A COMPREHENSIVE STUDY ON PARAMETRIC AIRPLANE NOSE DESIGN USING NURBS

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering with Honours

by

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DECLARATION

I hereby, declared this report entitled "A Comprehensive Study on Parametric Aeroplane Nose Design using NURBS" is the results of my own research except as cited in reference.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Hons.). The members of the supervisory committee are as follow:

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ABSTRAK

Dalam era moden ini, terdapat banyak teknologi moden yang dapat membantu untuk melukiskan lengkung bentuk bebas seperti spline yang merujuk kepada kelas fungsi yang bervariasi yang digunakan dalam aplikasi yang memerlukan data interpolasi atau melicinkan. Oleh itu, konsep NURBS dilaksanakan untuk reka bentuk hidung pesawat. Hidung pesawat Boeing 747 dipilih sebagai reka bentuk yang sedia ada dan reka bentuk pembaikan akan dilakukan dengan membuat reka bentuk profil baru dengan menggunakan NURBS. Pakej Solidworks SimulationXpress dan ANSYS Fluid Flow (FLUENT) adalah perisian yang telah digunakan dalam kajian ini. Hasil yang dicapai dalam Analisis Statik Linear menunjukkan bahawa penurunan dalam Tekanan Von Mises dan peningkatan dalam ubah bentuk akan membuat reka bentuk pembaikan perlahan-lahan mengalami keadaan kegagalan. Dengan menggunakan pengiraan polinomial interpolasi Newton untuk mengira Analisis Kelelahan, ia menunjukkan bahawa reka bentuk pembaikan akan menunjukkan keadaan kegagalan yang perlahan sebagai nilai tekanan awal yang digunakan, x adalah lebih tinggi jika dibandingkan dengan reka bentuk yang sedia ada. Di samping itu, keberkesanan reka bentuk disahkan oleh Kecekapan Reka Bentuk. Keputusan menunjukkan bahawa kedua-dua penambahbaikan dan reka bentuk sedia ada boleh diterima dan boleh dihasilkan. Sementara itu, keputusan untuk analisis dinamik membuktikan bahawa reka bentuk pembaikan mempunyai halaju yang lebih tinggi dan tekanan yang lebih rendah berbanding dengan reka bentuk yang sedia ada. Oleh itu, konsep prinsip Bernoulli dicapai. Selain itu, kebolehpercayaan reka bentuk hidung pesawat juga disahkan oleh Koefisien Variasi (CV). Reka bentuk penambahbaikan mempunyai peratusan terendah berbanding dengan reka bentuk yang sedia ada mengikut pengiraan CV. Oleh itu, kajian ini menunjukkan bahawa keupayaan NURBS telah meningkatkan kelancaran kelengkungan, kualiti, ketepatan dan kestabilan reka bentuk berbanding reka bentuk yang sedia ada.

ABSTRACT

In this modern era, there are a lot of modern technology that can help to draw freeform curve such as spline that refer to a varied class of functions that are used in applications requiring data interpolation or smoothing. NURBS models can be used in any process from illustration to manufacturing because of their flexibility and accuracy. Hence, the concept of NURBS is implemented to the airplane nose design. Airplane nose of Boeing 747 is chosen as an existing design and the improvement design will be done by making a new profile design by using NURBS. Solidworks SimulationXpress and ANSYS Fluid Flow (FLUENT) packages are the software that have been applied in this research study. The results achieved in Linear Static Analysis demonstrated that the decrement in Von Mises Stress and increment in the deformation will make the improvement design to slowly undergo failure condition. By applying the computation of Newton interpolation polynomial to calculate Fatigue Analysis, it indicates that the improvement design will show slower failure condition as the value of initial applied pressure, x is higher when compared with existing design. Additionally, the effectiveness of the design is validated by computing Design Efficiency. The results shows that both improvement and existing designs are acceptable and can be manufactured. Meanwhile, the results for dynamic analysis proved that the improvement design have higher velocity and lower pressure compared to existing design. Thus, the concept of Bernoulli principle is achieved. Moreover, the reliability of airplane nose design is also validated by computing Coefficient of Variation (CV). Improvement design has lowest percentage compared to existing design according to the CV calculation. Therefore, this research shows that the ability of NURBS to model complex free-form curves and surfaces has been implemented in improvement design and has increased the smoothness of the curvature, quality, precision and stability of the design compared to the existing design.

DEDICATION

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURES

2D	-	Two Dimensional
3D	-	Three Dimensional
CAD	-	Computer-Aided Design
CFD	-	Computational Fluid Dynamics
CV	-	Coefficient of Variation
DE	-	Design Efficiency
F	-	Force
FEA	-	Finite Element Analysis
FEM	-	Finite Element Method
FVM	-	Finite Volume Method
NURBS	-	Non-Uniform Rational Basis-Spline
P	-	Pressure
S_f	-	Factor of Safety
TET10	-	Tetrahedral Element
t	-	Time
v_i	-	Input velocity
v_0	-	Output velocity
$\geq$	-	Greater than or Equal to
$>$	-	More than
$<$	-	Less than
$=$	-	Equal to
φ	-	Phi

CHAPTER 1

INTRODUCTION

This chapter provides the general ideas of the research study, which provides five main sections, started with the background of research study and continued with the problem statement. Besides, the significance of this research study will be briefly explained through this chapter. Furthermore, the objectives of this research study are also stated in this chapter. This chapter will end with the explanation of the report organization.

1.1 Background of the Study

Design was drawn by hand on paper with various drafting tools before computers. Rulers were used for straight lines, protractors for angles and compasses for circles. But many shapes, such as the freeform curve could not be drawn with these tools. In the subfields of computer-aided design and computer graphics, the term spline frequently refers to a piecewise polynomial parametric curve. Splines are popular curves in these subfields because of the simplicity of their construction, their ease and accuracy of evaluation, and their capability to approximate complex shapes through curve fitting and interactive curve design (Boor, 1978).

The term spline is used to refer to a varied class of functions that are used in applications requiring data interpolation or smoothing. Spline functions for interpolation are normally determined as the minimizers of suitable measures of roughness subject to the interpolation constraints (Reinsch, 1967). One of the examples of spline is a Non-Uniform Rational B-spline curve or known as NURBS. NURBS outlines as mathematical representations of 3D geometry that can precisely define any shape from a simple 2-D line, circle, arc, or curve to the most complex 3D free-form surface or solid (Piegl and Tiller, 2012). NURBS models can be used in any process from illustration and animation to manufacturing because of their flexibility and accuracy. In this research study, the concept of NURBS will be applied to airplane nose of Boeing 747-8.

The airplane nose of Boeing 747-8 is chosen as the airplane's profile because of its longer hump that can lower the aerodynamics drag. The Boeing 747-8 is a wide-body jet airliner and is the third generation of the 747, with a lengthened fuselage, redesigned wings, and improved efficiency. The 747-8 is the largest 747 version, the largest commercial aircraft built in the United States and the longest passenger aircraft in the world (Bellis, 2017).

1.2 Problem Statement

NURBS have been widely used in aircraft design. The emergence of NURBS is due to a need for representing different types of curves and surfaces in a uniform format. Before 1950's, engineers computerized existing design and drafting methods, which were based on the use of conics (Liming, 1989). People realized that these two methods were incompatible. They had to be unified, and thus NURBS were born. NURBS can represent most parametric and implicit curves and surfaces including all conics and quadrics without loss of accuracy.

In manufacturing of transport industry, aerodynamic optimization has become a crucial element for any aerodynamic design over the past 60 years with applications to aircraft, cars, trains, bridges, wind turbines, internal pipe flows and cavities. Aerodynamic shape optimization has risen in popularity ever since, even among researchers from industry (Gagnon, 2015). Therefore, it is significant in many aspects of technology. Besides, Skinner and Zare-Behtash (2017) stated that automated design optimization actions have turn out to be more proficient.

The effectiveness of the airplane can be increased by improving the shape of the airplane nose (Andrew, 2011). Regularly, aluminium alloys is chosen as the material of the aeroplane nose (Titterton, 2013). Furthermore, Titterton (2013) stated that aluminium alloys have a high strength to weight ratio, ease of fabrication which means that it is easily worked because they are malleable and ductile. Nevertheless most importantly, it is light weight. Thus, the performance of the airplane will also increase as it is easy to manufacture with the combination of materials and shape.

According to Infante et al. (2016), there are an accident occurred in which the nose of a light aircraft have failed. It was observed that fatigue cracks established in the vicinity of the pointed surfaces, on the topside of the nose fork. Therefore, it can be concluded that the referred area was subjected to cyclic pressures originating and transmitting cracks in the material. This cracking is characteristic of the presence of stress deliberation areas.

1.3 Significance of the Study

The contribution that can be identified throughout this research study is by making some research about the concept of Non-Uniform Rational B-Spline (NURBS) and the existing airplane to obtain some facts and information. Following, Solidworks software will be used to design in 3D form of both existing design and improvement nose shape design of Boeing 747-8 that has implemented the concept of NURBS. Both of existing and improvement nose shape of airplane have to be design thoroughly to ensure that there will be no problem arise when running the simulation. This research will also be favorable to the manufacturer in designing the nose of airplane where the application of NURBS can be applied to improve the surface of the airplane's nose by increasing the smoothness of the surface.

Subsequently, both existing and improvement designs of the airplane nose design will be analysed by using three types of analyses which are linear static analysis, fatigue analysis and dynamic analysis. These analyses are done to analyze which designs are better based on the results obtained. Linear static analysis and fatigue analysis will be completed by using Solidworks SimulationXpress and the computation of Newton interpolation polynomial simultaneously. Then, the simulation analysis for both design models will determine the maximum Von Mises Stress and displacement while Newton interpolation polynomial equation is used as a fatigue predictor to identify the fatigue condition amongst the design models. Next, ANSYS Fluid Flow (FLUENT) package software will be used for dynamics analysis to analyze both design models in dynamic condition to determine the maximum velocity, maximum pressure and viscosity.

The validation for both existing and improvement design will be done to differentiate the better design between both of the designs. The comparison is done based on the results of Design Efficiency that is calculated by using the output parameter from linear static analysis. Meanwhile, Coefficient of Variation (CV) is calculated by using the output parameter of dynamic analysis.

1.4 Research Objectives

The objectives of this research study of airplane's nose profile design by using NURBS are listed as follows:

i. To study the basic concept of NURBS
ii. To redesign the existing model of airplane nose by using Solidworks software
iii. To analyze both existing and improvement designs using method of analyses
iv. To validate both existing and improvement designs using Design of Efficiency (DE) and Coefficient of Variation (CV)

1.5 Report Organization

This report begins in Chapter 1 by explaining the background of the research, problem statement, significant of the study, research objectives and report organization. Initially, research background will introduce about NURBS and the reason of using it as a method for the improvement design in airplane nose design. Furthermore, the discussion about the problem related to the existing or current airplane nose design profile will be clearly stated.

Chapter 1 also focuses on the explanations on the research objectives and report organization.

Chapter 2 reviews the history of the airplane, construction materials, Boeing 747 model development, major types of nose cone, nose cone design, non-uniform rational B-spline (NURBS) and aerodynamics. This chapter will begin with the technically based approach, followed by evolution of shapes of the airplane. Chapter 2 also reviews the Boeing 747 model development such as Boeing 747-100, Boeing 747-200, Boeing 747-300, Boeing 747-400 and Boeing 747-8. The explanation of the types of materials used in constructing the airplane will be discuss through this chapter. The major types of the nose cone such as sharp nose cone and blunt nose cone will also be described. Additionally, the nose cone design such as conical, elliptical, tangent ogive, secant ogive and power series are also covered in this chapter. This chapter also reviews with the definition of NURBS, advantages of it and applications that uses NURBS in their study.

Chapter 3 describes the methodology and the process flow of this research study. This chapter explains an introduction to airplane nose profile design and the concept of NURBS. Besides, the process flow diagrams of designing the airplane nose profile design models for existing and improvement designs will be described in this chapter. The 2D and 3D design models will be created through SolidWorks software. Then, the simulation analysis for both design models will determine the stress and displacement. Newton interpolation polynomial equation is used as a fatigue predictor to identify the fatigue condition amongst the design models. Next, the process flow diagram of dynamic analysis of the airplane nose profile design of both models will be clearly shown through ANSYS Fluid Flow (FLUENT) package. To analyze both design models in dynamic condition, the parameter input such as velocity, pressure and viscosity are chosen as the parameter condition. The results that are expected are such as the distributions of velocity, pressure, and viscosity amongst the design models. The validation process amongst the models will be implemented once all analyses are fully completed. Tools of validation such as Design of Efficiency (DE) and Coefficient of Variation (CV) will be applied through the optimization process.

Chapter 4 explains about the acquired results of analysis for linear static and fatigue analysis. The linear static analysis will be conducted by using Solidworks software to determine the stress and displacement on both existing and improvement design models. The Newton interpolation polynomial equation will be used to calculate the load of pressure and the factor of safety for both design models. Then, the design optimization for both models will be computed. Next, the computation of Design Efficiency (DE) for both design models is established. Therefore, the elaboration of finding discussion is covered in this chapter.

Chapter 5 conducts about the result of dynamic analysis by using ANSYS Fluid Flow (FLUENT) package. This analysis is a comprehensive finite element analysis (FEA) tool for structural analysis, including linear, nonlinear, dynamics, hydrodynamics and explicit studies. It provides a complete set of element behavior, material models and equation solvers for a wide range of mechanical design problem. Materials that have been chosen for both existing and improvement design models will be analyze. Besides, the results for dynamic analysis which are velocity and pressure will be attained in this research study. In addition, the calculation of Coefficient of Variation (CV) will also be shown in this chapter to ensure the quality assure of the product created.

Chapter 6 elaborates on the discussion, conclusion and recommendations regarding the entire of the research study. All of the results of Design Efficiency, safety factor, Coefficient of Variation and analyses from the previous chapter will be discussed and concluded in this chapter. Besides, the suggestion for recommendation related to research study will be recognized based on the results achieved in conducting analysis for future research. Lastly, the objective of the research will be reviewed to ensure the research has completely achieved.

CHAPTER 2

LITERATURE REVIEW

This chapter provides the preliminary reviews for the research study of airplane design study. This chapter will review the history of the airplane, construction materials that is used to produce an airplane. Besides, Boeing 747 model development will be explained in this chapter. Next, the major types of nose cone and nose cone design also will be discussed and explained. Additionally, the non-uniform rational B-spline will be discussed briefly.

2.1 History of Airplane

Airplane is one of the modern transportations that has been created for a modern human civilization almost two hundred years ago. The idea of soaring high like birds and kites has been the encouragement of the inventors of airplane. At first of its discovery, this creation drastically change human industry. Invention of airplane has revolutionized travelling experience for people across the world. The wide-ranging variety of uses for airplanes includes recreation, transportation of goods and people, military, and research. Commercial aviation is a huge industry involving the flying of tens of thousands of passengers daily on airliners (Verma, 2012).

According to Petrescu and Petrescu (2012), first real flying was launched by the Montgolfier brothers in 1786. Later in 1848, the first heavier than air powered flight was accomplished