CONCEPTUAL DESIGN OF A SMALL NON-RIGID AIRSHIP WITH PARTICULAR ATTENTION TO ITS STATIC AND DYNAMIC STABILITY

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To my beloved husband,

Hairul Nizat

For always being there when two hands were just not enough.

To my precious,

Harish Hannan & Imran Hannan

For never failed to put a big smile on my face even on tough day.

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In the name of Allah, Most Gracious, Most Merciful.

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ABSTRACT

Small size airships are traditionally designed and built based on experience rather than scientific approaches. Hence, its design approach has only been discussed in a very limited number of literatures. Thus, with these challenges at hand, a conceptual design study of airship in Malaysia was done to identify and explore the basic technology of airship design. This study focused on the conceptual design, determination of basic specifications and preliminary design of small size non-rigid airship for monitoring missions in Malaysia. The preliminary design focused on static stability, dynamic stability and development of a virtual simulator. The mathematical model of the designed airship for dynamic stability was rederived based on literatures and is then programmed to Graphical User Interface (GUI) with the aid of *Matlab* software. The airship was designed to fulfill the design specification suitable for monitoring with maximum speed of 40 km/h, cruising speed of 20 km/h, operating altitude of 120 m and able to carry payload of at least of 6 kg. The dimension of 10 m length with maximum diameter of 2.3 m was chosen with a pair of 0.25 hp engines to accomplish the desired specification. The designed airship was statically stable with trimmed angle of attack of approximately 0.18 degree. Through mathematical model of airship dynamics, following a detailed procedure including stability considerations, the airship had been analyzed and found to be dynamically stable with low control power and the time taken for the longitudinal response of elevator and vectored thrust to become stable was in the order of approximately 80 seconds while the lateral response of rudder becomes stable in approximately 30 seconds. The result of this study concluded that the designed airship fulfilled the design specification for monitoring mission and the designed airship was statically and dynamically stable during cruising speed. The virtual simulator also effectively provides a better understanding of the response of the designed airship through visualization.

ABSTRAK

Kapal udara bersaiz kecil secara tradisinya direkabentuk dan dibina menerusi pengalaman tanpa pendekatan saintifik. Oleh itu, pendekatan rekabentuknya hanya dibincangkan dalam bilangan literatur yang amat terhad. Walaupun dengan cabaran besar yang dihadapi, kajian rekabentuk konsep kapal udara di Malaysia ini dilakukan bagi mengenalpasti dan meneroka teknologi asas merekabentuk kapal udara. Kajian ini fokus kepada rekabentuk konsep, penentuan spesifikasi asas dan rekabentuk permulaan kapal udara untuk misi pengawasan di Malaysia. Rekabentuk permulaan ini pula fokus kepada kestabilan statik, kestabilan dinamik dan pembangunan penyelaku maya. Model matematik bagi kestabilan dinamik telah diterbitkan semula berdasarkan literatur dan diprogramkan ke antaramuka grafik (GUI) dengan bantuan perisian *Matlab*. Kapal udara direkabentuk bagi memenuhi spesifikasi misi pengawasan udara dengan halaju maksimum 40 km/h, halaju menjajap 20 km/h, altitud kendalian 120 m dan mampu membawa beban bayar sekurang-kurangnya seberat 6 kg. Dimensi panjang 10 m dan diameter maksimum 2.3 m telah dipilih bersama sepasang enjin berkuasa 0.25 hp bagi mencapai spesifikasi yang dikehendaki. Kapal udara yang direka bentuk adalah stabil secara statik dengan sudut serang semasa trim adalah 0.18 darjah. Bagi analisa kestabilan dinamik, sebuah model matematik dinamik kapal udara dibangunkan. Menerusi model dinamik ini, yang melalui prosedur yang terperinci termasuk analisa kestabilan, adalah didapati kapal udara adalah stabil secara dinamik dengan kuasa kawalan yang rendah dan masa yang diambil untuk sambutan membujur bagi penaik dan tujah vector menjadi stabil adalah 80 saat manakala bagi sambutan sisi oleh kemudi menjadi stabil setelah 30 saat. Dapatan kajian ini menyimpulkan kapal udara yang direkabentuk memenuhi spesifikasi yang dikehendaki untuk pengawasan udara dan adalah stabil secara statik dan dinamik semasa menjajap. Penyelaku maya yang dibangunkan juga secara efektif dapat memberikan pemahaman terhadap respon kapal udara yang lebih baik menerusi visualisasi.

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LIST OF SYMBOL

Airship Conceptual Design and Baseline Specification

A	-	Referencel area (volume) $^{2/3}$
a	-	½ length of envelope
B	-	Buoyancy
b	-	Radius of cylinder
C	-	Coefficient
C	-	Chord
D	-	Drag
d	-	Maximum diameter
E	-	Endurance
e	-	Length from chord tip control to chord root control of fins.
$f1.t$	-	Load or tension per unit width
f_2	-	Longitudinal membrane stress
g	-	Gravitational constant
H_p	-	Altitude
I	-	Membrane second moment of area
ISA	-	International Standard Atmosphere
k	-	Percentage of pure helium
k_D	-	Percentage of total drag coefficient
l	-	Length
L_g	-	Gross lift
L_n	-	Net lift
m	-	Mass
M_B	-	Maximum bending moment

N	-	Number
P	-	Power
p	-	Pressure
$\dot{Q}$	-	Fuel consumption rate
Re	-	Reynolds number
r	-	Envelope radius
S	-	Surface area
SL	-	Sea level
T	-	Temperature
t	-	Membrane thickness
Thrust	-	Thrust
U	-	Upstream velocity
u	-	Gust velocity
V	-	Velocity
V_0	-	Total speed
VDI	-	*Verein Deutscher Ingenieure*
Vol	-	Volume
W	-	Weight
w_e	-	Gross weight with fuel tanks empty
w_f	-	Gross weight with fuel tanks full
x	-	x axis coordinate
y	-	y axis coordinate

Greek Letter

α_e	-	Angle of attack at trim
β	-	Side slip
ΔP	-	Total internal pressure
Δp	-	Differential pressure
η_p	-	Propeller efficiency

θ_e	-	Body altitude
μ	-	Fluid viscosity
ρ	-	Density

Subscripts

0	-	Condition at ISA SL
aero	-	Aerodynamic
air	-	Air
ava	-	Available
cg	-	Centre of gravity
cha	-	Characteristic
cr	-	Cruising
ctr	-	Control
cyl	-	Cylinder
D	-	Drag
e	-	envelope
f	-	fin
fte	-	Fin trailing edge
helium	-	Helium
int	-	Internal
max	-	Maximum
p	-	Pressure
p	-	Propeller
req	-	Required
R	-	Root
T	-	Tip
V	-	Volumetric

Airship Stability

A	-	State matrix
a	-	Aerodynamic
a	-	Coordinate of centre of gravity
a1, a2, a3	-	Acceleration at arbitrarily point P relative to the body axes
Adj	-	Adjoint
B	-	Input matrix
B	-	Buoyancy force
b	-	Buoyancy
b	-	Coordinate of centre of buoyancy
C	-	Output matrix
C	-	Coefficient
c	-	Distance from centre of buoyancy to thrust
cb	-	Centre of buoyancy
cg	-	Centre of gravity
cv	-	Centre of volume
D	-	Feedforward matrix
d	-	Maximum diameter
d	-	Thrust coordinate
DCM	-	Direct cosine matrix
det	-	Determinant
e	-	Trim equilibrium
G	-	Transfer function matrix
g	-	Gravitational / Gravitational constant
GUI	-	Graphical User Interface
h	-	Distance from *cb* to *cg*
I	-	Moment of inertia
I	-	Identity matrix
J	-	Product of inertia
k	-	Step magnitude
k'	-	Lamb's inertia ratio for rotation about lateral axis oy
k_1	-	Lamb's inertia ratio for moment along longitudinal axis ox

k_2	-	Lamb's inertia ratio for moment along lateral axis oy
L	-	Airship's length
l	-	Distance from *cb* to *cg* of horizontal fin
l	-	Normalised rolling moment
J	-	Apparent product of inertia
L	-	Rolling moment
Lift	-	Lift
M	-	Pitching moment
$\mathbf{m}$	-	Mass matrix
m	-	Airship mass
m	-	Normalised pitching moment
$\mathbf{N}$	-	Matrix of numerator polynomials
N	-	Yawing moment
n	-	Normalised yawing moment
o	-	Origin of body axes
ox	-	Body axis
oy	-	Body axis
oz	-	Body axis
P	-	Arbitrary chosen point
p	-	Roll rate perturbation
power	-	Power
q	-	Pitch rate perturbation
r	-	Yaw rate perturbation
s	-	Laplace operator
S_{sd}	-	Horizontal/ vertical fin area
T	-	Thrust
T	-	Time constant
U	-	Axial velocity
$\mathbf{u}$	-	Input or control vector
u	-	Axial velocity perturbation
V	-	Lateral velocity
V_0	-	Total velocity
Vol	-	Volume

v	-	Lateral velocity perturbation
W	-	Airship weight
W	-	Normal velocity
w	-	Normal velocity perturbation
X	-	Axial force
$\dot{\mathbf{x}}$	-	Derivative of the state vector with the respect of trim
$\mathbf{x}$	-	State vector
x	-	Body axis reference
x	-	Normalised axial force
Y	-	Lateral force
y	-	Body axis reference
$\mathbf{y}$	-	output vector
y	-	Normalised lateral force
Z	-	Normal force
z	-	Body axis reference
z	-	Normalised normal force

Greek Letter

α	-	Angle of attack
β	-	Sideslip
Δ	-	Characteristic polynomial
δ	-	Control angle
δm	-	Incremental mass
θ	-	Pitch attitude
λ_i	-	Eigenvalues
λ_{ij}	-	Elements of DCM
μ	-	Thrust elevation angle
ρ	-	density
ϕ	-	Roll attitude

ψ	-	Yaw attitude
ζ	-	Damping ratio
ω	-	Frequency

Subscripts

0	-	Total
a	-	Aerodynamic
air	-	Air
b	-	Buoyancy
c	-	Coriolis and centrifugal
d	-	Sideslip mode
$ELVL$	-	Elevator left
$ELVR$	-	Elevator right
e	-	Trim equilibrium
g	-	Gravitational
H	-	Horizontal
h	-	Heave/ Pitch subsidence mode
L	-	Lift
m	-	Moment
P	-	Power
p	-	Port
p	-	Roll rate
q	-	Pitch rate
$RUDB$	-	Bottom rudder
$RUDT$	-	Top rudder
r	-	Yaw rate
δ	-	Control angle
s	-	Starboard
s	-	Surge mode

t	-	Tail
u	-	Axial velocity
V	-	Vertical
v	-	Lateral velocity
w	-	Normal velocity
x	-	Body axis reference
y	-	Body axis reference
y	-	Yaw subsidence mode
z	-	Body axis reference

Examples of Notation

Dimensional derivatives denoted thus

$\mathring{M}_q = \frac{\partial M}{\partial q}$ etc.

Normalised derivatives denoted thus

$y_v = \frac{\partial y}{\partial v}$ etc.

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CHAPTER I

INTRODUCTION

1.1 Overview

An airship is a lighter than air vehicle which produces the significant lift due to aerostatic effect or buoyancy force. It is basically an aircraft that derives its lift from a lifting gas usually helium while it is propelled forward by an engine. It differs from the conventional aircraft in terms of lift producing mechanism. The potential of the airship can be realized in terms of less fuel consumption, high endurance, and ability to hover.

A modern airship's advanced construction and sophisticated control systems make it extremely safe to operate even in bad weather. They do not rival aeroplanes and helicopters, but fulfilled entirely different roles, filling in the gaps left by these more conventional aircraft.

Airships mainly consist of three basic components which are the envelope/hull, gondola and fins as shown in **Figure 1.1**. A typical modern airship is usually equipped with vectored thrust system. Vectored thrust system is used to give convenience over the control during take-off, landing and hovering. The ideal thrust vector system would be available through a full 360 degree rotation. Engineering complexity and cost make this prohibitive, thus a typical vectored thrust moved on a certain degree range up and down the horizontal thrust line.

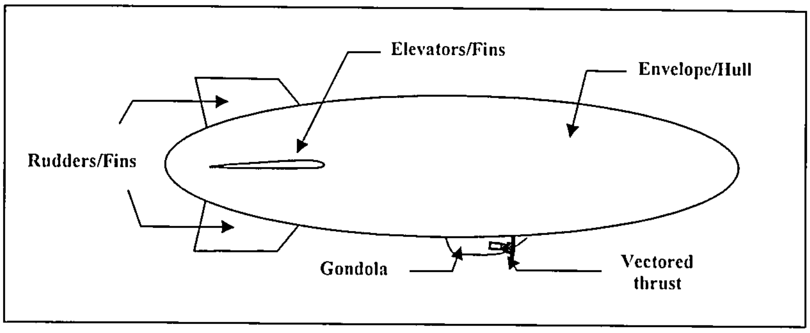

Figure 1.1: Airship's basic components

In the recent years, helicopter is the only way and tool used effectively for aerial surveillance. However, due to its high operational expenses, the usage of helicopters is limited to some specific moments and circumstances. One of the alternatives, which fulfill the need of monitoring from the air and with relatively low cost is by using airships.

For monitoring mission, there are specially designed camera equipments for use with airships. This equipments are used for monitoring prior to a given events that vary from auto racing, sports, border patrol, monitoring traffic condition, flooding areas and fire watching. The camera's image is transmitted to the ground by wave signal, where a receiver picks it up and feed it into network. The airships signal can be put on the air live or taped for replay.

It is not an easy task to fully understand the overall working principles of an airship, where it involves a high level mechanical, electrical and aeronautical based knowledge that needed time, experiences and a wide range of intelligence to cover the entire scientific facts.

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