the air lubrication created a turbulent mixture of air bubbles and water around the hull, rather than a consistent layer of air to isolate the hull surface and so drag was not reduced. Besides that, the method for retaining the cushion of air was also not yet resolved.

In 1920's, D.K. Warner, the head of Warner Research Laboratories at Tamiama Trail, Sarasota, Florida, had won the boat race in Connecticut, USA by using captured air bubble principal with sidewall craft which had been research and developed by him. Air lubrication has been pursued by engineers and scientists at various times after the early experiments of Gustav de Laval. Instead of creating a drag reducing air film, they found that an additional turbulent layer is added, increasing the water drag. Thus came out the ideas of capturing the air bubble. Warner's sidewall craft was the genesis of surface effect ship (SES) of taday.

After the Great War, engineers and scientists again began exploring the air cushion vehicles and some experimental models came to shape in the early 1920's. But because of many difficulties, these models were developed as flying boat rather than air cushion vehicles. Thus, many flying boats were built during the era of 1920's till 1940's but no real hovercraft came along until the 1950's (after the end of World War 2) by Christopher Cockerell, hovercraft Saunders Roe Nautical One (Figure 2.1).

Christopher Cockerell settled into boat building after his retirement from the British army and he got captivated by Thornycroft's problem of reducing the hydrodynamic drag on the hull of a boat by using some kind of air cushion. Instead of using plenum chamber as Thornycroft, air was pumped into a narrow tunnel circumnavigating the entire bottom and forms an air cushion. In 1955, Cockerell's theory was successfully tested and patented. 4 years later, the hovercraft SR.N1 crossed the English Channel for the first time (Figure 2.1). The SR-N1 was only powered by a single piston engine thus could carry two men. Thus, the true passenger-carrying hovercraft was only first appeared in summer of 1961, the Vickers VA-3.

Fig 2.2: The first passenger carrying and mail service hovercraft, Vickers VA-3 (*Source: http://www.mikekemble.com/mside/hovercraft.html*)

Vickers VA-3 was not only the first passenger carrying hovercraft but also was the first hovercraft mail service in the world. As Vickers VA-3 was powered by two turboprop engines and driven by propellers, thus this 10 tons machine was capable of hovering up to 8 inches above a solid surface, running at top speed of 60 knots and carried a payload up to 2 tons. It was run by British United Airways through Furness Withy Ltd.

The theories and ideas of Sir John I. Thornycroft, Christopher Cockerell, and Rostislav Alexeiev was later been rethink and developed by many other engineers and scientists. Until today, there are also many hovercraft built based on the principle of these people, such as amphibious hovercraft (ACV), sidewall hovercraft (SES), and wing-in-ground effect (WIG) or power augmented ram wing craft (PARWIG).

The amphibious hovercraft is the craft which supported totally by its air cushion with an air curtain or a flexible skirt system around its periphery to seal the cushion of air.

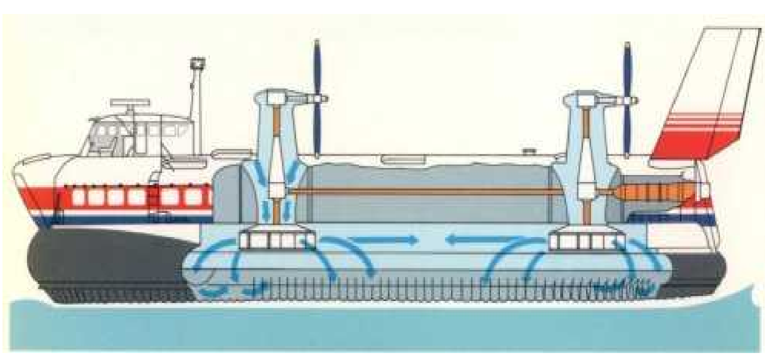

Fig 2.3: Amphibious hovercraft with momentum curtain (*Source: http://www.ic.sunysb.edu/Stu/tmelnico/*)

Sidewall hovercraft is the marine craft which use walls or hulls like a catamaran at the sides to reduce the flexible skirt to seal at the bow and stern. The purpose of the side walls or hulls and the bow seal installation are to minimize the lift power.

Fig 2.4: Chinese passenger sidewall hovercraft model 719-II (*Source: Theory and Design of Air Cushion Craft*)

Wing-in-ground effect craft is the craft which use the increase of lift force due to the ground surface effect and the aerodynamic shaped wing to lift. The craft is supported by dynamic lift rather than a static cushion therefore it also known as low flying aircraft or flarecraft.

Fig 2.5: Flarecraft L-325, an example of wing-in-ground effect craft (Source: *http://foxxaero.homestead.com/indwig_014.html*)

The air cushion craft can be divided to 5 major classes, which are hovercraft, hydrofoil, monohull, catamaran and wing-in-ground craft with respect to their operational features, applications, flexible skirt system, and mean of propulsion. These classes are shown in Figure 2.7 which been adopted from a book entitled: Theory and Design of Air Cushion Craft by L.Yun and A.Bliault.

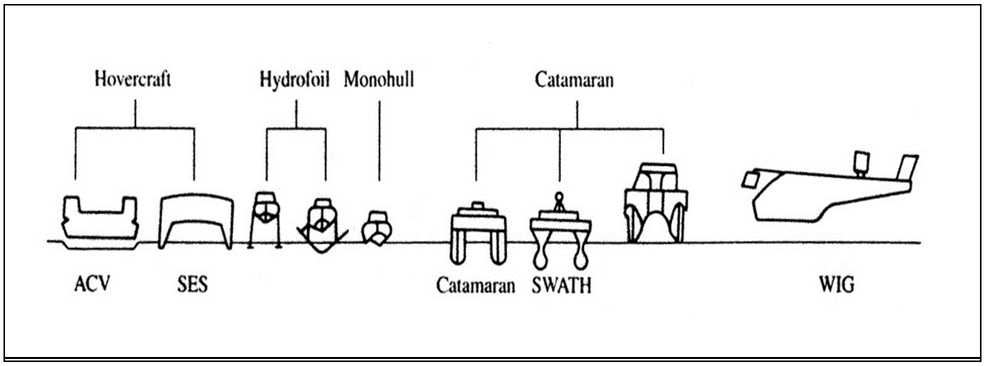

Fig 2.6: Classification of hovercraft (*Source: Theory and Design of Air Cushion Craft*)

Hovercraft are usually been mistaken as a boat or ship as it commonly being use as cross river and cross lake transportation. Actually hovercraft are neither boat nor car, it is a craft that work based on two main principles: the principles of propulsion and lift. Propulsion is that thrust force which allowed the craft to move forward and lift was the main factor which allowed a hovercraft to rise and ride on a cushion of air. The lift forces of hovercrafts are usually produced by using lifting fan. However, for wing-in-ground craft, the lift forces are produced by aerodynamic and wing-in-ground effect. For hovercraft, a skirt is required in order to quarantine the air under the air cushion to provide high pressure lift force. The amount of airflow must be attained properly in order to maintain the right pressure of air in the air cushion. Too much of airflow into the air cushion will causes the craft lift too high above the ground and resulting to craft to tip or crash. Too little airflow will cause craft to remain on ground without hovering capability because of it does not have enough lift. Thus, the lift analysis of hovercrafts is very important in order to come out with a good design of hovercraft.

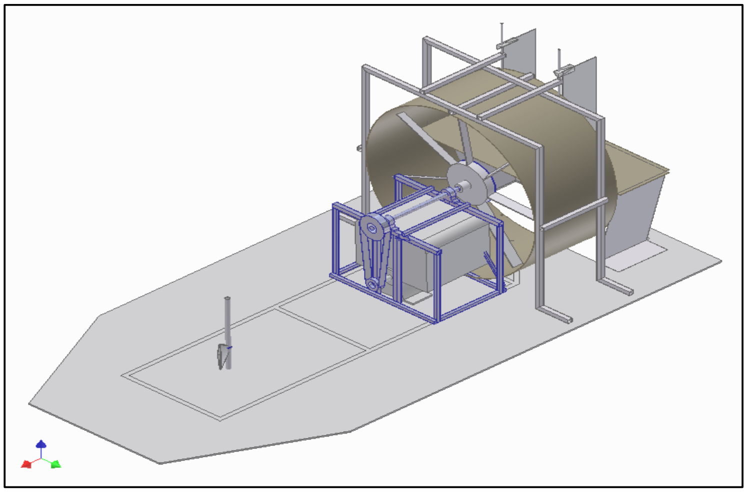

Fig 2.7: Schematic drawing MicKinJoi (*Source: Final Year Project Report 2003/04 - Hovercraft*)

Hovercraft lift analysis had been done on year 2003/04 by Mr. Phoon Lam Cheng under his final year project entitle ‘Hovercraft – Analysis, design and fabrication to move over marshy lands’. Based on the theory of hydrodynamic and finite element method analysis, he had come out with a MATLAB based hovercraft lift analysis program, HoverANALYSIS. This program had been verified refer to ‘Analysis of air film conveyors’ by Dr. Chandra et. al. and proven that it is compatible to analyze the load capacity, volumetric flowrate and power required of a hovercraft [Final Year Project Report 2003/04 by Mr. Phoon Lam Cheng, Chapter 5, Subtopic 5.1 – Verification of result’s value, 33 – 35].

From the analysis of Mr. Phoon, he had concluded that to increase the load capacity of the air film, the width of the supply slot need to be decrease or the distance between the supply slots have to be increased. Besides that, he also found out that the load capacity is independent to the air film thickness. However, by increasing the air film thickness, the volumetric flowrate and the power required will also be increased. ‘Final year project – Hovercraft – Analysis, design and fabrication to move over marshy lands’ had been finished successfully but they only manage to analyze the hovercraft with two supply slots installed parallel to the hovercraft length. Hence, Mr. Phoon had recommended that analysis should be carried out for multiple supply slots hovercraft and also different orientation of the slots. [Final Year Project Report 2003/04 – Hovercraft by Mr. Phoon Lam Cheng]

CHAPTER 3: ANALYSIS

3.1 Introduction

This project is a numerical analysis of lift of a hovercraft, Hovercraft MicKinJoi, which had been designed, analyzed and fabricated by the Mr. Lee Heng Hwa, Mr. Phoon Lam Cheng and Mr. Lim Jet Kit. The program which is use for this analysis project is a program called HoverANALYSIS which been written by the Mr. Phoon with the help of MATLAB software.

3.1.1 Background of the MATLAB Software

MATLAB® (stands for *matrix laboratory*) is a high-performance language for technical computing which has been licensed by Mathwork, Inc. It integrates computation, visualization, and programming in an environment where problems and solutions are expressed in familiar mathematical notation.

Typical uses of MATLAB include math and computation, algorithm development, data acquisition, modeling, simulation, prototyping, data analysis, exploration, visualization, scientific and engineering graphic, and application development (including graphical user interface building).

MATLAB is widely used by engineers and scientists for its easily used built-in function. It is a standard instructional tool for courses in mathematics, engineering, and science for educational purpose and also a tool for high-productivity research, development, and analysis for industrial uses.

The seniors had chosen to use MATLAB to write the program maybe because of its ability to perform numerical analysis, data visualization, and matrix computation.