DESIGN & FAILURE ANALYSIS OF A COMPLIANT WING

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Design and Failure Analysis of a Compliant Wing

by

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TOPOLOGY OPTIMISATION OF HIP IMPLANT DESIGN

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act: This work presents the application of ogy optimisation method to the hip implant n. Three-dimensional implanted femur was lled and defined as a design domain. The ant, modelled as type 1, was optimised while materials i.e. cement (type 2) and bone (type ere not be optimised. The domain was subjected load case, which corresponds to the loads ed when walking. Loads were employed at the mal end of the implant and the abductor le. Loads from other muscles were not dered. The goal of the study was to minimize energy of implant compliance subjected to al sets of volume reduction. Reductions were set 30%, 40%, 50%, 60%, and 70% from initial e (V_0). Result of each set was cut into several ns about x-y plane in z-direction to observe the ogy inside the stem. It was found that implants 30% V_0, 40% V_0, and 70% V_0 had developed boundaries whereas 50% V_0 and 60% V_0 had d boundary and produced possible shape. efore, these designs (50% V_0 and 60% V_0) were n and refined. Both were analysed using the boundary conditions as before they were ised. Results of stresses along medial and al line were plotted and compared.

duction

ver 800,000 artificial hip joints were implanted dwide annually suggesting that it is a well-accepted successful treatment [1]. The surgical procedure ves removing parts of the hip joint that have been ged and replacing the joint with an artificial nt. Normally, femur carries its external load by When an implant is introduced into the canal, it s the load with the bone. As a result, the bone is ed to reduce stresses, and hence stress shielded. phenomenon is called stress shielding. It is natural e bone to release calcium where it is not needed ore, and hence reduced the bone mass. Atrophy esorption lead to a loosening of the prosthesis and e of the implant. Nevertheless, this reaction does ccur spontaneously, instead, it is a slow process, n may take a few years [2].

one receives more load if stem can be eliminated the implant. Consequently, a stemless implant was designed. It was fixed with several screws [3] and cables to support the head [4]. However, it is difficult to position correctly during operation and may possible lose of initial stability [5]. In another work, hollow geometry has been introduced by increasing stem inner diameter to reduce stress shielding [6]. However, it has increased maximum stem stress dramatically when bending was applied.

Stress shielding can also be decreased if stem is made from non-stiff material such as polymeric [7-9]. But, flexible implant may produce higher stresses along the interface [10,11].

This paper tries to look at the potential of optimising the stem topology in order to reduce the same problem. The idea of topology optimisation is to get the best distribution of material within a fixed domain as we applied the boundary conditions. This method is previously used in many engineering applications such as components in material design [12], compliant mechanisms [13], bone remodelling [14], components in car [15], bus [16], and airplane wings [17].

Materials and Methods

Design domain

A study was performed using ANSYS 7.1. Figure 1(a) showed a model of implanted femur. The design was divided into three types, which correspond to three different materials. Implant was identified as type 1 and would be optimised. Other two types would not be optimised. Properties of materials used were shown in Table 1.

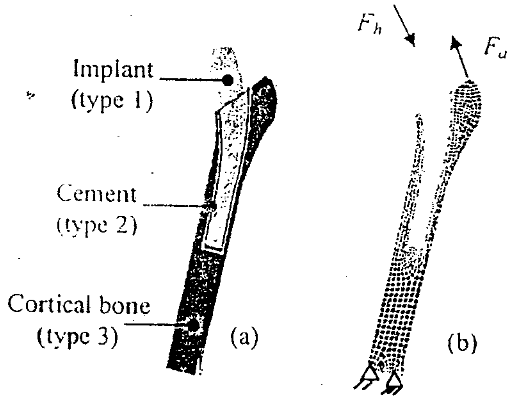


Figure 1: (a) Design domain (b) Meshed domain and applied boundary conditions

Table 1: Properties used in the FE model

Parts	Elastic modulus, E (GPa)	Poisson's ratio, μ
Implant (Titanium)	115	0.3
Cement	2	0.3
Cortical bone	20	0.3

Discretization/meshing

The model used twenty node hexahedral finite elements (ANSYS type SOLID95). The element length given to each material was varied. Implant should be meshed smoother otherwise, it would result coarser surface in the final topology. However, smooth mesh consume a lot of computing time. Finally, there were 12201 number of elements with 7287 elements for the implant, 1498 (cement) and 3416 (bone). The distal end of the bone was rigidly fixed and loads were applied at the proximal end of the stem (F_h) and the abductor muscle (F_a). Applied load cases that correspond during walking were as same as in [18]. It was shown in Table 2 below. Figure 1(b) showed a model of meshed implanted femur with applied boundary conditions.

Table 2: Applied load cases

Load	F_x (N)	F_y (N)	F_z (N)
F_a	-768	-726	1210
F_h	224	972	-2246

Topology optimisation method

The theory of topology optimisation seeks to minimize or maximize the objective function (f) subject to constraints defined. Design variables (ρ_i) are densities that are assigned to each finite element (i) in the topology problem. The density for each element varies from 0 to 1; where $\rho_i \approx 0$ represent material to be removed; and $\rho_i \approx 1$ represent material that should be kept. We want to minimize the energy of implant compliance for a given load case subject to its volume reduction. Minimizing the compliance is equivalent to maximizing stiffness. The optimisation problem is explained as follows:

Minimize the energy of the implant compliance (U_c)

In this case, we applied six load cases as shown in Table 2. Therefore, f would be stated as,

$$f(U_c^1, U_c^2, \ldots, U_c^6) = \sum_{i=1}^{6} W_i U_c^i, \quad W_i \geq 0 \tag{1}$$

Subject to: $0 < \rho_i \leq 1 \quad (i = 1, 2, 3, \ldots. N)$ (2)

$V \leq V_o - V^*$ (3)

Where:
W_i = weight for load case with energy U_c
V = computed volume
V_o = original volume
V^* = amount of material to be removed

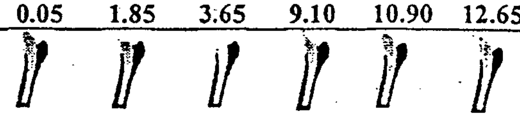
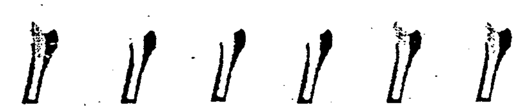
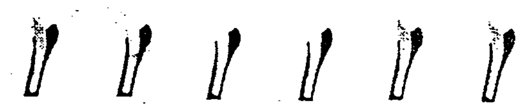
The reductions of volume were set to be 30%, 40%, 50%, 60% and 70% from the initial implant volume (V_o).

Results and Discussions

Topology results and design interpretation

Table 3 shows implant topology for each material constraint case about x-y plane in given z-direction. The topologies represent the value of density between 0.89-1. Although every solution is topologically different, tendencies are very similar. The main difference can be seen at the proximal end of the implant, especially between 1.85 mm to 10.90 mm. Solutions of 70% V_o, 40% V_o and 30% V_o had developed an open boundary whereas 50% V_o and 60% V_o had developed closed boundary and produced acceptable shape. Therefore, these designs were chosen for shape refinement.

Table 3: Implant topologies about x-y plane in z-direction with different implant volumes

% V_o	z-direction (mm): 0.05, 1.85, 3.65, 9.10, 10.90, 12.65
70	
60	
50	
40	
30	

Shape design

Topology optimisation results can be difficult to interpret since they contain zigzag border and some degree of grey zone. CAD was used to refine the model. Only half of the model was refined due to its symmetrical shape about x-y plane.

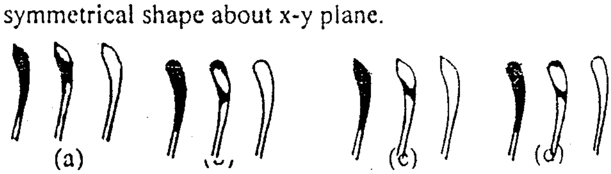


Figure 5: Topology optimisation results for (a) 60% V_o (c) 50% V_o and after shape refinement (b) 60% V_o (d) 50% V_o.

Comparison results

In order to see the performance of new models (Figure 2(a) and (b)), stresses along medial and lateral side in intact and implanted femur were plotted and compared with optimum models. Loading and boundary conditions applied were similar in the optimisation process.

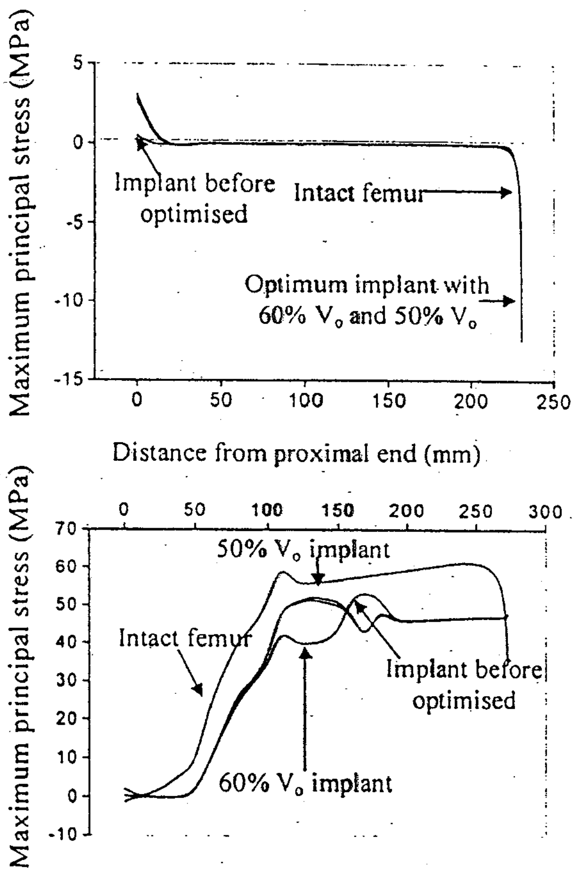


Figure 3: Maximum principal stresses in the femur along medial (top) and lateral (bottom) side

Figure 3 shows the variation of maximum principal stresses in the femur, which occur along medial and lateral side. By comparing both graphs, we can see that maximum compressive stress happens in medial side whereas maximum tensile stress occurs in lateral side. In all conditions, the trend is just about the same. It is obvious that the difference occurs in medial side is so small and almost zero except at the distal end of the femur. Optimum implants, 50% V_o and 60% V_o, increase the compression stress near the constraints. In lateral side, tensile stress is very low in the beginning, but it starts to increase after one fifth of the femur and maintain until the end. This is probably because of wide cross sectional area around greater trochanter. Stresses produce in both optimum models are very close to each other. Maximum stress occurs in the middle of the femur at the level of implant tip. This means that load transfer has increased in femur with the optimised implants compared to before optimise.

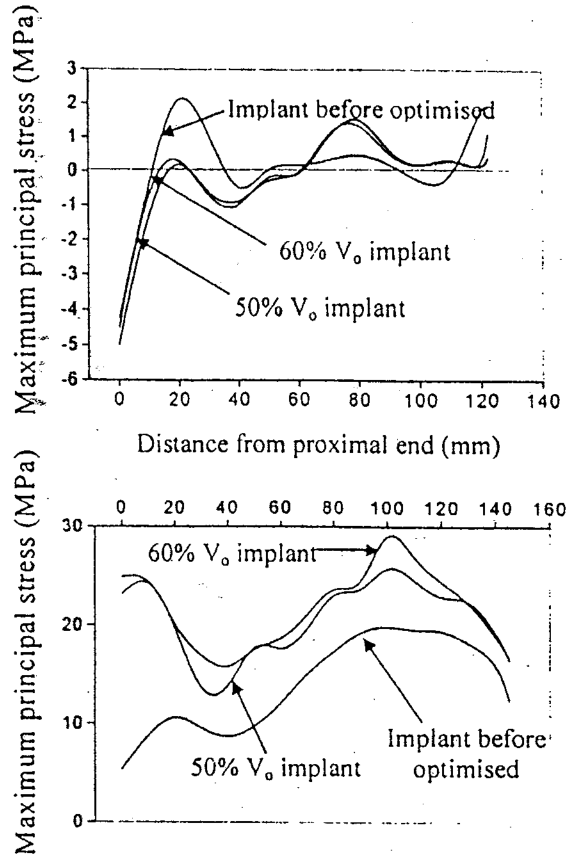


Figure 4: Maximum principal stresses in the cement along medial (top) and lateral (bottom) side

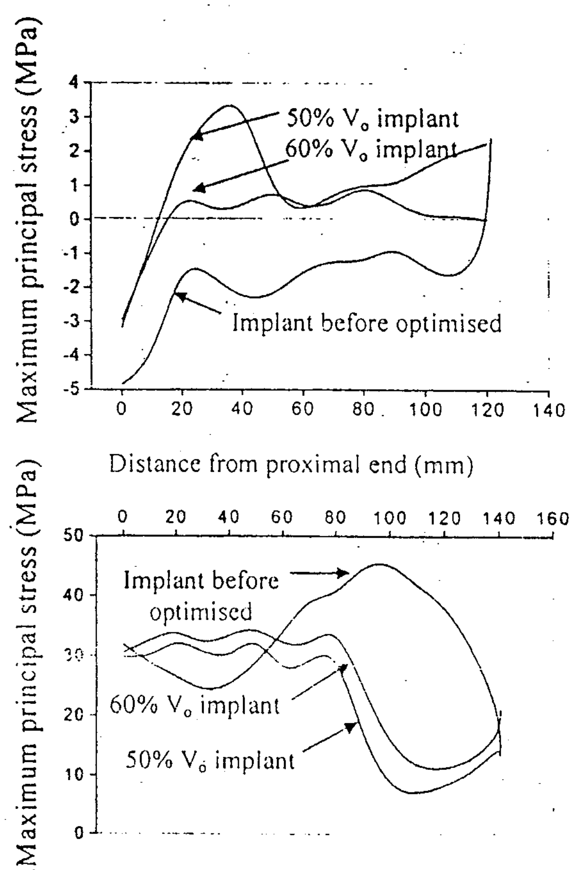


Figure 5: Maximum principal stresses in the implant along medial (top) and lateral (bottom) side

Figure 4 shows the comparison of stress distribution in the cement for optimised and non-optimised implant., thereby transferring more stress to the cement. In medial side, maximum compressive stresses occur underneath the implant's neck but it turns to tensile stress as it goes downward to the distal end. However, the difference is not too significant as in lateral side. As expected, the lateral stresses are tensile occurred in all implants. Both optimum implants have produced higher stress in cement compared to non-optimised implant. Maximum stresses happen in the beginning of proximal end and near the distal end. Higher cement stresses bring the meaning that load transfer occurs in proximally and distally. This is because optimised stem undergo more bending displacements. Figure 5 shows the maximum principal stresses in the implant, which occur near the implant/cement interface. In this case, the medial side maximum principal stresses occur in compressive near proximal end. The stresses in the implant become smaller in the middle of the stem and increase in the end. For lateral side, maximum principle stress occurs in the middle third of non-optimised stem. It is clearly shows a reduction in maximum principal stress especially in the final length of the optimal stem. The reduction is due to stem hollow topologies.

Conclusions

Topology optimisation method was applied to get the best material needed for an implant in order to minimize stress shielding problem. Stem topology was optimised to achieve minimum compliance for a given load case subjected to several sets of volume reduction. From ANSYS simulation, implant with 50% V_o and 60% V_o were chosen as the best and refined. Comparison between stress distribution in intact and implanted femur with optimal design was being carried out. Results of application problem showed the advantage of the method.

Acknowledgement

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PERFORMANCE ANALYSIS OF A COMPLIANT WING FOR A LIGHT AIRCRAFT

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A compliant mechanism is flexible structure that elastically deforms without joints to produce a desired force or displacement. This objective of the study was to analyze the performance of a compliant mechanism that has to be fitted to the leading edge of aircraft Beech King Air C90B wings. The compliant wing model was analyzed using Computational Fluid Dynamics (CFD) Software i.e. FLUENT 6.0. It focused in determining the value of lift coefficient and drag coefficient when applying different angle of leading edge. The analysis had shown that there was an improvement of the flight performance for the compliant wing in comparison to the conventional light aircraft. The result demonstrated a 25% increase in the lift coefficient and 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.

FREE CONVECTION ON VARIABLE TEMPERATURE WALL IN POROUS MEDIA

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Abstract

The problem of the free convection from a vertical heated plate embedded in a porous medium is investigated numerically in the present paper. The plate temperature is assumed to have exponential variation along the plate. The governing equations are simplified using the two-dimensional transient laminar boundary layer theory together with the Boussinesq and Darcy approximations. The fully implicit finite volume method is used with the power law scheme to solve the non-dimensional system of equations. The numerical results are presented for isothermal, exponentially increasing and exponentially decreasing plate temperatures. It is found that the results of the present algorithm for the standard isothermal plate agree well with the results in the open literature for transient temperature profiles, transient local and average Nusselt number along the vertical plate. It is observed that increasing the plate temperature leads to increase in the transient and the steady state Nusselt number compared with the isothermal plate or decreasing plate temperature along the plate.

Introduction

Free convection and, in general, buoyancy driven flows in porous media occur in many engineering applications and have been studied extensively by various authors. The applications include thermal insulation of buildings, storage of grain, vegetables and fruits, drying processes, solar collectors, geothermal engineering, petroleum reservoirs and others. Representative studies in this area may be found in the recent books by Nield and Bejan [1], Vafai [2], Pop and Ingham [3] and Bejan and Kraus [4].

Studies of free convection about vertical flat plate in porous media have been carried out by various authors. Johnson and Cheng [5] have studied the transient boundary layer flow in a porous medium and obtained similarity solutions for specific variations of wall temperature in time and position. Bejan and Khair [6] obtained similarity solutions for steady-sate natural convection heat and mass transfer in boundary layer flow about vertical plates in porous media. Cheng and Pop [7] used the integral method to investigate the transient free convection boundary layer in a porous medium adjacent to a semi-infinite vertical plate with step change in wall temperature or surface heat flux. Jang and Ni [8] used the finite difference method to investigate the transient free convection with mass transfer from an isothermal vertical flat plate embedded in a porous medium. They found the final steady state temperature and

AN IMPROVEMENT OF A DESIGN AND ANALYSIS OF A COMPLIANT WING

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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 0° until 6°. 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.

Keywords: Compliant; Wing; Leading-edge; topology-optimization; computational fluid dynamics

1. Introduction

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.

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.*

2.0 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 653-418 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.

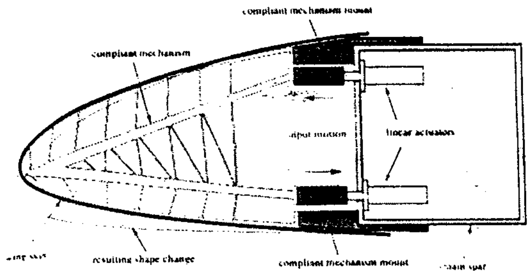


Fig. 2.1Complaint Mechanisms in Leading Edge [2]

2.3 Project Objectives

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.

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

2.3 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.

3.0 Analyisis

In aerospace, numerical simulation is an alternative way to predict aerodynamic characteristics of flow past body or vice versa. The CFD tools could save a lot of money and time because it can predict a result before a body such as an aircraft is tested in the wind tunnel or by doing a real flight test. Furthermore, CFD is used as a complimentary tool to validate the data getting from the pure theory and experiment. The most important thing in doing analysis is preparing the model using the modeling software available. In this particular case, I-DEAS is engineering tool that was use to build the model in 3-D. Before starting this, related data and information was collected from various way and most of it, were come form the aerospace company website. All these related information collected were able the modeling works were done. After the modeling part was completed, mesh is generated to that model because it was a part of procedure in doing the analysis using software. Analysis only can be done after mesh was generated on the model.

Now the mesh model is ready to key in the important value. as it for the boundary condition setup. It has to be carefully setup because most of the input parameters are based on the boundary conditions. In GAMBIT, setup for the boundary conditions will determine which part is set as velocity inlet, outflow, symmetry and wall boundary. In the end, the meshing data is now ready to be export to FLUENT 6.0 solver the calculation. Data such as flow types, velocity inlet and more were input. After these parameters have been set up, the solution is ready to be initialized and iterated. The calculation will stop when the calculations are converged. In the end, result which is needed can be obtain and some simple calculation was done on fundamental formula fluid mechanics to come out with the graph which is commonly used to determine the performance of flight.

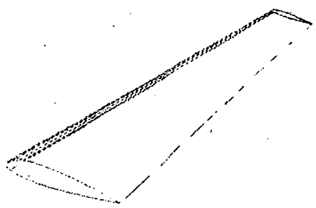
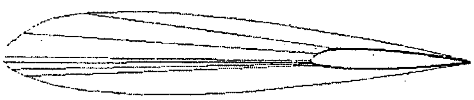
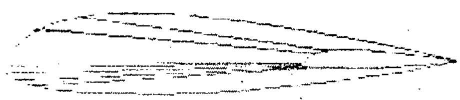


Fig. 3.1 Wing and wind tunnel modeling



(a)



(b)

Fig. 3.2 (a) Wing with 0° of leading edge
(b)Wing with 6° leading edge

4.0 Result and Discussion

4.1 Aerodynamics Characteristic

The performance of flight can be interoperate from the graph aerodynamics characteristic graph such as drag coefficient versus lift coefficient, lift coefficient versus angle of attack, drag coefficient versus angle of attack and lift drag ratio versus angle of attack. Figure 4.1 through 4.4 present the aerodynamics coefficient curves with 2 types of wing. In this study, the aerodynamics coefficient are determined against angle of attack varying from $\alpha = -6°$ to $\alpha = 33°$. Figure 4.1 shows the graph of drag coefficient, CD against lift coefficient, CL. In the graph, the lift coefficient is increase as the drag coefficient increase for both of the wing. It is observed that the lowest polar occurs on 0° angle of attack. At this point of angle, the drag coefficient is 0.0201 and lift coefficient is 0.0433 for the wing 0°. While for the wing 6°, the drag coefficient is 0.0255 and lift coefficient is 0.0283. Comparison has been made to using NACA 23018 and NACA 23012 as a benchmark that are shown in appendices. As example, NACA 23018 in lowest polar will give a drag coefficient and lift coefficient in the range between zero to one. These values are close compare to the benchmark. It is mean that wing modeling is has been analyze successfully through the CFD analysis.

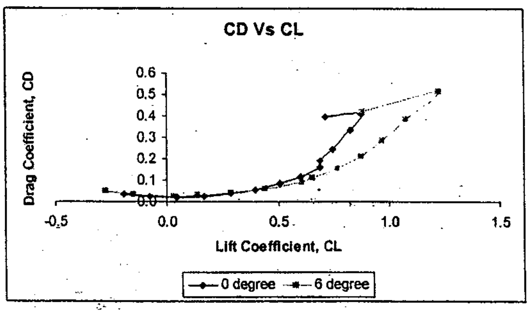


Fig. 4.1 Drag against Lift Coefficient graph

Another graph is lift coefficient, CL against angle of attack. As shown in Figure 4.2. From the graph, it is observed that the CL increases linearly with the angle of attack until it reaches stall point where the point lift coefficient start to decrease. The lift coefficient for wing 0° is much higher than wing 6° until it reaches the 6° angle of attack. Beyond the 6° angle of attack, the wing 6° will be higher lift coefficient than wing 0°. It is conclude that, the wing 6° is better than conventional wing after angle of attack come to 6°. The lift coefficient increase gradually until it reaches 30° angle of attack. In additional, the performance of flight will be better if wing with 6° leading edge is used in the range 6° and 33° angle of attack.

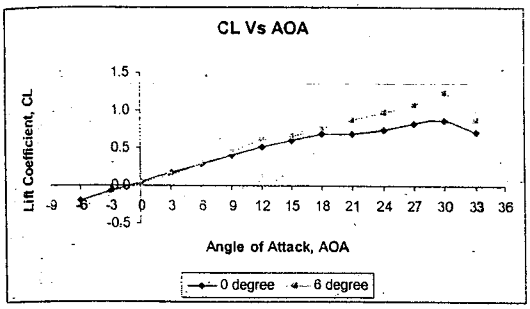


Fig 4.2 Lift coefficient against the angle of attack

Figure 4.3 shows the graph of drag coefficient, CD against angle of attack. Generally, drag coefficient of wing 0° is less than wing 6°. But the different between this two type of wings not too far between the certain range. The range is from 0° until 18° angle of attack. In this particular case, the less drag forces is the best flight performance should an airplane be.

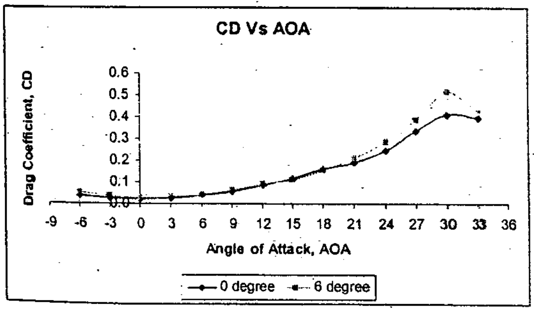


Fig. 4.3 Drag coefficient against the angle of attack

Another method to measure the aerodynamic efficiency is plotting the lift to drag ratio against angle of attack and this is shown in Figure 4.4. At 6° angle of attack, the plotted graph represent wing 6° is increase better than wing 0°. As a result, wing with 0° leading edge which is a conventional wing is perform better flight than wing with 6° leading edge in the range 0° until 6° angle of attack. When angle of attack reaches 6°, the performance of conventional wing will decrease and performance of wing with 6° leading edge is better than conventional wing.

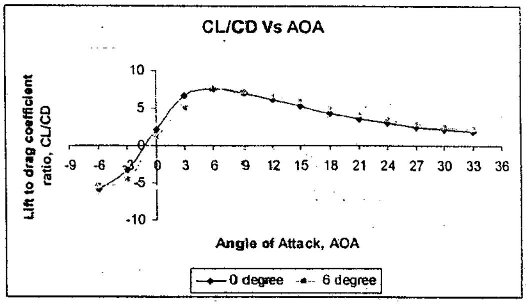


Fig. 4.4 Lift to drag ratio against angle of attack

4.2 Presssure Contour

Figure 4.5 to figure 4.8 present the general pressure contour on the wing when the aircraft is subjected to the certain angle of attack with different angle of leading edge. From figure 4.5 to figure 4.8, it is clearly seen that the highest pressure occurs at the leading edge of the wing part. The point location where the highest pressures are occurring is called as a stagnation point. The pressure at the lower surface body is higher than the upper surface as shown in all figure. From the overall observation, the pressure at the upper surface body is less than the lower surface body. The differences between this two pressure condition resulting force acting upward of lift force.

Figure 4.5 and figure 4.6 show the wing pressure contour at $\alpha = 0°$ for different angle of leading edge. Both wing have same pressure contour but with different amount of pressure distribution. High pressure indicated by red color commonly produced at the lower part close to the leading edge. While low pressure indicated by blue color produced at the upper surface of the wing. The different between this two wings is the wing with six degree leading edge produce more low pressure at the upper surface compare to the wing with zero degree.

As the angle of attack is increased to $\alpha = 6°$ in figure 4.7 and figure 4.8, the pressure increase gradually. At the upper surface, the pressure gradient increases. It is observed that the highest pressure is occurring near the upper leading edge. Low pressure at the upper wing with zero degree leading edge is decrease and becoming with increasing of pressure. But for wing with six degree leading edge, there is a little amount of low pressure more than low pressure gaining by the wing zero leading edge.

Figure 4.5 through figure 4.8 have show and proved that wing six degree leading edge is better than wing with zero degree leading edge. So, the new design of wing is provide us benefit in improving the flight performance compare to the conventional wing. Pressure distribution on the wing is main characteristic in order to obtain upward forces which is will lift the aircraft.

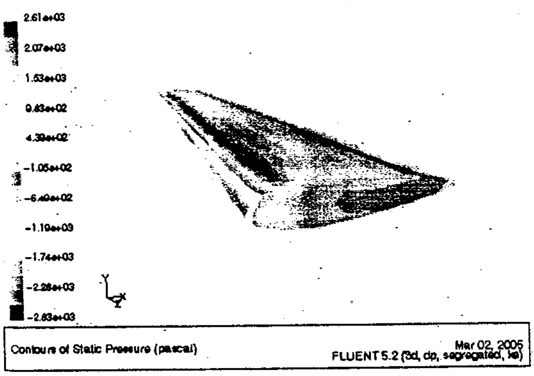


Fig. 4.5 Pressure distribution at $\alpha = 0°$ for zero degree leading edge

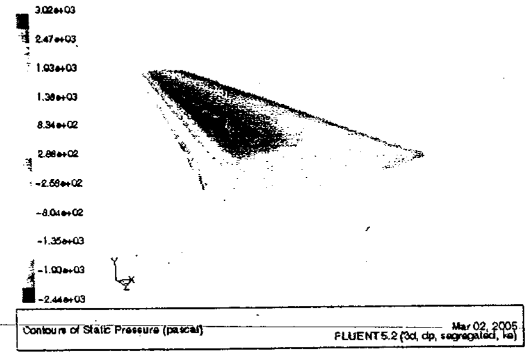


Fig. 4.6 Pressure distribution at $\alpha = 0°$ for six degree leading edge

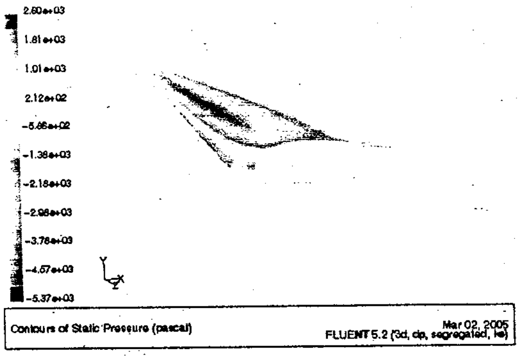


Figure 5.7 Pressure distribution at $\alpha = 6°$ for zero degree leading edge

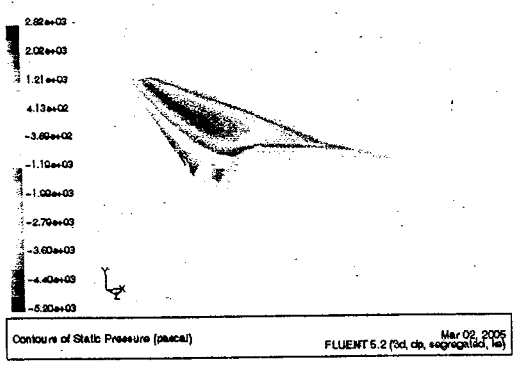


Fig. 4.8 Pressure distribution at $\alpha = 6°$ for six degree leading edge

4.0 Conclusion

For conclusion, compliant mechanism is one of a new domain that is able to replace the conventional design method. It brings a renewal in engineering field to be obtain for the implication in consumerism. Purpose of the project is to find the potential and compatibility compliant mechanism in aerospace industry.

Objective of this project has been achieved and successful proved that the new design of wing leading edge bring better airplane flight performance. Result from the testing conducted by Sridhar Kota demonstrated a 25% increase in the lift coefficient and 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.

For this project, design of compliant mechanism will effect on the Beech King Air C90B definitely on six degrees angle of attack. Coefficient of lift increase due to angle of attack increase but it began on six degrees angle of attack. Improvement in flight only occurs when leading edge camber was shifted from zero to six degrees at six degrees angle of attack.

Project result completely different from what S.Kota was conducted. But the similarity both of result is the value of lift coefficient is still increase. That makes for better flight performance. The reason of project result being different is the usage of different types of wing. Change of six degrees is more effective on NACA 653-418. But for combination of NACA 23012 and NACA 23018, the effectiveness only occur at up to six degree angle of attack.

As a conclusion, the compliant mechanism created by S.Kota of Beech King Air C90B flight. It will increase the value of lift coefficient compare to conventional value. But it start to increase when the airplane approach six degree angle of attack. So before that angle of attack, leading edge in zero degree or in conventional wing and at six degree angle of attack, pilot can shifted camber of leading edge from zero to six degree which is connected through actuator. Because of this, the airplane will fly in better flight performance.

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