UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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INVESTIGATION OF THE BUCKLING BEHAVIOR OF AXIALLY COMPRESSED TRUNCATED CONE WITH UNEVEN LENGTH

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours.

by

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DECLARATION

I hereby, declared this report entitled "Investigation of The Buckling Behavior of Axially Compressed Cone with Uneven Length" is the results of my own research except as cited in references.

Signature	:	....
Author's Name	:	....
Date	:	....

APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours. The member of the supervisory is as follow:

....

(Project Supervisor)

ABSTRAK

Penyelidikan ini bertujuan untuk mengkaji kesan panjang yang tidak rata pada lengkokan kon dipenggal yang tertakluk kepada mampatan paksi. Kerja penyelidikan ini melibatkan tujuh sampel kon dengan nombor gelombang yang berbeza yang dibuat menggunakan kepingan keluli lembut yang bersaiz 1mm. Perisian SolidWorks digunakan untuk mereka bentuk kon dalam lukisan 2D. Lukisan itu diimport ke perisian FlowPath manakala mesin jet air digunakan untuk memotong lembaran keluli lembut kepada tujuh sampel. Sampel itu telah menjalani proses rolling dan kimpalan untuk membentuk kon. Ujian mampatan paksi pada tujuh kon telah dijalankan dengan menggunakan masin uji sejagat. Penyelidikan ini fokus dalam hasil eksperimen dan berangka. Dua sampel dengan bilangan gelombang empat direka khas untuk memastikan kebolehulangan data yang diperoleh. Hasil eksperimen dan berangka menunjukkan persamaan purata 1.094 daripada 1.000. Data keputusan mengenai kesan panjang yang tidak rata telah dibentangkan dalam laporan ini. Keputusan eksperimen menunjukkan bahawa peningkatan bilangan gelombang akan mengukuhkan kon daripada gesper.

ABSTRACT

This research aims to investigate the effect of uneven length on the buckling behavior of truncated cone subjected to axial compression. This research work involves seven samples of cone with different wave number that were fabricated using 1mm mild steel sheet. SolidWorks software was used to draw the model of truncated cone in 2D drawing. The drawing was imported to the FlowPath software while water-jet machine was used to cut the mild steel sheet into seven samples of truncated cone. The seven samples undergone rolling and welding processes to form truncated cones. Axial compression test on seven truncated cones were done using universal testing machine. The research conducted was to compare experimental and numerical results. Two specimens with wave number of four were fabricated to ensure the repeatability of data obtained. The experimental and numerical results of seven samples had the average similarity of 1.094 out of 1.000. The results data on the effect of uneven length were presented in this report. The experiment results indicated that the increasing of wave number will strengthen the truncated cone from buckle.

DEDICATION

This report is dedicated to my beloved parents, my siblings and my friends, who always support me during this final year project work. Last but not least, my final year report group mates who were always with me to complete my final year project research.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

NASA	-	National Aeronautics and Space Administration
CAD	-	Computer-Aided Design
ABAQUS	-	Finite-element Computer Code
CFRP	-	Carbon Fiber Reinforced Plastic
DXF	-	Drawing Exchange Format
MIG	-	Metal Inert Gas
R	-	Radius
L	-	Length

CHAPTER 1

INTRODUCTION

1.0 Introduction

Conical shell structures are widely used in several industrial applications, especially in aerospace, marine structures, and pipelines (Maali et al., 2012). In aerospace industry, truncated thin walled conical shells are usually used to connect cylinders with different diameters, which are the reason why conical structures could be found in the important parts of space launcher transport systems (Khakimova et al., 2016).

Buckling is one of the major failure phenomenon of conical shells when in use; it may be influenced by the type of applied load, material properties of the shell and imperfections in construction. Investigation of buckling behavior towards conical shells proved that rolling and construction-induced imperfections give the direct effect to the conical structures. (Golzan & Showkati, 2008).

The other investigation about buckling behavior of conical shells with weld-induced imperfections proved that buckling strength of the general conical structures increased due to the weld-induced imperfections (Maali et al., 2012). From the past literature, it was found that the buckling strength of conical shell under axial compression is mainly dependent on the condition of the smaller end of the cone (Ifayefunmi, 2014a).

1.1 Problem Statement

In solid mechanics, buckling is categorized as treacherous phenomena due to instability where a small increment of the load can lead to a sudden catastrophic failure. Instability by buckling would give high impact to mechanical, aerospace and chemical engineering especially in applications of designing columns, shipbuilding, submarines, spacecrafts and vehicles.

The aircraft nacelle should provide some crucial function as it used to protect internal compartment from lightning, engine noise reduction, good aerodynamics, landing or taking off. The engine nacelle must not only protect the engine, but also isolate the plane of the engine (Bennouna & Langlois, 2012). Nowadays, there is a nacelle design with wave number shown in Figure 1.1 and 1.2 being used on Boeing 787 aircraft. There is another example shown in Figure 1.3 where the design applied on the Boeing 737. The design has received more attention along with its benefit such as good environment protection (Wang & Sun, 2015). In addition, when the exhaust jet velocity exceeds the local speed of sound, a regular shock pattern is formed within the exhaust jet core. This produces a discrete tone with single frequency and selective amplification of the mixing noise. A reduction in noise level occurs if the mixing rate is accelerated or if the velocity of the exhaust jet relative to the atmosphere is reduced. This can be achieved by changing the pattern of the exhaust jet (Soares, 2015). However, the changing of pattern can leads to the low structural strength possibility that has not been considered in details.

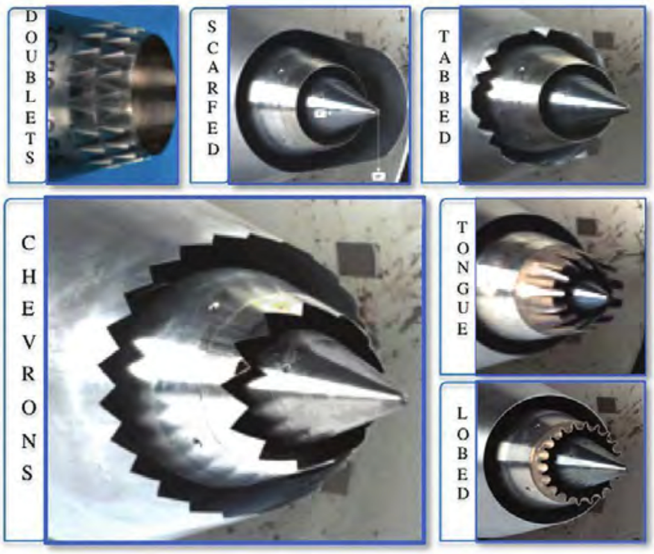

Figure 1.1: Several patterns of exhaust nacelle (Bargsten & Gibson, 2011).

In recent years, a chevron exhaust nozzle for a gas turbine had been designed and tested purposely for noise reduction. The results of an unusual shape showed that the noise could be significantly reduced and now it is commonly applied in new Boeing 787 aircraft. However, there are some safety factors that have not been considered during the design of exhaust nacelle especially buckling strength, external pressure that will damage the nacelle. The weather condition is another factor that needs to be considered especially in global north and south countries where the heavy drops tend to strike the body structure of aircraft. They can cause engine failures and structural damage if the particle size is large. In significant, there is no any research done for testing the buckling strength of unusual shape which applied at exhaust nacelle. The buckling of truncated cone mainly occurs at the uneven length due to low compression strength. By adding some possible factors such as aircraft speed, environment temperature and particle concentration, the bending of the unusual shape is possible to be happened and it would affect the stability of the engine turbine and aircraft during airflow. From this several facts, an investigation must be carried out to identify the buckling strength between an original cone and cone with uneven length.

Figure 1.2: New design of exhaust nacelle in Boeing 787 (Bargsten and Gibson, 2011).

Figure 1.3: Boeing 737 MAX separate flow nacelle (Konrad, 2017).

1.2 Objective

According to the problem statement above, the objectives of this study are:

i. To design and fabricate truncated cone with sinusoidal waves at the end of small diameter using mild steel.
ii. To investigate the influence of different wave number on buckling behavior of truncated cone.
iii. To compare the numerical and experimental results of truncated cone.

1.3 Scope

This research is conducted to investigate the effect of the number of waves with same height but in different wave number. This project involved truncated cone which uses mild steel plate with 1mm thickness as material. Six different sets of truncated cone with or without sinusoidal waves at the end of small diameter were used to conduct axial load compression experiment. To achieve high accuracy of experimental data, every specimen has nominal identical specimen and the total of 7 specimens will be made. There are two specimens with wave number of four to ensure repeatability of experimental result. The dimension of the specimens was sketched using CAD software to avoid material wastage before fabrication. Next, the experiments were conducted to compare the perfect cone and the other five truncated cone with different number of waves (n= 4, 6, 8, 10, 12), all specimens were tested using universal testing machine. The results were recorded and analyzed. ABAQUS analysis was used to analyze the buckling strength of specimens. A comparison between experimental results and theoretical calculations was conducted in the end of the process.

CHAPTER 2
LITERATURE REVIEW

2.0 Introduction

Conical shells have been widely used in various engineering applications such as hoppers, vessel heads, components of missiles and spacecrafts, and other civil, mechanical and aerospace engineering structures (Sofiyev & Karaca, 2009). The aerospace industry is always looking for new design methods and materials to reduce costs and weight of air and spacecraft structures (Khakimova et al., 2016). Nowadays, when composite materials are widely used in the aerospace industry, a deep understanding of the influence of their properties and the laminate stacking sequence on the mechanical behavior of shell structures is so important (Khakimova et al., 2014). The composite materials in manufacturing of shells have led to high strength to weight ratios. Hence, stability analysis of thin walled shells subjected to external loads has become a necessity for design (Jalili et al., 2014). To achieve a proper design of new structures and the checking of load carrying capacity of the existing structures, extensive understanding of the phenomena on critical and post critical equilibrium paths is compulsory because of restrictive requirements during their design and manufacture (Paczos & Zielnica, 2008). In aeronautical applications, the load carrying capacity of the conical shells is usually limited by elastic buckling due to their high value of the radius-to-thickness ratio. Conical shell structures with low values of the radius-to-thickness ratio is commonly found in marine and offshore applications, usually buckle or collapse in the elastic-plastic or plastic range. In general, conical shells are subjected to various loading conditions such as external pressure, internal pressure, axial compression, bending, torsion or combined loading which is axial compression and torsion, axial compression and external or internal pressure, torsion and etc (Ifayefunmi, 2014a). In applications especially in rocket interstages and payload adapters for spacecraft launchers, conical anisogrid composite lattice shells that made from carbon fiber reinforced plastic (CFRP) are extensively used due to their high structural and mass efficiency and they are capable of resisting the intensive loadings exerted during the launch and injection into orbit phases (Morozov et al., 2011).

For truncated thin-walled conical shells, they are commonly applied as the transition parts between cylinders with different diameters. Unfortunately, it drew less attention which motivates the present work. In space launch vehicles, thin-walled structures can carry heavy payloads. Therefore, they are easily subjected to axial compression with limiting design constraint. Moreover, conical structures are usually imperfection sensitive to initial geometric, boundary conditions, load introduction, thickness, etc. Thus, the buckling criterion accounting for imperfections especially in the design stage of conical structures must be considered. Existing design guidelines such as NASA SP-8007 (cylinders) and NASA SP-8019 (cones), dated from the late 1960s are currently used in the aerospace industry and employ conservative lower-bound knock-down factors. (Khakimova et al., 2016).

2.1 What Is Buckling

Buckling can be described as a sudden large or lateral deflection of a structure due to a minor increment of an existing compression load. A structure may breakdown if a member in compression buckles which moves laterally and shortens under a load loss support (Calvert, 2007). Buckling is considered as one of the complicated phenomena in solid mechanics. This phenomenon is menace for thin-walled shells subjected to compressive forces. Investigation towards stability of shells and buckling are important for many fields such as mechanical, aerospace engineering, marine industry and etc. In recent years, the shell structure has become larger and thinner and the buckling problem cannot be neglected. Thin-walled shells which are made of layered composites are widely used in various applications in aerospace, mechanical, civil and marine engineering structures. However, composite materials have good properties due to their high specific modulus compared to metallic material, but there are difficulties in their structure behaviors (Boorboor et al., 2012). Thin-walled conical shells are usually more vulnerable to early buckling due to the high length-to radius ratio. In designing a shell, the critical buckling load is an essential standard that must be considered. In the application of large-scale mechanism, the lightweight design of shells is often considered. The accomplishment of better buckling performance and lighter design weight has drawn some attention in engineering design (Wu et al., 2016).

The buckling of conical shell depends on the geometric and material properties, type of applied load and any initial geometric imperfections. There are several parameters which could affect the buckling behavior of the conical shell. Two geometric ratio which are slant-length to radius (L/R) and radius to thickness (R/t) will affect the buckling capacity of the shells (Maali et al., 2012). Determination of accurate buckling load of the conical structure is important as the critical load is usually masked by failure that influencing by large deformations such as initial imperfections (Ghazijahani & Zirakian, 2014). A study is carried out to evaluate the applicability of the few methods such as Southwell, Massey, Modified, and Meck plotting methods in predicting the accurate critical buckling loads of conical shell structures with various geometrical properties. These methods were successfully applied on both strain and displacement data and reliable predictions were obtained for the critical buckling loads of conical shell specimens in all cases. The conical shell at a certain aspect ratio, there will be dissimilarity in buckling modes correspond to the similar value of critical buckling (Spagnoli, 2003). Investigation by experiment is carried out in order to estimate the reduction of the classical buckling load due to its imperfection and pre buckling deflections (Spagnoli & Chryssanthopoulos, 1998). Buckling and loss of stability of stiffened conical shells is considered as crucial failure phenomena of such structures (Jabereen & Sheinman, 2009). Investigation towards buckling behavior of anisotropic grid composite lattice conical shells and it is found that buckling resistance can be improved by increasing the stiffness of a few hoop ribs with larger diameter or introducing the additional hoop ribs in the same part of the conical shell (Goldfeld, 2006).

2.2 Type of Buckling

Buckling is a state which defines a point where an equilibrium configuration becomes unstable under a parametric change of load and can manifest itself in several different phenomena. The buckling strength of a cone depends on the condition of the smaller diameter of the cone as the thinness of the cone brought stability loss. Shells subjected to a combination of loadings, can also fails through plastic buckling. One of the earlier studies into plastic buckling of conical shells was on axially compressed steep truncated conical shells. It appears that there has been only a limited research into buckling performance of conical shells, under the action of combined loads, and within the elastic plastic range (Ifayefunmi, 2014b). An investigation is carried out to evaluate the residual deflections of perfectly plastic conical shells with constant thickness subjected to the impact loading (Lellep & Puman, 2012). Besides that, the optimum configuration for the maximum buckling load of filament-wound laminated conical shells was investigated by setting the thickness and the ply orientation as the design variables, and it was concluded that there was a strong relation in buckling load (Wu et al., 2016). An investigation towards the interactive buckling tests on steel cones subjected to axial compression and external pressure (Ifayefunmi, 2014b). A study of plastic buckling of conical tanks with large geometrical imperfections is carried out to identify the reason of imperfections that can cause large circumferential tensile stresses leading to plastic collapse. The increase of circumferential stresses that causes yielding is significant. A semi-analytical method is proposed by Jamal et al. (2003) to compute the reduction of the buckling load under axial compression in presence of distributed and localized imperfections.

2.3 Buckling Behavior of Perfect Cone under Axial Compression

The stability of conical shells under axial compression has been studied in experimentally and theoretically by many researchers. The results obtained by them were indicated the same serious disagreement between the experimental results and data obtained from deflection theories of buckling for conical shells. It was found that load carrying capacity of shells was sensitive towards initial imperfections especially wall thickness, the non-uniformity and boundary conditions. However, the dependence of the buckling load on the cone semi-vertex angle α was studied. The research was conducted to keep the effect of the above factors and shell parameters involved in the stability analysis constant and to investigate the dependence of buckling load on the remaining free parameters. The perfect conical shells were fabricated using electroforming on wax mandrels. It has been chosen due to its cast free of air bubbles and had the proper machining characteristics. The experimental investigations showed that the differences between the results predicted by the linearized, small deflection theories of buckling the experimental values were much lower and data had a large scatter band. According to this research, it had a reason to believe that all local buckling would occur due to some pronounced localized defect in the test specimen.

2.4 Buckling Behavior of Imperfect Cone under Axial Compression

Investigation towards the effect of thickness variation of the stability of truncated conical shells under simply supported end and subjected to axial compression is carried out and it was found that the reduction of buckling load of cylinder and cone, due to their small thickness variation in axial direction, is proportional to the thickness reduction parameter. The result also suggested that the buckling resistance of conical shell may be increased by constraining at the edge (Thinyongpituk & El-sobky, 2003). Investigation towards the influence of initial shape imperfections on buckling strength of thick truncated steel cones subjected to axial compression is carried out. The results indicate axially compressed cones, the eigenmode type shape imperfections are not always the worst initial shape imperfections. Localized, axisymmetric outward bulge can significantly reduce the load carrying capacity marginally than the corresponding eigenmode type of shape imperfection. It can also be observed that the load carrying capacity of externally pressurized cone is sensitive to different profiles of eigenmode deviations from perfect geometry (Ifayefunmi & Blachut, 2013). Moreover, the structural stability is also a main consideration in the design of lightweight shell structures. However, the theoretical predictions of perfect geometrical structures often noticeably overestimate the buckling loads of inherently imperfect real structures. In