DESIGN AND MODELING OF A PORTABLE, ECONOMICAL AND HIGH PAYLOAD UNMANNED AERIAL VEHICLE FOR AERIAL SURVEILLANCE.

BAN SAU KEONG

A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor (Hons.) of Mechanical Engineering

Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

January 2010

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

C_L	Lift Coefficient
C_D	Drag Coefficient
Cp	pressure coefficient
K_d	discharge coefficient
M	mass flow rate, kg/s
P	pressure, kPa
P_b	back pressure, kPa
R	mass flow rate ratio
T	temperature, K
v	specific volume, m^3
G	Force of gravity,N
α	Angle of Attack, ^{o}
M	Mach Number
ρ	density, kg/m^3
ω	compressible flow parameter
AOA	Angle of Attack, ^{o}
UAV	Unmanned Aerial Vehicle
DOD	Department of Defend
EM	Electro-magnetic
Cg	centre of gravity
SAX	Silent Aircraft eXperimental
CAA	The civil aviation authority

CHAPTER 1

INTRODUCTION

Due to limitation of resources, we had broken down the project into few smaller stages. This final year project unmasked the first stage an UAV design of which is preliminary design of a UAV to prove the feasibility of our concept. There are 3 main stage of my final year project are designing, modelling and flight testing. Each is closely connected and need to constant refer to each other. As the preliminary design

Designing a UAV is alike airplane that they must conform to law of aerodynamic. Every aircraft no matter is manned or unmanned available will be studied from their design superiority. A conceptual design will be produce and intense calculation on the basic aerodynamic aspect will be carrying out. Then, basic concept will be put through blade element theory and do the performance simulation in the computer. After us finalised the conceptual design, we will move on to the next stage of modelling.

For Modelling of our UAV, we will further breakdown into material selection and construction of the concept UAV design. For material selection, a comparison regarding the material strength, construction complexity, and material cost will be examine. Then we will build our full size UAV from sketch. Various technical skill needed to be master when wing profile and the spacious fuselage. Any imperfectness will upset the stability and centre of gravity of the UAV. Imperfectness will also asserted unnecessary structural stress onto our UAV. Upon completion, we will move to third and final stage of the project.

Flight testing is the final stage of the final year project. The physical UAV will be put to the test with the design mission profile. UAV needed to fly in extreme manoeuvring UAV will be visually inspected for physical crack after the every mission. Under normal weather condition, our UAV will be able to survive from every mission according data retrive from the calculation and simulation.

With the entire element mention in this introduction, let us expect an unconventional, latitudinally and longitudinally stable, and structurally strong UAV design at the end of my final year project. Thank you.

1.1 Background

Research showed the global spending in 2009 on unmanned aerial vehicles (UAV) reached $5.1billion and the expanding market expected on acumulate $71billion over the year of 2010-2020. (Companiesandmarkets.com and OfficialWire, 2010). This tremendous amount of spending allows a phenomenal growth in the UAVs technology.

The UAVs are miniature aircraft. However the unconventional and odd shape of the UAVs had, it must conform to the law of physics and aerodynamics. Being pilotless, UAVs have vast flexibility on physical configuration. Some were bizarre shape that can hardly be readily identified.

The UAVs had eliminated the design constraints associated with onboard pilot. A minimal 40 ft^3 of space required on aircraft cockpit (space include manual control and pilot). The volume will increase when an ejection seat and others feature were installed. The multiple systems required for the safety of aircrews will be redundant in UAVs design; hence, it will improve the performance of the UAVs.

The pilotless nature gives UAV 3 distinctive characteristic in Size, Performance and electro-magnetic (EM) influence. In a manned aircraft, pilot must counter balance the centre of gravity (CG) so aircraft is inherently stable. The UAVs had minimal complication of system design hence allowing UAVs to have more inconsistency of design. The safety feature of tolerate multiple failures to allow the survival of the pilot is redundant and mitigate the performance of the propulsion system to avoid serious single-failure modes. The omitted weight of safety measure in UAVs design will adversely impact to performance.

Utilizing UAVs potential to our benefit, we will replace conventional aerial surveillance method with a UAV. UAV will be designed with reference of available aircraft configuration, complete with modelling and test flight of the UAV. Various configurations will be review, modified and improved to assure that our UAV relevance to the mission profile.

1.2 Aims and Objectives

1.2.1 Aim

In this Final Year Project, our aim is to prove feasibility of a novel conceptual design configuration of UAV with payload capability. Being pilotless advantage enables us to explore a bizarre conceptual design configuration. Detail study needed because the flight dynamic of the conceptual configurations. Scopes of this project include the preliminary design, basic aerodynamic calculation, Simulate flight envelop , fabrication, test flight capability under the open environment.

1.2.2 Objectives

In this project of portable, economical and high payload unmanned aerial vehicle (UAV) for aerial surveillance, the main objectives to meet are :-

a. Apply engineering knowledge.
b. Understand the design process and stages
c. Understand the flight dynamic
d. Potency of utilise simulation software on flight ability.
e. Enhancing hands on skill.

CHAPTER 2

LITERATURE REVIEW

2.1 Unmanned Aircraft Accident/Incident Data

We reviewed reliability of unmanned aerial vehical(UAV) (Kevin, 2004; DoD, 2001; Schaefer, 2003; Tvaryanas, 2004), noted that UAV had higher accident rate for than that of manned aircraft. We had understood some causal factors associated to improve the reliability UAV. Kevin (2004) had summarizes the data reported each UAV system in Figure 2.1. The percentages add up more than 100% because many of the accidents fell into more than one category.

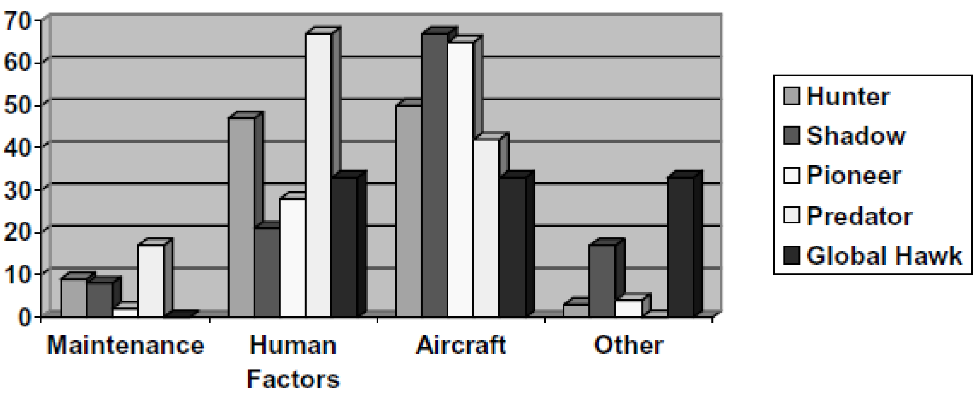


Figure 2.1: Summary accident percentages across aircraft systems. From FAA report

Electrical and mechanical reliability were major contributor for accidents. Office of the Secretary of Defense (Schaefer, 2003) had reviewed several factors affecting the electromechanical reliability of UAV. The most critical factor cited was cost savings. Cost-saving measures have a tendency to impact component reliability, system redundancy, and the inclusion of new component technologies.

The improvement in electromechanical reliability only when increase in the cost of the aircraft. However, a reduction of human errors leading to accidents might not necessarily entail increased costs if suggested changes can be incorporated early in the design process.

The investigation of the accident, which occurred on November 4, 2000, revealed that the damaged onboard antennas which cause human misjudgment led to the accident. The radar altimeter system had incorrectly track the altitude due to the faulty antennas had emitted incorrect signal (Strikenet, 2001). Engine being shut down at 498ft after Fire Scout (in figure 2.2) assume it had grounded.

Figure 2.2: The U.S. Navy Fire Scout (RQ-8A). From FAA

2.2 Blended Wing Design

J. I. Hileman et. al (2007) had involved in one of the research on Silent Aircraft eXperimental(SAX) with blended wing airframe design(in Figure 2.3). The aircraft operation was aimed for slow but steep climb-out and approach to the airfield. Furthermore, the undercarriage must be simple and fair and the high-lifted wing profile was selected.

The all-lifting and smooth air frame was design for advance low speed capability and efficient cruise performance to improve fuel burn. Simple and faired undercarriage will reduce the unsteady flow structures around the landing gear and strut. The droop leading edge and combination of upward deflect of elevons will increase the induced drag and reduce the lift effectively.

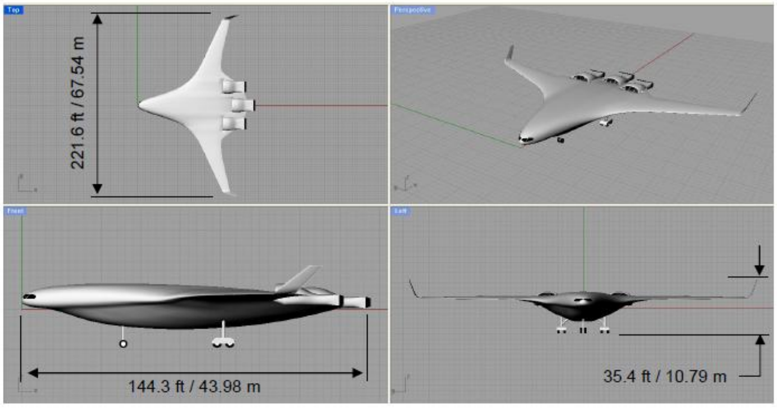


Figure 2.3: *S*ilent *A*ircraft e*X*perimental design SAX-40. From Airframe Design for "Silent Aircraft

Pitch trim can be achieved without tail but requires flexed airfoil on the center body. The tradeoffs of a tailless airframe are on the cruise performance, large control surface and actuation power to facilitate rotation.

Hileman et. al(2007) was using software simulation to solve 2-D and 3-D flows on structured grids(Figure 2.5). The result generated shows that viscous flow over the center body in a 2D vortex lattice solution marks almost identical location and magnitude of pressure coefficient, Cp (in Red) area than in CFL3DV6 solution. The reliability of the 2D data will assist in design phase.

Hileman et. al(2007) The outer wing profile configuration and loading distribution obtained from the two-dimensional vortex lattice solution for approach and cruise conditions are shown in Figure 2.5. For reference, the centerbody profile is shown to scale and the dot indicates the aircraft center of gravity. This loading is naturally balanced by the lift generated in the forward region of the centerbody.

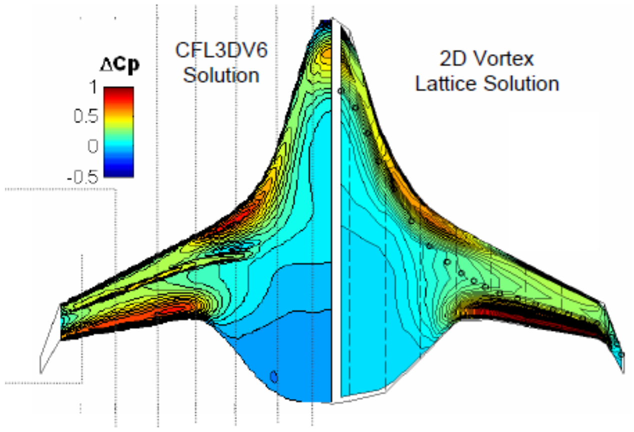


Figure 2.4: Distribution and contours of pressure coefficient for SAX-29 at M = 0.8. From Airframe Design for "Silent Aircraft"

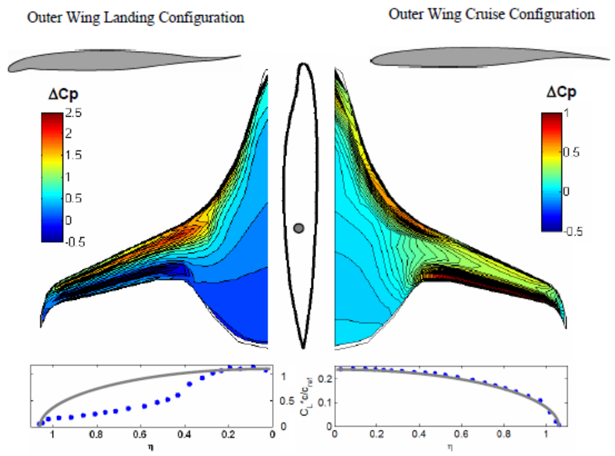


Figure 2.5: Two-dimensional vortex lattice estimate of airframe loading distribution during cruise and approach / landing. From Airframe Design for "Silent Aircraft"

Hileman et. al(2007) had also simulated the SAX-40 suction and pressure surface Cp distributions from the vortex panel solution are plotted in Figure 2.6.The centerbody airfoil design has minimal aft camber in order to avoid an untrimmable nose-down moment. Thought SAX-40 having payload capacity, fuel efficiency advantage but strengthen airframe were too costly, demanding the high precision complex internal design.

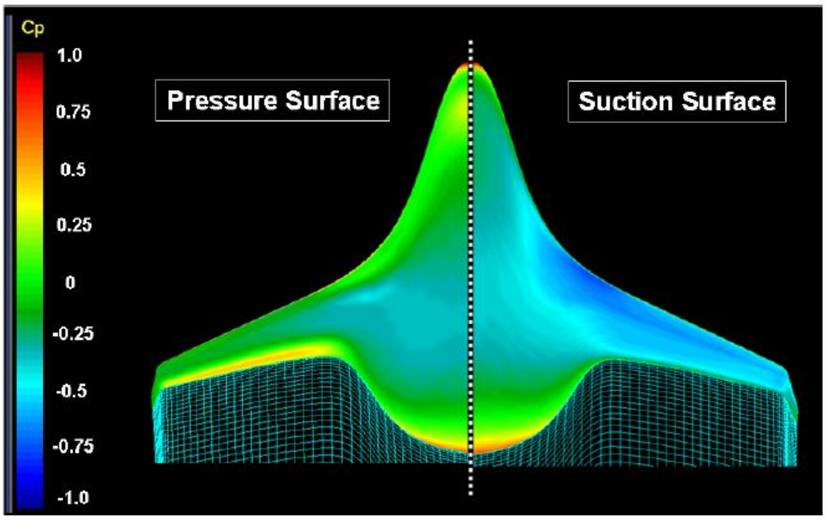


Figure 2.6: Pressure distribution at Mach 0.8 estimated with three-dimensional vortex panel method. From Airframe Design for “Silent Aircraft”

G.Zha et. al. (2006,2007, 2009) had research on implementing co-flow jet(CFJ) on blended wing design. CFJ airfoil avoids dumping of jet mass flow; achieve the performance enhancement without relying on coanda effect. The CFJ Airfoil concept, an injection slot near leading edge and a suction slot near trailing edge on the airfoil suction surface are introduced as sketched in Fig. 2.7. A high energy jet is injected near the leading edge in the same direction of the main flow and the same amount of mass flow is drawn near trailing edge.

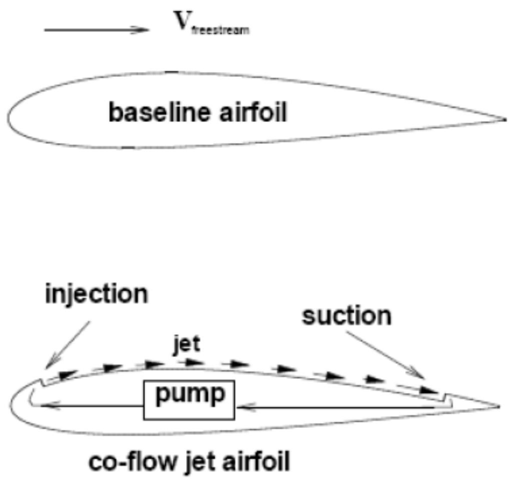


Figure 2.7: Baseline Schematic for CFJ Airfoil Showing Pump Concept. From Zha, G et al (2006)

The main flow to overcome the large adverse pressure gradient in a CFJ design and remain attached even at very high AOA. The stall margin is hence significantly increased. The high momentum jet had augments lift, reduces drag or even generates thrust (net negative drag). Figure. 2.8 showed baseline airfoil has a massive separation at high angle of attack, whereas the CFJ airfoil has a well attached flow.

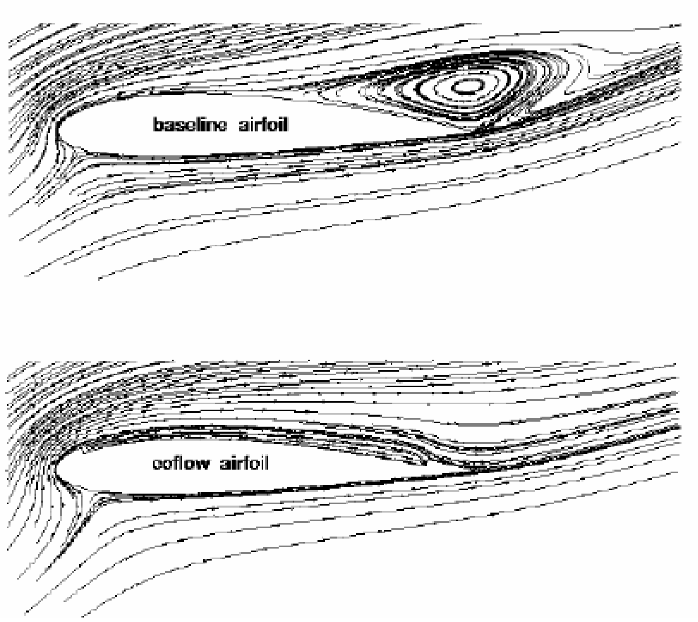


Figure 2.8: Flow Field for baseline NACA 2415 and CFJ Airfoil at High AoA

The injection near LE at a low pressure location and the suction near TE at a high pressure location create a mechanism to minimize the CFJ pumping energy expenditure. Due to the very high circulation, the LE suction is so strong that the low pressure at the leading edge results in a thrust at low AoA.

Aguirre et al(2007) discovered when the wing generates thrust and reduces drag, airplane fly forward just relying on the CFJ with no conventional engines or the required thrust from engines is reduced. Fig. 2.9 shows the measured lift coefficients for the baseline uncontrolled NACA 0025 airfoil and CFJ airfoil in proof-of-concept wind tunnel tests. The CLmax is increased from 1.52 to 5.02. The stall AoA is increased from 19º to 44º

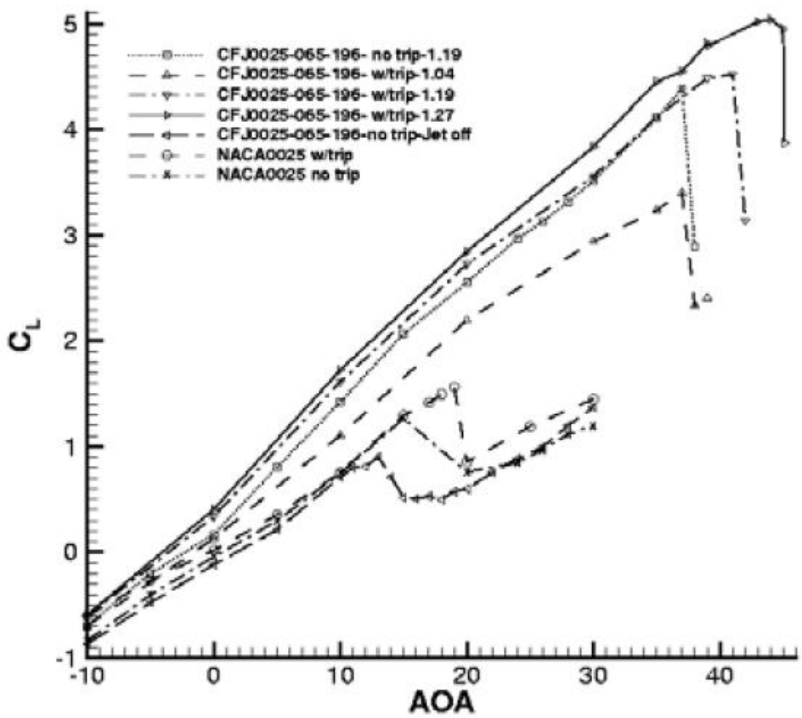


Figure 2.9: Measured lift vs angle of attack for NACA 0025 and CFJ0025-065-196 airfoil

Blended wing design is a tailless flying wing. Engines needed on each side of the aircraft centerline to create asymmetric thrust generated and cause the aircraft to yaw. The control feedback system must be looped with the propulsion system to control the amount of yaw needed to return the aircraft to coordinated flight at any instant but allow a constant lift force from the CFJ. There will be a split elevator (or aileron pair), as shown in Figure 1, located behind the engines that will cause the pitching moments and rolling about the longitudinal axis of the airplane.

The blended wing had the benefit of all lifting surface, hence increase in the payload capacity. With the introduction of the co-flow jet attach flow across airfoil at high AOA, hence flow separation will reduce, hence, increase the stall margin. However the complicated control system needed to compensate the tailless blended wing design will increase the control system variable (Trust control, pitch trim…) will increase the human error during the flight test. For this reason, the blended wing design is not a desired design for our UAV.

2.3 Airfoil design (Ogee Wing)

L. Stewart Roll et al. (1965) and L. C. Squire and D. S. Cappshad (1959) investigated low speed characteristic of ogee wing aircraft (example of ogee wing in Figure. 2.10). The Ogee had exhibits better low-speed or landing characteristics than some other plan forms of low aspect ratio. The Stable vortex flowed through high sweep angle of delta wing airfoil benefited ogee wing in low speed performance.

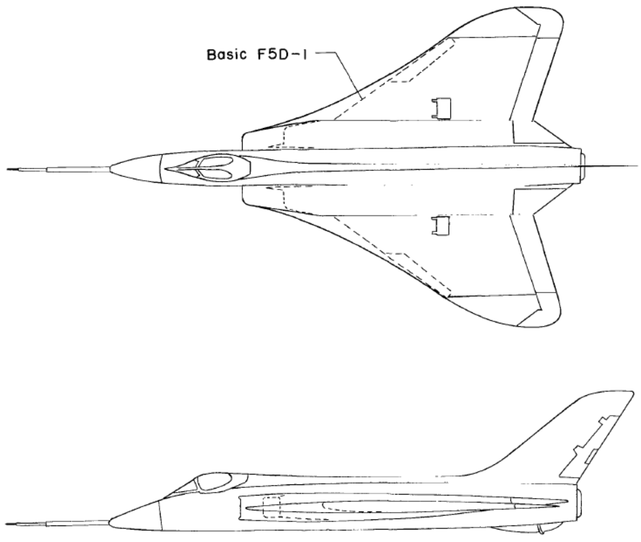


Figure 2.10: Two-view sketch of test airplane. *From Investigation Of The Aerodynamic Properties Of An Ogee Wing(1965)*

The static longitudinal aerodynamic characteristics of test configuration (with and without landing gear), as are shown in figures 2.1, 2.2 in the form of angle of attack, drag coefficient, with lift coefficient. At high AOA, flights are affected by slight buffeting. These data were obtained in steady flight at different airspeeds at the lower angles of attack, and during continuous maneuvers with slowly decreasing airspeed at the higher angles of attack. With the landing gear, we notice a slight decrease in lift as landing gear increase induced drag. L. C. Squire and D. S. Capps (1959) show the similar result of generated lift in different Mach number (Mach 1 = 1235 km/h).

Table 2.1: Variation of angle of attack and drag coefficient with lift coefficient; gear up. From *Investigation Of The Aerodynamic Properties Of An Ogee Wing(1965)*

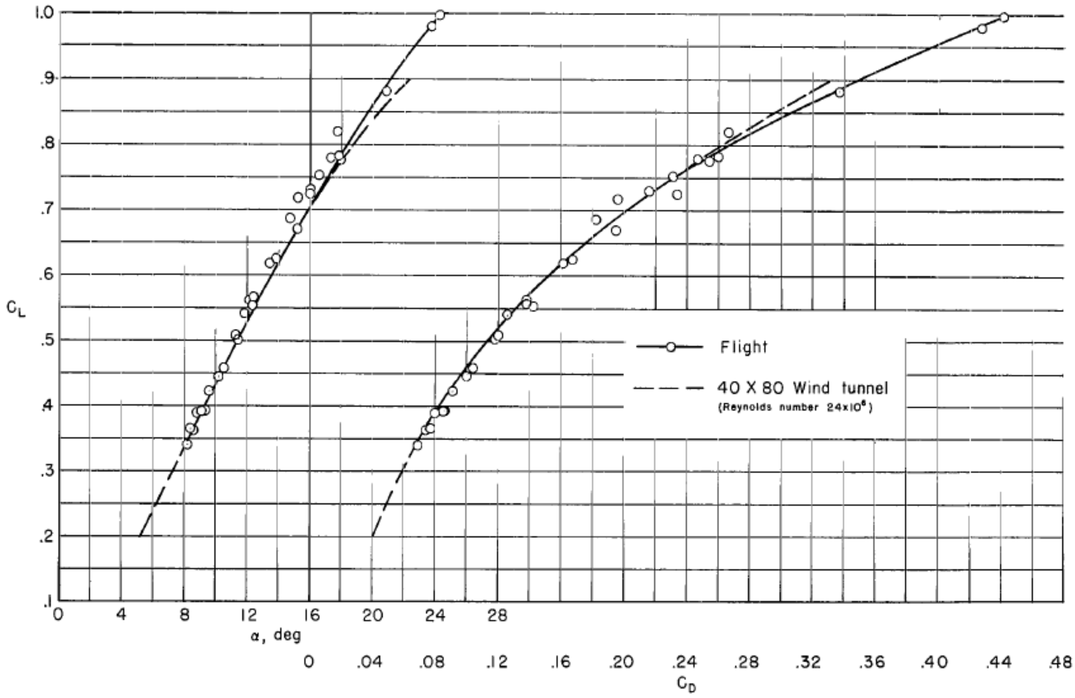
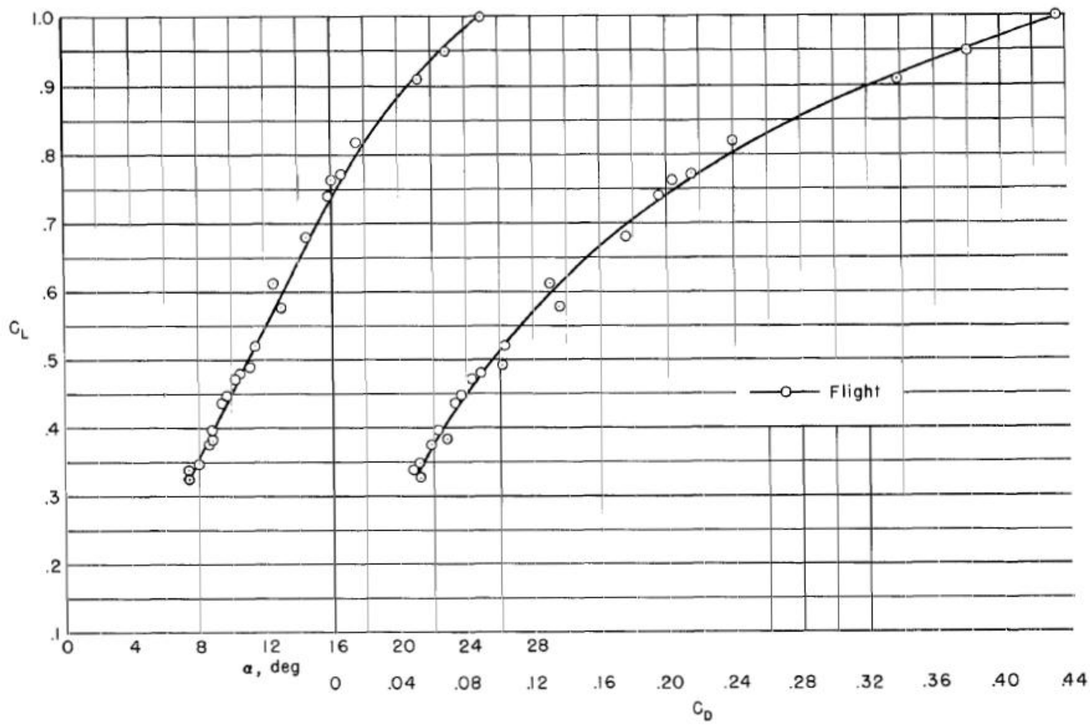


Table 2.2: Variation of angle of attack and drag coefficient with lift coefficient; gear down.From . From *Investigation Of The Aerodynamic Properties Of An Ogee Wing(1965)*



Werle (1964) had described the characteristics of the vortex, both observed and photographed; agree with the vortex behavior measured during the water tunnel tests on an Ogee plan form changes due to AOA. A set of sketches of the tuft patterns over the wing at various angles of attack, derived from photographs taken by the tail-mounted camera, are presented in figure 2.11. The first three sketches show the increase in the area of unsteady flow as the AOA. Figures 2.11(c) and 2.11(d) occurred in about 0.3 second and were continually changing, this disturbance is caused by the effect of the vortex flow on the vertical tail.

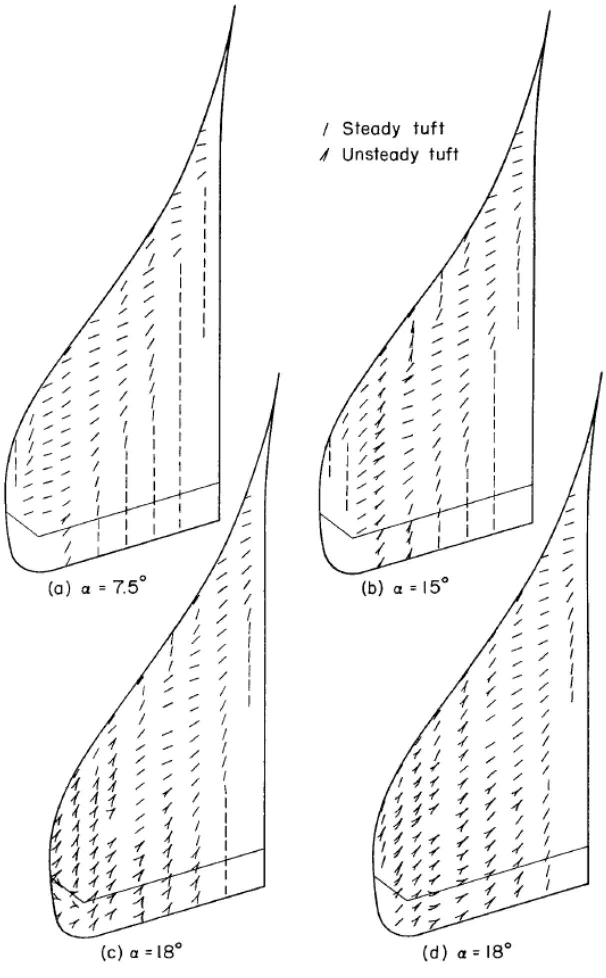


Figure 2.11:Tuft patterns at various angles of attack, zero sideslip. From *Investigation Of The Aerodynamic Properties Of An Ogee Wing(1965)*

2.4 Airfoil design (Acute angle Delta wing)

Ahmad z. Al-garni et al. (2005) had research on aerodynamic performance and longitudinal analyses of 65º delta wing and a 65/40º double-delta wing configuration (in Figure 2.12). They found the unconventional method of using voltex enhance low pressure region in high AOA to generate greater lift. Zhou Ji (1999) had confirmed the leading edge vortex existence and enhancement on a different experiment.

As flow separates along the leading edges of a delta wing at non-zero angle of attack, vertical flow results into leading edge vortices(in figure 2.13,2.14,2.15).These vortices produce a very low pressure region and can account for up to 30% of the total lift at moderate angles of attack. They had collected commercial CFD software fluent and compare with the experiment and theoretical data. The lift, drag, and pitching moment were collected to compute the linear stability. Result found that delta and double-delta wings provide lift at AOA(20-30º). High-lift and low drag forces in a wide range of AOA provide superior maneuverability.

(a) **(b)**

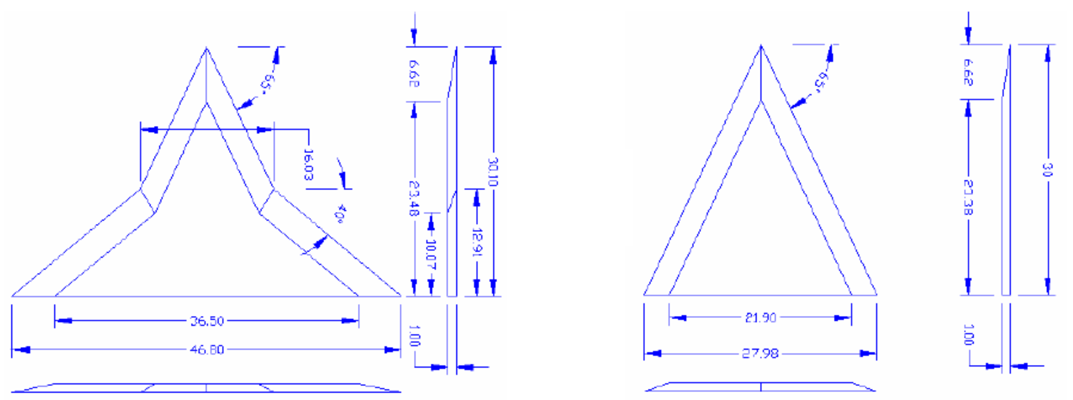


Figure 2.12: Schematics of (a) 65/40-deg delta and (b) 65-deg double-delta wings. www.kfupm.edu.sa

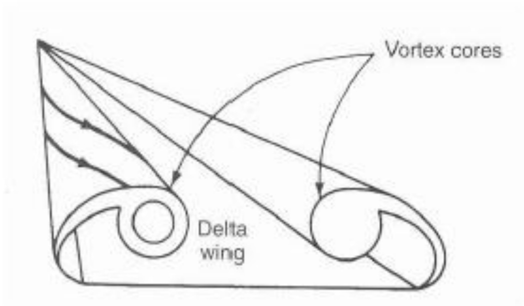


Figure 2.13: Vortex core development over a delta wing, from www.kfupm.edu.sa

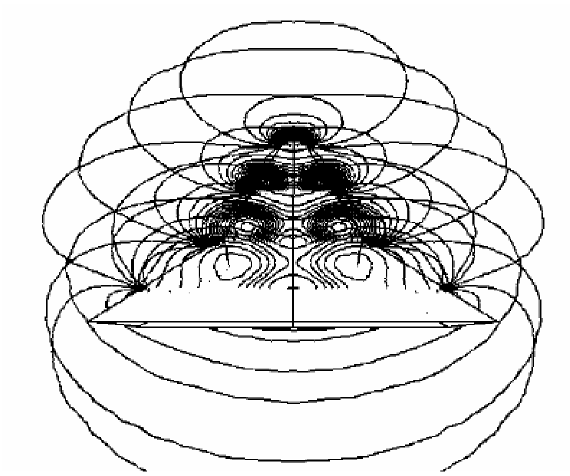


Figure 2.14: Static pressure contours predicted by FLUENT on the 65/40-deg doubledelta wing at α = 32 deg. From www.kfupm.edu.sa

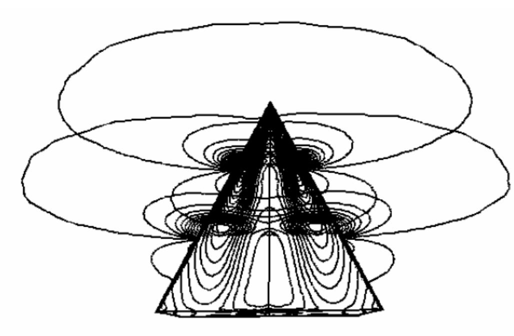


Figure 2.15:Static pressure contours predicted by FLUENT on the 65-deg delta wing at α= 28 deg. From www.kfupm.edu.sa

There are limits to the benefits produced by the delta/double-delta wing vortices. As the angle of attack is increased further, there is a sudden change in the vortex flow-field when the core and structure of the vortex breaks down. Furthermore, the method is applicable to wings for which the leading edges are of sufficient sharpness that separation is fixed at the leading edge.

Table 2.3: A comparison of 65-deg delta wing lift and drag coefficients based on theory (solid line) and experiments (circles). From www.kfupm.edu.sa

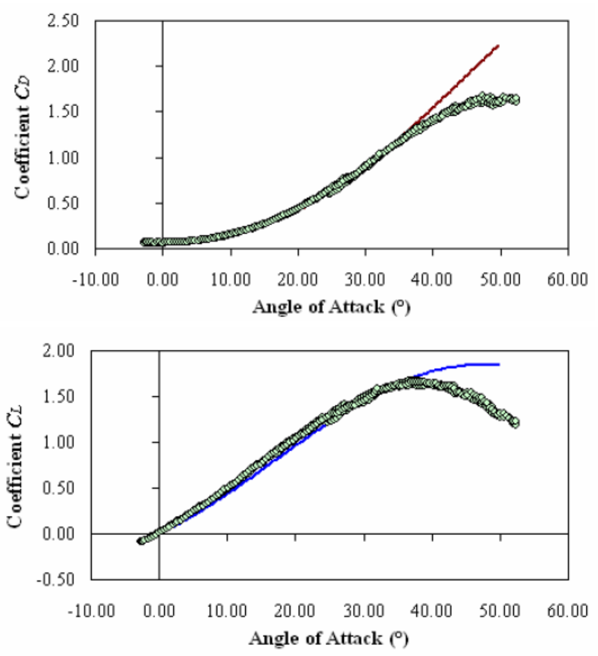
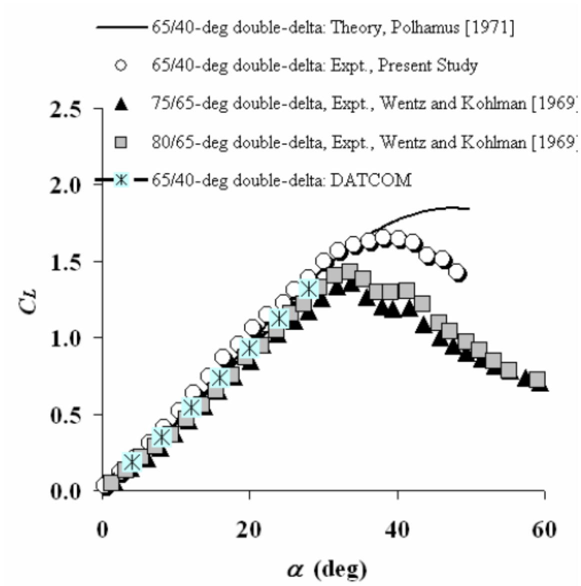
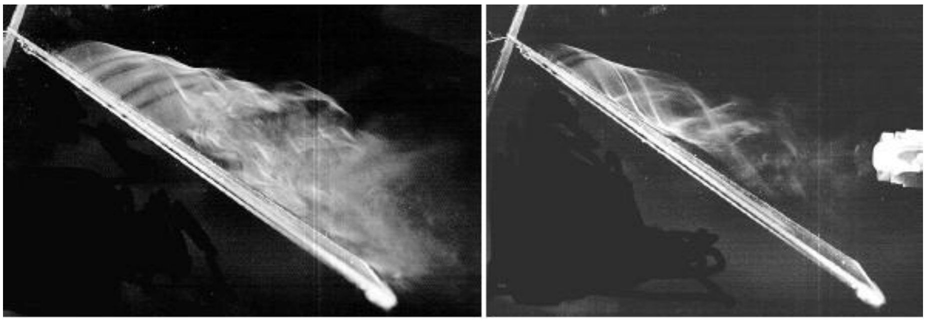


Table 2.4: A comparison of 65/40-deg double-delta wing lift coefficient based on theory, experiments and CFD. From www.kfupm.edu.sa



Zhang Ji et al (1999) had demonstrates the effectiveness of reduce vortex breakdown using a trailing edge fan of a delta wing. The fan had little effect on the vortical flow for low AOA, therefore trust needed to generate lift across the airfoil at low AOA. However, as the attack angle increased, the influence of the fan on the vortex core became very apparent. As AOA increase the relative unaided leading edge vortex cores had deteriorated quickly.

The optimal horizontal position of fan was directly perpendicular to the wing's trailing edge, and the height or vertical position (*h/c*) must direct in line with the vortex core. The Vortex enhancement was increased proportionately with an increase in the fan's speed. Thus, the introduction of trailing edge fan into the flow over a delta wing is a feasible alternative in vortical enhancement at high angles of attack with the continued advantage of vortex-induced lift.



(a) (b)

Figure 2.16. Example of Vortex flow at 35º (a. Unaided flow, b. Fan Aided flow) from Zhang Ji Experiment et al (1999)

Table 2.5: Comparison between Airfoil Configuration

Type / Charecteristic	Blended wing	Co-Flow Jet	Shape edge Delta Wing	Ogee Wing
Maximum AOA	19º	44 º	40 º	18º
High AOA Mechanism	Steady flow across airfoil	Suction at tailing edge attach flow on airfoil	Flow separation and voltexes enhance the low pressure region	Steady flow across airfoil
Payload bay	Large (Depend on Fuselage design)	Minimal (Additional Pump required for suction slot)	Minimal (Size of delta wing proportionally increase with payload bay)	Large (Depend on Fuselage design)
structural complexity	Complex to design detectable stucture	Complex to design detectable stucture	Simple (fuselage and wing construct separately and attach)	Simple (fuselage and wing construct separately and attach)
Manoeuvring system	Complex (Yaw motion depend on trust different)	Complex (Yaw motion depend on trust different)	Simple (Flap, Rudder and Elevator design)	Simple (Flap, Rudder and Elevator design)

Type / Charecteristic	Blended wing	Co-Flow Jet	Shape edge Delta Wing	Ogee Wing
Cost	Moderate (Design Complexity increase material used)	High (Design Complexity increase material used)	Low (Conventional and ready stock available)	Low (Convention al and ready stock available)
Flow attachment	Mild (Passive flow attachment)	Good (Suction inlet attach flow even in high AOA)	Mild (Passive flow attachment)	Mild (Passive flow attachment)

CHAPTER 3

METHODOLOGY

A preliminary design stage, the conceptual design is most important to be carefully study and put through flight test. Any negligence in stage will jeopardise the team effort on the other stage of the study. The preliminary design can be divided into 3 stages (Design, Modelling, and test flight.) and each have distinct characteristic and milestone to achieved. There are 4 critical parameters during evaluating the preformance UAV (Lift, drag, AOA, and Cg). The lift vs AOA will directly determine the stall speed and agility of the UAV.

3.1 Design

The civil aviation authority (CAA) has recognized the need to develop civil standards for Unmanned Aerial Vehicles (UAVs). Being a micro (target weight of 3Kg) and surveillance UAV, we have exempted for CAA certification of airworthiness.

The design stage is where we reviewed, conceptual design, detail design, simulate and calculate. We have intensive 10 hours of courses on basic aircraft design. A sharing session is held at the end of the course for student to converse their idea. Then study available aircraft design and consider possible configuration. Basic aerodynamic calculation will be carrying out with conceptual configuration. Using blade element theory in laminar research software, we are able to simulate the flight performance of the UAV. The main challenge is the Cg position and the stall margin will be recorded to future referencing.

3.2 Construct

Upon finalisation UAV configuration, we move into modelling stage. We choose between the use balsa wood for Fish bone structure, or Styrofoam moulding for our UAV entire UAV. We use both material because of their light weight, strong material strength and economical. Carbon Fibre only use for structural enhancement due high material price. The spacious interior and easy to shape will be the advantage of using balsa wood and Styrofoam. Modelling will be the most time consuming stage as high precision is expected to ensure the uniformity and stability of our UAV.

3.3 UAV Performance Test

CAA standard is adopted during the flight test and a check list will serve as a guideline. Data of handling characteristics are satisfactory and climb performance equals or exceeds the scheduled data is necessary to in order to assess any future deterioration of performance in service. The aircraft and its equipment function satisfactorily and the aircraft continues to comply with its type design standard.

To be appropriate, the schedules should cover the handling and performance test listed as below:-

Handling tests, including the effectiveness of primary controls and trimmers, with specific direction to evaluate the characteristics during the following phases of flight:

1. Take-off;
2. Climb;
3. Cruise;
4. Flight at maximum speed;
5. Flight at minimum speed;
6. Descent;
7. Landing;

Visual inspection after handling test will be carrying out and no visual craft or defect should be detected to gain the airworthiness.

Performance tests are including

1. Simple, free air pressure rate-of-climb measurements under known and predicted configurations and conditions; and

2. Measurement of low speed warnings and, if applicable, stall speeds.

We had draft out our mission profile for our flight testing. That will be take off, climb to max altitude of 300ft at uncontrolled airspace, cruise for 5 mins, loiter 5 mins , descend, and landing. UAV need to survive through the mission profile with the enough batteries capacity, structural integrity and

3.4 Optimisation

The correlation of design optimisation with UAV weight will be focus of study. UAV weights are a direct contribution of type and mount material used. This is will affect the incurred cost of the project. But the performance of the UAV must not be compromise with the optimisation of the UAV weight. An inherently stable UAV behaviour must be the ultimate goal of the project. Software will simulate the few optimised model of UAV designed and the best configuration will be adopted.

REFERENCES

Book

Darrol Stinton. (1997). *The Design Of The Aeroplane*. United Kingdom : Blackwell Science.

John D. Anderson,Jr (1999).*Aircraft Performance And Design*. United State : McGraw-Hill.

Jan Roskam. (1995). *Airplane Flight Dynamics and Automatic Flight Controls*. United State : DARcorporation.

T.H.G Megson (1990). *Aircraft Stuctures for Engineering Student* (2nd ed). London:Arnold.

PBS TV (2002): *Time Line of UAVs*. Retrieved June 1, 2010, from http://www.pbs.org/wgbh/nova/spiesfly/uavs.html November

Vladimir Socor (2008): *un mission confirms georgian, rejects russian version of air clash*. Retrieved June 1, 2010 from www.jamestown.org.

Marc Selinger (2003): *Using More Than 10 Types Of UAVs In Iraq War*. Retrieved June 1, 2010, from http://www.aviationweek.com/aw/generic/story_generic.jsp ?channel=aerospacedaily &id=news/uav03273.xml U.S.

Press Office (2010) *The Unmanned Aerial Vehicles (UAV) Market 2010-2020: Technologies For ISR And Counter-Insurgency - New Market Report Published New* *report provides detailed analysis of the Defence marketPublished* Retrieved on 10, July 2010, from www.officialwire.com

TJ Osborn (2009): A *review of Unmanned Aerial Vehicle Designs and Operational Characteristics*. national aviation reporting center on anomalous phenomena.

J. I. Hileman, Z. S. Spakovszky, M. Drela, M. A. Sargeant, (2007), *Airframe Design for "Silent Aircraft"*. Gas Turbine Laboratory, Massachusetts Institute of Technology, Cambridge, MA, AIAA 2007-453,15.

Kevin W. Williams (2004). *A Summary of Unmanned Aircraft Accident/Incident Data: Human Factors Implications*, Federal Aviation Administration

Department of the Army (1994). *Accident reporting and records*. Washington, DC. Army Regulation 385-40.

Department of the Army (1994b). *Army accident investigation and reporting*. Washington, DC. Army Pamphlet 385-40.

Department of Defense (2001). *Unmanned aerial vehicles roadmap, 2000-2025. Office of the Secretary of Defense*, Department of Defense, Washington, DC, April 2001.

Department of Defense (2002). *RQ-8A Firescout vertical takeoff and landing tactical unmanned aerial vehicle system (VTUAV). From the Director of Operational Test and Evaluation FY2001 Annual Report*, *Department of Defense*. retrive on 6/6/2010 from URL http://globalsecurity.org/military/library/budget/fy2001/dot-e/index.html.

Schaefer, R. (2003). "*Unmanned aerial vehicle reliability study*." Office of the Secretary of Defense, Washington, DC.

Strikenet (2001). *VTUAV P1 accident investigation board report*. Downloaded on 4/15/2004 from URL http://www.strikenet.js.mil/pao/vtuav_crash_in-vest_news_release.html

Tvaryanas, A.P. (2004). *USAF UAV mishap epidemiology, 1997-2003.* the Human Factors of Uninhabited Aerial Vehicles First Annual Workshop.

Englar, R. J., (1975)" Circulation Control for High Lift and Drag Generation on STOL Aircraft", Journal of Aircraft, 12, pp457-463.

Englar, R. J. and Trobaugh, L. A. and Hemmersly, R.A.(1978), *"STOL Potential of the Circulation Control Wing for High-Performance Aircraft"*, Journal of Aircraft, 14, pp175-181.

Zha, G.-C., Paxton, D.C.(2006), "*A Novel Flow Control Method for Airfoil Performance Enhancement Using Co-Flow Jet*." ,AIAA Journal, Vol. 214, p. 293-314,

Zha, G.-C., Carroll, B., Paxton, C., Conley, A., Wells, A.(2007), "High Performance Airfoil with Co-Flow Jet Flow Control." AIAA Journal, Vol. 45, No. 8, pp. 2087-2090.

Zha, G.-C., Paxton, C., Conley, A., Wells, A., Carroll, B.(2006), *"Effect of Injection Slot Size on High Performance Co-Flow Jet Airfoil,"* AIAA Journal of Aircraft, Vol. 43, No. 4, pp. 987-995.

Zha, G.-C., Gao, W., and Paxton, C. D.(2007) "*Jet Effects on Co-Flow Jet Airfoil Performance*" AIAA Journal, Vol. 45, No. 6, pp.1222-1231.

Aguirre, J., Wang, B.-Y.(2007), Zha, G.-C., "*Conceptual Design and Study of 'Engineless' Airplane Using Co-Flow Jet Airfoil*." AIAA Paper 2007-4441.

L. Stewart Rolls, David G. Koenig, and Fred J. Drinkwater III (1965*) Flight Investigation Of The Aerodynamic Properties Of An Ogee Wing,* NASA technical note,NASA TN D-3071, P.24.

Ahmad Z. Al-Garni, Farooq Saeed and Abdallah Al-Garni (2005) *"Aerodynamic Performance And Longitudinal Stability Analyses Of Delta- And Double-Delta Wing Configurations"*, Retrieved on 14/6/2010 from www.kfupm.edu.sa

1Jones, R.T. and Cohen, D., *High Speed Wing Theory*, Princeton University Press, Princeton, NJ, 1960.

Civil Aviation Aircraft (2003) *Flight Testing and Check Flights of of UK Civil Registered Aircraft,* Electronic Reference, retrieved on August,18 2010, from http://www.caa.co.uk/default.aspx?catid=1455&pagetype=90&pageid=

Zhou Ji, Jeff Marchetta, J. Hochstein and J. D. Mo (University of Memphis, Memphis), K. X. He, and Alan Chow (Alabama A & M University, Huntsville),(1999), *The Effect Of Downstream Suction On The Delta Wing Leading-Edge Vortex.* Proceedings of the Eighth Asian Congress of Fluid Mechanics 1999