PERFORMANCE ANALYSIS OF A COMPLIANT WING FOR A LIGHT AIRCRAFT

(ANALISIS PRESTASI SAYAP BERSIFAT PATUH BAGI PESAWAT UDARA RINGAN)

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$u_{out,\mathrm{m}}$	actual position of the *m* th point on the perimeter
$u_{out,\mathrm{m}}$	*m* th desired point
M	number of point in total
v	volume of an element
V	volume constraint
ρ	density of an element
u_{in}	actual displacement in input point
$U\ in$	constraint of the input point
A	projected area of the body
Uo	free stream velocity
C_D	drag coefficient
C_L	lift coefficient
L	lift force
D	drag force
C_L / C_D	lift to drag ratio
Leading edge	the front, or upstream, edge, facing the direction of flow
Trailing edge	the rear, or downstream, edge
Chord line	a straight line connecting the leading and trailing edge
Chord	the length of chord line between the leading and trailing edges
Camber line	the centerline of the airfoil section
Camber	the maximum distance between the camber line and the chord line
Angle of attack, AOA	the angle between the direction of the relative motion and the chord line

ABSTRACT

Main purpose of this project is to apply the compliant mechanism into aircraft wing. It can improve the flight performance of conventional light aircraft. A compliant mechanism is flexible structure that elastically deforms without joints to produce a desired force or displacement. This study was precisely to analyze a compliant mechanism that has to be fitted to the leading edge of aircraft Beech King Air C90B wings. An innovation by Prof. Sridhar Kota creates compliant which can change wing leading edge angle from 0º until 6º. This design created using topology optimization method. With help of ANSYS software, leading edge structure for conventional light aircraft will be optimizing until gaining the most suitable shape in certain condition. Analysis will able to prove the design improving the flight performance for conventional light aircraft. It focused on its computational fluid dynamic analysis in determining the value of lift coefficient and drag coefficient using FLUENT 6.0 software. Expected result through this analysis is it should be a different in value of lift coefficient and drag coefficient when applying different angle of leading edge. It should increase the lift and drag forces due to respect angle of attack.

ABSTRAK

Tumpuan utama dalam disertasi ini ialah mengaplikasikan mekanisma patuh ke dalam pesawat terbang. Rekabentuk yang dihasilkan ini dapat meningkatkan lagi prestasi penerbangan pesawat ringan yang sedia ada. Mekanisme patuh didefinisikan sebagai satu struktur tanpa sendi yang fleksibel dan memiliki ubah bentuk elastik bagi menghasilkan suatu daya atau sesaran yang dikehendaki. Kajian ini bertujuan untuk menganalisis mekanisma bersifat patuh yang dipasangkan pada pinggir depan sayap pesawat udara ringan Beechcraft King Air C90B. Rekabentuk oleh Prof. Sridhar Kota ini dapat mengubah kamber pinggir depan (*leading edge*) sayap pesawat dari sudut sifar darjah kepada enam darjah. Penghasilan rekabentuk ini menggunakan kaedah topologi. Struktur pada pinggir depan sayap akan dioptimumkan sehingga memperolehi bentuk yang paling sesuai di bawah kondisi-kondisi tertentu dengan menggunakan perisian ANSYS™. Analisis akan membuktikan rekabentuk telah meningkatkan prestasi penerbangan untuk pesawat udara ringan sedia ada. Model yang telah siap dilukis akan menjalani analisis *Computational Fluid Dynamics* (CFD) bagi mendapatkan angkali angkat dan nisbah angkali angkat dan angkali seret. Analisis CFD ini dilakukan dengan menggunakan perisian FLUENT™. Melalui analisis ini, keputusan yang dijangkakan adalah terdapat perbezaan dalam nilai angkali angkat dan angkali seret apabila berlakunya perbezaan sudut pada pinggir depan sayap. Ia sepatutnya meningkatkan daya angkat dan seret berkadaran dengan peningkatan sudut serang.

CHAPTER ONE

INTRODUCTION

1.1 General

Performance Analysis of Compliant Wing for Light Aircraft is one of the latest research that has been recently developed in world of aviation field. *Performance analysis* was done on the wing that embedded with the compliant mechanism so that we can prove that the design will improve the conventional aircraft flight performance. *Compliant* is a mechanism with flexible structure that elastically deforms without joints to produce a desired force or displacement [1]. Energy strain will stored when flexible members are deflecting. The strain energy is same as elastic potential energy in spring. Since product of force and displacement is a constant. There is trade-off between force and displacement as shown in figure 1.1 below.

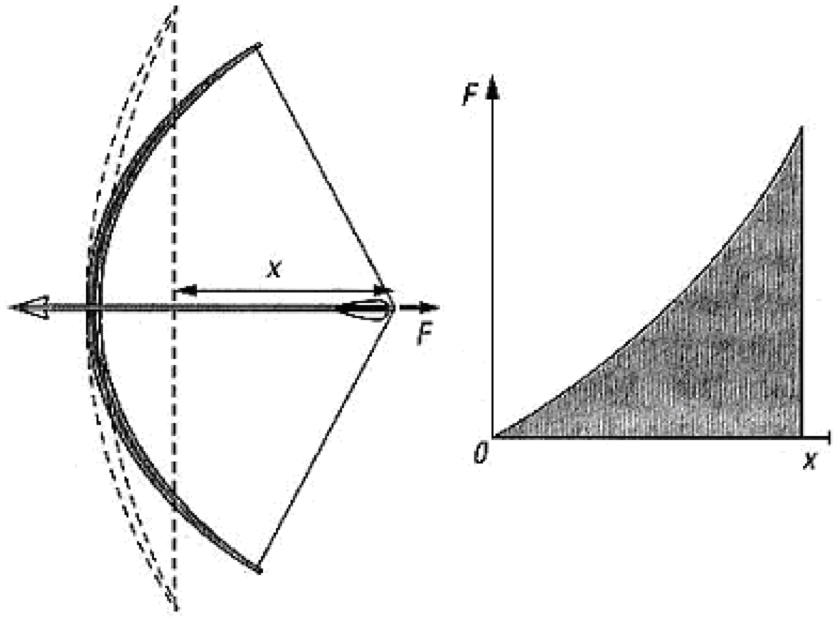


Figure 1.1 Longbow in strung position and it strain energy stores shown in graph [1]

Wings are the major characteristics of an airplane. Wing can be mounted above the cabin (high wing), below the cabin (low wing), or anywhere between (mid wing). Most modern airplanes are monoplanes that are they have one wing. Airplanes with two wings are called biplanes. The characteristic that most readily identifies the type and performance of wings is the shape of its airfoil. Airfoil defines as a structure that moves through the air for obtaining a useful reaction. Basically aerodynamic properties for an airplane is much more depend on the properties of airfoil aerodynamic. Aerodynamic properties such as the force of lift, drag, moment and more are very important because it will determine the performance and stability of the plane. Consequently, it is important to produce an airfoil with good aerodynamic properties for ensuring the wing perform at the best performance of flight. In order of that, the compliant mechanism was embedded into the wings and makes it called as the *compliant wing*.

1.2 Aviation History

Early concepts of flight sought to imitate birds by the use of flapping wings. A flying machine utilizing flapping wings is called ornithopter. These were based upon designs written in 1500 by Leonardo da Vinci. Detailed drawing showed the levers and pulleys through which the pilot would flap the wings. Needless, is to say that all attempts to fly using this type of machine failed because the remarkable physiological capabilities of birds can never be matched by human beings.

The second attempt to fly is come from the idea of filling a closed container with a substance that normally rises through the atmosphere in thirteenth century. Between 1650 and 1900, different substances came to be known as being lighter-than-air and being used to flight. The most common gases proposed was water vapor, helium and hydrogen. The first successful attempts at achieving flight using his type of crafts were made by the Montgolfier brothers in France in 1783. They achieved 6000 ft in a balloon with a diameter of more than 100 ft. Nowadays, the balloon air has become ubiquitous, appearing over the skies of ballgames and large outdoor events.

Human being start to realize that they should copy the soaring bird and not the flapping one. Sir George Cayley to be the first man built a glider in 1853. He founded the study of aerodynamics, and was the first to suggest a fixed wing aircraft with a propeller. Otto Lilienthal, a German, developed the first gliders in which the glider could be piloted. His work (1891-1896) inspired other inventors to take up the work of gliders. They included Percy Pilcher of Great Britain, and Octave Chanute of the United States. These early gliders were hard to control, but could carry the pilot hundreds of feet into the air. The Wrights first became interested in flight after they began reading of Lilienthal's gliding flights in Germany. Upon his death, they vowed to continue his progress. On December 17, 1903, Wrights finally demonstrated true powered flight near Kitty Hawk, North Carolina.

World War I gave a tremendous impetus to aircraft development. Airplanes were first considered useful only for reconnaissance. In few short years, 1914-1918, aircraft were first armed with pistols, machine guns and bombs. The end of World War I naturally terminated the high level of military aircraft design and construction. Very few of these aircraft were built in significant quantities, but some of them made their mark in attaining new levels of performance. Thousands of military planes were converted to civilian use. In 1919, bombers were being converted in Europe to form over twenty small new airlines.

The 1920s saw the beginnings of commercial transport aviation. Over 200 aircraft were build and operated until the late 1940s on airlines throughout Europe. In the United States, air transport was slower in developing during the 1920s. Among the early aircraft was the Fairchild FC-2W, a single-engine four-passenger monoplane. And Model 80A, an 18-passenger biplane introduced by the Boeing. During the 1930s some dramatic flying boats were built. These include the Sikorsky S-42 and the Martin M-130 China Clipper as were shown in figure1.2. These aircraft carried 32 to 48 passengers and were monuments to the belief that over water aircraft should be able to safely land on water. Before turning to the postwar period, we should mention that the advances in transport aircraft were paralleled or led by racing and military aircraft. During World War II, a whole series of fighters and bombers was developed, such as the North American Mustang, the Lockheed P-38 as were shown in figure 1.3, the Boeing B-17 and B-29, the Douglas A-20 and A-26, and the Convair B-24.

Figure 1.2 Martin China Clipper, 1935 [2]

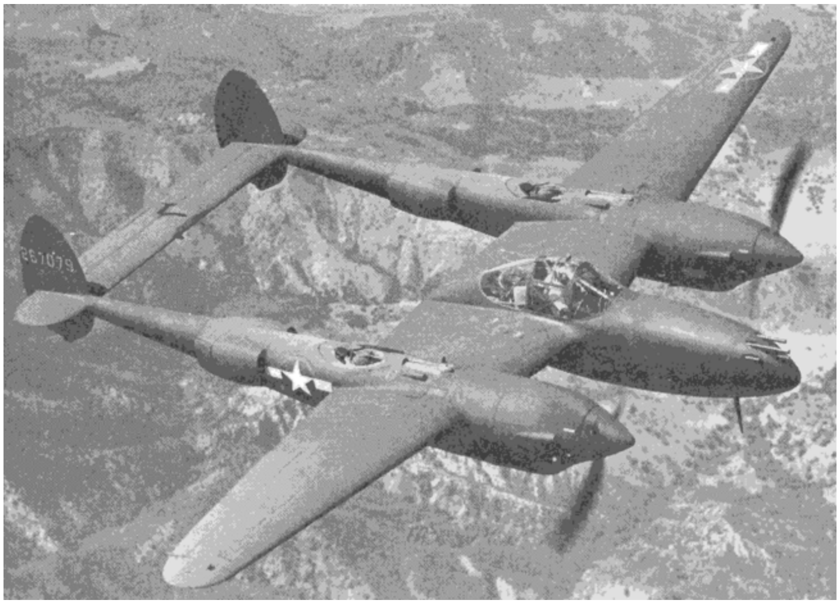


Figure 1.3 Lockheed P-38 fighter, 1940 [2]

Following the end of World War II, technological advances developed for combat were applied to commercial aircraft. In addition, developments that never got into wartime production appeared in military aircraft. Figure 1.4 shows the first new airlines were the Lockheed Constellation and the Douglas DC-6 introduced in 1946. Another prominent airplane of the postwar period was the Boeing 377 Strato-cruiser. Postwar military development ware focused on the aeronautical gas turbine engine. In modern aircraft, we call this kind of engine application a turboprop. The jet engine was rapidly improved to increase thrust and reduce fuel consumption. Wing sweepback was employed to ameliorate the adverse effects of high Mach number (the ratio of airplane speed to the speed of sound). In 1970s, a new generation of combat aircraft was developed. Powered by afterburning turbofans, the twin-engine Grumman F-14A Navy fleet defense fighter, the twin-engine McDonnell-Douglas F-15 air superiority fighter, and the General Dynamics F-16 fighter have supersonic capability to Mach 2 to 2.5.

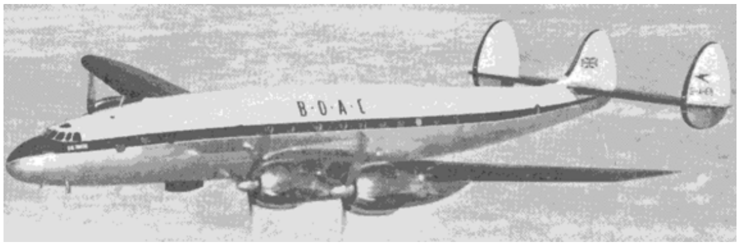


Figure 1.4 Lockheed Constellation [2]

Shortly after the introduction of jets into military aircraft, designer of commercial airplanes began exploring the technical and economic characteristics of jet transports. British Overseas Airways Corporation (BOAC) proceeded with the design of the world's first jet transport, the Comet I as shown in figure 1.5. While British were building the Comet, American companies were conducting intensive aerodynamics and structural studies of jet transports. In 1952, these studies, the experience gained in building the B-47, and advances in engine efficiency and reliability provided the confidence for Boeing to begin building a prototype jet transport. Boeing 707 entered commercial service in 1958 followed by the Douglas DC-8 in 1959. Air travel was made so much more pleasant, useful and economical by the jets that an enormous growth in air travel occurred in the 1960s. The growth in airline traffic produced a requirement for much larger aircraft. The numbers of flights required to carry the increasing numbers of passengers was leading to serious congestion both along the airways and on the airports. Because of that, Airbus was building an advanced 150-passenger airplane, the A-320, for service in the late 1980s.

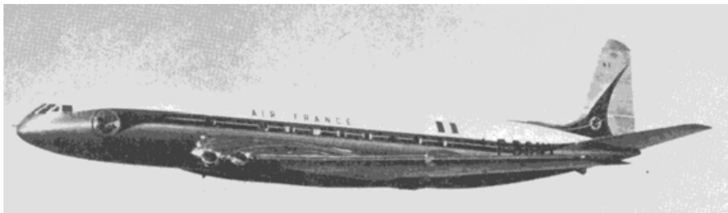


Figure 1.5 DeHavilland Comet, 1952 [2]

We cannot complete this historical review without mentioning the great technical achievement of British/French supersonic transport, the Concorde. Figure 1.6 show the airplane, which flies at a Mach number of 2, proved to be a great technical success but an economic disaster. Concorde's failure lies in its very high operating costs. The history of commercial aviation shows enormous technological growth. It is important to realize, however, that while commercial aircraft builders and operators were responsible for the progress of air transportation, most of the important technical development were derived from military aircraft. Figure 1.7 shows the speed history of military and research aircraft.

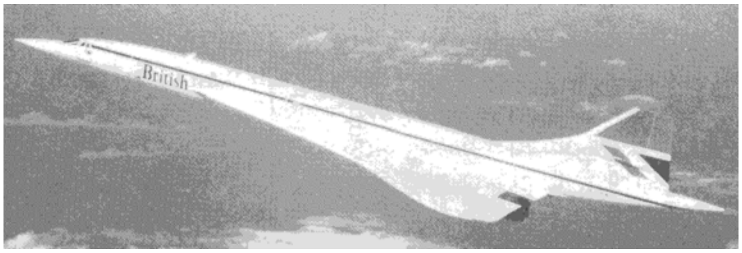


Figure 1.6 Concorde supersonic transport [2]

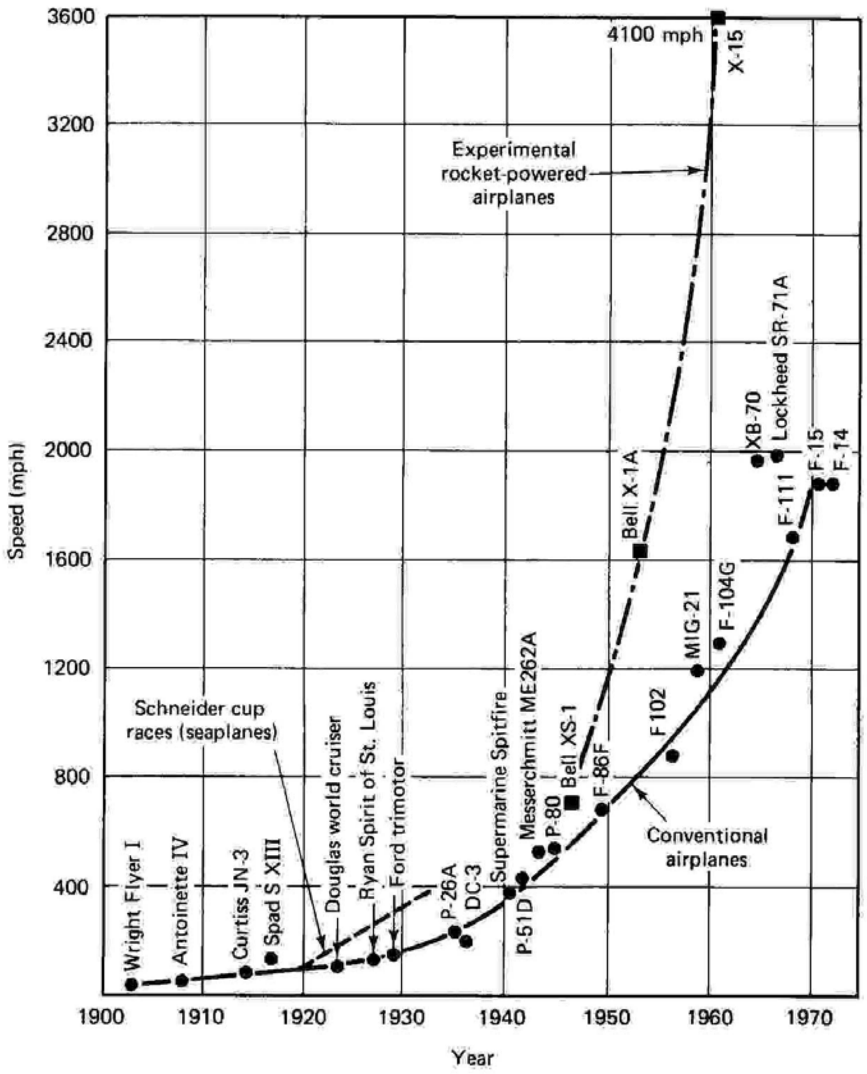


Figure 1.7 Speed history of military and research aircraft. [2]

1.3 Aircraft Categories

Different aircraft have different capabilities, and the physical characteristics of a machine that make it ideal for one purpose cause great inabilities in others. The Federal Aviation Regulations (FAR) divide civil aircraft into four categories. There are lighter-than-air (balloons, airships), gliders (powerless airplanes), rotorcraft (autogiros, helicopters, powered lift), and airplanes with certification standards specific to each.

Most hot-air balloons are used for sporting events and sightseeing. They use large propane burners as a heat source, filling their envelopes with hot gases, causing buoyancy. The pilot varies the burn for altitude control, and balloons go where the wind takes them. Their pilots adjust altitude to seek out winds aloft going in a desired direction. The fuel consumption is rather high compare with typical six-passenger light plane. Airship could lift huge payloads, but where difficult to maneuver. It also becomes danger when involving hydrogen gas because the gas can be easily blows off. Nowadays, hydrogen gas is replace by the safer helium gas.

Gliders and sailplanes have become great sport in recent years, spawning soaring groups around the world. Extremely efficient powerless aircraft, gliders are usually towed aloft and remain airborne for extended periods through the skills of pilots and the luck of the weather. The pilots simply try to find thermals or other types of "vertical wind" use such weather phenomena to climb. Soaring has produced records such as achieving altitudes near 50,000 feet and soaring powerless for distances exceeding 1300 miles. Hang-gliders and paragliders are yet another, far simpler version of the same concept that is using pilot skill and favorable weather to make a powerless machine soar like a bird.

Helicopters represent the majority of rotorcraft, although the category includes powered lift and autogiros as well. All machines of this category use a rotating wing of some kind to generate lift. Most varieties of rotorcraft possess the unique capability to operate without the need for runaway. By far the most common type of rotorcraft is the helicopter as shown in figure 1.8. Powered lift is a technical term referring to aircraft such as the Bell V-22 Tilt-rotor, which achieves vertical flight by varying the incidence of two very large propellers. Able to behave as a fixed-wing aircraft in forward flight, a powered lift offers a far greater speed envelope than typical helicopter. Gyroplanes also offer unique capabilities, such as low operating costs and natural stability that so eludes helicopters, but for the most part, have not been commercially popular. They have generated a resurgence of interest in recent times, however.

Figure 1.8 Robinson R-22 light helicopter [3]

Airplanes are by far the most numerous categories of all flying machines in practical use. They range from the smallest ultra lights to jumbo jets, using fixed airfoils for lift and internal combustion classifications, although there is some blurring between the air transport, military, and general aviation. Since the infancy of powered flight, the concept of public air transportation has always been motivated by profit. Attempting to duplicate the opulence and convenience of the well-established shipping industry, airline companies enticed passengers with promises of high speed and excellent service. Military equipment design has favored performance and mission requirements over economic concern much to Congress' and taxpayers' chagrin. Consequently, military aircraft hold most of the performance records such as the highest, fastest, furthest, and heaviest flights ever made. About 97% of civil aircraft belong to general aviation. Aviation has developed into one of the most valuable tools of all time for business. It speeds executives and skilled people to the places they are needed in unimaginably short period of time. So it not surprising that the greatest use of general aviation aircraft is for business travel.

CHAPTER TWO
LITERATURE REVIEW

2.1 Problem Statement

In order to optimize performance during all phases of a flight, the shape of aircraft feature such as wing should be smooth and continual adjusted to match different flight conditions such as take off, cruising, maneuvering, and landing. Researches have searched for a feasible way to continuous change the shape of aircraft wings. For a system to be successful, weight, strength, durability, and power consumption must meet the stringent limitations that modern aircraft pose. For now, researches are developing innovative ways to change the shape of full-scale leading edge. With sophisticated structural optimization techniques and expertise in materials and manufacturing methods, have allowed researches to design, analyze, prototype, and test adaptive leading edges that offer continuous and seamless functionally; actuation rates that are compatible with high performance control surfaces; and the ability to twist or change deflection, over the span.

The first applied compliant system technology to an aerodynamics problem in 1998. This effort objective is to prove the flight performance will increase when leading edge camber change by six degree. It with helps of compliant mechanism embedded in an aircraft wing. There has been tested a three foot NACA 65_3-418 wing in the wind tunnel. That wing was design and construct with leading edge compliant mechanism. The design allowed discrete actuation power to produce a continuous leading edge shape change. A low speed wind tunnel test of the prototype experimentally validated the variable camber aerodynamic performance projections. Testing was conducted in the University of Michigan 1.52 m by 2.13 m low speed wind tunnel. Data recording was conducted at test speeds of 44.5 m/s. In addition, several high-speed runs up to 70 m/s were performed with no observable aero elastic instability or structural degradation. Wind tunnel testing demonstrated a 25% increase in the lift coefficient and a 51% increase in lift-to-drag ratio. These performance improvements were primarily observed at high angles of attack (up to 15 degrees) as the leading edge camber was shifted from zero to six degrees.

2.2 Compliant Wing Inventor

The adaptive Compliant Wing was first design in 2004 by Professor Sridhar Kota from Department of Mechanical Engineering, University of Michigan. He uses topology optimization method in novel approach and a scaleable solution to adaptive shape change applications. Topology optimization is a method in design of distributed compliant design. It develops kinematics design to meet input/output constraints but optimization routine is incompatible with stress analysis. He claims that a leading edge camber change of six degree, which led to 25% increase in the lift coefficient. Figure 2.1 shows the S. Kota invention of adaptive compliant wing.

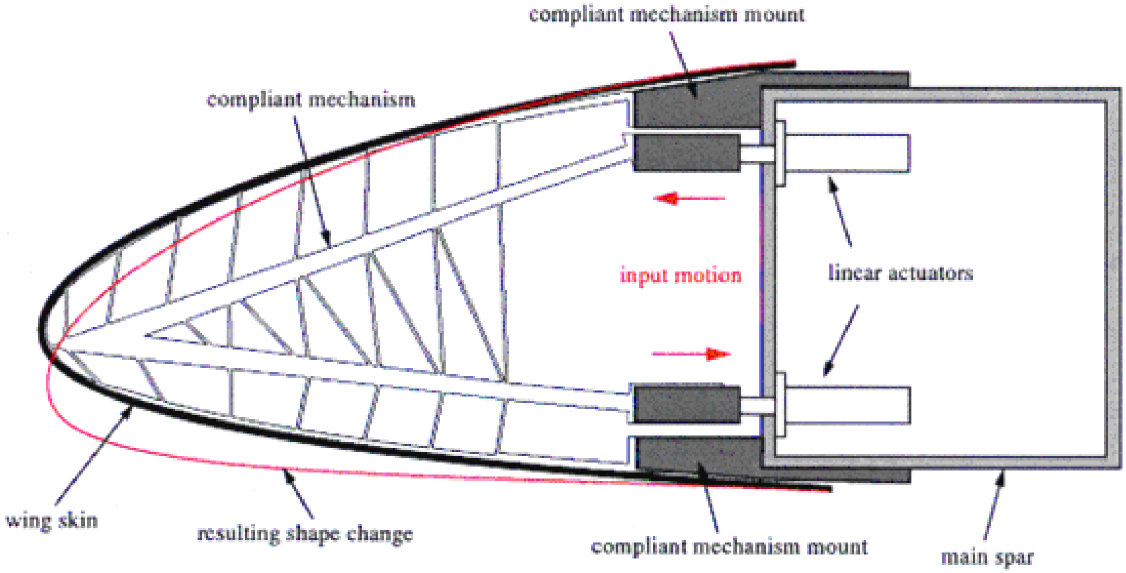


Figure 2.1 Complaint Mechanisms in Leading Edge [4]

Figure 2.2 Adaptive Compliant Wings [4]

2.3 Project Objective

The main purpose of this project is to analyze the wing performance after the compliant mechanism was applied at leading edge of the wing. This compliant mechanism will upgrade the conventional light aircraft leading edge and produce high performance of flight. Implementation of this project is guide according to objectives shown below.

a) Using I-DEAS for modeling and mesh part include the wing and compliant design.
b) Convert design into GAMBIT to apply boundary conditions setup for pre processing part.
c) Analyze the wing model using Computational Fluid Dynamics technology such as FLUENT.
d) Claims that the complaint wing design will improve in performance of flight compare with conventional wing.

2.4 Project Scope

Over the past 100 years of aviation history, researches have searched for a feasible way to change continuously the shape of various aircraft components. For a system to be successful, weight, strength, durability, and power consumption must meet the stringent limitations that modern aircraft pose. Nowadays, improving the leading edge of the flight will be more focus on design of leading edge that embedded with compliant. This effort was to change the leading edge camber by six degree. This compliant mechanism also allowed discrete actuation power to produce a continuous leading edge shape change. A light aircraft known has been choose to be upgrading it wing with the compliant design and analysis will be conducted through software in determining the flight performance of the wing.

2.5 Selected Aircraft

The most efficient twin-engine turbine aircraft in the world, the *Beech King Air C90B* represents the most productive aircraft in the air. With an extremely high ‘ready rate’, the *C90B* can be counted on to fly a variety of mission on very short notice. The *C90Bs*’ short field performance, its outstanding strength, and the long-term sturdiness on its wing, landing gear, and airframe make it an excellent choice for the flight inspection mission. In addition, a new level of cabin quietness has been achieved through advanced acoustical engineering.

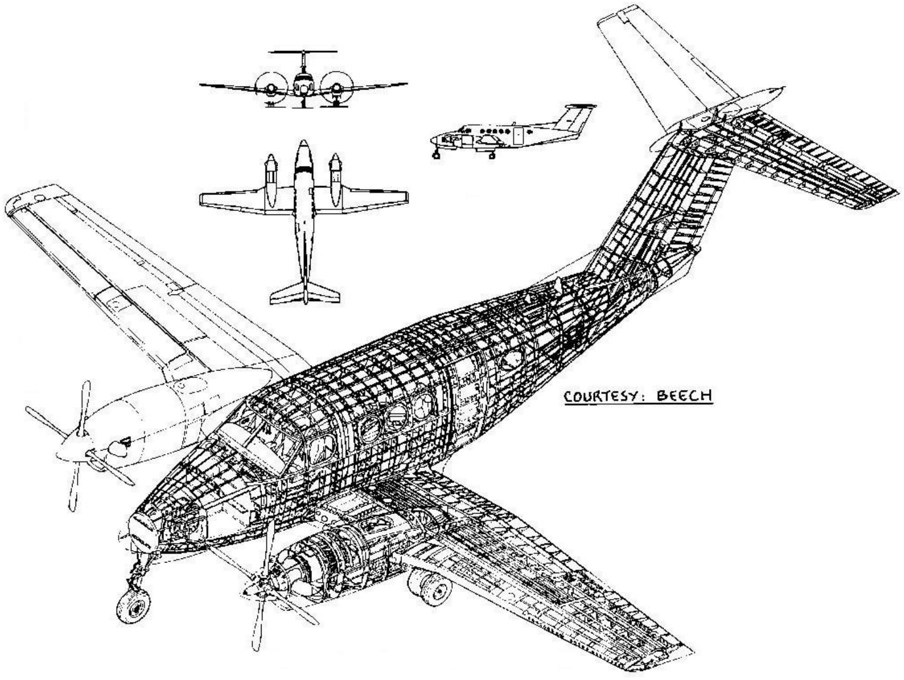


Figure 2.3 Beech King Air C90B [2]

2.5.1 Selected Aircraft Wing Types

The characteristic that most readily identifies the type, performance and purpose of an airplane is the shape of its wings. The shape of a wing greatly influences the performance of an airplane. The speed of an airplane, its maneuverability and its handling qualities are all very dependent on the shape of the wings. There are four basic wing types: straight wings, sweep wings (forward-sweep/sweepback), delta wings and the swing-wing (or variable sweep wing). Each shape allows for premium performance at different altitudes and at different speeds.

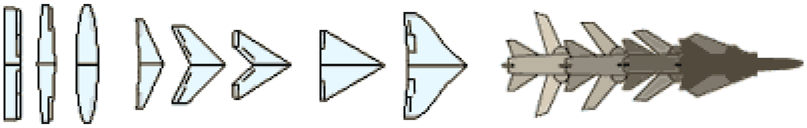
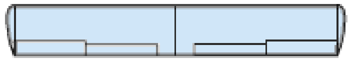
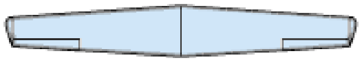


Figure 2.4 Types of modern aircraft wings [7]

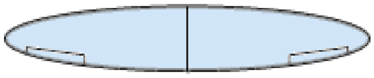
The *Beech King Air C90B* wing type is a straight wing, which is found mostly on small, low-speed airplanes. General Aviation airplanes often have straight wings. These wings provide good lift at low speeds, but are not suited to high speeds. Since the wing is perpendicular to the air flow it has a tendency to create appreciable drag. However, the straight wing provides good, stable flight. It is cheaper and can be made lighter, too.



Rectangular Straight Wing



Tapered Straight Wing



Rounded or Elliptical Straight Wing

Figure 2.5 Types of straight wings [7]

CHAPTER THREE

METHODOLOGY

3.1 Compliant Technique (Topology Optimization)

Topology optimization is at the highest level in structural optimization and is the most general. When a design domain in which the compliant mechanism has to fit and use only limited amount of material to create the mechanism, consideration must be into all possible ways of distributing the material within the domain. Like type synthesis techniques of rigid-link mechanism, topology optimization procedures bring a multitude of possible designs into the hand of designer. The designer does not have to commit to any particular topology; rather, the optimization algorithm determines the optimal topology for the problem at hand. There are two such approaches in topology optimization, *ground structure parameterization* and *continuous material density parameterization*.

In this project, *Ground Structure Parameterization* was used. The easiest topology design parameterization is to use an exhaustive set of truss or beam/frame elements in the design domain, and to vary their individual cross-section dimensions by defining them as design variables. For a truss element, the area of cross section is the appropriate optimization design variable. When the area of cross section of an element goes to zero, that element is removed. Thus after the optimization procedure converges, some elements will be removed from the original exhaustive set. The remaining elements will define the topology and shape for the compliant mechanism. The exhaustive set of structural elements is known as the ground structure or structural universe or super-structure [1]. Figure 3.1 shows the ground structure using truss elements and a possible topology after removing some elements. By increasing the resolution of the ground structure, a more refined topology can be obtained. That also increases the number of elements in the ground structure, and hence the optimization problem becomes large. In the practical implementation, we not really let any element vanish completely from the finite element model. Instead of use a very small value for the lower bound on the variables so that no numerical difficulties arise. Similarly, an upper bound is also used in some cases. The variables that do not reach either the lower or the upper bound will have values in between defining the size-related features of the segments in the compliant mechanism. Thus this procedure gives not only the optimal topology but also the optimal shape and size. There is no need for re-meshing in this procedure because the mesh remains unchanged and undistorted.

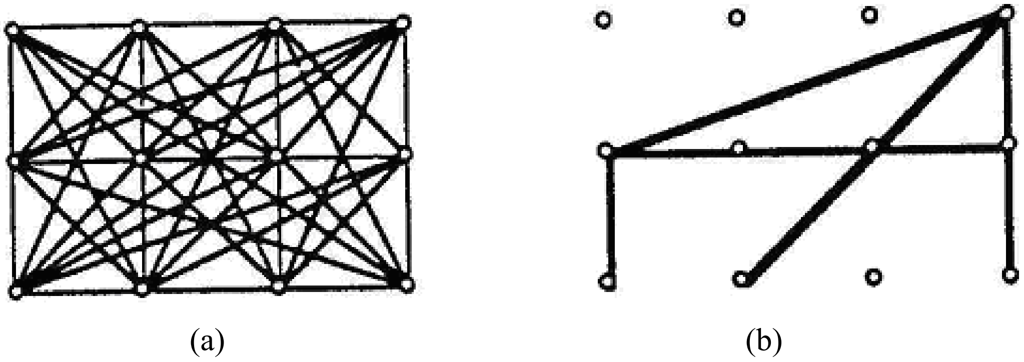

(a) (b)

Figure 3.1 (a) Truss element ground structure for topology optimization, and (b) possible topology after removing some elements. [1]

3.2 Example of Topology Optimization-Compliant Adaptive Trailing Edges

In figure 3.2 the design domain is shown for the following example. The design domain is supported on the lower and upper fourths of the right edge. The actuator is placed in the middle of the right edge. The flap contour is set to be fixed solid material while the material outside the flap is set to be fixed void.

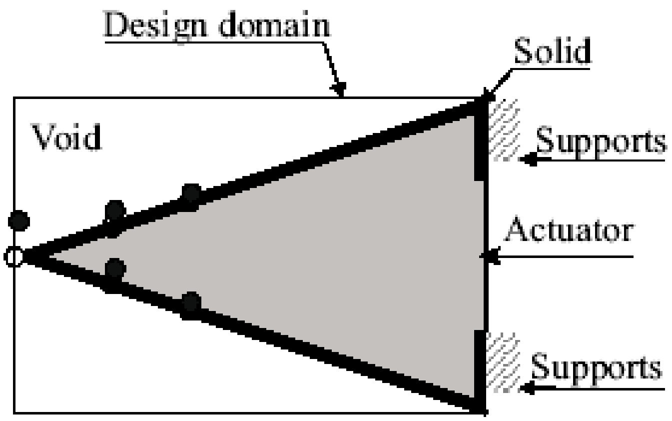


Figure 3.2 Conceptual layout of the design domain [6]

The gray color in figure 3.3 represents the area where the mechanism can be formed. The flap should follow 5 given point marked with solid circles in figure 3.2. The points on the flap (marked with hollow circles) should in the deformed configuration coincide with the solid circles.

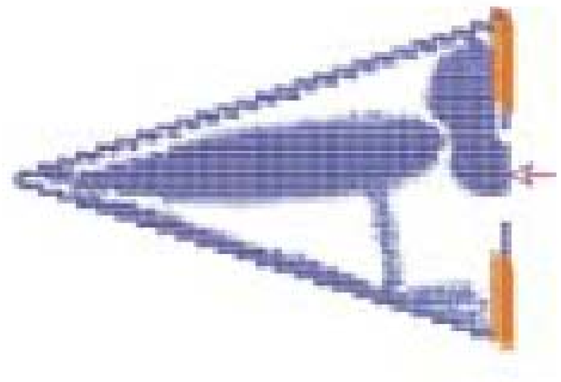


Figure 3.3 The optimized flap mechanism in undeformed configuration [6]

The optimization problem was solved in 712 iterations and error is less than 10.6. The internal mechanism is a simple rod delivering all its actuation to the out corner of wedge. Optimal topology should in the final configuration consist of only solid and void elements which ensured by the SIMP-model. A continuation approach is used on the filter radius such that the possibility of ending in a local minimum is less likely. A set of points describing the outer shape of the flap in actuated configuration is given from the aerodynamic and aero elastic calculations. Another set of point on the actual outer perimeter must coincide with the given set of points. This is done by formulating the optimization problem as a minimization of the summed squared error between the two sets of points in the deformed configuration. The optimization problem has like most standard topology optimization problems with mechanism design constraint on the input displacement and a volume constraint. The objective function for this optimization problem can be written as

$$\left.\begin{array}{rl} \underset{\rho}{\min} & : \quad \Phi = \sum_{m=1}^{M} \left(u_{out,m} - u^{*}_{out,m}\right)^{2} \\ \text{subject to} & : \quad \mathbf{v}^{T}\,\boldsymbol{\rho} \leq V^{*}, \\ & : \quad u_{in} \leq U^{*}_{in}, \\ & : \quad \mathbf{0} < \boldsymbol{\rho}_{min} \leq \boldsymbol{\rho} \leq 1 \end{array}\right\} \tag{3.1}$$

where $u_{out,m}$ is the actual position of the mth point on the perimeter, $u_{out,m}$ is the mth desired point, M is the number of point in total, v is the volume of an element, V is the volume constraint, ρ is the density of an element, u_{in} is the actual displacement in input point and U_{in} is the constraint of the input point. The design variable has the upper bound of one while the lower bound for ρ is ρ_{min}. [6]

The topology optimization problem of finding the optimal mechanism, to make the trailing edge of a blade follow a given shape, has been solved. The optimization problem was written as an error function where a number of points on the flap should go through the same number of given points. The error between the two sets of points are minimized. The optimization problem was solved with an acceptable error in 712 iterations.

3.3 Computational Fluid Dynamics

The phrase “Computational Fluid Dynamics” needs to be fully understood. First, the words are broken down. *Computational* is have to do with mathematics and *Computation Fluid Dynamics* is the dynamics of things that flow. Computational Fluid Dynamics (CFD) is a computational technology that enables a person to study the dynamics of things that flow. By utilising CFD, a computational model that represents a system or device that that needs to be studied is modelled using certain modelling programmes. Then, the fluid flow physics is applied to this virtual prototype, and the software generates a prediction of the fluid dynamics. CFD is a sophisticated analysis technique. It not only shows fluid flow behaviour, it also predicts the transfer of heat and mass, phase change, chemical reaction, mechanical movement, and stress or deformation of related solid structures.

The three main reason of the usage of CFD is as follows:

(i) Insight

Many devices and systems are very difficult to prototype. Often, CFD analysis shows parts of the system or phenomena happening within the system that would not otherwise be visible through any other means. CFD gives a means of visualising and enhancing understanding of designs and fluid flow over bodies.

(ii) Foresight

Because CFD is a tool for predicting what happens under a given set of circumstances, it answers many questions, queries, doubts and uncertainties of designs and types of flow over objects, very quickly. When variables are entered, the CFD programme gives the outcome. In a short period of time, prediction can be made as to how fluid will flow over a given object or how a certain design will perform, and many variations can be tested until an optimal result is achieved. All of this can be done before physical prototyping and testing. The foresight gained from CFD helps to achieve better designs, at a much faster rate.

(iii) Efficiency

Better and faster design or analysis leads to shorter design cycles. Time and money are saved. Products reach the market faster. Equipment improvements are built and installed with minimal downtime. CFD is a tool for compressing the design and development cycle.

There are a number of CFD programmes in the market. Of all of them, the largest used in the world is Fluent, which is the CFD programme utilised in this project. Fluent version 5.2 is used. The modelling programme that was used to model the airfoils is Gambit, a modelling programme provided by Fluent. In Fluent, pre-processing is the first step in building and analysing a flow model. It includes modelling or building the model, applying a mesh, and entering the data. The pre-processing tool used is Gambit, which is supplied with the Fluent software. After pre-processing, the CFD solver does the calculations and produces the results. The CFD solver that was used is Fluent. Fluent is used in most industries. Post-processing is the final step in CFD analysis, and involves organisation and interpretation of the data and images. After the CFD software does the calculations, the results that are produced need to be transformed into a format that can be easily read, produced and printed. The Fluent software includes full post-processing capabilities.

3.4 Airfoils Theory

An airfoil is any surface that is designed to obtain lift from the air through which it moves. In aerodynamic discussion, airfoil means a section of “wing” of infinite span (length); airplane fuselage and wing-tip effects may be ignored in the study of a simple airfoil. The National Aeronautics and Space Administration (NASA) and the other research agencies have developed and classified families of airfoils.

3.4.1 Airfoil Geometry Parameter

The generated lift and the stall characteristics of the wing depend strongly on the geometry of the airfoil sections that make up the wing. Geometric parameters that have an important effect on the aerodynamics characteristics of an airfoil section include (1) the leading-edge radius, (2) the mean camber line, (3) the maximum thickness and the thickness distribution of the profile, and (4) the trailing-edge angle. Figure 5.5 shows the airfoil section.

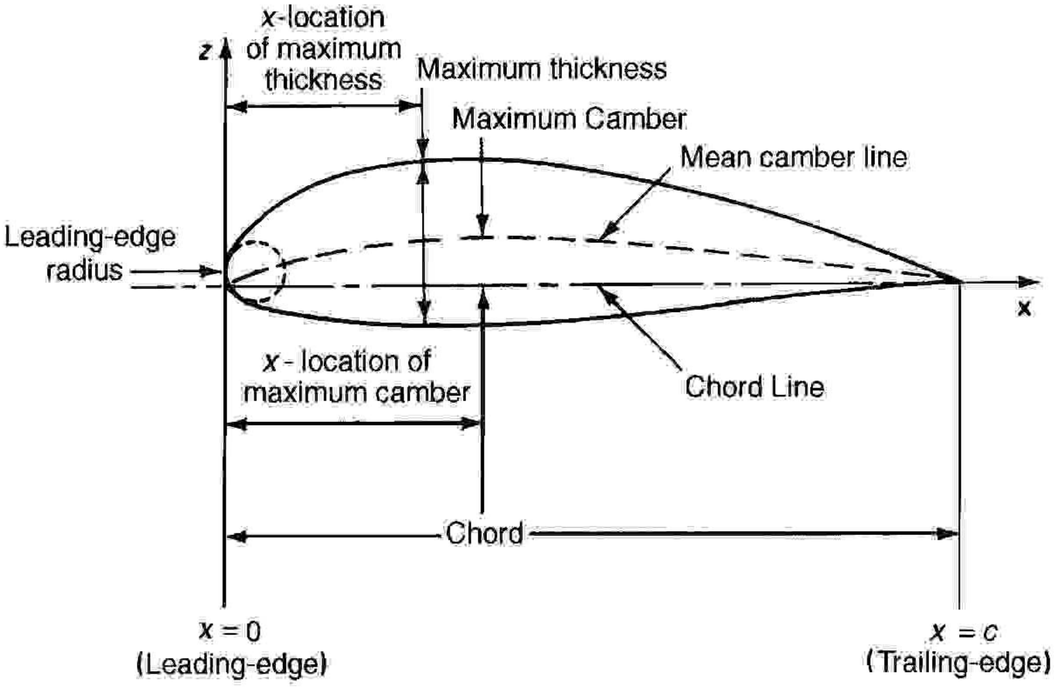


Figure 3.4 Airfoil-section geometry [5]

3.4.2 Airfoil-section Nomenclature

The geometry of many aerofoil section is uniquely define by the NACA designation of the aerofoil. There are a variety of classifications, including NACA four-digit wing sections, NACA five-digit wing sections, and NACA 6 series wing sections.

For the NACA four-digit wing sections; the first integer indicates the maximum value of the mean camber-line ordinate in percent of the chord. The second integer indicates the distance from the leading edge to the maximum camber in tenths of the chord. The last two integers indicate the maximum section thickness in percent of the chord.

The NACA five-digit series uses the same thickness distribution as the four-digit series. But the five-digit series numbering system is not as straight forward as the four-digit series. The first digit multiplied by 3/2 gives the design lift coefficient of the aerofoil. The next two digits are twice the position of maximum camber in percent of chord. The last digits give the percent thickness.

In explanation, NACA 23012 aerofoil will be used. The aerofoil is a 12% thick aerofoil having a design lift coefficient of 0.3 and a maximum camber located 15% of chord back from the leading edge.

2 30 12

Last two digit : gives the section thickness in percent of chord.

$$\rightarrow \frac{12}{100} = \frac{\text{thickness}}{\text{chord}}$$

Next two digit : gives twice the position of maximum camber in percent chord.

30 = 2 (x); where x will be the maximum camber.

$\therefore x = 15$.

So the maximum camber will be located 15% of the chord from the leading edge.

first digit : multiplied by 3/2 gives the design lift coefficient (in tenths).

→ [2 x 3/2] / 10 = 3 / 10 = 0.3

The airfoils that will be used in this project will be the NACA five-series 23012 and NACA five-series 23018. NACA 23012 will be the aerofoil section for wing tip and NACA 23018 will be the aerofoil section for the wing root. This is taken from the Beech King Air C90B prototype wing.