Design of aeration ploughing tool for poultry litter within shed to reduce odour generation

A dissertation submitted by

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Abstract

Odour impacts from ‘broiler’ farms are a major issue facing the Australian meat chicken industry. Urban encroachment into traditionally rural areas, as well as intensification of the broiler farms in recent times, have exacerbated the problem. This issue is placing poultry producers under increasing pressure to control and reduce odour emissions.

At present, there are three main categories which deal with the treatment or mitigation of the odour emissions from broiler sheds:

1. Using dispersion to dilute odour before reaching sensitive receptors;
2. Preventing odours from reaching the outside environment (e.g. by using an odour treatment system); and
3. Preventing the production of odours at the source (i.e. within the broiler house).

Odour dispersion is used as the primary method for preventing odour impacts. When broiler farms are built, appropriate separation distances must be maintained between the farm and neighbours. If large separation distances are required, the costs for purchasing large parcels of land can be significant. Treatment of odour leaving the broiler shed is not currently a viable option due to excessive cost and a lack of available technology. Perhaps the most effective way to reduce odour impacts, at reasonable cost, is to prevent the generation of odours at the source, that is, within the broiler house.
Aeration of the litter is one technique that may be able to reduce the generation of odours within the broiler house by preventing the formation of anaerobic zones within the litter. Anaerobic zones are believed to be responsible for significant odour generation. The aim of this project is to test the efficacy of an automated plough system to regularly disrupt and aerate the litter.

Several plough designs were investigated. Two designs that were investigated in detail were a blade plough, which runs underneath the litter, and a paddlewheel plough, which rotates while moving through the litter and causes significant disturbance of the litter material. Both theoretical systems would be powered by an electric motor installed at one end of the shed connected to a fully reversible winch system to pull the plough through the litter. Each plough system was designed to meet the following requirements:

- Ease of operation;
- Low maintenance and cleaning requirements;
- Minimal impact upon the chickens;
- Compliance with workplace heath and safety requirements;
- Low infrastructure and operating costs; and
- Effective odour reduction.

These systems were modeled using the solid modelling package ProEngineer, Wildfire V2.0 and engineering analysis was performed on each of the designs. Reduction of odour generation was not assessed during this investigation.
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Certification

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Kevin Charles Hicks

Student Number: Q12205960

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Signature

____________________________
Date
Acknowledgements

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Firstly to the research project supervisor, Dr. Guangnan Chen of the University of Southern Queensland, Engineering and Surveying Faculty and Mr. Mark Dunlop of the Primary Industries and Fisheries, Queensland for their valued guidance and suggestions.

Lastly, I would like to express my deepest gratitude to my parents and sister for their patience, never ending support and encouragement. Extra thanks must be given to my father for giving up time from his busy schedule and providing me with his technical knowledge of over 30 years. Without their continuous love and encouragement throughout this academic study, this research project would not be possible.

K. Hicks

University of Southern Queensland
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Chapter 1 :  INTRODUCTION

This chapter outlines the background, purpose and objectives of the project as well as providing an introduction into the necessity of this study.

1.1 Introduction

With odour emissions from broiler sheds increasing due to industry and infrastructure growth, steps must be taken in order to reduce amenity impacts for the surrounding community. With these efforts frequently centered on the treatment of odour after leaving the shed, it seems obvious that by taking a step back and placing emphasis on treating the source, odour reduction possibilities may be realized. While the theory of odour and its treatment is ever evolving, little information exists on the methods of aerating poultry to reduce the anaerobic decomposition within the litter in an effort to reduce the generation of offensive odours.

This project seeks to investigate the theoretical foundation of odour reduction in poultry litter as well as implement engineering methods to design a conceptual plough that will aerate and disrupt poultry litter.
1.2 Research Purpose

The sponsor "Department of Primary Industries and Fisheries" is extensively involved in researching odour issues for intensive animal production. The Department of Primary Industries and Fisheries has guided the direction of this project, and assisted with the collection of information. A review of existing literature has ensured that previous research on disruption and aeration of poultry litter was not being repeated, thus design and experimentation could continue. The overall purpose of this project was to conceptually design a system for odour reduction that can be implemented in broiler sheds and used in conjunction with other odour reduction systems in an effort to reduce odour release and increase amenity of life for surrounding communities.

1.3 Research Objectives

The primary objective of this project was to design and optimize a prototype poultry litter plough based on its aeration and disruption efficiency. In order to achieve this, background information regarding odour generation, poultry production systems and plough system design must first be research. Once completed and documented, this information was combined to develop a number of optimized plough designs. To accomplish this, solid modelling and stress analysis computational software packaging were utilized. Since the project is primarily based in the structural design of the prototype, the majority of the study will focus on the analysis of critical aspects of the design. Using solid modelling software, “ProEngineer”, the components and overall design can be analysed and evaluated to determine the appropriate cohesion of components that will make up the conceptual design.
1.4 Conclusion

This project aims to develop and utilize a design method to theoretically construct a poultry litter plough, which can aerate and disrupt poultry litter efficiently. The study is expected to provide several plough design configurations that will provide optimal performance. A literature review is provided in the following chapters in order to present the research undertaken on this topic to date, and to demonstrate what further research is required on this issue. The outcomes of this project provide several key designs that could be incorporated into poultry production to aerate litter and ideally reduce offensive odour generation.
Chapter 2 : LITERATURE REVIEW

The information presented in this chapter is a summarization of previously researched and documented information from individuals, institutes and organisations in the poultry and odour field. This information is provided to illustrate the state of knowledge for the project.

2.1 Introduction

To fulfill the project objectives as stated previously, a detailed literature review is conducted in order to investigate the relevant background information and previous research methods and design methods were employed in reducing odour emissions and designing farming machinery. Information was sourced textbooks, journals, websites and data bases.

2.2 Background

The information contained within this section provides the relevant background information necessary to understand the reasoning and design choices presented within this project.

2.2.1 The Australian Poultry Industry

Best, P.R. and Ormerod, R. (2005) produced a draft guide and a set of principle for the Best Practice Environmental Management (BPEM) applicable to meat chicken
farms in Queensland. They provided information on the current state of the meat chicken industry broiler grow-out shed designs and various policies, acts and laws relevant to the industry. The information identified several key constraints the conceptual design must take into consideration when designing the plough.

Runge, G.A., Blackall, P.J. and Casey, K.D. (2007) each provided comprehensive information with regard to poultry litter. This information was pertinent to the understanding of the poultry litters composition, source and cost.

2.2.2 Odour

Jiang and Sands (2000) provided significant information on odour emission rates, odour intensities and ammonia emissions associated with broiler farms and the development of an improved understanding of odour generation and dispersion from broiler farms. This information was vital in understanding the nature of odour, anaerobic decay and bacteria while providing insight on how to delay such degradation.

Stuetz and Frechen (2001) presented various sources of information on odour treatment in the wastewater industry. These sources provided detailed information on odour perception, regulations, policies, odour measurement and analysis methodologies.

Nielsen, Voorburg and L’Hermite (1991) presented the proceedings on a seminar regarding odour and ammonia emissions from livestock farming. The presentations were used to clarify the role of ammonia as a main odourant source and determine what odour reduction techniques and management practices are deemed most effective by the industries professionals.

2.2.3 Existing Odour Reduction Systems and Technologies

McGahan, Kolominskas, Bawden and Ormerod (2002) provided a broad range of information on technologies and systems currently used to manage and reduce odour.
This information was vital in understanding the operation and effectiveness of each system/technology capability to manage reduce odour emanating from broiler sheds.

Briggs (2004) presents various methods of odour management in meat chicken farms. Her findings provided various management techniques that are recommended for incorporation and use with the operation of the conceptually designed plough.

Allen, Hughes, Chastain, Skewes, Bridges, Armstrong and Thomas (1998) researched the effects of aerating poultry broiler litter to reduce production of odour and presented their subsequent test results. This information was used to determine the possible effect the conceptually designed ploughs will have when aerating and disrupting poultry litter.

### 2.3 Design Methodology

This section details the significant contributors to component, plough and power system design methods.

#### 2.3.1 Design Standards

As with any machine, there are various standards and guidelines that need to be adhered to. The conceptual designs outlined for the project were developed into actual plans for the production of a machine. Checks were made to ensure that all appropriate standards have been met should be made. Standards adhered to during the design process were:

- **AS 1418.1-2002** Cranes, hoist and winches – Part 1: General requirements
  This standard was employed to design and determine appropriate components for the power winch cable system used pull through the conceptually designed ploughs.
- **AS 1403 – 1979** Design of Steel Shafts for Transmission of Power
- **OH&S Act 1995**
- **OH&S regulation 1997**
2.3.2 Design Requirements and Analysis

Juvinall and Marsheck (2000) and Hosking and Harris (1988) provided specifications for the key components constituting the plough. These were used during the design process to select bearings, shafts, shaft keys, materials and bonding processes.

2.4 Conclusion

Although there are numerous amounts of literature pertaining to the poultry industry, odour field, odour reduction technologies / systems and management methods, it was found that little information existed on the actual design, development and implementation of poultry litter aeration and disruption machinery in an attempt to reduce odour generation at the source. Of the literature reviewed Allen, Hughes, Chastain, Skewes, Bridges, Armstrong and Thomas (1998) provided the most comprehensive details and results on the possible effects the conceptually designed plough will achieve, while Hosking and Harris (1988) provide comprehensive details on design optimization and the methods through which to obtain this. The information presented this chapter is designed to provide a brief overview of the previous research and aid in the understanding of the project.
Chapter 3 : THE AUSTRALIAN POULTRY INDUSTRY

3.1 Introduction

The Australian Poultry Industry is divided into several sectors; the chicken meat and egg industries and, on a smaller scale, turkey and game bird production. It is primarily based on the production of two types of products namely eggs and meat.

The poultry industry employs some 40,000 people directly and another 140,000 people indirectly. The Australian poultry industry primarily services the domestic market with exports of poultry products currently accounting for less than 2% of the total value of the industry.

Egg production and the broiler chicken production for food are segments of the chicken raising industry sharing many of the same difficulties of:

- Stock health;
- Flock nutrition; and
- Flock hygiene.

A preliminary overview of each industry has been included to assist with gaining an understanding of the poultry industry and its importance to the Australian economy.
3.2 The Australian Egg Industry

Eggs are produced by selectively bred layer hens. The eggs of other avian species are not often used for human consumption. Layer hens are reared to maturity (18-22 weeks) in a rearing shed or farm. Traditionally, adult hens are kept in production for about 12 months. However, a significant proportion of producers recycle hens at the end of a first cycle of production after a spell in moult for a further cycle of production.

Egg production is in the hands of individual producers or family companies. Since deregulation in 1992, the size of farms has increased with a consequent result of many smaller producers leaving the industry. Layer farms vary in size where the average is about 12,000 hens to an increase of over 200,000 hens.

The Australian egg industry has an estimated annual turnover of $340 million and comprises 450 commercial farms with around 13,290,000 hens. In addition to the commercial production there is estimated to be 1 million hens in backyard production, many of the eggs from which are sold commercially.

Of the 203 million dozen eggs produced annually, 85% are sold in shell form, primarily through grocery stores with the remaining 15% sold in processed form as liquid, frozen or diced form. It is estimated that 95% of commercial egg production is sourced from caged layer farms, with the remainder produced in deep litter free range or barn laid farms. Approximately 6 - 7% of households in Australia have a backyard flock where an additionally estimated 12% of Australian egg production is sourced.

The egg industry is concentrated on the east coast with over 80% of national production occurring in NSW (30%), Victoria (25%) and Queensland (27%) (see Figure 3.1) where the majority of eggs produced are from caged birds (see Figure 3.2).
3.3 The Australian Chicken Meat Industry

The Australian chicken meat industry is a relative newcomer compared to other major livestock industries. It is not certain when Australia began mass poultry production, as records were not kept until the mid 1960s, but it has been estimated that three million broilers were produced in 1950/51, compared with around 420 million in 2003/04 (see Figure 3.3) ([A.C.M.F. Website, 2007]).

As a leading source of protein, chicken plays an important part in the Australian diet. To this effect, the Australian meat chicken industry has grown dramatically over the last thirty years and has recently overtaken beef as the most consumed meat per
The continued growth of the chicken meat industry and associated costs proving to be significantly cheaper when compared to the rival meat industries costs only strengthens its position and market share. This can be attributed to increasingly automated poultry plants and improvements in how efficiently chickens convert feed into meat (these gains are due to improved breeds of chicken more suited to meat production). The price competitiveness of chicken as seen in Figure 3.5, has increased product diversity, improved quality, better consistency and targeted marketing, have made chicken one of Australia’s favourite meats.
Meat chicken production begins when batches of day old chicks are introduced to a broiler farm where they are raised in large naturally or mechanically (new industry standard) ventilated sheds with subsequent climate control systems and on demand fed in order to increase their body mass. Common industry practice involves the day old chicks being placed in an insulated hot air brooding section, which occupies about one third to half of the shed. As the chicks grow, the floor space is increased over the next 10-14 days with the chicks ultimately occupying the entire shed for the remainder of the batch. Part of the flock is usually processed after about five weeks (first thin-out), with the remainder of the flock harvested between six to eight weeks of age (see Figure 3.6). Sheds are generally empty for one to four weeks after bird harvest for shed cleaning, disinfection and maintenance between batches.
As the birds grow larger, the amount of manure they excrete increases. As production is related to the manure with the shed, it is worst at the latter end of batch and peaks before the first tin out. The strength of the odour decreases after thin-out, but maintains intensity until the end of the breeding cycle (Sansom, 2000). Indeed residents’ complaints have highlighted that even as quickly as three weeks into the cycle, the odour can cause a nuisance, to the point of unbearable at its peak (McPherson, 2000). Farms will usually raise five to six batches of meat chickens per year.

The meat chickens are fed on demand via automated auger operated feeder lines (Figure 3.7) continually supplied from bulk bins or silos while designated waterer lines provide a continuously available drinking source (Figure 3.7). The meat chickens are reared on litter, consisting of either sawdust, wood shavings, paper or chopped straw depending on availability, cost logistics and absorbency. The litter is
Initially laid to a height of 50 mm, which will vary over time due to chicken activity. It may be cleaned out and replaced at the end of each batch (single batch), partially cleaned out after each batch (partial reuse), or cleaned out after several batches (multi-batch). Refer to section 3.5 for more information.

![Automated feed and waterer lines](image)

**Figure 3.7: Automated feed and waterer lines**

Most meat chicken production is in the hands of individual producers who have contracts with processing companies. The processing companies also have their own growing facilities. The producer owns the land, shed and equipment and is paid a rearing fee by the processor who owns the chickens and the feed. The poultry processors are usually vertically integrated companies with ownership of the breeding and hatching operation, feedmills, processing plants and wholesale marketing. (AUSVETPLAN Edition 2.0, 1996).
## 3.4 Meat ‘Broiler’ Shed Location and Shed Configuration

Due to the rapid increase in demand for chicken meat and related products over the last thirty years, there has been a need for individual farms to expand existing infrastructure to remain competitive. Such development has resulted in an intensification of the industries operations and infrastructure situated at traditional chicken meat producing areas. To ensure the environmental sustainability of the industry and of the individual farms, it is important that all farms carefully manage environmental concerns.

Existing meat chicken farms were traditionally located in urban fringe areas due to the proximity of processing plants and markets (McGahan et al. 2002). As the growing sector of the industry is concentrated into nearby rural areas, the increasing urban expansion from people seeking cheaper land and a rural lifestyle has encroached onto these “traditionally” rural areas which has given rise to complaints by neighboring residents. These complaints are primarily concerned with odour, dust, noise and flies emanating from the broiler farms in question.

There is a need for the expansion of ‘traditional’ infrastructure to allow farmers to meet the industries increasingly demanding quotas, but increasing land prices limit the capacity of existing poultry farms to acquire additional buffer areas and the substantial investment in existing infrastructure inhibits relocation. Zoning and setback rules also eliminate many potential expansion sites. Future growth of the industry may be inhibited in many locales.

Queensland has approximately 100 commercial meat chicken farms. Most of these are located in the south-eastern corner of the state, within reasonable transport distance of processing facilities. Hence, in south-east Queensland, the industry has historically concentrated in areas such as the Redland, Beaudesert and Caboolture Shires and the outlying parts of Brisbane City. Until fairly recently these areas have been predominantly rural in nature ([Best, P.R. and Ormerod, R., BPEM Draft, 2005]).

Meat “Broiler” chicken sheds in operation within Queensland, Australia and around the world are predominately designed around the same construction blueprint
specifications (plus or minus several meters at the farmers request) (see Figure 3.8). The sheds are predominantly 100-150 m long by 12-20 m wide and houses approximately 20,000 to 50,000 meat chickens at any one time (see Figure 3.9). In order to control the air quality and temperature inside the chicken shed for the livestock and farmers well being, the shed must be well ventilated. Older installation make use of natural ventilation, however, modern sheds are now required to use mechanical ventilation systems (new industry standard). The setup achieved by the use of 8 to 10 ventilation fans located at one end of the shed. Each fan usually operates near its maximum capacity. The fans are approximately 1.4 meters in diameter and at full capacity remove about $10 \text{ m/s}^3$ of air from the shed and expel it into the outside environment. Farms will usually have three to four sheds per farm with newer farms generally having a larger number of sheds.

Figure 3.8: Meat ‘Broiler’ Chicken Shed (Outside)
Most growers have contracts with large vertically integrated meat chicken companies (eg: Inghams) that dominate the meat chicken industry. The farmer provides labour, management, shedding, equipment and bedding material. The integrator provides the day old chicks, feed, medication, technical advice, and chicken pick-up crews and transport.

Future trends within the chicken meat industry are tending towards much larger facilities that are mainly based on a controlled climate (tunnel ventilation) philosophy and major complexes made up of several farms (each with many sheds) separated apart due to bio-security requirements. The potential improvements of using larger, newer sheds will improve environmental outcomes by the use of more specialist staff and facilities and superior animal welfare and performance.
3.5 Poultry Litter

Poultry litter is comprised of bedding material (which is placed on the floor of a clean and disinfected shed), for the purpose of managing bird excreta, feathers and other detritus from the chickens plus wasted feed and water.

Litter is broadly comprised of proteins, carbohydrates, lipids and fats. Carbohydrates comprise the majority of biodegradable materials in the form of cellulose, starch, and sugars. After it has been removed from the shed, litter forms free flowing granular material including varied proportions of large caked pieces (Figure 3.10). The chemical and physical composition of litter is highly variable due to differing bird species, diets, bedding retention times and other farm management practices (Turnell, J. 2005)

There is approximately 4,274,000 m² of shedding devoted to meat chicken production in Australia in more than 2,750 sheds. About 1.17 million m³ of bedding material is used by the industry each year and with approximately 1.60 million m³ of chicken
litter available for utilization. The average price paid for new bedding material is $11.71/m³ (see Table 3.1 for comparative prices). The industry spends $10.78 million annually on bedding material and receives about $0.71 million in return for the used litter (Runge, G.A., Blackall, P.J. and Casey, K.D. 2007).

### Table 3.1: Cost of new bedding material per state
(Runge, G.A., Blackall, P.J. and Casey, K.D. 2007)

<table>
<thead>
<tr>
<th>State</th>
<th>New Bedding Material Cost ($/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sawdust</td>
</tr>
<tr>
<td>NSW</td>
<td>$11.00-14.50</td>
</tr>
<tr>
<td>QLD</td>
<td>$11.00-14.00</td>
</tr>
<tr>
<td>SA</td>
<td>$11.50-13.50</td>
</tr>
<tr>
<td>TAS</td>
<td>$7.80</td>
</tr>
<tr>
<td>VIC</td>
<td>$6.70</td>
</tr>
<tr>
<td>WA</td>
<td>$10.00-14.50</td>
</tr>
</tbody>
</table>

Communities living in chicken production areas are becoming more aware and concerned regarding the odour emanating from broiler farms. They are also concerned about litter being spread on the land resulting in odour emissions and the potential contamination of water tables and streams with nutrients and pathogenic organisms. Therefore, the management of chicken litter, from sourcing the initial bedding material through to utilisation of the waste product, is not just a concern to Australian farms, but to the world poultry industry and community at large.

#### 3.5.1 Poultry Litter Material Selection and Laying Depth

Various products are available on the market that can be used as bedding material. The most widely available materials commonly used as bedding is sawdust, wood shavings, rice hulls, straw and paper. It must be clean and dry. While these materials serve one purpose in the shed, material selection is based on the availability and cost logistics. Queensland most commonly use sawdust and shavings as their primary material (see Figure 3.2). This is influenced by the fact that many of these farms are set near wood plantations and have an agreement with the industry in acquiring the sawdust and shavings. Rice hulls are not a logical choice for Queensland because the climate, compared to South Australia, is not optimal for growing of rice and
importing the product is too costly when compared to the sawdust and shavings options.

Table 3.2: Type of new bedding material used per state  
(Runge, G.A., Blackall, P.J. and Casey, K.D. 2007)

<table>
<thead>
<tr>
<th>State</th>
<th>New Bedding Material Type Used (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sawdust</td>
</tr>
<tr>
<td>NSW</td>
<td>40.2</td>
</tr>
<tr>
<td>QLD</td>
<td>26.4</td>
</tr>
<tr>
<td>SA</td>
<td>0.0</td>
</tr>
<tr>
<td>TAS</td>
<td>100.0</td>
</tr>
<tr>
<td>VIC</td>
<td>0.0</td>
</tr>
<tr>
<td>WA</td>
<td>100.0</td>
</tr>
</tbody>
</table>

The depth of new litter or bedding material placed on the shed floor varies between growers, processors, states and locality. Unevenness in the depth of bedding spread on house floors presents a problem for litter contractors and value adders. Uneven floors add to the problem. The unevenness in the thickness causes inconsistency in the product hence it leads to patches of bedding material that contain no manure requiring the litter to be mixed at added cost before the contractor can sell it. An additional objective of this project aims to address this problem. During the ploughs operation when it is aerating and disrupting the litter it shall redistribute the litter as evenly as possible along the shed floor.

More litter is required to absorb moisture in regions that have cold wet winters. A minimum of 50 mm is considered adequate to provide sufficient absorbent material for the chickens to start on and to avoid caking in Queensland, New South Wales, South Australia (drier winter region) and Western Australia. In Victoria, Tasmania and parts of South Australia which have cold wet winters, a depth of 75 mm is required to absorb the extra moisture. A survey of the industry shows that the depth of bedding material used in Queensland, New South Wales, South Australia (drier winter region) and Western Australia is roughly 40- 50 mm. In Victoria, and Tasmania it varies between 65-75 mm and for South Australia (wet winter region) it is 70-75 mm (see Figure 3.3). (Runge, G.A., Blackall, P.J. and Casey, K.D. 2007)
### Table 3.3: Initial laying depth of material per state  
(Runge, G.A., Blackall, P.J. and Casey, K.D. 2007)

<table>
<thead>
<tr>
<th>State</th>
<th>New Bedding Material Depth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sawdust</td>
</tr>
<tr>
<td>NSW</td>
<td>40-50</td>
</tr>
<tr>
<td>QLD</td>
<td>40-50</td>
</tr>
<tr>
<td>SA</td>
<td>40-50</td>
</tr>
<tr>
<td>TAS</td>
<td>65-75</td>
</tr>
<tr>
<td>VIC</td>
<td>40</td>
</tr>
<tr>
<td>WA</td>
<td>40</td>
</tr>
</tbody>
</table>

### 3.6 Regulations and Policies

Workplace environmental quality is becoming relatively important as government extends regulation to agricultural industries. Worker awareness to health issues is growing rapidly. The plight of the tobacco industry is a current example of the effects of public concern over health related issues. Laws and acts are created and enforced to ensure the wellbeing of personnel, livestock and the potentially affected surroundings from degradation and harm. A brief description of these acts that the industry must abide by is given below.

The Environmental Protection Act 1994 (EPA) is to protect Queensland’s environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends. This is known as ‘ecologically sustainable development’. In seeking to protect Queensland’s environment, the EPA places a responsibility on all Queenslanders to exercise a general environmental duty. That is “A person must not carry out any activity that causes or is likely to cause environmental harm unless they take all reasonable and practicable measures to prevent or minimise the harm”. (Best, P.R. and Ormerod, R., BPEM Draft, 2005).

Poultry Farming has been classified as an Environmentally Relevant Activity (ERA) since 1995 where an ERA is one in which:
1. A contaminant will be or may be released into the environment when the activity is carried out; and
2. The release of the contaminant will or may cause environmental harm.

An ERA requires a development permit and registration to operate lawfully under this legislation. The administration of poultry farming ERA, including meat chicken production, has been devolved from the Environmental Protection Agency to Local Government to administer. One exception to this rule is if the activity is considered a ‘deemed approval’ (i.e: in operation prior to 1995 and there has not been any change in owner or expansion of the activity), then only a registration is required.

In conjunction with the Environmental Protection Act, there is a number of Environmental Protection Policies (EPP) that places a responsibility on all Queenslanders to protect the states environment, namely:

- Environmental Protection (Air) Policy 1997 (EPP Air).
- Environmental Protection (Water) Policy 1997 (EPP Water).

### 3.7 Conclusion

This chapter has explained briefly the poultry industry, its effects on its personnel, livestock and off-site surroundings and the current problems these encroached farms are now facing. It can be seen that this odour amenity problem is ever increasing due to urban and residential expansion of people looking for a rural lifestyle and cheaper land, this coupled with Queensland’s increasing population rate being the highest in Australia. These factors have led the industry to source alternative solutions to address the odour problem and to reduce potential future conflicts.
Chapter 4: ODOUR

4.1 Introduction

The release of unpleasant odours from contract broiler grow-out farms can have an impact on the local communities. The number of odour related complaints received by a number of local councils has been ever increasing in recent years. This has resulted in some areas receiving increased pressure to impose stricter development controls on the extension of existing farms and the establishment of new farms. This is a direct result of the urban encroachment by people looking for cheaper land, a rural lifestyle, the raised awareness of public rights over environmental issues and the expectation of the public towards the industries ability to eliminate odours emanating from farms. Consequently, careful management and treatment is required to avoid the creation and release of annoyance odours without unfairly disadvantaging the businesses and industries that communities rely on for their economic prosperity.

Odourous compounds that are present and dispersed at broiler grow-out farms tends to not attract the level of attention given to higher profile environmental problems such as contaminated industrial sites and water pollution. Yet for those communities that experience odour problems, the impacts are significant. Odour can have a marked effect on people’s quality of life. To avoid the formation of odourous compounds requires an understanding of the process involved. To control and prevent their release, the mechanism by which odours are formed and then released and dispersed into the atmosphere must be understood.
4.2 Odour Nature and Perception

The sense of smell is by far the most powerful of our senses. It can discriminate between tens of thousands of different odours, and is capable of detecting some compounds at levels of about a single part per trillion. Odours that humans perceive are not due to a single compound but are rather the results of a combined impact of a mixture of separate compounds. This impact can vary with time because the volatility and diffusivity of the different compounds also vary (Gardner and Bartlett 1999).

An odour is defined as a sensation resulting from the reception of a stimulus by the olfactory sensory system. Information is provided in the below section to aid in the understanding of the olfactory sensory system and subsequent human reactions to them.

The olfactory system consists of three major components, each of which has a specific role in converting the presence of an odorous stimulus to a perception. These components are:

1. The olfactory epithelium;
2. The olfactory bulb; and
3. Higher order parts of the brain.

The epithelium is involved in the sensation stage of odour processing. It is a small patch of yellowish tissue, approximately 20 mm$^2$ located in the top rear of the nasal cavity. It consists of three major cell types, however only one of these, the receptor cell, is directly involved in odour processing. A typical epithelium contains approximately 3 million receptor cells. Incidentally, these cells only have a lifespan of about 3 weeks. As they die, other underlying cells morph into new receptor cells. This gradual loss of receptor cells in part explains the typical loss of olfactory acuity with advancing age (typically beginning at the age of 45).

“The receptor cell is roughly the shape of a bowling pin. The top portion of the receptor cell gives rise to between 5 and 20 long filaments called cilia. These cilia protrude into a mucus layer that protects the epithelium and provides access for the aroma molecules to the epithelium. Embedded into these cilia are molecular sized
proteins that serve as the receptor sites for the aroma molecules. The exact number of different types of proteins types is unclear. However fairly recent genetic studies have shown that each receptor cell is peppered with only one of the estimated 100 to 1000 different types. As each of the receptor proteins are large and complex molecules, it is likely that each one can serve as a "docking site" for many hundreds of different odour molecules” (Gawel, 2004).

“At the opposite end of the receptor cell is an axon. You can think of an axon as a piece of electrical conducting material that connects the receptor cell to the next part of the olfactory system, the olfactory bulb which in turn is connected to other parts of the brain. The olfactory bulb is a small part of the brain located adjacent to the epithelium. Its exact role is still being hotly debated, however inspection of how the cells comprising the bulb are connected points to at least one role; that of increased differentiation between similar smelling odours” (Gawel, 2004).

“The olfactory bulb connects to other areas of the brain including the olfactory cortex, the thalamus and the hippocampus. These areas are involved in odour perception and interpretation. The cortex seems to be involved in discrimination while the latter two areas are involved in long term memory. The strong linkages between the epithelium and the parts of the brain responsible for memory may explain why humans can recall odours experienced in the distant past and why odours evoke such strong feelings” (Gawel, 2004). We perceive odours by sucking in these various molecules which then dissolve in the mucus and pass through until it reach the cilia. The next step is a crucial one. Each different type of odour molecule has a different size and shape, which will allow it to attach itself to some receptor proteins but not others. As the cilia on each receptor cell is likely to contain only a single receptor protein, then each odour molecule will have an affinity for some receptor cells but not others. When there are sufficient numbers of odour molecules attached, the receptor cell will send out a burst of electrical activity that will pass down the axon to be processed by the olfactory bulb. This electrical activity signals to the brain that odour molecules are present. The odour is thus perceived by the receptor. The greater the total electrical activity, the stronger the smell, and the pattern of activity across the epithelium allows the receptor detect and discriminate between different odours, but also allows us to indicate the intensity of an odour that can permit us to move away from hazardous or
unpleasant environments or move towards favourable ones. Odour annoyance is considered to occur at a point in time which exposure to an odour is perceived by a person to be unwanted.

### 4.3 Principles of Odour Generation in Broiler Farms

Schmidt and Jacobson (1995) describe unpleasant odours as a recognized nuisance due to its affects on living beings as it will cause discomfort and possibly lead to nausea. Odour has been shown to alter a person’s mood, although the response is currently understood to be psychological as people naturally dislike being exposed to odours which they have no control over. These unpleasant / offensive odours and gases will always be emitted from all livestock facilities to a certain extent, therefore the problem is universal.

Jiang and Sand (2000) report that odours generated in broiler litter are a result of biodegradation of accumulated faecal matter which can take place under aerobic or anaerobic conditions. The generation, transfer and transport processes occur simultaneously while limiting the reaction rate of each other. Aerobic conditions where uric acid, proteins and animal fats are biodegraded usually occur in poultry litter with the presence of oxygen, where it must be noted that water can act as a catalyst in the processes of odour generation, transfer and transport. The aerobic biodegradation (decay) processes produces nitrogen-containing odorants such as ammonia, amines, indole, skatole and volatile fatty acids. In the presence of oxygen, sulfide containing compounds such as methionine are oxidised microbially into sulfur containing odorants such as hydrogen sulfide, dimethyl disulfide, and dimethyl trisulfide. But due to limited oxygenation throughout the litter, anaerobic conditions may occur creating patches of caked manure. Under anaerobic conditions, sulfur-containing compounds are biodegraded into thiols, volatile organic sulfides and mercaptans. However, these anaerobic processes can be reduced by increasing the exposure of litter to air (oxygen) and reducing water ingress into the litter. To conclude, odourants produced during anaerobic decomposition are generally more offensive and stronger than those produced aerobically.

Jiang, Sands and McPherson (2000) describe that odour generation from broiler grow-out sheds are complex as some 75 compounds have been recognised within these
sheds. It is noted however that the dominant odorous compounds are ammonia, hydrogen sulfide and mercaptans. McPherson (2000) further explains that certain compounds such as sulfides are readily detected by humans than others or are perceived as more offensive even in low concentrations. The combination of compounds may also mask certain odours or create an odour that is greater than the sum of the individual components. Additionally, perceptions of an odours acceptability and individual capacity to detect particular odours can vary greatly.

As the broiler flock ages and reaches the end of their life cycle, their faeces accumulates in the litter within the shed consequently accelerating the odour generation process and odour concentrations. After the first harvest thin-out, as the remaining birds grow in size, the excretion rates per bird will increase and the air exposure and bird movement will be reduced. However, the harvesting of birds during a batch results in increased bird movements and stirring of the litter which can expose pockets of trapped odorants, potentially leading to higher odour generation during the harvesting process. As a result odour generation and shed air odour concentration can be expected to plateau at a maximum level during the last weeks of a batch (Jiang and Sand 2000).

Following the final harvest of birds, odour generation in the empty shed may increase if the litter is allowed to remain undisturbed and oxygen becomes depleted, causing accelerated biological breakdown of organic compounds in the spent litter. When birds are present, their movement provides the aeration needed to reduce formation of a crusted anaerobic condition. In some regions, integrators and/or regulators require removal of spent litter in closed vehicles, immediately following final harvesting. During the removal process, fresh surfaces may be exposed, also leading to transient higher odour generation (Jiang and Sand 2000).

4.4 Odour Transportation

Odour is transported primarily by dispersion and diffusion. Dispersion is the gradual dilution of the odour by mixing it with ambient air, transporting it with the bulk flows assisted by the wind. Once the odours particles are released from the manure, they are
transferred into the surrounding airspace, where air currents and turbulence disperse and dilute it (Greaves, 1995).

The anaerobic biodegradation occurring inside the litter produces odours compounds that occur as gases. The movement of air across the litter and livestock results in the transport process of odorant particulate matter from the litter to the air in the shed and thus expelled via the cooling fans. It is theorised that this dust material, consisting mainly of material such as litter or feather follicles, aids in the transport process when odour compounds adsorb onto the surface of these particles, and are subsequently carried along with the particle. Once ingested by a person, the compounds absorb into in the nasal cavities where their odorous character can be recognised (Greaves, 1995).

Shed design plays a significant part in the transportation of odour from within the shed to the ventilation and dispersion of odour to the atmosphere. Traditional naturally ventilated sheds movements and dispersion of odour is almost exclusively dependent on natural air currents through the shed, while the new style tunnel ventilated sheds have the capability to transfer the odour out to the atmosphere in high volume, low concentration air streams. This allows for greater stocking densities per shed, but increases odour point source generation by a substantial amount.

4.5 Conclusion

This chapter has explained briefly the problem of odour, the perception of odour, generation of odour in broiler farms and the transportation of odour. Several critical points are presented within this chapter verifying the justification of this projects aim. Odour annoyance is considered to occur at a point in time which exposure to an odour is perceived by a person to be unwanted. Odourants produced during anaerobic decomposition are generally more offensive and stronger than those produced aerobically, hence the reason of justification for trying to aerate and disrupt poultry litter. This is the key point to the research topic.
Chapter 5 : EXISTING ODOUR REDUCTION SYSTEMS

5.1 Introduction

Odour released from poultry sheds can cause a nuisance to neighbours. This level of nuisance can increase if the concentration of perceived odours increased or the frequency of detection of the nuisance odours increases. When the level of odour nuisance escalates, odour may become a source of conflict between the poultry farm and neighbours. When other treatment options have been exhausted, the only remaining strategy is to manage and control the odour generating process at the source, especially during peak emission times while maintaining positive communication with neighbours. The industry uses a set of guidelines, which can be used to try and reduce odour impacts from “extremely strong” to more acceptable intensity levels of “faint” or “very faint”.

5.2 Preventative Measures

The most effective way of minimizing odour impacts is by minimizing the odour generated at the source. To prevent the production of odour would be the ideal solution, but as is commonly found, this is not easy. The most effective methods of prevention are aimed at slowing down or ceasing anaerobic bacterial activity that creates the odorous compounds which previous research has determined the poultry litter is the predominant source of odour. Good practice, design and adequately
managing the litter, providing optimum ventilation and controlling temperature should always be considered before other odour control strategies are implemented. These practices are generally part of normal meat chicken production as they are quite often implemented with the primary purpose of optimizing production. Controls at the receiver only warrant consideration where the aforementioned management and systems fail. For example, air conditioning system installation for affected receptor houses is an example of a control approach. However, this may be expensive if there are many houses to treat. It also provides no control over odour outside the treated building. Controls at the receiver are rarely a viable odour reduction strategy.

Clarkson and Misselbrook (1989) present data and results acquired from tests performed on the exhaust air of commercial broiler houses under different management regimes to assess odour concentration, emission and intensity. Data demonstrated that odour concentration and emission increase sharply after the livestock has reached 30 days of age. This rapid increase in emission may be due to the formation of a dry, impermeable ‘cap’ on the litter which results in a reduction in moisture absorbing capacity. Theoretically it may be possible to introduce fresh wood shavings at this point or to break up the capped layer of litter in an attempt to increase it moisture carrying capacity, but practically, this is not easy to accomplish. The data demonstrated the low moisture content litter produced lower emissions than high moisture content litter. The conceptually designed plough is designed to achieve the destruction of the capped layer to increase the litter moisture absorbing capacity while also aerating the litter in an effort to reduce litter moisture.

The methods of controlling, treating or mitigating odour emission from broiler farms can be classified into three categories and are further discussed below:

- Prevention of the production of odorous compounds at the source;
- Prevention of odour between the source and receiver by treatment or entrapment; and
- The use of dispersion to dilute odour before reaching the receiver.
5.2.1 Managing Shed Litter Moisture Content

Odour and dust emanation levels from broiler sheds depends primarily on the moisture content of the shed litter. The optimal shed litter moisture content to minimise odour generation and provide a healthy environment for workers and birds is between 15% and 30% (wet basis). Litter with this moisture content is relatively dry and friable. When the litter is too dry it becomes dusty and can cause dust nuisances, poor bird health and discomfort or health problems for farm workers. Jiang & Sands (2000) reported that when litter became excessively wet, it became the main source of odour from broiler sheds as it can begin to decompose anaerobically, producing increased odour and ammonia emissions greater than dryer litter. These areas can easily be maintained by either topping up with clean dry bedding material, breaking up or removing and replacing the wet litter. Further more, reducing the moisture content within sheds and maintaining litter pH above 7.5 could effectively reduce odour emission from meat chicken sheds by inhibiting anaerobic bacterial activity.

5.2.2 Providing Adequate Shed Ventilation

Ventilation influences odour emission rates by affecting the rate and extent of drying of the poultry litter. Effective air exchange within the shed helps removes excess heat, water vapour and odorous compounds from the sheds and encourages optimal litter moisture levels by promoting bird health, reducing the need for fogging and increasing drying rates. The concentration of odorous compounds in the air depends on the degree of dilution of the odorous substances with air in the shed or in the ventilation system. Good ventilation also dilutes the concentration of odorous gases released to the outside air.

Maintaining the maximum possible airflow through the shed will assist in keeping the litter as dry as possible and promote aerobic conditions within the litter. Removing accumulated dust and regularly cleaning ventilation fans and shafts will minimise odours that are absorbed and carried through the air by dust particles. Shed ventilation is closely related to shed temperature. By providing appropriate ventilation, temperature can be regulated inside the shed, which assists the control of odour generation.
5.2.3 Controlling Shed Temperature and Humidity

The effect of internal shed temperature has an important influence on the degradation of poultry manure and the volatilization of odorous compounds within the litter. Jacobs (1994) discuss how bacterial activity within the poultry litter does not favour low temperature conditions, however studies have proven that large reductions in internal shed temperature is not optimal for chickens growth, and thus cannot be employed as a major odour reduction strategy. Installing roof insulation will help prevent large net heat gain from external radiation and assists the regulation of the temperature inside the broiler shed. For sheds with inadequate roof insulation, the air beneath the shed roof may radiate heat into a meat chicken shed at significant rates during the hot part of the day. However, there is strong anecdotal evidence that odour production is far higher in summer than in winter.

5.2.4 Dietary Manipulation

There is limited information on the effectiveness of dietary manipulation to control the production of manure and subsequent odour production. Further research is required to assess the effectiveness of dietary manipulation as an odour control strategy. Publicly available literature does indicate this control technique has the potential to control odour emission rates from poultry litter in broiler grow-out sheds.

Gates (2000) presented the effects of enhancing the amino acid levels while simultaneous documenting the resulting effects of reducing crude protein levels below current commercial levels. The subsequent results and conclusions were taken from three meat chicken flocks raised on the same litter and diet. On a reduced crude protein and enhanced amino acid diet concentrations of equilibrium ammonia gas (90%) litter total ammoniacal nitrogen (50%), pH and moisture content were all lower, while bird production performance was not compromised.

Another study undertaken by Elwinger and Svensson (1996) studied the effect of varying dietary protein content on ammonia emission from meat chicken sheds. Subsequent results indicate increased dietary protein content increased the ammonia concentrations in the litter and atmosphere. But as mentioned previously, reduced concentrations of ammonia in the litter do not necessarily lead to the reduction of
odour emission rates. Research into the relationship between odour and ammonia concentration has produced varied results. This is due to the complex nature of odour because typically a reduction in ammonia concentrations does not typically correspond to a proportional decrease in odour emission rates. However, the inconclusive nature of tests, along with the potential negative effects to chicken body mass, make this option dangerous without strong evidence of its effectiveness.

5.3 Odour Reduction Systems and Technologies

Pain and Misselbrook (1993) states that there are relationships between odour concentration and odour intensity, leading to the assumption that over a 90 percent reduction in odour concentration is needed for effective abatement of odour nuisance problems. They imply that if we are to find an effective solution for odour nuisance, there will have to be substantial reductions in the odour concentrations emitted from the chicken shed to make a noticeable difference.

Technologies for reducing odour emissions from a broiler grow-out farms can be categorized into three sections:

- Biological: These controls either inhibit biological activity causing the odorous gases, or utilise biological interactions to eliminate the odorous gases;
- Chemical: These controls eliminate the odorous gases through chemical reactions; and
- Dispersion: These controls promote the dispersion of odorous gases to an extent where they are not regarded as offensive at sensitive receptors, such as at a neighbours property.

A list of odour control techniques are shown below in Table 5.1;
### Table 5.1: Options for Odour Minimisation, Treatment or Isolation

<table>
<thead>
<tr>
<th>Process</th>
<th>Odour Removal</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategic Planning</td>
<td>Structured Farm development</td>
<td>Preventative</td>
<td>Existing Layout may not suit</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Buffer zone expensive</td>
<td></td>
</tr>
<tr>
<td>Good Design &amp; Management</td>
<td>Controlling litter moisture content reduces odour emission</td>
<td>Odour Source Control</td>
<td>Requires consistent application</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost Savings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dietary Manipulation</td>
<td>Optimizing litter moisture content to reduce odour emission</td>
<td>Odour Source Control</td>
<td>Further research required</td>
<td>Unknown</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Production benefits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odour Neutralising Agents</td>
<td>Low</td>
<td>Easy application</td>
<td>Uncertain link between odour and ammonia</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>But odour less offensive</td>
<td>Operates at source</td>
<td>More research required</td>
<td></td>
</tr>
<tr>
<td>Windbreak wall</td>
<td>Moderate</td>
<td>Very simple</td>
<td>Relies on dispersion</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Aids dispersion</td>
<td>Easy cleaning</td>
<td>Unproven</td>
<td></td>
</tr>
<tr>
<td>Short stacks</td>
<td>Moderate</td>
<td>Simple</td>
<td>Relies on dispersion</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Aids dispersion</td>
<td>Low maintenance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree Barriers</td>
<td>Fair dust removal</td>
<td>Visual barrier</td>
<td>Relies on dispersion</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Low odour removal</td>
<td>No maintenance</td>
<td>Low odour removal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aids dispersion</td>
<td>May remove dust</td>
<td>Time to establish</td>
<td></td>
</tr>
<tr>
<td>Air scrubbers</td>
<td>Unsure Amount</td>
<td>Pollutant removal</td>
<td>High water use and effluent</td>
<td>Moderate to</td>
</tr>
<tr>
<td></td>
<td>Uses water flow to remove ammonia and other particles</td>
<td>Removes dust</td>
<td>Ventilation rate critical</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Uses in other industries</td>
<td>High capital cost</td>
<td></td>
</tr>
<tr>
<td>Biofilters</td>
<td>Excellent</td>
<td>Effective</td>
<td>High maintenance</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Uses in other industries</td>
<td>Proven</td>
<td>High capital cost</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Uses in other industries</td>
<td>Toxic Effluent Complex</td>
<td></td>
</tr>
<tr>
<td>Ozone treatment</td>
<td>Potentially high</td>
<td>Sterilizes</td>
<td>High capital cost</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>More research required</td>
<td>Removes dust</td>
<td>Humid weather</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>More research required</td>
<td></td>
</tr>
</tbody>
</table>

#### 5.3.1 Odour Neutralising Agents

Various commercially available products are used as additives to litter, feed and drinking water (depending on type of chemical agent) to reduce the moisture content of the waste and inhibit anaerobic microbial degradation.

The commercial meat chicken industry has been attracted to odour neutralising agents as a cheap fix approach as most are relatively easy to adopt and involve low capital costs. However, many of these products are poorly defined and there is limited scientific assessment on their effectiveness to control odours. Many neutralizing agents use chemical interactions to remove (adsorb) or reduce ammonia released.
inside the shed to the atmosphere but this does not necessarily correspond to a reduction odour emission rates. Jiang (2000) found no correlation between ammonia and odour concentration in a study of odour emissions from meat chicken shed litter. However it is generally agreed that ammonia emissions correspond to the odour generation from meat chicken sheds. The first 5 weeks of meat chicken growing cycles corresponds to minimal odour nuisance complaints. Hence, the control of ammonia generation and release are likely to have little effect on the peak odour emission rates from a meat chicken shed.

A study performed on clinoptilolite zeolite and De-odorase, two commercially available products that claim to reduce ammonia and odour emissions from meat chicken sheds is presented by McGahan et al. (2002). The results of the study concluded that Clinoptilolite zeolite increased ammonia emissions while De-odorase® decreased the ammonia. The results show that zeolite based compounds may be effective in removing odours but because they also attract moisture, hence increased ammonia emissions, therefore impractical in poultry sheds. It was further noted neither had any significant effect on the odour emission rate. Jiang & Sands (2000) suggested that adding lime to fresh litter may limit the anaerobic microbial growth and breakdown, limiting and inhibiting odour generation. Further research in this area is required to quantify the effects on odour emission rates, possible impacts on bird health and the cost-effectiveness of this option.

5.3.2 Aeration / Ozone Treatment

Ozone is one of the most powerful oxidizing agents currently available. Oxygen is poisonous to odour producing bacteria. Highly oxygenated litter promotes aerobic digestion where low-odour compounds are produced. When energy is provided to oxygen to increase the energy level of stable O₂ molecules, it promotes the oxidising potential of oxygen. This property of ozone is utilized as oxygen (O₂) to oxidize these odorous compounds in the air. During the oxidation-reduction reaction both the ozone and odorous gas are eliminated, and in theory neither the odorous compounds nor the ozone remain.

Ozone is used in various industries to destroy airborne bacteria, remove particles and eliminate odours. Cargill (2001) describes how ozone operates reducing odours
compounds by killing off micro-organisms by blocking their enzyme control system and deodorises both gaseous and particulate matter by the process of oxidation. Another use of ozone technology is the potential to reduce ammonia concentrations in broiler sheds however further research is needed to verify this effect. Currently, two methods are used to treat poultry sheds with ozone. Firstly, the use of high concentrations of ozone to sterilize sheds when they are empty following removal of birds and spent litter, and secondly, the use of low levels of ozone (0.1 ppm) to deodorize sheds and improve air hygiene when sheds are stocked with birds. The results of trials using low levels of ozone (0.1 ppm) to deodorize and reduce airborne bacteria during the growth cycle are promising and further studies are needed to investigate the cost effectiveness of ozone in reducing odour and dust, any impacts on production or bird health and its safety (Cargill, 2001).

There are some concerns with the safety of the technology. Sigrist Design indicated, “Ozone technology is the best technology to remove odours, however it does not work with humidity”. Humid conditions are a result of high water vapour concentrations in the atmosphere. Water vapour will undergo an oxidation-reduction reaction with ozone to produce hydrogen and oxygen and eliminate ozone prior to the removal of odorous compounds. However, while the benefits of ozone use seem optimal, indications exist that as high concentrations of ozone can be dangerous to both workers and birds. This presents many OH&S issues that would need to be address and operational protocols would need to be implemented to ensure a safe environment for workers and livestock.

Quantifiable information relating to removal efficiencies for ozone treatment is limited. Suppliers of ozone technology are generally reluctant to supply documentation of the systems removal efficiencies, but claims of efficiency greater than 90 percent have been made by a number of suppliers. There is considerable operating and capital costs associated with an ozone system, which is commonly above budget and affordability for the chicken meat industry (McGahan, Kolominskas, Bawden and Ormerod, 2002).
5.3.3 Short Stacks

Short stacks is a systems comparable to chimneys stacks (Figure 5.1) attached to exhaust fans at the exhaust end of broilers sheds to direct odorous exhaust air upwards into the atmosphere increasing plume dispersion with a large volume of fresh air before reaching the ground.

![Figure 5.1: Chimney Stack](image)

A study carried out by Pollock & Friebel (2000) determined the effectiveness of 5m high stacks in diffusing night time odours exhaust air, that indicated the predicted area of farm land impacted by odour is significantly reduced by this system, where a mean radial distance till the acceptable reading of 5 Odour Units (OU) range was detected (99.9 percentile for an averaging period of 3 minutes) was found to be reduced from 300 to 170 m. However, the effectiveness of a short stack is limited to this range and reductions in exhaust air odour concentrations beyond these distances are expected to be minimal. The additional turbulence from short stacks and corresponding reduction in odour concentration at ground level is most effective over relatively short distances (200 m – 500 m) from the sheds exhaust fans. Strong winds or unstable conditions will minimize this effect. Reported research by Mc Gahan et al. (2002) identified 5m tall short stacks as being more effective than stacks taller than 5m because of the additional air flow turbulence in the shed creates a more predominant wake effect (60-70%) in the stack and discharge zone. However, it is found that the effects be less pronounced in stacks higher than 5m and during calm conditions.
5.3.4 Windbreak Walls

Windbreak walls are basically a three meter high wall placed several meters away from the exhaust end of a tunnel ventilated shed (Figure 5.3) for the purpose of enhancing the dispersion of exhausted odorous air by directing it upwards into the surrounding wind where increased turbulence and subsequent wake affect will lead to enhanced mixing conditions. This may help reduce the concentration of odours and odour nuisance effect at sensitive receptors. The Windbreak walls can be constructed from a variety of materials (Figure 5.2) including vegetation screens (which can improve visual amenity as well as reducing the visual recognition of the odour source) tarpaulin, grain bails, corrugated iron or wood.

Figure 5.2: Examples of Windbreak Walls
(Bottcher et al., 2000a)

Figure 5.3: Odour intensity Dispersion Mechanism of Windbreak Walls
(Bottcher et al., 2000a)
Preliminary studies by Bottcher et al. (2000) identified that windbreak walls constructed from tarpaulin can reduce the odour concentration at sensitive receptors by 30% to 90%. Furthermore, Bottcher, et al. (2000b, 2001) reports that the dispersion effect helps prevent the visible dust build up on neighbouring properties. The dispersion principles depend on mechanical mixing by force exerted by the outlet ventilation fans, windbreak walls and turbulent wind over the meat chicken shed. However, the dilution effect is limited to relatively short distances and is significantly reduced during calm conditions. In strong wind conditions the dilution effect is also reduced due to the existing high levels of airflow and turbulence. There is currently limiting information available to the public about the odour abatement effectiveness of windbreak walls. Bottcher et al. (2001) reported that dispersion principles and modelling results suggest that short stack systems are a more effective dispersion mechanism than windbreak walls. It is imperative to remember that screening requirements are site-specific and that an effective barrier at one site may not be appropriate at other sites depending on the factors such as general visual amenity of the property, sensitive receptors location to the farm, Temperature and humidity, Prevailing wind direction, Topography and available buffer areas.

5.3.5 Air/Bio Scrubber

Air scrubbers are used in many industries used to control both ammonia and odour emissions. An air scrubber is a packed-bed unit through which exhaust air passes and removes contaminants from air through the process of absorption. Water trickles and circulates through the packed bed, which has been designed to ensure the best possible contact between water and air in order to increase the mass transfer rate between the two phases. Spraying, atomization, agitation and impingement are mechanisms used to maximise the contact of the gas and absorption media. In the water and on the packed bed a biologically activated sludge develops. The Ammonia absorbed in the process water is first converted into nitrite and then into nitrate, which is called nitrification. The odour components absorbed in the same process are decomposed into CO₂ and H₂O. As a result the process water can again absorb ammonia and other odours compounds. To prevent the activity in the activated sludge to be curbed by accumulating nitrogen concentrations, the process water has to be replaced at regular intervals.
In modern air scrubbers, the nitrogen content is controlled by draining a certain amount of the process water as effluent. Ammonia continues to be absorbed at low ammonium concentrations and at a pH value lower than 7.8. Nitrification, however, is a sensitive microbiological process. Additionally, air scrubbing may also involve the use of an oxidizing solution such as sodium hypochlorite to remove the soluble odorous gases from the water. This will although increase the associated operating cost.

The removal efficiency of odorous gases from air, by air scrubbers in the fish processing industry is quoted at 99.5 percent (Prokop, 1992), and the efficiency of similar equipment used to treat rendering odours is quoted at around 99 percent. However such efficiency appears to be closely related to the amount of effluent water. If the effluent flow is below the ‘critical’ value, the efficiency diminishes. This is due to the fact that a certain quantity of effluent water can remove only a limited amount of nitrogen. To therefore allow the air scrubber to operate at the designed operating efficiencies the process water and effluent must be continually bled off and replaced with fresh water to ensure that volatile odours are not released when the water becomes loaded with odorous material. The odours components removed (ammonia and nitrite concentrations) make the effluent very toxic. The disposal of effluent water from air scrubbers is a problem of the actual operation. The large amount of effluent does not make disposal to a slurry pit a viable option due to its toxic nature, however in many cases there is no other solution.

### 5.3.6 Biofilter

A biofilter consists of a packed bed of organic material through which a steady flow of odorous exhaust air is passed. Bacteria that specialize in breaking down odorous compounds inhabit the bed, allowing intimate contact between the odorous gases and the bacteria, producing non-odorous byproducts instead and the process is self-sustaining.

To maintain an optimal living environment for the micro-organisms, constant airflow, temperature and moisture levels are required. However, several controls must be implemented to maintain optimal operating conditions. Excessive moisture should be avoided as it increases airflow resistance and may encourage anaerobic conditions,
however insufficient moisture deactivates the microbes and allows channels to form in the substrate. Ongoing control of rodents and excessive vegetative growth is also necessary to ensure effective operation.

Correctly designed and maintained biofilters have proven successful treatment options in other industries such as calf and pig sheds overseas and also at wastewater treatment facilities but are less suitable for commercial chicken meat sheds. Biofilters are rarely used in meat chicken farms because of the cost to treat large exhaust air quantities, the operation performance that does not always meet designed expectations and the problematic handling and treating of effluent water needed to remove the nitrogen absorbed by the biofilter material.

Biofilters require continuous maintenance as it treats all of the ventilation air throughout the growth cycle. Therefore to implement such a system on an existing shed would require a major change in the ventilation design and could impose significant capital and operating expenditure. To achieve high levels of odour control, typically in the range of 86% - 99% odour removal, biofilters require reasonably steady environmental conditions to operate effectively also so that no part of the substrate medium becomes dried out and develops channels for odorous air to escape directly to the atmosphere. There is considerable capital and operating costs associated with biofilters and as such for the average chicken farmer, the cost is prohibitively too great.

5.4 Previous Poultry Litter Aeration Research

5.4.1 Aeration of Poultry Broiler Litter

Allen, Hughes, Chastain, Skewes, Bridges, Armstrong and Thomas (1998) performed a pilot study in the fall of 1996 on the effects of aerating poultry broiler litter to reduce the production of odour and ammonia. The subsequent test results were published, “Aeration of Poultry Broiler Litter to reduce production of odor and A hazardous gas”, 1998, Clemson University, South Carolina, and this information was utilized to determine the possible effect the conceptually designed ploughs will have when aerating and disrupting poultry litter.
The work conducted had similarities and differences with the work of Kroodsma and of Van Middelkoop who forced air through litter to achieve aeration. One primary difference is the idea used of partitioning the hazardous elements away from the area of the bird and the worker. The work carried out revised the litter airflow methodology by Van Middelkoop and pushed the flow of air down below the litter to achieve separation of gases from the bird/worker space, as seen in Figure 5.4. The relationship between the rate of litter aeration and degree of results were also investigated. The work reported in the publication attempted to extend the emphasis on ammonia to other gases, to odour, and to the effect upon dust levels.

![Diagram of airflow for treatment rooms](Allen, Hughes, Chastain, Skewes, Bridges, Armstrong and Thomas, 1998)

Results reached and conclusions drawn at the completion of the experimental trial, determined:

- Moisture values obtained before and after was found to decrease with increasing litter aeration rate, as expected.
• Temperature was not significant compared to other variables, but the differences recorded would indicate that the microbial activity in the litter would have been affected and control room remained consistently warmer than the aerated rooms.

• Odor units seemed to form a trend of decreasing odor as aeration rates increased from 6 to 36%. For aeration rates of 12, 24 and 36% of total ventilation, reductions of total ammonia production were similar.

• Results obtained were confounded by one of the experiment trial results that did not follow the trend. None of their statistical analyses indicated a significant result relative to odor measurements.

• One of the primary goals of the research to suppress ammonia production was achieved as the control treatment appeared to produce more ammonia than the aerated rooms.

• Separation of the ammonia from the bird/worker space was successfully achieved. Ammonia concentrations in the rooms at the end of six weeks indicate that using a negative pressure sub-floor plenum was highly effective in separating ammonia from the bird/worker space. Thus, significant separation can be attained using small aeration rates. A substantial increase in environmental quality within the production facility is attained.

• The quantity of airborne dust within the room was not significantly affected by the downward flow of air used to aerate the litter.

There is potential marketability for the system used for testing in a broiler or egg laying shed to reduce ammonia and odour emissions from broiler litter, however, the initial infrastructure cost would be similar to the conceptual blade plough cost and the publishers recommend additional trials are first needed to strengthen the statistical power of the research.

The information obtained from their publication on the experiment, is further validating the beneficial effects of aerating poultry, while demonstrating the need for further research and testing for the effectiveness of litter aeration in an attempt to reduce odour and ammonia emissions from poultry litter.
5.5 Conclusion

Given the present ‘state of the art’ in odour abatement technology, it is unlikely that any single device could operate at such high (>90%) odour abatement efficiencies identified by. Therefore combinations odour control measures will need to be combined in order to achieve a significant odour concentration reduction. After the odour control systems and facilities installed, the odour removal efficiency should be checked for a certain period of time. This confirmation is necessary for the effective operation and maintainence of the odour removal facilities applied.
Chapter 6: Poultry Litter Plough Conceptual Designs

6.1 Introduction

Consideration of the tasks and objectives presented in the project overview at the inception of the project gave no hint to the designs and the final plough design, if indeed a plough design capable of performing the required task was even possible. The process of reviewing the required needs and wants of the customer against the knowledge and inexperience of an Undergraduate Engineer and then nurturing the ideas often diametrically apposed into conceptual designs is often underestimated.

The conceptual design process involved investigating several plough and paddlewheel operating systems whose operating principles were sought after for guidance in the design of the project ploughs. To achieve disruption and aeration of poultry litter, several alternative plough designs were developed up to 3D modeling and testing with ProEngineer software. Three conceptual designs were developed, being:

- Inversion plough;
- Reversible blade plough; and,
- Rotary tiller plough.
A decision matrix was then constructed to choose the best overall design to suit the farmer’s needs. Once the final conceptual design is chosen, further development and construction of working models can commence.

### 6.2 Mechanical Operation / Actuation in Broiler Sheds

Tillage of the soil in preparation for planting of crops has been used by farmers from the time of the ancient Egyptians. The principle benefits obtained from ploughing the ground include the breaking up of the compacted earth into smaller friable pieces which also aerates the soil assisting aerobic bacteria into breaking down organic material whilst at the same time releasing trapped nutrients. The ploughs mechanical principles are important and relates directly to this project. The plough design selected for use in this project were chosen for their abilities to: turn the litter bed, to break the caked areas into smaller pieces, to aerate the litter bed to encourage aerobic bacteria decomposition, reduce offensive odour generation and increase the general health of the chicken flock by improving living conditions.

The operation of mechanical equipment within broiler grow-out sheds during all growth stages of the poultry livestock has placed constraints on the type of equipment that could potentially be employed. To overcome these operational constraints various plough systems were designed to fulfill the clients requirements and specifications.

### 6.3 Design Criteria and Constraints

One of the biggest limitations of the research is the unknown and unpredictable nature of odour production in broiler sheds. To date the exact causes of odour in offensive odour producing industries (eg: poultry, pig, cattle, fish, etc) is relatively unknown; however research has identified wetter zones where anaerobic decay is a likely contributor to offensive odour production, which is linked to caked sections of poultry litter as a concentrated source of anaerobic decay. At present there are no real viable systems around that will disrupt and aerate the litter in an effort to prevent the caking sections while allowing safe operation with livestock in the shed.

The aim of the project is to develop a plough system to disrupt and aerate the crusting litter regularly and automatically within the shed. However, there are many issues that
need to be addressed if this device is to work effectively. The design constraints and criteria are presented briefly so informed decisions can be made as to what style of ploughing mechanism and system should be design for the farmers requirements.

System requirements:

- Able to break up and aerate caked poultry litter within the shed;
- Be Semi-automatic in operation;
- Implement shall be reversible;
- Operation of unit through broiler chicken production cycle;
- Reduce generation of dust;
- Minimal noise levels;
- Reduce danger of mortality to chickens from crush and impact loads; and

Able to break up and aerate caked poultry litter within the shed:
Researching implements and operational mechanics that incorporate the ability to break apart soil segments/compounds and systems that could be used to aerate soil and water, it was possible to produce several conceptual plough designs that will break up and prevent caked sections in poultry litter in an effort to reduce odour generation. The implements and operational mechanics that the designs are based around replicating are offset discs and chisel ploughs, the old push lawn mower and a steamboats paddle wheel system.

Semi-automatic in operation:
The ploughing system must be able to carry out the pre-determined operations with the minimal amount of human interactions. This is required because the farmers time is needed for other tasks rather than spending additional time operating the plow. Operation of the plough system will be initiated by a start button, or timed start, and will automatically shut down when it reaches the end of the shed. This is designed for ease of operation for the farmer. When the farmer finishes doing their daily shed check of systems and removal of dead livestock, upon exiting the shed, the start button can be initiated for the ploughs pass, eliminating the hazard of risk of injury to
workers while in operation. This gives the farmer the ability to resume their other duties while also achieving the benefits of the ploughs interaction with the litter.

**Reversible Plough Operation:**
Reversible operation has a direct relationship to Semi-automatic operation design criteria. Designing the plough to be reversible allows the system to perform the required pass of the shed without involving the farmer in the meticulous task of realigning and configuring the plough to perform another pass. This saves the farmers time and makes allowances in the system for different configurations to adapt semi-automated or fully automated operation if the farmer so desires.

**Operation of unit through broiler chicken lifecycle:**
To cater to the prevention of caked sections within poultry litter, the plough must continually disturb the litter particles, breaking clumps back to a friable mixture. To achieve this, the operation must be carried out while the livestock is in the shed, however, as previously noted the odour nuisance does not become a severe issue until four weeks into the growth cycle. Therefore operation of the plough will not commence until the livestock is of three weeks of age. This will guarantee the livestock is of sufficient size to take the impact of being dropped off the trailing lip of the plough but also guarantees the increased height of the automatic feeder bases off the top of the litter bed. The allows to litter to be raised due to the blade plough running underneath the litter or allow room for the operation of the paddlewheel plough without the need to order and implement specially designed feeder trays. As the saying goes, “Prevention is better than the cure”.

**Minimal generation of dust:**
Dust generation is a potential health and machinery hazard that is ever present at broiler grow-out farms. It affects machines by building up in undesirable areas resulting in a reduction in performance (exhaust fan efficiency) or become a contributing factor to wear and degradation. For facilities that stores animals and material that produces dust that is made airborne when continually disturbed, it has been documented from several industries where the same problem is present; all respirated dusts must be considered harmful in some degree. Even where there may be only slight danger to the lungs, there is very likely some adverse effect on the respiratory system, particularly to asthmatics or sufferers from hayfever. Dust
particles of size ranging from 0.001 to 0.1 mm (1 to 100 microns) pose a threat to health when they become airborne, reducing visibility, creating an uncomfortable environment (irritating the skin with rashes and itchiness, the eyes with watering and redness, the upper respiratory tract with sneezing, dry and sore throats and the lower respiratory tracts with asthma-like symptoms and a cough) and possibly resulting in damage to the tissues of the lungs.

A poorly designed plough system could stir up excessive dust and contribute to allergen generation while increasing the likelihood of symptoms developing and their severity. To help alleviate and prevent these systems, regulations state that protection such as face masks and full protective clothing must be used when entering enclosures where this problem is potential damaging to the workers health. Suitable extraction systems and ventilation may help to control exposure to dust and airborne allergens for workers and livestock. It is in the best interest to design a plough that will have a minimal impact if any on dust generation for the reason mentioned previously.

**Minimization of noise levels:**

Sound is usually described as the sensation produced at the ear by very small and rapid pressure fluctuations in the surrounding air. The ear is particularly fragile, therefore design considerations must ensure that sound levels do not exceed those that produce damage. The ear is most sensitive at frequencies around 4 kHz and is quite insensitive at very low frequencies. Hearing loss is a major problem in the community. Prolonged exposure to loud sounds also causes damage to the hair cells. Loss tends to be greatest at the frequencies that the ear is most sensitive: 2-4 kHz. The damage is energy related and is cumulative over time. It is like fatigue damage, in that every “load cycle” or “sound overload” causes some damage (System Design, 2005). Therefore all systems and subsystems are designed to prevent sound emanations reaching the damaging frequencies (2-4 kHz). If it is not possible to prevent the emanation of these damaging frequencies, analysis of sounds paths and subsequent sound barriers will be implemented to reduce the noise pollution to tolerable levels.

A common way to attempt to reduce the effect of a noisy source is to place barriers between the source and the listener to reduce the noise level. The term noise reduction is defined as the reduction in sound level that the barrier or change in paths provides.
It should be noted that there may be more than one path for the sound to travel along to get to the listener. Analysis will need to take all of these paths into account.

**Mortality from Crush and Impact:**
The design of the plough system has taken into consideration the affects it will potentially have on the poultry livestock during operation. At three weeks of age the livestock has grown to a weight of 350g to 500g. It is deemed unsafe to allow the operation of any ploughing implement within the litter during the first three weeks of the livestock's lifecycle. The physical size and structure of the chickens do not allow any impact or crush loads to be experienced because their bodies are still developing and will not be able to withstand the loads safely without health repercussions. However after three weeks of age, it is the consensus of farmers and breeders that the birds structure will allow them a greater chance to survive these potential loads without health repercussion issues. One exception to this statement is the forces due to crushing loads from implements such rotary hoes or the paddlewheel. The problem is overcome with the incorporation of safety covers designed into the plough to guard against the possibility of chickens being exposed to the blades. When the chickens are of three weeks age, the body structure should ensure the bird is too large to fit underneath the protecting cover lip even if there is no litter at the entrance.

**Comply with Australian Standards & Queensland Workplace Health & Safety:**
Compliance with Queensland OH&S requires staff to not be permitted within the operational area of the ploughing implement whilst the plant is operational. To assist with safety emergency stops, emergency stop buttons will be also located within the broiler shed. Appropriate safety signage will be placed at relevant sections of the shed and power system to help workers identify areas of potential danger.

The system is designed to be flexible enough for manipulation or linking into a variety of different configurations at the desecration of the farmer. Use of stainless steel cables to pull the plough through the litter creates a flexible layout frame that could be fitted into many different shed configurations and sizes as possible.
6.4 Conceptual Design Methodology

Design can be defined as the creation of products or systems to fulfill a given client requirement or specification. Engineering design is the process of devising a system, compartment, or process to meet desired needs. It is a decision making process in which the basic sciences, mathematics and engineering sciences are applied to convert resources optimally to meet a standard objective (Ertas & Jones, 1996).

There are various design methodologies currently available that has a proven track record of working exceedingly well with the design process, however the aforementioned design methodologies do contain pitfalls that could work against the design process. These various design methodologies approach the design problem at hand in a similar manner, consulting about the overall system design descending down through to the sub level systems detail design. In order to extract the most beneficial aspects of each methodology while avoiding as best as possible the pitfalls attached to using each one. The design methodology used for this project will attempt to extract the most beneficial aspects of the separate methodologies and implement them at various stages of the project while trying to avoid the pitfalls that can arise by using them.

Aims and objectives of this project are twofold; to design a plough capable of disrupting and aerating poultry litter. The research, conceptual design and manufacture processes can be intimidating when first viewed and considered. It was decided to be methodical and to break down the project into more manageable sections. That is by adopting the generalised engineering design process flowchart, as indicated in (Figure 6.1). This methodology would allow the design to proceed in a logical manner, with clear targets and deadlines to aim for, drawing on the parts of the project already completed and the model structure should allow the designer to frame their overall thought processes.
The overall system design methodology (first breakdown) is a combination of the top-down and bottom-up approaches. During the initial stages of the process, the final design concept and desired plough that is aimed for (highest part of the hierarchy tree) is broken down into its various tasks and components. These components and tasks (i.e. manufacture of the plough, specifying power system, etc.) were likewise broken down into various sub-tasks, and this process was repeated at all levels until the tasks to be completed can be divided no further. Once this point was reached the various sub-systems required were then designed from the bottom upwards, progressively combined together (modifying and redesigning as needed) until the final device was produced.

After a variety of poultry litter ploughs where designed, the next step taken to bring the design into reality was implementing the use of 3D solid modelling software. ProEngineer was chosen to create the solid models for the selected conceptual design plough. It was chosen for its excellent visualisation capabilities (models can be moved around the screen, zoomed in/out and rotated about), its library of features providing capabilities for detailed and accurate models to be created, ability to produce and reproduce technical drawings for manufacture and assembly of components, carrying previous experience and knowledge of the program and allows easy importation of the
3D solid model into the Finite Element Analysis (F.E.A.) package, Ansys, for stress analysis checks of components and overall design. This has helped in the designing and will further help in the building of mechanical components and metal fabrication. A parts library is constructed in ProEngineer and then an assembly is created, using relationships between parts to hold the assembly together. After the conceptual design components were created, the virtual prototype was build and initial tests were carried out to insure that the concept would work. The testing of each design was evaluated in regards to the project objective. These initial tests were needed to ensure the prototype concept would effectively carry out the design requirements. Once the conceptual designs had been chosen and its operation capabilities demonstrated, further design and tests are to be carried out.

6.4.1 Conceptual Design One: Inversion Plough

The inversion plough conceptual design was loosely based on the principles and operation of a plough used to hill prepared plots for small crop production and planting. The theory; It is possible and feasible to lift and separate the top 20mm to 30mm of the litter bed. To open a furrow beneath the suspended litter into which the top suspended litter will collapse and be covered by fresh shavings. Whilst conceptual in nature and prone to failure, a simulation was conducted, model manufactured and testing conducted.

Anticipated advantages of this design include:

- Basic principles of engineering laminar flow;
- Able to be mass produced and a number added together to make an operational plough assembly;
- Able to be connected to standard farm equipment drawbars; and
- High operational speeds (15 m/min) with low noise levels and low level dust generation.
Testing of the model in the test bed (using softwood shavings composted for two months for the test median) revealed a number of problems and disadvantages, which included:

- Shavings built up at the front of the top box section not permitting the manure to pass through and over the suspension plate;
- Modules could only be operated in the forward direction. Whilst the plough design was simple, rotating the modules for reverse operation was not;
- System components were too high and bulky to fit under the automatic water and feeder units; and
- System prone to extensive injury and high mortality rates of livestock (chickens).
The Inversion plough conceptual design shows great promise in the other areas of agriculture. Not however in a broiler shed. When the limitations of the design were revealed at modelling the decision was made to cease further development in favour of the **reversible blade plough** and the **rotary tiller plough**.

### 6.4.2 Conceptual Design Two: Reversible Blade Plough

In discussions with Mr. Mark Dunlop of the Primary Industries and Fisheries at an onsite visit the idea of using a sled pulled by a rope was raised. Initially, the thought of using a single plough operating the full width of the shed being pulled by a single rope seemed impractical. It was concluded the plough would skew when going through different litter densities.

Hurdles and problems with the original design concept were detailed, priority listed and remedies found. The single pull rope was changed to two ropes, one at each end of the plough; this was found to be unsatisfactory. To operate successfully with no warping, twisting or excessive deflection the plough would need to be a structural member. A long heavy plough is difficult to remove from the shed when it comes time to clean the litter and sterilize the shed on completion of the production cycle.
Design of the wedge shaped plough progressed with continual improvements in the concept; major hurdles still had to be overcome, which included:

- Modular design with each plough module to be able to be lifted and carried by two men;
- Raised tail to increase tumbling effect and better mix the litter bed;
- Modify the plough design to make it reversible; and
- Change from a winch to a closed loop capstan system.

The plough design was modified to now include a central spine and two flaps that could be raised or lowered depending on the direction of travel and the plough now required a means to be pulled in the opposite direction. After consideration of the technical difficulty, space requirements and cost, it was decided to use two capstan winches driven by an electric motor and worm gearbox. The rope from the plough changes direction around a sheave to the capstan drum. It circles around the drum four times, the rope again changes direction around another sheave, then lays on the ground beneath the litter bed going to the unpowered capstans at the other end of the building and from there to the opposite side of the plough.

Operation of the flaps using no power source proved to be difficult. This lead to a major review of the design and lead to the development of a tilting flap or blade, tilting from side to side depending on the direction of pull of the rope (Figure 6.4). Fine tuning was further required to modify the actuating mechanism from rope to a hinged pivot (Figure 6.5). A Model was made and testing was conducted to determine the most appropriate blade angles.

On trialing the final design model (Figure 6.9) extensively, it was concluded the plough had an efficiency of 50% when pulled through the litter in the operational orientation. This efficiency is low, but based on the premise that the plough will operate over multiple periods in a day, be semi or fully automatic, will not affect the welfare of the poultry or the equipment. The system has a bright future within the broiler industry.
Figure 6.4: Blade Plough Mach 1

Figure 6.5: Blade Plough Mach 2
Figure 6.6: Conceptual Blade Plough – Final Design

Figure 6.7: Conceptual Blade Plough – Default Position

Figure 6.8: Conceptual Blade Plough – Loaded Position
To overcome operational constraints the Blade style of plough was chosen. The principle benefits of using the blade plough are varied and include:

1. Low manufacturing cost;
2. Simple in design with few moving parts;
3. Top of the plough has minimal projection above the litter bed of 100mm, this permits the plough to pass under the automatic waterers and feeders;
4. Will not distress or frighten the flock whilst operating;
5. Low operating speeds reduce generation of dust and noise;
6. Semi automatic operation – no personnel required except to start the cycle by pressing the on button then pressing the Forward or Reverse push button, on completion of the pass a control limit switch switches the unit off. A Full Current limit switch operates in the advent of the control limit switch failing;
7. Easily to remove at end of production cycle and easy to reset up;
8. Low operating cost. Used daily for 1 cycle of 1 hour with a 1Kw electric motor electricity cost would be $40.15 per annum per module; and
9. All electrical and mechanical components are located external to the building permitting full use of the production area.

The disadvantages associated with the blade plough design are limited, but include:

1. Incomplete mixing of the litter bed. Site constraints made it essential to minimize the height of the plough, limiting the freefall height of the litter. To overcome this problem the design was modified to enable semi automatic operation with minimal disturbance to the flock;
2. Compliance with Queensland OH&S requires staff not be permitted within the area whilst the plant is operational. To assist with safety emergency stop buttons will be located within the broiler shed;
3. The V shape of the plough by its very nature only permits movement in one direction. To overcome this problem the base plate was made identical and top plate was pivoted, the direction the top plate is pivoted is controlled by the direction of pull of the winch cables; and
4. Corrosive nature of chicken manure. The Capstan ropes operate beneath the litter bed to overcome this corrosive environment. The capstan ropes are made from 316 grade stainless steel.
The blade plough provides an opportunity for intensive poultry farmers to eliminate existing problems of odour from caking of the litter, which until now has required physical effort and costly labour to remediate. After the initial financial outlay for the acquisition of capital equipment and installation, future operational costs are minimal.

6.4.3 Conceptual Design Three: Reversible Paddlewheel Plough

Both the Inversion and blade ploughs are simple in the manner they operate. A more sophisticated design was developed to raise the litter bed, mix and aerate and lay back in a smooth uniform layer. The reversible paddlewheel plough (seen in Figure 6.9 and Figure 6.10) provides all operational functions from the action of being pulled by a capstan winch external to the shed end, the motive force to turn the paddle wheel comes from a step up gearbox driven by the bogie wheels. This principle was used in hand push mowers of yesteryear. The advantages of the reversible paddlewheel plough include, but are not limited to:

- Complete mixing and aeration of the litter bed;
- Level, even and fluffy finish after plough has passed;
- Complete breakup of caked litter;
- No electrical power or engine required to operate within the shed. All power is provided by twin capstan winches mounted externally to the building and production area; and
- Low impact with livestock (chickens). Height of the unit is 100mm above the litter bed. Paddlewheel covers, self adjusting for height, ensure livestock do not get trapped, crushed, drawn into or beneath the paddlewheel.

There are disadvantages associated with the rotary tiller plough, most emanating from the complexity of the design and the cost associated with the need to use four (4) step up gearboxes (Figure 6.11). This system is theoretical in design, although a similar use of a step up gearbox in the form of a push cylindrical mower is well known to the public, due to cost and time constraints it was not possible to manufacture a model for testing.
Figure 6.9: Conceptual Paddlewheel Plough – Whole Final Design

Figure 6.10: Conceptual Paddlewheel Plough – Cover Removed
6.5 Decision Matrix for Poultry Litter Plough

The decision matrix is a value managing chart that allows analysis and ratings to be given to any number of alternatives in question. The function of the decision matrix is to allow direct comparisons between the alternatives in question where the highest score is regarded the best option for implementation.

Upon completing the three different conceptual designed ploughs, a set of key criteria was created to provide an assessment of importance for each criterion relating to each design. The criteria deemed important in the plough design are:

<table>
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<tbody>
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<td>Low Cost</td>
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<tr>
<td>Ease of Assembly</td>
</tr>
<tr>
<td>Ease of Maintenance</td>
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<td>Weight</td>
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<tr>
<td>Lifecycle</td>
</tr>
<tr>
<td>Litter Results</td>
</tr>
</tbody>
</table>

Table 6.1: Criterion for Plough Conceptual Design
It must be noted that there are other design factors influencing the design process, however the criteria provided in Table 6.1 was determined to be the significant qualities required when deciding the final plough design to use.

The next requirement is to assign a weighting value for each criterion. This is done to ensure the most significant design requirements were given a higher importance and the less significant requirements would not significantly affect the final design decision. The weighting values given to each criterion provide an indication of importance where a higher weighting value will indicate the importance of the criterion to the overall design and were assigned as seen in Table 6.2.

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<th>Weighting</th>
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<tr>
<td>Ease of Assembly</td>
<td>2</td>
</tr>
<tr>
<td>Ease of Maintenance</td>
<td>2</td>
</tr>
<tr>
<td>Weight</td>
<td>1</td>
</tr>
<tr>
<td>Lifecycle</td>
<td>3</td>
</tr>
<tr>
<td>Litter Results</td>
<td>3</td>
</tr>
</tbody>
</table>

From Table 6.2, the significant criteria that will affect the design choices are low product and infrastructure cost, the total operational life of the design and the resulting ability of the plough to constantly aerate and disrupt the poultry litter. The importance of low product and infrastructure cost stem from the project budget and the desire to design a cost effective solution to reduce odour emissions for farmers. The plough has to be designed to take the repetitively high numbers of load cycles experienced as well as a high resistance to the corrosive compounds in the litter due to poultry excrement. Ease of assembly and maintenance are important design factors as the design should be built to allow construction and assembly to be performed easily by labouring/workshop staff, while allowing easy access for technicians and farmers to perform maintenance and service all plough equipment. The weight of the plough is considered of less importance, however, it must be noted that these ploughs
required a certain degree of weight to provide stable operation, as a certain amount of
downforce is used to keep the plough running parallel and true to the shed floor. However excessive weight will be a detrimental to the design performance, because
the plough would require a more powerful power unit to pull the plough through the
litter and well as adding additional stresses to key components.

Regarding criterion value allocation, a range of value from 1 to 5 is used where 1 is
the lowest rating and 5 the highest rating. Values have been assigned to each of the
criteria for both conceptual designs, providing an overall score for both therefore
allowing a decision to be made upon the plough design. The completed decision
matrix is shown in Table 6.3.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Weighting</th>
<th>Blade</th>
<th>Paddlewheel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Cost</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Ease of Assembly</td>
<td>2</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Ease of Maintenance</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Weight</td>
<td>1</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Lifecycle</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Litter Results</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total Rating</strong></td>
<td></td>
<td><strong>49</strong></td>
<td><strong>39</strong></td>
</tr>
</tbody>
</table>

The total rating values for each design is obtained by multiplying the given score from
each criterion by the associated weighting value in the same row and then adding
together all the values to obtain the total rating score.

### 6.5.1 Decision Matrix Discussion

As viewed from Table 6.3: Decision Matrix, each conceptual design score has shown
some similarity for certain criterion while other criteria varied significantly. The
reasoning for such scoring is discussed below.
Cost:
The cost components of each conceptual design and subsequent externally mounted power winch system will require a moderate amount of investment to set up the infrastructure and pay for the labour to construct the design (see section 7.4 & 7.5), however, the cost will be significantly lower compared to buying and trying to use rotary tiller equipment in the shed with livestock in it. As there is currently no other systems that currently perform the desired operation on a small scale, the cost can only be compared to the current method of farmers using tractors with rotary and blade implements to disrupt the litter, however this is very problematic which is the reason such a design is warranted, to reduce the need for such operation.

The power winch system infrastructure cost will be similar for each design, except the paddlewheel plough is four times heavier than the blade plough requiring an increase in motor and gearbox performance that is commonly obtained by designating a higher capacity motor which is more expensive. This is the first consideration towards the paddlewheels low score. The blade plough received a mid-range score of 3 due to the simplicity of the design and ease of manufacture. As it can be seen from the blade plow costing sheet, significantly less man hours and materials is required manufacture the 3m long blade plough unit and related components when compared to the paddlewheel plough. The paddlewheel plough design will be significantly more expensive compared to the blade plough because of the need for more complex components such as the bogie wheel gearbox used to turn the centrally mounted paddlewheel. The significant increase in cost regarding the gearbox include; the need for 14 custom cut and treated spur gears and subsequent supporting shafts per unit, high levels of labour requirements needed for the repetitive precise machining and drilling (including tapering) for screws and bearing covers with lower tolerances to provide a sealed fit to prevent the spur gear lubricant from seeping out and the need for a high power rated electric motor/gearbox unit to pull/power the dry weight of the plough \( m = 145 \text{ kg} \) and addition of livestock resting atop the plough. For the reasons discussed, the paddlewheel plough was given a much lower score of 1.

Ease of Assembly:
The blade plough received a perfect value for ease of assembly because the blade plough would only require basic mechanical and numerical skills to assembly as all
the support hinges are simple bolted together and the location for attachment that requires welding on the plough base and cover are easily marked out or setup by use of a jig. The paddlewheel plough is not significantly harder to assemble, however the shear amount of components that encompass the design will dramatically increase the labour hours required for assembly. Aligning the spur gears with their shaft keys which is supported either side by ball bearings to allow for efficient power transmission and uni-directional movement of the internal components, there is a need for extra time and effort for calibration. The shear number of bolts used to hold together the lid and cover are time sink elements that in future designs may overcome. For the reasons discussed, the paddlewheel plough was again given a much lower score of 2 for ease of assembly.

**Maintenance:**
The blade plough scored slightly higher than the paddlewheel plough in the maintenance criterion. The blade plough will be easier to maintain and service due to simplicity of the design. Maintenance and service of either ploughs will occur after livestock has been harvested and the preparation for the next livestock batch commences (usually 1-3 week period for disinfecting, litter cleanout and relaying). During this time the farmer will disconnect the winch cables and pull the plough out with their tractor for maintenance and cleaning. The blade plough must be able to withstand these loading conditions, however the paddlewheel plough will require a gentler and more time consuming approach to bring it outside for maintenance to avoiding awkward and extreme loadings that could deform or destroy components. Visual inspection of blade plough is basic, however the paddlewheel plough requires disassembly of the cover and gearbox lid for the visual inspection of gears, shafts, keyways, seals and lubrication levels. For the reasons discussed, the blade plough scored a slightly higher value of 4, compared to the lower value of 3 given to the paddlewheel plough for ease of maintenance.

**Weight:**
The weight criterion was not weighted very highly because most agricultural machinery and implements must be heavily overbuilt to cope with extreme conditions, meaning that much more material is used in the manufacture of the equipment than is needed during normal operation. (Bullock, B. K. 2006). This factor coupled with a
minimum weight requirement to keep the plough running horizontal along the shed floor are the only positive factors for additional weight, however the weight of both plows will significantly affect power requirements to mechanically pull the plough through the litter via winch system. Data acquired from the imported conceptual 3D solid model blade plough from ProEngineer into Ansys, the total material volume was obtained while designating the material choice to be AISI 1020 with a material density $\rho = 7700 \text{ kg/m}^3$, thus allowing the total mass of the plough to be found using the mass formula;

$$m = \rho \times V$$  \hspace{1cm} (6.1)

Where $m$ is mass [kg]; $\rho$ is density [kg/m$^3$]; and $V$ is volume [m$^3$];

$$m = 7700 \times 7.1468 \times 10^{-3}$$

$$m = 55.03 \text{ kg}$$

Repeating the procedure above of importing of the completed 3D paddlewheel solid model conceptual design from ProEngineer into Ansys, the total material volume $V = 1.7967 \times 10^{-2} \text{ m}^3$ was obtained while designating the material choice to be AISI 1020 with a material density $\rho = 7700 \text{ kg/m}^3$, thus allowing the total mass of the plough to be found using equation (6.1);

$$m = \rho \times V$$

$$m = 7700 \times 1.7967 \times 10^{-2}$$

$$m = 138.35 \text{ kg}$$

Additional masses that must be considered for the design load calculation include the potential additional mass of chickens resting upon the plough during operation and the total weight of litter onto and in the plough. As can be seen the dry weight of the blade plough nearly one third the weight of the paddlewheel plough. The overall implication of this means the winch power system will not have to be over designed as greatly, for example smaller winch drum shafts and smaller motor and gearbox needed to pull the unit through the litter, which equates to cost reductions for everyone. For this reason, the blade plough scored a high value of 4, compared to the lower value of 2 given to the paddlewheel plough due to the extra cost needed to design the power winch system to accommodate the greater weight.
Life Expectancy:

The operational life expectancy of the ploughs is an important design consideration as designing a plough system for long life will reduce ongoing costs such as maintenance and reduce the need to replace components that wear out or break. Both conceptually designed ploughs scored an equal value for this criterion due to the possible failure nature of certain components and materials used for each design. To design for long / infinite life is desirable but not always possible. Regarding the motor that powers the winch system connected to the plough, both systems require reversible power delivery from the motor for the system to provide automated operation from the push of a switch. However, after the plough has completed one pass in an hour, the system will shut off, requiring a restart of the motor to perform another pass. While the total motor operation hours per year may be low, the fact that the motor has to restart for each pass, will experience a shock loading and reverse of direction from the output shaft will shorten the operational life of the motor. However, a special electric motor can be specified for power delivery that is specifically designed for reversible direction power delivery (refer to Chapter 8).

Material:

Material selection will help overcome the constant cyclic loads and vibration that are placed upon the plough during operation. AISI 1020 mild steel (low carbon) is the material chosen for construction because it is heavy but strong with a potential ‘infinite’ fatigue, an endurance limit – a stress level for which an infinite number of load reversals may be endured and higher resistance to excessive creep. For low carbon steel, the major environmental problem is corrosion and due to the corrosive nature of manure and odours compound this is a major design factor. However with material coating treatments to prevent corrosion, such as hot dipping (galvanizing), conversion coatings, organic coatings or powder coating we are able to overcome this problem. The components that are of some concern with the blade plough design is shear stresses experienced in the top hinge support cylinder elbows that hold and tilt the plough blade cover (Figure 6.12) and in the bottom hinge support cylinder elbows (Figure 6.12) that the winch cable system pull upon to tilt the blade in the direction of pull. However, higher grade material can be used to take the high stress incurred and provide a safe design (as discussed in Chapter 7).
Litter Testing Results:

Litter results refer to the ability of the plough to effectively and reliably reproduce litter disruption and aeration results. The conceptual blade plough design scored a moderate value of 3 due to the effective litter disruption and aeration demonstrated during the testing phase. The blade plough that was constructed for testing was made to imitate the operation of the actual plough running underneath the litter. The trailing lip that provided a fall and tumble effect while aerating particles of the litter during the fall was set at a height of 100mm and the litter was set to an average depth of 100mm (to enact worst litter pile up scenario). After several passes it was determined that an average litter disruption effect of 50% was achieved on wetter and broken down litter. While the disruption effects found was average, the blade plough would be used more often compared to the paddlewheel plough to achieve results of the same quality. The paddlewheel plough is theoretical in design and operation and it is beyond the budget of this project to construct a prototype to test its effectiveness. However when comparing the how effectively a steamboat paddlewheel moves, disrupts and aerates large volumes of water when in operation, it can be inferred the conceptual plough designed to mimic this operation would, for this project also
produce effective litter disruption and aeration results, resulting in the reasons discussed previously a top score of 5 has been given to the paddlewheel plough for reproducibility of results.

### 6.6 Conclusion

As shown in Table 6.1, the conceptually designed blade plough has scored the highest value of the two designs after finishing the decision making process. Therefore, conceptually designed blade plough, shown in Figure 6.6, has been chosen as the final design, and the remaining components and specification will be designed to be compatible only with the blade plough design.
Chapter 7: REVERSIBLE BLADE PLOUGH SYSTEM DESIGN

7.1 Introduction

Analysis of the 3 plough designs including: performance, cost, development, timeline for completion and compliance with project guidelines, lead to the selection of the reversible blade plough as the most appropriate for this type of situation. The plough with its operational ability to move beneath the litter bed without causing harm to equipment or livestock, this means that the plough modules can be operated at any time over a 24 hour period. With a Programmable Logic Controller (PLC) included with a multi module installation full automation can be achieved with each module operating on a one hour single pass every 3 hours (more or less) over daylight hours at the farmers discretion.

Operating cost for each module are comparatively low, with the annual cost being (0.18kW x 1 hour x 365 x $0.12/kWh) $7.88 per annum (one cycle pass per day). As an example if a 12 meter wide shed had 4 units, which operated 4 times per day, the total power costs would be $126.08 per annum. The amortization of cost of $60,000 over a 10 year period requires a payment of $712.21 / month to offset interest and principle.

The reversible blade plough is not only effective in meeting the project criteria but does so at a tax deductible amortization cost less than the weekly wage for one
workman. In comparison the reversible blade plough operates 7 days per week 52 weeks of the year

7.2 Material Selection

Three main requirements of the construction material to be used for the plough are high strength, high fatigue resistance and low cost. Other material requirements that require some considerations include:

- Availability;
- Ease of manufacture;
- Strength; and
- Fatigue resistance.

Required to deal with the loads that will be placed upon the plough but also avoid destructive failure of components due to stresses incurred during operation. Fatigue resistance is needed to deal with the cyclic loads and vibration that result from travelling along the shed base as well as the constant cyclic loading from the poultry livestock. Cost is a major requirement as agricultural machinery will be commonly overbuilt and over designed to cope with extreme conditions, meaning that much more material is used in the manufacture of the equipment than is needed during normal operation therefore increasing cost which is not favourable and weight which is favourable for this situation (as previously discussed).

Availability of material resources is of importance as large quantities of material will be needed to manufacture the required number of units for each shed. Upon completion and installation on the shed floor the units operating systems will be interlinked and operate in sequence to produce the desired litter disruption and aeration effect. Therefore the material will need to be readily available and cost effective to manufacture.

Steel is a highly versatile alloy of iron and carbon. Other alloying elements such as Silicon, Manganese, Sulphur, Molybdenum, Phosphorus, Nickel and Chromium, can be added to improve its material properties. Due to the abundance of iron in the form of mineable iron ore and carbon in the form of coking coal, steel is one of the cheapest and readily available manufacturing materials available. Heat treatment and
tempering processes carried out on these steels can improve their hardness and/or toughness properties. Many different forms of steel are available depending on its individual makeup of elements.

Plain carbon steels contain only carbon as a significant alloying element with small amounts of other elements added. The strength of plain carbon steel will increase with the percentage of carbon (Figure 7.1). However, while an increase in carbon will improve the yield and tensile strength of the material, the ductility will decrease incurring a greater susceptibility to brittle fracture. Plain Carbon Steel group is categorized into three main sections which are graded on their percentage of carbon content.

- Low carbon steel has less than 0.3 % carbon content and is the most widely used steel. Low carbon steel is easy to form and cast. It is commonly used for applications where extreme loading conditions are rare and high strength is not required. It is also the cheapest of the three categories.
- Medium carbon steel has between 0.3 % to 0.5 % carbon content while still retaining a certain degree of ductility. It still provides moderate strength while still maintaining affordability.
- High carbon steel carbon content greater than 0.5 % and is specifically made for applications where high strength, hardness, stiffness and high resistance to wear are crucial factors required for the design.

![Figure 7.1: Hardness and Tensile Strength of Plain Carbon Steels (Askeland, 2001)](image-url)
Low carbon steel is suitable as it is strong and heavy, with a potential ‘infinite’ fatigue life, easy to weld and needing no special heat treatments. It is very agreeable to ‘Owner modifications’ and can be easily cut to shape with a variety of methods. Low carbon steel is inexpensive and readily available ‘off the shelf’ in a large range of sizes. Though prone to rust, low carbon steel is easily painted, and with the correct coating choice, is easily and successfully repaired. These shapes can be joined together to form strong parts using inexpensive welding methods.

Therefore consideration of material requirements and cost preclude the use of all but one material, which is steel. Bullock, B. K. (2006) explains how a significant majority of agricultural machinery is constructed almost totally from steel due to aforementioned reasons. Steel can be purchased in a variety of different alloy types and treatments ranging in yield strength from AISI 1015 at 284.4 MPa to AISI 8650 at 688.1 MPa (Juvinall & Marsheck 2000). As a general rule, the higher the AISI number, the more carbon is present in the alloy, the higher the strength and the costlier the steel. It is concluded that the most suitable steel for the proposed plough construction is AISI 1020 in a as-rolled state with the material properties presented below in Table 7.1.

Table 7.1: Mechanical properties of AISI 1020 Mild Steel (As-rolled)
Appendix C-4a (Juvinall & Marshek 2000)

<table>
<thead>
<tr>
<th>Material Property</th>
<th>AISI 1020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young's Modulus (E)</td>
<td>207 GPa</td>
</tr>
<tr>
<td>Poisson's Ratio (ν)</td>
<td>0.3</td>
</tr>
<tr>
<td>Density (ρ)</td>
<td>7700 kg/m³</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>448.2 MPa</td>
</tr>
<tr>
<td>Yield Strength</td>
<td>330.9 MPa</td>
</tr>
</tbody>
</table>

AISI 1020 mild steel was selected primarily because of its considerable low cost, ease to weld, form and machine while repairs and modifications can safely be done by owner. AISI 1020 will be used for all of the structural components except on shaft keys, bolts and where otherwise noted.
7.3 Design Calculations

Determining the minimum power and torque requirements was the first of many
design decisions and calculations performed. The mass of the plough and associated
masses found during operation will determine the static loads that will be used to find
minimum power and torque requirements.

The mass of blade plough unit three meters in length = $m_{\text{plough}} = 55 \text{ kg}$. Total mass of
chickens resting upon plough at any one time, where one chicken at their largest and
oldest phase during its lifecycle weighs 4 kg at an estimated diameter of 300mm,

$$3000 \div 300 = 10 \text{ chickens upon the plough at any one time}; \text{ therefore,}$$
Mass $\text{chickens} = m_{\text{chickens}} = 10 \times 4\text{ kg} = 40\text{ kg}$

Total mass of poultry litter at depth of 100mm (worst case pile up depth) on top of
plough during operation, estimated at $m_{\text{litter}} = 40\text{ kg}$.

Total Static Loads:

$m_{\text{plough}} = 55\text{ kg}$
$m_{\text{chickens}} = 40\text{ kg}$
$m_{\text{litter}} = 40\text{ kg}$

Estimated total mass of plough:
$m_{\text{total}} = 135\text{ kg}$

![Figure 7.2: Free Body Diagram of Blade Plough](image)
The calculations for force due to the gravitational force acting upon an object (Figure 7.2) are; Newton's second law equation (1/1) (Meriam & Kraige 1998);

\[ F = mg \]  

(7.1)

where:

\( F \) = Force (N)

\( m \) = Mass (kg)

\( g \) = acceleration due to gravity (m/s²)

Normal force acting on the plough base (Figure 7.2);

\[ F_N = m_{\text{total}} \times g = 135 \times 9.81 = 1324.35 \, N \]

Friction force generated from the contact of the plough base on the shed floor (Figure 7.2), where the Coefficient of Friction used is concrete on steel because steel on soil C.O.F. could not be found. Therefore; \( \mu = 0.45 \)

\[ F_R = F_N \times \mu = 1324.35 \times 0.45 = 595.96 \, N \]

Additional force is required to overcome the resistance force due to the volume of litter and chickens in front of the plough impeding the ploughs forward motion. Therefore by adding the additional weight of litter and chickens permissible on top of the plough cover to the friction force of the plough, a minimum required force will be found to permit the plough to operate in the direction of pull underneath the poultry litter while dropping them over the back of the plough cover disrupting and aerating the litter.

\[ m_{\text{additional}} = m_{\text{chickens}} + m_{\text{litter}} = 40 \times 40 = 80 \, kg \]

\[ F_{\text{additional}} = m_{\text{additional}} \times g = 80 \times 9.81 = 784.8 \, N \]

Therefore the total minimum force required to overcome static and friction forces allowing the plough to operate and run below the poultry litter is;

\[ F_{\text{total}} = F_R + F_{\text{additional}} = 595.96 + 784.8 = 1380.76 \, N \]

It is now possible to determine the required torque at the shaft to pull the plough;
As seen from Figure 7.3, the force transmitted by the stainless steel cables through the bottom sheaves is the same in the x and y components, therefore as the cables leave the sheave at the same diameter the x component force is equal to the y component force.

Shaft loading – the required torque that must be provided by the motor and gearbox to the shaft that is connected to two 300 mm diameter capstan drums either side of the shaft for the purpose of pulling the plough through the litter, is found by using the equation for torque;

\[ T = F \times r \]  

(7.2)

Where:  
T = torque (Nm)  
F = force (N)  
r = radius (m)

Total torque produced in shaft:

\[ T = F_{\text{total}} \times r = 1380.76 \text{N} \times 0.150 \text{ m} = 207.114 \text{ N.m} \]

Therefore, the plough requires a motor and gearbox system that can provide a minimum 207.114 Nm of torque at plough speeds of 2 meters / minute.
To meet these requirements, a motor and gearbox package (Figure 7.4 Bonfiglioli Model VF/W 44/75_400 P71 BN71A6 M) was found at “Bonfiglioli, Power and Control Solutions”, 1048 - 1054 Beaudesert Road, Coopers Plains, QLD, 4108, Australia. The motor gearbox package specified would deliver 361 Nm of torque at the 30mm diameter output shaft, compared to the smaller sized package that could only deliver 195 Nm of torque. Over designing and over specifying allows a greater factor of safety (FOS) to be included during the calculation process.

Using this new output torque, the new force acting at the end of the capstan drum in the cable can be found. Rearranging equation (7.2) gives:

\[
F_{\text{Total}} = \frac{T}{r} = \frac{361}{0.015} = 2406.67 \, N
\]

There is now a total force of 2406.67 N acting in the both stainless steel cables at the end of both the capstan drums that pull the plough. Using this force, it is found that there is a factor of safety equal to 1.75 being used when calculating to the torque specifications of the motor gearbox unit. The FOS found will suffice for this design because of the nature of the operation of the plough in the litter as almost all loading
conditions are static with minimal shock loadings resulting from the friable nature of litter and the slow operational speed of the unit (Motor gearbox operate at 2.3 RPM and the operating velocity of the plough is 2.17 m/min). However, future design and redesign should be calculated to a FOS of about 5, which is commonly used when designing agricultural equipment.

The next area of design calculations regarding the blade plough unit will be centered around the plough cover tilting mechanism (Figure 7.5) when a pulling force is applied the cover tilts down in the direction of pull. The tilting mechanism will contain the highest loadings and stress points and be the most likely area for potential failure within the plough system.

![Figure 7.5: Plough Cover Tilting Mechanism](image)

The areas of interest to check for failure during operation is in the top and bottom hinge support cylinders failing due to shearing from the hinges at (a) the bottom hinge from being pulled by the cables and (b) the top hinge from the compressive loads incurred from the plough cover, litter, chickens and additional forces to overcome pulling resistance. The first area for calculation is the bottom hinge support cylinder and the force acting in the center of the elbow due to the force in the wire.
Initially, the force acting in the machined elbow which the bottom hinge rests upon needs to be found first to allow the subsequent shear stress to be calculated. If the elbow is strong enough to withstand the shear stresses, the bending moment generated by the hinge force in the support cylinder elbow that is welded to the support bracket will then be found. Due to slow operation speeds the loading effects on the plough is mostly static and as there are no real dynamic and shock loadings and the small change in pheta in the hinge when force is applied, static loads will be used for the subsequent calculations. The reaction force ($F_R$) at the top hole of the hinge will be equal to the force generated at the bottom hole of the hinge ($F_{Total}$) due to the pulling force in the cable. Therefore the force on the elbow is equal to the sum of all forces;

$F_{Total} = 2406.67 \, N$

$F_{Total} = F_R$

$\sum F_x = F_{Total} + F_R - F_{elbow} = 0$

$F_{elbow} = F_{Total} + F_R = 2406.67 + 2406.67$

$F_{elbow} = 4813.34 \, N$

Calculating the shear stress on the cylinder elbow due to the hinge forces is found by using equation (4.2) (Juvinall & Marshek 2000) for direct shear loading, where;
\[ \tau = \frac{F}{A} \]  

(7.3)

Where:

- \( \tau \) = Shear Stress
- \( F \) = force (N)
- \( A \) = area (mm\(^2\))

Where the area of the elbow affected by shear is the Outer Diameter (OD = 14 mm) minus the Inner Diameter (ID = 10 mm) and the force used will be for worst case scenarios when all the torque is delivered to only one end of the shaft due to a cable breaking, bogging, snagging or the plough getting caught in an even part of the compacted earth.

\[
A = \frac{\pi \times d_{OD}^2}{4} - \frac{\pi \times d_{ID}^2}{4} = \frac{\pi \times 14^2}{4} - \frac{\pi \times 10^2}{4} = 153.94 - 78.54 = 75.4 \text{mm}^2
\]

\[
\tau = \frac{F}{A} = \frac{4813.34}{75.4} = 63.84 \text{MPa}
\]

Therefore, the shear stress generated is much lower than the maximum permissible shear strength of AISI 1020 during worst case loading, therefore an acceptable loading stress for this situation.

The pure bending stress of the hinge support cylinder due to the hinge will be calculated next. The aim is to find the highest tensile and compressive forces generated at the welded base to determine if material failure will occur. Modelling the cylinder as a rigidly supported cantilever beam with a concentrated load at the end allows the free body and force diagrams to be created as shown in Figure 7.7.
To calculate the pure bending stress, imagine the elbowed hinge cylinder as a hollow shaft rigidly supported at one end with the elbow cut off and the force applied at the cylinder end surface in the direction of pull. The reasoning for modelling this as a hollowed cylinder is due the possibility of the bolt in the cylinder becoming loose and not forming a solid and tight tolerance fit, therefore by designing for the worst case, the hollowed shaft is used for calculations.

Referring to Figure 7.8, the expected bending stresses are located at points A & B, where A is in tension and B is in compression. It is noted that both the bending
moment and distance from the neutral bending axis are a maximum at these two locations. Transverse shear stresses are relatively small compared to bending stresses, and equal to zero at points A & B, thus will be neglected. Investigation of points A & B is required. The normal stresses due to bending formulas were sourced from (Beer & Johnston 2002).

\[
\sigma = \frac{Mc}{I}
\]

where:
- \( M \) = Bending moment (Nm)
- \( I \) = Moment of inertia (m^4)
- \( c \) = Radius of shaft (m)

\[
F = 4813.34 \, N
\]
\[
d_{OD} = 16 \, mm
\]
\[
d_{ID} = 10 \, mm
\]
\[
M = 129960.18 \, Nmm
\]
\[
c = 8 \, mm
\]
\[
I = I_{OD} - I_{ID}
\]
\[
= \frac{\pi \times d_{OD}^4}{64} - \frac{\pi \times d_{ID}^4}{64}
\]
\[
= \frac{\pi \times 16^4}{4} - \frac{\pi \times 10^4}{4}
\]
\[
= 2726.12 \, mm^4
\]

Bending stresses at worst loading case:

\[
\sigma = \frac{Mc}{I} = \frac{129960.18 \times 8}{2726.12} = 381.38 \, MPa
\]

The stress found is greater than the yield strength of AISI 1020, therefore the elbow support shaft will fail during a worst case loading scenario.

Calculating bending stresses at normal operating loads;
\[
M = \frac{F \times l}{2} = \frac{4813.34}{2} \times 27
= 64980.09 \, Nmm
\]

\[
\sigma = \frac{Mc}{I} = \frac{64980.09 \times 8}{2726.12}
= 190.69 \, MPa
\]

The stress found is smaller than the yield strength of AISI 1020, therefore the elbow support shaft will not fail during a worst case loading scenario. However, while the component may not fail and these loads, there is still a significant amount of stress generated which is less than desirable.

Further improvement of the bottom elbow hinge support cylinder would comprise of specifying a higher grade AISI grade steel with higher rating material properties (greater yield and tensile strength) while reducing the length of the cylinder will greatly reduce bending moment generated.

The second area to calculate is the force on the top hinge due to the weight of the blade cover, litter, chickens and the additional force is required to overcome the operating resistance.

Figure 7.9: Top Elbow Support Cylinder Analysis
First, the force acting on the machined elbow is found to then calculate the shear stress on the cylinder elbow due to the hinge and finally calculate the bending stresses generated in the top welded support cylinder due to the force at the machined elbow. As previously mentioned, static loading values will be used due the aforementioned reasons. To obtain the force acting on the elbow due to the top hinge cover supports (Figure 7.9), the mass of the plough cover and surface loads are calculated.

\[ m_{total} = m_{cover} + m_{litter} + m_{chickens} + m_{additional} = 14.1 + 40 + 40 + 80 = 174.1 \text{ kg} \]

Total force (F) acting down upon the elbow due to the masses;

\[ F = 174.1 \times 9.81 = 1707.9 \text{ N} \]

The force is uniformly distributed along the top of the plough cover supported by 4 hinges, therefore the total force found is divided evenly among the 4 support hinges. However, worst case scenario dictates the U.D.L. being carried by the 2 outer most hinge supports only and therefore calculated as such.

\[ F_R = \frac{1707.9}{2} = 853.95 \text{ N} \quad \text{Factoring in the factor of safety found previously,} \]
\[ F_R = 853.95 \times 1.7 = 1451.72 \text{ N} \]

Direct shear loading stress on the cylinder elbow due to the hinge force is found by using equation (4.2) (Juvinall & Marshek 2000), where;

\[ F = 1451.72 \text{ N} \]
\[ d_{od} = 15 \text{ mm} \]
\[ d_{id} = 10 \text{ mm} \]

\[ A = \frac{\pi \times d_{od}^2}{4} - \frac{\pi \times d_{id}^2}{4} = \frac{\pi \times 15^2}{4} - \frac{\pi \times 10^2}{4} = 98.17 \text{ mm}^2 \]

\[ \tau = \frac{F_R}{A} = \frac{1451.72}{98.17} = 14.79 \text{ MPa} \]
Therefore, the shear stress generated is much lower than the maximum permissible shear strength of AISI 1020 during worst case loading, therefore an acceptable loading stress for this situation.

The pure bending stress of the hinge support cylinder due to the hinge will be calculated next. To calculate the pure bending stress, imagine the elbowed hinge cylinder as a hollow shaft rigidly supported at one end with the elbow cut off and the force applied at the cylinder end surface in the direction of pull as previously done.

![Figure 7.10: Force Diagrams For Top Cylinder](image)

![Figure 7.11: Expected Maximum Bending Stress Locations](image)
Referring to Figure 7.11, the expected bending stresses are located at points A & B, where A is in tension and B is in compression. Therefore, investigation of points A & B is required. The normal stresses due to bending are found, where;

\[ F_R = 1451.72 \text{ N} \]
\[ d_{OD} = 20 \text{ mm} \]
\[ d_{ID} = 10 \text{ mm} \]
\[ M = 24679.24 \text{ Nmm} \]
\[ c = 8 \text{ mm} \]

\[ I = I_{OD} - I_{ID} \]
\[ = \frac{\pi \times d_{OD}^4}{64} - \frac{\pi \times d_{ID}^4}{64} \]
\[ = \frac{\pi \times 20^4}{64} - \frac{\pi \times 10^4}{64} \]
\[ = \frac{\pi \times 40000}{64} - \frac{\pi \times 10000}{64} \]
\[ = 7363.11 \text{ mm}^4 \]

Bending stresses at worst loading case;

\[ \sigma = \frac{Mc}{I} = \frac{24679.24 \times 10}{7363.11} \]
\[ = 33.52 \text{ MPa} \]

Therefore, the bending stress generated is much lower than the maximum permissible material strength of AISI 1020 during worst case loading, therefore, it will not yield of deform and is an acceptable loading stress for this situation.

Determined from the calculations, the plough cover tilting mechanism will work and withstand the loads experienced during operation, however, the bottom hinge support elbow would be the first point of failure in the mechanism. Therefore, redesign would be required for this component in the future to ensure safe operation and a long lifecycle of the mechanism.
7.4 Parts, Material and Manufacturing Cost

Manufacture of the reversible plough has been simplified by the use of geometric shapes in its design. This simplicity in design enables components to be cut on a guillotine and bent into shape from a standard 3000mm x 1220mm sheet of 1.6mm zinc anneal steel, gussets were added for additional strength and to carry the tilting mechanism pivot points without dramatic increases in weight. Each component was costed from quotes received by specialist manufacturing companies, service providers and propriety equipment suppliers.

7.4.1 Plough

Figure 7.12: Blade Plough Parts Numbering
### Part No. 1 – plough base - folded 1.6mm zinc annealled steel

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 metre plough base</td>
<td>1</td>
<td>$151.15</td>
<td>$151.15</td>
</tr>
</tbody>
</table>

### Part No. 2 – base rib

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base plate strengthening rib</td>
<td>2</td>
<td>$59.50</td>
<td>$119</td>
</tr>
</tbody>
</table>

### Part No. 3 – reversible top blade – folded & welded 1.6mm Zinc annealed steel

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 metre long top blade</td>
<td>1</td>
<td>$179.25</td>
<td>$179.25</td>
</tr>
</tbody>
</table>

### Part No. 4 – top actuating lever – 25 x 8 flat steel

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top leaver welded to top blade</td>
<td>2</td>
<td>$9.00</td>
<td>$18.00</td>
</tr>
</tbody>
</table>

### Part No. 5 – bottom actuating lever – 25 x 8 flat steel

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tilt bottom actuating lever</td>
<td>2</td>
<td>$9.00</td>
<td>$18.00</td>
</tr>
</tbody>
</table>

### Part No. 6 – lower pivot point

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower machined pivot point</td>
<td>2</td>
<td>$21.45</td>
<td>$42.90</td>
</tr>
</tbody>
</table>

### Part No. 7 – top pivot point

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top machined pivot point</td>
<td>2</td>
<td>$21.45</td>
<td>$42.90</td>
</tr>
</tbody>
</table>

### Part No. 8 actuator connecting pin

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lever connecting pivot pin</td>
<td>2</td>
<td>$9.75</td>
<td>$19.50</td>
</tr>
</tbody>
</table>
7.4.2 Winch System

The capstan winch drive system is the heart (motor, gearbox & capstans) and the mind (electrical control equipment) that provides the motive power to pull the plough beneath the litter bed. The mechanical and electrical system is practical in design and layout, robust in construction, whilst still retaining a ‘simple artistic beauty’. Cost estimates for each sub assembly and/or component was costed from written and verbal quotations provided by specialist manufacturing companies, service providers and propriety equipment suppliers.

![Image of Winch System]

**Figure 7.13: Winch System Numbering**

<table>
<thead>
<tr>
<th>Part No. 1 – electric motor with worm gear reduction gearbox</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITEM</td>
</tr>
<tr>
<td>BONFIGLIOLI worm gearbox VF/W 44/75-400 P71 BN71AG</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part No. 2 – 30mm gearbox output shaft</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITEM</td>
</tr>
<tr>
<td>30 mm Dia. Stub shaft</td>
</tr>
</tbody>
</table>
### Part No. 3 – Flexible coupling

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible coupling pin half</td>
<td>4</td>
<td>$203.40</td>
<td>$813.60</td>
</tr>
<tr>
<td>Flexible coupling bush half</td>
<td>4</td>
<td>$69.74</td>
<td>$278.96</td>
</tr>
</tbody>
</table>

**SUB TOTAL COST – FLEXIBLE COUPLINGS** $1092.56

### Part No. 4 – Intermediate drive shaft

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>40mm Dia. Bright steel shaft</td>
<td>2</td>
<td>$24.50</td>
<td>$49.00</td>
</tr>
</tbody>
</table>

### Part No. 5 – Pillow block bearing

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSK UCPG206D1</td>
<td>16</td>
<td>$21.00</td>
<td>$294.00</td>
</tr>
</tbody>
</table>

### Part No. 6 – Capstan drive stub shaft

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>30mm Dia. bright steel machined and keyway</td>
<td>4</td>
<td>$15.00</td>
<td>$60.00</td>
</tr>
</tbody>
</table>

### Part No. 7 – Capstan winch drum

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capstan winch drum</td>
<td>4</td>
<td>$190.00</td>
<td>$760.00</td>
</tr>
</tbody>
</table>

### Part No. 8 – Sheave with stub shaft

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheave</td>
<td>8</td>
<td>$25.80</td>
<td>$206.40</td>
</tr>
<tr>
<td>Stub shaft</td>
<td>8</td>
<td>$2.50</td>
<td>$20.00</td>
</tr>
</tbody>
</table>

**SUB TOTAL COST - SHEAVES** $226.40

### Part No. 9 – 6mm 7/19 Stainless steel rope

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rope</td>
<td>2 x 254m</td>
<td>$2.70</td>
<td>$1371.60</td>
</tr>
</tbody>
</table>

**SUB TOTAL COST - ROPE** $1371.60
Part No. 10 – Electrical operating system

<table>
<thead>
<tr>
<th>ITEM No</th>
<th>DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1, K2, K3</td>
<td>contactors</td>
<td>3</td>
<td>$17.50</td>
<td>$52.50</td>
</tr>
<tr>
<td>TOL</td>
<td>Thermal overload</td>
<td>1</td>
<td>$26.00</td>
<td>$26.00</td>
</tr>
<tr>
<td>LS1 &amp; LS2</td>
<td>Shunt limit switch</td>
<td>2</td>
<td>$78.00</td>
<td>$156.00</td>
</tr>
<tr>
<td>N20FW</td>
<td>Control fuse</td>
<td>2</td>
<td>$6.30</td>
<td>$12.60</td>
</tr>
<tr>
<td>GIS1 &amp; GIS2</td>
<td>Gate access switch</td>
<td>2</td>
<td>$125.00</td>
<td>$250.00</td>
</tr>
<tr>
<td>FCLS</td>
<td>Over travel switch</td>
<td>2</td>
<td>$329.46</td>
<td>$658.92</td>
</tr>
<tr>
<td>ES</td>
<td>Emergency stops</td>
<td>4</td>
<td>$37.00</td>
<td>$148.00</td>
</tr>
<tr>
<td>MI</td>
<td>Main isolator</td>
<td>1</td>
<td>$83.24</td>
<td>$83.24</td>
</tr>
<tr>
<td>RB</td>
<td>Rotating beacon</td>
<td>1</td>
<td>$139.60</td>
<td>$139.60</td>
</tr>
<tr>
<td>Mc</td>
<td>Meter cabinet</td>
<td>1</td>
<td>$300.00</td>
<td>$300.00</td>
</tr>
<tr>
<td>Provision</td>
<td>Cable, conduits &amp; fittings</td>
<td>1</td>
<td>$200.00</td>
<td>$200.00</td>
</tr>
<tr>
<td>Lab</td>
<td>labour</td>
<td>16</td>
<td>$60.00</td>
<td>$960</td>
</tr>
<tr>
<td></td>
<td><strong>SUB TOTAL COST – ELECTRICAL</strong></td>
<td></td>
<td></td>
<td><strong>$2986.26</strong></td>
</tr>
</tbody>
</table>

Part No. 11 – Motor and gearbox plinth

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor and gearbox plinth</td>
<td>1</td>
<td>$231.00</td>
<td>$231.00</td>
<td></td>
</tr>
</tbody>
</table>

Part No 12 – Capstan drum and sheaves support

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capstan drum &amp; sheaves support</td>
<td>4</td>
<td>$279.00</td>
<td>$1116.00</td>
<td></td>
</tr>
</tbody>
</table>

Part No. 13 – Machinery guards and enclosures

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
<th>No. ITEMS</th>
<th>COST/ITEM</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed quote supply and install safety enclosures</td>
<td>1</td>
<td>$1174.00</td>
<td>$1174.00</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL MANUFACTURING COST OF SYSTEM** = $11,062.62
7.5 *Installation and site cost*

Site preparation and installation involves the following processes:

- Site layout,
- Site excavation and formwork,
- Pouring of foundations,
- Mounting plinths and machinery
- Installing machinery enclosures;
- Mounting, installing and connecting electrical
- Operational field and acceptance testing
- Manuals including “as built” drawings and operating instructions

**TOTAL SYSTEM MODULE INSTALLATION COSTS** = **$5120**

7.6 *System Cost and cost analysis*

System manufacturing cost $11,062.62
System installation costs $5,120.00

**TOTAL COST BASE** $16,182.62

7.6.1 *Project and Product Cost Analyses*

Manufacturing in a commercial environment, where volume purchasing was established, discounts will greatly reduce the cost base, as an Example; Bonfiglioli will discount up to 40% off the list price for Original Equipment Manufacturers (OEM’s), this would reduce the price of the motor gearbox by $641.52. Other price gains may be made by consolidating purchasing for fabricated products or alternately manufacturing in house. It is anticipated that increases in productivity and reduction in direct manufacturing cost would provide for a reduction in sale price whilst still providing a 30% provision for profit.

Consideration of the effect of GST also needs to be taken into consideration. All pricing includes a 10% GST component. In a commercial environment all direct GST
cost would be passed on to the purchaser as an extra item on the Invoice. All industry quotes are base on a “plus GST” bases.

### 7.6.2 Amortization of Cost

Based on the assumption that the average broiler shed is 12 meters wide and 120 meters long, the cost to fit out the first shed with 4 modules would be in the vicinity of $60,000 dollars. Based on an annual interest rate of 7.5% the cost can be amortized over a 10 year period with a monthly (180) payment of $712.21.

![Amortization Table](image)

**Figure 7.14: Amortization Table**

### 7.7 Test Results

A test platform replicating a broiler shed litter bed was built from wooden sleepers, as seen in Figure 7.16, to test the operation of the conceptual plough designs. Testing was conducted by both pushing and pulling the ploughs to ascertain the suitability of the plough design and determine the optimal operating speed. The reversible blade plough was constructed from 4 mm sheet steel, as seen in Figure 7.15, and door hinges are used to provide pivoting point for the two plough cover sections to test different configurations.

#### 7.7.1 Testing Methodology

To determine the disturbance of the litter, a grid was placed on the surface of the litter bed, utilizing a template and powdered lime, providing a reference baseline for comparison of recorded results as seen in Figure 7.19. The plough was pulled through the litter by rope through drilled holes in the base of the wooden planks (Figure 7.17)
to emulate the steel ropes orientation of pull. It was noted that the rope must run parallel to the floor and under the litter or else it will increase the ploughs attack angle and influence it to plough towards the surface and run atop of the litter. The plough was buried underneath the litter (Figure 7.19), then pulled through at various speeds, recording litter disruption profiles (Figure 7.20) and upon completion (Figure 7.21), the results were recorded and tabulated (Table 7.2) for further reference.

Figure 7.15: Side View and Dimensions of Testing Plough

Figure 7.16: Test Bed
Figure 7.17: Pulling Rope Position

Figure 7.18: Test Plough and Operating Position

Figure 7.19: Litter/Potting and Powered Lime Grid (Initial Test Phase)
Figure 7.20: Operational Test Phase

Figure 7.21: Final Test Phase
Table 7.2: Test Results Table

<table>
<thead>
<tr>
<th>Litter Depth (mm)</th>
<th>( h_1 ) (mm)</th>
<th>( h_2 ) (mm)</th>
<th>Time (sec)</th>
<th>Grid Disruption (After)</th>
<th>Velocity (m/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>55</td>
<td>150</td>
<td>100</td>
<td>Poor</td>
<td>2.88</td>
</tr>
<tr>
<td>50</td>
<td>55</td>
<td>150</td>
<td>142</td>
<td>Poor</td>
<td>2.02</td>
</tr>
<tr>
<td>50</td>
<td>60</td>
<td>60</td>
<td>131</td>
<td>Poor</td>
<td>2.19</td>
</tr>
<tr>
<td>50</td>
<td>60</td>
<td>100</td>
<td>150</td>
<td>Average</td>
<td>1.92</td>
</tr>
<tr>
<td>50</td>
<td>60</td>
<td>100</td>
<td>122</td>
<td>Average</td>
<td>2.36</td>
</tr>
<tr>
<td>100</td>
<td>60</td>
<td>100</td>
<td>140</td>
<td>Average</td>
<td>2.05</td>
</tr>
<tr>
<td>100</td>
<td>60</td>
<td>100</td>
<td>135</td>
<td>Average</td>
<td>2.13</td>
</tr>
<tr>
<td>100</td>
<td>60</td>
<td>150</td>
<td>151</td>
<td>Poor</td>
<td>1.91</td>
</tr>
<tr>
<td>100</td>
<td>65</td>
<td>65</td>
<td>132</td>
<td>Poor</td>
<td>2.18</td>
</tr>
</tbody>
</table>

The results of testing for plough speed are detailed in Table 7.2. It was determined from this data that the plough achieved a maximum average litter disruption of 50% at an optimum operating speed of 2 meters per minute, providing sufficient time and adequate performance for:

- Livestock to move away from the operating plough;
- Low level velocity impact which would not kill or maim livestock;
- Low levels of operating noise and vibration:
- Minimal dust generation;
- Provide tumbling, mixing and aeration of the litter bed.

This optimal velocity result obtained will now be used for calculations throughout the project regarding the plough and winch power system specifications and design considerations.
7.8 Conclusion

This chapter has presented and explained the reasoning for material selection, total costing structure and design calculations to verify the blade ploughs design will withstand the operating conditions while also providing an estimated dollar value to provide insight into the cost of the system.
Chapter 8 : CABLE WINCH POWER SYSTEM DESIGN

8.1 Introduction

The decision to use a reversible tilt blade plough to disrupt and aerate the litter bed has lead to the need to develop a means to move the plough both forward and reverse, in such a way as not to affect broiler production. In this chapter, system power options are put forward, discussed and decisions made based on the special needs of the project, suitability of the materials and the practicality of designs.

8.2 System Components

Power system:

Motive force to the plough can be provided by a number of sources limited only by design, operation, safety and cost constraints. Consideration will be given to two power sources, the internal combustion engine and electrical powered motor and lineal actuators, and whether the power source is applied within the building structure or external to the building.

Determination of power system:

Terms of reference for this project key criteria, include:

- Ability for the plant to operate through all stages of the broiler production cycle;
• Be semi automatic in operation;
• System reliability;
• Compliant with the Queensland OH&S Act, and Regulations; and
• Fulfill designated design role.

Internal Combustion Engine
Internal combustion engines are available in either Diesel or Petrol, with variants as to configuration and size. Typically, the number of cylinders can vary from a single cylinder to 8 cylinders and in capacity from 125cc to 8000cc. Due to the increased toxicity of carbon monoxide emissions and the increased risk of fire associated with petrol engines. It has become common for diesel engines to be used in agriculture, industry and in confined spaces. In mines, the uses of diesel engines are mandated by Regulation, to quote;

“Queensland Coal Mining Safety and Health Regulation”, 2001, states that:

s261 Using plant powered by internal combustion engines;

1(b) only if—

(i) the engine is—

(A) a compression ignition type

Electrically powered:
Methods to supply electrical power to moving plant and equipment within a broiler shed are typically the same as those used to supply power to electric hoist and overhead travelling cranes. The principle operational difference lays in the fact that cranes and hoists operate on steel rails or beams with limited side movement, usually of no more than 20mm, whereas the plant within the broiler shed will not have a guidance system.

There are 3 separate types of power systems available for consideration:
1. Busbar or open wire with spring loaded collectors (see Figure 8.1);

![Figure 8.1: Busbar system drawing courtesy of Insul-8 Australia](image)

2. Catenary (see Figure 8.2);

![Figure 8.2: Catenary system drawing courtesy of Insul-8 Australia](image)

3. Cable reel (see Figure 8.3);

![Figure 8.3: Cable reel system drawing courtesy of Insul-8 Australia](image)
Electrification systems are available commercially from specialist providers to the hoist and crane industry, such as “Insul-8” and “Wampfler” or by crane manufacturers who have their own propriety products, such as “Mannesman Demag”. Each system has advantages and disadvantages. On investigation it was concluded that of the 3 systems none were able to meet operational needs.

**Busbar system** whilst compact was not able to accommodate the degree of side movement associated with an unguided system.

**Catenary system** required a push and pull bar to reduce side tension and jamming of the lead cable trolley, the depth of the cable loops were too deep and become a hazard to staff working within the shed.

**Cable reel** was not able to provide sufficient cable length and the additional effort required to operate against the retracting spring force would require additional cost to upgrade the drive system.

It was decided to utilize an electric motor & gearbox to drive a capstan and steel rope system mounted external to the building within safety enclosures. Factors leading to the decision were:

- Electrical and mechanical components are external to the production area;
- Limited cost to semi-automate;
- No modification required to existing buildings and/or plant;
- Ease of system set up and removal during the shed cleaning cycle;
- Low initial capital cost;
- Low operating cost; and
- Minimal maintenance required.

### 8.3 Cable Winch Systems

The operating system is modular in design with a broiler shed having a series of modules; each module can be varied in length depending on the broiler shed width and the required operating sequence. It is proposed in the design concept that only one
(1) module will operate at any one time, thus enabling the chickens to move to another area of the shed and not create undue stress in the flock. Each drive module will be fully self contained comprising:

- Integral Electric motor and worm reduction gear box, with a 400:1 ratio;
- Drive shafts;
- Two drive capstan (winch) drums, equidistant on each side of the gearbox. Each capstan drum is supported on 2 heavy duty pillar block bearings, one each side of the capstan drum;
- Two non powered tail capstan drums to enable cable pull in the reverse direction;
- Each capstan has two sheaves mounted close to the ground to change the direction of pull of the steel cable, from vertical to horizontal, the diameter of the sheave (18 time cable diameter) and 55 degree included angle.

Compliance with the requirements of SAA Standards AS1418.1 Hoist & Crane Code.

Compliance with Workplace Health & Safety will be assured by having the winch drive machinery and capstans within locked security enclosures to prevent access to unauthorized personnel. The access gates will be electrically interlocked with the capstan winch drive and will isolate power to the capstan winch if any gate is opened. Emergency stops will be positioned at key locations within the shed and will deactivate all capstan drives. When the emergency stops are reset the capstan units will not restart unless the forward/ reverse buttons are once again pushed. A Rotating yellow warning light will operate when the units are operating. The use of an audible alarm was considered and rejected as it was considered that its use may distress the chicken flock resulting in high mortality rates and annoyance to neighbours.

### 8.4 Motor and Worm Reduction Gearbox Selection

In keeping with the design principle “simpler is better” the different types and styles of motor gearbox combinations were reviewed to determine the most operational and cost effective combination. Available types and styles of reduction gearboxes include: Straight cut spur gearbox, helical cut spur gearbox, epicyclic gearbox (sun gears),
torsional gear box and worm gearbox. On review of the gearboxes styles available, including variants and the project need for a reduction of 344:1 (8 pole motor) for an output shaft speed of 2.12 RPM and rated torque of 208 Nm. Gearbox reduction is determined by selecting the required shaft output speed and dividing this into the electric motor full load speed.

**Output shaft speed calculations:**

\[
R = \frac{S}{(C \times \pi)}
\]

(8.1)

\[
= \frac{2000}{(300 \times \pi)}
\]

\[
= 2.12 \text{ rpm}
\]

Where:  
R = Drive output speed  
S = Desired plough travel speed  
C = Capstan drum diameter

**Electric motor speed calculations:**

Electric motor speed will determine the ratio of the required gearbox. Motor speed is determined by the number of electrical poles and the frequency of supply (in Hertz) and can best be described by equation (8.2):

\[
\text{Motor synchronous speed} = \frac{120f}{P}
\]

(8.2)

Where:  
f = supply frequency in Hertz  
P = number of poles of the motor

Commercial standard electric motors do not operate at synchronous speeds as slip is required to develop torque, as the number of poles increase the speed of the motor reduces but the physical dimensions increase. Table 8.1 provides details of alternate motor speed specification.
Table 8.1: Electric Motor Speeds

<table>
<thead>
<tr>
<th>NUMBER POLES</th>
<th>SYNCHRONOUS SPEED RPM</th>
<th>FULL LOAD SPEED RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3000</td>
<td>2800</td>
</tr>
<tr>
<td>4</td>
<td>1500</td>
<td>1440</td>
</tr>
<tr>
<td>6</td>
<td>1000</td>
<td>980</td>
</tr>
<tr>
<td>8</td>
<td>750</td>
<td>730</td>
</tr>
</tbody>
</table>

Table 8.2: Motor/Gearbox Reduction Ratio Comparison table

<table>
<thead>
<tr>
<th>Number motor poles</th>
<th>Full load speed</th>
<th>Drive shaft output speed</th>
<th>Required ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2800</td>
<td>2.12</td>
<td>1320:1</td>
</tr>
<tr>
<td>4</td>
<td>1440</td>
<td>2.12</td>
<td>679:1</td>
</tr>
<tr>
<td>6</td>
<td>980</td>
<td>2.12</td>
<td>462:1</td>
</tr>
<tr>
<td>8</td>
<td>730</td>
<td>2.12</td>
<td>344:1</td>
</tr>
</tbody>
</table>

Worm reducers are manufactured in standard sizes and ratios, the highest ratio available in a single gearbox is 350:1. Higher ratio gearbox drives require the coupling together of two or more gearboxes at increased complexity and cost. The increased cost of the electric motor is more than offset by the gains made using a single gearbox. For these reasons it is proposed to use an 8 pole electric motor direct coupled to a worm gearbox with hollow keyed output drive shaft with the ratio of 344:1.

Availability of a gearbox to meet with project requirements has been complicated by the availability of the required combination of motor and gearbox. An 8 pole motor frame size is too large to fit on to the mounting flange of the specified gearbox. This sizing problem has been overcome with the use of a Bonfiglioli combination gearbox, Model No. VF/W44/75_400 P71 BN71A6, with ratio’s of 400:1, driven by a 6 pole 0.18kw motor, resulting in 361N/m torque at the output shaft.
8.5 Capstan Drum and Shaft Design

A solid bright carbon steel drive shaft is keyed and fitted into the hollow output shaft of the drive gearbox; spacers and the pin half of a flexible coupling are fitted and keyed on each side of the gearbox. The assembly is held in position by a M10 x 30 grade 8.8 bolt screwed into each end of the shaft and a heavy duty washer to clamp the assembly together. The 40mm drive shafts transmit the rotational force from the gearbox to the two capstan drive drums, equidistant on each side of the gearbox drive assembly. The 40mm intermediate shaft is reduced in diameter to 32mm each end and fitted with a flexible coupling bush half. Two 30mm bore pillar block ball bearings support the 30mm capstan drive shaft, capstan drum and flexible coupling pin half. The main benefit of the flexible couplings is to:

- Compensate for misalignment;
- Provide a cushion effect for shock loads; and
- Enable removal of the 40mm drive shaft without removal of drive components.

Power transmission from the capstan drum to the cable system is achieved by using 4 turns of steel cable around the 300mm diameter capstan drum, the large diameter drum and 4 turns of cable wrapped around it to provide positive grip coefficient, as the drum rotates cable is pulled onto the drum pulling the plough forward or reverse whilst an equal amount of cable is feed the other side of the drum. The cable feed off the capstan drum lays on the ground and runs beneath the litter bed, outside the operating area of the plough to the unpowered capstan drum at the other end of the building, around the capstan drum 4 times then to be connected to the other side of the plough, the capstan cable operates on a closed loop system. Rope tensioners are included in the concept design, but have not been shown for clarity.

8.6 Capstan Drum Shaft and Bearing Analysis

The analysis of the capstan drum shaft involves calculations of loading, stresses, fatigue and deflection. The result of this analysis will verify the strength of material required.
The solid capstan drum shaft will be constructed from AISI 1020 mild steel, which has a yield and ultimate strength of 331MPa and 448MPa respectively in the as rolled state (Appendix C-4a, Juvinall & Marshek 2000). Before the stress and fatigue calculations can be undertaken, the loading of the shaft must be analysed.

### 8.6.1 Shaft Loading

Shaft torsional deflection is generated from the gearbox to either capstan drum side check. Initially a 30 mm diameter shaft was to be used to transmit the torque from the gearbox to the capstan drums, where the drums and gearbox will be attached to the shaft by keys & keyways. But first the torsional deflection stress must be verified. Torsional deflection within the shaft needs checking from the torque loading point to the area of interest (capstan drum) to ensure the torsional deflection is well within the deflection limits of shafts.

Stated general deflection limits in the shafts for torsional deflection is 3° per meter (Hosking & Harris, 1990). It is essential to check the shafts ability to transfer the torque to the capstan drums, because excessive deflections (lateral and/or torsional) should be avoided because:

- Can cause secondary stress;
- Result in unsatisfactory machine performance as a whipping shaft can cause shock loading in transmission; and
- In some circumstances can cause bad gear meshing that will look unsightly.

![Figure 8.4: Proposed Shaft System](image-url)
The proposed shaft system, a solid 30 mm diameter continuous shaft is used from the left capstan drum to the gearbox to the right drum (Figure 8.4). Calculating the deflection due to torsion (from the gearbox) will determine if the designated shaft diameter is satisfactory for providing a torque loading over the given length. Torsional deflection formula is:

\[ \theta = \frac{Tl}{GJ} \text{ radians} \]  

(8.3)

Where:  
- \( T \) = Torque (N.mm)  
- \( l \) = length of shaft under consideration (mm)  
- \( G \) = Modoulus of Rigidity (MPa)  
- \( J \) = Polar second moment of aera (mm\(^4\))

\[ T = 361 \times 10^3 \text{ N.mm} \]  
\[ G = 79 \times 10^3 \text{ MPa} \]  
\[ l = 2910 \div 2 = 1455 \text{ mm} \]  
\[ d = 30 \text{ mm} \]

\[ J = \frac{\pi d^4}{32} = \frac{\pi \times 30^4}{32} \]  
\[ = 79521.56 \text{ mm}^4 \]

\[ \theta = \frac{Tl}{GJ} = \frac{361 \times 10^3 \times 1455}{79 \times 10^3 \times 79521.56} \]  
\[ = 0.0836 \text{ rad} \]  
\[ = 4.79^\circ \]

Therefore, use of the 30mm solid shaft is not permissible as \( \theta = 4.79^\circ / \text{m} > 3^\circ / \text{m} \). The torsional deflection value found is greater than the stated torsional deflection limit. It is concluded that the shaft diameter used from the gearbox to either capstan drum is too small. Specifying a larger shaft size should bring the torsional deflection within limits. Next shaft diameter specified is 40 mm diameter that will be coupled between the 30mm diameter shaft used through the bearing housing, capstan drums and the power take-off from the gear box as seen in Figure 8.5.
Therefore, use of the 40mm solid shaft coupling system is permissible because $\theta = 3^\circ / m > 1.49^\circ / m$. The torsional deflection value found is lower than the stated torsional deflection limit, therefore, the new proposed shaft layout will be sufficient for the torque loading.

The significant loads on the shaft are due to the capstan drums pulling the plough. The weight of the shaft components are considered negligible so it will not be considered in the analysis of the shaft. The steel cables attached to the plough produces a tangential force on the capstan drums resulting in a minimum required torque of 207.114 Nm, but specifying at larger capacity motor, there is now 361 Nm of torque being shared between the two drums with a subsequent new force of 2506.67 N in the wire at the end of the capstan drum, as found in the previous chapter. Under normal operating conditions the motor/gearbox will share torque equally between both drums. However this analysis will also consider the extreme condition of all the torque being transferred through only one drum.
The analysis requires simplifying the power transmitting shaft to the area of one capstan drum and its supporting bearings. The capstan drum is mated and keyed centrally on the shaft, which is centrally supported on bearings at 130 mm centers. The stainless steel cables pass from the bottom sheave and over the drum onto the trailing sheave to create the reversible rope/plough system. Therefore the side with the cable in tension will only be used for these calculations onwards as the other cable will have negligible forces acting through it, therefore neglected. It is assumed the shaft to be simply supported at the center of the bearings.

A bending moment is created in the shaft by the force of the cable on the drum pulling the shaft downwards, in the direction of the smaller sheaves. The bearings hold the shaft in place so they carry the reaction forces to this loading. The angular displacement at the bearings is assumed adequate enough, that no movement is produced. Finding the bearing reactions on the left and right are illustrated in Figure 8.6.

\[ F = 2406.67 \text{ N} \]

![Figure 8.6: Free Body Diagram of Capstan Drum Section](image)

The beam loading is a concentrated center load; therefore the reaction forces in the bearings are equal to half the applied load (Appendix D-2, Juvinall & Marshek 2000).
\[ L_r = \frac{F}{2} = \frac{2406.67}{2} = 1203.34 \text{ N} = R_r \]

The shear force and bending moment diagrams are illustrated below in Figure 8.7.

8.6.2 Stress Analysis

The next point of concern is the shearing of the shaft due to the drum from the force exerted by the cables when pulling the plough. Two different cases will be analysed to determine the shear stress due to torsion. The first is under normal operating conditions where the torque is evenly distributed between the two capstan drum and secondly in the extreme case where all the torque is transferred to one drum only. Using equation (4.3) (Juvinall & Marshek, 2000) for shear stress:

\[ \tau = \frac{T_r}{J} \]

Where:

\[ T = \text{Torque (Nm)} \]
\[ r = \text{Radius (m)} \]
\[ J = \text{Polar moment of inertia (mm}^4) \]

The radius of the shaft and torque applied to the shaft are known, the polar moment of inertia for a solid steel shaft. The polar moment of inertia is found from Appendix B-1 (Juvinall & Marshek, 2000) for a circle where:

\[ J = \frac{\pi d^4}{32} \]  \hspace{1cm} (8.5)

Under a normal loading condition, \( T = 361 \div 2 = 180.5 \text{Nm} \) the shaft shear stress will be;

\[ \tau = \frac{180.5 \times 0.015}{\pi \times 0.03^4} \times \frac{32}{32} = 34.27 \text{ MPa} \]

To predict the equivalent tensile yield strength from figure (6.10) (Juvinall & Marshek, 2000), the maximum distortion energy criterion for ductile materials used;

\[ \sigma_y = \frac{\tau_{\text{max}}}{0.58} \]  \hspace{1cm} (8.6)

Where: \( \sigma_y = \text{Yield Strength (MPa)} \)

\( \tau_{\text{max}} = \text{Maximum Shear Stress (MPa)} \)

Therefore the equivalent tensile strength under normal loading conditions is;

\[ \sigma_y = \frac{34.27}{0.58} = 59.09 \text{ MPa} \]

Repeat the above calculation for worst case torque loading of 361 Nm;

\[ \tau = \frac{361 \times 0.015}{\pi \times 0.03^4} \times \frac{32}{32} = 68.54 \text{ MPa} \]

Therefore the equivalent tensile strength under worst case loading conditions is;
\[ \sigma_y = \frac{68.54}{0.58} = 118.17 \text{ MPa} \]

The shaft could potentially fail due to the combined loading of shear stress and torsion or bending stress and torsion. Using the formulas below sourced from (Beer & Johnston, 2002) will predict these combined stress and determine if failure will occur;

\[ \tau = \frac{VQ}{Ib} \quad (8.7) \]

\[ \sigma = \frac{Mc}{I} \quad (8.8) \]

Where:
- \( V \) = Shearing force (N)
- \( Q \) = First moment of area (m³)
- \( I \) = Moment of Inertia (m⁴)
- \( b \) = Width of Section (in question) (m)
- \( c \) = Radius of Shaft (m)

Referring to the shear force diagram constructed in Figure 8.7, the maximum shearing force induced is equal between the left and right side bearings, however the bearing surface closest to the motor/gearbox side is the area where the critical analysis will be carried out.

It is assumed a worst case loading scenario where 361 Nm of torque is applied at one of the 30 mm diameter shafts supporting the capstan drum and bearings. Use of the following formula will find the induced combined stresses. The direct shear stress is found using equation (8.7);

\[ \tau_d = \frac{VQ}{Ib} \]

Where:

\[ Q = Ay \]

\[ = \left( \frac{1}{2} \pi r^2 \right) \left( \frac{4r}{3\pi} \right) \]

\[ = \frac{2}{3} r^3 = \frac{2}{3} \times 0.015^3 \]

\[ = 2.25 \times 10^{-6} \text{ m}^3 \]
\[ I = \frac{\pi d^4}{64} = \frac{\pi \times 0.03^4}{64} \]
\[ = 3.9 \times 10^{-8} \text{m}^4 \]
\[ b = 2r = 2 \times 0.015 \]
\[ = 0.03 \text{m} \]

Therefore the direct shear stress is;
\[ \tau_d = \frac{1203.34 \times 2.25 \times 10^{-6}}{3.9 \times 10^{-8} \times 0.03} = 2.31 \text{MPa} \]

Torsional shear is found using equation (8.4);
\[ \tau_t = \frac{Tr}{J} = \frac{361 \times 0.015}{\pi \times 0.03^4/32} = 68.54 \text{MPa} \]

Total shear stress is found by adding the direct and torsional stresses together;
\[ \tau_{\text{max}} = \tau_d + \tau_t = 2.31 + 68.54 = 70.85 \text{MPa} \]

The equivalent maximum tensile stress due to combined shear stresses is found using equation (8.6); 
\[ \sigma = \frac{70.85}{0.58} = 112.16 \text{MPa} \]

Now considering the combined bending and torsional stresses, the bending moment diagram (Figure 8.7) shows the maximum bending moment occurring at the center of the capstan drum. Therefore the bending stresses due to the 78.22 Nm moment is found using equation (7.4);
The torsional shear stresses are again calculated under worst case loading conditions using equation (8.4);

\[ \tau_t = \frac{T_r}{J} = 68.54 \text{ MPa} \quad \text{(found previously)}; \]

Using the formula for Mohr’s Circle for biaxial stress, the total combined stresses can be found. The principle stresses are found using equation (4.16) (Juvinall & Marshek, 2000);

\[ \sigma_1, \sigma_2 = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\frac{\sigma_x + \sigma_y}{2}^2 + \left(\frac{\tau_{xy}}{2}\right)^2} \tag{8.9} \]

Substituting in the normal stress in the x-direction and the torsional stress into equation (8.9);

\[ \sigma_1, \sigma_2 = \frac{30.08}{2} \pm \sqrt{68.54^2 + \left(\frac{30.08}{2}\right)^2} \]

\[ \sigma_1 = 84.12 \text{ MPa} \]
\[ \sigma_2 = -54.04 \text{ MPa} \]

These principle stresses equate to a yield strength equivalent based on the maximum distortion energy criterion by equation (7.6) (Stress Analysis, 2004).

\[ \sigma_y^2 = \sigma_1^2 - \sigma_1 \sigma_2 + \sigma_2^2 \tag{8.10} \]

\[ = 84.12^2 - (84.12 \times -54.04) + (-54.04)^2 \]
\[ = 14542.33 \]
\[ \sigma_y = 120.59 \text{ MPa} \]
Tabulating the subsequent results for comparison allows determination of points with the highest probability of failure in the shaft. Factor of Safety calculations were carried out relative to the yield strength of AISI 1020.

Table 8.3: Factor of Safety Summary for AISI 1020

<table>
<thead>
<tr>
<th>Load Condition</th>
<th>Induced Stress (MPa)</th>
<th>Factor of Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>59.09</td>
<td>5.6</td>
</tr>
<tr>
<td>Worst loading case</td>
<td>118.17</td>
<td>2.8</td>
</tr>
<tr>
<td>Equivalent max tensile stress due to combined shear stress at worst loading</td>
<td>112.16</td>
<td>2.9</td>
</tr>
<tr>
<td>Yield strength equivalent based on principle stresses</td>
<td>120.59</td>
<td>2.74</td>
</tr>
</tbody>
</table>

From the results obtained, the shaft almost shares the same FOS values of 2.7 and greater when calculated for worst loading case scenarios. The results obtained reinforce the choice of using AISI 1020 is acceptable as a shafting material for the loading situation. Even if the plough under normal loading and working conditions will only experience half the applied torque, and with these safety factors, it is assured that if the mechanism or stainless steel cable breaks, the shaft will be able to handle a full torque load and return the plough to end of the shed without destroying auxiliary components in the shaft power system.

8.6.3 Fatigue

The fatigue life of the torque transmitting shaft is analysed based in the fundamentals of machine component design textbook (Juvinall & Marshek, 2000). It is assumed the greatest stress concentration located in the shaft will be the keyway (see Figure 8.8).

Figure 8.8: Keyway and key in shaft
8.6.3.1 Key and keyway calculations

The shaft diameter section of 30 mm used where the shaft is subsequently keyed at the capstan drums and gearbox output to transmit the reversible torque of 361 Nm. The drive key must be able to transmit the torque load and withstand the induced stress. Assuming the whole key would be under shear, the key length is found using $L = 1.8d$ (Juvinall & Marshek, 2000).

$$L = 1.8 \times d = 1.8 \times 30 = 54 mm$$

Because of the nature of the torque, a rectangular taper key will be used. According to (Redford, G.D. 1975) table for keyways for rectangular taper keys, the key will have a width $b = 10$ mm and a thickness $h = 8$ mm.

Tangential force on the key = $\frac{\text{torque}}{\text{shaft radius}} = \frac{361}{0.015} = 24066.67 N$

Area in shear = $b \times l = 10 \times 54 = 540 \text{ mm}^2 = 540 \times 10^{-6} \text{ m}^2$

Shear stress = $\frac{\text{tangential force}}{\text{area in shear}} = \frac{24066.67}{540 \times 10^{-6}} = 44.57 \text{ MPa}$

Therefore, use of this key in the current setup is acceptable as the calculated stress is below the yield strength of AISI 1020.

8.6.3.2 Fatigue Life

The alternating loads experienced by the shaft are reversible torsional loading which creates torsional stresses due to the uni-directional pulling operation of the plough. Equation (4.4) (Juvinall & Marshek, 2000) - Surface torsional stress in a solid shaft gives;

$$\tau_{nom} = \frac{16T}{\pi d^3} \quad (8.11)$$

$$= \frac{16 \times 180.5}{\pi \times 0.03^3} \quad T = 180.5 \text{ N (Normal loading conditions)}$$

$$= 34.05 \text{ MPa}$$
The fatigue stress concentration factor, \( K_f \) for a sled-runner cut keyway of annealed steel is found from figure (17.8) (Juvinall & Marshek, 2000).

\[
K_f = 1.3 \text{ (annealed and torsion)}
\]

Equation (4.21) (Juvinall & Marshek, 2000) is used to incorporate the fatigue stress concentration factor to determine the maximum torsional shear stress.

\[
\tau_{\text{max}} = \tau_{\text{nom}} \times K_f
\]

\[
= 34.05 \times 1.3
\]

\[
= 44.27 \text{ MPa}
\]

Now the minimum shear stress caused from reversing the direction of applied torque is found to be:

\[
\tau_{\text{min}} = \frac{16T}{\pi d^3} \times K_f
\]

\[
= \frac{16 \times -180.5}{\pi \times 0.03^3} \times 1.3
\]

\[
= -44.27 \text{ MPa}
\]

The mean and alternating shear stress loading from figure (8.15) (Juvinall & Marshek 2000).

\[
\tau_m = \frac{\tau_{\text{max}} + \tau_{\text{min}}}{2}
\]

\[
= \frac{44.27 + (-44.27)}{2}
\]

\[
= 0 \text{ MPa}
\]

\[
\tau_a = \frac{\tau_{\text{max}} - \tau_{\text{min}}}{2}
\]

\[
= \frac{44.27 - (-44.27)}{2}
\]

\[
= 44.27 \text{ MPa}
\]

From table (8.1) (Juvinall & Marshek 2000) the \( 10^6 \) – cycle strength, \( S_n \) is found.

AISI 1020 mild steel has;

- Ultimate strength, \( S_u = 448.2 \text{ MPa} \); and
- Yield strength, \( S_y = 330.9 \text{ MPa} \).

\[
S_n = S_n' C_L C_G C_s
\]
Where:

\[ S'_n = 0.5 \times S_n \]
\[ C_L = \text{Load factor} \]
\[ C_G = \text{Gradient factor} \]
\[ C_s = \text{Surface factor} \]

\[ (\text{figure 8.13}) \] (Juvinall & Marshek 2000)

\[ S_n = S'_n C_L C_G C_s \]
\[ = 0.5 \times 448.2 \times 0.58 \times 0.9 \times 0.79 \]
\[ = 92.41 \text{ MPa @ } 1.0 \times 10^6 \text{ cycles of stress} \]

The mean and alternating stress calculated previously is smaller than the \( S_n \) value indicating the mean and alternating stresses will be inside the infinite life line on a Goodman diagram during normal operation. Therefore under normal operating conditions the shaft has a predicted infinite cycle life.

The deflection of the shaft is conducted after the stress and fatigue calculation are concluded. The maximum deflection under worst loading case conditions (Appendix D-2, Juvinall & Marshek 2000);

\[ \delta_{\text{max}} = \frac{PL^3}{48EI} \] (8.12)
\[ = \frac{2406.67 \times 0.13^3}{48 \times 207 \times 10^9 \times 3.9 \times 10^{-8}} \]
\[ = 1.36 \times 10^{-5} \text{ m} \]

Selected shaft is safe for this application when construction material used is AISI 1020.

### 8.6.4 Bearings

Supporting the capstan drums that winch the plough through the litter requires the use of two bearings and housings located at each side of the drum while been affixed to the solid steel support structure holding the shaft and motor/gearbox in place.

After reviewing bearing types, it was concluded that bearing number UCPG206D1, a deep groove ball bearing fulfilled the application design and function requirements. This pillow block bearing was chosen because it is designed to carry radial loads,
capable of carrying small amounts of axial loading and misalignment. Also the bearings have their own seals to keep the elements such as water and dirt out. The pillow block bearing selected to support the shaft was obtained from a NSK catalogue, part number UCPG206D1. The bearing ratings include, ID = 30 mm, Radial load capacity = 19.5 KN dynamic and 11.3 KN static. The pillow block housing is a cast iron heavy duty housing part number PG2016D1, and the deep groove ball bearing with part number UC2016D1 combining to create the pillowblock bearing UCPG206D1. The outside of the bearing and the inside housing are spherical to allow self alignment, a good choice of selection of a proprietary product and the loads rating capabilities are far in excess of application needs.

Mounting of pillowblock bearing on matching plinth require the surfaces to be level, parallel and at the same height to keep the capstan drum truly horizontal and prevent misalignment and wear.

8.6.4.1 Bearing Loads

The most significant load on the bearing will be the force of the cable pulling the capstan drum shaft downward. The two bearings equally spaced either side of the drum carry equally the greatest bearing load of 1203.34 N as seen in Figure 8.6 during worst loading case. The formula to find the dynamic equivalent radial load is;
\[ P_r = X F_r \times Y F_a \]  \hspace{1cm} (8.13)

Where:
- \( P_r \) = Dynamic equivalent radial load (N)
- \( X \) = Radial load factor
- \( F_r \) = Actual radial load (N)
- \( Y \) = Axial load factor
- \( F_a \) = Actual axial load (N)

It is assumed there is no axial load, therefore the axial load factor is zero and radial load value is one, therefore;

\[
P_r = X F_r \times Y F_a
= 1 \times 1203.34
= 1203.34 \text{ N}
\]

Comparing the dynamic load rating of the UC2016D1 bearing of 19.5 KN from NSK catalogue to the dynamic equivalent radial load of 1203.34 N, the bearings either side of the drum are more than capable of supporting the radial loads from the shaft. Even if shock loading occurs which potentially could double the required dynamic load rating, the bearing is still within the design limitations given the range of acceptable loads.

\textbf{8.6.4.2 Bearing Life}

The bearing during operation is an important design consideration that must be found. The bearing life can be calculated using:

\[
L_{10} = \left( \frac{C}{P} \right)^p
\]  \hspace{1cm} (8.14)

Where:
- \( L_{10} \) = Basic rating life in millions of cycles
- \( C \) = Basic dynamic load rating
- \( P \) = Equivalent dynamic bearing load
- \( p=3 \) for ball bearings
\[ L_{10} = \left( \frac{19500}{1203.34} \right)^3 = 4255.38 \]

Taken from the motor/gearbox specification, the 361 Nm of output torque is delivered to the shaft at 2.3 rpm. Converting to angular velocity for the shaft;

\[ \omega = 2 \times \pi \times \text{shaft speed} = 2 \times \pi \times 2.3 \]
\[ = 14.45 \text{ rad} / \text{s} \]

Therefore the expected bearing life is estimated to be;

\[ L = \frac{4255.38 \times 10^6}{60 \left( \frac{14.45 \times 60}{2 \pi} \right)} = 513981.96 \text{ Hrs} \]

Therefore it can be seen that the loads exerted on the bearings are relatively small as well as the slow operating speeds of the plough, it is expected the bearings life will exceed the life of the other major components, giving infinite operating life.

### 8.7 Manufacture

Manufacture of the blade plough, capstan winches, electrical control equipment, safety enclosures, assembly and commissioning of this project will require collaboration of:

- Suppliers of proprietary products such as: motor & gearbox, bearings, flexible couplings and steel supplies;
- Specialist engineering & machine shop companies to manufacture components such as: Capstan drums, sheaves, drive shafts, blade plough and tilting mechanism components;
- Electricians to manufacture and wire the control system including the site installation of: Emergency Stops, rotating light, control panel, limit switches and safety gate access switches;
- Facilities in which to assemble the components with suitably qualified and skilled tradespersons.
Component will be manufactured and sourced using the Just In Time (JIT) system, where components are scheduled and ordered for delivery in time for when the components are required for assembly. Production estimates for delivery of this system from placement of order will to be 6 working weeks.

### 8.8 Winch Cable Selection

The family of steel ropes is vast and varied with different construction, material and surface treatments available. Prior to determining the required rope for the capstan winch it is necessary to review the rope construction, specifications and terminology used within the industry.

**Lay of wire rope:**

The lay of the rope describes the manner and direction the strands are laid, types of lay are: Right hand of Lay (RHOL), left hand of lay (LHOL), non-rotating (NR) and Langs lay (LL).

**Construction:**

The specification of a wire rope includes:

- The number of wires per strand;
- Number of strands;
- Core material;
- Tensile strength of material; and
- Lay of the rope.

A typical example of a wire rope specification would be: 6 x 36 FC RHOL galvanized

Where:

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Number of strands on the rope</td>
</tr>
<tr>
<td>36</td>
<td>Number of wires per strand</td>
</tr>
<tr>
<td>FC</td>
<td>Fibre Core</td>
</tr>
<tr>
<td>RHOL</td>
<td>Right hand of lay</td>
</tr>
</tbody>
</table>
The steel rope for use on the capstan winch system will need to be flexible yet resistant to corrosion. Basing selection criteria on resistance to corrosion two alternatives were investigated. 304 and 316 grade stainless steel wire ropes in 6mm diameter with a 7 x 19 RHOL construction with a Minimum Breaking force of 2584kg and a mass of 17kg/100m, these ropes are available from Bullivants Australia and Beaver Sales Australia. Both of these companies will cut ropes to length, against order. Cost has not been a consideration in the evaluation process. Stainless steel ropes are highly resistant to corrosion whilst being flexible. They do have a downside, being prone to work hardening and requiring programmed maintenance and replacement.

### 8.9 Electrical Operating & Control Systems

Operation of the plough would not be possible without inclusion of some type of electrical operating and control systems (Figure 8.10). Operational constraints on this project required the system to be semi automatic in operation. This was achieved whilst keeping cost to a minimum, keeping the system simple and repairable by local electricians. In the modular system, many of the electrical components are shared, for example: the main isolator, emergency stops, start/stop contactors and controls, operating rotating beacon, electrical switch gear enclosure and gate interlocks.

Each operating module will have a Forward and Reverse push button. By pushing the Forward or Reverse button the circuit energizes closing the operating contactor supplying power to the operating motor. The capstan drums commence to slowly rotate pulling the plough forward or reverse. The extent of travel is controlled by a shunt geared limit switch (which counts the number of rotations of the capstan drum) with motion ceasing when the plough reaches a predetermined number of turns.

The system has a back up safety full current (3 phase) over travel limit switches. The operation of one or both of these switches will cease operation of the capstan in both directions, and the FCLS will operate only if the shunt limit switches fail to trip before a critical position is reached. When tripped, the full current over travel limit switches are required to be reset manually.
Figure 8.10: Wiring Diagram
8.10 Conclusion

The use of a winch, capstan or hoist to move or lift a load, often of many Tonnes in weight, is not new or novel, such systems have been used for centuries. For example, to pull logs into a sawmill using a steam engine. What is novel is the use of an automated capstan winch system to operate a reversible blade plough in a forward or reverse direction. The plough to disrupt and aerate the litter bed within the broiler chicken raising shed, whilst the broiler shed is fully occupied with livestock from day old chickens through the production cycle to chickens ready to be processed at 6 to 10 weeks of age.

The underlying engineering principles for the proposed capstan winch to operate the reversible blade plough are considered sound and the project is considered feasible. The theoretical assumptions made have been tested on ProEngineer modelling software and manual calculations were performed to determine strength, life and fatigue values of the components to ensure a prolonged working life without failure.
Chapter 9 : CONCLUSION AND RECOMMENDATIONS

9.1 Introduction

The original scope of this project was to develop a plough to disrupt and aerate the litter bed in a broiler shed with the ultimate aim to reduce the strong odours emitted. Work undertaken throughout this project has been aimed to:

- Research the broiler industry;
- Design and develop a plough;
- Test results achieved; and
- Make recommendations.

This dissertation has made major advances in knowledge and information available to the amateur enthusiast and professional farmer, for the care of poultry in confined areas and assists in the reduction of odours from their flocks. This work to date is the starting point, possible future work could and should be undertaken to further enhance the conceptual plough designed.

9.2 Achievement of Objectives

The aim and intent of this project was to design a poultry litter plough to operate during the broiler chickens life rearing cycle and test the aeration capability of a plough system. Research carried out provided little information on previous work aiming to aerate poultry litter via disrupting and breaking larger sections to reduce anaerobic decay to reduce odour reduction. Therefore this project was carried out on a
try and see basis and provides the basis for further work for future students. In addition to the original aim, further design was undertaken with the intent to design a more complete and saleable packaged design. The additional design tasks undertaken included the winch system design and motor / auxiliary components design and specification. Throughout the design process of this project, many difficulties were encountered and overcome to reach a successful completed design. Unfortunately due to time constraints, some of the subsidiary objectives were unable to be completed, although recommendations have been suggested for future design improvements and development. The outcomes of the research and design are summarised below.

### 9.3 Study Outcomes & Discussion

Overall, the conceptually designed blade plough was the most appropriate design that fulfilled the farmers requirements. Analysis guidelines used to determine the appropriate plough comprised of performance, cost, development, timeline for completion and compliance with project guidelines. This lead to the recommendation of the reversible blade plough as the most appropriate for this type of situation and project. However, the conceptually designed paddlewheel plough shows tremendous potential but was not recommended due to the time constraints and significant material and construction cost compared to the blade plough. Nevertheless, both concepts are valid designs with regard to their respective litter aeration and disruption constraints. The plough with its operational ability to move beneath the litter bed without causing harm to equipment or livestock allows the plough modules to be operated at any time over a 24 hour period. With a Programmable Logic Controller (PLC) included with a multi module installation full automation can be achieved with each module operating on a one hour single pass every 3 hours (more or less) over daylight hours at the farmers discretion.

Furthermore, the component analysis carried out found that the intended design could withstand the worst loading cases with the exception of the bottom hinge cylinder support of the blade cover hinge mechanism and the shaft mechanism used to pull the winches. It is determined that the bottom hinge cylinder support would require a higher grade material to withstand worst loading case conditions without yielding and failing and the shaft diameter between the motor and capstan drum needed to be
increased to comply with torsional deflection limits for shafts. Shaft length and diameter will vary dependant on length of the plough modules and the distance the capstan drums are apart.

The total cost of the plough and electrical module system calculated out to be an estimated $11,062.62 with an additional charge of $5,120.00 to install the power system modules at each end of the shed. Operating cost for each module are comparatively low, with the annual cost being \((0.18\text{kW} \times 1 \text{ hour} \times 365 \times \$0.12/\text{kWh})\) $7.88 per annum per cycle pass per day. As an example if a 12metre wide shed had 4 units, which operated 4 times per day, the total power costs would be $126.08 per annum. The amortization of cost of $60,000 over a 10 year period requires a payment of $712.21 / month to offset interest and principle.

The reversible blade plough is not only effective in meeting the project criteria but does so at a tax deductible amortization cost which is less than the weekly wage for one workman. In comparison the reversible blade plough operates 7 days per week 52 weeks of the year.

### 9.4 Recommendations for Future Research and Work

Due to the limited time available for the project and research, there are several areas unable to be investigated in greater detail. If these areas are further investigated and researched, it would provide more information that could be used to improve the overall structure of the design and enhance the conceptual designs litter disruption and aeration efficiency. These areas include:

- The use of finite element analysis (FEA) software to analyse the potential failure locations of the plough and shaft, verifying the manual design calculations and further improving the conceptual design;
- Further system design and analysis of plough and power system components;
- Manufacture of full scale prototype for testing purposes;
- Testing and evaluation of the prototype for effective litter disruption and aeration as actual testing is a major part of product development. Once the initial calculations of the design have been conducted, prototype testing of the
plough will enable confirmation of design assumptions and calculations, enabling continual improvements to the design.

- Testing the poultry litter odour emanations before and after the ploughs operation over a lifecycle of a chicken batch to determine if any effective reduction in anaerobic decay and odour emanation.

### 9.5 Conclusion

The primary objective to design and a conceptual plough for litter aeration and disruption was successfully completed. Towards that objective, a power winch system was subsequently designed to power the plough unit. The results from the scaled down test plough suggests that the final design is capable of moderate litter disruption and fulfill the farmers requirements, however, other plough design alternatives should be explored.

In closing, this project proved to be interesting and challenging throughout its duration. It is hoped that the information and designs presented within this project may contribute to future system designs aiming to achieve a similar objective.
REFERENCES


15. Jiang, J. & Sands, J. 1998a & 1998b, “Odour emissions from poultry farms in Western Australia”, principal and supplementary technical reports respectively, prepared by Odour Research Laboratory, Centre for Water and Waste Technology, School of Civil and Environmental Engineering, University of New South Wales for Western Australia Department of Environmental Protection.


23. Standards Australia (1999), Design Standards for mechanical engineering students, Standards Association of Australia, Homebush, NSW.


APPENDIX A

PROJECT SPECIFICATION
FOR: KEVIN CHARLES HICKS

TOPIC: Design of aeration ploughing tool for poultry litter within poultry sheds to reduce odor generation.

SUPERVISOR: Dr. Guangnan Chen (USQ)
Mr. Mark Dunlop (Department of Primary Industries)

ENROLMENT: ENG 4111 – Semester 1, ONC, 2007
ENG 4112 – Semester 2, ONC, 2007

PROJECT AIM: This project aims to research current litter aeration systems, analyse past methods of odor control, and design a system to reduce odor emission from within the poultry shed.

SPONSORSHIP: Department of Primary Industries

PROGRAMME: Issue B, 22nd August 2007

1. Research information relating to the odor problems within the meat “broiler” chicken industry

2. Research current literature relating to odor reduction.

3. Research current and past poultry litter aeration methods, and analyse their advantages, limitations and market acceptance.

4. Develop, design and cost a prototype using a solid modelling program.

As time permits

5. Construct the prototype (if the funding is available from DPI).

6. Test and evaluate the performance and effectiveness of the prototype

AGREED:

_______________ (Student) _______________ , _______________ (Supervisors)

___ / ___ / ___  __ / __ / ___  ___ / ___ / ___
APPENDIX B

Preliminary Risk Assessment

**Preliminary Risk Assessment:** Installation & Operation of Automated Rotary Litter Tiller and Associated Winch System.

Specified tasks: Manufacture, install and prototype test devices to aerate ground litter bed used in the production of broiler chickens.

<table>
<thead>
<tr>
<th>Project Hazard/Risk</th>
<th>Method of Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crush Hazards or pinch points</td>
<td>• Design to eliminate crush zones and pinch points.</td>
</tr>
<tr>
<td></td>
<td>• Provide guards or barriers to restrict entry to hazardous areas.</td>
</tr>
<tr>
<td></td>
<td>• Use of an electrical interlock system, such as: push bar, emergency stop button or electric sensors or sensor curtains.</td>
</tr>
<tr>
<td></td>
<td>• Enclose winch equipment within enclosed locked areas.</td>
</tr>
<tr>
<td>Unauthorized public access to the site and exposure to site hazards.</td>
<td>Barricade to be erected to prevent access. Signage to be placed at and on the barricades indicating ‘Work Site’, ‘Safety Boots Required’ and ‘Unauthorized Entry Prohibited.’</td>
</tr>
<tr>
<td>Workers are appropriately trained to site requirements and qualified to perform specific work.</td>
<td>All personnel to undertake site induction and must hold appropriate licences and authorities.</td>
</tr>
<tr>
<td>Operation of power tool and machinery</td>
<td>Affected area barricaded to prevent entry. Hand power tools to be inspected and tagged. Personal Protection Equipment (PPE) to be used whilst on site, such as: helmets, glasses, gloves, dust masks, long cotton pants and shirts.</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Dust and Vapours</td>
<td>Minimize generation of dusts. Ventilate area to remove dust particles.</td>
</tr>
</tbody>
</table>
| Chemicals and paints intended for use – risk to personnel and surrounds. Fumes, hazardous material (acid or caustic), vapours and flammable | • Eliminate or substitute dangerous substances if possible.  
• All materials to be risk assessed using MSDS and site-specific approval for product to be given prior to use.  
• Site permit board to include a register of hazardous materials. |
| Electrocution and use of electrical power leads | • All electrical work to be compliant with Queensland Electrical Safety Act & Regulation 2002.  
• Appliances and electrical leads are to be connected through a Residual current device (RCD) rate at 30ma.  
• All electrical appliances shall have current Electrical Safety Tags affixed.  
• Electrical leads shall be suspended a minimum of 2 metres from the ground at intervals so as not to place excessive strain on the electrical conductors.  
• Only one electrical lead is permitted of sufficient size to prevent voltage drop. |
| House keeping               | • Entry to site to be kept clear at all times.  
• Empty containers to be removed from site and disposed of as specified by policy.  
• Areas are to be clean of contaminated material at frequent intervals. |
APPENDIX C

SAFETY SWITCH CATALOGUE EXTRACT
<table>
<thead>
<tr>
<th>Catalogue Number:</th>
<th>AZ 17-02ZI/B1 SP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description:</td>
<td>SWITCH SAFETY INDICODE &amp; ACT</td>
</tr>
<tr>
<td>List Price:</td>
<td>Refer to our eCatalogue</td>
</tr>
<tr>
<td>Unit Of Measure:</td>
<td>EA</td>
</tr>
<tr>
<td>Price Schedule:</td>
<td>B2</td>
</tr>
</tbody>
</table>

All prices are exclusive of GST

Safety Interlock Devices / Safety interlock switch

**Brand:** Schmersal  
**Actuator type:** B1, B5, B8  
**Contact arrangement:** 2 NC  
**Dimensions:** 60 x 30mm

**Features**
- Self extinguishing material
- Conforms to all international standards
- Safety category 2
- IP 67 protection
- Positive break contacts
- Suitable for any mounting position

**Benefits**
- Ease of mounting saving time.
- Security of product.
- Increased safety to equipment.
- Increased safety to personal.
- Versatile applications

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image

www.nhp.com.au
APPENDIX D

BEARINGS CATALOGUE EXTRACT
Catalog Review of Rolled Steel Housings

NSK Rolled Steel Housings Ensure A Safer Design

1. Features

Superior Housing Strength
Consistent Microstructure
Interchangeability

Made of precision gas cut rolled steel, NSK steel housings offer superior strength characteristics when compared to cast iron and cast steel housings. The rolled steel microstructure is more consistent than cast iron or cast steel, reducing the risk of housing fracture under severe conditions. Rolled steel housing dimensions are consistent with cast units, allowing them to be interchanged with NSK standard housings and other manufacturers' ISO standard.

2. Bearing housing material

The bearing housings use material classified as SS400 of JIS G 3101 (Rolled Steel for General Structures). The table below lists the material's general mechanical properties.

<table>
<thead>
<tr>
<th>Class code</th>
<th>Steel thickness mm</th>
<th>Yield strength N/mm²</th>
<th>Tensile strength N/mm²</th>
<th>Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS400</td>
<td>Thickness 16 to 40</td>
<td>235 or more</td>
<td>400–510</td>
<td>No. 1A 21 or more</td>
</tr>
<tr>
<td></td>
<td>Thicker than 40</td>
<td>215 or more</td>
<td></td>
<td>No. 4 23 or more</td>
</tr>
</tbody>
</table>

3. Allowable load for bearing housings

The allowable load for rolled steel housings is approximately 5 times the insert bearing's dynamic capacity. In most applications, the load is transmitted through the bearing onto the housing. As shown below, the static bending strength of NSK rolled steel housings is considerably higher than that of cast iron and cast steel housings.

![Static Breaking Strength of Pillow Type Bearing Housing (upward loading)](image)

The above chart shows the application of an upward load. This testing was applied for testing purposes only and is not recommended for actual use.

4. Applications

NSK rolled steel housings provide superior strength to cast steel and cast iron. Their ability to resist impact loads makes them suitable for applications involving heavy loads and vibration. Possible applications for NSK rolled steel housings include but are not limited to conveyors, trucks, and overhead cranes at steel mills, mining machinery, and pollution control equipment.
# Catalog Review of Rolled Steel Housings

## Pillow Block Unit; UCPG2 series

Cylindrical bore with set screw

<table>
<thead>
<tr>
<th>Part number</th>
<th>Boundary dimensions mm</th>
<th>Nominal part number</th>
<th>Insert bearing number</th>
<th>Mass kg (max.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCP2010D1</td>
<td>H: 12 L: 25 A: 217</td>
<td>UC2010D1</td>
<td>PG2010D1</td>
<td>0.7</td>
</tr>
<tr>
<td>UCP2020D1</td>
<td>H: 12 L: 25 A: 217</td>
<td>UC2020D1</td>
<td>PG2020D1</td>
<td>1.3</td>
</tr>
<tr>
<td>UCP2030D1</td>
<td>H: 12 L: 25 A: 217</td>
<td>UC2030D1</td>
<td>PG2030D1</td>
<td>1.6</td>
</tr>
<tr>
<td>UCP2040D1</td>
<td>H: 12 L: 25 A: 217</td>
<td>UC2040D1</td>
<td>PG2040D1</td>
<td>1.9</td>
</tr>
<tr>
<td>UCP2050D1</td>
<td>H: 12 L: 25 A: 217</td>
<td>UC2050D1</td>
<td>PG2050D1</td>
<td>2.2</td>
</tr>
<tr>
<td>UCP2060D1</td>
<td>H: 12 L: 25 A: 217</td>
<td>UC2060D1</td>
<td>PG2060D1</td>
<td>2.6</td>
</tr>
<tr>
<td>UCP2070D1</td>
<td>H: 12 L: 25 A: 217</td>
<td>UC2070D1</td>
<td>PG2070D1</td>
<td>3.3</td>
</tr>
<tr>
<td>UCP2080D1</td>
<td>H: 12 L: 25 A: 217</td>
<td>UC2080D1</td>
<td>PG2080D1</td>
<td>4.6</td>
</tr>
<tr>
<td>UCP2090D1</td>
<td>H: 12 L: 25 A: 217</td>
<td>UC2090D1</td>
<td>PG2090D1</td>
<td>5.9</td>
</tr>
<tr>
<td>UCP2100D1</td>
<td>H: 12 L: 25 A: 217</td>
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</tr>
<tr>
<td>UCP2110D1</td>
<td>H: 12 L: 25 A: 217</td>
<td>UC2110D1</td>
<td>PG2110D1</td>
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<tr>
<td>UCP2120D1</td>
<td>H: 12 L: 25 A: 217</td>
<td>UC2120D1</td>
<td>PG2120D1</td>
<td>9.0</td>
</tr>
<tr>
<td>UCP2130D1</td>
<td>H: 12 L: 25 A: 217</td>
<td>UC2130D1</td>
<td>PG2130D1</td>
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</tr>
<tr>
<td>UCP2140D1</td>
<td>H: 12 L: 25 A: 217</td>
<td>UC2140D1</td>
<td>PG2140D1</td>
<td>13</td>
</tr>
</tbody>
</table>

**Note:**
1. Stamped steel or cast iron dust covers are also available upon request.
2. Roller is bearing E 1154.
3. Full bearing tolerances according to JSB 1558.
4. Housing tolerances according to JSB 1669.
APPENDIX E

BONFIGLIOLI GEARBOX CATALOGUE EXTRACT
Orientamento morsettiera | Terminal box position | Ausrichtung des Klemmenkastens | Orientation boîte à bornes

<table>
<thead>
<tr>
<th>DW1</th>
<th>COW1</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNI</td>
<td>COW2</td>
</tr>
<tr>
<td>DW4</td>
<td>COW3</td>
</tr>
<tr>
<td>DNI</td>
<td>COW4</td>
</tr>
</tbody>
</table>

Nella configurazione HR (albero veloce cilindrico) è possibile ottenere tutte le esecuzioni di montaggio riportate.

Nella configurazione P (IEC) determinate esecuzioni di montaggio possono essere ottenute solo utilizzando flange IEC (B5 o B14) di grandezza uguale o inferiore a quelle riportate nella tabella.

For units with the HR input (free shaft), all the mounting options shown are available.

For units with the P (IEC), certain mounting options can be obtained only by using IEC flanges (B5 or B14) of the same size or smaller than those shown in tables.

Bei der Ausführung HR (Getriebe) sind alle abgebildeten Montageausführungen möglich.

Bei der Ausführung P (IEC) können bestimmte Montageausführungen nur durch Verwendung von IEC-Flanschen (B5 oder B14) erreicht werden, die gleich groß oder kleiner als die in den Tabellen angegeben sind.

Dans la configuration HR (réducteur, il est possible d'obtenir toutes les exécutions de montage présentées.

Dans la configuration P (IEC), certaines exécutions de montage ne peuvent être obtenues qu'en utilisant des brides CEI (B5 ou B14) de taille inférieure ou égale aux tailles indiquées dans les tableaux.
<table>
<thead>
<tr>
<th>CW1</th>
<th>CCW1</th>
<th>CW2</th>
<th>CCW2</th>
<th>CW3</th>
<th>CCW3</th>
<th>CW4</th>
<th>CCW4</th>
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<tbody>
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<td></td>
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<td></td>
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<tr>
<td>V</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>VFVF 3045</strong></td>
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<tr>
<td><strong>VFW 3063</strong></td>
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<td>UF-UFPC</td>
<td>UF-UFPC</td>
<td>UF-UFPC</td>
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<td>UF-UFPC</td>
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<tr>
<td>V</td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>VFW 4475</strong></td>
<td>U</td>
<td>UF-UFPC</td>
<td>UF-UFPC</td>
<td>UF-UFPC</td>
<td>UF-UFPC</td>
<td>UF-UFPC</td>
<td>UF-UFPC</td>
</tr>
<tr>
<td>V</td>
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**Consultare il manuale tecnico**. **Consultare il manuale tecnico**. **Consultare il manuale tecnico**. **Consultare il manuale tecnico**. **Consultare il manuale tecnico**. **Consultare il manuale tecnico**.
12.1 Designazione riduttore 12.1.1 Gearbox designation 12.1.2 Getriebe-Bezeichnung 12.1.3 Désignation réducteur

**W 63 L1 UF1 — 24 S2 — B3 ... ...**

**OPZIONI / OPTIONS / OPTIONEN / OPTIONS**

ESERCZ. DI MONTAGGIO / MOUNTING ARRANGEMENT
BAUFORM / ASSEMBLAGE
CW (1, 2, 3, 4)
CCW (1, 2, 3, 4)

POSIZIONE DI MONTAGGIO / MOUNTING POSITION
EINBAULAGEN / POSITION DE MONTAGE
B3 (default), B6, B7, B8, V5, V6

INTERFACIACZA MOTORIE IEC / MOTOR MOUNTING
MOTOR BAUFORM / FORME DE CONSTRUCTION MOTEUR
B5 (VF30...VF250, VFR40...VFR250, W, WR)
B14 (VF30...VF110, W83...W110)

**DESIGNAZIONE INGRESSO / INPUT CONFIGURATION**
**BEZEICHNUNG DER ANTRIEBSEITE / DESIGNATION ENTREE**

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**RAPPORTE DI RIDUZIONE / GEAR RATIO / ÜBERSETZUNG / RAPPORT DE REDUCTION**

**DIAMETRO ALBERO LENTO / OUTPUT SHAFT BORE**
**ABSTREIBWELLE DURCHMESSER / DIAMETRE ARBRE LENT**

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**FORMA COSTRUTTIVA / VERSION / BAUFORM / FORME DE CONSTRUCTION**

**LIMITATORE DI COPPIA / TORQUE LIMITER / RUTSCHKUPPLUNG / LIMITEUR DE COUPLE**

| VF, VFR | L1 |
| W, WR   | L2 |
| VF / VF | LF |

**GRANDEZZA RIDUTTORE / GEAR FRAME SIZE / GETRIEBEBAUGRÖSSE / TAILLE REDUCTEUR**

| VF   | 27, 30, 44, 49, 130, 150, 185, 210, 250 | VF/VF | 30/44, 30/49, 130/210, 130/250 |
| VFR  | 44, 49, 130, 150, 185, 210, 250         | VF/W  | 30/63, 44/75, 44/86, 49/110   |
| W - WR | 63, 75, 86, 119                         | W/VF  | 63/130, 86/150, 86/185 |

**TIPO RIDUTTORE / GEARBOX TYPE / GETRIEBETYP / TYPE DU REDUCTEUR**

| VF, W | Riduttore a vite senza fine / Worm gearbox / Schneckengetriebe / Réducteur à vis sans fin |
| VFR, WR | Riduttore con precoppia elicoidale / Helical-worm gear unit / Schneckengetriebe mit Vorwurfl / Réducteur avec paree helicoidale |
| VF/VF, VF/W, W/VF | Riduttore combinato / Combined gearbox / Doppelschneckengetriebe / Réducteur combiné |
### 0.18 kW

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Note: The table represents various combinations of speed (\( n_2 \)), torque (\( M_2 \)), reduction ratio (\( i \)), and output power (\( R_{22} \)) for a 0.18 kW motor, along with the corresponding models and code numbers for reference.