UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

STRESS AND STRAIN ANALYSIS OF VARIANT FORCES ACTING ON ANIMAL DRAWN MOULDBOARD PLOUGH USING ANSYS

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A Thesis in the Department of Mechanical and Automotive Technology Education, Faculty of Technology Education, Submitted to the School of Graduate Studies in Partial Fulfillment of the Requirement for the Award of the Degree of Master of Philosophy (Mechanical Engineering Technology) in the University of Education, Winneba

NOVEMBER, 2021

DECLARATION

STUDENT'S DECLARATION

I, declare that this thesis is my own original research and that no part of it has been submitted for another certificate in this university or elsewhere.

SIGNATURE: ………………………… **DATE**: ……………………………

STUDENT’S NAME: NYAABA ISAAC AZEGURA

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SUPERVISOR'S DECLARATION

I hereby declare that, the preparation and presentation of this thesis was supervised by me in accordance with the guidelines on supervision of research work laid down by the University of Education Winneba, Kumasi Department of Mechanical and Automotive Technology Education

SIGNATURE: …………………………… **DATE**: ……………………………

SUPERVISOR’S NAME: MR. CHIBUDO KENNETH NWORU

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DEDICATION

I sincerely dedicate this write-up to my late uncle, Mr. Thomas Aniah Ayinselya and to my mother, Nyaaba Nmah for making me who am I today. Also, to my dear wife and friend, Gifty and to my lovely children: Success, Zimran and Wishgrant, not forgetting of my siblings especially Sister Stella for their unflinching support throughout this work and my education.

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ABSTRACT

In the field of agriculture, an advanced application of technology has taken full force as large scale of farms are nowadays manned with tractors, cultivators, harvesters, and other farm equipment. However, due to the high cost of maintenance coupled with past failures of tractor mechanization schemes, farmers need reliable and low cost agricultural tools that may be hand driven or bullock driven for small scale farming in Northern Ghana. The object of this paper is to re-design an improved animal drawn plough to complement tractor services. Autodesk Inventor and ANSYS software were used for the design and analysis of the models. Material of high quality was selected for the proposed model and appropriate engineering design principles were adopted in designing it. The selected material (Low alloy steel, AISI 4140) was used for the new model and compared with the existing cast iron designs. The analytical comparison of the two models shows that, the low alloy steel (AISI 4140) made share and mouldboard exhibits favorable results. The percentage difference in terms of total deformations were found to be 40.8% and 40.64%, and the equivalent elastic strain of about 41.24% and 41.46% respectively in favour of the low alloy steel (AISI 4140) made share and mouldboard. The implication is that, the cast iron models will deform and reach the yield point faster than the low alloy steel models. The results of this study predict that the low alloy steel (AISI 4140) could be a suitable material for making farm implements such as mouldboard ploughs because the factor of safety of the low alloy steel (AISI 4140) made share is 1.4 and mouldboard is 1.8 however, the cast iron share has a factor of safety of 0.3 and the mouldboard having 0.4. The results of the developed model could be useful for the design and subsequent fabrication of new tillage tools adaptable to different types of soil, in terms of application.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Modern machine design employs very sophisticated design and simulation software. Adequate knowledge of the mechanism and working principle of machines and forces are paramount to the engineer. Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to optimally convert resources to meet a stated objective (Haik and Shahin, 2011). Professional designers use intellectual instincts and well established and proven scientific knowledge in designing to ensure the product satisfies an agreed market need and product design specification whilst permitting manufacture by the optimum method. The design process is only complete when the product is capable of providing a considerable level of performance and a well acceptable mode of disposal (Ken, 1999).

Therefore, the study of the design methods and application of forces acting on bodies of machines in relation to their design mechanisms and construction is vital to the engineer. The form of static structures assumes that they invariably have the same geometry but the so-called stationary structures can move significantly disposal (Ken, 1999). As so, structural engineering designers must take this into account where necessary. The design of moveable structures must account for fatigue, variation in the method in which load is resisted and significant deflections of structures. The forces, which act on parts of a machine can vary significantly and can do so at a great rate. The forces which a boat or aircraft is subjected to partially change enormously and will do so a thousand times over the structure's lifetime. The structural design must ensure that such structures can endure such loading for their entire design life without failing (Hosford, 2005). A machine is a mechanical device that alters the path or magnitude of a force. Generally, they can be defined as the simplest mechanisms that use mechanical advantage to multiply by force (Paul et al., 2006). Machines are devices assembled from one or more components that are constructed to achieve a particular purpose in mind. They are usually mechanically, chemically, thermally or electrically powered and can be frequently motorized. Historically, a device needed locomotive parts to be classified as a machine. However, the discovery of electronics technology has led to the development of stationary devices that are considered machines. A common example of this is a computer. Furthermore, they can be driven by animals and people, by natural forces such as wind and water as well. They include a system of interconnected components that triggers the actuator input to achieve a particular application of output forces, action and movement. They can also be manufactured with embedded devices such as computers and sensors to track performance and plan movement, often called mechanical systems (Marwedel, 2021).

A machine is a mechanism used to transmit power from source(s) to load(s). The tack of a mechanical device is congregated from components called machine elements. These elements provide structure for the frame and control its movement. The structural components are usually, the frame members, bearings, splines, springs, seals, fasteners and covers. The shape, disposition and appearance of covers provide a styling and operational interface between the mechanical device and its users. The number of genealogy of freedom of a mechanism, or its locomotion, depends on the number of links and joints. It is largely based on the types of joints used to construct the mechanism. The general mobility of a mechanism is the difference between the free movement of the links and the number of constraints imposed by the joints (Stanišić, 2015),.

The agricultural sector plays a very important role in the development of Ghana. In a 2020 report by foreign trade administration – your connection to Israeli innovation, Israel"s Trade and Economic Mission to Ghana, agriculture contributed 19.7% to Ghana"s Gross Domestic Product (GDP), which accounted for over 30% of export earnings and serves as a major source of input to the manufacturing industry. The Agricultural sector in Ghana is the second largest employer in the economy but considered to be the smallest sector in comparison to services and industry. As so, the sector is viewed by many as a key factor in Ghana"s economic growth and development progress. In the developing countries, there are approximately 100 million smallholdings of less than five hectares (Lowder et al., 2016). Therefore, tractors would be uneconomical for most of these small and marginal farmers, except on a hire service basis. For paddy cultivation and in waterlogged areas, the uses of tractors are not practicable. Such conditions exist in parts of Bangladesh and Thailand, and in some rice-growing areas in India and the People's Republic of China. „Draught animal power is essential for hilly regions and narrow, terraced fields (Ramaswamy, 1979). The advent of modern technology and its associated sophisticated industrialization drive in agriculture is unprecedented. This is as a result of improved farm implements and new mechanized farming practices adopted over the years. The technologies employed in farming over the years have shifted instantaneously from the monochromatic traditional farming practices to modern mechanized practices of farming (Food and Agriculture Organization of the United Nations, 2017). The area of agricultural mechanization is quite broad an area to be handled holistically. Therefore this research is geared towards machineries for tilling and harrowing the land for farming purposes. Specific machine of interest is the animal draught plough usually pulled by at least a pair of bullocks or animals used for similar purposes.

Modern technology has made it much easier in tilling the land with the application of the tractor and other means. For cultivating 176.66 million hectares (gross cropped area in 1987) over a 60-day period, the work animal force required was 8.6 million pairs of bullock whilst only a 35 horse power tractor can plough with the mouldboard plough some 2.5 hectares in an eight-hour shift and would consume some four to five liters of diesel per hour for such operation (Phaniraja and Panchasara, 2009). Based on this, the tractor unlike the others used for tilling the land is easier, faster and convenient though very expensive. The cost of fuel and regular maintenance and lack of experience operators are major challenges, due to that, few farmers and individuals are able to own tractors. However, the use of animals for farming purposes is still relevant especially in the Northern parts of Ghana and some countries around the world. Many farmers in Northern Ghana rear bulls among other livestock. According to Phaniraja and Panchasara (2009), several male species of animals are used as draught animals in different parts of the world. These animals include: - cattle, buffalo, equines (horses, mules and donkeys), camels and llamas, elephants (used for logging in forests), and dogs (used for transportation in snow-covered areas). However, cattle and buffalos are predominantly used in agriculture operations to pull agricultural implements e.g.

plough, weeder, puddler among others. But, modern plough draught requirements do not correspond to the draught capacity of the domestic animals (Betker and Kutzbach, 1989). Besides, when draught animals are used continuously, they deliver a limited pull or traction equal to only 10% of their combined weight (Inns, 1990). Animals such as bullocks, horses and donkeys are trained to be used in conjunction with a mouldboard plough for farming. The farmers in this regard require a mouldboard plough to be used with at least one bullock or other animals. These ploughs are usually made of cast iron and other steels of less quality. Again, how they are fabricated and the materials used for their couplings leave little to be desired. The design and construction of these devices are still rampant by local blacksmiths with inadequate knowledge of modern technological applications. There are software that are used to first of all model the design and simulate it to gain in-depth knowledge on the strength, durability, functionality among other applications. In short, this is done to see whether the model meets all the design specifications and requirements before the final fabrication. The operation, price, cost of maintenance, design and construction of the mouldboard plough is less expensive as compared to that of the tractor. It is also less difficult to operate. However, operators are often faced with problems with frequent breakdown of their ploughs. This is usually as a result of rocky grounds, stumps, roots and embedded stones (Paman et al., 2017). Therefore, frantic efforts are being sought to ensure that plough breakdown is minimized drastically (Paman et al., 2017). In order to do this, the design principles of machines must be considered. These include but not limited to the mechanical behaviour such as statics, dynamics, vibration, reliability, and fatigue as well as the type and strength of material to be used for manufacturing the equipment.

Currently, manufacturing is moving towards a more advanced, flexible, and environmentally-friendly and so it demands intelligent Computer Aided Production and Planning (CAPP) systems (Yusof and Latif, 2013). Hamou et al., (2014) developed a CAPP simulation module in order to optimize manufacturing tolerances, overcome stochastic aspects, and complexity, and compute manufacturing dimensions. The availability of software such as this and many others can be effectively and efficiently used to design and simulate a well modified mouldboard plough capable of meeting modern standards and application conditions.

1.2: Statement of the Problem

Modern methods of farming have become prominent and demanding such that the farmers cannot do without them especially to those who have taken farming as a full time business. Notwithstanding, majority of the populace within the Northern and Middle belt of Ghana are peasant farmers with little resources to hire the services of tractors always. Though the tractor provides efficient, convenient and faster means of tilling the land, it is very expensive for the average farmer. Due to rising global fuel cost and the past failures of tractor mechanization projects in many developing countries, there is renewed interest in research and extension activities on efficient use of animal traction especially, for ploughing and carting since few individuals, both farmers and non- farmers own tractors due to their price and cost of maintenance (Bobobee, 2007). However, the uses of bullocks still gain popularity in agricultural operations in some countries around the world. The considerable demand for animal ploughing services within the Eastern and Southern Africa and Northern part of Ghana to be precise is enormous; though the frequent breakdown of the plough during farming is a blow to the owners.

This phenomenon is as a result of embedded stones, rocks, roots and stumps which need to be tackled with the requisite engineering finesse. The animal drawn ploughs which were brought from Kenya, India, UK and the Netherlands to some of the sub-Saharan nations were rejected by farmers due to their heavyweight and high draught requirement because of the traditional design approaches and materials used, the friction was very high making operation difficult and tedious for both operators and the animals (Aberru, 1987). Therefore, the new model will be designed with a high durable, light weight and quality material with enhanced features for efficient and effective output.

1.3. General Objective of the Study

The main objective of this research is to re-design and analyze the different types of forces acting on a plough during farming activities and numerically determine its deformation levels**.**

1.4. Specific Objectives

The specific objectives of the research are to:

1. Model a typical plough and evaluate the loads on the various components.
2. Numerically determine the deformation, stresses and strains exerted on the mouldboard plough share and other elements for the different plough materials.
3. Compare results of the different plough –material –models chosen with the

existing ones.

1.5. Significance of the Study

The agricultural tools production industry emerged in Britain and the United States in the 19th century. Until then, the common tools for farming were the plough and the sickle (Gifford, 1992). However, draught animals remain a major power source utilized by a significant number of small farm holding farmers. The frequent breakdown of the plough during ploughing with particular mention of the mouldboard and share is a worrying phenomenon (Haik and Shahin, 2011). It is therefore imperative to operators, owners and farmers to wish that, the plough is in good condition. This research seeks to determine; the best way of overcoming the extent to which the reaction forces that tend to damage the plough can be reduced using modern design mechanisms and materials with very high quality and durable properties. The weight of the plough will be reduced to leverage the bearing on the animals and the operators as well. The study will provide expert knowledge to manufacturers to guide them select the best material for plough fabrication. It will also serve as a reference material for further studies.

1.6. Organization of the Study

The outline of this research is given hereunder for easy reading and reflection. Chapter One contains a brief introduction of the entire report, which include; the background, the statement of the problem, general objective and specific objectives. It also discusses the significance and organization of the study.

In Chapter Two, the relevant literature of the research area is examined. Diversified opinions from different authorities in the field of interest to the work are outlined.

In Chapter Three of the study, the researcher discusses the methodology employed in gathering and analyzing the data. The conceptual design work, the designed parts and the assembled model are captured here.

Chapter Four throws more light on the main findings of the study and the discussions of such results.

Chapter Five consists of summary of the study, conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Historical Background of the Mouldboard Plough

When agriculture started, soil was tilled using simple hand-held digging sticks and hoes (Godwin et al., 2007). Hoe farming is the traditional tillage method in tropical and sub-tropical nations, which are marked by stony soils, steep slope profiles, predominant root crops, and coarse grains, grown at wide distances apart. In spite of the fact that, hoe-agriculture is ideal for these regions, it is used distinctively everywhere. Preferably, in certain parts of the world, some cultures use pigs to trample the soil and grub the earth (Godwin et al., 2007). Strong pointed wooden sticks, hoes, cutlasses and mattocks were not invented in any one place. Certainly, the use of hoe for cultivation must have been common everywhere agriculture was practiced. A considerable number of ancient hoes, such as the Egyptian mr (ancient wooden plough) were pointed and strong enough to clear rocky soil and make seed drills, which is why they are known as hand ards.

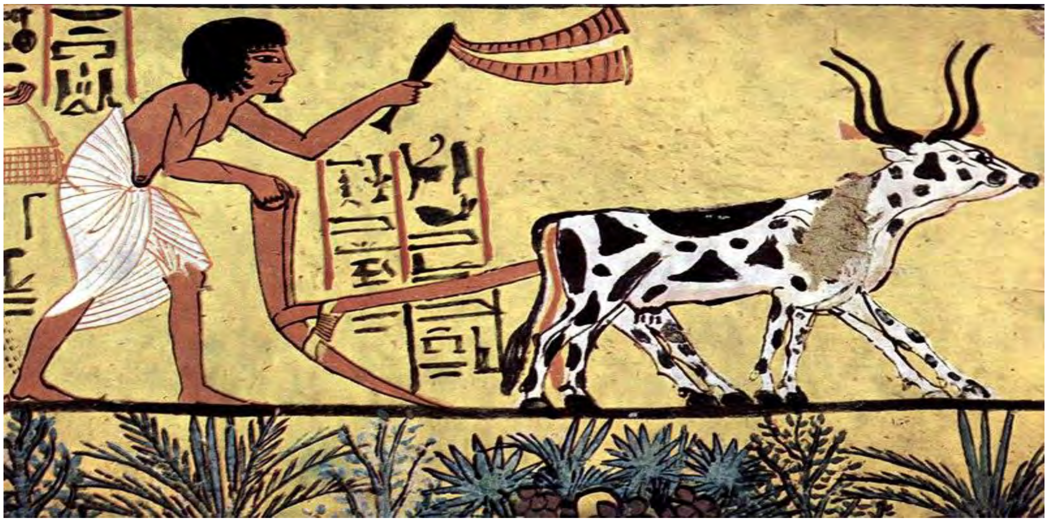


Figure 2.1. Ancient Egyptian Ard being drawn by Oxen.

Source: http://horticultureinfoworld.com/organic-fertilizers/

However, adaptation of oxen in Mesopotamia and the Indus valley civilization, perhaps as early as the 6th millennium BC, provided mankind with the draft power needed to develop the larger animal drawn true ard also known as scratch plough. The earliest surviving evidence of ploughing has been dated to 3500 – 3800 BC at a site in Bubeneč, Czech Republic (McIntosh, 2008). A terracotta model of the early ards were found at Banawali, India, giving insight into the form of the tool used (McIntosh, 2008). The ard when damaged remained easy to replace and to replicate. It is best used for loamy or sandy soils that are naturally fertilized by annual flooding as in the Nile Delta, and to a lesser extent any other cereal-growing region with light or thin soil. Yearly flooding influences Plant-Available Nutrients (PAN) by the deposition of sediments from floods which increases the level of nitrogen, phosphorus, silicon and potassium in the soil (Jennewein et al., 2020). To grow crops regularly in less-fertile areas, it is believed that the soil must be turned to bring nutrients to the surface. Pearson (2005) estimated that draught animals and humans provide 80% of the power input on farms in developing countries, but lamented that welfare and comfort of work animals are often neglected, because they belong to members of the poorest sections of society.

2.2. Reformation of the Early Mouldboard Plough

In the basic mouldboard plough, the penetration of the soil profile is determined by lifting the wheel against the runner in the furrow that limited the weight of the plough to what the ploughman could easily lift. These ploughs were often frail and not suitable for the harden farmlands of Northern Europe. The addition of wheels to replace the runner allowed the weight of the plough to increase, and in turn necessitated the use of a larger mouldboard faced made with metal. These heavy ploughs led to increase in food production and eventually a pronounced population increase, beginning around AD 1000 (Webber and William, 2014). Additionally, before the Han Dynasty (202 BC – AD 220), Chinese ploughs were made almost wholly of wood except for the iron blade of the plough share. By the period the Chinese were distinguished from the non-Chinese, the entire ploughshare was made of cast iron. These are the earliest known heavy mouldboard iron ploughs (Greenberger, 2006). The Romans achieved a heavy-wheeled mouldboard plough in the late 3rd and 4th century AD, for which archaeological evidence appears, for instance, in Roman Britain (Evi and Martin, 2008). The acceptance of the medieval heavy plough in Europe seems to have accompanied adoption of the three-field system in the later 8th and early 9th centuries. This was accompanied by larger fields, known variously as carucates, plough lands, and plough gates.

A major advance for this type of farming was the turn plough, also known as the mouldboard plough (UK), moldboard plow (US), or frame plough. The mouldboard plough introduced in the 18th century was a major advance in technology (Godwin et al., 2007). The mouldboard plough over the years has been an essential basic tillage implement on the farm. Historically, it is still useful and widely employed for primary tillage. It is capable of cutting the soil into slices and lifts it over the surface of the mouldboard and inverts it. Animal traction is an appropriate, affordable, easy and sustainable technology that is still essential throughout Eastern and3 Southern Africa. Nowadays in any agricultural crop production system, humans, draught animals and engines or motors provide the motive power in various proportions for crop production, harvesting, transport and processing (FAO, 2003; Pearson, 2005). Although there will continue to be contributions from tractor power to land preparation, much of the region will continue to be cultivated using hand and animal power (FAO, 2003).Animal drawn mouldboard plough is widely applied for farming in developing countries in Africa. In Ghana, notably the Northern regions greatly rely on this means for tilling the farms. Even those who do not own that source of animal power still prefer the service because of low cost among other factors. This is largely so due to the availability of oxen, cattle, donkeys and horses. Moreover, the mouldboard plough works well as a less speed soil inverting tool and significant improvement in its design could be obtained efficiently by reducing draught and wear. According to Betker and Kutzbach (1989) draught forces in animals drawn ploughs vary from 850N to 2000N depending upon the type of soil and its moisture content. The Pulling force (draught force) increased linearly with increasing load ranging from 505N to 2,209N (Bobobee,2007). The animal drawn plough significantly lessen the time needed to prepare a field and so allowed a farmer to work a larger area of land (McIntosh, 2008). In addition, the pattern under the mouldboard and beside it ridges in the soil, forms water channels allowing the soil to drain.

Figure 2.2 a Scots wooden plough

Figure 2.2 b. James Small's plough

Source: http://www.dunsehistorysociety.co.uk/small.shtml

In 1791, James Small further advanced the design using mathematical methods, and eventually came out with a shape casted from a single piece of iron (Fig. 2.2b) This was an improvement on the Scots plough (Fig 2.2a) of James Anderson of Hermiston (Wilson, 2015). A single piece cast-iron plough was also designed and patented by Charles Newbold in the United States in 1797. The development was further improved on by Jethro Wood, a blacksmith of Scipio who made a three-part Scots plough such that a broken piece could be replaced. In 1837, John Deere, a famous American blacksmith introduced the first steel plough. It was stronger and durable than the cast iron designs that it could work on soil in US areas previously thought unsuitable for farming. Improvements on this were followed by developments in metallurgy where steel coulters and shares were made with softer iron mouldboards to prevent breakage. The chilled plough was an example of surface-hardened steel mouldboard plough with faces strong enough to dispense with the coulter.

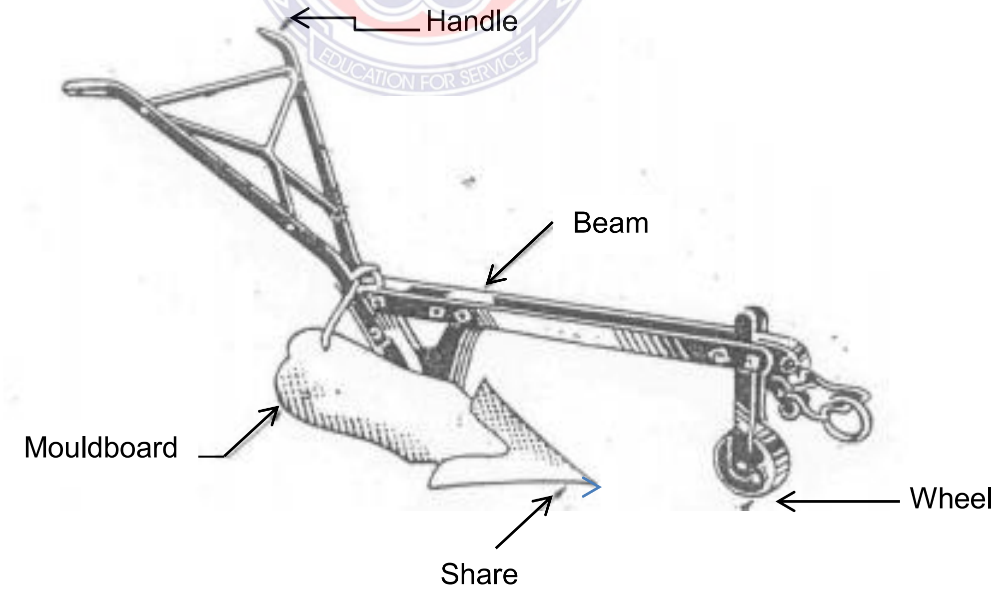


Figure 2.3. Traditional mouldboard plough and its parts.

Source: https://www.advance-africa.com

This plough is very heavy and has a V-shape share, narrow mouldboard and metal handles.

Figure 2.4. Traditional Ploughing, Farmers Work The Land With Cattle And Plough

Source: https://magazine.libarts.colostate.edu/article/sowing-the-seeds-of-scrutiny-are-gmos-good-bad-or-in-between/

2.3. Type of Mouldboard Plough

Mouldboard ploughs come in different designs for specific and general purposes. Some are pulled by tractors and others by animals. The following are some of the mouldboard ploughs in use;

2.3.1. Fixed type (one way)

This type of plough is capable of throwing the furrow slice to one side of the direction of movement and is commonly used almost everywhere. It may have a long or short beam. This plough works usually clockwise around each side of the land, ploughing the long sides and being drawn across the short sides without ploughing. The length of the strip is limited by the distance oxen could comfortably work without rest, and the width is constrained by the distance the plough could conveniently be dragged.

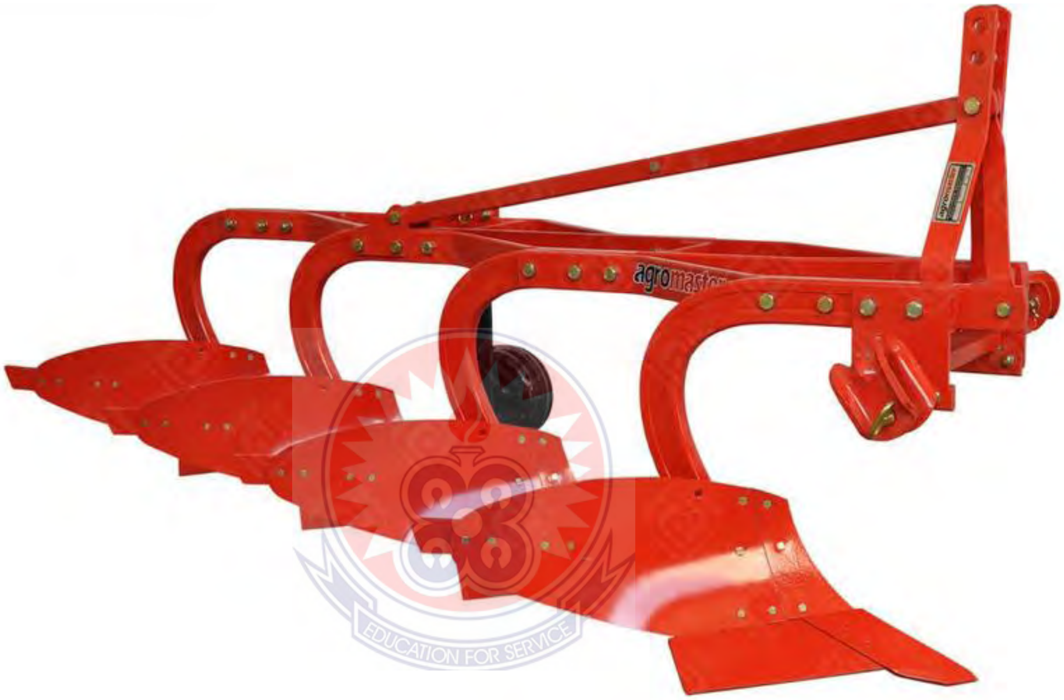


Figure 2.5. Fixed Mouldboard Plough

Source: http://rewardbloggers.com/assets//upload/494195mouldboardploughjpg.jpg

2.3.2. Two-way Plough

This type of plough is capable of turning furrow slice to the right or left side of direction of travel as required in an ideal application. Such ploughs have two sets of opposed bottoms on both sides. In the application of such a plough, all furrows are turned towards the same side of the field by using one bottom for one direction of travel and the other bottom on the return trip. Both sets of bottom are so mounted such that, they could efficiently and easily be raised or lowered independently or rotated along an axis. The advantage of the two way plough is that it neither upsets the slope of the land nor leave any dead furrows or back furrows in any portion of the field. These ploughs have been in existence since the days of the steam engine and the horse. In almost universal use on farms, they have right and left handed mouldboards, enabling them to work up and down the same furrow. The reversible ploughs are either mounted or semi-mounted and are much heavier and expensive than right-handed models. They have a great advantage of leaving a level surface that facilitates seedbed preparation and harvesting. The operation of a tractor with furrow-side wheels in the furrow bottom provides the most efficient line of draught between tractor and plough. It is also easier to steer the tractor when it is coupled to it with the front wheel against the furrow wall which will help keep the front furrow at the correct width. This is less satisfactory when using a tractor with wide front tires. Although these make better use of the tractor power, the tires may compact some of the last furrow slice turned on the previous run. This problem is solved by using a furrow wider or longer mouldboard on the rear body. Driving with all four wheels on unploughed land is another solution to the problem of wide tires. A Properly-designed semi-mounted ploughs can be fixed in a way that will allow the tractor to run on unbroken land and pull the plough in correct alignment without any sideways movement.

Figure 2.6. Two-way or Reversible Plough

Source:https://5.imimg.com/data5/SELLER/Default/2021/3/YP/RN/WB/25264314/12-inch-reversible-plough-500x500.jpg

2.3.3. Turn Wrest Lough

There are some reversible ploughs with a single bottom arrangement that the bottom can be changed from right to left hand or vice versa by tilting the bottom through approximately 180° about a longitudinal axis. This type of model is often called turn wrest plough. Whiles moving in one direction, the plough throws the soil in one direction and at the return travel the direction of the plough bottom is changed, and thus the plough begins to invert the soil in the same direction as before.

Mouldboard ploughs have been designed in different kind of shapes, each producing its own furrow profile and surface finish, but basically they still conform to the original plough body configuration.

The various types traditionally, are classified as general purpose, digger, and semi-digger, as described below.

The general purpose mouldboard has a low draft body with a gentle cross-sectional convex curve from top to bottom. It turns a furrow three parts wide by two parts deep which is about 300mm wide by 200mm deep. It also turns the furrow slice slowly without breaking it. It is normally used for shallow ploughing with maximum of 200mm deep (Wilson, 2015). It is ideal for grassland ploughing and sets up the land for weathering by winter frosts, which reduces the time taken to prepare a seedbed for spring sown crops.

The digger mouldboard is short and abruptly curved with a concave cross-section both from top to bottom and from shin to tail. It turns the furrow slice rapidly while giving a maximum shatter deeper than its width. It is normally used for very deep ploughing of 300mm deep approximately. It has a higher power requirement and leaves the soil surface very broken.

Digger mouldboards are mainly mostly applicable for potatoes and other root crops land preparation. This type is a bit shorter than the general-purpose mouldboard, but with a concave cross-section and a more abrupt curve. They are intermediate between the two mouldboards as described and have a performance that is approximately 250mm deep and with less shattering than the digger moldboards. It turns approximately a square sectioned furrow and leaves an even broken surface finish.

Semi-digger mouldboards are designed suitably for most general ploughing of farms at various depths and speeds.

There are five major parts of a moldboard plough: Moldboard, Share, Landside (short or long), Frog (sometimes called a standard) and Tailpiece. Other parts include: handles, beam, hitch and wheel.

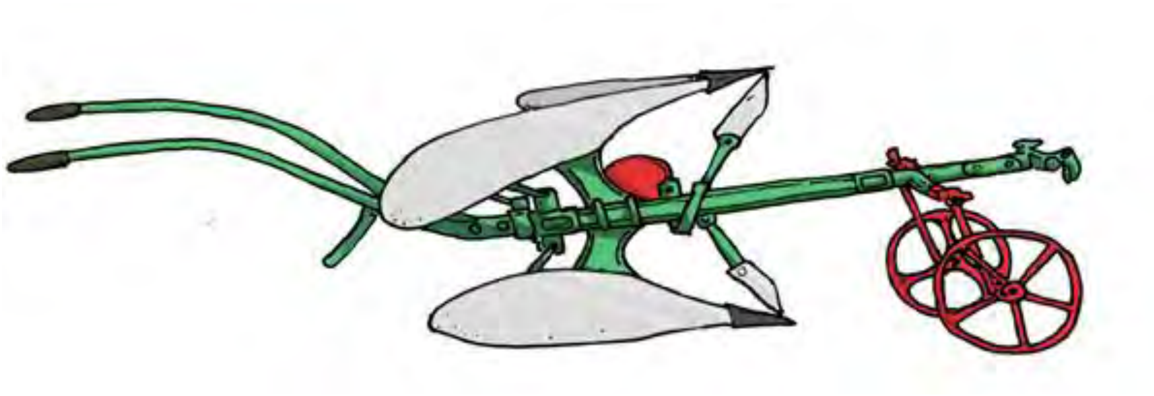


Figure 2.7. Turn Wrest/One-Way Reversible Plough

Source: https://blogs.reading.ac.uk/merl/files/2013/06/62-524-copy-1024x535.png

2.4. Mouldboard Materials and Construction

The very early mouldboard ploughs were designed with wood having a very strong pointed end known as the share for easy penetration into the soil. The earliest was the bow ard, which consisted of a drafted wooden pole (beam) pierced by a peck-like vertical pointed stick called the head.

An example is the traditional Filipino water buffalo-drawn plough used for rice farming in the 1874.

The share, landside, mouldboard which were bolted to the frog were made of piece of cast iron at the base of the plough body (Chatizwa and Khumalo, 1996; Chatizwa and Jones, 1997). Advancement on the basic design was the ploughshare which was replaceable and made of Cast iron by improved materials of high durability and wear resistant. Many materials are now been experimented such as High Speed Steel (HSS), High Carbon Steel (HCS) or Alloy Steel (AS).

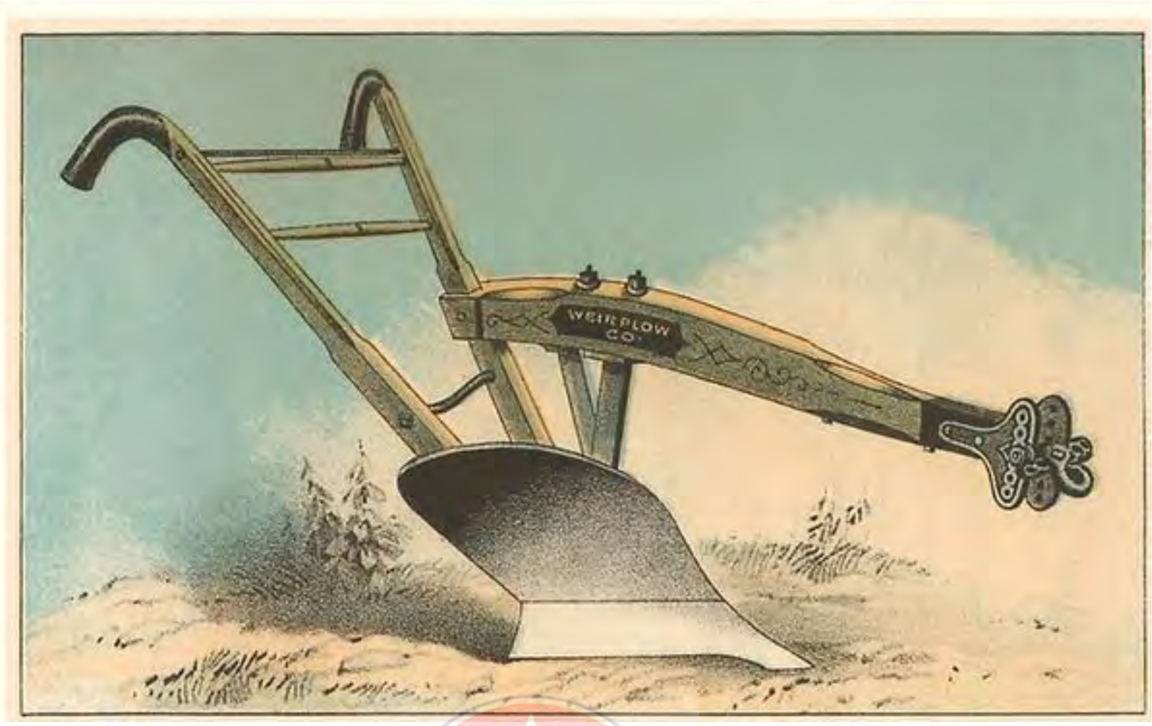


Figure 2.8. Egyptian Wooden Plough

Source: https://cdn.shopify.com/s/files/1/0033/0131/0510/products/AG-00068_043ea9e1-8f94-4ec8-8a94-4ecb3f9c5bc0_720x.jpg?v=1606878762

The Egyptian Ard is an old wooden made farming tool that was drawn by at least one bullock or any animal capable of providing similar service.

2.5. Challenges Associated with the Mouldboard Plough

The challenges farmers encounter in using and maintaining the animal drawn implements for land preparation and weeding is a disturbing phenomenon. Complaints by smallholder farmers in Zimbabwe revealed that, ploughs are heavy and difficult to use (O"Neill et al., 2005) There is also evidence that these smallholder farmers do not keep the ploughs in good condition by paying heed to the repair and maintenance of their ploughs (Chatizwa and Khumalo, 1996; Chatizwa and Jones, 1997).

Figure 2.9. Broken Mouldboard Plough

Source: https://www.dreamstime.com/photos-images/moldboard-plow.html

The causes of broken down mouldboard ploughs are embedded stones, rocks, roots and storms; others include wear and rusting which are chemical processes. This is the reddish brittle coating formed on the plough in Figure 2.9. This occurs, when parts come into contact with moisture and air essentially composing of hydrated ferric oxides. When this happens, with time the parts become susceptible to frequent damage. These challenges are almost the same farmers in Ghana go through with mouldboard ploughs.

Figure 2.10. Replacement of Some Broken Parts of a Mouldboard Plough

Source: https://www.agropomoc.com//Uploads/agrox/2016/draw/-angle-piece-56016%20120645231-2.jpg

Studies have shown that the parts of a plough which is in direct contact with the soil are mostly affected. Figure 2.10 shows a farmer replacing some broken parts of a plough.

According to (O‟Neill et al., 2005), the four different types of parts needed frequent replacement were the wheel, landside, share, mouldboard and regulator hake. It was discovered that though farmers are aware of the need to replace the main soil-engaging components, they do not do so frequently enough.

2.6. Simulation of Design Models

Computer Aided Design (CAD) in engineering practice is the application of computer systems for creation, visualization, presentation, communication, and information processing purposes that define the future education in universities and graduates employment opportunities into small to mid-sized companies (Iyendo and Alibaba, 2015). The complexity of such systems leads to an inability for analysis by using just mathematical methods or to allow realistic models to be evaluated analytically. But with the application of design software, these models are easy to be studied through the means of simulation (Fowler and Rose, 2004). Design simulation provides product manufacturers a pictorially insight to verify and validate the intended function of a product under development, as well as the manufacturability of the product. The word "simulation" is often used interchangeably for computer-aided engineering (CAE). Many design simulation approaches have become standardized for components of product development in many industries. They continue to grow in importance, and are inexpensive, faster and affordable. The easy-to-use design simulation software allows users to address new technologies and applications challenges effectively.

Simulation models are sets of mathematical equations representing the behaviour of the system in a physical domain of interest. The value of simulation as a tool for the extensive use of modeling and decision support tool is widely recognized especially for highly-complex manufacturing systems (Fowler and Rose 2004). These are mostly found in automotive, aerospace, electronics and semi-conductor industries. The complexity of the mathematics depends on availability of information and often varies in function of the application and the design stage.

In early development, typically more simple system representations use analytical assumptions to verify the interaction between several physical aspects on a concept level. In late development level of a product, typically very complex application-specific models are used for validation and refinement. The applications can cover aspects such as structural behaviour, acoustics, system dynamics, crash-worthiness, thermal and flow analysis, stress analysis, fuel economy, controls development and much more (Chung 2004). Simulation modeling and analysis are conducted in order to gain insight into these complex systems, testing new operating or resource policies and new concepts or systems before implementing them (Chung 2004). It could aid in gathering information and knowledge without disturbing the actual system (Mourtzis et al., 2014). Following the work of Goldsman, et al., (2010) on the recent technological advancement, five historical periods could be identified: the pre-computer era from Buffon to World War II starting back on 1777 and closed on 1945, the formative period from 1945 to 1970, the expansion period starting on 1970 and ending on mid-80s, the period of Consolidation and Integrated Environments mid-80s to 2000 and after that the ongoing era of digitalization starting back on 2000. Simulation is an ever-growing part of manufacturing that may support its different aspects Dimitris (2019). Further technological advancement in the last few decades concern software applications enhanced by virtual reality, improved interfaces and utilities, and agent-based modeling, indicating the inclusion of intelligent components in sophisticated software (Mourtzis, 2020). Bodein, et al., (2014) presented innovative CAD methods for complex parts modeling in parametric CAD system and their application in an industry context.

2.7. Improvements on Ploughs Design and Construction

„The design process is a sequence of events and a set of guidelines that helps define a clear starting point that takes the designer from visualizing a product in his/her imagination to realizing it in real life in a systematic manner-without hindering their creative processes‟(Haik and Shahin, 2011). John Deere, an American blacksmith, identified that ploughing longer in sticky, non-sandy soils might be beneficial from modifications in the design of the mouldboard and the metals used. He noticed that, a polished needle would enter leather and fabric with greater ease with less effort. Looking for a polished, slicker surface for a plough, he experimented with portions of saw blades, and by 1837 was making polished, cast steel ploughs. The effort required was minimal which enabled the use of larger ploughs and more effective use of horse power. He found that cast-iron plows were not working very well in the tough prairie soil of Illinois. He quickly remembered the needles he had previously polished by running them through sand whiles he was growing up in his father's tailor shop in Rutland, Vermont. Deere came to the conclusion that a plow made out of highly polished steel and a correctly shaped moldboard (the self-scouring steel plow) would be better able to handle the soil conditions of the prairie, especially its sticky clay. Considerably, when a plough hits a rock or other solid obstruction, serious damage may result unless the plough is equipped with some safety devices. The damage may be bent or broken shares, bent standards, beams or braces. The three basic types of safety devices used on mouldboard ploughs are a spring release device in the plough drawbar, a trip beam construction on each bottom, and an automatic reset design on each bottom commonly found in tractor ploughs. The simplest mechanism is a breaking (shear) bolt that needs replacement (Haik and Shahin, 2011). Shear bolts that break when a plough body hits an obstruction are a cheaper overload protection device. Moreover, it is also employed to minimize costs for replacement of broken shares, beams and other parts.

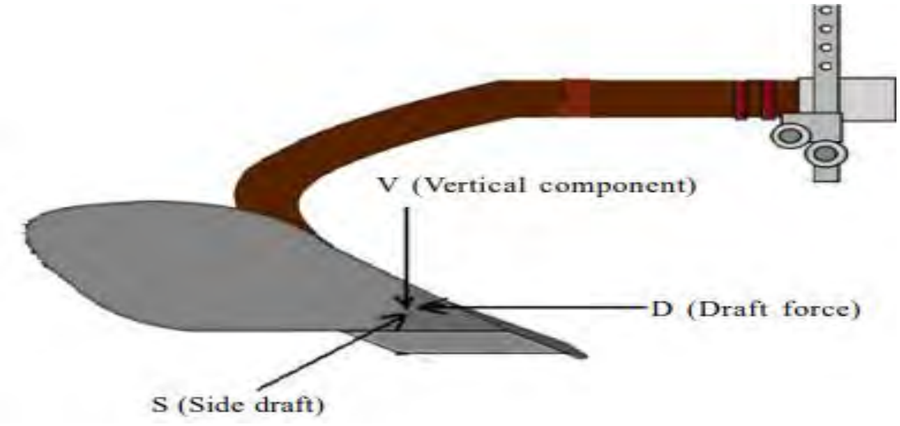
2.8. Operational Challenges in Ploughing

Overturning stability and vibration levels need to be seriously considered with respect to field machinery. This is necessary because farm lands for upland crops are usually uneven and sloped, which may cause work-related fatalities (Chowdhury et al., 2020). Vibration is a phenomenon that affects operator comfort and also reduces the durability of machinery components. The inadequate overturning stability of agricultural field machinery is a major cause of farming incidents. This comprises of a large segment of agricultural machinery hazard statistics, and the result may be serious injuries that could result in the death of operators (Gao et al., 2017). The rollover efficiency of agricultural field machinery is dependent on the stability. Stability is related to the static, dynamic, and operational parameters of the machinery. Static and dynamic parameters are affected by wheelbase, tread width, and center of gravity, and the operating parameters are related to forward speed, turning radius, slope of the land, and surface conditions (Chowdhury et al., 2020). Among several approaches used for determining static stability angles, two commonly used methods are theoretical calculation of the center of gravity and stability angles, and secondly, the direct measurement of the tilt angle for vehicle overturning. Vibration affects user comfort and machinery durability, and also partially affects the stability (Cutini et al., 2016). It usually occurs due to rapid forward, backward, or oscillating movement of the mechanical components. The vibration effect may vary as a result of component speed, position, loading condition, operational site, and environmental factors (Gao et al., 2017). The measurement of vibration is essential for maintaining stability such as static, couple, dynamic, and overhung. The reduction of dynamic stress, preventing of misalignment relating to belt and shaft, looseness, resonance are all measures towards improving the overall working environment as well as maintaining the safety of off-road agricultural machinery or vehicles. According to the vibration regulations, the amount of daily exposure to whole-body vibration is 0.5 meter per second square (ms^{-2}) and should not exceed 1.15 ms^{-2} (Krajnak, 2018). Generally, vibration is measured according to the direction along with the intensity, frequency, and duration parameters (Sepulveda and Sinha, 2020). Therefore, extensive vibration affects machine performance as well as the operator.

2.9. Typical Models and Forces Distributions

Godwin (2007) reported components of tillage forces on tools to include, horizontal or draught force which is the amount of force required for pulling or pushing the implement through the soil, vertical force which is the implement force assisting or preventing penetration into the soil, and lateral or sideways forces which are applied to overcome the direction of a side draft. These have then to be counterbalanced by implement weight or weight transfer from the operator. In vertical analysis, there is typically one downward force; this is the force of gravity which is related to the mass of the object. There are two or more upward force components which are the result of the tension forces. The sum of these upward force components is equal to the downward force of gravity.

Horizontal forces: These forces are equal in size and opposite in direction. They are balanced, so the horizontal resultant force is zero. This means that, there is just a horizontal constant speed but no horizontal acceleration.



Source: (https://www.researchgate.net)

Figure 2.11. Types of Forces Acting on Plough Bottom

Draft (D) = $P \times \cos\theta \times \cos\alpha$

Side draft (S) = $P \times \cos\theta \times \sin\alpha$

Vertical force (V) = $P \times \sin\theta \times \cos\alpha$

Where,

P = pull of plough, kg or N,

θ = Angle of pull with horizontal plane, degree.

α = Angle of pull with vertical plane, degree, (Yoganandi and Yadav, 2016)

CHAPTER THREE

MATERIALS AND METHODS

3.1. Introduction

This chapter deals with the materials and methods employed in carrying out the research including procedure and the analytical approach used for the study.

3.2. Method Used for the Design and Numerical Analysis

The study is aimed at re-designing a mouldboard plough with the main focus being to improve strength and reduce the weight. The plough is designed using similar data from an existing model but with significant modification. Parameters such as the weight and dimensions were taken into consideration. Analysis will be done to check whether or not maximal stresses at the highest workloads exceeds yield or ultimate strength limits of the materials with imposed of 1,900 N and 900 N on share and mouldboard respectively. In order to evaluate and check design solutions, selection of materials, stiffness and stresses in the share and mouldboard, two different software solutions were used. Drawings of the structural parts and assembly of them was made with the help of Autodesk Inventor 2020, while all the numerical calculations were performed with ANSYS Workbench.

The model consists of the mouldboard, share, beam, frog, handles, hitch, wheel, wheel holder, handle braces, bolts and nuts. Each of these parts was designed separately before the assemblage.

3.3 Meshing and Grid Independence Test of Components

Meshing is an essential step in static structural and modal analysis process. Meshing is an integral part of the engineering simulation process where complex geometries are divided into simple elements that can be used as discrete local approximations of the larger domain. The mesh influences the accuracy, convergence and speed of the simulation. If meshing is accurate, then the results are also anticipated to be feasible. The meshing details of the models of the plough share are: number of nodes 13,451 and elements 6355 and that of the mouldboard are: nodes 13,451 and elements 6355. The meshed geometries are shown in Figure 3.9.

The mesh sizes of the models were carefully selected since the validity of the mesh can influence the results. Independent test for five (5) iterations were conducted with mesh sizes 3.5 mm, 3 mm 2.5 mm, 2mm and 1.5 mm and the best iteration number which produced better results was selected as the mesh size with a resolution and defeature size of 2 mm as shown in Table 3.1.

Table 3.1 Meshing and Grid Independence Test of Components

Mesh Size	Fixed support	Magnitude (Force in N)	Number of Nodes	Elements	Total Def.mm	Eq. Von Mises Stress, MPa	Eq.Von Strain mm/mm
PLOUGH SHARE							
3.5mm	4 Edges	1900	10589	4922	0.48135	644.5	0.0021836
3mm	4 Edges	1900	14125	6674	0.48254	626.96	0.002333
2.5mm	4 Edges	1900	19959	9593	0.484	561.7	0.0028374
2mm	4 Edges	1900	8020	3703	0.47916	489.16	0.0030434
1.5mm	4 Edges	1900	13451	6355	0.480	461.55	0.003107
PLOUGH MOULDBOARD							
5mm	2 Edges	900	2706	1203	6.3935	364.52	0.0030936
4mm	2 Edges	900	3321	1479	6.6768	452.25	0.0037479
3mm	2 Edges	900	5226	2400	7.1304	605.64	0.0048273
2mm	2 Edges	900	4775	2176	7.0737	637.81	0.0047782
1mm	2 Edges	900	5188	2377	6.9803	628.9	0.0044694

From Table 3.1, it is evident from the independent grid test that, the mesh size that yielded the satisfactory induced Von Mises stresses, total deformations and equivalent elastic strains are mesh sizes 1.5 mm and 5mm for the share and mouldboard respectively which is good for the purpose of the study. The imposed forces on the share and mechanical models were 1900 N and 900 N respectively. The parameters that were considered during the static structural analysis were: total deformation, equivalent elastic strain equivalent (Von Mises) stress and safety factor of the models were calculated.

3.4. Material used for the Manufacture of Mouldboard Plough

The choice of an appropriate material for engineering purpose is one of the most complex challenges for the designer. The best material is considered to be the one which serves the desired objective at the minimum cost. Factors considered during the selection of the material for the plough were: availability of the material, high strength and durability, wear and corrosion resistance, cost of the material, and resilience.

For the purpose of this research, low alloy steel (AISI 4140) was selected for the new model as against the cast iron that was used for the existing mouldboard ploughs observed from previous studies. A safety factor of 1.85 was selected based on the plasticity reduction factor which reflects the shear buckling behavior of low alloy steel in the inelastic range.

Table 3.2. Mechanical Properties of Selected Materials

Low alloy steel (AISI 4140)	**Cast iron**
It has high ductility	Cast iron tends to be brittle
It is tougher than plain carbon steels.	It is resistant to damage by oxidation.
Low melting point	Relatively low melting point
Desired hardness	Good fluidity
It has high fatigue strength, abrasion and impact resistance	Wear resistance
It has good machinability in the annealed condition.	Excellent machinability
	Castability

Excellent wear and shock resistance	Resistance to deformation
Density 7,850 kg$\mathbf{mm}^{-3}$	Density 6,999kgmm^{-3}
Tensile Yield Strength 652.2 MPa	Tensile Yield Strength 79.81 MPa
Tensile Ultimate Strength 1015 MPa	Tensile Ultimate Strength 141.4 MPa
Shear Modulus 82,364 MPa	Shear Modulus 35,492 MPa
Young‟s Modulus 212,500 MPa	Young‟s Modulus 89,440 MPa
Poisson‟s Ratio 0.29	Poisson‟s Ratio 0.26

Source: https://blog.eaglegroupmanufacturers.com/overview-of-mechanical-properties -of-metals

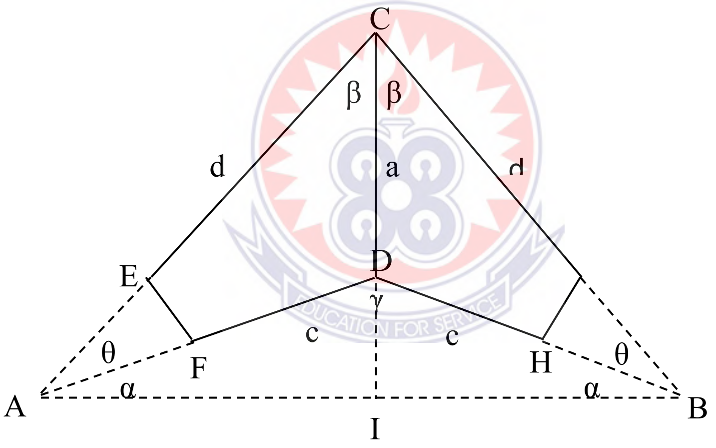


Figure 3.1. Schematic Diagram for Calculation of Area of Share

Table 3.3. Dimensions of the Plough Share

AB = 355mm	FD = 98.26mm
AC = 328.52mm	GH = 57.50mm
CD = 179.99mm	AE = 115mm
CE = 213.60mm	AF = 100.93mm

AD = 199.19mm

Source: Field data

From Figure 3.1 triangles (Δ) ACD and BCD, are similar triangles Hence, angle (< CAD = <CBD and <ACD = <BCD)

Using cosine rule, $a^2 = b^2 + c^2 - 2bc\cos\theta$ ……

$179.99^2 = 328.52^2 + 199.19^2 - 2(328.52 * 199.19\cos\theta)$

32396.40 = 107925.40 + 39676.66 – 130875.8 cosθ

32396.4 = 147602.06 – 130875.8 cosθ

-115205.66 = -130875.8 cosθ

$\frac{-115205.66}{-130875.80} = \frac{-130875.8\cos\theta}{-130875.80}$

Cosθ = 0.88

$\theta = \cos^{-1}(0.88)$

$\theta = 28^{o}$

From Δ ACD, $\frac{\sin A}{a} = \frac{\sin C}{c}$ ………………………………………………………… (3.1)

$\frac{\sin 28}{179.99} = \frac{\sin C}{199.19}$

179.99sinC = 199.19sin28

SinC = $\frac{93.514}{179.99}$

sin C = 0.52

$C = \sin^{-1}(0.52)$

$C = 31^{o}$

But C = β

Therefore, β = 31°

Again, ΔABD is an isosceles triangle so base angles are equal.

$\alpha + \alpha + \gamma = 180$ …………………………………………………………………. (3.2)

$2\alpha + 120 = 180$

$\alpha = 30^{\circ}$

From Figure 2.11, the various forces can be determined as follows: Since pull (P) of plough, θ and α are now known, the Draft, D is given by Equation 3.3

Draft (D) = $P \times \cos\theta \times \cos\alpha$ ………….. (3.3)

Where, P = pull of plough, kg or N

θ = Angle of pull with horizontal plane,

α = Angle of pull with vertical plane, degrees.

D = 2000 x cos28 x cos30

D = 1,529.31N

Side draft (S) = $P \times \cos\theta \times \sin\alpha$ ……………………………………………………... (3.4)

S = 2000 x cos28 x sin30

S = 882.95N

Vertical component (V) =$P \times \sin\theta \times \cos\alpha$ ……………………………………….. (3.5)

V = 2000 x sin28 x cos30

V = 813.15N

Total sum of draft = 1,529.31N + 882.95N + 813.15N = 3,225.41 N

The derived force-values are supported by the study of Mari et al., (2015) who postulated that, draft forces followed almost similar trend and had the least value of 308.17 N. This experimental draft force was found at 1 m/s speed and 5 cm depth under 33% moisture content. Cumulative soil forces found were too smaller than the draft as they represented the force spatial distribution of specific parts of plough.

All the above forces are acting on the two bottoms of the plough. Analytically, the draft, side draft and vertical force components on each bottom of plough are one half of its original value.

Design of the share of mouldboard plough bottom: The best throat angle (share angle) of the share should be an angle along which soil rupture takes place. Soil shear angle (θ) = 45°- Φ where, Φ = angle of friction between metal and soil. Now, the share may be assumed like a rectangular plate of area (ΔACD + ΔBCD) subjected to bending as shown in Figure 3.1

Area of share = area of ΔACD + area of ΔBCD. Since there is no height, Heron‟s triangular formula is applied. Let a, b and c represent the sides and S represent one half of the perimeter.

From Figure 3.1, Perimeter, S of ΔACD = $\frac{1}{2}$(AC+ CD+ DA)… …………………… (3.6)

a = c = 328.52mm, d = e = 199.19mm, b = 179.99mm

AE = 115mm, AF = 100.93mm, EF = 57.50mm

S = $\frac{1}{2}$(328.52 + 179.99 + 199.19) = 353.85mm

Therefore, perimeter of ΔACD (S_1) = 353.85mm

Therefore, area (A) of ΔACD = $\sqrt{S(S-AC)(S-CD)(S-DA)}$ ………………… (3.7)

$$A=\sqrt{353.85(353.85-328.2)(353.85S-179.99)(353.85S-199.19)}$$

$$A=\sqrt{353.85(52.33)(173.86)(154.66)}$$

$$A=\sqrt{497{,}906{,}294.58}$$

A = 22,313.814mm^2

Area of Share = Area of ΔACD + area of ΔBCD and ΔACD = ΔBCD

Area of share = 22313.814 + 22313.814

Total Area of Share = 44,627.628mm^2

Again, Perimeter, S of ΔAEF = $\frac{1}{2}$(AE+ EF+ FA)… ……………………………….. (3.8)

S = $\frac{1}{2}$(115 + 100.93 + 57.50)

S = $\frac{1}{2}$(273.43)

S= 136.715mm

Therefore, perimeter of ΔAEF (S_2) = 136.715mm

Therefore, area (A) of ΔAEF = $\sqrt{S(S-AE)(S-EF)(S-FA)}$ ………………… (3.9)

$A = \sqrt{136.715(136.715-115)(136.715-100.93)(136.715-57.50)}$

$A = \sqrt{136.715(21.715)(35.785)(78.215)}$

$A = \sqrt{841557.669}$

A = 917.365mm^2

Area of ΔAEF = Area of ΔBGH and ΔAEF = ΔBGH

Area = 917.365 + 917.365

Area = 1,834.73mm^2

Area of required shape of Share = (Area of ΔACD + Area of ΔBCD) – (Area of ΔAEF + Area of ΔBGH)

44,627.628mm^2 − 1,834.73mm^2

Therefore, area of required Share = 42,792.90mm^2 or 0.0427929 m^2

According to Betker and Kutzbach (1989), draught forces in animals drawn ploughs vary from 850N to 2,000N depending upon the type of soil and its moisture content. Based on their point of view, taking minimum force to be 850N and maximum force as 2,000N and the calculated area of share, then, the Pressure acting on the plough share can be determined.

According to the American iron and steel institute, alloy steel cold-formed structural design manual, 1974 edition, the critical buckling stress for shear of a flat element can be expressed. The plasticity reduction factor is used to reflect the shear buckling behavior of low alloy steel in the inelastic range with a safety factor of 1.85. The unit draft is dependent upon the type of soil under consideration. And for the purpose of this study and clarity, the unit draft of medium soil is considered in Table 3.4.

Table 3.4. Speed, Field Efficiency and Draft Requirements

EQUIPMENT	**SPEED (MPH)**	**DRAFT(LB. PER UNITOF WIDTH)**	**AVERAGE RANGE**
Tillage			
Moldboard plow (16in. bottom, 7 in. deep) – (406.4mm, 177.8mm)			
Light soil	5.0	320	220 - 430 per foot
Medium soil	4.5	500	350 - 650 per foot
Heavy soil	4.5	800	580 - 1,140 per foot
Clay soil	4.0	1200	1,000 - 1,400 per foot
Chisel-plow (7-9 in. deep)	5.0	500	200 - 800 per shank

Source: Siemens, J.D. and W. Bowers. 1999. Machinery Management. John Deere Service publication.

Considering the factor of safety of alloy steels to be 1.85 Yoganandi and Yadav, (2016) and unit draft of medium soil in Table 3.4, the following equations and values were obtained.

Unit draft of share = unit draft of soil × factor of safety……………………………… (3.10)

Unit draft of share = 3,225.41N x 1.85 = 5,967 N

Total design draft of mouldboard plough share = width × depth × unit draft……… (3.11)

From Table 3.4, depth of cut and width of mouldboard plough is estimated to be 177.8mm or 0.1778m and 224mm or 0.224m respectively.

Total design draft of mouldboard plough share = 0.224 × 0.178 × 5,967 = 237.92 N/m^2

The total draft force will act on entire area of share. It is assumed that the soil pressure is uniformly distributed on the share.

Therefore, soil pressure on share = $\frac{\text{Total design draft of plough share}}{\text{Total area of share}}$ ………………… (3.12)

$= \frac{237.92\ N/m^2}{0.0427929\ m^2} = 5{,}559.8\ N = 0.00556\ MPa$

$= 5.56 \times 10^{-3} MPa$

This pressure acts on the share at an angle Ψ = 20°.

Therefore, uniformly distributed load = Soil pressure on share × sinΨ ……………. (3.13)

Uniformly distributed load (Pressure) = 0.0556 x sin20 = 0.0019 MPa = 1,900 N

Length breadth ratio of share = L/b = 0.23/0.224 = 1.0

Share thickness (t) = 0.003m

For uniformly distributed loads on rectangular plate:

$S_{max} = B \times F \times b^2/t^2$………………………………………………………… (3.14)

Where,

Smax= Maximum stress developed load, MPa/m^2

F = uniformly distributed load, MPa/m^2

b = Width of share, m

t = Thickness of share, m

B = A constant which depends on length and breadth ratio of share.

$S_{max} = B \times F \times b^2/t^2$

$S_{max} = 1.0 \times 0.0019 \times 0.224^2/0.003^2 = 10.59 MPa/m^2$

3.5.2 Estimating Forces Acting on the Mouldboard Plough

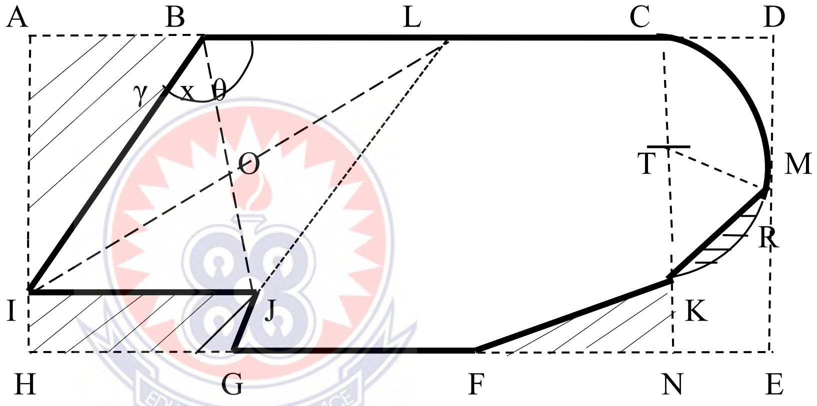


Figure 3.2. Schematic Diagram for the Calculation of Mouldboard Area

Table 3.5. Dimensions of Mouldboard

AB = 61.48mm	AH = 169.34mm
BC = 191.02mm	AI =108.25mm
CK= 109.60mm	HI = 61.09mm
KF = 48.86mm	GH = 100mm
FG = 160.28mm	BI = 125mm
GJ = 61.11mm	FN = 152.50mm
	KN = 49.34mm

JI = 102.21mm	KM = 48.8mm

Source: Field data

α = 60° and the bent angle along the bent line JL = 15°

Given that parallelogram, IBLJ has BI // LJ, BL // IJ and opposite angles equal.

Considering the mouldboard as a rectangular plate of metal, the area can be determined as follows: Rectangle ACNH, AC = HN = 252.5mm and AH = DE = 169.34mm. Area of rectangle (A) = Length (L) x Breadth (B) ……………………………….... (3.15)

A = 252.5 x 169.34 = 42,758.35mm^2

Since the mouldboard is a cut out shape of the rectangular plate, all the shaded parts can be determined and taken away to get the resultant mouldboard shape as shown in Figure 3.3. Considering ΔABI, its area (A) = $\frac{1}{2}$b x h …………………………………… (3.16)

= $\frac{1}{2}$ x 108.25 x 61.48

A = 3,327.605mm^2

Considering IJGH as a trapezoidal shape, its area as B, then B = $\frac{1}{2}$ h (a + b) ……. (3.17)

= $\frac{1}{2}$ 61.09 (102.21 + 100) = 6,176.50

B = 6,176.50mm^2

Again, considering FKN as another triangle, its area (C) will also be $\frac{1}{2}$ b x h = $\frac{1}{2}$ (152.50 x 49.34)

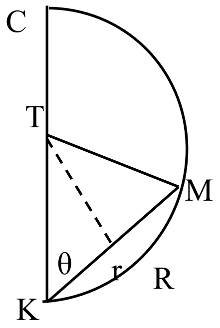
C = 3,762.18mm^2

Adding areas A, B, and C = 3,327.605 mm^2 + 6,176.50mm^2 + 3,762.18 mm^2 = 13,266.27mm^2

Therefore, area of rectangle ACNH = 42,758.35mm^2 - 13,266.27mm^2

= 29, 492.07mm^2

Semi- circular part of mouldboar



Again considering CMRK as a semi-circle with area as X = $\frac{1}{2}\pi r^2$……………….. (3.18)

$= \frac{1}{2}(3.143 \text{ x } 60^2)$

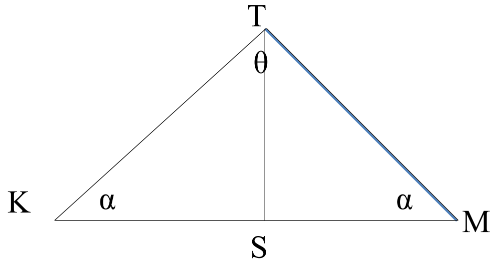
X = 5,657.14mm^2

Let Z be area of sector TMRK = $\frac{\theta}{360}\pi r^2$, Let N be area of ΔKTM and let P be area of segment KMR. P = Z – N, Using Pythagoras theorem,

TS = $\sqrt{\left[r^2 - (\frac{KM^2}{2})\right]}$ ……………………………………………………………… (3.19)

But TS = $\sqrt{\left[60^2 - (\frac{48.8^2}{2})\right]}$ = 49.08mm

TS = 49.08mm



Now, area N = $\frac{1}{2}$ b x h = $\frac{1}{2}$ (MK x TS) = $\frac{1}{2}$(48.8 x 49.08) = 1,197.55mm^2

N = 1,197.55mm^2

Sinα = $\frac{49.08}{60}$ = 0.818 = α = $\sin^{-1}(0.818)$

α = 54.89°. Since it is an isosceles triangle, base angles are equal.

Therefore, θ = 70.22°

Now Z = $\frac{70.22}{360}$ x 3.143 x60^2 = 2,207mm^2

Z= 2,207mm^2,

and then P = Z – N = 2,207mm^2 - 1,197.55mm^2

Therefore, P = 1,009.46mm^2

Now area of CMK = area of semi-circle – area of segment = 5,657.14 – 1,009.46

Area of CMK = 4,647.68mm^2

Area of one-half of the mouldboard = 29, 492.07+ 4,647.68 = 34,139.75mm^2

Total area of mouldboard = 2 x 34,139.75mm^2 = 68,279.5mm^2

or 0.0682795m^2

Now, according to Betker and Kutzbach (1989), draught forces in animals drawn ploughs vary from 850N to 2,000N depending upon the type of soil and its moisture content. Based on their point of view, taking minimum force to be 850N and maximum force as 2,000N and the calculated area of the mouldboard of 68,279.5mm^2 or 0.0682795m^2,

then the pressure (P) = $\frac{\text{FORCE (F)}}{\text{AREA (A)}}$

Considering the factor of safety of low alloy steel, 1.85 and unit draft of medium soil in Table 3.4

Unit draft of mouldboard = unit draft of soil × factor of safety …………… …… (3.10)

Unit draft of mouldboard = 3,225.41 x 1.85 = 5,967 N

Total design draft of mouldboard = width × depth × unit draft …………………. (3.11)

From Table 3.4, depth of cut and width of mouldboard plough is estimated to be 177.8mm or 0.1778m and 169.34mm or 0.16934m respectively.

Total design draft of mouldboard = 0.16934 × 0.178 × 5,967 = 179.86 N/ m^2

The total draft force will act on area of mouldboard. It is assumed that the soil pressure is uniformly distributed on the mouldboard.

Therefore, soil Pressure on mouldboard = $\frac{\text{Total design draft of mouldboard}}{\text{Total area of mouldboard}}$ ………. (3.12)

$= \frac{179.86\ \mathrm{N/m^2}}{0.0682795\mathrm{m^2}}$ = 2,634.17N = 0.00263417MPa

2.634 x 10^{-3}MPa

This Pressure acts on the mouldboard at Ψ = 20°.

Therefore, uniformly distributed load = Soil pressure on mouldboard × sinΨ…. (3.13)

Uniformly distributed load = 0.00263417 × sin20 = 0.0009 MPa = 900 N

Length and breadth ratio of mouldboard = L/b = 0.253/0.169 = 1.50

Mouldboard thickness (t) = 0.003m

For uniformly distributed loads on rectangular plate:

Smax = B x F x b^2/t^2 ………………………………………………………… (3.14)

Where,

Smax= Maximum stress developed load, MPa/m^2

F = uniformly distributed load, MPa/m^2

b = Width of mouldboard, m

t = Thickness of mouldboard, m

B = A constant which depends on length and breadth ratio of mouldboard.

Smax = B x F x b^2/t^2

Smax $= 1.50 \times 0.0009 \times 0.169^2/0.003^2 = 4.284\text{MPa/m}^2$.

Table 3.6. Detail Information of Mouldboard Plough

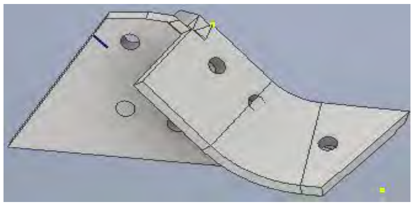
Table 3.6 shows the materials, number of parts and dimensions of the various components of the mouldboard plough.

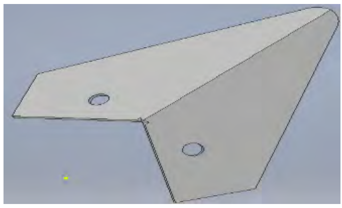
PART/CUTTING LISTS

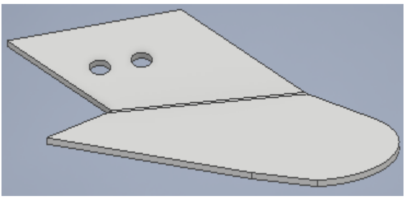
	ITEM	NO OFF	MATERIAL	DIMENTIONS (MM) ACTUAL					OPTIMIZED				
				L	W	T	°	HØ	L	W	T	°	HØ
1	Mouldboard	2	CI/Low alloy steel (AISI 4140)	315.6	211.6	3.75	-	18.75	252.5	169.34	3	-	15
2	Share	1	CI/Low alloy steel (AISI 4140)	287.5	280	3.75	150	18.75	230	224	3	120	15
3	Frog	1	CI/Low alloy steel (AISI 4140)	210	-	16.25	-	15	168	-	13	120	15
4	Beam	1	CI/M.S	1625	65	18.75	178.8	25	1300	52	15	143	20
5	Wheel	1	CI/M.S	-	50	3.8	-	25	-	40	3	-	20
6	Wheel holder	1	CI/M.S	450	56.3	11.3	-	18.8	360	45	9	-	15
7	Handle frame	2	CI/M.S	1043.8	43.75	7.5	-	18.8	1043	D=35	6	45	15
8	Hitch	1	CI/M.S	147.5	87.5	12.5	-	-	118	70	10	-	-
9	Chain hook	1	CI/M.S	137.5	87.5	12.5	-	-	110	70	10	-	50
10	Beam-Handle brace	2	CIM.S	705	50	3.75	-	-	564	40	3	-	-
11	Beam-Frog brace	1	C/IM.S	327.5	50	18.8	-	18.8	262	40	15		15
12	Handle	2	CI/Thermoset-bakelite	175	SLOT=43.66*8.8	-	-	I = 50 E = 60	140	SLOT=34.93*7	-	-	I=40, E=50

13	Bolt	16	HSS	85		15			85				15
	Nut	15	HSS	-	-	10	-	I = 15 E = 25	-	-	10	-	I=15 ,E= 25
14	Washer	15	M.S	-	-	4	-	I = 15 E = 15	-	-	4	-	I=15 , 30

Source: Field data


(a)


(b)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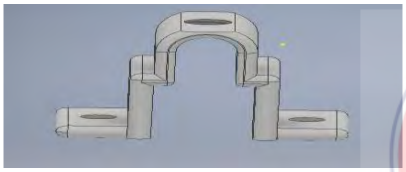
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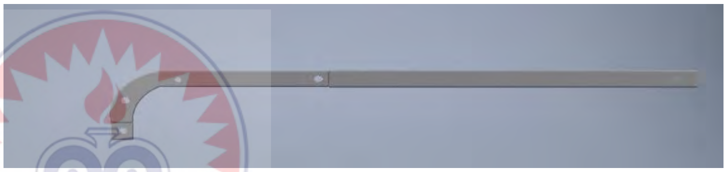
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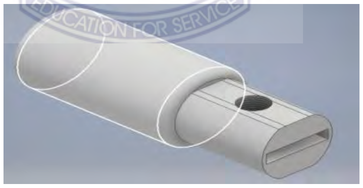
(f)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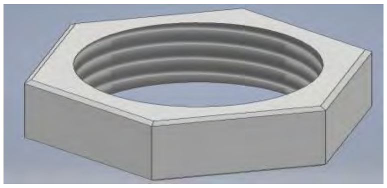
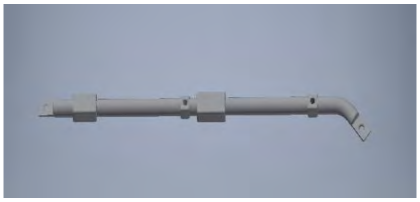

(h)


(i)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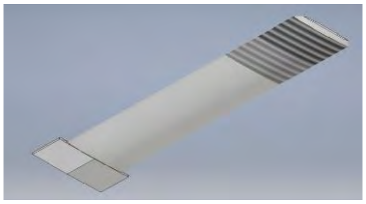
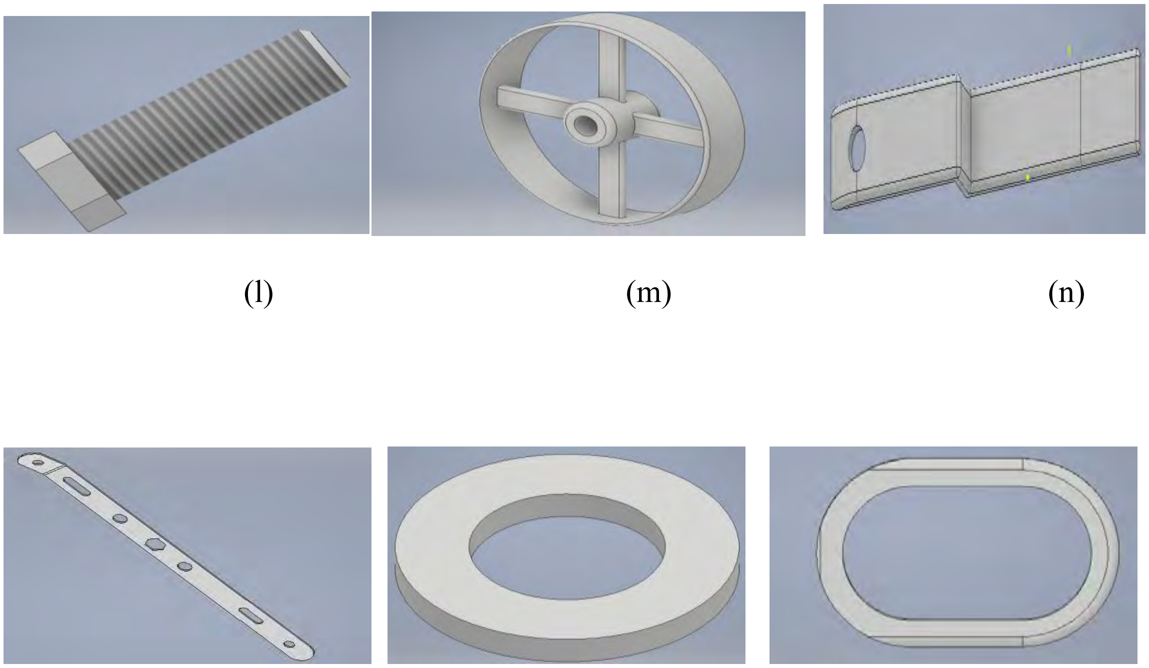

(k)



(l) (m) (n)

(o) (p) (q)

Figure 3.3. Components of mouldboard plough

(a) Frog (b) Share (c) Mouldboara (d) Hitch (e) Beam (f) Beam-frog brace (g) Handle (h) Nut (i) Handle brace (j) Handle frame (k) Part threaded bolt (l) Full threaded bolt (m) Wheel(n) Wheel holder

Figure 3.4. Assembled Mouldboard Plough

3.5. Mode of Operation

The implement could be pulled by either one or a combined pair of bullocks or other animals for similar purposes. One or two ploughmen are required to control the animals and the plough. A chain or very strong robe is used to hook it in between to a wooden bar that holds the draught animals‟ necks.

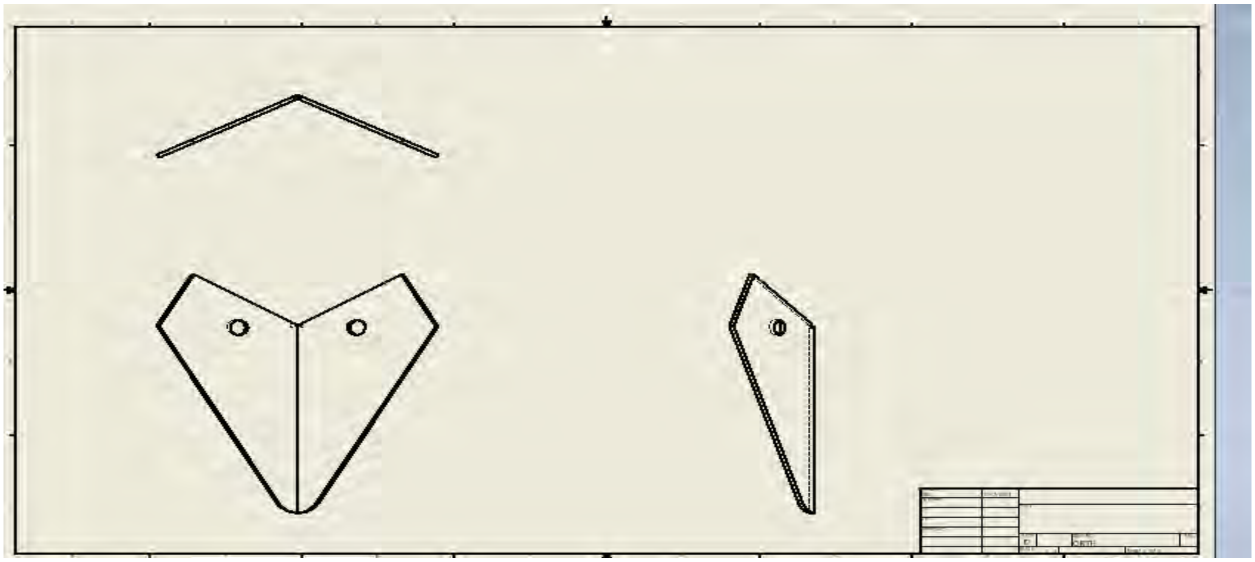


Figure 3.5. Orthographic Projection of Share

The Orthographic Projection of the plough share (Figure 3.5) clearly shows the front elevation, the plan view and the end elevation of the component.

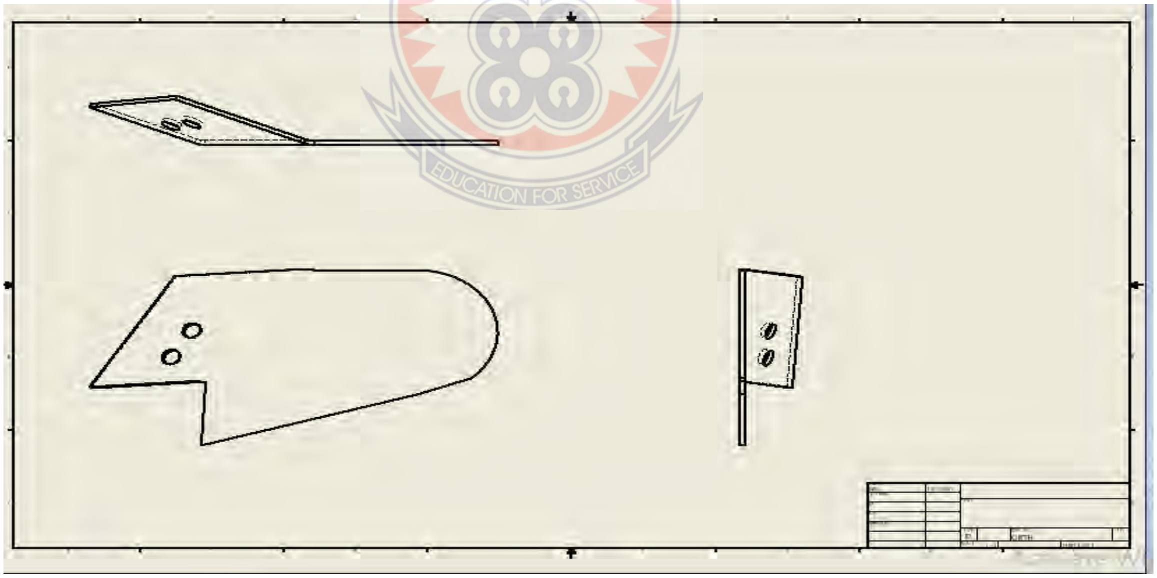


Figure 3.6. Orthographic Projection of Mouldboard

The Orthographic Projection of the plough mouldboard (Figure 3.6) clearly shows the front elevation, the plan view and the end elevation of the component.

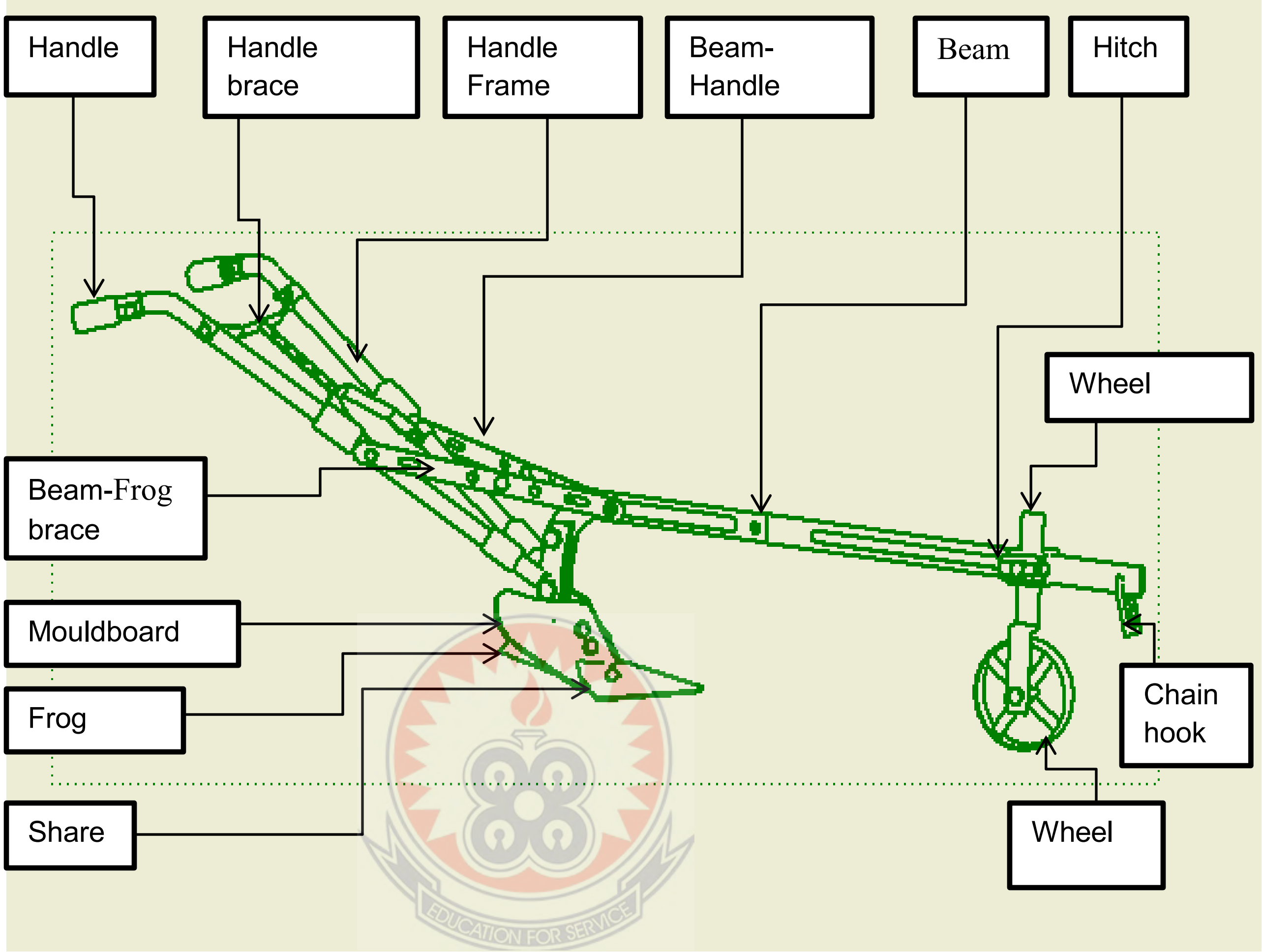


Figure 3.7. Parts of the Mouldboard Plough

3.7. Orthographic View of Plough

The Orthographic projection is a means of representing three-dimensional objects in two dimensions. It is a form of parallel projection, in which all the projection lines are orthogonal to the projection plane, resulting in every plane of the scene appearing in affine.

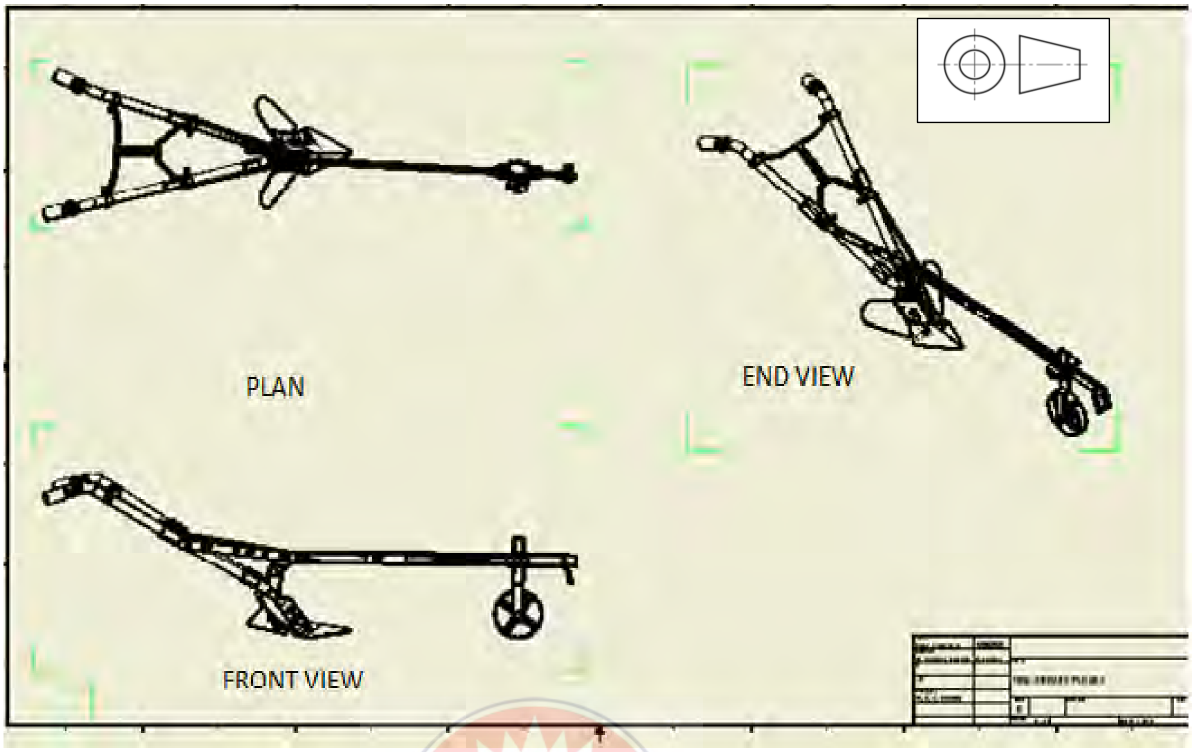


Figure 3.8. Orthographic Projection of the Mouldboard Plough

The Orthographic Projection of the plough (Figure 3.10) clearly shows the front elevation, the plan view and the end elevation of the component.

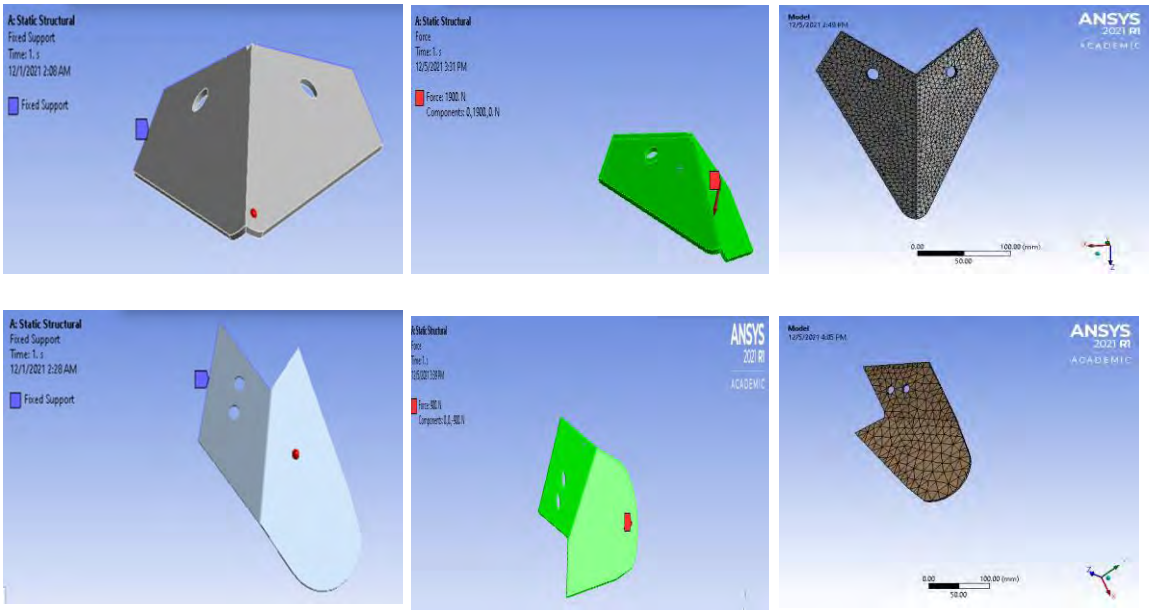


Figure 3.9. Boundary Conditions of the Geometries

Figure 3.9 shows the geometries of the plough share and mouldboard boundary conditions. The share has a meshed size of 1.5mm, 13,451 nodes and 6,355 elements while the mouldboard has a total of 2,706 nodes, 1,203 elements and a bent angle of 15º. The derivative magnitudes applied over the determined areas (0.427929M^2) of the plough share was 1900 N and the mouldboard, (0.0682795M^2) was 900 N respectively.

CHAPTER FOUR

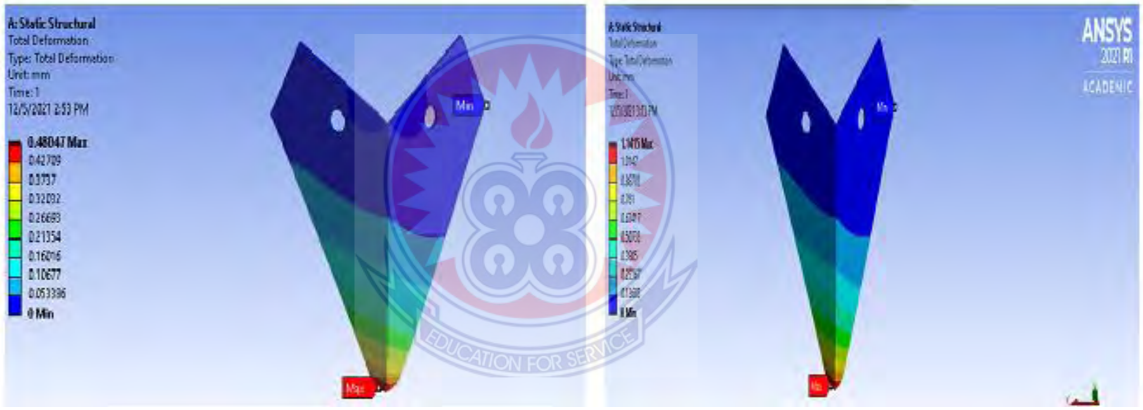
RESULTS AND DISCUSSION

4.1. Introduction

This Chapter presents the analyses and discussions of results. The designed models were exported from Autodesk Inventor software to ANSYS Workbench R21 software for the analysis. The results that were obtained are discussed below.

4.2. Static Structural Analysis of the Plough Share and Mouldboard

4.2.1 Total Deformation of Share

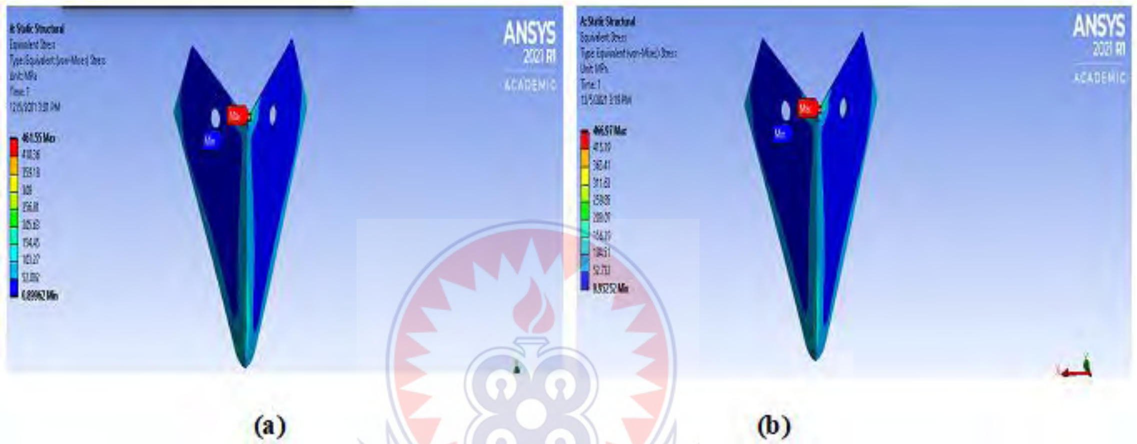


(a) (b)

Figure 4.1. (a) Low alloy Steel Share (b) Cast Iron Share

The maximum total deformation as indicated in Figure 4.1a is 0.480 mm and the minimum total deformation is 0.0503 mm with the imposed 1900 N relative to its area, it can be observed that a maximal deformation has occurred at the tip which penetrates the soil directly during ploughing while the minimal deformation is located at the top edge. In Figure 4.1b, the maximal total deformation occurred at the same point but with a value of 1.1415 mm and a minimum value of 0.127. When compared to the yield and ultimate tensile strengths of low alloy steel (AISI 4140) and Cast iron in Table 3.2, it is very clear to suggest that the selected materials are likely durable and can adequately serve the intended purpose however the former has better resilience. This agrees with the findings in the study of Mourtzis, (2020).

4.2.2. Equivalent Von Mises Stress of Share

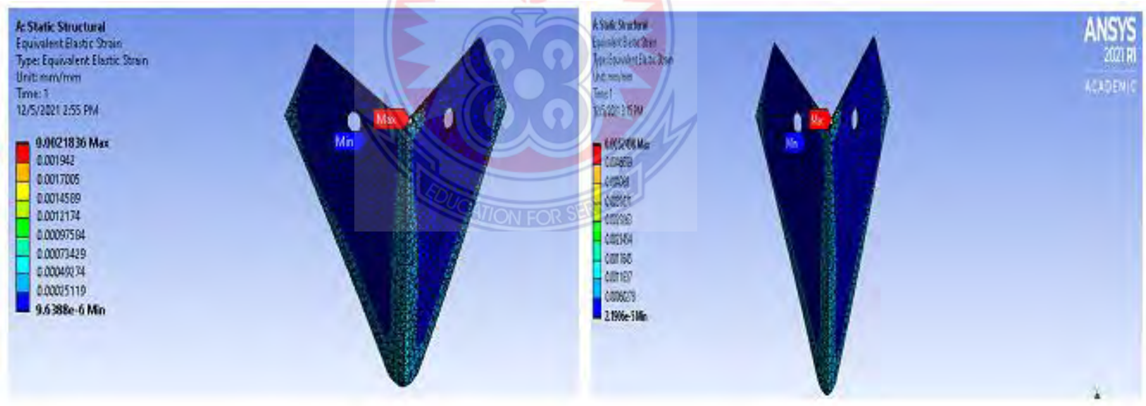


(a) (b)

Figure 4.2. (a) Low alloy Steel Share (b) Cast Iron Share

Using Von Mises yield criterion which depends solely on the value of the scalar Von Mises stress as basis for comparison, the maximal equivalent von Mises stress (Figure 4.2a) occurred at the middle vertex corner and the minimal is at the top surface of the share which is 461.55MPa and 0.8996MPa respectively. However, the yield stress developed on the Low alloy AISI 4042 steel share is far lesser than its yield strength of 652.2 MPa. It can therefore be postulated that the material selected for use have very good properties that are capable of withstanding the force with a safety factor of 1.4 that is, the ratio of the yield strength and the developed stress since it is a ductile material and the margin of safety is 0.4. Furthermore, in Figure 4.2b the same can be said of the stress locations however, the maximal stress is 466.97MPa and minimal of 0.9525MPa. When juxtaposed to the yield strength of the material (79.81MPa) and ultimate strength of 141.4MPa it is noticed that the developed stress is higher than its yield strength but has safety factor of 0.3 that is, the ratio of the ultimate yield strength and the yield stress developed since it is a brittle material. According to von Mises yield criterion, which depends solely on the value of the scalar von Mises stress, a larger von Mises value implies that the material is closer to the yield point. Based on this, the implication is that the share will fail at a point undesirably due to permanent deformation.

4.2.3. Equivalent (Von Mises) Elastic Strain of Share

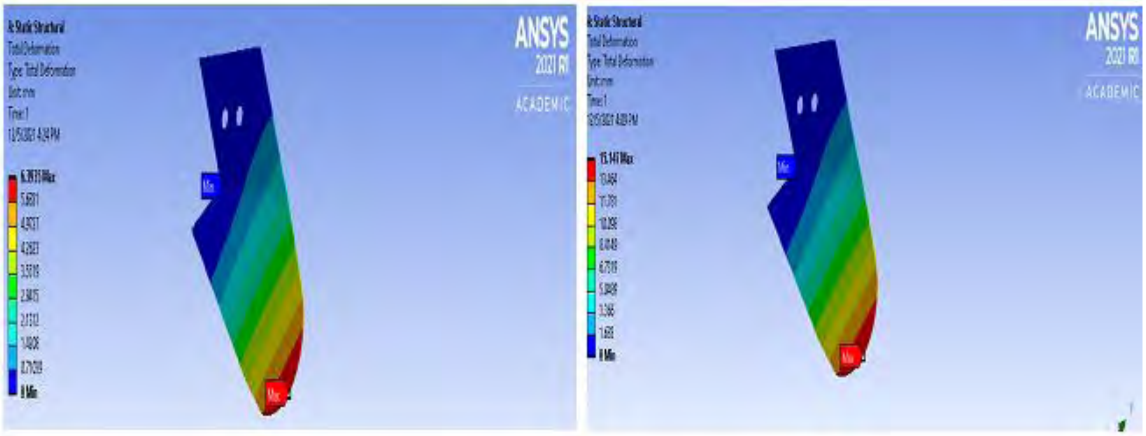


(a) (b)

Figure 4.3. (a) Low Alloy Steel Share (b) Cast Iron Share

The equivalent elastic strain which occurred at the middle vertex corner in both Figure 4.3a and b has a maximum values of 2.184 x 10^{-3} mm/mm and 5.250 x 10^{-3} mm/mm and a minimum values of 9.640 x 10^{-6} mm/mm and 2.191 x 10^{-5} mm/mm. Both values are way below the Young"s modulus of elasticity as shown in Table 3.2 which implies that the material has the ability to stretch but with former having better elasticity.

4.2.4. Total Deformation of Mouldboard

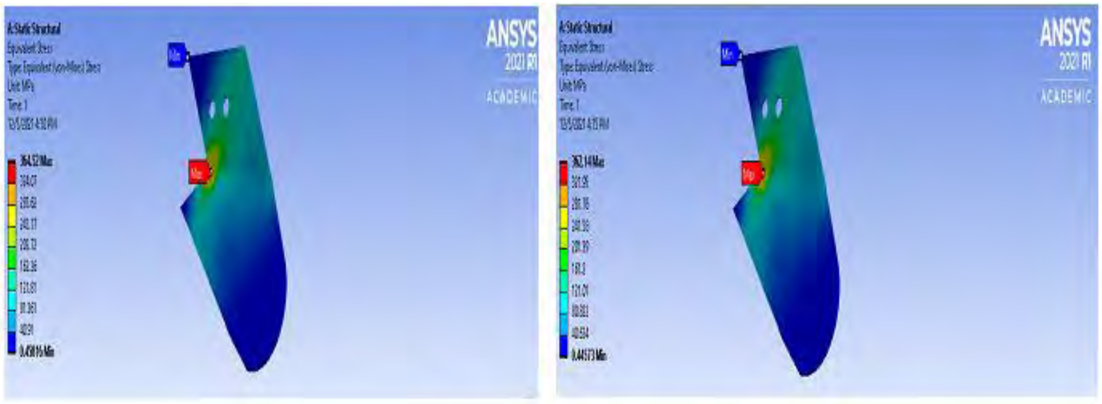


(a) (b)

Figure 4.4. (a) Low Alloy Steel Mouldboard (b) Cast Iron mouldboard

Other working part which is in contact with the soil during tillage is mouldboard. When plough hits an obstacle, force can concentrate on the side edge (Fig. 4.4a and b) or over upper surface of it. The total maximum deformation has occurred at the tail end edge of the mouldboard as shown with a red contour whilst the total minimum deformation occurred at the top corner. With the exerted force of 900N relative to the area and juxtaposed to the results, the maximum is 6.394 mm and the minimum is 0.710 mm Figure 4.4a whilst the maximum and minimum total deformations for Figure 4.4b are 15.147 mm and 1.683 mm respectively. Comparing both models, the margin of deformation is significantly large meaning that cast iron model will deform faster than the low alloy AISI4140 steel model.

4.2.5. Equivalent Von Mises Stress of Mouldboard

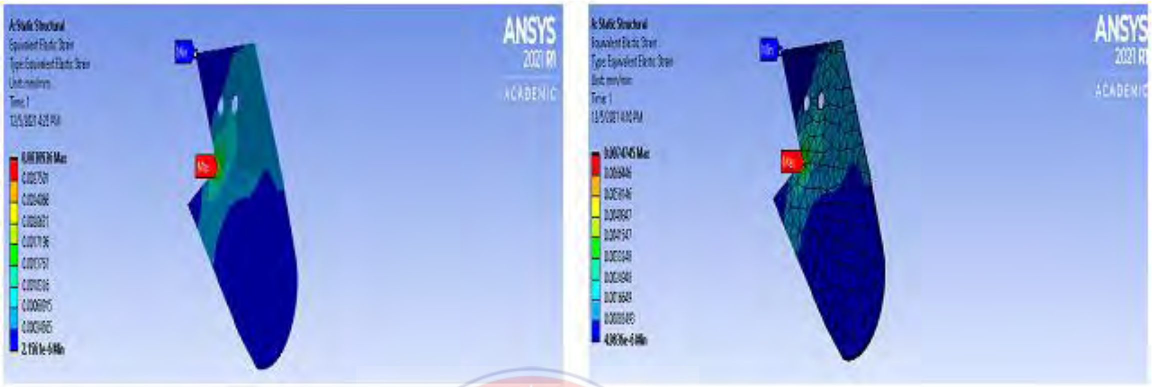


(a) (b)

Figure 4.5. (a) Low Alloy Steel Mouldboard (b) Cast Iron Mouldboard

Using Von Mises yield criterion which depends solely on the value of the scalar Von Mises stress as basis for comparison, the maximal equivalent von Mises stress as shown in Figures 4.5a and b, occurred at the same corner and the minimal is at the top vertex of the mouldboards which is 364.52MPa and 0.458MPa respectively. However, the yield stress developed on the Low alloy AISI4140 steel mouldboard is almostone-half lesser than its yield strength of 652.2 MPa. It can therefore be asserted that the material selected for use have very good properties that are capable of withstanding the force with a safety factor of 1.8 that is the ratio of the yield strength and the developed stress since it is a ductile material and the margin of safety of 0.8. Furthermore, in Figure 4.5b the same can be said of the stress locations however, the maximal stress is 362.14MPa and minimal of 0.445MPa. When related to the yield strength of the material (79.81MPa) and ultimate strength of 141.4MPa it is noticed that the developed stress is higher than its yield strength but has safety factor of 0.4 that is, the ratio of the ultimate yield strength and the yield stress developed since it is a brittle material. According to von Mises yield criterion, which depends solely on the value of the scalar von Mises stress, a larger von Mises value implies that the material is closer to the yield point. Based on this, the implication is that the share will fail at a point undesirably due to permanent deformation.

4.2.6. Equivalent Elastic Strain of Mouldboard



(a) (b)

Figure 4.6. (a) Low Alloy Steel Mouldboard (b) Cast Iron Mouldboard

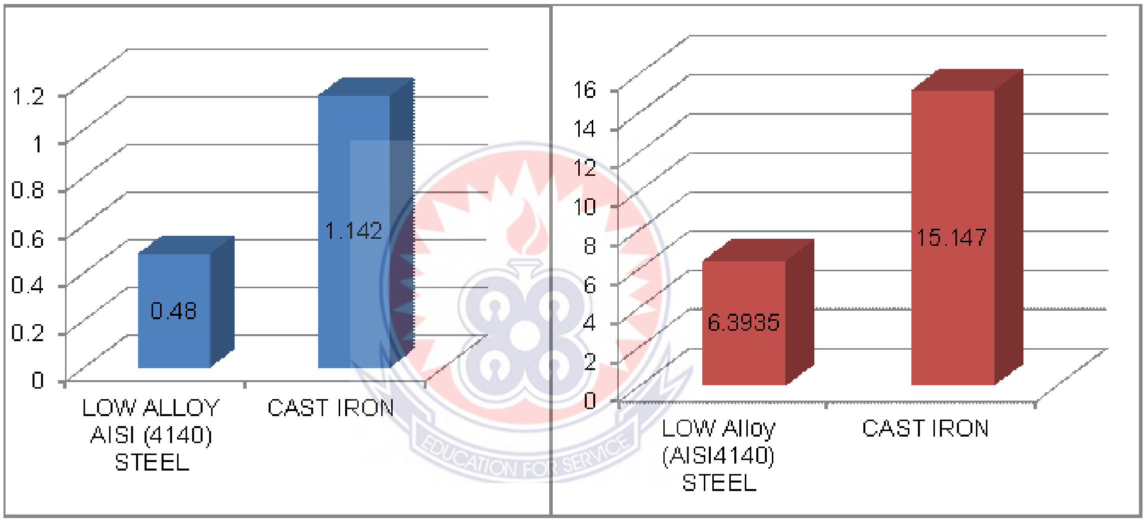
A marginal deformation has occurred at the middle corner (Figure 4.6a) along the bent line with a maximal equivalent elastic strain of 3.094 x 10^{-3} mm/mm and the minimal of 2.1561 x 10^{-6} mm/mm at the top vertex corner. Juxtaposing these values to the Young‟s modulus of elasticity in Table 3.2, it can be asserted that the material has adequate properties for the intended purpose. In Figure 4.6b, a maximal equivalent elastic strain of 7.475 x 10^{-3} mm/mm and the minimal of 4.9836 x 10^{-6} mm/mm at the same locations as shown in Figure 4.6a.

4.3. Discussion of Static Structural Analysis Results

The results of the static structural analysis are discussed below.

4.3.1. Summary of Total Deformation of Share and Mouldboard

The comparison between the maximum total deformations of the low alloy AISI4140 steel models are seen to be far less than that of the cast iron ones for both the share and the mouldboard as shown in Figure 4.7a and b respectively.

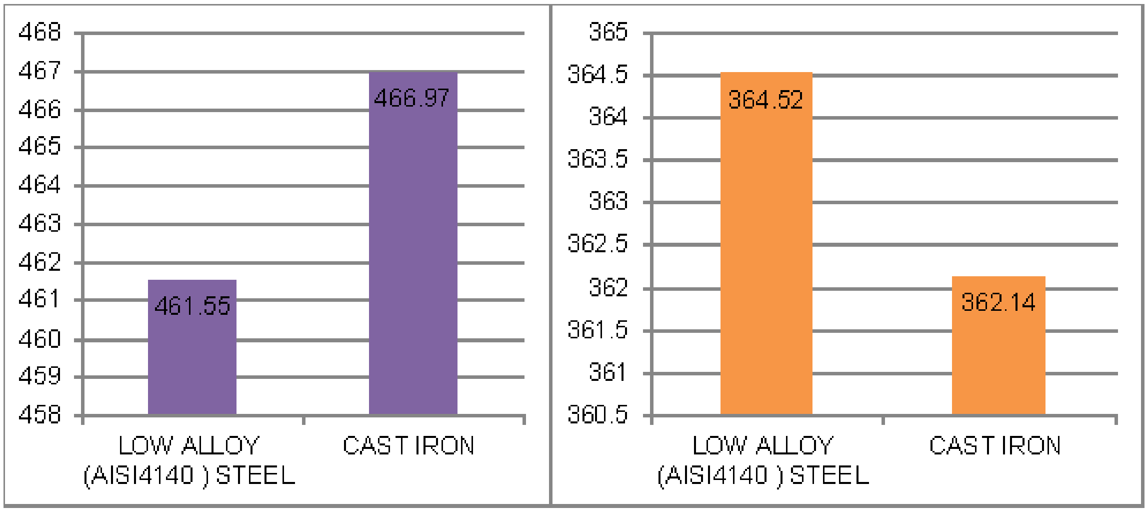


(a) (b)

Figure 4.7. (a) Low alloy (AISI4140) steel (b) Cast iron

4.3.2. Summary of Stresses of Share and Mouldboard

In comparing the maximum stresses of the low alloy AISI4140 steel models and the cast iron ones for both the share and the mouldboard as shown in Figure 4.8a and b respectively, it is noticed that, the low alloy AISI4140 steel share has the lowest value but rather the highest value in the case of the mouldboard. This implies that there is more stress development on the low alloy AISI4140 steel share in relation to the cast iron mouldboard but way below the material‟s yield strength as shown in Table 3.2.

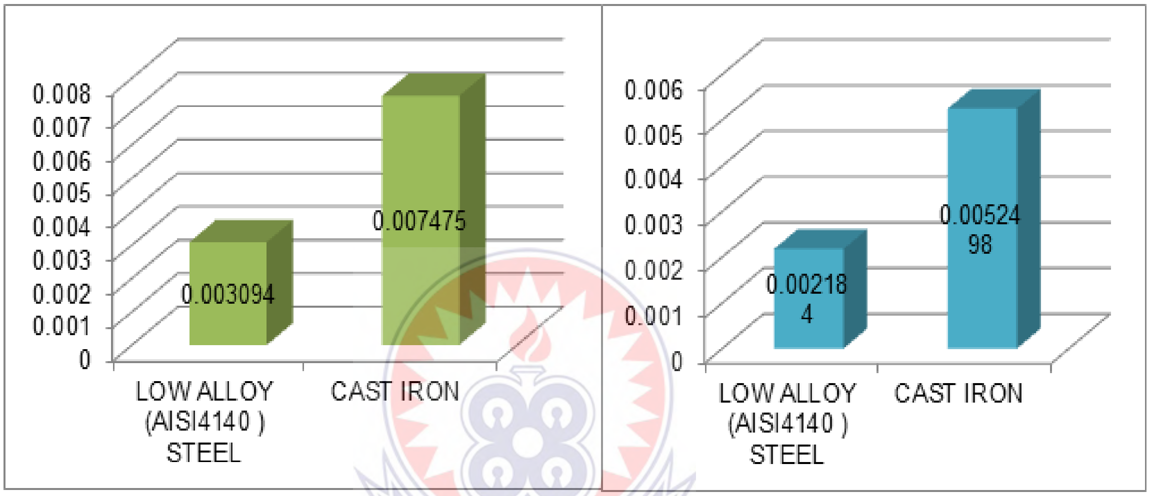


(a) (b)

Figure 4.8. (a) Low Alloy (AISI4140) Steel (b) Cast iron

4.3.3. Summary of Strains of Share and Mouldboard

Juxtaposing the maximum strain developed on the low alloy AISI4140 steel models to that of the cast iron ones have shown a significant variation between them with the cast iron having the higher values for both the share and mouldboard in Figures 4.9a and b respectively.



(a) (b)

Figure 4.9. (a) Low Alloy (AISI4140) Steel (b) Cast Iron

4.4. Analysis of low alloy steel (AISI 4140) and cast iron share and mouldboard

When the pressure increases then the depth of the vertical (lift) angle, α will automatically increase resulting in a corresponding increase in draught force of the plough. The results concerning the lift angle, α is in good agreement with the analytical results of Rucins and Arvids (2006) and the experimental published data cited in (Bentaher et al., 2013). The difference of draught between 20º and 30º of the lifting angle is half of that between 30º and 40º. The reported best experimental lifting angle to minimize the draught force is between 28º and 32º. The optimal value of the lifting angle of the plow body according to my results, α = 30º whilst that of (Bentaher et al., 2013) is 22º.

4.5. Comparison of Low Alloy Steel (AISI 4140) Share and Cast Iron Share

A very close analysis of the results of the low alloy steel (AISI 4140) and cast iron share indicated that, the former has superior qualities than the later. The same amount of force (1900 N) was imposed on both models made of different materials but having the same area in square meters. When the results were juxtaposed to each other, it was noted that, the total deformations, the equivalent Von Mises stresses and the equivalent elastic strains of the cast iron made share are much higher than that of the low alloy steel (AISI 4140) made share. Based on this and according to Von Mises yield criterion, which depends solely on the value of the scalar Von Mises stress, a larger Von Mises value implies that the material is closer to the yield point. A yield point is a point on the stress – strain curve where there is a sudden increase in strain without a corresponding increase in stress. Based on this, it presupposes that, the low alloy steel (AISI 4140) made share is stronger, durable, robust and will last longer than that of the cast iron made share since it has lower stress values based on the their factor of safeties. This results strongly agree with the findings of (Bobobee, 2007) which indicated that Nickel (Ni), Silicon (Si) and Sulphur (S) are more strongly correlated with wear than Chromium (Cr), Manganese (Mn) and Phosphorous (P) which Cr contributes to hardness and abrasion resistance while phosphorus in small quantities helps in fluidising cast material which are properties of low alloy steel (AISI 4140). This ability helps carbide distribution in the material, thus increasing volume fraction of carbides in the share microstructure and improves wear resistance in agreement with the findings of Owsiak (1997). In the cast iron share, though carbon improves hardness in the form of carbide, it negatively influences wear.

4.6. Comparison of Low Alloy Steel (Aisi 4140) Mouldboard and Cast Iron Mouldboard

After imposing the same amount of force (900 N) on the mouldboard made of low alloy steel (AISI 4140) and that of the one made of cast iron with the same square meters of area, it was noticed that, the total deformations, the equivalent Von Mises stresses and the equivalent elastic strains of the cast iron made mouldboard are much higher than that of the low alloy steel (AISI 4140) made mouldboard. According to Von Mises yield criterion, which depends solely on the value of the scalar Von Mises stress, a larger Von Mises value implies that the material is closer to the yield point. Based on this, it can be concluded that, the low alloy steel (AISI 4140) made mouldboard is stronger, durable, robust and will last longer than that of the cast iron made mouldboard based on their factor of safeties.

4.7. Comparison of Low Alloy Steel (AISI 4140) Mouldboard Plough and Cast Iron Mouldboard Plough

In the analysis of both components based on their materials composition, it is arguably right that, both met design requirements and can serve the intended purpose. It is however distinctively clear that animal drawn mouldboard ploughs made of low alloy steel (AISI 4140) will have unique, durable and stronger, wear resistance and robust qualities than the ones designed with cast iron. Apart from the figures and facts from the simulated results of the force-acting parts, the weight of the modified plough has been slightly reduced because pipes were used for the handle frames which are lighter than solid bars used for the existing ones made of cast iron. The handles of the modified plough are covered with bakelite (thermoset material) to eliminate burns from extreme scorching sun during ploughing. The modified plough has a U-shape tip because it inverts the soil at 180° so weeds are covered and there will not be any unplowed soil line between two furrows. V- shape furrow needs cross plow so, U- shape furrow is better according to the work of (Avvari, 2018). It also has very unique and aesthetic features giving it a beautiful look than the compared one in Figure 2.3.

The main findings of the study are that; the low alloy steel (AISI 4140) share and mouldboard are more durable, stronger and robust than cast iron ones. This can be postulated based on the report thus, the higher the strain the faster the deterioration. This is so because,

- cast iron components are less likely to withstand stress from increasing pressure with time compared to the low alloy steel for share and mouldboard respectively which agrees with the findings in the study of Mourtzis, (2020) however, the findings are not in support of the claim of Dibbits and Shetto(1999). Again the findings support the work of Rucins and Arvids (2006).
- the total deformation of cast iron share are extremely higher than low alloy AISI4140 steel ones for share and mouldboard.
- the equivalent elastic strain of the cast iron components are higher than low alloy steel ones for share and mouldboard.

Apart from that, the enhanced features of the new design model make it more efficient, effective and adaptive to both animals and operators. Moreover, since the selected material is of high quality and durable, breakdown of parts would be minimal. This reduces cost of maintenance and replacement of parts. Also, the modified plough has plastic handles to reduce heat transmission unlike the existing ones with metal handles. Additionally, it has been clearly shown that the gradual increase in pressure on both components produces a corresponding deformation as a result of the stress. However, what is more interesting to note is that the rates of change of shape of the cast iron made components were more divergent implying yielding.

Finally, based on the materials‟ characteristics, the low alloy steel (AISI 4140) model is expected to be harder and tougher than the cast iron plough in practice. Other potential features of the new model which are that, the plough would be of high fatigue strength and wear resistant. It would also be highly resistant to abrasion, shock and impact and would be capable of lasting longer than the cast iron ploughs which concretizes with findings of Ziemelis and Verdins, (2017).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Autodesk inventor software was used for the designing of the various parts of the plough as well as the assembly. The simulation analysis was run with the application of ANSYS workbench 2021R1 software. Again, it is important to emphasize that the study was focused on the re-designing of an animal drawn mouldboard plough with a durable material which is more likely to minimize frequent replacement of parts due to wear and breakages. The study was also aimed at analysing the total deformations, stresses and strains developed on the components under study in order to compare them. Based on the results, it is certain that the proposed model has many enhanced features which will improve output and efficiency than the existing models; again the material chosen for the new design model better mechanical properties suitable for the purpose.

Two different magnitudes of forces were imposed on the share and mouldboard to run the simulation. A low alloy steel (AISI 4041) steel was used for the new model whereas a cast iron was used for the existing model. The analyses were centered on the stresses and strains of the susceptible plough parts. The parameters considered were total deformations, equivalent von Mises stresses and equivalent elastic strains. Again, in all cases the equivalent (von Mises) stresses values were noticed to be very significant compared to the yield strength of the materials. In a nutshell, even though cast iron mouldboard ploughs are available and in use, there is the need to enhance them by coming out with improved designs with high quality materials having very low wear rate, high fatigue strength, hard and tough. Although animals‟ draught forces and soil requirements from previous literature have been used to determine the force exerted on them, it is however necessary to indicate that, the designed model has not been physically experimented with various types of soil to draw conclusions. However,

1. The findings have established that low alloy AISI4140 steel made model is a suitable engineering material for animal drawn mouldboard plough based on its factor of safety.
2. The study has again shown that the cast iron components are less likely to withstand stress from increasing pressure with time compared to the low alloy AISI4140 steel for share and mouldboard respectively of low factor of safety.
3. It has also been revealed that the total deformation and equivalent elastic strain of the cast iron components are extremely higher than that of the low alloy AISI4140 steel components. The implications of these are that, the cast iron components will deform permanently (deteriorate) faster reaching the yield point than the low alloy AISI4140 steel components. It is worth noting that, the proposed model apart from likelihood suitability it is aesthetically attractive.

5.2. Recommendations

The following are the recommendations

1. The availability of current data was a critical problem to the study. Even though there were data on mouldboard ploughs, particular mention of animals drawn ploughs were very scanty. Therefore, researchers should make data available for references in future studies.
2. Government should support local manufacturers to fabricate enhanced indigenous animal drawn mouldboard ploughs farmers.

3. Local artisans should acquire and adopt modern design principles to enhance their knowledge and skills to aid them in their work and also be able to determine the best material for use. Paramount design principles to focus on should include: “keep it simple” (KISS), “keep the target user in mind” testability, integrity and management just to name but a few.
4. Farmers should not leave the implement (if fabricated) at the mercy of the weather since some of the parts may rust when gets in contact with moist soil or rain.

5.3. Suggestion for Further Studies

1. Further research on the improvement of the design should consider coupling the plough to an internal combustion (IC) engine that can be used as an alternative source of power.
2. The proposed model should be practically fabricated and experimented to validate the numerical analytical results.

REFERENCES

Aberru, K. (1987). Extension and training of agricultural mechanisation in RRC. In: Agricultural Mechanisation Seminar, Nazreth-Melkassa, Ethiopia.

Avvari, D., M. (2018). June 2018 G.C Bahirdar, Ethiopia.

Bentaher, H., Ibrahmi, A., Hamza, M., Kantchev, G., Maalej, A. & Arnold, W. (2013). Finite element simulation of mouldboard-soil interaction-Soil and Tillage research.

Betker, J. & Kutzbach, H., D. (1989). Influence of design on the draught force characteristics of animal-drawn carts. In: Hoffmann.

Bobobee, E., Y., H. (2007). Performance Analysis of Draught Animal-Implement System to Improve Productivity and Welfare.

Bodein, Y., Rose, B. & Caillaud, E. (2014). Explicit reference modeling methodology in parametric CAD system. Computers in Industry.

Chowdhury, M., Islam, M., N., Iqbal, M., Z., Islam, S., Lee, D., H., Kim, D., G., Jun, H., J., & Chung, S., O. (2020). Analysis of Overturning and Vibration during Field Operation of a Tractor-Mounted 4-Row Radish Collector toward Ensuring User Safety. Machines.

Chung, C. (2004). Simulation Modelling Handbook: A Practical Approach. (1st ed). Boca Raton: CRC Press.

Conway, J. H., Johnson B., M., & Maxwell W., L. (1960). An Experimental Investigation of Priority Dispatching. Journal of Industrial Engineering 11 (3).

Cutini, M., Costa, C., & Bisaglia, C. (2016). Development of a simplified method for evaluating agricultural tractor‟s operator whole body vibration. Terramech.

Dimitris, M. (2019). Simulation in the design and operation of manufacturing systems: state of the art and new trends, International Journal of Production Research.

Dibbits, H.J.; Shetto, R.M. (1999). Agri-business sector support to promote sustainable draft animal power and agro-processing in Dodoma and Morogoro regions of Tanzania

Evi, M., & Martin K., J. (2008). Greek and Roman Agriculture. The Oxford Handbook of Engineering and Technology in the Classical World. Oxford University Press.

FAO, (2003). Bruinsma, J (Editor). World agriculture: Farm power.

Fowler, John W., & Oliver R. (2004). Grand Challenges in Modelling and Simulation of Complex Manufacturing Systems. Simulation 80 (9): 469–476.

Food and Agriculture Organization of the United Nations (Ed.). (2017). The future of food and agriculture: Trends and challenges. Food and Agriculture Organization of the United Nations.

Gao, Z., Xu, L., Li, Y., Wang, Y., & Sun, P. (2017). Vibration measure and analysis of crawler-type rice and wheat combine harvester in field harvesting condition. Trans. Chin. Society Agricultural Engineering.

Gifford (1992). Agricultural Engineering in Development: Concepts and principles.

Godwin, R., J. (2007). A review of the effect of implement geometry on soil failure and implement forces, Soil & Tillage Research.

Godwin, R. J., O‟Dogherty, M., J., Saunders, C., & Balafoutis, A., T. (2007). A force prediction model for mouldboard ploughs incorporating the effects of soil characteristic properties, plough geometric factors and ploughing speed. Biosystems Engineering, 97(1), 117–129.

Goldsman , D., Richard E., N, James, R. W. (2010). A Brief History of Simulation Revisited.

Haik, Y., & Shahin, T., M., M. (2011). Engineering design process (2nd ed). Cengage Learning.

Hamou, S., Cheikh A., Linares J., M., & Benamar A. (2014). Machining Dispersions Based Procedures for Computer-aided Process Plan Simulation. International Journal of Computer Integrated Manufacturing 17 (2): 141–150.

Hosford, W., F. (2005). Mechanical Behavior of Materials. Cambridge University Press, New York

Inns, F., M. (1990). The mechanics of animal draft cultivation implements. Part I. Chain pulled implements. Agricultural Engineering.

Iyendo, T., O., & Alibaba H., Z. (2015). Computer Aided Design (CAD) Technology versus Students‟ Learning in Architectural Design Pedagogy. International Journal of Development Research. Eastern Mediterranean University, Famagusta, North Cyprus via Mersin 10-Turkey.

Jennewein, S. P, Jehangir, H. B., Lang, T. A. J., McCray, M., Singh, M.P., Cooper, J. & Daroub, S. H. (2020). Impacts of flooding, Nitrogen-fertilizer, and soil-depth on sugarcane nutrients grown on Histosols. Journal of Plant Nutrition.

Krajnak, K. (2018). Health effects associated with occupational exposure to hand-arm or whole body vibration. J. Toxic. Environ.

Lowder, S., K., Skoet, J., & Raney, T. (2016). The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide. World Development, 87, 16–29.

Mari, I., A., Ji, C., Chandio, F., A., Arslan, C., Sattar, A., & Ahmad, F. (2015). Spatial distribution of soil forces on moldboard plough and draft requirement operated in silty-clay paddy field soil. Journal of Terra-mechanics, 60, 1–9.

McIntosh, J. (2008). The Ancient Indus Valley: New Perspectives. ABC- CLIO.

Mourtzis, D., Doukas, M., & Bernidaki, D. (2014). Simulation in Manufacturing: Review and Challenges. Procedia CIRP.

Mourtzis, D. (2020). Simulation in the design and operation of manufacturing systems: State of the art and new trends. International Journal of Production Research, 58(7), 1927–1949.

Marwedel, P. (2021). Embedded System Design: Embedded Systems Foundations of Cyber-Physical Systems, and the Internet of Things. Springer International Publishing.

OʽNeill, D., Koza, T., Magumise, J., & Ellis-Jones, J. (2005). The use and maintenance of animal-drawn equipment for smallholder crop production: Costs and benefits.

Owsiak, Z. (1997). Wear of symmetrical wedge-shaped tillage tools. Soil & Tillage Research.

Paul, A., R., Roy, P., & Mukherjee, S. (2006). Mechanical sciences: Engineering mechanics and strength of materials. Prentice-Hall of India.

Phaniraja, K., L., & Panchasara, H., H. (2009). Indian Draught Animals Power.

Pearson, R., A. (2005). Contributions to Society: Draught and Transport. Encyclopedia of Animal Science. Marcel Dekker Inc., USA.

Paman, U., Uchida, S., Inaba, S., & Kojima, T. (2017). Causes of Tractor Breakdowns and Requisite Solutions. A Case Study of Small Tractor use in Riau Province, Indonesia. ASEAN Journal on Science and Technology for Development, 25(1), 27–36.

Rucins A., Vilde A. (2006). Impact of the plough body parameters on the soil tillage efficiency. Riga, Latvia. Riga.

Ramaswamy N., S. (1979). Management of animal energy resources and management of the bullock cart system. IIM-B, India.

Sepulveda, N., E., & Sinha, J. (2020). Parameter Optimisation in the Vibration-Based Machine Learning Model for Accurate and Reliable Faults Diagnosis in Rotating Machines. Machines, 8(4), 66.

Stanišić, M., M. (2015). Mechanisms and Machines: Kinematics, Dynamics, and Synthesis. 428.

Weber & William (2014). Production, Growth, and the Environment: An Economic Approach. CRC Press.

Wilson, R. (2015). Scots Who Made America. Birlinn.

Yoganandi, C., Y., Yadav, R., & Gautamray, M., V. (2016). Simulation of components of mouldboard plough bottom using computer software

Yusof, Y., & K. Latif. (2013). Computer Aided Process Planning: A Comprehensive Survey. Advances in Sustainable and Competitive Manufacturing Systems.

Ziemelis, M., & Verdins, G. (2017). Plough parts wear resistance depending on their material composition and processing technology.

APPENDICES

Appendix A: Model Geometry Results of Low Alloy (AISI 4140) Steel Share

Object Name	Geometry
State	Fully Defined
Definition	
Source	C:\Users\DELL\Desktop\FINAL COMPONENTS\FINAL SHARE.0002.stp
Type	Step
Length Unit	Millimeters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	199.19 mm
Length Y	60.5 mm
Length Z	230.05 mm
Properties	
Volume	96224 mm³
Mass	0.75536 kg
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	13451
Elements	6355
Mesh Metric	None
Update Options	
Assign Default Material	No

Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	No
Parameters	Independent
Parameter Key	ANS;DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	Yes
Compare Parts On Update	No
Analysis Type	3-D
Mixed Import Resolution	None
Import Facet Quality	Source
Clean Bodies On Import	No
Stitch Surfaces On Import	Program Tolerance
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

Appendix B: Meshed Geometry of Low Alloy Steel (AISI 4140) Share

Object Name	Mesh
State	Solved
Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	1.5 mm
Sizing	
Use Adaptive Sizing	Yes
Resolution	Default (2)
Mesh Defeaturing	Yes
Defeature Size	2. mm
Transition	Fast
Span Angle Center	Coarse
Initial Size Seed	Assembly
Bounding Box Diagonal	310.26 mm
Average Surface Area	3077.5 mm²
Minimum Edge Length	2.5948e-002 mm
Quality	
Check Mesh Quality	Yes, Errors
Error Limits	Aggressive Mechanical
Target Quality	Default (0.050000)
Smoothing	Medium
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	No
Rigid Body Behavior	Dimensionally Reduced
Triangle Surface Mesher	Program Controlled
Topology Checking	Yes
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Statistics	

Nodes	13451
Elements	6355

Appendix C: Model Static Structural Loads of Low Alloy Steel (AISI 4140) Share

Object Name	Fixed Support	Force
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	4 Edges	2 Faces
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Applied By		Surface Effect
Coordinate System		Global Coordinate System
X Component		0. N (ramped)
Y Component		1900. N (ramped)
Z Component		0. N (ramped)

Appendix D: Model Static Structural Results of Low Alloy AISI4140 Steel Share

Object Name	Total Deformation	Equivalent Elastic Strain	Maximum Principal Elastic Strain	Maximum Shear Elastic Strain	Equivalent Stress	Maximum Principal Stress	Maximum Shear Stress
State	Solved						
Scope							
Scoping Method	Geometry Selection						
Geometry	All Bodies						
Definition							
Type	Total Deformation	Equivalent Elastic Strain	Maximum Principal Elastic Strain	Maximum Shear Elastic Strain	Equivalent (von-Mises) Stress	Maximum Principal Stress	Maximum Shear Stress

By	Time						
Display Time	Last						
Calculate Time History	Yes						
Identifier							
Suppressed	No						
Results							
Minimum	0. mm	9.6388e-006 mm/mm	2.7633e-006 mm/mm	6.2969e-006 mm/mm	0.89962 MPa	-26.783 MPa	0.51864 MPa
Maximum	0.48047 mm	2.1836e-003 mm/mm	2.1528e-003 mm/mm	3.0939e-003 mm/mm	461.55 MPa	468.15 MPa	254.83 MPa
Average	7.1743e-002 mm	2.0561e-004 mm/mm	1.2179e-004 mm/mm	2.6506e-004 mm/mm	41.629 MPa	18.874 MPa	21.832 MPa
Minimum Occurs On	FINAL SHARE-FreeParts|Solid1						
Maximum Occurs On	FINAL SHARE-FreeParts|Solid1						
Information							
Time	1. s						
Load Step	1						
Substep	1						
Iteration Number	1						
Integration Point Results							
Display Option		Averaged					
Average Across Bodies		No					

Appendix E: Model Static Structural Results of Cast Iron Share

Object Name	Total Deformation	Equivalent Elastic Strain	Maximum Principal Elastic Strain	Maximum Shear Elastic Strain	Equivalent Stress	Maximum Principal Stress	Maximum Shear Stress
State	Solved						

Scope							
Scoping Method	Geometry Selection						
Geometry	All Bodies						
Definition							
Type	Total Deformation	Equivalent Elastic Strain	Maximum Principal Elastic Strain	Maximum Shear Elastic Strain	Equivalent (von-Mises) Stress	Maximum Principal Stress	Maximum Shear Stress
By	Time						
Display Time	Last						
Calculate Time History	Yes						
Identifier							
Suppressed	No						
Results							
Minimum	0. mm	2.1906e-005 mm/mm	5.8339e-006 mm/mm	1.5473e-005 mm/mm	0.95252 MPa	-23.205 MPa	0.54916 MPa
Maximum	1.1415 mm	5.2498e-003 mm/mm	5.1548e-003 mm/mm	7.2406e-003 mm/mm	466.97 MPa	466.43 MPa	256.98 MPa
Average	0.17059 mm	4.8939e-004 mm/mm	2.8165e-004 mm/mm	6.1586e-004 mm/mm	41.685 MPa	18.903 MPa	21.858 MPa
Minimum Occurs On	FINAL SHARE-FreeParts|Solid1						
Maximum Occurs On	FINAL SHARE-FreeParts|Solid1						
Information							
Time	1. s						
Load Step	1						
Substep	1						
Iteration Number	1						
Integration Point Results							
Display Option		Averaged					

Average Across Bodies		No

Appendix F: Model Geometry of Mouldboard

Object Name	Geometry
State	Fully Defined
Definition	
Source	C:\Users\DELL\Desktop\FINAL COMPONENTS\Mouldboard-2.0002.stp FINAL.stp
Type	Step
Length Unit	Millimeters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	309.6 mm
Length Y	170.38 mm
Length Z	42.742 mm
Properties	
Volume	1.3843e+005 mm^3
Mass	1.0867 kg
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	2706
Elements	1203
Mesh Metric	None
Update Options	
Assign Default Material	No
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	No
Parameters	Independent
Parameter Key	ANS;DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	

Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	Yes
Compare Parts On Update	No
Analysis Type	3-D
Mixed Import Resolution	None
Import Facet Quality	Source
Clean Bodies On Import	No
Stitch Surfaces On Import	Program Tolerance
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

Appendix G: Model Mesh of Mouldboard

Object Name	Mesh
State	Solved
Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	5.0 mm
Sizing	
Use Adaptive Sizing	Yes
Resolution	3
Mesh Defeaturing	Yes
Defeature Size	5. mm
Transition	Fast
Span Angle Center	Coarse
Initial Size Seed	Assembly
Bounding Box Diagonal	355.96 mm
Average Surface Area	4050.3 mm²
Minimum Edge Length	3.2781 mm
Quality	
Check Mesh Quality	Yes, Errors

Error Limits	Aggressive Mechanical
Target Quality	Default (0.050000)
Smoothing	Medium
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	No
Rigid Body Behavior	Dimensionally Reduced
Triangle Surface Mesher	Program Controlled
Topology Checking	Yes
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Statistics	
Nodes	2706
Elements	1203

Appendix H: Model Static Structural Loads of Mouldboard

Object Name	Fixed Support	Force
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Edges	2 Faces
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Applied By		Surface Effect
Coordinate System		Global Coordinate System
X Component		0. N (ramped)
Y Component		0. N (ramped)

Z Component		-900. N (ramped)

Appendix I: Model Static Structural Results of Low Alloy Aisi4140 Steel Mouldboard

Object Name	Total Deformation	Equivalent Elastic Strain	Maximum Principal Elastic Strain	Maximum Shear Elastic Strain	Equivalent Stress	Maximum Principal Stress	Maximum Shear Stress
State	Solved						
Scope							
Scoping Method	Geometry Selection						
Geometry	All Bodies						
Definition							
Type	Total Deformation	Equivalent Elastic Strain	Maximum Principal Elastic Strain	Maximum Shear Elastic Strain	Equivalent (von-Mises) Stress	Maximum Principal Stress	Maximum Shear Stress
By	Time						
Display Time	Last						
Calculate Time History	Yes						
Identifier							
Suppressed	No						
Results							
Minimum	0. mm	2.1561e-006 mm/mm	1.6174e-006 mm/mm	3.2103e-006 mm/mm	0.45816 MPa	-37.961 MPa	0.26442 MPa
Maximum	6.3935 mm	3.0936e-003 mm/mm	1.6274e-003 mm/mm	2.5149e-003 mm/mm	364.52 MPa	349.78 MPa	207.14 MPa
Average	1.5165 mm	3.2094e-004 mm/mm	1.6201e-004 mm/mm	3.2517e-004 mm/mm	49.078 MPa	25.712 MPa	26.783 MPa
Minimum Occurs	Mouldboard-2-FreeParts|Solid1						

On		
Maximum Occurs On	Mouldboard-2-FreeParts|Solid1	
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	
Integration Point Results		
Display Option		Averaged
Average Across Bodies		No

Appendix J: Model Static Structural Results of Cast Iron Mouldboard

Object Name	Total Deformation	Equivalent Elastic Strain	Maximum Principal Elastic Strain	Maximum Shear Elastic Strain	Equivalent Stress	Maximum Principal Stress	Maximum Shear Stress
State	Solved						
Scope							
Scoping Method	Geometry Selection						
Geometry	All Bodies						
Definition							
Type	Total Deformation	Equivalent Elastic Strain	Maximum Principal Elastic Strain	Maximum Shear Elastic Strain	Equivalent (von-Mises) Stress	Maximum Principal Stress	Maximum Shear Stress
By	Time						
Display Time	Last						
Calculate Time History	Yes						
Identifier							

Suppressed	No						
Results							
Minimum	0. mm	4.9836e-006 mm/mm	3.7865e-006 mm/mm	7.1676e-006 mm/mm	0.44573 MPa	-31.999 MPa	0.25439 MPa
Maximum	15.147 mm	7.4745e-003 mm/mm	3.8543e-003 mm/mm	5.7773e-003 mm/mm	362.14 MPa	346.64 MPa	205.05 MPa
Average	3.5939 mm	7.6503e-004 mm/mm	3.7516e-004 mm/mm	7.5565e-004 mm/mm	49.143 MPa	25.767 MPa	26.82 MPa
Minimum Occurs On	Mouldboard-2-FreeParts|Solid1						
Maximum Occurs On	Mouldboard-2-FreeParts|Solid1						
Information							
Time	1. s						
Load Step	1						
Substep	1						
Iteration Number	1						
Integration Point Results							
Display Option		Averaged					
Average Across Bodies		No					

GLOSSARY

Archaeological	Remains of the culture of people
Ards	An old wooden farm implement commonly used in Egypt
Chilled plough	A plough having the share and mouldboard of chilled semi steel or cast iron
Configuration	Relative arrangement of parts or elements
Congregated	Fastening individual components to form a whole
Constraint	Restricting movement
Coulter	A cutting tool that is attached to the beam of a plough that permits effective covering of soil
Crash-worthiness	The ability of a structure to protect its occupants during an impact
Digitization	The process of converting something to digital form
Draught animal power	An output from large ruminants for farming or the act of pulling a load by animals
Equivalent stress	It is a scalar indicator to determine material failure
Frails	Easy to break or damage
Frosts	A thin layer of ice on a solid surface from water vapour
Furrow	A plowed land or a trench in the earth made by a plow
Furrow slice	A ridge of earth turned by a plow
Genealogy	The origin or historical development of something
Grub the earth	Dig or poke the soil
Harrowing	Land preparation operation that helps to further break clod of soil

	into smaller bits for cultivation
Instantaneously	Occurring or acting without any perceptible duration of time
Juxtapose	Compare results
Medieval	Extremely outmoded
Metallurgy	The scientific study of metals
Monochromatic	Traditional or outdated practice of farming
Mouldboard	A curved iron plate attached above a plowshare to lift and turn the soil
Patented	Originated by or peculiar to one person or a group
Resilience	The capability of a strained body to recover its size and shape after elastic deformation caused especially by stress
Scotish plough	A swing plough made chiefly from wood or cast iron which is drawn by many animals
Scratch plough	It is a simple light plough without a mouldboard
Seed drills	An agricultural device for sowing seeds by positioning and burying them at a specific depth
Shattering	To damage badly
Shear modulus of elasticity	It is the ratio of shear stress to shear strain
Shear stress	A force that tends to cause deformation of a material by slippage along a plane parallel to the imposed stress
Slicker	A tool usually of stone or glass for scraping, smoothing and working tanning (browning) agents into a skin or hide

Stochastic	Involving a random variable
Tack	Parts
Terraced fields	A level ordinarily narrow plain usually with steep front bordering a water body
Terracotta plough	A plough made with clay
Tillage	The operation of cultivating land
Tilling	To work by ploughing, sowing and raising crops
Total deformation	An alteration in shape or structure
Traction	The action of drawing or pulling
Ultimate tensile strength	It is the maximum stress that a material can withstand while being stretched or pulled before breaking
von Mises stress	It is a value used to determine if a material will yield or fracture
von Mises yield criterion	It is a criterion that states that if the von Mises stress of a material under load is equal or greater than the yield limit of the same material under simple tension then the material will yield
Yield strength	A stress at which a predetermined amount of permanent deformation occurs
Young modulus of elasticity	It is the ratio of tensile stress to tensile strain