TRANSIENT AERODYNAMICS EFFECT ON V–TAIL AIRCRAFT IN LATERAL STABILITY

NUR AMALINA BINTI MUSA

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Mechanical Engineering)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

NOVEMBER 2017

Special dedicated to my family:

Arwah Ayah (Omar bin Awang)
Mak (Meriam binti Ahmad)
Arwah Abah (Musa bin Ali)
Ma (Zainab binti Omar)
Faiz (Muhammad Faiz bin Musa)

"Sesungguhnya setiap kesulitan itu disertai dengan kemudahan"
[Al-Insyirah: 5-6]

ACKNOWLEDGEMENT

First of all, I am grateful to The Almighty Allah for giving me this opportunity. This thesis is totally devoted to Arwah Ayah and Ma who keep on believed that I can do everything even it seems hard to others. You were the driving force behind me, instilling courage and determination in all my difficult moments. My appreciation to Assoc. Prof Ir. Dr Shuhaimi Mansor for his patience, assistance, guidance and continuous support throughout my study from Bachelor's to Doctorate. Also would like to thank Dr Wan Zaidi Wan Omar for advice, guidance and helping me to complete my study. I would like to express my gratitude to Airi Ali for helping me throughout my study, without him, I am unable to finish this research work. I also thank to Dr Nik Ahmad Ridhwan Nik Mohd for given me a trust and believe in my capabilities to conduct my research during my proposal defend.

I also wish to thank to all my friends for cheer me up and coloured my life (Nurul Farhanah Muarat, Nor Atiqah Zolpakar). Special thanks to Mazuriah Said for helping me in everything, a words of encouragement and listening ears. Thanks to Nur Syafiqah Jamaluddin and Noor Izzati Hidayah Ab Hamid for spend time to comment on my thesis. Also thanks to Khushairi Amri Kasim for the support to keeping my motivation strong to complete my thesis. Last but not least, thanks to Muhammad Alias Ahmad Pauzi for a words of encouragement and your concern to push me reach the end of the line. I am sincerely grateful meeting you guys.

My sincere acknowledgment also goes to all Aerolab technical staff who has been involved in the project. Also would like to thank my sponsor (MyPhd) by Ministry of Higher Education Malaysia for their funding throughout the study. Finally, I thank all my well-wishers who have directly or indirectly contributed to my research work.

ABSTRACT

The trend in applying unconventional aircraft configurations for aerodynamic efficiency has caused some problems in flight dynamics especially in aircraft stability. Although, the mathematical modelling of flight dynamics has been established, however the accuracy of aerodynamic data, normally in the form of aerodynamic derivatives may affect the actual motion responses of the aircraft in design process for stability and control simulation. The aerodynamic derivatives may differ from small to large aircraft motion amplitude and may also vary in transient conditions. Clear that it is important to establish methods in estimating the aerodynamic derivatives accurately. This research work presents the effort in introducing a reliable method in estimating the aerodynamic derivative for V-tail aircraft in lateral motions focusing on Dutch roll mode using wind tunnel testing technique. Two methods of estimation are presented, first the steady-state measurement by static wind tunnel test and second transient measurement by dynamic oscillatory test. CAMAR UTM-UAV has been used in this study for several V-tail configurations with dihedral angles of 35°, 47°, 55° (later use V35, V47, V55 respectively) including a conventional tail for reference. In static wind tunnel test, the static derivatives of C_{y_β}, and C_{n_β}were measured for different tail configurations within ±25° yaw angle with range of wind speed from 10 m/s to 40 m/s. Meanwhile in dynamic oscillatory test, the transient condition was simulated at range of reduced frequencies, K_m of 0.05 - 0.25 by varying oscillation frequency through various spring stiffness, K_s. Hence, the dynamic oscillatory test was measured within yaw angle (±10°). Static wind tunnel test results showed that within ±10° yaw angle, all configurations possess positive yaw stability. When compare with conventional tail, found that V47 and V55 have higher degree of stability except for V35. For yaw angles more than ±10°, the V-tail showed better stability as it reaches neutral stability later than the conventional tail. However, measurements by static wind tunnel tests indicated there are discrepancies in representing the derivatives during transient condition and unable to measure dynamic derivatives of C_{y_r} and C_{n_r}. Meanwhile, aerodynamic derivatives of C_{y_β}, C_{n_β}, C_{y_r} and C_{n_r} were measured in the dynamic oscillatory test. The result from the dynamic oscillatory test are then compared with static wind tunnel test results and presented in the form of amplification factor. Within tested reduced frequencies, C_{n_β} measured dynamically for all V-tail are more than static measured (amplification factor more than unity). This factor highlights the existence of the transient effects in the estimation of aerodynamic derivatives where it indicated the steady-state measurement underestimated the derivatives. At the same time, the steady-state derivative has also overestimated the aerodynamic damping in Dutch Roll simulation with crosswind input about 50%-90% depending on tail configurations. Meanwhile, through dynamic simulation using state-space equation of Dutch roll motion resulted the V55 has a higher sensitivity in response to crosswind followed by V47 and V35 respectively.

ABSTRAK

Tren penggunaan pesawat bukan konvensional untuk meningkatkan kecekapan aerodinamik telah menyebabkan masalah didalam dinamik penerbangan terutamanya kestabilan pesawat. Walaupun, model matematik telah diperkenalkan akan tetapi ketepatan data aerodinamik iaitu terbitan aerodinamik boleh memberi kesan kepada respon sebenar pesawat terutamanya semasa proses rekabentuk yang melibatkan kestabilan dan kawalan simulasi pesawat. Terbitan aerodinamik berbeza dari gerakan kecil ke gerakan amplitud besar dan juga berubah-ubah didalam keadaan fana. Ini menunjukkan kepentingan untuk memperkenalkan kaedah anggaran yang terbaik diperlukan untuk terbitan aerodinamik. Kajian ini akan memperkenalkan kaedah yang boleh diguna pakai untuk menganggarkan terbitan aerodinamik untuk pesawat berekor V semasa gerakan melintang terutamanya mod olengan Belanda menggunakan kaedah ujian terowong angin. Dua kaedah anggaran telah diperkenalkan iaitu pengukuran mantap melibatkan ujian terowong angin statik dan pengukuran fana oleh ujian dinamik berayun. Model CAMAR UTM-UAV telah digunakan dalam kajian ini yang melibatkan beberape konfigurasi berekor V dengan sudut dwisatah 35°, 47°, 55°(kemudian dikenali V35, V47 dan V55) termasuk ekor konvensional sebagai rujukan. Didalam ujian terowong angin statik, terbitan statik iaitu C_{y_β}, and C_{n_β} telah diukur untuk konfigurasi ekor yang berlainan dalam julat sudut rewang ±25° dengan kelajuan angin dari 10 m/s hingga 40 m/s. Sementara itu, semasa ujian dinamik berayun, keadaan fana telah disimulasikan dalam julat frekuensi setara, K_m 0.05 - 0.25 dengan mempelbagaikan frekuensi berayun melalui beberapa pemalar spring, K_s. Oleh itu, pengukuran ujian dinamik berayun diukur didalam julat sudut rewang (±10°). Ujian terowong angin statik mendapati kesemua konfigurasi ekor mempunyai kestabilan rewang yang positif untuk sudut rewang ±10°. Apabila dibandingkan dengan ekor konvensional, didapati V47 dan V55 mempunyai darjah kestabilan yang tinggi kecuali V35. Untuk sudut rewang yang lebih daripada ±10°, ekor V menunjukkan kestabilan yang lebih baik kerana lewat mencecah kestabilan neutral berbanding ekor konvensional. Walaubagaimanapun, pengukuran oleh ujian terowong angin statik mendapati percanggahan dalam terbitan semasa keadaan fana dan tidak dapat mengukur terbitan dinamik seperti C_{y_r}dan C_{n_r}. Sementara itu, terbitan C_{y_β}, C_{n_β}, C_{y_r} dan C_{n_r} telah diukur didalam ujian dinamik berayun. Perbandingan hasil dari ujian dinamik berayun dan statik dibentangkan dalam bentuk faktor amplifikasi. Didapati C_{n_β} yang diukur secara dinamik untuk semua konfigurasi ekor adalah lebih tinggi dari pengukuran statik (faktor amplifikasi melebihi satu). Ini menunujukkan kewujudan kesan fana didalam pengangaran terbitan aerodinamik dimana pengukuran mantap terkurang anggaran. Pada masa yang sama, terbitan mantap juga terlebih mengangar redaman aerodinamik sebanyak 50%-90% bergantung kepada konfigurasi ekor. Sementara itu, melalui simulasi dinamik menggunakan persamaan keadaan ruang didapati V55 mempunyai kestabilan yang tinggi untuk respon kepada angin lintang diikuti V47 dan V35.

TABLE OF CONTENTS

4 DEVELOPMENT OF TEST FACILITY 82

5 RESULT AND DISCUSSION: STEADY-STATE MEASUREMENT 124

6 RESULT AND DISCUSSION: TRANSIENT MEASUREMENTS 153

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACG	-	Aft Center of Gravity
A/D card	-	Analogue to digital
(AF)	-	Amplification Factor
BMC	-	Balance Moment Centre
CAMAR	-	Consolidated Advanced Model for Aeronautical Research
CFD	-	Computational Fluid Dynamic
CG	-	Center of Gravity
DAQ	-	Data acquisition
ESDU	-	Engineering Sciences Data Unit
FCG	-	Forward Center of Gravity
NSR	-	Noise to Signal Ratio
(PSD)	-	Power Spectral Density
R-C	-	Resistor-Capacitor
(SHM)	-	Simple Harmonic Motion
USAF-Datcom	-	United States Air Force Stability and Control Digital DATCOM
V	-	Volt
V35	-	V-tail with 35° dihedral angle
V47	-	V-tail with 47° dihedral angle
V55	-	V-tail with 55° dihedral angle
fs	-	Full scale
ms	-	Model scale

LIST OF SYMBOLS

A - State matrix

AC_t - Location of aerodynamic chord of the tail

Amp (m/s) - Amplitude of Disturbance Intensity

B - Input matrix (rudder and elevator)

b (m) - Wing span

b_t (m) - Tail span

b_{arm} (m) - Moving arm

C - Disturbance matrix

c_t (m) - Tail chord

$\bar{c}$ (m) - Wing Mean chord

C_a (Nms/rad) - Aerodynamic damping

C_D - Aerodynamic drag coefficient

C_n - Aerodynamic yaw moment coefficient

C_{Roll} - Aerodynamic rolling moment coefficient

C_r (Nms/rad) - Mechanical damping

$C_{L_{\alpha_v}}$ (rad^{-1}) - Vertical tail lift curve slope

C_{n_β} (rad^{-1}) - Yaw moment due to yaw angle/ Aerodynamic yaw moment derivative

$C_{n_{\dot\beta}}$ (rad^{-1}) - Yaw moment due to sidesliping velocity

C_{n_r} (rad^{-1}) - Yaw moment due to yaw rate / Aerodynamic yaw damping derivative

C_{y_β} (rad^{-1}) - Side force due to yaw angle / Aerodynamic side force derivative

C_{y_r} (rad^{-1}) - Side force due to yaw rate / Aerodynamic side force damping derivative

f (Hz) - Oscillation frequency during wind-on condition

f_n (Hz) - Natural frequency of the rig in wind-off
$f_\circ$ (Hz) - Oscillation frequency during wind-off condition
f_d (Hz) - Oscillation or damped frequency
$f_{d_{on}}$ (Hz) - Oscillation or damped frequency during wind-on
$f_{d_{off}}$ (Hz) - Oscillation or Damped frequency during wind-off
f_{LO} (Hz) - Lower limit scaled model frequency
f_{MO}(Hz) - Frequency of interest for the scaled model oscillation frequency
f_{UP} (Hz) - Upper limit scaled model frequency
K_m - Reduced frequency
${K_{m_{UP}}}^*$ - Upper limit reduce frequency for actual full-scaled model
${K_{m_{LO}}}^*$ - Lower limit reduce frequency for actual full-scaled model
$\frac{f_{d_{on}}}{f_{d_{off}}}, \left(\frac{f}{f_\circ}\right)$ - Frequency ratio
g - Disturbance vector
I_{ZZ} (kgm^2) - Mass moment of inertia
K_s(N/m) - Linear spring stiffness
$K_{m_{ms}}$ - Reduced frequency for scaled model
$K_{m_{fs}}$ - Reduced frequency for actual full scaled
K$_\mathrm{p}$ - Steady-state gain to gust input
K_r(Nm/rad) - Torsional stiffness of the mechanical system/ mechanical stiffness
K_a (Nm/rad) - Aerodynamic stiffness
L$_\mathrm{f}$ (m) - Length of fuselage
L (m) - Length of total wing span
l_{FS} (m) - Fuselage length of full scale model
l_{MS} (m) - Fuselage length of scaled wind tunnel model
l_v (m) - Distance from CG to vertical tail aerodynamic center
ℓ_{AC_t} (m) - Distance between pivot point and AC$_\mathrm{t}$
L_v (N) - Lift on vertical tail

N (Nm) - Yawing moment

N_a (Nm) - Aerodynamic yaw moment

N_β (Nm/rad) - Aerodynamic yaw moment stiffness

N_{β_g} (Nm/rad) - Aerodynamic yaw moment stiffness of atmospheric disturbance

N_r (Nms/rad) - Aerodynamic yaw moment damping

N_{r_g} (Nms/rad) - Aerodynamic yaw moment damping of atmospheric disturbance

$\dot{N}_\beta$ ($\frac{Nm}{rad}kgm^{-2}$) - Dimensional derivatives of aerodynamic stiffness / Aerodynamic stiffness

$\dot{N}_r$ ($\frac{Nms}{rad}kgm^{-2}$) - Dimensional derivatives of aerodynamic damping / Aerodynamic damping

N_{δ_r} (s^{-2}) - Rudder control derivatives

Q (kpa) - Dynamic pressure

r (Nms/rad) - Yaw rate

Re - Reynolds Number

S_h (m^2) - Horizontal tail area

S_v (m^2) - Vertical tail area

S_w / S (m^2) - Total wing area of the model /Wing surface area

$T_\circ$ (s) - Wind off period of oscillation

$\left(t_{\frac{1}{2}}\right)_\circ$ (s) - Wind off time to half amplitude

$t_{\frac{1}{2}}$ (s) - Time to half amplitude

U (m/s) - Free stream velocity / Aircraft Velocity / Wind speed

U_c - Control vector

V_{cruise} (m/s) - Cruising speed

V_R (m/s) - Resultant Forward Velocity

V_g (m/s) - Crosswind Velocity

x - State vector

X_b - Axial Force Aircraft body axis

X_f - Axial Force Earth axis

Y_b - Side Force Aircraft body axis

Y_f - Side Force Earth axis

Y_β (N.rad^{-1}) - Aerodynamic side force stiffness

Y_{β_g} (N.rad^{-1}) - Aerodynamic side force stiffness of atmospheric disturbance

Y_r (Ns.rad^{-1}) - Aerodynamic side force damping

α_v (deg) - Angle of attack on vertical tail

σ (deg) - Sidewash angle

β (deg) - Sideslip angle (use as a sideslip angle in simulation model)

β_g (deg) - Atmospheric Disturbance (Crosswind and Lateral Gust) / Relative Crosswind Angle

β_i (deg) - Initial yaw displacement

$\dot{\beta}$ (deg/s) - Model yaw velocity

$\ddot{\beta}$ (deg/s^2) - Model Yaw Acceleration

e_{ss_β} - Steady-state error for sideslip angle

e_{ss_r} - Steady-state error for yaw rate

δ_r (deg) - Rudder Deflection angle

ε_t - Total wake and solid blockage correction

θ_r (deg) - Angle of rotation

ξ - Effective mechanical damping ratio

ψ (deg) - Yaw angle

ϕ (deg) - Phase angle

ψ_g (deg) - Crosswind Angle

ω_d (rad/s) - Oscillation frequency / angular damped frequency

ω_n (rad/s) - Natural frequency

η_v - Efficiency factor of the vertical tail

$+\sigma, -\sigma$ - Standard deviation

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

The external shape of an aircraft general arrangement is known as aircraft configuration. Aircraft configuration design evolves based on mission requirements. Most of the aircraft configurations were designed to satisfy its mission requirements, technology advancements, rules and regulations set by aviation authorities. Development of unconventional aircraft configurations had started as early as 1930s, where most of the attempts were considered unsuccessful due to poor flying and handling qualities with subject to dangerous flight characteristics and were unsafe to fly. Then in mid-1970s, the development of fly by wire flight control system technology made it possible to design unconventional aircraft configurations that are safe to fly and even have excellent handling qualities (Colgren and Loschke, 2002). These had caused the aircraft configuration design to develop from time to time and had led to the development of unmanned aircrafts (UAV) with various configurations that were designed to fulfil their specific missions, operations and requirements. For example, Figure 1.1 shows the variation in aircraft configuration designs related to UAV.

Basically, aircraft configuration design can be divided into three major phases which is conceptual design, preliminary design and detail design. The conceptual and preliminary design phases are called configuration development, which is the process prior to the freeze of the external shape. During the development of a new aircraft concept, the entire aircraft design phase has to be considered as each component is related to other components of the aircraft as shown in Figure 1.2. Clearly one of the important elements to be considered is the stability and control part. This is related to the estimation of accurate aerodynamic stability derivatives which directly affected by the aircraft configurations. Getting the derivatives correct would result in good stability and control at the earliest possible time. This is important to avoid major changes during detail design phase and reduce the development risk as much as possible.

In the conceptual design, the basic configuration arrangement, the size and weight and performance are all being determined through the decision making process and a selection technique (Raymer, 1992; Raymer, 2002; Sadraey, 2013). During preliminary design, an aircraft design concept is subjected to a continued refinements and optimizations (Raymer, 2002). Hence, any new feature of the aircraft must be studied in more detail, including the new testing methods to produce a more comprehensive detailed and accurate data. This new data should increase confidence in the new design. Otherwise, modifications would have been conducted with full knowledge of the new data. Since, the main objective is to freeze the configuration and to improve the confidence level that the new aircraft configuration will work (Raymer, 1992; Sadraey, 2013). There are numbers of disciplines related to the preliminary phase and one of them is the flight mechanics (Torenbeek, 1976; Etkin and Reid, 1996). The flight mechanics can be divided into five areas which are analysis of aircraft performance, stability and control, aircraft sizing, flight simulation and flight testing (Hull, 2007).

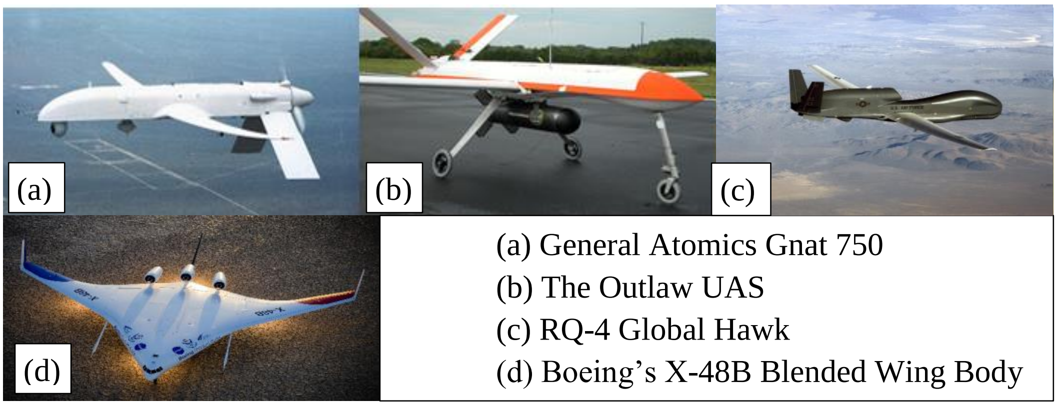

Figure 1.1 Unconventional Aircraft Configuration (Parsch, 2007; Mortimer, 2011; Official United States Air Force Website, 2004; Gibbs, 2016)

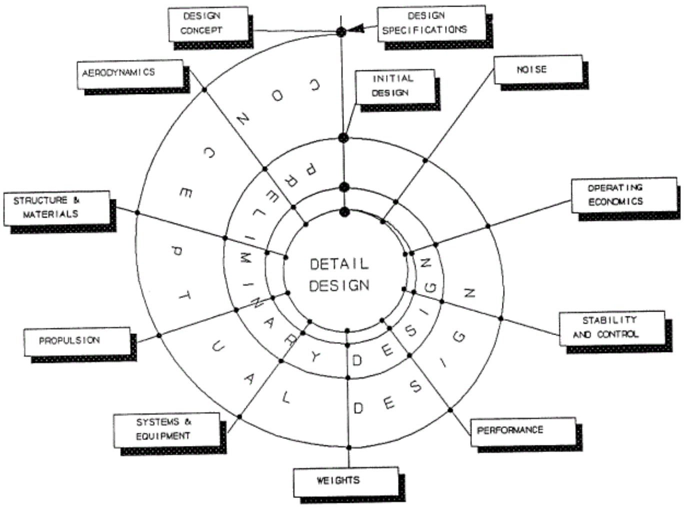

Figure 1.2 Design Spiral (Fielding, 1999)

The design process becomes more challenging if unconventional configuration is applied in aircraft design. This is due to the fact that changing the external shape will consequently change the aerodynamic conditions of the aircraft hence the aerodynamic stability derivatives as well. In addition, most of the available analysis methods are based on conventional aircraft configurations especially related to the estimation of aerodynamic stability derivatives in the aircraft equations of motion such as through the semi-empirical method as in USAF-DATCOM and ESDU (Greenwell, 1998; Murphy and Klein, 2003; Greenwell, 2004; Murphy and Klein, 2011). The formulation assumed the aerodynamic forces and moments could be represented by differentiable functions and therefore expanded into Taylor Series with only the first order linear terms and is applicable for small perturbations. There are known as stability and control derivatives (Murphy and Klein, 2003). A good prediction of the aerodynamic stability and control derivatives at the preliminary phase is significant in getting accurate stability and control derivatives which would lead to good flying qualities and safe flights.

The stability of the aircraft can be divided into two categories which is static and dynamic stabilities. The static stability is the initial tendency of an aircraft to return to its initial equilibrium state after being disturbed from its trim values while the dynamic stability is describing by the time taken to damp to half of its amplitude of disturbances (Nelson, 1998; Sadraey, 2013). The new aircraft configuration should possess dynamically stable state in order to have a good static stability (Nelson, 1998).

Figure 1.3 (a) V-tail Beechcraft Bonanza V35 (Flight Training Blog, 2012) and (b) Bonanza Conventional Aircraft (Aircraft in Focus, 2016)

An aircraft configuration consists of several major components which are fuselage, wing and tail. Each component has different functions. For instance, the conventional tail configuration consists of horizontal tail and vertical tail as in Figure 1.3(b). Both were used to control and direct the aircraft attitude and flight directions. The primary function of horizontal tail is to trim the aircraft longitudinally while vertical tail is related to directional stability (Sadraey, 2013). This is true for unconventional tail designs which are required to cater for both functions as to provide stability to the aircraft during flight. Due to that reason, the tail is designed based on stability, control and trim requirements.

Ever since the invention in aircraft design configurations had evolved with many innovations in empennage design configurations such as the tail configuration like T, V, H, +, Y, and inverted V. It has been the subject of interest for many years due to the visible feature that distinguish various aircraft designs and potentially improve their aerodynamic performance. The main improvements are due to the reduction in wetted surface area and the corresponding decrease in drag (Carrier and Gebhardt, 2005; Hoover et al., 2013). On the others hand, the uniqueness in tail design had caused a major selling point for Beech Model 35 Bonanza. There are efforts to completely remove the tail part like the B-2 aircraft as removing the tail part will also help reduce radar detection (Colgren and Loschke, 2002). Figure 1.4 shows variations of aircraft aft tail designs.

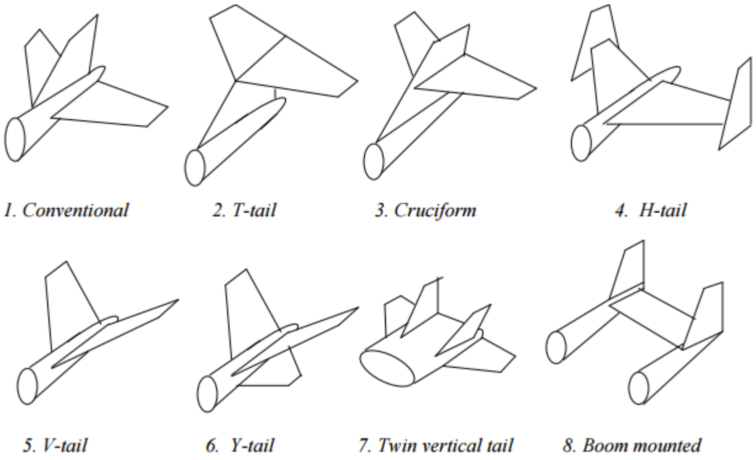

Figure 1.4 Example of Variation of Aft Tail design (Sadraey, 2013)

In this research work, the V-tail empennage configuration is used as a case study since it has potential aerodynamic benefits and a best compromise between tailless and conventional tail design (Carrier and Gebhardt, 2005; DeLuca et al., 2004).

There are frequent reports of cases of pilot's complaints on the difficulties of flying the V-tail aircrafts. There are also several reports of fatal accidents due to loss of control during flight especially related with lateral motion in gusty conditions (unsteady condition) (Landsberg, 1994; Imperial Aviation, 2003; Kroo, 2005; Collins, 2012). This is due to the asymmetrical flow deflect the aircraft path. Hence, cause an aircraft may had been flying outside the tested flight envelope causing difficulties in controlling the aircraft (Murch, 2007; Stenfelt and Ringertz, 2013; Kwatny et al., 2013).

The problem can be studied by proper modelling of the aerodynamic forces and moments in the aircraft equation of motions to describe the aircraft motions and responses. This could be done with good predictions of aerodynamic stability and control derivatives. That is a basic problem in flight dynamics. Consequently, it is prudent to consider the accurate aerodynamic stability derivatives as an input for aircraft dynamic simulation at the earliest design phase. This is due to the changes in the aircraft configuration will influence aircraft dynamic response. At the same time, help to improve the flight control system design by provide an accurate aerodynamic stability derivatives input (Stenfelt and Ringertz, 2013). Since, the aerodynamic stability derivatives of an aircraft represent the vehicle's handling and flying qualities. It is important to develop a reliable method to estimate aerodynamic stability derivatives.

The conventional approach to estimate the aerodynamic stability derivatives is through semi-empirical method (i.e Datcom, ESDU). This method has been used for a long time as a preliminary estimation of aerodynamic stability derivatives especially related with conventional aircraft shape configuration (Nelson, 1998; O'Neill, 2000: Cook, 2013). Although this approach has been quite useful to flight dynamicist in predicting the characteristic for conventional aircraft, there is still a gap in obtaining accurate and reliable aerodynamics derivatives for unconventional aircraft which requires a refinement through wind tunnel test. As the research work is using unconventional configuration, the semi empirical method is not expected to be able to correctly estimate the aerodynamic characteristics of the aircraft with higher confident level. On the other hand, the computational method (i.e.: CFD) is widely used nowadays for estimating the aerodynamic stability derivatives provided the geometry of the aircraft can be described in sufficient detail. The main disadvantages are that it is time consuming to get one derivative and the correct choice of computational algorithm is necessary (O'Neill, 2000; McDaniel et al., 2009). Due to these reasons, a wind tunnel test is considered the safest way to estimate the aerodynamic stability derivatives. However, most of the available wind tunnel tests techniques to estimate aerodynamic stability derivatives are based on steady-state measurements. There is also still some gap in obtaining a reliable method of estimation of aerodynamic stability derivatives in transient condition especially within linear region (Mansor, 2006). This is because in this condition, unsteady aerodynamic phenomena such as flow separation and vortex formation dominate the air flow surround the body. In such situation, force acted on the body will be much different from static and steady condition. As a result, the result may be either under predicted or over predicted.

Based on the issues discussed above, there is a clear need to conduct a further research related to the estimation of aerodynamic stability derivatives especially in transient conditions for unconventional aircraft shapes.

1.2 Problem Statement

Recent studies had shown that V-tail aircrafts have lateral directional stability problem due to the V-tail dihedral effect (Sadraey, 2008; Hoover et al., 2013). This is due to the fact that the vertical surface was removed from the empennage design. The V-tail configuration created a couple effects to the directional stability of an aircraft especially when encountering side flow disturbances. This has created problems in determining accurate aerodynamic stability derivatives which affect the prediction of aircraft stability during design stage. Previous research had confirmed that the accurate estimation of dynamic derivative is also becoming significant to predict aircraft motions (Murch and Foster, 2007).

The semi-empirical method depended on the external shape of the aircraft and was developed mainly for conventional tail aircrafts. The assumptions had to be made for unconventional aircraft configurations to determine the area of the tail (Phillips, Hansen, and Nelson, 2006). For instances for the V-tail configuration, the resulting derivatives of C_{n_β} have to be normalised to vertical and horizontal tail as to estimate it. On the other hand, the estimation of C_{n_r} is based on steady data which is not accurate as the C_{n_r} is a function of time (Murch et al., 2007). These had caused problems in estimating the accurate aerodynamic derivatives.

Many researchers had works to improve the estimations by conducting static wind tunnel test. This experimental method was capable to obtain a greater fidelity than semi-empirical methods due to measurements made from real aerodynamic flow conditions. However, the discrepancy in static wind tunnel test is due to the interpretations of the aerodynamic stability derivatives are taken from the gradient of the graph plotting. But only linear region (i.e: small yaw angles) have been consider characterising the directional stability of the aircraft and this data is known as quasi-static aerodynamic derivatives. A quasi-static aerodynamic derivative is an evaluation of aerodynamic stability derivatives at steady equilibrium condition and for small perturbation motions only. This technique in many cases had caused the underestimation of the aircraft response when aircraft is faced with an abrupt change in gusts or any other disturbances. As the aircraft goes into transient conditions or in higher yaw angles (i.e: nonlinear region) where the aerodynamic derivatives C_{n_β} is no longer valid as a constant value as defined by the gradient from linear region (Cook, 1987).

Due to that the estimation of aerodynamic stability derivatives has now reached a stage that it is believed the transient effects may in some instances be significant as the magnitude of the perturbation is increased and is also subject to transient aerodynamic loads. The problem in estimating aerodynamic stability derivatives are normally encountered in combat aircrafts with highly manoeuvrability (Greenwell, 1998; Murphy and Klein, 2001; Green, Spence and Murphy, 2004; de Oliveira Neto, 2007; Murphy and Klein, 2011). However, this does not mean that transport aircrafts do not encounter these conditions. A transport aircraft would encounter such conditions when the aircraft lost its control due to weather or system failures or even flying at higher angles of attack, causing the aircraft to fly in transient or unsteady flight regimes which is not well understood (Murch and Foster, 2007; Belcastro and Foster, 2010; Jacobson, 2010; Boeing, 2015; International Air Transport Association, 2015).

All the above discussions had pointed that there is a clear need for better aerodynamic stability derivatives estimation technique in order to understand the aircraft dynamic response of V-tail configuration with variation of V-tail dihedral angles (V35, V47, and V55) especially its effect on the stability of the aircraft during transient conditions and in the region of higher yaw angles (i.e: nonlinear region) as to improve the aerodynamic derivatives as an input parameter in the aircraft simulations at preliminary design phase.

1.3 Objective of the Study

The main objective of this research work is to develop a reliable method in estimating the aerodynamic stability derivatives (C_{n_β} and C_{n_r}) for unconventional aircraft especially V-tail configuration in transient flight conditions through dynamic wind tunnel tests.

Another subsequent objective of the research work is to optimise the selection of dihedral angle for V-tail aircraft configurations through wind tunnel testing at different dihedral angles (V35, V47 and V55) compared to the standard conventional configuration. The different dihedral angles have been chosen for investigation because the dihedral factor is known to be a strong determinant to the sensitivity of directional stability.

Finally, the work would continue to simulate a Dutch roll mode of the aircraft with the disturbance input of crosswind and lateral gust for each tail configuration. This work would determine the aircraft flying qualities within disturbance conditions.

The three objectives can be summarised as:

1. Development of dynamic wind tunnel test for accurate estimation of aerodynamic stability derivatives of aircraft in transient case.
2. Optimization of V-tail dihedral angle for steady-state and transient cases.
3. Modelling and simulation of aircraft Dutch roll motion under crosswind and lateral gust effect.

1.4 Scope of the Study

In order to achieve the three main objectives, the scope has been devise as listed:

1. Design and fabrication of 1:5 CAMAR UTM-UAV scale model where the tail part can be removed and installed with different tail configurations (i.e.: V-tail $35^{\circ}, 47^{\circ}, 55^{\circ}$and a conventional tail). The same model will be used in conventional static wind tunnel tests and dynamic oscillatory test.

2. Two types of tests are executed in this research work, which are conventional static wind tunnel tests and dynamic yaw oscillations tests.

3. The static wind tunnel tests was conducted by yawing the wind tunnel model within $\pm 25^{\circ}$ yawing angles with increments of 5°. The yawing angles are expected to cover both linear and nonlinear regions in yaw. Two derivatives were derived from static wind tunnel tests which are static C_{n_β} and C_{y_β}. The study of effect of Reynolds number on aerodynamics stability derivatives is also included.

4. The special dynamic test rig was designed and fabricated to operate in one degree of freedom in which the model is allowed to freely oscillate in the yaw axis. The dynamic tests cover the specific frequency range 0.2 to 2.0 Hz which equivalent to reduced frequency,K_m of 0.0166 to 0.1656 Hz based on fuselage length,l_{FS} of 2.5m and wind speeds from 0 to 40m/s. Then the pilot-tests were performed as to evaluate the performance of the rig. Due to the constraint of rig design, the dynamic oscillatory test is able to measure the lower yawed angles only (linear region). The aerodynamic stability derivatives are then estimated by analysing the oscillatory time response. The response from the dynamic oscillatory tests is governed by the aerodynamic stiffness and damping which then represented the aerodynamic stability derivatives.

5. The aerodynamic stability derivatives involved in this research work are related to lateral-directional motion which are aerodynamic stiffness, C_{n_β} and aerodynamic damping, C_{n_r}. By shifting the location of the pivot point either backward or forward from the previous pivot

point, the side force derivatives, C_{y_β} and side damping derivatives, C_{y_r} can be measured. However, the static wind tunnel test unable to measure the dynamic derivatives ($C_{n_r}$and C_{y_r}). Thus, they are roughly estimated by applying the formulation in Nelson which originated from USAF-DATCOM (known as semi-empirical method).

6. The simulation model with an input disturbance (consist of combination between crosswind and lateral gust) was developed for both steady-state measurement and transient measurement. The simulation model in steady-state measurement will cover the lower to higher yaw angles. Meanwhile, the lower yaw angle simulation is then compared to the simulation model using transient measurements. This is to highlight an improvement of the modelling and simulations due to transient effects in the estimation of the aerodynamic derivatives as input parameters into the aircraft simulation.

1.5 Significance of the Study

The accurate estimation of aerodynamic stability derivatives become a challenge due to the rapid growth in aircraft configuration design. At the same time, the estimation using conventional static wind tunnel test was found to be inaccurate to describe the transient aerodynamic stability derivatives. By understanding the needs of the flight dynamicists and benefit of accurate estimation of derivatives has justifies the need for consideration of estimation of aerodynamic stability derivatives within transient condition. The new testing technique using dynamic oscillatory rig will introduce to cater the problem. The results of the research work will suggest a correlation between steady-state measurement and transient measurement through Amplification Factor (AF). This study also serves as a future references and guidelines for researchers to take into consideration the transient aerodynamic loads in estimation of derivatives.

REFERENCES

Abbott, I., & Von Doenhoff, A. (1949). *Theory of Wing Sections: Including a Summary of Airfoil Data.* New York: Dover Publications.

Abdulrahim, M., & Sheridan, J. (2010). Dynamic Sensitivity to Atmospheric Turbulence of Unmanned Air Vehicles with Varying Configuration. *Journal of Aircraft, 47*(6), 1873-1883.

Abdulwahab, E. N. (2009). Aircraft Dutch Roll and State Variables Analysis Using Yaw Damper and Washout Filter. *Engineering & Technology Journal, 27*(7), 1351-1369.

Abdulwahab, E. N., & Hongquan, C. (2008). Aircraft Response to Atmospheric Turbulence at Various Types of the Input Excitation. *Space Researc Journal, 1*(1), 17-28.

Abzug, M. J. (1999). V-Tail Stalling at Combined Angles of Attack and Sideslip. *Journal of Aircraft, 36*(4), 729-731.

Aircraft in Focus. (2016). *Beech 35 Bonanza*. Retrieved 2012, from Aircraft in Focus - Celebrating History's Finest Flying Machines: http://aircraft-in-focus.com/beech-35-bonanza/

AlphaWire. (2009). Understanding Shielded Cable. New Jersey: AlphaWire. Retrieved July, 2012, from https://www.digikey.it/en/pdf/a/alpha-wire/understanding-shielded-cable

American Bonanza Society. (2002). *V-Tail Fact Sheet-35 through B35 (including 35R).* Retrieved July, 2012, from American Bonanza Society: 192.185.192.40/downloads/VTailFctSht%20-35-B35.pdf

Aviation Safety. (2014). *Statistical Summary of Commercial Jet Airplane Accidents Worldwide Operations | 1959 – 2014.* Aviation Safety Boeing Commercial Airplanes.

Balakrishna, S., Niranjana, T., Rajamurthy, M. S., Srinathkumar, S., Rajan, S. R., & Singh, S. K. (1993). Estimation of Aerodynamic Derivatives Using Dynamic

Wind Tunnel Simulation Technique. *Symposium on System Identification.* 24-25 Nov. Bangalore: NAL's Institutional Repository.

Barlow, J. B., Rae, W. H., & Pope, A. (1999). *Low-Speed Wind Tunnel Testing* (3rd ed.). United States: John Wiley & Sons.

BBC News. (2015). *Why is in-flight turbulence so unpredictable?* Retrieved January, 2016, from BBC News: http://www.bbc.com/news/world-us-canada-35201135

Belcastro, C. M., & Foster, J. V. (2010). Aircraft Loss-of-Control Accident Analysis. *AIAA Guidance, Navigation, and Control Conference.* 2-5 August. Toronto: AIAA 2010-8004.

Belden. (2007). *Cable 101: The Basics of Wire & Cable - Belden.* Retrieved February, 2012, from Belden: www.belden.com/resourcecenter/cablebasics/upload/Cable101all.pdf

Bergmann, A. (2009). Modern Wind Tunnel Techniques for Unsteady Testing-Development of Dynamic Test Rigs. *Hermann Schlichting–100 Years* (pp. 59-77). Springer Berlin Heidelberg.

Bird, J. D., Fisher, L. R., & Hubbard, S. M. (1953). *Some Effects of Frequency on the Contribution pf a Vertical Tail to the Free Aerodynamic Damping of a Model Oscillating in Yaw.* Washington: NACA Report 1130.

Boeing. (2015). *Statistical Summary of Commercial Jet Airplane Accidents: Worldwide Operations 1959 – 2014.* Washington, U.S.: Aviation Safety (Boeing Commercial Airplanes).

Brezoescu, A., Espinoza, T., Castillo, P., & Lozano, R. (2013). Adaptive Trajectory Following for a Fixed-Wing UAV in Presence of Crosswind. *Journal of Intelligent & Robotic Systems, 69*(1), 257-271.

Bryan, G. H. (1911). *Stability in Aviation: An Introduction to Dynamical Stability as Applied to the Motions of Aeroplanes.* London: Macmillan and Co.

Cao, Y., & Yuan, K. (2007). Aircraft Flight Characteristics in Conditions of Windshear and Icing. *The Aeronautical Journal, 111*(1115), 41-49.

Carrier, G., & Gebhardt, L. (2005). A Joint DLR-ONERA Contribution to CFD-based Investigations of Unconventional Empennages for Future Civil Transport Aircraft. *2005 CEAS/KATnet Conference on Key Aerodynamic Technologies.* Bremen: DGLR.

Ceccarelli, N., Enright, J. J., Frazzoli, E., Rasmussen, S. J., & Schumacher, C. J. (2007). Micro UAV Path Planning for Reconnaissance in Wind. *Proceedings of the 2007 American Control Conference.* 11-13 July. New York: IEEE.

Chang, R. C. (2013). Fuzzy Logic-Based Aerodynamic Modeling with Continuous Differentiability. *Mathematical Problems in Engineering, 2013*.

Chang, R. C. (2016). Fuzzy Logic-Based Models of Transport Aircraft in Avoidance of Runway Excursion. *International Conference on Applied Mathematics, Simulation and Modelling* (pp. 228-232). Beijing: AMSM 2016.

Chang, R. C., Lan, C. E., & Guan, W. L. (2014). Evaluations of Flying Qualities for a New and an Aging Transport Aircraft in Severe Atmospheric Turbulence. *29th Congress of the International Council of the Aeronautical Sciences.* 7-12 September. St Petersburg: ICAS 2014.

Chang, R. C., Ye, C. E., Lan, C. E., & Guan, M. (2009). Flying Qualities for a Twin-Jet Transport in Severe Atmospheric Turbulence. *Journal of Aircraft, 46*(5), 1673-1680.

Chang, R. C., Ye, C. E., Lan, C. E., & Guan, W. L. (2010b). Stability Characteristics for Transport Aircraft Response to Clear-Air Turbulence. *Journal of Aerspace Engineering, 23*(3), 197-204.

Chang, R. C., Ye, C. E., Lan, C. E., & Lee, Y. (2010a). Nonlinear and Dynamic Aerodynamic Models for Commercial Transport Aircraft with Adverse Weather Effects. *Mathematical Problems in Engineering, 2010*.

Chudý, P. (2004). Response of a Light Aircraft Under Gust Loads. *Acta Polytechnica, 44*(2), 97-102.

Clemets, B. D. (1986). *Task Force Report V-Tail Bonanza Investigation.* Massachusetts: U.S. Department of Transportation.

Coe, P. L., Graham, A. B., & Chambers, J. R. (1975). *Summary of Information on Low-Speed Lateral-Directional Derivatives Due to Rate of Change of Sideslip [Greek Letter Beta Surmounted by Dot]*. Washington: NASA TN D-7972.

Colby, D. (2005). *The Ultimate V-Tail*. Retrieved July, 2012, from Plane&Pilot: http://www.planeandpilotmag.com/aircraft/pilot-reports/beechcraft/the-ultimate-v-tail/

Colgren, R., & Loschke, R. (2002). To Tail or Two Tails? - The Effective Design and Modeling of Yaw Control Devices. *AIAA Modeling and Simulation*

Technologies Conference and Exhibit. 5-8 August. Monterey: AIAA 2002-4609.

Collins, R. (2012). *What was Wrong with V-Tail Bonanza Pilots?* Retrieved December, 2012, from Air Facts: http://airfactsjournal.com/2012/06/tail-tale-what-was-wrong-with-v-tail-bonanza-pilots/

Cook, M. V. (1987). On the Use of Small Scale Aircraft Models for Dynamic Wind Tunnel Investigation of Stability and Control. *Transactions of the Institute of Measurement and Control, 9*(4), 190-197.

Cook, M. V. (2013). *Flight Dynamics Principles: A Linear Systems Approach to Aircraft Stability and Control* (3rd ed.). Massachusetts: Elsevier Ltd.

Davison, P. M., di Bernardo, M., & Lowenberg, M. H. (2003a). Modelling and Control of a Single Degree-of-Freedom Dynamic Wind Tunnel Rig. *2003 European Control Conference (ECC)* (pp. 2242-2247). 1-4 September. Cambridge: IEEE.

Davison, P. M., Lowenberg, M. H., & di Bernardo, M. (2003b). Experimental Analysis and Modelling of Limit Cycles in a Dynamic Wind-Tunnel Rig. *Journal of Aircraft, 40*(4), 776-785.

de Oliveira Neto, P. J. (2007). *An Investigation of Unsteady Aerodynamic Multi-axis State-Space Formulations as a Tool for Wing Rock Representation.* Doctoral Dissertation. Virginia Polytechnic Institute and State University.

DeLuca, A. M., & Reeder, M. F. (2004). Experimental Investigation into the Aerodynamic Properties of a Flexible and Rigid Wing Micro Air Vehicle. *24th AIAA Aerodynamic Measurement Technology and Ground Testing Conference.* 28 June-1 July. Portland: AIAA 2004-2396.

Doshi, A. A., Singh, S. P. N., & Postula, A. J. (2013). An Online Motion Planning and Control Strategy for UAVs in Wind using Reduced Order Forward Models. *Proceedings of Australasian Conference on Robotics and Automation.* Sydney: ARAA.

Dyer, D. J., Lewis, D. J. G., & Stevenson, A. (1995). Control and Guidance of a UMA using GPS. *IEE Colloquium Control and Guidance of Remotely Operated Vehicles* (pp. 9/1-9/3). 6 June. London: IET.

Etele, J. (2006). *Overview of a Wind Gust Modelling with Application to Autonomous Low-Level UAV Control.* Carelton University, Mechanical and Aerospace Engineering Department, Ottawa.

Etkin, B., & Reid, L. D. (1996). *Dynamics of Flight: Stability and Control* (3rd ed.). New York: John Wiley & Sons.

Fielding, J. P. (1999). *Introduction to Aircraft Design.* Cambridge: Cambridge University Press.

Fisher, L. R. (1956). *Experimental Determination of the Effects of Frequency and Amplitude on the Lateral Stability Derivatives for a Delta, a Swept, and an Unswept Wing Oscillating in Yaw.* Washington: NACA RM L56A19.

Fisher, L. R., & Wolhart, W. D. (1952). *Some Effects of Amplitude and Frequency on the Aerodynamic Damping of a Model Oscillating Continously in Yaw.* Washington: NACA TN 2766.

Fletcher, H. (1971). *Comparison of Several Methods for Estimating Low Speed Stability Derivatives for Two Airplane Configurations.* Langley Research Center. Hampton, Va: National Aeronautics and Space Administration. Retrieved from NASA TN D-6531

Flight Training Blog. (30 July, 2012). *Photo of the Day: V is for Victory*. Retrieved 2012, from AOPA - your freedom to fly: http://blog.aopa.org/flighttraining/?tag=bonanza

Foster, J. V., Cunningham, K., Fremaux, C. M., Shah, G. H., & Stewart, E. C. (2005). Dynamics Modelling and Simulation of Large Transport Airplanes in Upset Conditions. *AIAA Guidance, Navigation, and Control Conference and Exhibit.* 15-18 August. San Francisco: AIAA 2005-5933.

Gatto, A., & Lowenberg, M. H. (2006). Evaluation of a Three-Degree-of-Freedom Test Rig for Stability Derivative Estimation. *Journal of Aircraft, 43*(6), 1747-1762.

Gerlach, O. H. (1971). *The Determination of Stability Dervatives and Performance Characteristics from Dynamic Manoeuvres.* Delft: Delft University of Technology Report VTH-163.

Ghosh, A. K., Raisinghani, S. C., & Khubchandani, S. (1998). Estimation of Aircraft Lateral-Directional Parameters Using Neural Networks. *Journal of Aircraft, 35*(6), 876-881.

Gibbs, Y. (3 Februari, 2016). *X-48B Blended Wing Body*. Retrieved December, 2016, from NASA Langley Research Center (NASA): https://www.nasa.gov/centers/dryden/research/X-48B/index.html

Gili, P., Visone, M., Lerro, A., De Vivo, F., & Scognamiglio, G. (2015). A New Approach for the Estimation of Longitudinal Damping Derivatives: CFD Validation on NACA 0012. *WSEAS Transactions on Fluid Mechanics, 10*, 136-144.

Goman, M., & Khrabrov, A. (1994). State-Space Representation of Aerodynamic Characteristics of an Aircraft at High Angles of Attack. *Journal of Aircraft, 31*(5), 1109-1115.

Gordon Leishman, J. (2006). *Principles of Helicopter Aerodynamics* (Vol. 2th ed). Cambridge, United Kingdom: Cambridge University Press.

Green, L. L., Spence, A. M., & Murphy, P. C. (2004). Computational Methods for Dynamic Stability and Control Derivatives. *42nd AIAA Applied Aerospace Sciences Conference and Exhibit.* 5-8 January. Reno: AIAA 2004-0015.

Greenberg, H. (1941). *Comparison of Vee-Type and Conventional Tail Surfaces in Combination with Fuselage and Wing in the Variable-Density Tunnel.* Washington: NACA Technical Note No. 815.

Greenwell, D. I. (1998). Frequency Effects on Dynamic Stability Derivatives Obtained from Small-Amplitude Oscillatory Testing. *Journal of Aircraft, 35*(5), 776-783.

Greenwell, D. I. (2004). A Review of Unsteady Aerodynamic Modelling for Flight Dynamics of Manoeuvrable Aircraft. *AIAA Atmospheric Flight Mechanics Conference and Exhibit.* 16-19 August. Providence: AIAA 2004-5276.

Grishin, I., Khrabrov, A., Kolinko, A., Sidoryuk, M., & Vyalkov, A. (2014). Wind Tunnel Investigation of Critical Flight Regimes Using Dynamically Scaled Actively Controlled Model In 3 DOF Gimbal. *29th Congress of the International Council of Aeronautical Sciences.* 7-12 September. St Petersburg: ICAS 2014.

Habib, M., Quimby, P. W., Chang, S., Jackson, K., & Cummings, M. L. (2011). Wind Gust Alerting for Supervisory Control of a Micro Aerial Vehicle. *2011 IEEE Aerospace Conference.* 5-12 March. Montana: IEEE.

Henderson, A. P. (2002). *Neural Network Model of Unsteady, Nonlinear Aerodynamics.* Master thesis. University of Tennessee, Knoxville.

Hoe, G., Owens, D. B., & Denham, C. (2012). Forced Oscillation Wind Tunnel Testing for FASER Flight Research Aircraft. *AIAA Atmospheric Flight Mechanics Conference.* Minneapolis: AIAA 2012-4645.

Hoh, R. H., Mitchell, D. G., Ashkenas, I. L., Klein, R. H., Heffley, R. K., & Hodgkinson, J. (1982). *Proposed MIL Standard and Handbook - Flying Qualities of Air Vehicles. Volume 2. Proposed MIL Handbook.* AFWAL TR-82-3081.

Hoover, K., Fowler, W. T., & Stearman, R. O. (n.d.). *Studies in Ethics, Safety, and Liability for Engineers : The V-tail Bonanza*. Retrieved April, 2013, from Texas Space Grant Consortium: http://www.tsgc.utexas.edu/archive/general/ethics/vtail.html

Howe, D. (2000). Aircraft Conceptual Design Synthesis. In *Butterfly Tail* (1st ed., p. 43). London and Bury St Edmunds, U.K.: Professional Engineering Publishing.

Huang, M., & Wang, Z. W. (2015). A Review of Wind Tunnel Based Virtual Flight Testing Techniques for Evaluation of Flight Control Systems. *International Journal of Aerospace Engineering, 2015,* 1-22.

Hull, D. G. (2007). *Fundamental of Airplane Flight Mechanics* (1st ed.). New York: Springer Berlin Heidelberg.

Ignatyev, D. I., & Khrabov, A. N. (2014). Model of the Unsteady Aerodynamic Characteristics at High AOA with Nonlinear Dependency in Angular Rate. *29th Congress of the International Council of the Aeronautical Sciences.* 7-12 September. St Petersburg: ICAS 2014.

Imlay, F. H. (1938). *The Estimation of the Rate of Change of Yawing Moment with Sideslip.* Washington: NACA Technical Notes No. 636.

Imperial Aviation. (2003). *Pilot report - Beech Bonanza V-tail*. Retrieved July, 2012, from PlaneCheck: http://www.planecheck.com/bonanza.htm

International Air Transport Association (IATA). (2015). *Loss of Control In-Flight Accident Analysis Report 2010-2014.* Montreal: International Air Transport Association.

Jacobson, S. R. (2010). Aircraft Loss of Control Causal Factors and Mitigation Challenges. *AIAA Guidance, Navigation and Control Conference.* Toronto: AIAA 2010-8007.

Kilgore, R. A., & Averett, B. T. (1964). A Forced-Oscillation Method for Dynamic-Stability Testing. *Journal of Aircraft, 1*(5), 304-305.

Kroo, I. (2005). *Tail Design and Sizing.* Retrieved 13 December, 2012, from Aircraft Aerodynamics and Design Group: http://adg.stanford.edu/aa241/stability/taildesign.html

Kroo, I. (2005). *Tail Design and Sizing*. Retrieved November, 2012, from Aircraft Aerodynamics and Design Group: http://adg.stanford.edu/aa241/stability/taildesign.html

Kroo, I. (2007). *AA-200B Applied Aerodynamics II.* Retrieved from Aircraft Aerodynamics and Design Group: adg.stanford.edu/aa200b/lecturenotes/lecture13.pdf

Kumar, R., Ghosh, A. K., & Misra, A. (2013). Parameter Estimation from Flight Data of Hansa-3 Aircraft Using Quasi-Steady Stall Modeling. *Journal of Aerospace Engineering, 26*(3), 544-554.

Kwatny, H. G., Dongmo, J. E. T., Chang, B. C., Bajpai, G., Yasar, M., & Belcastro, C. (2013). Nonlinear Analysis of Aircraft Loss of Control. *Journal of Guidance, Control, and Dynamics, 36*(1), 149-162.

Lamar, J. E., Capone, F. J., & Hall, R. M. (2003). AWS Figure of Merit (FOM) Developed Parameters From Static Transonic, Model Tests. *41st Aerospace Sciences Meeting and Exhibit.* 6-9 January. Reno: AIAA 2003-745.

Lan, C. E., Bianchi, S., & Brandon, J. M. (2008). Estimation of Nonlinear Aerodynamic Roll Models for Identification of Uncommanded Rolling Motions. *Journal of Aircraft, 45*(3), 916-922.

Lan, C. E., Kaiyuan, W. U., & Jiang, Y. U. (2012b). Flight Characteristics Analysis Based on QAR Data of a Jet Transport During Landing at a High-altitude Airport. *Chinese Journal of Aeronautics, 25*, 13-24.

Lan, C. T. E., Keshmiri, S., & Hale, R. (2012a). Fuzzy-Logic Modeling of a Rolling Unmanned Vehicle in Antarctica Wind Shear. *Journal of Guidance, Control and Dynamics, 35*(5), 1538-1547.

Landsberg, B. (1994). *Bonanza Safety Review*. Retrieved December, 2012, from AOPA: https://www.aopa.org/news-and-media/all-news/1994/february/pilot/bonanza-safety-review

Lee, R. G., & Zan, S. J. (2002). Wind Tunnel Testing to Determine Unsteady Loads on a Helicopter Fuselage in a Ship Airwake. *23rd International Congress of the Aeronautical Sciences.* 8-13 September. Toronto: ICAS 2002.

Lee, Y. N., & Lan, C. E. (2000). Analysis of Random Gust Response with Nonlinear Unsteady Aerodynamics. *AIAA Journal, 38*(8), 1305-1312.

Liu, X., Liu, W., & Zhao, Y. (2015). Unsteady Vibration Aerodynamic Modeling and Evaluation of Dynamic Derivatives Using Computational Fluid Dynamics. *Mathematical Problems in Engineering, 2015*.

Loeser, T., & Bergmann, A. (2003). Development of the Dynamic Wind Tunnel Testing Capabilities at DNW-NWB. *41st Aerospace Sciences Meeting and Exhibit.* 6-9 January. Reno: AIAA 2003-453.

Louge, M. Y. (2004). *Mars Unmanned Aircraft 2003-2004.* New York: Oysseus Team, Cornell University.

Luchtenburg, D. M., Rowley, C. W., Lohry, M. W., Martinelli, L., & Stengel, R. F. (2015). Unsteady High-Angle-of-Attack Aerodynamic Models of a Generic Jet Transport. *Journal of Aircraft, 52*(3), 890-895.

Lykins, R. (2013). *Unsteady Aerodynamic and Dynamic Analysis of the Meridian UAS in a Rolling-Yawing Motion.* Master thesis. University of Kansas.

Mansor, S. (2006). *Estimation of Bluff Body Transient Aerodynamic Loads Using an Oscillating Model Rig.* Doctoral Dissertation. Loughborough University.

Mansor, S., & Passmore, M. (2011). Measurement of a Bluff Body Aerodynamic Yaw Moment Magnification and Damping Using a Dynamic Wind Tunnel Facility. *Journal of Applied Mechanic, 78*(3), 031004-1.

Mansor, S., & Passmore, M. A. (2013). Effect of Rear Slant Angle on Vehicle Crosswind Stability Simulation on a Simplified Car Model. *International Journal of Automotive Technology, 14*(5), 701-706.

McDaniel, D. R., Cummings, R. M., Bergeron, K., Morton, S. A., & Dean, J. (2009). Comparisons of Computational Fluid Dynamics Solutions of Static and Manoeuvring Fighter Aircraft with Flight Test Data. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering. 223*, pp. 323-340. SAGE Journals.

McRuer, D. T. (1994). Interdisciplinary Interactions and Dynamic Systems Integration. *International Journal of Control, 59*(1), 3-12.

Morris, R. L. (1966). Utilization of a free oscillation wind tunnel model in conjunction with an analog computer to determine the dynamic stability derivatives. *AIAA Aerodynamic Testing Conference.* 21-23 September. Los Angeles: AIAA 66-770.

Mortimer, G. (15 August, 2011). *Griffon Aerospace Introduces the Extended Range Outlaw UAV*. Retrieved 2012, from sUAS News - The Business of Drones: https://www.suasnews.com/2011/08/griffon-aerospace-introduces-the-extended-range-outlaw-uav/

Murch, A. M. (2007). *Aerodynamic Modelling of Post-Stall and Spin Dynamics of Large Transport Airplanes.* Master Thesis. Georgia Institute of Technology.

Murch, A. M., & Foster, J. V. (2007). Recent NASA Research on Aerodynamic Modeling of Post-Stall and Spin Dynamics of Large Transport Airplanes. *45th AIAA Aerospace Sciences Meeting and Exhibit.* 8-11 January. Reno: AIAA 2007-463.

Murphy, P. C., & Klein, V. (2001). Estimation of Aircraft Unsteady Aerodynamic Parameters from Dynamic Wind Tunnel Testing. *AIAA Atmospheric Flight Mechanics Conference and Exhibit.* 6-9 August. Montreal: AIAA 2001-4016.

Murphy, P. C., & Klein, V. (2003). Validation of Methodology for Estimating Aircraft Unsteady Aerodynamic Parameters from Dynamic Wind Tunnel Tests. *AIAA Atmospheric Flight Mechanics Conference and Exhibit.* 11-14 August. Austin: AIAA 2003-5397.

Murphy, P. C., & Klein, V. (2011). Estimation of Unsteady Aerodynamic Models from Dynamic Wind Tunnel Data. *NATO RTO AVT-189 Specialist Meeting.* 12-14 October. Portsdown West: NTRS RTO-MP-AVT-189.

Murphy, P. C., Klein, V., & Frink, N. T. (2016). Nonlinear Unsteady Aerodynamic Modeling Using Wind-Tunnel and Computational Data. *Journal of Aircraft, Article in advance*, 1-25.

Musa, N. A., Mansor, S., Ali, A., Wan Omar, W. Z., Abdul Latif, A., & Perumal, K. (2014). Effects of Aircraft Tail Configurations on Sensitivity to Yaw Disturbances. *Applied Mechanics and Materials, 629*, 197-201.

Nelson, R. C. (1998). *Aircraft Stability and Automatic Control* (2nd ed.). McGraw-Hill.

Nexans. (2013). *Why Screening Screened Cabling vs Unscreened.* Retrieved June, 2014, from Nexans UK&Ireland: http://www.nexans.co.uk/eservice/UK-en_GB/fileLibrary/Download_540239149/UK/files/FTP%20vs%20UTP_V5_GBA_HFO%20DWI2%20NR3_PBE_V2_1.pdf

Nicolaides, J. D., & Eikenberry, R. S. (1966). Dynamic Wind Tunnel Testing Techniques. *AIAA Aerodynamic Testing Conference.* 21-23 September. Los Angeles: AIAA 66-752.

Nicolosi, F., Vecchia, P. D., & Ciliberti, D. (2013). An Investigation on Vertical Tairplane Contribution to Aircraft Sideforce. *Aerospace Science and Technology, 28*, 401-416.

Noback, R. (1986). Comparison of Discrete and Continuous Gust Methods for Airplane Design Loads Determination. *Journal of Aircraft, 23*(3), 226-231.

Noor, A. M., & Mansor, S. (2013). Measuring Aerodynamic Characteristics Using High Performance Low Speed Wind Tunnel at Universiti Teknologi Malaysia. *Journal of Applied Mechanical Engineering, 3*(1).

Official United States Air Force Website. (27 October, 2014). *RQ-4 Global Hawk*. Retrieved 5 May, 2017, from U.S. Air Force: http://www.af.mil/About-Us/Fact-Sheets/Display/Article/104516/rq-4-global-hawk/

Olwi, I. A. (1995). Side Gust Loads on a Fighter Aircraft During Maneuver. *20th Atmospheric Flight Mechanics Conference.* 7-10 August. Baltimore: AIAA 95-3465.

O'Neill, C. R. (2000). *Determination of Flight Stability Coefficients using a Finite Element CFD.* Oklahoma State University, Mechanical and Aerospace Engineering, Stillwater, Oklahoma.

Owens, D. B., Brandon, J. M., Croom, M. A., Fremaux, C. M., Heim, E. H., & Vicroy, D. D. (2006). Overview of Dynamic Test Techniques for Flight Dynamics Research at NASA LaRC (Invited). *25th AIAA Aerodynamic Measurement Technology and Ground Testing Conference.* San Francisco: AIAA 2006:3146.

Owens, D. B., Capone, F. J., Hall, R. M., Brandon, J. M., Cunningham, K., & Chambers, J. R. (2003). Free-To-Roll Analysis of Abrupt Wing Stall on Military Aircraft at Transonic Speeds. *41st Aerospace Sciences Meeting & Exhibit.* 6-9 January. Reno: AIAA 2003-0750.

Parsch, A. (2007). *General Atomics Gnat*. Retrieved 2012, from Directory of U.S. Military Rockets and Missiles (Appendix 4: Undesignated Vehicles): http://www.designation-systems.net/dusrm/app4/gnat.html

Pattinson, J., Lowenberg, M. H., & Goman, M. G. (2009). A Multi-Degree-of-Freedom Rig for the Wind Tunnel Determination of Dynamic Data. *AIAA*

Atmospheric Flight Mechanics Conference. 10-13 August. Chicago: AIAA 2009-5727.

Pattinson, J., Lowenberg, M., & Goman, M. (2013). Multi-Degree-of-Freedom Wind-Tunnel Maneuver Rig for Dynamic Simulation and Aerodynamic Model Identification. *Journal of Aircraft, 50*(2), 551-566.

Pflimlin, J. M., Soueres, P., & Hamel, T. (2007). Position Control of a Ducted Fan VTOL UAV in Crosswind. *International Journal of Control, 80*(5), 666-683.

Phillips, W. F., Hansen, A. B., & Nelson, W. M. (2006). Effects of Tail Dihedral on Static Stability. *Journal of Aircraft, 43*(6), 1829-1837.

Plane&Pilot. (2005). *1959 Beech K35 Bonanza*. Retrieved June, 2013, from Plane&Pilot: http://www.planeandpilotmag.com/article/1959-beech-k35-bonanza/#.WFEaR1P5iUk

Polhamus, E. C., & Moss, R. J. (1947). *Wind-Tunnel Investigation of the Stability and Control Characteristics of a Complete Model Equipped with a Vee Tail.* Washington: NACA TN No. 1478.

Purser, P. E., & Campbell, J. P. (1945). *Experimental Verification of a Simplified Vee-Tail Theory and Analysis of Available Data on Complete Models with Vee Tails.* Washington: NACA Report No. 823.

Qing, W., Weiqi, Q., & Kaifeng, H. (2015). Unsteady Aerodynamic Modeling at High Angles of Attack Using Support Vector Machines. *Chinese Journal of Aeronautics, 28*(3), 659-668.

Rajamurthy, M. S. (1997). Generation of Comprehensive Longitudinal Aerodynamic Data Using Dynamic Wind-Tunnel Simulation. *Journal of Aircraft, 34*(1), 29-33.

Rao, K. D. (1995). Modeling Nonlinear Features of V Tail Aircraft Using MNN. *IEEE Transactions on Aerospace and Electronic Systems, 31*(2), 841-845.

Ratliff, C. L., & Marquart, E. J. (1995). An Assessment of a Potential Test Technique: Virtual Flight Testing (VFT). *Proceedings of the AIAA Flight Simulation Technologies Conference* (pp. 198-206). 7-10 August. Baltimore: AIAA 95-3415.

Raymer, D. P. (1992). *Aircraft Design: A Conceptual Approach* (2nd ed.). Washington: American Institute of Aeronautics and Astronautics.

Raymer, D. P. (2002). *Enhancing Aircraft Conceptual Design Using Multidisciplinary Optimization.* Doctoral Dissertation. KTH Royal Institute of Technology.

Riley, D. R., Bird, J. D., & Fisher, L. R. (1955). *Experimental Determination of the Aerodynamic Derivatives Arising from Acceleration in Sideslip for a Triangular, a Swept, and an Unswept Wing.* Washington: NACA RM L55A07.

Riseborough, P. (2004). Automatic Take-Off and Landing Control for Small UAV's. *2004 5th Asian Control Conference. Volume 2*, pp. 754-762. 20-23 July. Melbourne: IEEE.

Ronch, A. D., Vallespin, D., Ghoreyshi, M., & Badcock, K. J. (2012). Evaluation of Dynamic Derivatives Using Computational Fluid Dynamics. *AIAA Journal, 50*(2), 470-484.

Roskam, J. (1987). *Airplane Design Part VI : Preliminary Calculation of Aerodynamic Thrust and Power Characteristics.* Ottawa: Roskam Aviation and Engineering Corporation.

Ross, A. (1965). *The Calculation of Lateral Stability Derivatives of Slender Wing at Incidence, Including Fin Effectiveness, and Correlation with Experiment.* London: Ministry of Aviation (Aeronautical Research Council Reports and Memoranda). Retrieved from Reports and Memoranda No. 3402

Ross, J. G., & Lock, R. C. (1952). *Wind-Tunnel Measurements of Yawing Moment due to Yawing (nr) on a 1/5.5 Scale Model of the Meteor Mark F.III.* London: ARC No. 2791.

Sadraey, M. H. (2013). *Aircraft Design: A Systems Engineering Approach.* Chichester: John Wiley & Sons, Ltd. doi:10.1002/9781118352700.fmatter

Sadraey, M., & Colgren, R. (2008). A Systems Engineering Methodology for the Design of Unconventional Control Surfaces. *46th AIAA Aerospace Sciences Meeting and Exhibit* (pp. 1-19). Nevada: AIAA.

Samardžić, M., Isaković, J., Miloš, M., Anastasijević, Z., & Naurapac, D. B. (2013). Measurement of the Direct Damping Dervative in Roll of the Two Callibration Missile Models. *FME Transactions, 41*(3), 189-194.

Sheu, D., & Lan, C. T. (2011). Estimation of Turbulent Vertical Velocity from Nonlinear Simulations of Aircraft Response. *Journal of Aircraft, 48*(2), 645-651.

Smith, N., Lykins, R., & Keshmiri, S. (2015). Effect of Competing V-Tail Models on a UAS 6-DOF Nonlinear Simulation. *2015 International Conference on Unmanned Aircraft Systems (ICUAS)* (pp. 1330-1337). 9-12 June. Denver: IEEE.

Sri-jayantha, M., & Stengel, R. (1988). Determination of Nonlinear Aerodynamic Coefficients Using the Estimation-Before-Modeling Method. *Journal of Aircraft, 25*(9), 796-804.

Stenfelt, G., & Ringertz, U. (2013). Yaw Departure and Recovery of a Tailless Aircraft Configuration. *Journal of Aircraft, 50*(1), 311-314.

Stewart, E. C. (2000). A Study of Airline Passenger Susceptibility to Atmospheric Turbulence Hazard. *Atmospheric Flight Mechanics Conference.* 14-17 August. Denver: AIAA 2000-3978.

Teofilatto, P. (2001). Preliminary Aircraft Design: Lateral Handling Qualities. *Aircraft Design, 4*, 63-73.

Torenbeek, E. (1976). *Synthesis of Subsonic Airplane Design: An Introduction to the Preliminary Design of Subsonic General Aviation and Transport Aircraft, with Emphasis on Layout, Aerodynamic Design, Propulsion and Performance.* Delft: Delft University Press.

van Dam, C. P., Holmes, B. J., & Pitts, C. (1981). Effect of Winglets on Performance and Handling Qualities of General Aviation Aircraft. *Journal of Aircraft, 18*(7), 587-591.

Wang, Q., He, F. F., Qian, W. Q., Zhang, T. J., Cheng, Y. Q., & Wu, K. Y. (2012). Unsteady aerodynamics modeling for flight dynamics application. *Acta Mechanica Sinica*, *28*(1), 14-23.

Wang, Z., & Lan, C. E. (1998). Fuzzy Logic Modelling of Nonlinear Unsteady Aerodynamics. *23rd Atmospheric Flight Mechanics Conference* (pp. 565-579). Boston: AIAA 98-4351.

Wells, W. R., Banda, S. S., & Quam, D. L. (1981). Aircraft Lateral Parameter Estimation from Flight Data with Unsteady Aerodynamic Modeling. *Journal of Aircraft, 19*(3), 206-210.

Weng, C. T., Ho, C. S., Lan, C. E., & Guan, M. (2006). Aerodynamic Analysis of a Jet Transport in Windshear Encounter During Landing. *Journal of Aircraft, 43*(2), 419-427.

Williams, J., & Vukelich, S. (1979). *The USAF Stability and Control Digital Datcom.* Ohio: AFFDL TR-79-3032.

Xi-qi, D., Wei-dong, H., & Chen, B. (2006). Summary of the Dynamic Test Capabilities at Caria Low Speed Wind Tunnel. *25th International Congress of the Aeronautical Sciences.* 3 - 8 September. Hamburg: ICAS 2006.

Yang, M. H., Ho, C. S., Lan, C. E., & Hsiao, F. B. (2010). Longitudinal Handling Quality Analysis of a Civil Transport Aircraft Encountering Turbulance. *Journal of Aircraft, 47*(1), 32-40.

Yoshinaga, T., Inoue, K., & Tate, A. (1984). Determination of the Pitching Characteristics of Tumbling Bodies by the Free-Rotation Method. *Journal of Spacecraft, 21*(1), 21-28.

Zhang, G. Q., Yu, S. C. M., Chien, A., & Xu, Y. (2013). Investigation of the Tail Dihedral Effects on the Aerodynamic Characteristics for the Low Speed Aircraft. *Advance in Mechanical Engineering, 2013*.

Zhang, J., Tang, Y. K., Sun, H. S., & Liu, Z. T. (2015). Dynamic Test Experiment Experiment System of Single Degree of Freedom of Φ3.2 m Wind Tunnel. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 229*(7), 1300-1309.